Energy, Environment and Climate Action

Technical Guidelines for Waterway Management

Acknowledgements

The Technical Guidelines for Waterway Management have been developed for the Department of Energy, Environment and Climate Action (DEECA) through a collective effort with many organisations and individuals. In particular the department thanks:

- Project consultants: Alluvium Consulting Australia Pty Ltd (Stuart Cleven, Ross Hardie, Dr Alex Sims, Marnina Tozer, Prof Ian Rutherfurd).
- Steering Committee: Chris Saunders (DEECA, Project Manager), Peter Vollebergh (DEECA), Kelly Snell (Corangamite CMA), Andrew Briggs (North East CMA), Sean Phillipson (East Gippsland CMA) and Dylan McWhinney (then Goulburn Broken CMA).
- Peer reviewers: Dr Dean Judd (Water Technology), Greg Peters (Streamology), Dr Rob Hale, Dr Zeb Tonkin and Dr Ashley Sparrow (DEECA, Arthur Rylah Institute) and Anne Buchan and Angela Muscatello (DEECA, Biodiversity).
- **Representatives from all CMAs** who provided feedback on the scope, structure and final draft of the Guidelines and many of the photos included in the Guidelines.

Note

The Guidelines provide hyperlinks and references to external related information, current at the time of publication. Information includes relevant waterway management related topics/reports by other agencies or persons in the context of the use of these Guidelines. It is the responsibility of users to check the currency and suitability of information for its intended purpose.

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria’s land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

DEECA is committed to genuinely partnering with Victorian Traditional Owners and Victoria’s Aboriginal community to progress

ISBN 978-1-76136-632-1 **(pdf)**

Contents

List of Tables

List of Figures

Definitions

A set of definitions for a selection of common terms is provided below. The definitions were developed to assist with the application of these Technical Guidelines for Waterway Management.

AEP	Annual exceedance probability (AEP) is the probability of an event occurring in any given year. i.e. A 1% AEP means there is a 1% chance in any given year of the event occurring.
Aggradation	The process of net sediment deposition within the waterway channel that results in a rise in the bed elevation.
Avulsion	The process of abandonment of a waterway channel in favour of a new, more hydraulically efficient channel.
Catchment management	The development and implementation of programs and projects of education, engagement, regulation, on-ground works and monitoring on land, riparian and instream areas aimed at achieving a balanced outcome for the catchment. In Victoria, integrated catchment management underpins the sustainable management of land and water resources and contributes to biodiversity management.
Geomorphic stability	Refers to agreed rates of channel change that sustain essential geomorphic and ecological processes while limiting the adverse impacts of such change. This rate of channel change may approximate pre-colonisation rates of change.
Incision	A channel deepening process. Incised waterways have previously or are currently undergoing a process of channel enlargement.
Meander migration	Consists of bank erosion on the outside bank of curved channels and point bar and floodplain building on the inside bank.
Meandering channel	A meandering waterway has a single channel that winds snakelike through its valley, so that the distance ‘as the channel flows’ is greater than ‘as the crow flies.’
Natural bed armouring	A process whereby gravel-channel beds typically have an “armouring” layer of coarse grains on the surface, which acts to protect finer particles underneath from erosion.
Point bar	A depositional feature made of alluvium (material deposited by rivers) that accumulates on the inside bend of streams and rivers below the slip-off slope.
Programs	Activities and works undertaken over a medium to long term (5 to 10 years) within a sub catchment, catchment or region, often

	consisting of a combination of engagement, education, regulation, on-ground works and monitoring activities.
Projects	A limited selection of activities and/or works often undertaken over a short period (1 or 2 seasons) at a site or within a reach or sub catchment.
Reach	A section of a waterway. The length of a reach varies between hundreds of metres to tens of kilometres depending on the scale of the processes being managed. A single reach may contain multiple sites.
Regional Waterway Strategy	A single planning document for river, estuary and wetland management in each region. Regional waterway strategies drive implementation of the management approach outlined in the Victorian Waterway Management Strategy.
Riparian land	Riparian land is the land that runs along rivers, creeks, estuaries, lakes and wetlands. Riparian land can vary in width from a narrow strip to a wide corridor.
Riverward	In the direction of the river, rather than the riverbank.
Site	A particular location on a waterway where on-ground works are implemented. The scale of a site is generally between tens to hundreds of metres. Multiple sites may be within a single reach.
Stream power	The concept of stream power describes the total energy expended across the channel bed and banks per unit of time.
Victorian Waterway Management Strategy	A statewide strategy that provides the framework for government, in partnership with the community, to sustain rivers, estuaries, floodplains and wetlands so that they can continue to provide environmental, social, cultural and economic values for all Victorians.
Waterway	A generic term for a river, stream, creek or watercourse. While estuaries and wetlands can also be considered as a waterway (as per the Water Act), the management of these features has not been included in the Guidelines. For the purpose of the Guidelines the use of the term waterway excludes estuaries and wetlands.
Waterway health	Sometimes called waterway condition or river health, waterway health is an umbrella term for the overall state of key features and processes that underpin functioning waterway ecosystems (such as species and communities, habitat, connectivity, water quality, riparian vegetation, physical form and ecosystem processes including nutrient cycling and carbon storage).

Waterway management	The development and implementation of programs and projects comprising planning, community engagement, on-ground works, monitoring and evaluation focussed on waterways, riparian land and floodplains and seeking to achieve agreed outcomes.

Document guide

These guidelines have been structured so that users can work through the document sequentially, building an understanding of geomorphic processes, deciding on whether to intervene in a waterway with on-ground works and then making decision about how and where to intervene. This mirrors the 4-step decision making process embedded in these guidelines. Users can also enter the guidelines at specific sections (using the hyperlinks contained within the diagram below and throughout the document), quickly drawing on relevant material without the need to move through material irrelevant to the task at hand.

Part 1 – Introduction

Scope of the guidelines and document structure

Part 2 – Geomorphic processes

Fundamental theory of the processes of incision, aggradation, meander migration and avulsion

Part 3 – A four-step decision-making process

A framework to guide the decision to intervene, or not, and select intervention options

Part 4 – Management option summaries

Summaries of management options and key considerations

Part 5 – Supporting analyses

Tools and methods to aid in the development of a management approach

Part 6 – Design aids

Tools and methods to aid the design of on-ground works

Part 7 – Worked example of the four-step decision making process

Example application of the four-step process

Part 8 – Standard drawings

Example design drawings for a selection of structures commonly used in waterways

1 Part 1 – Introduction

1.1 Background

This third edition of the Technical Guidelines for Waterway Management (the Guidelines) has been developed by the Department of Energy, Environment and Climate Action (DEECA) in association with Victoria's catchment management authorities (CMAs). The updated version of the Guidelines reflects the considerable advances in best practice waterway management that have occurred since the second edition of the Guidelines were published in 2007.

1.2 Scope

The Guidelines have been developed to help Victoria's waterway management industry manage waterway physical processes and form. Fundamentally, the Guidelines help practitioners decide which, if any, on-ground interventions to use at the reach or site scale, and how to design, implement and monitor those works. The purpose of such interventions, and of the Guidelines, is the protection and enhancement of the environmental, cultural, social and economic values of waterways. As such the Guidelines complement related waterway management strategies including the Victorian Waterway Management Strategy and regional waterway strategies. Waterway management decisions, supported by the Guidelines, should be made within the context of the broader catchment and waterway management framework in Victoria.

It is the responsibility of users to ensure that all statutory requirements are met when undertaking any waterway interventions.

1.2.1 Audience

The Guidelines have primarily been developed to assist the implementation of on-ground waterway interventions by Victoria's waterway managers, particularly CMAs and Melbourne Water[1]. They are also aimed at consultants working with waterway managers in Victoria's waterway and catchment management industry. The Guidelines will also be of relevance to Traditional Owners, community groups, landholders, and other organisations with an interest and role in the implementation of effective waterway management programs.

It is also intended that the Guidelines can be used by Victoria's CMAs and Melbourne Water to assist in the regulation and management of works proposed by other organisations and stakeholders.

---

[1] CMAs and Melbourne Water are authorities with formal waterway management powers under the Victorian W*ater Act 1989.*

The Guidelines also include material that may be suitable for training purposes.

1.2.2 Issues addressed

The Guidelines address the on-ground management of physical processes occurring in waterways. The Guidelines do not specifically address the management of wetlands or estuaries, although some of the intervention options included in the Guidelines may, in some cases, apply to wetland and estuary management. More particularly, the Guidelines have been developed to assist with the management of Victoria’s waterways that are subject to unacceptable rates of channel change, including waterway incision (degradation), meander migration, waterway aggradation (sedimentation), and channel avulsions.

The Guidelines consider how the waterway manager can directly influence these physical geomorphic processes and hence waterway condition and resilience by manipulating instream and riparian elements such as the:

- Extent and condition of riparian vegetation; and
- Physical form of the waterway channel and floodplain.

As a consequence, the Guidelines deal only with a subset of the suite of challenges that face waterway managers and a subset of management options available to influence waterway condition and processes. The Guidelines do **not** address other important elements of waterway management programs, but they do provide links to the relevant guidelines or policies where available.

A note on terminology used in the Guidelines

Waterways, streams, creeks, and rivers

Many people use different terms for waterways, including channel, watercourse, river, stream or creek. Adding to the confusion, these same terms can be used in different ways by different disciplines (e.g. engineers vs. geomorphologists) and in different places (Victoria vs. Queensland). Rivers tend to be larger than streams, which tend to be larger than creeks. But in practice these terms can be used interchangeably. 'Waterway' is a useful generic term for a river, stream, creek or watercourse and is the term used throughout the Guidelines. Some exceptions to the use of the term, waterway, occur where the use of stream or channel is common and better expresses an idea. For example, the channel bed or channel boundary (rather than waterway bed or waterway boundary).

Waterway managers

The Guidelines use the generic term waterway manager to describe the intended users of the Guidelines – staff working for Victoria's CMAs and Melbourne Water, Traditional Owner groups, other government agencies or other organisations or individuals that are undertaking waterway management activities.

1.2.2.1 Exclusions

The Guidelines do not address:

- **Environmental water.** The diversion of water for consumptive use alters the natural flow regime of waterways, which can have a significant impact on the extent and quality of instream habitat and physical processes in waterways. Approaches to determining environmental watering requirements and the delivery of environmental flows are not addressed by the Guidelines.
- **Runoff & erosion outside of the waterway.** Land use practices that lead to catchment based soil erosion can have a significant impact on the quantity and quality of water, sediment and nutrients entering waterways and are a major control on overall waterway condition. Approaches to address these issues are not specifically covered by the Guidelines. Sediment extraction can be used to address the consequences of increased sediment delivery to the waterway and this intervention option is summarised in section 4.2.19.
- **Biological management.** The physical processes addressed in the Guidelines have biological implications. The Guidelines consider the management of geomorphic processes for the protection and reinstatement of biological processes. However, the Guidelines do not directly address biological issues. Ongoing control of invasive flora and fauna is crucial to the maintenance and improvement of riparian land and instream habitat. Similarly, the provision of fish passage over or around instream barriers such as weirs will be essential to the protection of native fish populations. The Guidelines do not address these matters in detail. The Guidelines provide reference to relevant guidelines

where the issues of biological management are not directly connected to physical geomorphic processes of erosion and sedimentation (e.g. references to fishway guidance content can be found in section 6.7.2.6). Importantly, the Guidelines do provide guidance on the establishment of instream habitat lost as a result of physical process such as channel incision and aggradation and on biological management where this is directly relevant to the management of physical stream processes (e.g. willow management). Further, the Guidelines identify intervention options that seek to avoid adverse impacts on ecological processes. Native vegetation is recognised in the Guidelines as the most useful and effective material available to the waterway manager (as summarised in section 6.11.2). Vegetation establishment and management are essential components of waterway management projects and are covered in section 4.2 of the Guidelines.

- **Community engagement.** Successful waterway management programs rely on successful long-term partnerships with adjoining landholders and the community. A technically correct action, without reference to the social context invites failure. The Guidelines do not provide guidance on effective engagement processes but do recognise the essential role that such engagement has on the direction and success of waterway management programs and projects. Further details on how to design and implement an effective engagement program is available in *Effective engagement: Building relationships with community and other stakeholders* (DELWP, 2015c).
- **Traditional Owner engagement.** Traditional Owners have cultural, spiritual and economic connections to land, water and resources through their associations and relationship with Country. Traditional Owners have managed land and water sustainably over thousands of generations and connectedness to land, waters and resources on Country is important for Aboriginal health and wellbeing.

  It is recognised that Traditional Owners have rights and obligations to care for Country and many Nations are actively involved in waterway management programs for which these Guidelines are applicable.

  When other agencies and groups undertake waterway management, partnering with Traditional Owners is critically important. Partnering with Traditional Owners in waterway planning and management includes:

  - Incorporating Aboriginal customary knowledge, where appropriate. Examples include the use of cultural burns and the selection and maintenance of culturally appropriate vegetation.
  - Ensuring their cultural, ecological and economic values and expertise are integrated into climate change adaptation planning.
  - Increasing decision-making and resources for Traditional Owners in the management of waterways.
  - Improving access to water for Traditional Owners and Aboriginal Victorians, providing opportunities for economic development.

The specific objectives and arrangements of the partnership will vary between regions and by project but early and continued partnership with Traditional Owners is essential in waterway management projects to deliver on Victorian government commitments in Water is Life.

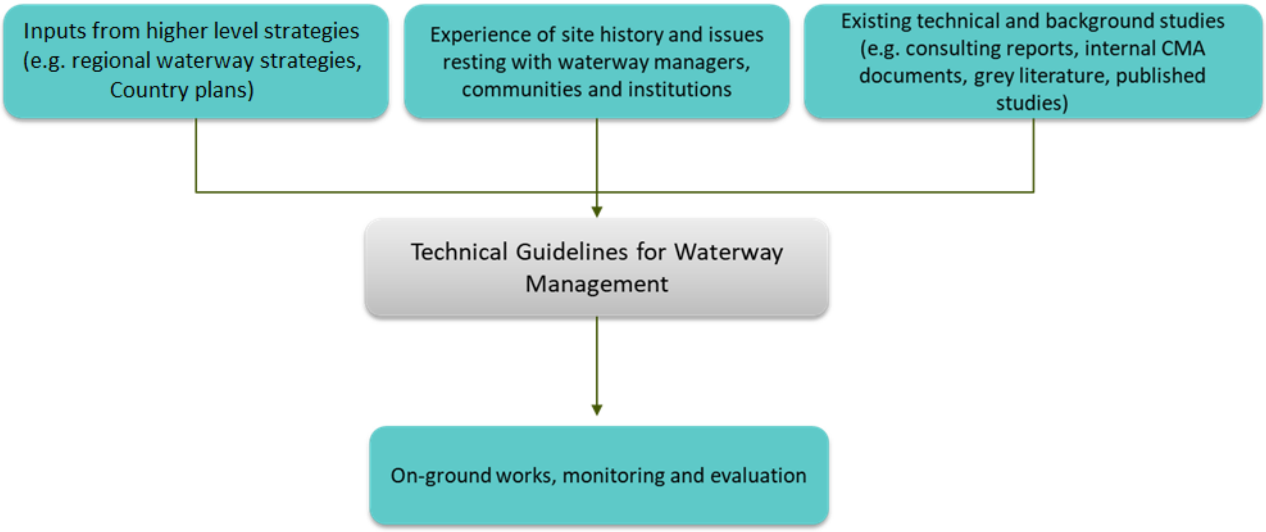
The Guidelines do not provide guidance on effective Traditional Owner engagement. Further information and guidance on Traditional Owner engagement can be found at: Engaging Traditional Owners.

- **Statutory planning and advocacy.** Achieving waterway condition objectives will often depend on influencing the opinions or actions of other groups, agencies, or individuals through processes of regulation and advocacy. In Victoria, activities that have potential to harm waterways are regulated through referrals made within the statutory planning system (e.g. advice to local councils and works on waterways permits issued by CMAs). Much of the material in the Guidelines is relevant to those decisions, and complements (but does not supersede) more specific guidelines such as CMA online guides (e.g. Works on waterways).
- **Monitoring and evaluation.** Monitoring and evaluation programs allow for continuous improvement in the planning, design and implementation of on-ground interventions. The Guidelines do not provide comprehensive guidance on the development of monitoring and evaluation programs, but the approaches set out in the Guidelines have been developed in a manner that encourages the development of monitoring and evaluation programs. Further details on how to design and implement monitoring and evaluation programs is available here: Monitoring, evaluation and reporting framework (DSE, 2012).
- **Floodplain (re)engagement.** Interventions that reconnect channels to their floodplains have the potential to restore the natural movement of water, sediment and nutrients from channels to floodplain, increasing available habitat and improving waterway and floodplain condition. The Guidelines do not address interventions explicitly intended to restore channel-floodplain connectivity, such as flow modification or removal of physical barriers on the floodplains.

1.2.3 How the Guidelines relate to state and regional strategies

The Guidelines have not been developed for the purpose of regional, catchment or sub-catchment scale planning and prioritisation. The Guidelines help give effect to regional waterway strategies by guiding on-ground implementation of regional work programs at the reach and site scale. However, the Guidelines can be used to assist with decisions about intervening on any waterway. The Guidelines should be implemented to align with the policies and principles of the *Victorian Waterway Management Strategy* and should sit within the context of a comprehensive planning process.

Figure 1. How the Guidelines use a range of inputs, including higher-level strategies, to plan and then implement on-ground works.



1. Inputs from higher level strategies (e.g. regional waterway strategies, Country plans)

   Experience of site history and issues resting with waterway managers, communities and institutions

   Existing technical and background studies (e.g. consulting reports, internal CMA documents, grey literature, published studies), all guide the…

2. Technical Guidelines for Waterway Management, which guides…
3. On-ground works, monitoring and evaluation

1.2.4 Spatial and temporal scale

The Guidelines have been developed to assist in the selection, design and implementation of interventions at the reach and site scale in waterways for which Victoria's CMAs and Melbourne Water have waterway management responsibilities. The Guidelines can be used to support the implementation of higher-level plans and strategies such as regional waterway strategies and Country plans and also more specific targeted stream or reach based plans such as waterway action plans developed by some CMAs. For example, the Guidelines may assist with the identification of sites within a reach or system where on-ground works will most effectively treat threatening processes.

The Guidelines can also be used to guide decision making in waterways which may not be a strategic management priority in a regional waterway strategy, but which may have other drivers for activities and works.

The Guidelines have been produced to assist the development and implementation of long-term programs and shorter-term projects that together can constitute a strategic approach to waterway management at appropriate scales e.g. whole-of-Country, regional or reach. Shorter-term projects are likely to be at site scales, where managers might be responding to a specific problem with activities such as fencing and/or revegetation, yet these are still planned in the context of the larger waterway system e.g. considering upstream and downstream values).

1.2.5 Content

The Guidelines include sections on:

- Waterway management planning – including a four-step process that waterway managers can use to plan for, and then implement, on-ground interventions.
- The threats and processes that trigger management interventions.
- The selection of an appropriate reach scale management approach and the specific interventions to address threats.
- Supporting analysis methods that can be used to identify the type and scale of intervention required for a reach or site, and to design specific interventions.
- Standard design drawings and guidance on their use.

In addition, the Guidelines include a worked example and a comprehensive set of references, related reading, and web sites. Where appropriate the Guidelines provide references and links to other sources rather than repeating detailed information that is available elsewhere.

1.3 How to use the Guidelines for waterway management

The Guidelines have been developed in a format that enables users to enter at any point. In this respect users may seek options for addressing a particular issue or problem or may seek more specific information on a particular design approach. Users may also choose to read the document from cover to cover.

The Guidelines have been structured around a four-step process to guide decision making by waterway managers. This four-step process provides waterway managers with an 'entry point' for common waterway management decisions. An example of a common waterway management decision occurs when a waterway manager is contacted about bank erosion, triggered by a recent flood. How should the waterway manager respond? The Victorian Waterway Management Strategy sets the overarching policy to guide decisions on intervention and who should pay for any potential interventions. The Guidelines then further inform what could be done to address the erosion. The four-step process for making decisions about interventions is written with this common situation in mind.

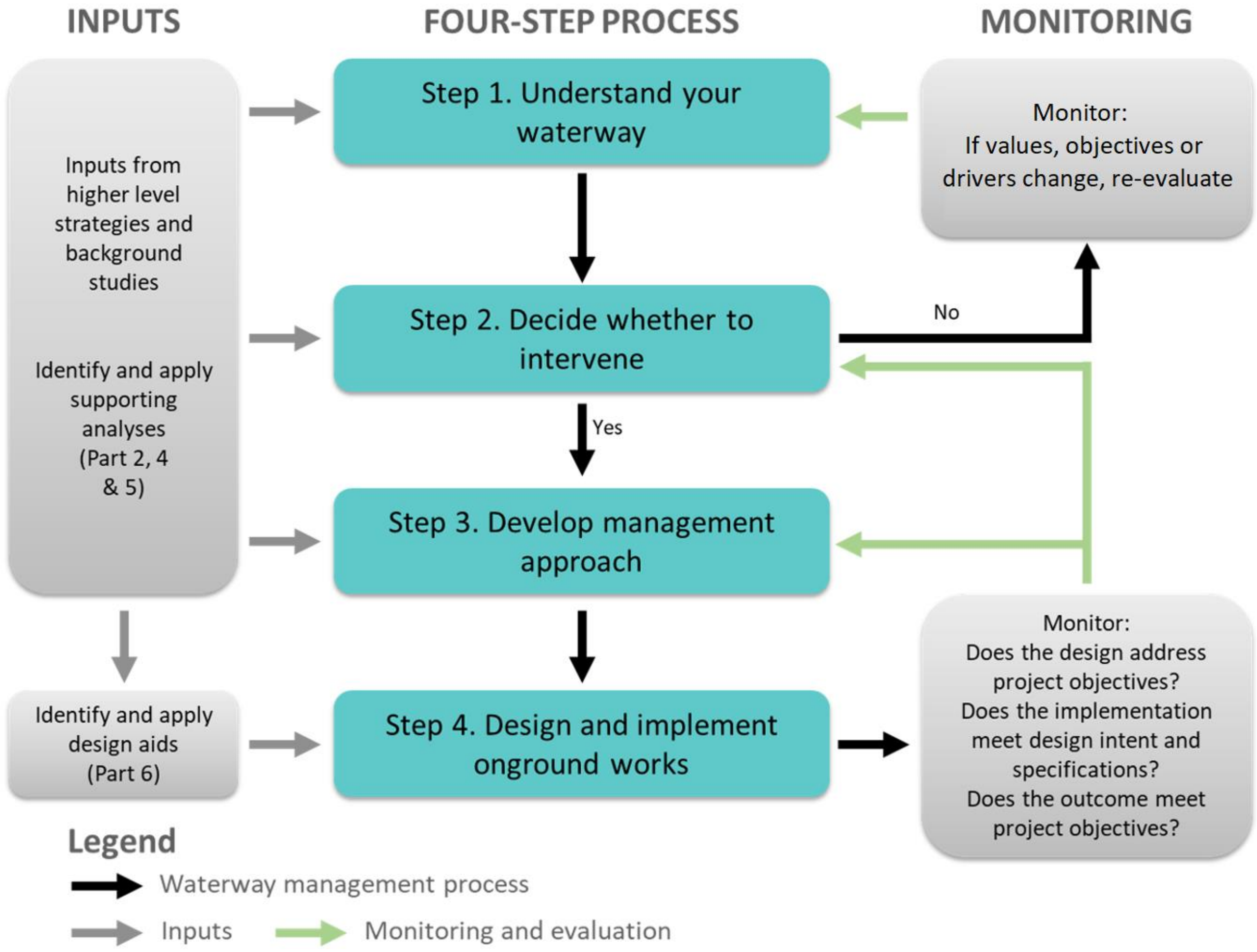
By stepping through the four-step process, waterway managers can answer these questions and make decisions about the need for, and aims of, on-ground works in waterways.

The four-steps are:

1. Understand your waterway: Identify values and define objectives for your waterway reach.
2. Decide whether to intervene.
3. Develop a management approach: Identify opportunities and constraints and apply supporting analyses.
4. Design and implement on-ground works.

The content of these Guidelines, including the supporting analyses detailed in Part 5, can be used at multiple stages of this four-step process. The four-step process is shown in Figure 2.

Figure 2. The four-step process included in the Guidelines and how the four-steps relate to the document structure.



The Guidelines are intended to be used in both electronic format and in hardcopy format (if users wish to print the document or relevant parts of it). The Guidelines have been designed to assist with document navigation and useability, for example by including references to other relevant sections and providing the document guide at the beginning of the Guidelines. The electronic document includes hyperlinks that direct users straight to other sections, to relevant related guidelines and to supporting material that addresses subject matter not covered within the Guidelines (for example, fishway design). The electronic version is available on the DEECA website at Technical guidelines for waterway management.

1.4 Structure

The Guidelines have been structured in six parts as follows:

Part 1, Introduction: This part introduces the Guidelines, outlining the background and structure of the document and a philosophy for waterway management that is reflected throughout the Guidelines.

Part 2, Geomorphic processes: This part describes the four dominant physical processes occurring within, and impacting on, Victoria's waterways. Each of the four dominant physical processes of incision, meandering, aggradation, and avulsion summarised in Part 2 is used during the four-steps to build geomorphic trajectories and understand how threats can be addressed through specific on-ground interventions.

Part 3, The four-step process: This part sets out the four-step process that waterway managers can use to identify values and threats, decide whether to intervene at a reach or site and then select and implement on-ground works to improve or maintain waterway condition and resilience at the site. It also contains 'levers' or management options available to waterway managers to identify, sequence, and design interventions that address threats identified at the reach or site.

Part 4, Management option summaries: Part 4 provides additional information on the waterway management options available to waterway managers that are relevant to the management of waterway physical processes.

Part 5, Supporting analyses: This part outlines the supporting analyses that can be used to establish an impact logic, build a geomorphic trajectory, and identify the type and scale of intervention required in a reach or at a site.

Part 6, Design aids: This part provides tools that aid in the design of on-ground works at the site scale.

1.5 Philosophy for waterway management adopted in the Guidelines

The actions in the Guidelines reflect a philosophy based on the following principles.

1. Waterway management is directed at achieving environmental, cultural, social and economic objectives for waterway related values. However, the objectives for these values can sometimes be in conflict. For example, protecting an economic value such as an infrastructure asset on a waterway may compromise the environmental objectives for the waterway. Managers always need to balance these, sometimes competing, objectives. Management intervention in waterways is therefore **purpose**

driven with **clear objectives** (refer to section 3.2) for waterway values, striking a balance between competing demands and considering the current and future impacts of climate change. This requires effective stakeholder consultation and engagement and clear distinction between public and private benefit outcomes.

2. Recognition that waterways are inherently **dynamic** systems that change their shape and alignment in response to both natural and human induced changes in flow regime, riparian vegetation and sediment supply. The waterway manager should only seek to intervene in these processes when past interventions have accelerated this rate of channel change, or where current or projected rates of channel change threaten **identified values and defined objectives**. Before intervening, the waterway manager should use impact logics and a geomorphic trajectory to understand what will happen if they **do not intervene**. The dynamic nature of waterways is further highlighted in the box below and section 2.1.1.

‘Stability’ in waterway management

The Guidelines have emphasised that waterways are naturally dynamic and move around. In fact, this is how floodplains are formed. Riverbanks erode, channels incise, and waterways avulse into different parts of the floodplain. Many of these channel changes can damage infrastructure and make it difficult to carry on businesses. From the perspective of landholders along waterways, it might be perceived that it is the ‘government’s river’ that is damaging their interests.

For this reason, in the past, community expectation drove government and waterway managers to try to maintain a ‘stable’ waterway that did not interfere with private assets and infrastructure. Typical activities included rock riprap on riverbanks or attempts to halt erosion and avulsions. Government and waterway managers have also seen it as their role to protect people from flooding, but perhaps ironically, programs to channelise waterways and reduce flooding at one location have tended to accelerate flows, and so trigger accelerated rates of erosion and increase downstream flood risk.

Over the last few decades this view has shifted and waterway managers must take a more nuanced view of ‘stability’ as a goal of management. The waterway manager must decide whether to intervene or not and the level of intervention that is appropriate. These decisions need to be made considering:

- A ‘healthy’ waterway is a dynamic waterway. Biological processes rely on erosion, deposition and resulting interactions between sediment and vegetation that occur along a waterway and through time.
- Human activity has accelerated most geomorphic processes relative to natural rates so that they now trigger greater erosion and sedimentation, which threatens a range of waterway values.
- Managers should aspire to waterways that have geomorphic processes that support ecosystem resilience and natural diversity rather than waterways that are completely static. In this respect, and for the purpose of these Guidelines, the term ‘geomorphic stability’ has been used to refer to agreed rates of channel change that sustain essential geomorphic and ecological processes while limiting the adverse impacts of such change. This rate of channel change may approximate pre-colonisation rates of change.
- It is expensive, unsustainable and ecologically undesirable to strive for completely ‘static’ waterways. Hence the emphasis throughout the Guidelines on vegetation as a means to reduce the rate of change and build and promote resilience where viable, but not halt all change.

This idea is further expanded later in this document, by making a distinction between geomorphic stability and the stability of engineered structures.

3. A clear **understanding** of the physical, ecological, and social processes that dominate in the system allows threats to the desired waterway management outcomes to be identified and effectively managed. Options for management intervention will be those that directly or indirectly address the threats and processes. This requires development of an impact logic for the reach or site of interest. The impact logic is used to predict how physical and ecological processes, and their interaction, respond to intervention and how that response can steer the reach or site towards the desired outcomes.
4. The most effective **approaches** for management will be those that address the underlying processes leading to a decline in waterway condition and resilience, rather than the symptoms of those processes. The decline and or loss of native riparian vegetation has been a cause of many waterway management problems. Fundamental to the success of waterway management programs and projects in Victoria will be the re-establishment of continuous, connected reaches of waterway with wide, structurally and age diverse, native riparian vegetation.

Floristically, structurally and age diverse native vegetation

The loss of structurally and age diverse native vegetation has been a primary cause of accelerated channel change impacting on waterway condition and the values waterways support.

Native riparian vegetation serves a variety of purposes in a waterway by providing:

- Increased resistance of the channel banks against the erosion forces generated by floods and accelerating the recovery of a waterway following floods. Quality native riparian vegetation, established via a revegetation program, has been found to reduce erosion by up to 95% compared to non-vegetated sites (Alluvium, 2011).
- Shading of the channel, which regulates stream temperatures, which benefits a range of biological processes and species.
- A supply of food for fish and other instream organisms from organic matter entering the water.
- A connection for native plants and animals to move between patches of vegetation in the landscape.
- A filter for nutrients and sediment from catchment runoff, which improves water quality.
- A source of wood e.g. from falling branches and when natural erosion undermines trees that then collapse into the channel bed. Once instream, the wood can accumulate more woody debris and organic matter creating more complex habitat.
- Increased amenity values and providing recreational and tourism opportunities, such as walking, picnicking, swimming and fishing.

The re-establishment and protection of wide, floristically, structurally, and age diverse native riparian vegetation to Victoria's waterways will be essential, not only in terms of reducing rates of channel change towards pre-disturbance levels but enhancing waterways so that they meet the broader aspirations of society.

Vegetation structure and species composition should align with appropriate Ecological Vegetation Class (EVC) benchmarks consistent with the context and objectives for the waterway. The approaches to management of physical processes set out in the Guidelines are reliant on the protection, restoration and ongoing management of native riparian vegetation across Victoria.

5. Interventions should aim to protect or maintain waterway value or improve waterway condition and resilience for least cost while retaining maximum flexibility for the future. The Guidelines aim to assist in understanding and selection of intervention options to be applied at the reach and site scale.

6. Effective outcomes rely on skill and experience in the **design, implementation and maintenance** of intervention options. The Guidelines are designed to help waterway managers develop those skills and to help prevent poor outcomes and unintended consequences from works.

2 Part 2 – Geomorphic processes

This section of the Guidelines provides a summary of the key concepts used throughout the Guidelines and introduces the four main geomorphic processes shaping the form of Victoria's waterways:

1. Incision.
2. Aggradation.
3. Meander migration.
4. Avulsion.

Recognising and understanding these processes is a critical step in managing waterways. It will help with understanding the changes occurring in the reach and waterway, to distinguish between cause and effect (or causes and symptoms) and to identify the appropriate actions.

These four processes can occur whenever a waterway has a floodplain: at reach scale, over kilometres or tens of kilometres. Further, all of these processes interact with each other: for example, incision in an upstream reach generates sediment that can cause aggradation in a downstream reach, reducing rates of meander migration, and potentially triggering an avulsion. The four processes are not necessarily mutually exclusive, and many waterways will have elements of each process operating within a single reach. For example, a reach may be both meandering and incising, or may be aggrading and undergoing avulsion.

Understanding the erosion and deposition linkages between these processes underpins a great deal of waterway management. This is why many higher-level strategies (such as regional waterway strategies) will have identified these processes as being important, either explicitly or by way of the threats each process generates and identified management actions to address those threats. When background information on geomorphic processes is unavailable for a reach or site, waterway managers can use the descriptions provided in this section to identify the processes and understand the activities that may accelerate rates of channel change.

2.1 Key concepts

2.1.1 The dynamic nature of waterways

A common misconception is that waterways are static features and the movement of waterways, for example by meander migration, is a costly and undesirable tendency to be controlled using on-ground interventions. However, when the processes of erosion and deposition occur at natural rates (rather than at an accelerated rate due to human intervention in a waterway or catchment), they play an important role in maintaining waterway condition and supporting environmental and cultural values.

In the past, the desire to maintain a ‘static’ channel combined with a focus on asset protection frequently led to interventions that sought to halt channel change completely (for example, the use of rock or concrete to prevent meander migration). Many of the efforts to control waterways by preventing channel change have had unintended consequences, for example:

- The loss of habitat from the channel banks by preventing the formation of undercut banks.
- The transfer of erosion impacts to adjoining reaches, which in turn are treated with erosion control works that further shift erosion impacts. The net outcome is the transfer of impacts from one site to another, at significant expense.
- Loss of riparian vegetation due to the loss of bank substrate on which vegetation establishes and grows.
- Loss of waterway amenity due to the introduction of foreign materials (e.g. large rock, concrete, and steel) into the waterway.
- Loss of, or adverse impacts on, cultural values from any of the above.

Allowing the natural processes of erosion, deposition, and change in channel alignment to occur uninterrupted, or slowing (but not preventing) the rate of these processes towards their natural, pre-disturbance rates have several advantages:

- Lower initial and ongoing costs.
- Once channel adjustments such as length, grade, and width have restored the waterway to dynamic equilibrium, the rate of channel change will decline without the need for on-ground intervention.
- Erosion and deposition maintain the supply of sediment, nutrients, and large wood to downstream reaches necessary for instream habitat to form.

For the reasons outlined above, waterways should be viewed as inherently dynamic features that can be expected to change their width, depth and alignment over time. The waterway manager should resist the desire to create static waterways and instead focus on implementing on-ground works that strike a balance between the need for erosion and deposition to occur and any adverse impacts that erosion and deposition may have on waterway or floodplain values, including infrastructure.

2.1.2 How the concept of stability is used in the Guidelines

The preceding section discussed geomorphic ‘stability’ as a goal of management. Here the distinction between geomorphic stability and the stability of engineered structures is outlined.

In waterway management the term stability has historically been influenced by the notion of a ‘stable channel’, an engineering concept that describes a constructed channel designed so that the bed and banks remain fixed under a set of design flows. More broadly, the popular use of the term ‘stability’ describes a waterway with dimensions and alignment that remain fixed through time: i.e. a static channel that does not erode.

Geomorphologists often use stability to describe channels that adjust their width, depth, alignment and planform via erosion and deposition of sediment (Newson, 2022) at natural rates. The key differentiator between a geomorphically stable and unstable waterway is the *rate* of that change. To a geomorphologist, an unstable waterway is one in which the rates of erosion and deposition have been accelerated above natural or historic rates and where rapid change in waterway width, depth or alignment are impacting waterway values. Human intervention is a common trigger for rates of waterway change to shift from natural and ‘stable’ rates to rapid ‘unstable’ rates.

The Guidelines use the term stability in two ways:

- In the geomorphic sense (geomorphic stability) to describe waterways that change
  - at a natural rate if the waterway is currently in natural to near-natural condition (e.g. many headwater streams in forested catchments), or
  - at a new ‘quasi-natural’ rate if in a very modified environment (as many waterways are after the impacts of colonisation) whereby a new geomorphic equilibrium is reached.

  Waterways are inherently dynamic and are expected to be continuously moulded by erosion and deposition.
- In the engineering sense, to describe a desired state for engineered structures or earthworks that do not erode or move under the expected design flows. This definition of stability is largely restricted to the design of specific on-ground works (see Part 6 – Design Aids).

2.1.3 Sediment continuity vs thresholds for erosion

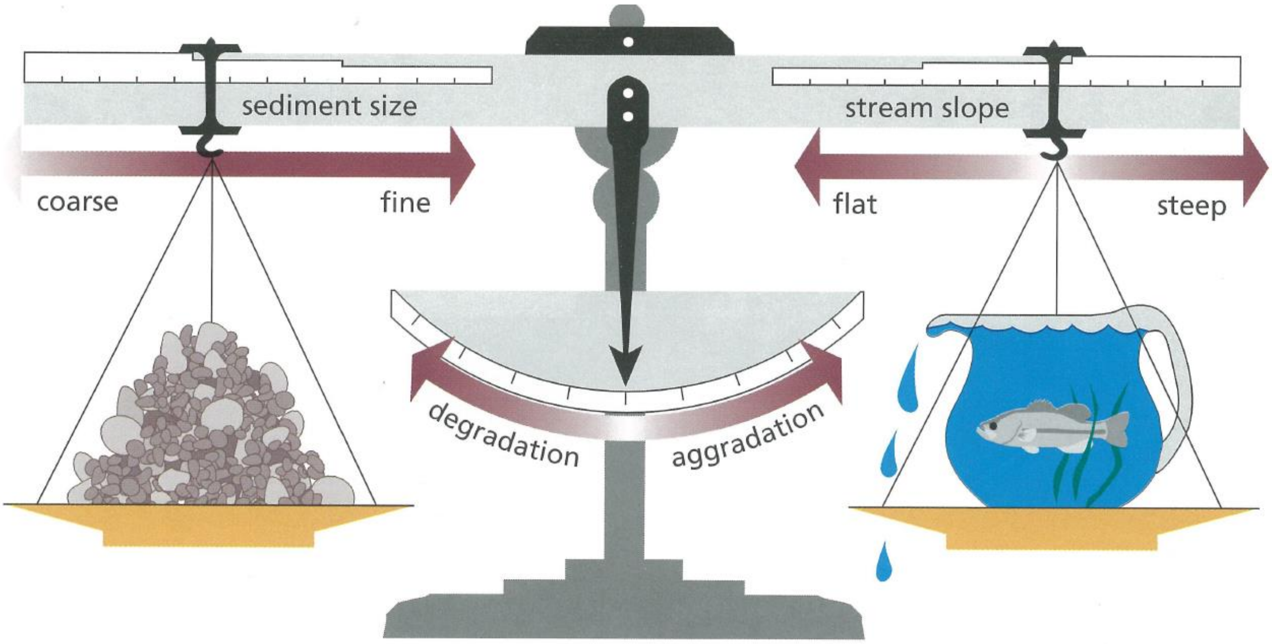
2.1.3.1 Sediment continuity, supply and transport

Many waterways are considered to be in a ‘dynamic equilibrium’, that has established in response to, and reflects the long-term inputs of, water and sediment. The theory of dynamic equilibrium relies on sediment continuity – the principle that the difference between sediment entering and leaving a reach of waterway must be added to storage (aggradation) or removed from storage (degradation).

The model of dynamic equilibrium can be represented as a set of balanced scales that predict whether the bed of a waterway will undergo aggradation or degradation in response to changes in discharge, channel slope, sediment load and sediment size. Over time, the mutual adjustment of these factors restores equilibrium in the waterway, so that neither net aggradation or degradation is occurring. The relationship between these factors is summarised below in a conceptual model first introduced by Lane (1954).

Note: The concept of sediment continuity discussed in the Guidelines is particularly relevant to bed load rather than suspended and wash loads. For brevity this document often adopts the more generic terms sediment supply, sediment transport, sediment deposition and sediment continuity with reference to the more specific terms bed load sediment supply, bed load sediment transport, bed load sediment deposition and bed load sediment continuity.

Figure 3. Lane's balance: The relationship between aggradation and degradation in response to sediment supply (left) and transport capacity (right) (adapted from Lane, 1954).



Lane's balance is a qualitative model that can be used by waterway managers to predict the direction of waterway change (aggradation or degradation), but not the magnitude of that change (for example the total depth of aggradation) or the spatial scale over which that change occurs.

2.1.3.2 Thresholds for erosion and resistance forces in waterways

Whether or not the potential for degradation (erosion) predicted by Lane's balance is realised at a reach or site ultimately depends on the balance between erosion and resistance forces at the reach or site. Waterways erode when erosion forces exceed resistance forces i.e. no erosion (e.g. bed degradation) occurs until a threshold is reached at which point erosion forces exceed the resistance forces.

Factors that influence erosion forces include:

- Channel slope (flow in steeper waterways exerts a greater force on the bed for given discharge and flow depth), and
- Discharge (larger flows frequently generate greater flow forces against the bed and banks).

Factors that control resistance forces include:

- The size of sediment in the channel or on the banks (cohesive silt, clays and larger sized sediment requires greater forces to be mobilised than non-cohesive sands and fine gravels), and
- The extent and type of instream and riparian vegetation.

Waterways respond to a change in the balance of erosion or resistance forces by either eroding or not. Whether deposition occurs will be dependent on the availability of sediment. The resultant erosion or deposition creates adjustments to the waterway characteristics (e.g. bed grade, channel sinuosity) that restores the balance between erosion and resistance forces.

By considering how activities and drivers alter sediment continuity and the balance between erosion and resistance forces in a waterway, managers can explain past channel changes, and predict how on-ground interventions will influence channel change in the future using conceptual models.

2.1.4 Conceptual models

Management should begin with understanding why waterway change has occurred, whether this change is a problem, what happens if nothing is done and where intervention will be most effective. By considering how activities and drivers alter sediment continuity and the balance between erosion and resistance forces in a waterway, managers can explain past channel changes, and predict how on-ground interventions will influence channel change in the future. Conceptual models can greatly aid this understanding.

Conceptual models can be used for a diversity of management scenarios and they vary in complexity and definition for different disciplines. For the purposes of the Guidelines conceptual models are simple descriptions of changes in erosion, deposition and morphology over time that can be used to predict how on-ground interventions will influence channel change in the future. They can be expressed as simple diagrams, as flow charts or as descriptions, and range from general to specific. Waterway conceptual models are available in published literature, within previous studies commissioned by CMAs and Melbourne Water and are often embedded as the intuition and understanding held by experienced waterway managers.

Example conceptual models

Lane’s Balance diagram (Figure 3) is an example of a ‘steady state’ conceptual model that relies on the premise that waterways return to some central ‘equilibrium’. Waterway managers can use conceptual models such as Lane’s balance to predict whether a waterway will degrade (incise) or aggrade in response to changes in discharge, slope, sediment supply or sediment size.

Other conceptual models, such as the ‘avulsion cycle model’ (refer to section 2.5) describe a system that moves progressively out of equilibrium (through reduced flow conveyance) until a threshold is crossed where the waterway moves into a new state (an avulsion) and the cycle starts again.

Conceptual models usually focus on the physical and ecological processes in a waterway. Managers can use a type of conceptual model known as an impact logic to relate the physical processes described by more generalised conceptual models to the history and particulars of a subject site or reach. In doing so, an impact logic provides a clear, explicit link between physical processes, management actions, and waterway objectives at a reach or site. More detail on building an impact logic is provided in section 3.2.2.

2.2 Incision

2.2.1 Definition

Incised waterways are waterways that have previously or are currently undergoing a process of channel deepening (i.e. degradation or incision) and resultant channel widening. Incision occurs first as an increase in channel depth, followed by an increase in channel width. These waterways are part of what are known as cut and fill waterway systems and are a natural feature of the south east Australian landscape. However, the temporal and spatial distribution of waterway incision has increased as a result of colonisation and development. This type of waterway can include large waterways within well-developed floodplains and much smaller gullies that extend up into un-channelised valleys (see Figure 7 for an example). Examples of incised waterways in Victoria include:

- Hodgson Creek, Burgoigee Creek, Barwidgee Creek, Boggy Creek and Fifteen Mile Creek in north east Victoria.
- The Cann River and Clifton Creek in east Gippsland.
- The Avon River in west Gippsland, and Bruthen Creek in south Gippsland.
- The Bunyip River in the Westernport catchment, and Gardiners Creek in the Yarra River catchment.
- Retreat Creek and Wormbete Creek in the Barwon River catchment.
- Bryan Creek and Pigeon Ponds Creek in the Glenelg River catchment.
- Hughes Creek and Brankeet Creek in the Goulburn River catchment.
- Bendigo Creek near Huntly in the Loddon River catchment.
- Glen Lofty Creek and O’Shays Creek in the Wimmera River catchment.

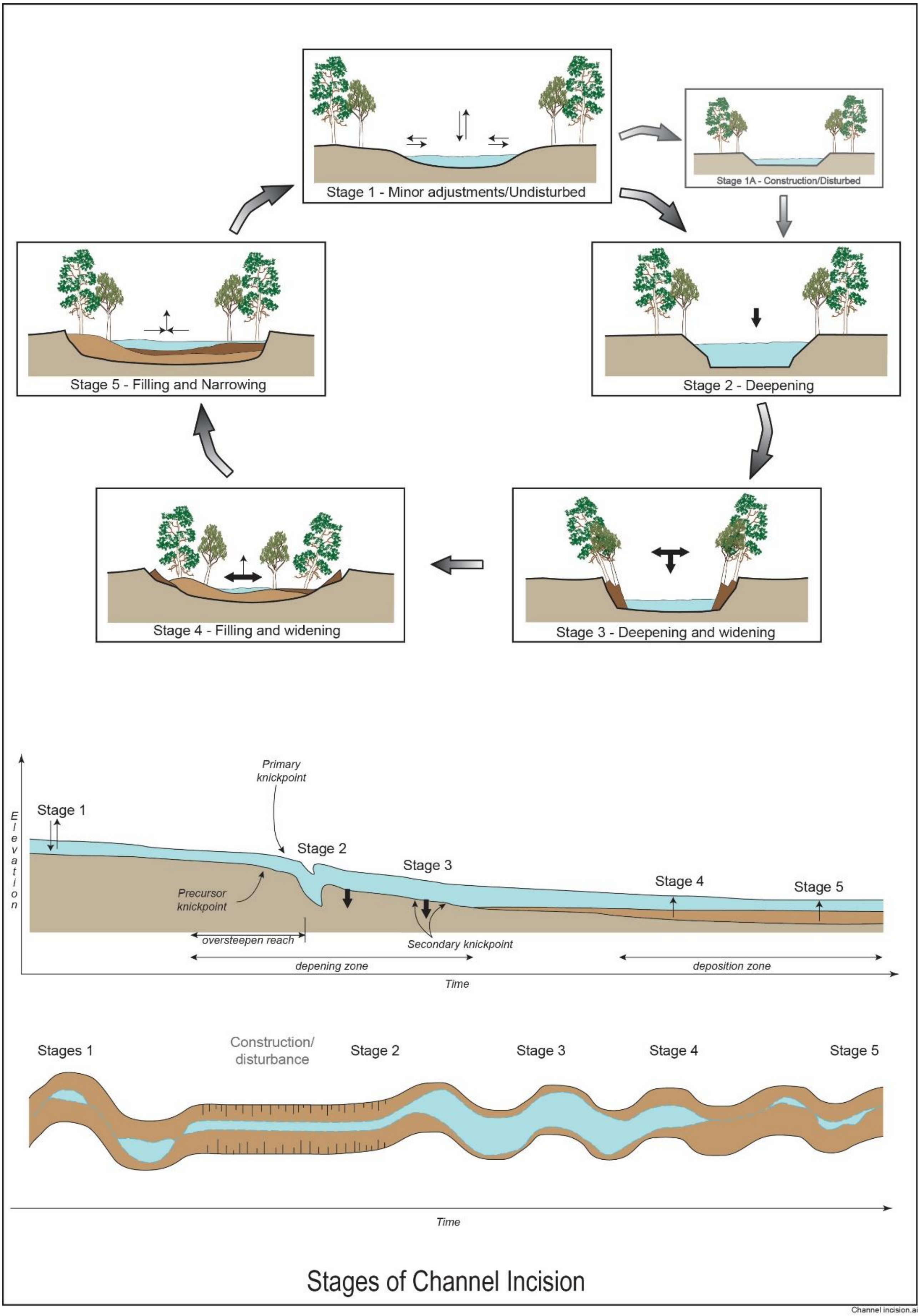
Bed load sediment continuity in combination with erosion and resistance forces can be used to understand the factors that influence incision (degradation). Incision can be expected in waterways where the bed load sediment transport capacity exceeds sediment supply, and where erosion forces on the bed of the waterway exceed the resistance of the bed material. The Lane balance model (Figure 3) explains some of these factors that influence incision and predicts how the waterway will respond, but not the more detailed sequence of channel changes that occur once incision is initiated.

Stages of incision

An additional and well-known conceptual model of incised waterways divides the incision process into six stages (Simon, 1989). Each stage is a snapshot in time of the incision process. An adaptation of Simon's model of the incision process is shown in Figure 4. An understanding of the processes of incision and knowledge of the stages of incision will assist the development of an incision management program. The stages of incision are outlined below.

- *Stage 1: Minor adjustments/undisturbed:* This stage represents the undisturbed or fully recovered stage of incised channel evolution. Waterways in this stage will have regular overbank inundation. For example, overbank inundation could be expected in a 50% annual exceedance probability (AEP) event.
  - Stage 1A: Constructed stage: Waterways pass though the constructed stage if direct physical intervention in the waterway is used to reshape, or construct, the waterway. Construction of a new channel involves reshaping the existing channel banks or repositioning the entire channel. This stage can include activities that result in an increase in reach sediment transport capacity, decrease in bed load sediment supply and/or change in resistance of bed material.
- *Stage 2: Deepening:* This is the initial stage of incision. The incision (deepening) leads to an increased proportion of the flow regime carried within the channel (rather than the floodplain), increasing the energy expended in the channel and erosion of the stream bed.
- *Stage 3: Deepening and widening:* Following initial incision, the waterway will undergo further incision accompanied by channel widening. The widening can be driven by processes such as the undercutting of banks and associated slumping. Waterways in this stage of incision can contain events up to the 1% AEP event.
- *Stage 4: Filling and widening:* Waterways in this stage have ceased incising, with active incision having moved upstream. The waterways are subject to aggradation arising from sediment delivered from the upstream progressing erosion. Some widening may occur as a result of erosion forces in flood events exceeding the bank resistance.
- *Stage 5: Filling and narrowing:* This stage represents the final phase of channel incision where the capacity to export sediment is less than the sediment delivered from upstream and erosion forces are largely less than the bank resistance. The bed aggrades and sedimentation leads to the formation of a narrow, meandering channel inset within the wider incised system.

Figure 4. The five stages of channel incision and recovery (adapted from Simon, 1989).



2.2.2 How to recognise incision

Many incised waterways across SE Australia have moved to either stage 4 or 5 of the 5-stage sequence above. At these stages, the rate of channel change is declining and the channel is no longer degrading (incising). A slow rate of, or complete lack of aggradation can be the result of low sediment supply to the recovering sections of waterway. During stages 4 and 5 vegetation is likely to establish, and channel change occurs in the form of meander development and migration. Sediment yield in Stage 4 will have declined from the peaks in Stages 2 and 3. Figure 5 shows an actively incising stream and the halt in the incision process arising from the construction of a chute at the eroding bridge, which stopped migration of the head-cut. Vegetation (mostly weed species) then invaded and inhibited further deepening. The cut in sediment supply that has arisen by preventing headward erosion has prevented the aggradation at the subject site. The system now remains in stage 4 of incision, not completing the incision cycle through to stage 5. Figure 6 shows a similar system that has been subject to historic incision that is now stabilised and held in stage 4 of incision.

Figure 5. Fells Creek, west Gippsland, actively eroding (above) and held in stage 4 of incision (below).

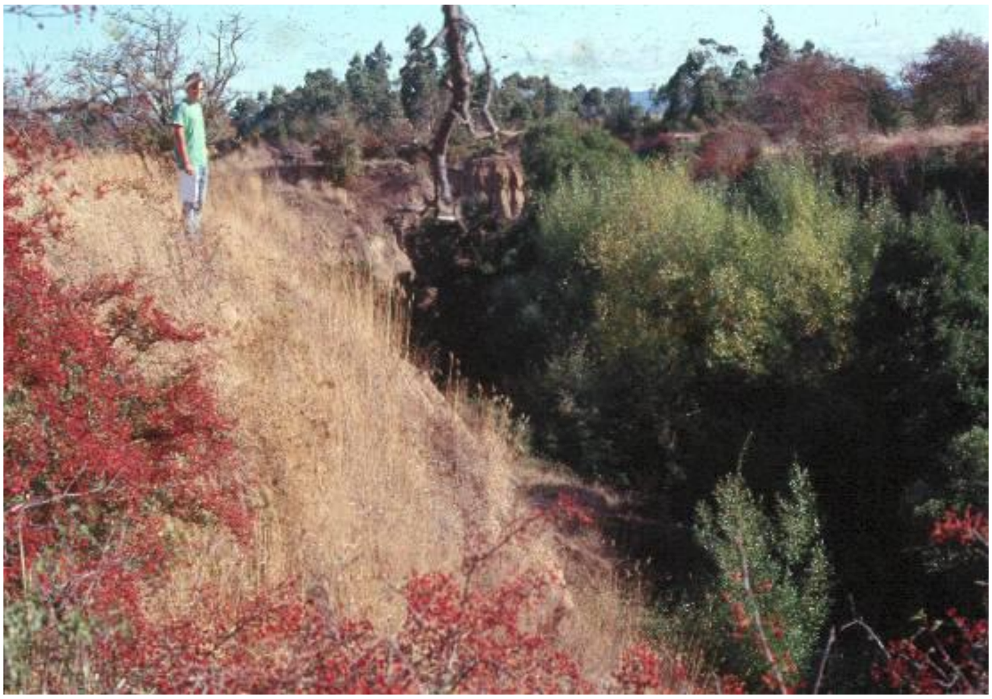


Figure 6. A stabilised gully held in stage 4 of incision that is now filled with trees (the peak of erosion in this gully was probably between the 1930s and 1950s).

Incised waterways can be identified using field inspections, by comparing historic and contemporary photos of the channel, and by assessing change in channel dimensions using repeat cross-section, LiDAR (light detection and ranging) or bathymetric surveys.

The characteristic signs of incision will depend on which stage of the incision cycle a subject reach is passing through. Incised waterways can be recognised by:

- Stage 2 (deepening):
  - A low width to depth ratio.
  - A simplified channel bed that lacks features such as pools and riffles, loss of instream bars, erosion of benches and erosion scarps on both sides of the bed.
  - The presence of a steep headcut at the upstream extent of channel incision, and in some waterways the presence of knickpoints (step changes in bed elevation) on the channel bed (Figure 7 left).
- Stage 3 (deepening and widening):
  - A sharp break in slope between the floodplain and channel, which gives way to vertical channel banks that are very high, devoid of vegetation and are being undermined at the toe (Figure 7 right).
  - Bank slumping and possibly the preservation of slumped material at the toe of the bank.
- Stages 4 and 5 (filling and widening and filling and narrowing):
  - Streambed aggradation in downstream reaches, which have received the increased sediment inputs from the upstream channel incision.
  - The presence of terraces, that may or may not support vegetation, set within the over-widened channel banks.
  - A sinuous low flow channel that meanders between terraces or near vertical banks that form the boundary of a large trench.

Incised waterways can also be recognised through hydraulic analysis of channel capacity, bed grade and unit stream power. These assessments are discussed in section 5.3 of the Guidelines.

Incision can occur in smaller waterways in the catchment headwaters, often described as gullies (see examples in Figure 7 of a true gully – this section of the waterway is passing through stage 3 – deepening and widening). Many incised streams also occur in floodplains, or in larger streams located in wide valleys, often termed valley floor incised streams.

Seven Creeks is an example of an incised waterway in a floodplain (Figure 8). This waterway was a small, sinuous creek with dense vegetation. Clearing and flow concentration led to incision. Evidence that this is a waterway modified by incision: (1) historical descriptions (2) the channel is unusually deep for its width (3) vertical banks on both sides of the creek (although these are disappearing as the creek moves into stage 3 of its evolution).

Figure 7. A headcut at the upstream end of an incising gully adjacent to the Brodribb River, east Gippsland (Left). Incising tributary of Korkuperrimul Creek, Bacchus Marsh, Victoria (Right).

Figure 8. An incised section of Seven Creeks (a tributary of the Goulburn River).

2.2.3 Drivers of change

The drivers of incision operate at the local, reach and catchment scale. Changes that cause an imbalance between sediment supply and sediment transport capacity are summarised by Lane's balance model (1955), which can be used to identify the types of changes that trigger or accelerate incision (tipping the scales in Figure 3 to the right). Those changes are:

- An increase in discharge (without a corresponding increase in sediment supply or grain size). For example the increase in peak discharge following catchment urbanisation.
- An increase in slope. For example, the channelisation of a waterway by removing meander bends.
- A decrease in sediment supply without a corresponding decrease in discharge, for example instream sediment extraction.

Incision can also be triggered by a more localised change in either erosion or resistance forces, for example:

- The concentration of flow, that was previously widely dispersed, into a narrow channel, locally increasing erosion forces. For example, excavation of drainage lines to drain swampy areas.
- The removal of instream vegetation, large woody debris or an armour layer from the bed of the waterway, locally decreasing resistance forces.

Often, incision occurs in response to changes in land use and in-channel management. Much of the incision in Victoria can be attributed to removal of the stabilising vegetation combined with concentration of flow by drains or roads. However, extensive areas have been subject to incision as a result of physical disturbance of waterways. For example:

- Channelisation to reduce waterlogging in Bunyip Creek, west Gippsland and Fifteen Mile Creek, north east Victoria.
- Channelisation to reduce the impacts of sedimentation and construction of barriers that starve sediment from downstream reaches, both associated with mining in Hodgson Creek, north east Victoria and Bendigo Creek, northern Victoria.

Waterway bed incision in the Cann River has been attributed to the removal of instream wood, which decreased channel roughness and led to higher unit stream power. In some areas of metropolitan Melbourne (e.g. Gardiners Creek/Kooyongkoot) incision has been attributed to changes in catchment hydrology associated with catchment urbanisation. However, waterway incision can also be the result of entirely natural processes. Distinguishing between natural and human-induced waterway incision is difficult using observations of channel change alone. A wider, catchment context and an understanding of the natural and current hydrology, sediment supply, vegetation condition, and history of physical disturbance to the waterway is needed.

2.2.4 Impacts of incised waterways

Incising waterway systems can have a significant adverse impact on the health of waterways and the integrity of adjoining infrastructure. Typical adverse impacts of incision include (but are not limited to):

- The releases of large volumes of sediment, which are delivered to downstream reaches and waterways, where it can trigger aggradation, loss of instream habitat and a decline in water quality.
- Bank collapse and the loss of adjoining infrastructure, riparian vegetation, and access to the waterway.
- The loss of instream habitat such as pools and riffles, and the loss of instream wood.
- The loss of connection between the channel and floodplain via a reduction in overbank flows, which decreases or eliminates the frequency that floodplain habitat features such as billabongs or wetlands are inundated.
- A decrease in channel bed roughness, which increases flow velocity that exacerbates the incision process.
- The loss of land due to channel enlargement, often associated with loss of cultural values or loss of agricultural production.
- A loss of waterway amenity and recreation opportunities.
- Damage to, or loss of, waterway infrastructure such as roads, bridges or buildings which are undermined by channel deepening or bank erosion.

- Secondary impacts due to the decrease in mean water level in the incised channel, including the potential for incision to migrate into adjoining tributaries and a decrease in groundwater levels on the adjoining floodplain.
- Headward erosion leading to the loss of upstream intact waterway forms including remnant wetlands.

Figure 9. Waterway bed incision, Barwidgee Creek catchment, north east Victoria (top); Waterway bed incision, Mathews Creek, near Deans Marsh, south west Victoria (bottom).

2.3 Aggradation

2.3.1 Definition

Waterway aggradation is a process of net sediment deposition within the waterway channel that results in a rise in the bed elevation. Aggrading waterways are common across south east Australia and many formed in response to historic changes in land use following colonisation. For example:

- The Glenelg River, western Victoria, which underwent streambed aggradation due to increased sediment input from the catchment following a change in land use practices (and accelerated catchment erosion) after colonisation.

- The Tambo River, east Gippsland which underwent streambed aggradation after large volumes of sand liberated from the catchment accumulated in the lower reaches.
- Creightons Creek, Castle Creek and Pranjip–Nine Mile Creek in the Goulburn River catchment in Victoria which underwent stream aggradation due to sand inputs following incision and gullying in upstream reaches.

2.3.2 How to recognise streambed aggradation

Excessive or rapid streambed aggradation is easy to identify; channels that previously stored sediment on their beds at modest depths dramatically fill with sediment to the point that the channel becomes much shallower. Aggradation that occurs more slowly, over many decades can be more difficult to identify. Typical signs of streambed aggradation include:

- A gradual rise in bed elevation over time, which can be identified by:
  - Comparing historic and contemporary photos of the channel.
  - Using a combination of repeat channel cross-section, LiDAR or bathymetric surveys.
  - Anecdotal reports of channel change from landholders, such as the loss of pools, burial of instream wood, or channel widening.
- A change in the type and size of sediment on the channel bed. Accumulation of coarse sand is responsible for streambed aggradation in many south east Australian waterways and may bury bed sediments that are considerably finer (clay and silts) or coarser (gravels).
- Changes in planform that occur in response to the increased sediment supply. For example, an overall channel straightening, increased meander cut-offs and avulsions, and the transition from single thread low flow channel to a braided channel form.
- Just as meandering waterways may also be incising, aggrading waterways may also meander and undergo avulsion or a waterway recovering from incision.

Given that streambed aggradation is the net accumulation of sediment on the bed of an existing channel, identifying whether a meandering waterway is undergoing streambed aggradation relies on identifying the signs outlined above.

Whether an aggrading waterway is undergoing an avulsion (or is likely to in the future) is more challenging and requires an assessment of the aggrading waterways relationship with the surrounding floodplain. Identifying whether an aggrading waterway forms part of a wider avulsion complex is described in section 2.5.

2.3.3 Drivers of change

Streambed aggradation can be triggered by one or more of the following types of changes in a catchment or waterway:

- A reduction in sediment transport capacity due to either:
  - a reduction in discharge, for example due to large scale flow diversion or the development of an anabranch.
  - A reduction in the slope of the reach, for example the lengthening of a channel by meander development or the installation of a dam downstream that raises the local based level.
- An increase in the grain size of bedload sediment being supplied to the reach, for example when a tributary delivers a pulse of coarse sediment to a reach.
- Increased sediment delivery to the subject reach. The more sediment supply is increased above background levels for a subject reach, the more rapid and deep the streambed aggradation.

In Victoria the low gradient of many waterways that have received increased sediment supply has meant that accumulating sediment moves downstream very slowly, so that sediment generated many decades in the past, continues to impact large sections of waterways today.

Drivers that can increase sediment supply to downstream reaches include:

- Historic clearing of native vegetation from hillslopes and their replacement with pasture grasses to support agriculture. The change in land use has resulted in significant and widespread increase in erosion from hillslopes, and incision of low order drainage lines that feed larger waterways. The sediment liberated by catchment erosion accumulates downstream in lower gradient waterways.
- Clearing of native vegetation from riparian land or the channel in upper reaches, which initiates incision or accelerated meander migration that delivers increased sediment to downstream reaches.
- Activities at the catchment or sub-catchment scale such as the large scale construction and management of roads.
- Large scale fire events that trigger vegetation loss and increase runoff and sediment delivery in the short to medium term.
- Direct physical intervention in the channel, such as excessive sediment extraction or channel realignment, that triggers an erosional response in adjacent/upstream reaches.

Additionally, past activities such as alluvial gold mining and historic forestry operations deposited large volumes of sediment directly into waterways. Over time, these large pulses of sediment migrate downstream where they trigger streambed aggradation.

2.3.4 Impacts of aggrading waterways

Streambed aggradation can have a significant adverse impact on the health of waterways and the integrity of adjoining infrastructure. Typical adverse impacts of aggradation include (but are not limited to):

- Filling of the channel and an increase in meander cut-offs that lead to overall channel straightening of the channel. This straightening can lead to higher rates of sediment transport (and hence, more rapid sediment delivery to downstream reaches).
- Loss of instream habitat and amenity due to the filling of pools, smothering of riffles and the burial of instream wood and vegetation.
- A decrease in channel capacity, which leads to an increase in the magnitude and frequency of overbank flows, impacting floodplain assets and further slowing the rate sediment moves downstream.
- Triggering of secondary channel changes, including channel widening, the blocking of tributary junctions, the formation of anabranch channels and accelerated channel avulsion development.

Figure 10. Streambed aggradation in Bryan Creek, a tributary of the Wannon River, photo taken in 1947 (top), and streambed aggradation in Reedy Creek, north east Victoria (bottom).

2.4 Accelerated meander migration

2.4.1 Definition

Meandering channels are abundant throughout Victoria. Notable examples of meandering channels include:

- The Birrarung/Yarra River that flows westwards through Melbourne.
- The Warring/Goulburn River, north central Victoria.
- The Durt-Yowan/La Trobe River, west Gippsland.
- The Barringgi Gadyin /Wimmera River, north west Victoria.

A meandering waterway has a channel that winds snakelike through its valley, so that the distance ‘as the waterway flows’ is greater than ‘as the crow flies.’ The channel constitutes successive meander bends, each of which naturally migrates across-valley and downstream by erosion of the channel bank on the outside of the meander bend.

Meandering is a natural part of waterway evolution, and its commencement can be observed even in artificially straightened waterways, such as those with high stream power and in incising systems.

2.4.2 How to recognise accelerated meander migration

Meander bends are straightforward to identify in the field and using aerial photography. Meander bends are concave sections of channel bank where the waterway changes course. Identifying the subset of meander bends whose migration has accelerated relative to background rates can be done by:

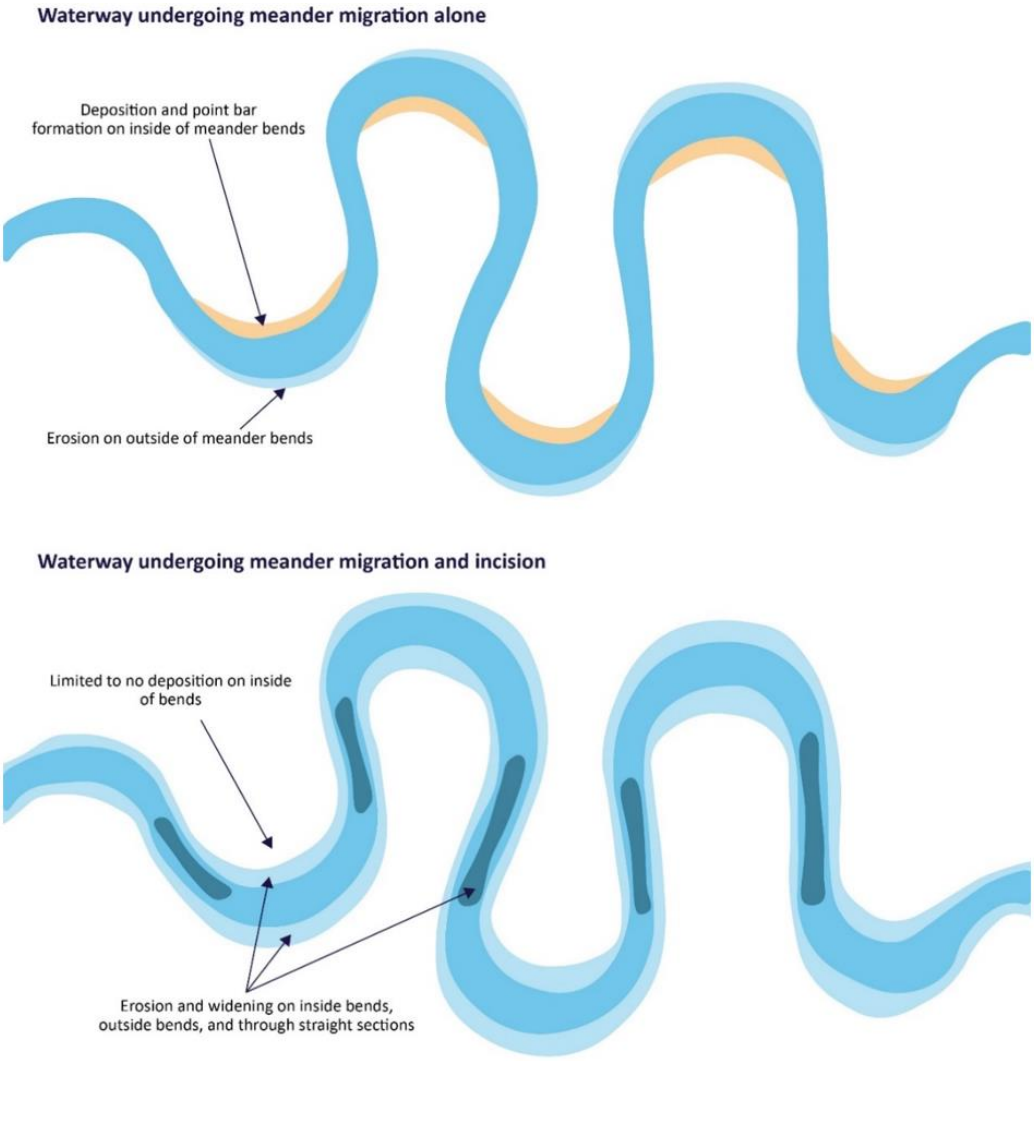
- Mapping channel bank lines in sequential, georeferenced aerial imagery and calculating rates of meander migration between successive image captures.
- Identifying unconfined reaches of waterway where meander migration is not inhibited by bedrock outcrops, natural features such as terraces, or the valley margins. Meander bends within these unconfined reaches have the potential to migrate.
- Speaking with local landholders who have observed bank erosion and/or experienced loss of floodplain land.
- Using field inspection of waterways: Meander bends undergoing accelerated meander migration may exhibit a steep or vertical bank on the outside of the bend, with exposed sediment and signs of recent erosion. Signs of recent erosion include:
  - Undercut banks which are prone to mass (block) failure,
  - Notching along a consistent elevation along the bank face or at the toe of the bank.

While vertical banks are one sign of bank erosion, not all steep or vertical banks are actively eroding. Bank angle and height should be used in conjunction with other observations to diagnose active mender migration. It should be noted that none of the methods above 'prove' that meander migration rates have been elevated above natural/pre-colonisation rates. Whether or not the rate of meander migration has been accelerated, identifying contemporary rates of meander migration allows the future position of the meander bends to be predicted, and the potential impact of meander migration on waterway values to be understood.

Meandering channels may also be undergoing incision. Distinguishing between channels that are undergoing meander migration without incision from those undergoing meander migration due to incision requires that the evidence for channel incision be evaluated in the meandering channel (Figure 11).

Meandering channels undergoing incision exhibit erosion on the inside and outside of meander bends, whereas waterways undergoing meander migration alone will be characterised by erosion on the outside of meander bends and deposition on the inside of meander bends. Further, incising channels tend to become deeper over greater lengths of waterway that span multiple meander bends, whereas any deepening of meandering channels not undergoing incision will tend to be restricted to pools on the outside of bends.

Figure 11. Top – waterway undergoing meander migration alone with erosion on outer bends and deposition on inner bends. Bottom – meandering waterway undergoing incision with widespread erosion (widening).

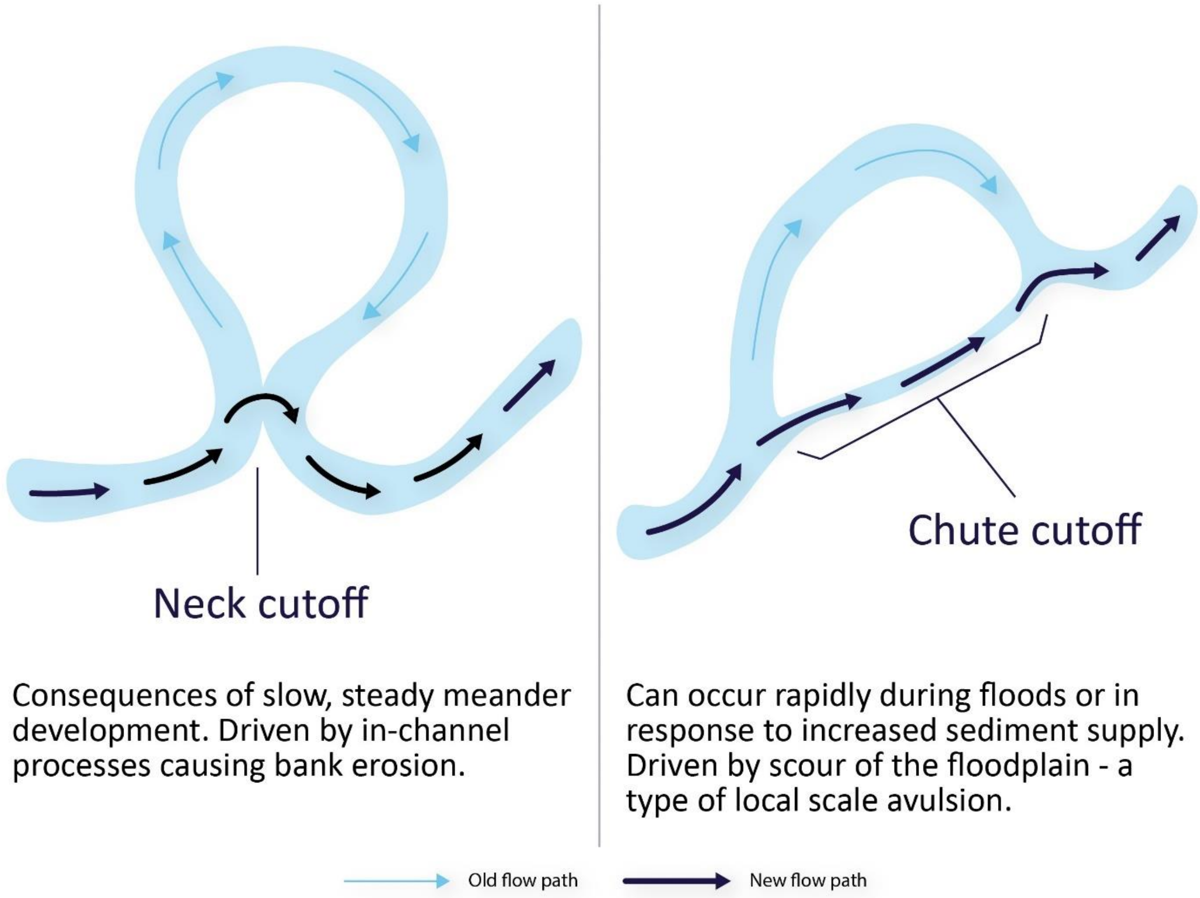


Meander cut-offs (Neck and chute cut offs)

Meander cut-off refers to the process by which a meander bend, or series of meander bends, are abandoned as the channel becomes straighter. Over time the former meander bends, which are isolated on the floodplain, can fill with fine sediment and become billabongs. There are two types of meander cut-off, each driven by different processes:

- Neck cut-off occurs when two migrating meanders intersect, pinching-off the main channel. Neck cut-off is driven by the in-channel processes that drive erosion on the outside of the meander bend.
- Chute cut-off occurs when floodplain scour creates a new, straight channel, that connects two meander bends. Chute cut-offs are the result of floodplain scour and could be considered as a type of small-scale channel avulsion.

Both neck cut-offs and chute cut-offs result in a straighter channel with a steeper grade, but the causes and the appropriate response to these two types of meander cut-off are different.

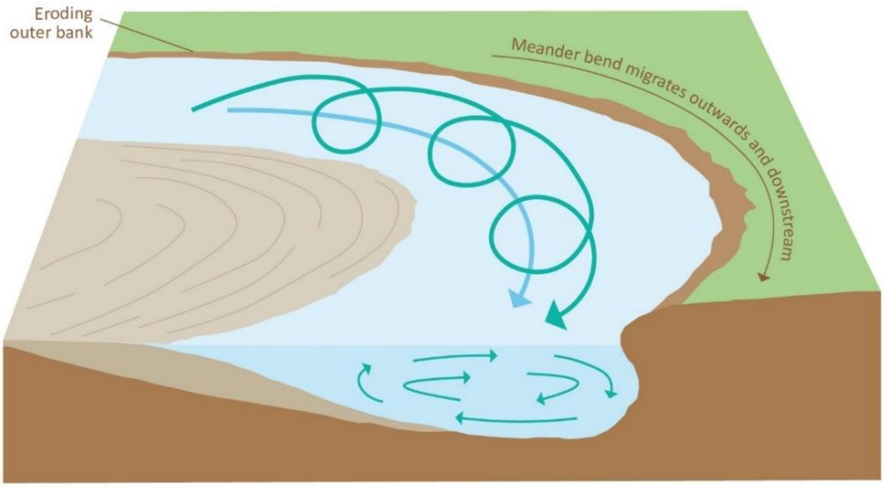


2.4.3 Drivers of change

Natural meander migration is an important part of a healthy waterway, and is responsible for floodplain development, the generation and maintenance of pool habitat, and point bar development. All waterways meander and with all other things being equal, meander bends in waterways with high stream power tend to migrate faster than waterways with lower stream powers. However, the rate of meander migration has been greatly accelerated in many of Victoria's waterways since colonisation, often in response to the removal of riparian vegetation or increases in stream power due to altered flow regimes.

Meander bends create a difference in flow velocity between the outside of the meander bend, where velocity and water surface elevation are higher, and the inside of the meander bend, where flow velocity and water surface elevation are slightly lower. The difference in flow velocity between the inside and outside of the bend creates a corkscrew like (helical) flow that causes flow to plunge downwards towards the channel bed on the outside of the bend while at the same time sweeping sediment across the channel bed and towards the inside of the meander bend. This cross-channel flow is called secondary flow and the shifting of sediment to the inside of the bend leads to the formation of a point bar. This process is shown in Figure 12.

Figure 12. Streamflow through a meander bend, causing erosion on the outside of the bend and deposition and point bar formation on the inside of the bend.



Meander migration occurs when the erosion forces on the outside of the meander bend are greater than the resisting forces of the channel bank.

Activities and drivers that decrease the resistance forces of channel banks on the outside of a meander bend include:

- The loss or removal of riparian and instream vegetation, which decreases resistance forces by:
  - reducing soil cohesion and bulk strength due to the loss of vegetation roots
  - the loss of shielding provided by ground cover in riparian land, instream vegetation, and instream wood, exposing bank sediment to erosion

- Erosion at the toe of the bank which causes the bank to become over steepened and to collapse.

Activities and drivers that lead to an increase in erosion forces on the outside of meander bends include:

- Hydrologic change that causes an increase in stream power for example an increase in the peak discharge for some reference flow in the waterway (e.g. an increase in the peak flow magnitude for the 20 % AEP event).
- The loss of instream wood, which decreases channel roughness, increases flow velocity, and eliminates the shielding effect instream wood provides to the channel banks.
- Direct physical disturbance of the waterway. Disturbances such as channel straightening decreases overall channel length, leading to an increase in bed grade and stream power.
- “Cementing” of point bars by excessive instream woody vegetation (particularly invasive species such as willow, and poplar) that reduces natural stripping of point bars and increases pressure on the outside bend.

Push or pull?

A common observation is that meander bends often migrate at the same time that the point bars on the inside of the bend grow in size. This can lead to the question – does sediment deposition and point bar growth ‘push’ the meander bend outwards by directing flow towards the outside bank, or does erosion on the outside bank ‘pull’ the point bar across the channel by shifting the secondary flow outwards?

The answer: It is erosion on the outside of the meander bend that leads to the development of a point bar, not vice versa. i.e., meander migration is a ‘pull’ not a ‘push’ process. Once the erosion on the outside of the meander is halted, either through encountering a more resistant bank material or through physical intervention (e.g. rock armouring), energy is held up within the bend. This in turn sees sediment being stripped from the face of the point bar until it reaches a state of localised equilibrium.

The implication for management: removing sediment from a point bar aimed at reducing erosion on an opposite riverbank is misguided and will not reduce the rate of erosion. More than likely, such sediment extraction will starve downstream reaches of sediment and lead to increased rates of erosion.

2.4.4 Impacts of accelerated meander migration

Accelerated meander migration, which is expressed as rapid bank erosion and subsequent point bar development, can lead to a number of adverse impacts on waterway condition and values, examples include:

- Increased sediment delivery to downstream reaches, and in particular, increased inputs of fine sediment with high concentrations of adsorbed nutrients.
- Decline in water quality in downstream reaches.
- Declines in bank habitat quantity and quality (e.g. loss of burrows and undercut banks).
- Significant channel change and/or avulsion risk if the meander engages with a pre-existing floodplain feature such as an old flow path.
- The loss of productive land on the adjacent floodplain.
- The loss of cultural values on the floodplain.
- The loss of infrastructure from the floodplain or riparian land (including habitat provided by any remnant riparian vegetation).

Figure 13. Accelerated meander migration following past removal of riparian vegetation.

2.5 Avulsion

2.5.1 Definition

Avulsion is the process of abandonment of a waterway channel in favour of a new, more hydraulically efficient channel. Avulsions occur in almost all alluvial waterways with sufficient accommodation space and take place at multiple scales, from a few meander bends to valley-scale movement of the waterway, when a waterway carves a new course across its floodplain. For the purposes of the Guidelines, avulsions have been identified as changes in channel alignment associated (to some degree) with floodplain scour processes. As such, chute cut-offs have been included into this grouping. As with all of the geomorphic processes discussed in the Guidelines, humans have accelerated the frequency of avulsions.

- Avulsion refers to both the processes of channel abandonment and new channel formation, and the final, potentially very rapid, switching of a waterway course form the old to the new channel (i.e. the avulsion 'event' that connects the parent and daughter channels). The channel that is being abandoned is termed the parent channel and the new channel that has, or is, forming on the floodplain is termed the daughter channel.
- In some systems a single channel will change course and rapidly adopt a new, single, course. In other systems multiple channels can co-exist in various stages of formation and abandonment. The latter are termed anabranching rivers. The newly formed channel may be scoured during a series of floods or may be an existing waterway channel that captures flood flows from the parent channel. In Victoria, the newly formed channel will typically re-join the original channel downstream. Some avulsions are short (hundreds of metres) whilst some can be over a hundred kilometres long (e.g. the major avulsions on the Murray River over the last 40,000 years).
- In general, avulsions only occur where there is a floodplain, but the higher upstream the floodplain is located, the more frequent the avulsions. For example, prior to colonisation, avulsions in the Ovens River in north east Victoria would have occurred every few hundred years at the top of the valley (around Bright/Porepunkah), every few thousand years in the lower floodplain, and at tens of thousands of years on the Murray floodplain through the Barmah-Millewa forest below the Ovens Junction.

Avulsions are fundamentally caused by a combination of reduced channel capacity (meaning that more water is diverted onto the floodplain), formation of an alluvial ridge or levee and sufficient space for a new channel to develop. The different scales of avulsions are driven by different geomorphic processes, but can be grouped in order of increasing scale and frequency, for example:

1. Small scale avulsions in headwater channels, which are usually triggered by sudden sediment inputs (most frequent).
2. Those that occur between confining terraces or former, wider, channel boundaries or as meander chute cut-offs driven by floodplain scour (rather than meander development alone).
3. Avulsions within confined valleys when the active channel switches its alignment between the valley sides. The floodplain in confined valleys is too narrow to accommodate more than two channels at a time.
4. Larger, valley-scale avulsions that generate a network of paleochannels across the floodplain.
5. Very large scale, delta like avulsions within distribution channel networks (least frequent).

The formation of avulsions can be gradual (incrementally developing over multiple flow events) or spontaneous (high energy systems, where the waterway breaks away in a flood and avulses to the daughter channels).

2.5.2 How to recognise avulsion

Abundant abandoned channels on Victoria's floodplains attest to the frequency of avulsion over millennia. In fact, there are few waterways in Victoria that do not have evidence of past waterway channels on their floodplains. There have been numerous major avulsions along Victorian waterways since colonisation. Avulsions from the Barwon River and Thomson River are shown in Figure 14 and Figure 15 respectively. Rainbow Creek was formed in 1954 when floodwaters spilling from the Thomson River scoured a new, much straighter, channel along the southern edge of the Thomson River alluvial fan.

Figure 14. Avulsion channel off the Barwon River west branch. Showing landscape setting (a), aerial view inset (b), and oblique view inset (c).

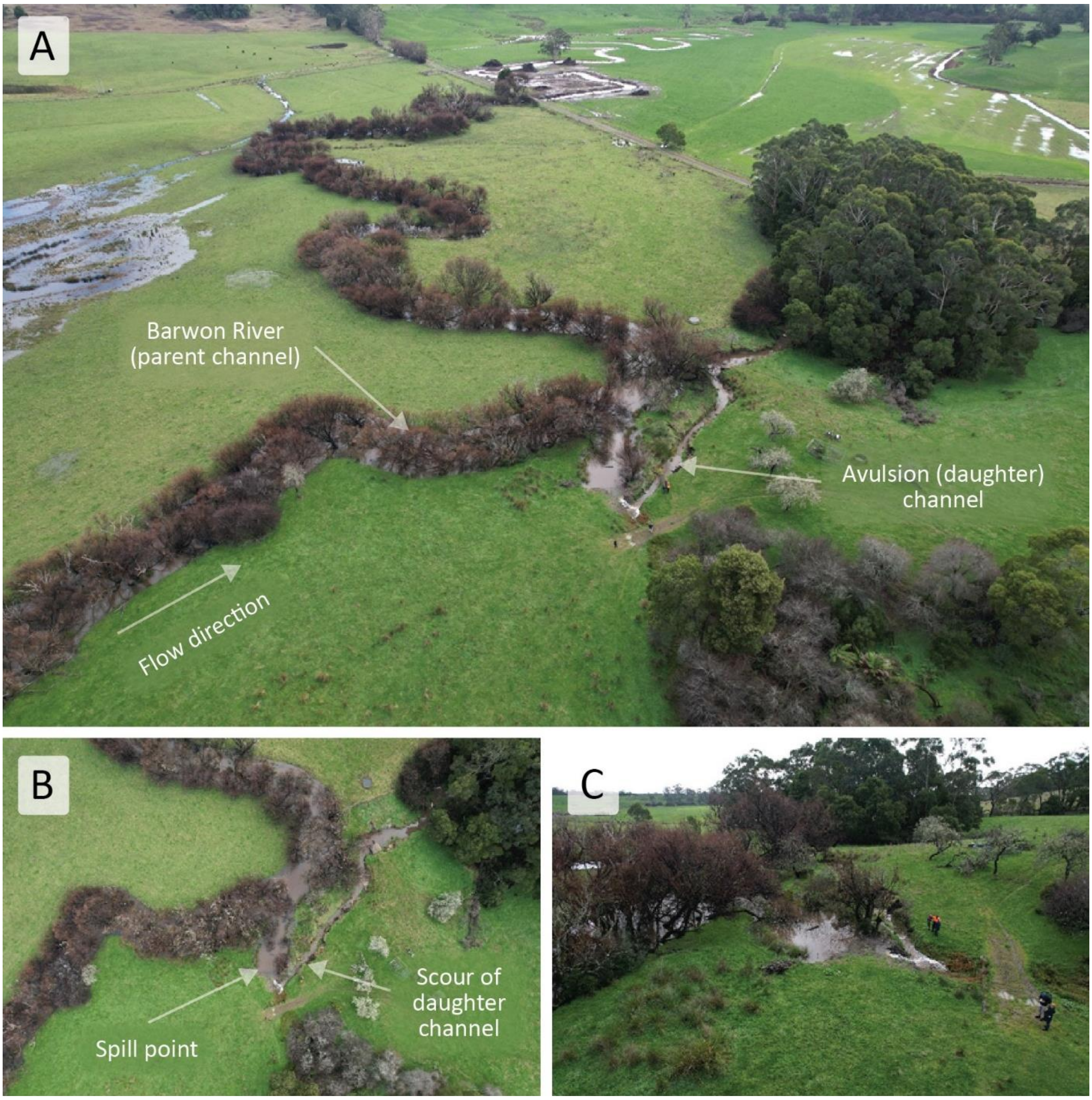


Figure 15. Avulsion from Thomson River to form Rainbow Creek.

Table 1. Major historic avulsions along Victorian Rivers

River	Year	Major Cause
Tambo River, east Gippsland	1893	Reduced capacity of the trunk channel due to a pulse of sand and gravel from gold mining upstream
Avulsion from the Thomson River to form Rainbow Creek, west Gippsland	1952	Reducing capacity of the Thomson River due to high sinuosity, and development of an alluvial ridge
King River, north east Victoria	Various periods up to 1970s	Multiple avulsions along the upper valley related to natural channel evolution accelerated by willow encroachment and floodplain clearing
Ovens River, north east Victoria	1970s	Avulsion of Ovens River into Deep Creek downstream of Everton. Note: ongoing avulsion development continues in this area
Snowy River, east Gippsland	1950s to 1970s	Multiple avulsion channels, form on the floodplain and are artificially blocked by walls. The crevasse splays at the head of the developing channels are locally known as gulches.

Avulsions are not a rare phenomenon and are ubiquitous in Victoria's alluvial rivers. While very large, valley-scale avulsions, that have the potential for significant local, regional, and state-wide impacts, often garner the most attention, even smaller scale avulsions, such as cut-offs that bypass a small number of meander bends, can adversely impact waterway condition and local assets for decades. Furthermore, the rate and magnitude of the geomorphic processes that drive avulsion (i.e. meander migration, streambed aggradation and channel incision) have accelerated since colonisation.

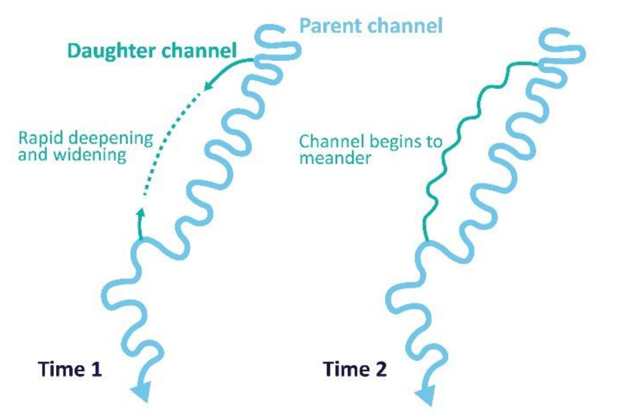
There are a number of developing waterway avulsions in Victoria which have the potential to adversely impact local communities and the values those waterways support. Notable examples include the:

- Avon River at Nuntin, central Gippsland.
- Ovens River at Myrtleford, (Happy Valley Creek) north east Victoria.
- Ovens River at Markwood, (Deep Creek) north east Victoria.
- King River at Oxley, north east Victoria.
- King River at Moyhu, north east Victoria.
- Snowy River downstream of Jarrahmond (Lynns Gulch), east Gippsland.

Identifying waterways undergoing channel avulsion or with potential to be subject to an avulsion relies on identifying the parent channel and the daughter channel (Figure 16). In waterways in the earlier stages of avulsion, or avulsions that occur within a well-defined trench on the valley floor, the daughter channel may not yet have fully formed into a distinct, continuous channel. Instead, the likely location of the future daughter channel can be predicted using elevation data or hydraulic modelling (Figure 17). Typical characteristics that can be used to identify the parent and daughter channels in an avulsing waterway are:

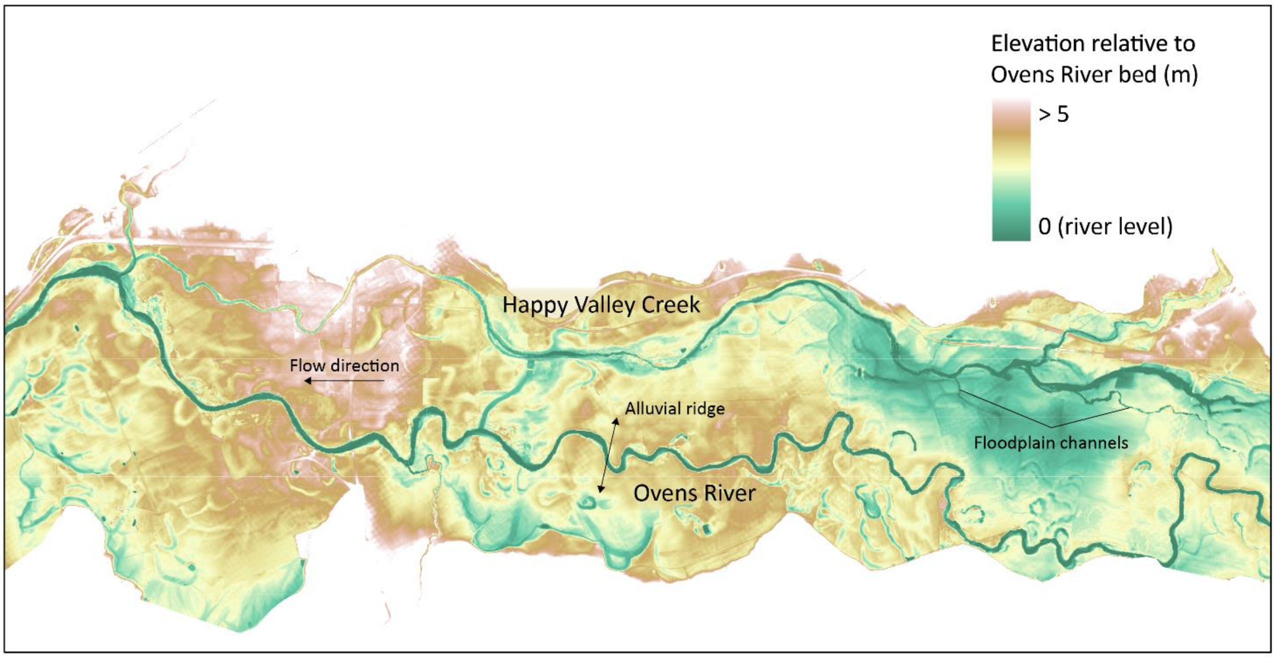
- The parent channel tends to be elevated (or perched) above the surrounding floodplain.
- In larger, valley-scale avulsions, the banks of the parent channel are capped by well-developed (natural) levees, which may contain breakout points where flow preferentially spills from the main channel.
- Parent channels are more sinuous, have lower flow capacity, and often show signs of streambed aggradation and channel narrowing.
- Daughter channels are less sinuous than the corresponding parent channel and may not yet be fully connected to the parent channel.
- Depending on the stage of channel development, daughter channels may either terminate abruptly at their upstream end before meeting the parent channel, or gradually transition to a more subtle network of smaller floodplain channels. The potential alignment of future daughter channels that have not yet developed on the floodplain can be estimated by identifying low-lying areas of the floodplain, where floodwaters naturally accumulate and/or travel. Alternatively, existing channels on sections of the floodplain that are at a lower elevation than the perched parent channel can be identified as potential daughter channels.

Figure 16. Left – the development of the daughter channel in a valley-scale avulsion. Right – the development of smaller scale avulsion channel on a floodplain of Nariel Creek, north east Victoria.



Because avulsing waterways include two channels, and may occur at a variety of scales, high resolution elevation data and hydraulic modelling are often required to identify parent channels primed for avulsion and the actual or potential location of daughter channels that will eventually receive all flows from the parent channel (see Figure 17 for an example in the Ovens River valley).

Figure 17. A relative elevation model map showing the Ovens River (parent channel) in relation to the Happy Valley Creek (daughter channel) and developing floodplain flow paths.



Meandering channels, incising channel, and aggrading channels can all be found as part of a developing avulsion. The parent channel in the process of being abandoned is usually highly sinuous and undergoing active meander migration. Channel changes that increase the displacement of flow onto the floodplain will drive avulsion. Examples of such changes that displace flow in Victoria include meander development, streambed aggradation and willow colonisation. The streambed aggradation can be triggered by the reduction in grade due to meandering, by vegetation encroachment, by sediment inputs from upstream, or by a combination of all three mechanisms. Thus, the parent channel of an avulsion is often a combination of a meandering and aggrading waterway.

The daughter channel of an avulsion is more likely to be undergoing incision. The formation of a new daughter channel on the floodplain follows a particular sequence of channel changes overt time; incision, widening and eventually meandering. When the daughter channel is an existing meandering waterway, then incision and meander migration may occur simultaneously. The criteria used to identify incision (section 2.2) and meandering (section 2.4) can be applied to characterise the daughter channel and to manage the process accordingly. However, for chute cut offs, the daughter channel may comprise a floodplain with no obvious low flow channel. A history of past floodplain scour may be the only sign of a potential avulsion path.

2.5.3 Drivers of change

The process of streambed aggradation, meander development and willow colonisation increase displacement of flow onto the floodplain, leading to floodplain accretion and incision of the daughter channel. Each of these processes occur at a different location and at a different stage in the avulsion cycle, and to a lesser or greater extent depending on the scale of the avulsion. For example, in small, high-energy waterways in catchment headwaters, debris flows may cause rapid channel bed aggradation that quickly triggers an avulsion. Whereas in larger, wider, low-gradient valley floors, waterway lengthening via meander migration and channel contraction may be the primary drivers of avulsion. While avulsion is a fundamental behaviour of alluvial waterways, there are several factors that can accelerate the process by increasing the mismatch in hydraulic efficiency between the parent and daughter channel. Processes that accelerate the decline in hydraulic efficiency of the parent channel include:

- Channel blockages that force floodwater to spill from the parent channel and concentrate in developing daughter channels. Blockages may arise due to large wood jams in the channel, beds of willow on the channel bed, pulses of sediment causing rapid streambed aggradation, or bank collapse that dams the channel. (Typically associated with spontaneous channel avulsions).
- Colonisation of the channel banks by willows, that trap sediment and promotes channel contraction.
- Removal of riparian vegetation that results in accelerated meander migration, channel lengthening and a decrease in channel grade.
- An increase in sediment supply that causes streambed aggradation in the parent channel.

Processes that lead to an increase in the hydraulic efficiency of the developing daughter channel include:

- Removal of floodplain vegetation that would otherwise decrease the velocity of floodwaters and limit floodplain scour.
- Removal of riparian vegetation that would otherwise limit the rate of channel widening in the daughter channel.
- Changes to the flow regime or sediment supply of an existing daughter channel, leading to incision and channel expansion.
- Structures that re-direct floodwaters towards low-lying areas of a floodplain and promote floodplain scour and daughter channel development.

Construction of artificial levees alter flow and sediment transport, and interact with other processes to produce both incision and aggradation depending on the geomorphic context. While levees can limit the displacement of water onto the floodplain, such levees also prevent sediment export from the parent channel and accelerate the rate of channel aggradation. The point here is that levees have the potential to impact on the avulsion process and such impacts should be carefully considered before establishing levees on avulsion-prone waterways.

The relationship between avulsion and floods

Floods drive both the gradual decrease in parent channel capacity and provide the flows that enlarge the daughter channel. Floods also act as the final ‘trigger’ for completion of the avulsion cycle when the parent channel fully connects with the daughter channel. However, the risk posed by flood inundation (flooding) is fundamentally different to the risk posed by an avulsion, triggered by a flood event.

Flood hazards include inundation, damage to assets by fast moving waters or flood debris and blocking of road access by flood water.

The primary hazard arising from an avulsion is the complete loss of land to erosion. Erosion caused by an avulsion may also deliver large volumes of sediment to downstream reaches, which can cause secondary hazards where material can block culverts or bury infrastructure.

While flood inundation and avulsions are closely related to flood events they are different and as a result different approaches are required to manage the risks they pose to assets and waterway condition.

Avulsion may occur spontaneously during a single flood event, for example when debris or sediment blocks a channel. These spontaneous avulsions are less predictable due to the absence of a developing daughter channel on the floodplain prior to the avulsion and are common in high energy waterways (for example in headwater streams).

Larger, valley-scale avulsions undergo a predictable cycle as the hydraulic capacity of the parent channel declines. The steady decrease in flow conveyance and sediment transport capacity initiates a positive feedback loop that culminates in an avulsion. Overall, the avulsion cycle for larger-scale avulsions is:

1. The parent channel becomes increasingly hydraulically inefficient, and overbank flooding becomes more frequent. Sediment is deposited on the bed and banks in the lengthening parent channel. Sediment deposition and channel contraction increase the frequency of flow spilling from the parent channel and onto the floodplain.
2. During floods, a wedge of sediment is deposited along the channel banks, forming natural levees.
3. Over time, repeated floods cause the channel levees to grow upwards and outwards. Levee growth eventually develops an alluvial ridge; a wedge of sediment that runs along both (left and right) banks of parent channel and is elevated above the surrounding floodplain. As a result, the parent channel becomes perched increasingly higher above the surrounding floodplain (and the daughter channel).
4. The elevation difference between the alluvial ridge and developing daughter channel (or other existing channel on lower lying areas of the floodplain) means that flood flows are concentrated into the daughter channel, causing the daughter channel to become wider, deeper and to migrate in an up-valley direction.
5. Floodwaters flowing into the developing daughter channel scour new channels across the floodplain, which feed water to the daughter channel. Over time, the scour channels migrate in an upstream direction towards the parent channel. The scour channels eventually meet (‘capture’) the parent channel, diverting all of the water and sediment into the daughter channel, triggering an avulsion. The daughter channel undergoes a repeat of that cycle.

2.5.4 Impacts of avulsing waterways

The scale and location of impacts arising from channel avulsion depend on the scale of the avulsion, and whether there has been sufficient time to prepare for the consequences of avulsion. Local scale avulsions, such as those in headwater waterways or meander chute cut-offs generated by floodplain scour have more limited impacts than larger valley-scale avulsions, but such local impacts can still be significant if high value assets lie in the avulsion pathway. Overall, the scale of impacts increases with the scale of the avulsion, which leads to the following:

- The development of a new channel on the floodplain. The new channel will be much wider and deeper than any existing floodplain scour channels. Formation of the channel can lead to the loss of floodplain, isolate the sections of land between the parent and daughter channel, damage assets within the pathway of the daughter channel, and alter the future frequency and depth of flooding across the valley floor.
- A sudden increase in the width and depth of an existing daughter channel. Expansion of the daughter channel will initially occur by bed and bank erosion. Increases in the width of the daughter channel will lead to the permanent loss of assets with river frontage on

the daughter channel. Bed and bank erosion will severely damage any bridges or pipes that cross the channel.

- In addition, large-scale erosion of the daughter channel will deliver large volumes of sediment to downstream reaches of both the parent and daughter channel. Increased sediment supply may have adverse impacts on waterway condition and rates of channel change in the short-term. The impacts will dissipate with distance downstream as the pulse of sediment disperses, and over the medium- to long-term the scale of downstream impacts will decline as sediment is re-worked and transported downstream.
- A significant decrease in flows in the abandoned reach of the parent channel. Flow inputs may decline slowly or may cease abruptly. In some systems multiple channels may co-exist for long periods. Decreased flows will adversely impact instream habitat, riparian vegetation, amenity values of the reach and lead to the loss of reliable water source for landholders with a licence to extract from the waterway in the affected reach.
- The potential for bed incision upstream of the avulsion point, due to the much steeper grade of the daughter channel following avulsion. Upstream progressing incision could undermine channel banks causing slumping and channel widening, which is likely to lead to a loss of riparian land and adverse impacts on waterway condition.

The deepening, widening and eventual meandering of the newly formed daughter channel has similar impacts to those caused by incised waterways (refer to Figure 18 for an example on Reedy Creek). Channel expansion in the daughter channel releases large volumes of sediment, which is transported into downstream reaches where it may trigger streambed aggradation and associated impacts. Similarly, the gradual (and then possibly sudden) abandonment of the parent channel in favour of the daughter channel is accompanied by streambed aggradation and loss of flow in the parent channel. The impacts of channel abandonment are at first similar to those in aggrading waterway but become more severe if they are starved of all flow.

There remains considerable uncertainty as to the timeframe of the avulsion cycle. In some cases, the abandonment of the parent channel and development of the daughter channel occurs gradually, providing time for floodplain assets or infrastructure to be relocated. In other instances, the final change from parent to daughter channel may occur during a single flood event, and the expansion of the daughter channel may occur very rapidly. The rapid expansion of the daughter channel means that there may be little time to relocate floodplain assets away from the developing channel.

Figure 18. Avulsion development at Reedy Creek, north east Victoria. Top – Reedy Creek looking downstream with avulsion channel (left of photo) and Reedy Creek (right of photo). Bottom – avulsion pathway through floodplain of Reedy Creek.

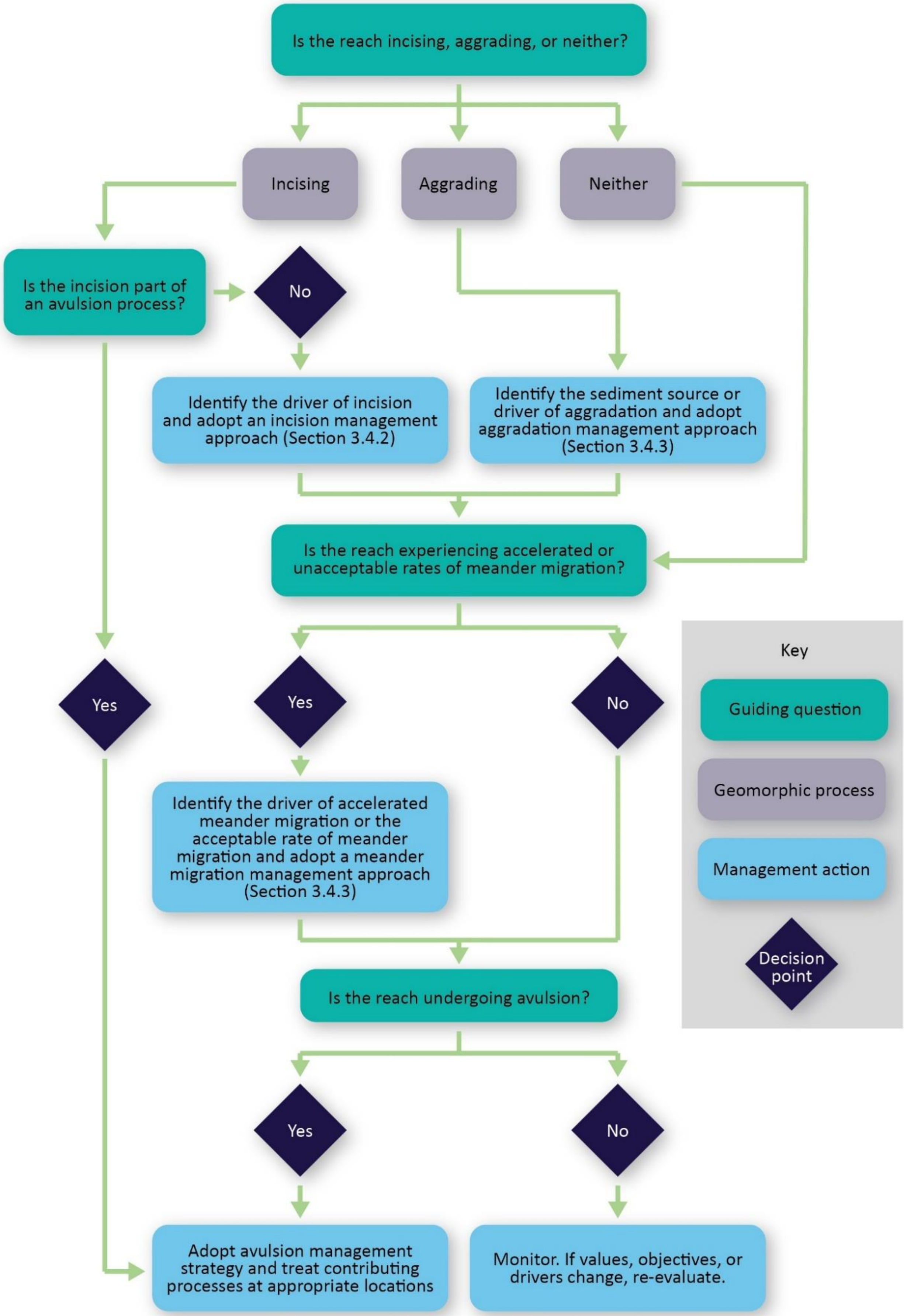
2.6 Deciding which geomorphic process to manage first

In some cases, more than one geomorphic process will be operating in a single reach and waterway managers must choose which geomorphic processes to manage first. Failure to manage the right geomorphic processes in the right order risks intervention failing to achieve the intended objective for the reach either because interventions are undermined by future channel change, or interventions fail to treat the process impacting values in the reach (i.e. interventions treat the symptom rather than the cause).

The decision tree in Figure 19 can be used to help waterway managers choose which geomorphic process to manage first. The order of the guiding questions and resulting management actions reflect the following principles:

- Wherever possible, treat the cause of the geomorphic process not the symptom. In some cases the cause of a geomorphic process cannot be treated directly, either because that cause is a past activity that is no longer occurring, or because the cause of occurs at a scale that makes intervention infeasible.
- Treat the bed before the banks. This mantra applies to both incision and aggradation. Incision is the most important geomorphic process to manage and should be the first priority. Treating other geomorphic processes, such as meander migration, is futile if incision is not first address because incision will continue to undermine the channel banks. Similarly, if streambed aggradation is ongoing then intervention to address meander migration or avulsion may be compromised.
- Interventions to manage avulsion are most effective when all three processes are managed in unison, rather than in isolation. When managing avulsion, the interacting geomorphic processes of incision (scour) in the daughter channel, and aggradation and meander migration in the parent channel should be managed together, at appropriate locations.
- The four geomorphic processes described in Part 2 of the Guidelines can occur together across a catchment and interact across that catchment (both up and downstream). Regardless of whether the geomorphic process and the impacts of that process occur in the same reach, or whether the process and impacts are in different reaches, geomorphic processes should be managed in the order expressed in Figure 19. The management approaches for each of the four geomorphic processes considered in Figure 19 are summarised in section 3.4 of the Guidelines.

Figure 19. Decision tree to support the decision of which geomorphic processes to address first.



3 Part 3 – A four-step decision-making process

3.1 Introduction

This part describes a four-step decision making process that waterway managers can use to decide whether to intervene in the physical processes of a stream, and how they should intervene if intervention is warranted. The framework below provides one tool which waterway managers may use and should be considered in line with other tools/guidelines available.

Reach and site scale interventions are best undertaken within a clearly articulated and communicated framework, drawn from, or informed by, higher-level and larger-scale strategies and work plans. The foundation of this framework is identifying the values that are to be protected, identifying and defining agreed objectives for these values, identifying the threats to those values and their objectives, what happens if you do not intervene, and what happens if you do intervene.

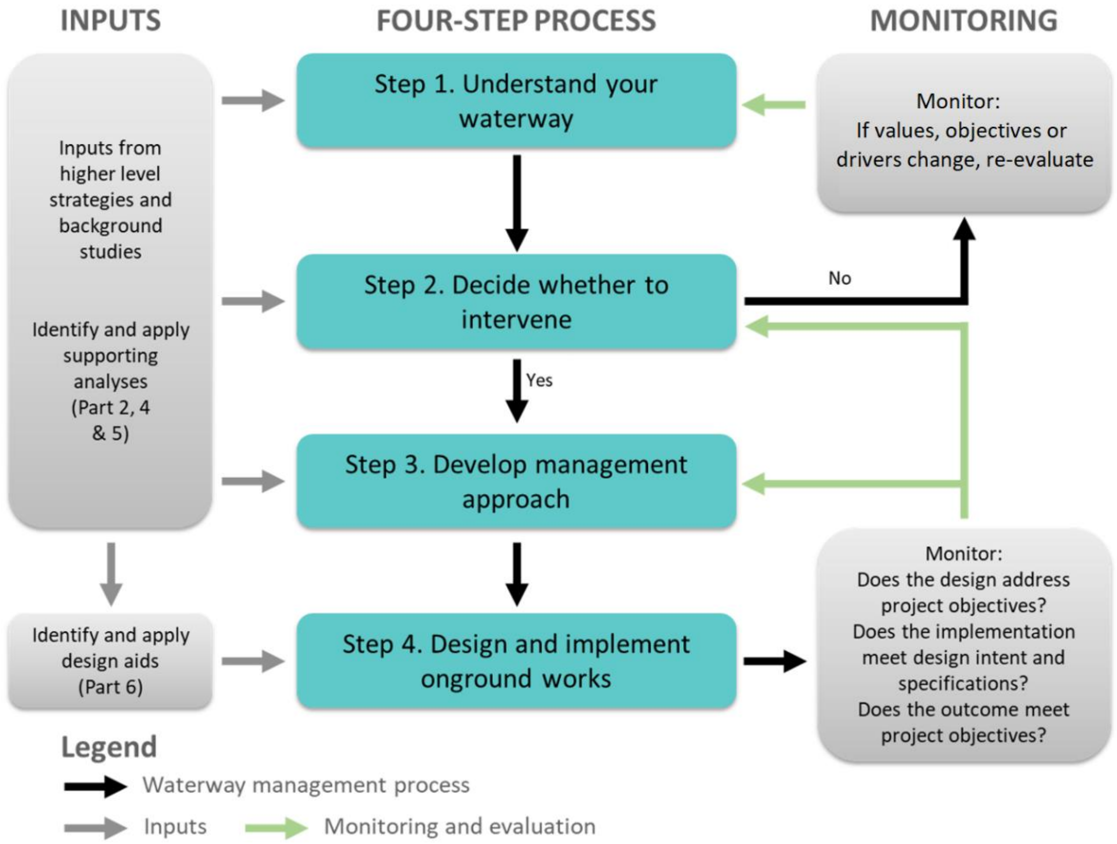
Importantly, the framework should facilitate determining and clearly articulating the objectives for the waterway reach and its accompanying values in the context of the waterway in its entirety, the processes being targeted by intervention and the expected outcomes of interventions.

A number of management frameworks have been developed to assist the implementation of waterway management programs in Australia. The aim of the four-step process is to ensure:

- That on-ground interventions are aligned with the relevant regional waterway strategy where applicable, and/ or to ensure that an appropriate process is adopted for sites and circumstances where regional waterway strategies do not cover the site or do not address the subject reach in sufficient detail to guide an appropriate management response.
- That the default action of not intervening (the base case) is explicitly considered at the outset of any potential project.
- That a clear link has been established between the proposed management option and the activities, drivers and impacts to values and agreed objectives.

The four-step process includes several decision points where waterway managers may choose to either not intervene at a site, or to pause and then re-evaluate the project objective as the system and the scale of intervention required is better understood. The four-step process is shown schematically in Figure 20 below.

Figure 20. An overview of the four-step process used in the Guidelines.

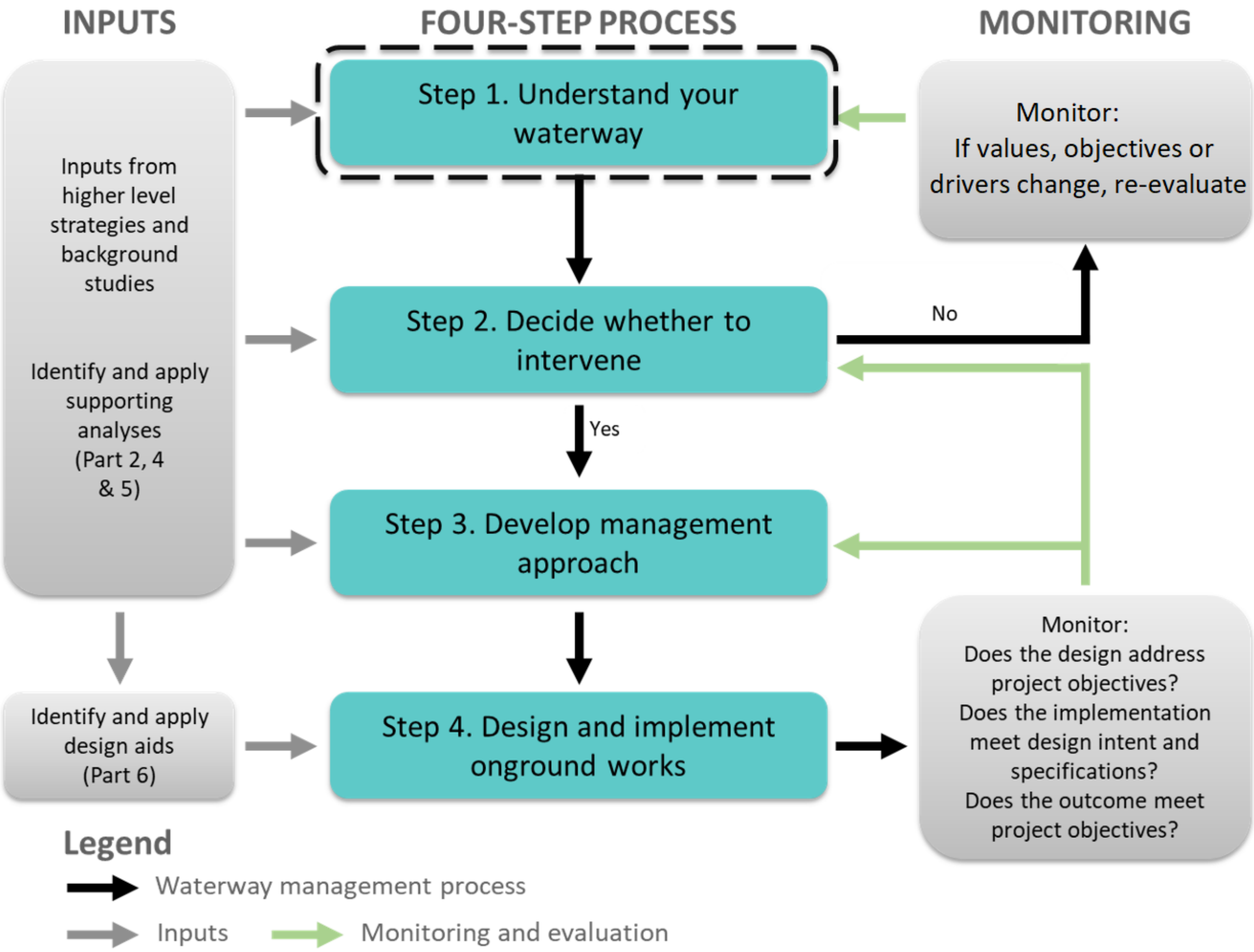


The remainder of this Part 3 has been structured into sections that correspond to each step in the four-step process. In addition, this Part 3 includes a selection guide for management options. Additional detail for several of the steps in the four-step process is provided in other sections of the Guidelines, and the reader is directed to those where appropriate.

3.2 Step 1: Understand your waterway

The first step in the four-step process is to identify the waterway values at the reach or site, derive agreed objectives for these values, understand the geomorphic processes operating within the waterway reach and the threats these pose to the agreed objectives. Supporting analyses to guide the assessment of geomorphic processes are provided in Part 5 of the Guidelines.

Figure 21. Step 1: Understanding your waterway reach.



3.2.1 Identifying waterway values and objectives

The success of waterway management projects relies on identifying the waterway values, and the objectives for these values, in the subject reach or at the subject site in the context of the waterway in its entirety. For example, is the project aimed at protecting the local government bridge from ongoing waterway incision – with upstream and downstream values that will need to be considered; or is the project aimed at protecting the environmental values of a river of State or National importance from multiple threats? Is the project aimed at maintaining resilience in the waterway in consideration of a range of threats especially the current and future impacts of climate change or is the project aiming to transition or transform a waterway due to those climate change impacts? The answer to such questions can lead to very different project scope and management options.

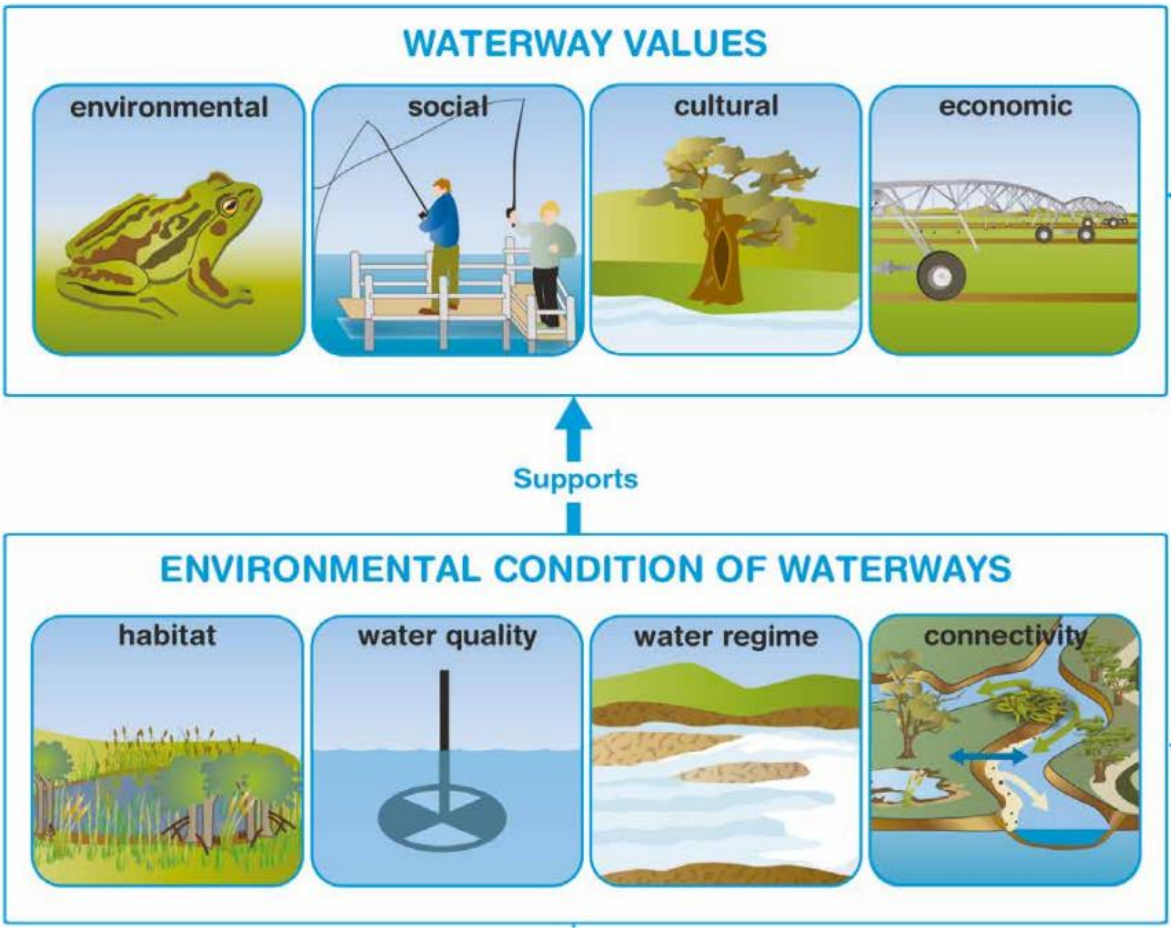
In setting site or reach scale objectives waterway managers should consider the drivers of environmental condition of waterways that help support the waterway values (Figure 22). Waterway condition is the overall state of key features and processes that underpin functioning waterway ecosystems (such as species and communities, habitat, connectivity, water quality, riparian vegetation, physical form and ecosystem processes including nutrient cycling and carbon storage).

Values for which waterways are managed include (but may not necessarily be limited to):

- Environmental values: are supported by waterway condition and the ability of waterways to provide values and services to humans. These can include individual species of aquatic or terrestrial plants and animals and whole ecological communities, water quality, vegetation condition and ecological functions such as drought refuge and connectivity.
- Economic values: public and private assets that are at risk as a result of ongoing geomorphic processes. These can include assets that support community viability such as quality of water supply, urban and rural flood security, bridges, roads, telecommunications infrastructure, and fences and can also include reinstating cultural practices that offer employment for Traditional Owners.
- Cultural values: for the purposes of the Guidelines, Traditional Owner cultural values include tangible natural resources and places and intangible values such as obligations to care for Country and the role of waterways in supporting physical and mental wellbeing. It's also important to note that waterways and land within 200m of a waterway are most often areas of cultural heritage sensitivity under the *Aboriginal Heritage Regulations 2018* – refer to section 3.3.2.2 for further information.
- Social values: this can include recreational use of waterways e.g. fishing and canoeing, the amenity waterways provide to local communities and post-colonisation historic and landscape values.

Values may also relate to a single feature at a site such as the habitat for a particular threatened species, through to an entire waterway reach such as a Heritage River. The types of values may also be interrelated, for example environmental values (a particular species) may have significant social or cultural value.

Figure 22. The drivers of environmental condition that support environmental, social, cultural and economic values in Victoria's waterways (Source: *Victorian Waterway Management Strategy* (DEPI, 2013a).



In many instances, the values present in the reach or at the site will be drawn directly from the relevant regional waterway strategy and supporting information typically developed by Victoria's CMAs. Traditional Owner Country plans, Water is Life Nation Statements, or equivalent, may also indicate cultural values for a waterway. The mapping of values and threats undertaken in support of the regional waterway strategy provides the clearest guidance on whether actions at a site or reach should be considered a priority to protect the values.

If the relevant regional waterway strategy and its supporting information does not identify the values present at a reach or site (or those values located in downstream reaches that are likely to be threatened by processes at the subject reach or site), then the waterway manager must identify those values. Identification of values could include:

- Commissioning background studies that document the waterway values in the reach or at the site. This could include:
  - A review of existing databases.
  - Flora or fauna studies, such as those that identify native vegetation, or rare or threatened species.
  - Mapping of infrastructure within the waterway corridor or on the floodplain.

- Engagement with the local community to identify social values of the waterway.
- Partnership with Traditional Owners to understand cultural values within the reach or site.

Additionally, project feasibility is a key objective that should be considered in line with project values. This includes consideration of whether the design is constructable, materials readily available, safety in design has been considered and is acceptable, and if the project is financially feasible considering available budgets.

The clear identification of values, feasibility and the setting of objectives around these will be essential for project success and avoiding disappointment associated with misunderstandings and false expectations.

Managing waterways for multiple objectives

Waterways support environmental, social, cultural and economic values. In many cases, on-ground interventions undertaken in support of one set of values also support other values. For example, interventions that halt or reverse erosion that threatens instream habitat may also protect or enhance social values by maintaining waterway amenity.

In other cases, the on-ground interventions that address a threat to one set of values may conflict with other values. For example, an on-ground intervention to stabilise an eroding riverbank to protect a nearby road may lead to the loss of bank habitat suitable for platypus. When the motivation for, or the outcomes of, on-ground interventions are in conflict with one another, the waterway manager must manage the trade-off between these competing aims.

The important point is that waterways are managed for multiple objectives. The waterway manager should be clear about the motivation for on-ground works at the project outset (i.e. which threat/s are targeted for management and which value/s will benefit from mitigating the threat/s), and clearly reflect this motivation in the project objectives.

3.2.2 Build an impact logic

Waterway managers use a combination of conceptual models and an impact logic to understand a reach or site and to make predictions about the type and rate of geomorphic processes in a waterway. Ultimately, these predictions must be clearly linked to both the drivers of the geomorphic process and the impacts those processes have on waterway values. Impact logics provide a clear and simple means of stating that link for a specific reach or site.

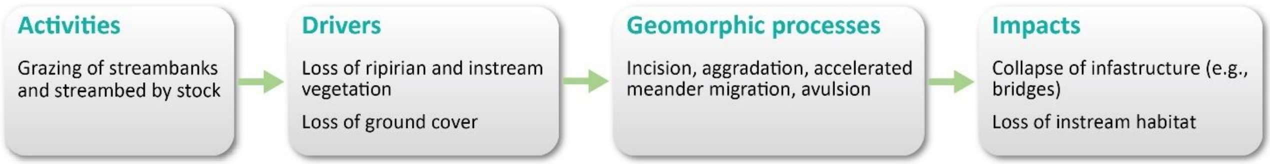
A key step in deciding whether to intervene at a reach or site is identifying the activities, drivers and geomorphic processes that impact on values and objectives for these values. When considering a process that threatens achievement of objectives, the ultimate aim is to understand the underlying cause of that process, to predict how a waterway would change in the future without any intervention (the waterway’s trajectory), and the impacts the predicted change will have on waterways and related values.

When identifying the geomorphic processes within a reach or site, it is useful to distinguish between the following concepts:

- **Activities** are actions undertaken by humans (directly or indirectly) in the catchment or within the waterway. For example, grazing of streambanks by livestock.
- **Drivers** are changes (or predicted changes) in a catchment or waterway that trigger or accelerate incision, aggradation, meander migration or avulsion (geomorphic processes). For example, the loss of riparian and instream vegetation is a driver that may accelerate meander migration (the geomorphic process).
- **Geomorphic processes** are changes in channel form resulting from drivers acting at a variety of scales. For example, accelerated meander migration due to a decrease in bank strength following vegetation loss.
- **Impacts** are the consequences of geomorphic processes for waterway values or the reach or site objectives. For example, the loss of infrastructure (e.g. a bridge) or the loss of habitat for instream fauna, due to accelerated meander migration.

Activities result in drivers, which trigger or accelerate geomorphic processes, which impact on values. The relationships between these concepts are shown in Figure 23.

Figure 23. Example impact logic – with activities, drivers, geomorphic processes and impacts.



3.2.2.1 Identify activities (that lead to adverse impacts on values and objectives)

Activities undertaken by humans since colonisation (directly or indirectly, past or future) in the catchment or within the waterway have resulted in accelerated rates of channel change. Past land uses and management activities such as land clearing, mining and de-snagging have created ongoing geomorphic processes within waterways across Victoria and these continue to threaten to waterway values. Mining, and in particular hydraulic sluice mining, is a prime example of a past activity, no longer in practice, that continues to impact waterway values today. Past hydraulic sluice mining (a form of mining activity that uses high-pressure jets of water to dislodge rock) has led to substantial releases of sediment (driver) into many waterway systems in Victoria (Figure 24). While the mining (the activity) that led to those sediment releases (driver) has ceased, intact reaches of waterway are now subject to streambed aggradation (geomorphic process) and the loss of ecologically important channel features (impact), such as large wood and pools. Other examples of past activities that continue to impact waterways include land clearing, de-snagging (removal of instream wood) and channelisation (direct intervention to artificially straighten meandering channels).

Ongoing and future activities that can lead to adverse impacts include ongoing grazing of riparian lands, physical disturbance of waterways such as sediment extraction from the channel bed, channel realignment (straightening), construction of road crossings or the installation of instream barriers such as weirs or storages.

Physically disturbing the channel can accelerate channel change in four main ways:

- By altering the channel slope, width or depth, which then triggers a cascade of other changes via erosion or aggradation.
- By disturbing sediment and vegetation in the channel or riparian land, which decreases erosion resistance and accelerates erosion.
- By creating instream barriers to the movement of water and sediment, which can reduce sediment supply or alter the hydrologic regime of downstream reaches.
- By removing sediment (instream sediment extraction) with the potential to create a sediment transport discontinuity and thereby cause bed degradation.

Figure 24. Hydraulic sluice mining at the Percival Cochrane Pioneer Mine (Mitta Mitta Catchment) in the 1870s (Source: State Library of Victoria).

3.2.2.2 Identify drivers

This section focuses on how drivers alter geomorphic processes, rather than the activities which may give rise to those drivers. For example, the loss or decline of riparian vegetation (driver) that leads to an increase in bank erosion (geomorphic process), rather than the activities such as riparian grazing that leads to declines in riparian vegetation condition. Most activities that give rise to drivers are self-explanatory (e.g. removal of large wood, construction of barriers to fish passage, grazing of frontage vegetation), and can be effectively addressed through the management of the activity.

Broadly speaking, there are four main drivers that alter (by either triggering or accelerating) geomorphic processes in such a manner that these processes adversely impact waterway values or attainment of waterway objectives. These drivers comprise:

- Instream and riparian vegetation loss.
- Hydrological change.
- Changes in sediment supply.
- Loss of instream woody habitat.

The geomorphic processes altered by these drivers may also be accelerated by climate change and increased occurrence of extreme weather events.

3.2.2.2.1 Instream and riparian vegetation loss

The ongoing loss of native riparian vegetation and decline in native vegetation condition is one of the most common and widespread drivers of adverse geomorphic processes in Victoria's waterways. This decline can include loss of vegetation from the catchment, riparian land or from instream, increased fragmentation of remaining patches of vegetation, reduced condition of remnant vegetation, weed invasions and the loss of vegetation diversity. A decline in riparian vegetation condition results in not only increased rates of erosion but a loss of broader waterway condition and resilience, including reduced water quality, reduced shading and the loss of replacement sources for instream wood.

The complete loss of vegetation, or a decline of vegetation condition reduces the erosion resistance of riverbanks, and in the case of instream vegetation, the channel bed, in three main ways:

- A loss in soil cohesion (bulk soil strength) provided by vegetation roots.
- A loss in protective shielding provided by ground cover or macrophyte beds, which exposes the underlying bed or bank material to scour.
- A decrease in in-channel, bank and riparian land roughness, which leads to an increase in flow velocity and an increased likelihood of fluvial scour.

A decline in instream vegetation also reduces or eliminates the tendency for instream vegetation patches to promote sediment deposition and storage, which can result in an increased supply of sediment to downstream reaches, and the loss of instream habitat.

3.2.2.2.2 Hydrologic change

Hydrologic change refers to modifications to the timing, duration, frequency and/or volume of flow in a waterway system, collectively known as the flow (or hydrologic) regime. Changes in the flow regime can trigger accelerated channel change via two mechanisms:

- By directly increasing or decreasing the total flow energy (and erosion forces) in the waterway system, which can lead to erosion or aggradation, respectively.

- By altering the availability of water to instream and riparian vegetation, which can lead to vegetation decline or loss.

An increase in total flow energy may be expressed as an increase in peak flow magnitude, an increase in the frequency of flows of a given magnitude, or some combination of both. The altered flow regime may lead to an increase in the duration or frequency that instream vegetation is submerged, leading to die-off, or a decrease in total water availability, which also leads to die-off.

3.2.2.2.3 Changes in sediment supply

Increased rates of hillslope runoff and soil erosion can alter the hydrology of downstream reaches and lead to increased sediment supply, which can trigger bed aggradation, channel avulsion and the loss of instream habitat.

Increased runoff and soil erosion are closely related. An increase in runoff is a common cause of increased soil erosion and sediment delivery. Changes in runoff and soil erosion are often triggered by a change in catchment land use, for example the clearing of vegetation for agriculture, or an increase in impervious surfaces due to urban development.

While catchment scale or hillslope-centric interventions are outside the scope of the Guidelines, waterway managers may choose to intervene in waterways to address the consequence of increased runoff and soil erosion. While catchment scale or hillslope-centric interventions is preferred, waterway intervention may be used when those changes occurred in the distant past and controlling the activity is no longer an option.

Modifications to a catchment or waterway can also lead to a reduction in bed load sediment supply. Reductions in bed load sediment supply can arise from construction of onstream dams and urbanisation of catchments. Such reductions in sediment supply can result in sediment transport rates exceeding supply and the initiation of incision and/or loss of point bars and associated channel widening.

3.2.2.2.4 Loss of instream woody habitat

Instream woody habitat is a characteristic feature of waterways in Australia and Victoria. Wood in waterways provides direct and indirect habitat by creating structure, flow diversity and local scour. The loss of wood in waterways refers to short- and long-term removal and burial of wood; and the failure to recruit wood to waterways. The loss on instream wood results in the loss of the major form of instream habitat in lowland waterway systems and a decrease in channel roughness, which results in higher flow velocities, sediment transport and channel erosion.

Loss of instream wood can arise from:

- A loss or decline in the supply of timber. This may be a direct result of past clearing of riparian lands or ongoing grazing of riparian lands, or a complete cessation in meander migrations arising from rock beaching of a waterway.

- Smothering from bed load sediment (e.g. sand) associated with an aggradation processes.
- Removal of large wood from the waterway (de-snagging).

Note: When saturated, Australian hardwood has greater density than water and as a consequence does not float. If instream hardwood is partially submerged on a permanent basis and partially buried or locked in place, it is unlikely to be mobilised by flood events. As a consequence, flood events are rarely the cause of the loss of instream wood. Large wood observed to be floating down waterways in flood events, will often be catchment or floodplain sourced or exotic timber such as willow.

3.2.2.2.5 Extreme events

The geomorphic processes outlined in Part 2 of these Guidelines occur naturally but can, and often have been, accelerated or inhibited by activities in the catchment or within the channel. Extreme but naturally occurring events such as floods, bushfires and droughts exert a major impact on these processes. For example, large bushfires cause vegetation loss from hillslopes or riparian land, which increases runoff and soil erosion, reduces the erosion resistance of burnt riverbanks, and can accelerate or trigger incision, accelerated meander migration or aggradation in downstream waterways.

The impacts of extreme events should be considered insofar as they accelerate or trigger certain causes of channel change.

Climate change

The predicted impact of climate change on waterway systems relevant to physical form include:

- Changes in hydrology, including changes in timing, duration, frequency, and the volume and rate of flow.
- Ecological responses to climate change such as vegetation dieback, reduced ability for vegetation establishment or regeneration.
- Increased magnitude and frequency of extreme weather events, including bushfires, and increased sediment/debris flows.

Current and future impacts of climate change will always need to be considered when setting project objectives. Some waterways will be able to withstand climate-related impacts and remain relatively unchanged or have the ability to recover (i.e. the waterway has adequate resilience), while other waterways will be impacted and will not recover to their previous state but will transition or transform to a new state.

Summaries of regional climate change projections can be found in CMA publications such as the regional catchment strategies and CMA climate change strategies/plans. For additional information the following links may be useful for your project:

- Victoria's changing climate
- Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria
- Victoria's Water Cycle Climate Change Adaptation Action Plan 2022-2026
- Climate Change in Australia webpage

3.2.2.3 Identify geomorphic processes

Assuming the waterway manager has successfully identified the activities and drivers of change, the next task is to build an understanding of the geomorphic processes (changes in channel form resulting from drivers acting at a variety of scales). This may include both qualitative (field inspections, landholder observations, Aboriginal waterway assessments etc.) and quantitative analysis (repeat topographic surveys, modelling and stability assessments).

As a starting point the waterway manager should compile exiting literature that describes the geomorphic processes at the reach or site. Relevant literature may include the relevant regional waterway strategy, published studies, relevant research, government reports and accounts from community, landholders or other managers familiar with the history of a site. In many instances, such background material will provide some detail on the dominant processes within the reach or site.

However, in most cases additional work (site inspections, specific investigations) will be required to identify the dominant processes operating within, or impacting upon, the site. Identifying these processes requires two levels of understanding:

- **Understanding of fundamental geomorphic processes**. Knowledge of waterway hydrologic, hydraulic, geomorphic and ecological processes is a prerequisite to the effective use of the Guidelines. The Guidelines do not provide readers with details of fundamental geomorphic processes. Further information on fundamental geomorphic processes can be found in sources such as: *Geomorphic analysis of river systems: an approach to reading the landscape* (Fryirs and Brierley, 2012).
- **Understanding of specific processes within the reach**. Development of an understanding of the specific processes at work within an individual reach or at a site can be achieved using the supporting analyses in Part 5 of the Guidelines, through site inspections and commissioning of specific investigations. Specific investigations and data gathering that may assist the identification of geomorphic processes can include:
  - Hydrologic and hydraulic analysis.
  - Geomorphic assessments including investigations into sediment sources, transport and fate.

- Topographic surveys including initial and repeat longitudinal, cross-section, LiDAR or bathymetric surveys.
- Vegetation surveys and investigations into vegetation dynamics.

Approaches (and elements) to assessing sites to understand the processes at work can be further found in Part 2 (geomorphic processes) and Part 5 (supporting analyses) of the Guidelines.

Information gathering and analyses should be undertaken in a staged approach with initial assessments providing an overview of causes and process. More detailed data collection and investigations should only be commissioned to address geomorphic processes identified as impacting on values of interest and those processes likely to influence the success or otherwise of the project.

3.2.2.4 Identify impacts to values and related objectives

An understanding of what happens if the waterway manager does nothing is the basis for deciding if, when and where to intervene in waterway geomorphic processes. The no-intervention scenario serves as a base case against which the expected impact of interventions can be compared.

The waterway manager can use the understanding of the waterway system gained by identifying waterway objectives, activities, drivers and geomorphic processes, to develop a trajectory for the study reach or site in the absence of any intervention.

A waterway trajectory is a prediction of the future changes in waterway form, condition, and processes. Key to deciding whether and how to intervene in a waterway is an understanding of a reach or site’s trajectory if waterway managers do not intervene and how this may impact on defined objectives.

A trajectory without intervention can be described as an expected sequence of channel changes and impacts. Wherever possible, the best available data and conceptual models should be used to quantify the rate of channel change, and the timescales involved in predicted future channel changes. As more processes are considered and the timeframe considered increases, more assumptions about future activities and processes are likely to be required. These processes and assumptions should be clearly outlined, and the uncertainty of the trajectory stated explicitly.

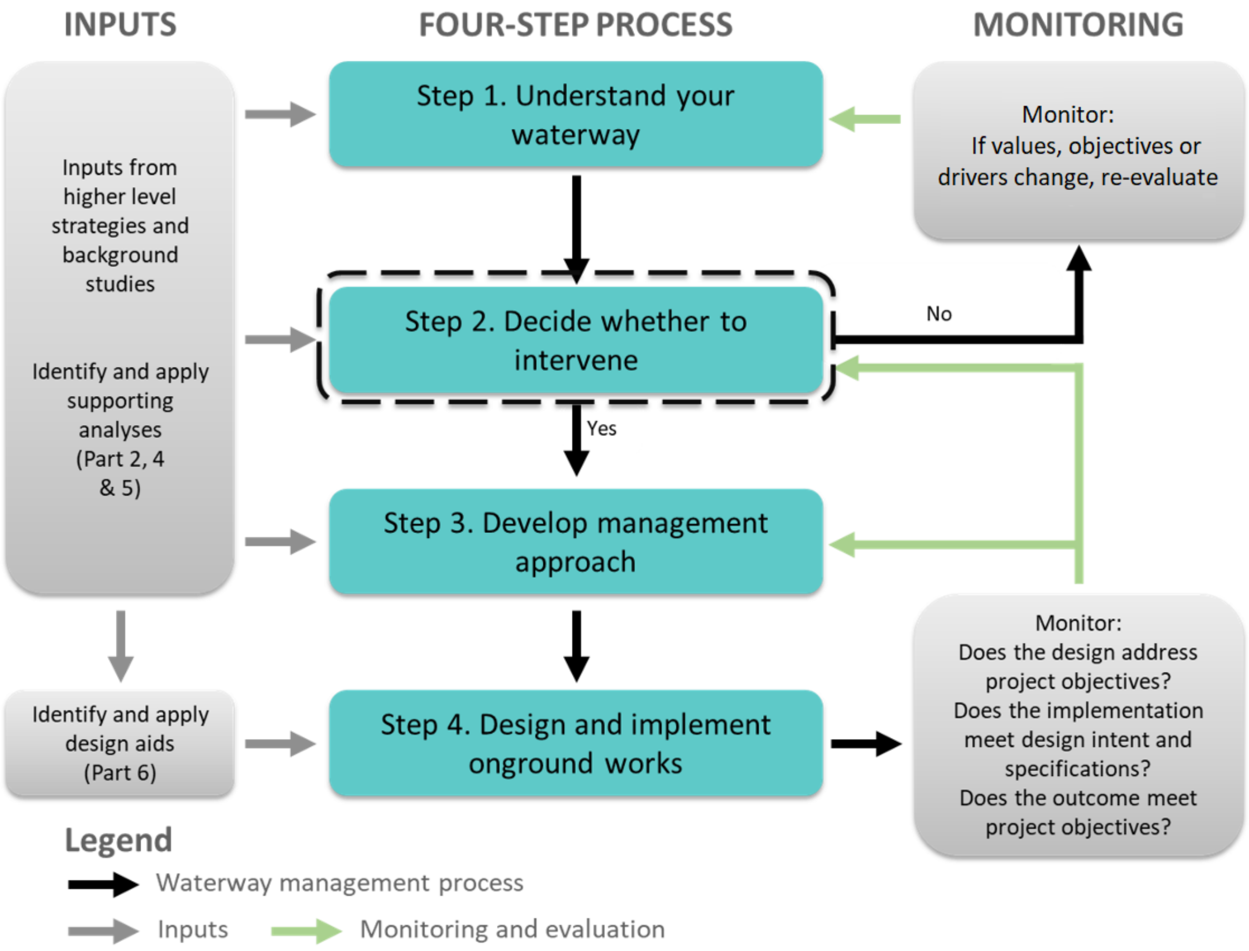
The trajectory may be a simple continuation of an existing process, for example continued meander migration at a rate of x metres per year. The trajectory could also be described as a progression through a well-established sequence of channel changes, for example the shift from deepening to widening in an incising reach is expected to occur gradually over the next ten years. The form and complexity of the trajectory will vary depending on whether a timeframe of 5, 10 or 50 years is considered.

This trajectory without intervention can then be used to define impacts on values or to the objectives for the value, the reach or site.

3.3 Step 2: Decide whether to intervene

The second step in the four-step process is to consider the identified impacts and geomorphic processes and decide whether to intervene (Figure 25). Although the waterway manager may face pressure to quickly intervene in a waterway using on-ground physical works to resolve an immediate and obvious issue, the first step is always to understand what will happen without intervention, i.e. what happens if the waterway manager does not intervene? What happens if the geomorphic processes don't actually impact on the values that are important at the site, or if the intervention causes more harm elsewhere in the system than good at the project site? It is at this step that the waterway manager must also reflect on the broader social, statutory, policy, environmental and cost-benefit considerations.

Figure 25. Step 2: Decide whether to intervene



Waterway managers may use conceptual models and geomorphic trajectories to decide whether to intervene. The decision on whether to intervene at all, should be just that, an active decision, rather than an assumption. Greater understanding of the site, gained through development of the impact logic and building of a geomorphic trajectory (Step 1), should make clearer the scale of intervention required to address the underlying geomorphic processes.

When deciding if intervention is warranted at the site, the waterway manager should ask:

- Are the identified geomorphic processes likely to pose a real and significant risk to important waterway values at the site or elsewhere (for example, upstream or downstream) without intervention?
- Are there alternatives to on-ground physical works that can be used to address the potential impacts of the geomorphic processes? For example, the relocation of floodplain assets likely to be impacted by bank erosion.
- Are on-ground interventions in the waterway the most appropriate way to address the geomorphic processes in the reach or at the site?
- Is the likely scale of intervention required to address the geomorphic processes likely to render the project unworkable?
- Is the project identified as a strategic priority for management in the relevant strategy or plan such as a regional waterway strategy or Country plan?
- Is the work required to meet statutory or regulatory obligations?
- Do the benefits of the intervention outweigh the costs (i.e. public benefits if using public funds)?

It is at this early stage that the necessary permits and assessments likely to be needed should be identified.

3.3.1 Do not intervene

The first option available to waterway managers is not to intervene. Waterway managers can use conceptual models to predict how the channel will change in the future without intervention. This prediction is made by building a geomorphic trajectory, describing the processes driving channel change, and the consequences of not intervening for waterway values and infrastructure.

Understanding what happens if managers do not intervene is the cornerstone of management, and it is the base case against which all other options/interventions should be compared. It may be that after building a geomorphic trajectory under a no intervention scenario, no further action is taken. Alternatively, the no intervention scenario may reveal that some form of intervention is required or beneficial.

If the waterway manager decides not to intervene, then a suitable alternative may be to monitor the condition of the reach or site (particularly if uncertainties exist). The purpose of this type of ongoing monitoring, in whatever form that takes, is to identify emerging threats to values identified at the reach. Identifying new threats, which may include new activities or drivers or the acceleration of geomorphic processes already operating at the reach or site, can trigger a reconsideration of the need to intervene.

The choice not to intervene is informed by the likely geomorphic trajectory of the reach, which is driven by one or more geomorphic processes. The main considerations when deciding not to intervene to address the four geomorphic processes are outlined below.

3.3.1.1 Do not intervene and let the incision cycle naturally complete

The choice not to intervene in the waterway with on-ground physical works will depend on the scale of the intervention required to halt the incision process, the stage of the incision cycle the subject reach has progressed to, any priority assets (built or natural) under threat due to the incision processes and the available project budget.

The no intervention approach recognises that incision is a cycle; post incision the system will continue on to the filling and narrowing stage (refer to Figure 4). In cases where the scale of intervention required is beyond the scope of the project, the waterway manager can choose not to intervene and instead focus on dealing with any adverse consequences of incision in upstream and downstream reaches. For example, by intervening in downstream reaches where sediment liberated by the incision process has accumulated on the channel bed, or to protect specific assets threatened by the incision processes on a site-by-site basis (e.g. public infrastructure). Many incised waterways in Victoria actively incised many decades ago, are no longer active, and do not require intervention.

In all cases, especially if the subject reach has a recovery phase (stage five), activities such as fencing to exclude livestock can be used to aid the establishment of native vegetation along riparian land and on the inset floodplain that forms as the channel narrows. Halting activities such as grazing by stock reduces erosion and increases the likelihood that a healthier and more resilient waterway emerges from the incision process.

3.3.1.2 Do not intervene and let the meander migration continue

Meander migration seldom continues at a constant rate indefinitely. As meander bends migrate and evolve, their curvature and total length can increase. Eventually, meander cut-offs may occur, and the channel of the original meander bend is abandoned. Waterway managers can use a trajectory of channel change without intervention to predict whether meander cut-off is likely, the timescale of meander cut-off, and the consequences that meander cut-off may have to determine the necessity to intervene.

The bank erosion processes that drive meander migration are somewhat self-limiting. Scour that leads to erosion at the toe of the bank can trigger bank collapse, and the bank material that slumps into the channel shields the channel bank from further erosion, temporarily halting meander migration. Meander migration will resume once the slumped bank material is removed by erosion.

The possibility of meander cut-offs, the influence of slumping on meander migration rate and the value of assets impacted by meander migration should be weighed against the cost of intervention when the waterway manager is deciding whether or not to intervene in the meander migration process.

3.3.1.3 Do not intervene and allow the sediment to be transported downstream

When deciding whether to intervene to address streambed aggradation, the waterway management priority should be to identify whether the source of the additional sediment has been controlled. If sediment supply to a reach remains elevated and cannot be feasibly controlled, and is likely to remain elevated in the future, then waterway managers should focus on addressing the consequences of elevated sediment supply in the aggrading reach.

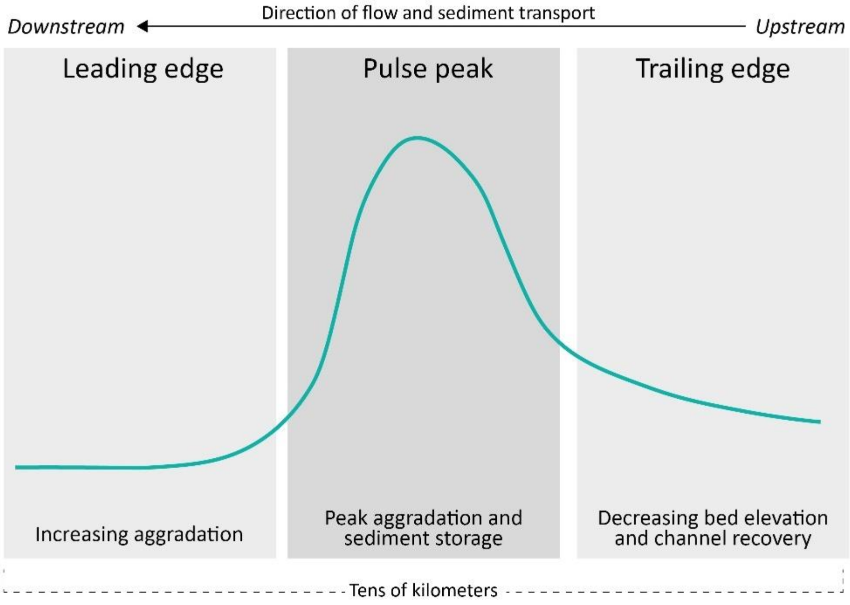
The sediment inputs that cause streambed aggradation tend to migrate downstream in a wave like fashion with its rate of movement influenced by instream vegetation and associated stream powers within the system. When sediment inputs are large, those inputs will migrate downstream over a period of decades or centuries, and streambed aggradation will occur along a long length of waterway, in the form of a sand slug moving downstream. When sediment inputs are relatively small and the source discrete, the sediment wave may quickly disperse downstream, and there may be little opportunity (or point) in intervening.

Managers can use the concept of a wave to predict future changes in the subject reach, and to make decisions about whether to intervene. Sediment waves can be broken into three broad zones:

- The downstream leading edge of the wave, where streambed aggradation has only just begun. Without intervention, sediment will continue to accumulate in the reach and impacts on waterway health and channel capacity and form will begin to materialise.
- The peak of the sediment wave, where streambed aggradation is most pronounced. These reaches, which in reality may be long stretches of waterway, have already undergone significant channel change. Without intervention, the depth of sediment in the channel will remain relatively constant, while at the same time high sediment loads are transported through the reach and downstream.
- The tail of the sediment wave, where sediment supply is decreasing, and the reach is entering a recovery phase. Without intervention, bed elevation will decline, channel complexity (pools, riffles and a meandering low flow channel) will slowly emerge. In some cases, the waterway may resume a trajectory of channel change that was occurring prior to bed aggradation (for example, incision).

The parts of a sediment wave are shown in Figure 26. One approach for the waterway manager is not to intervene at all and allow the sediment to naturally pass downstream. Over time the aggraded reach will enter a phase of channel recovery.

Figure 26. The three zones of a sediment pulse and the trend in streambed aggradation in each zone.



3.3.1.4 Do not intervene to stop the avulsion

The choice not to intervene in the waterway with on-ground physical works will depend on the scale of the intervention required to halt the avulsion process, the stage of the development of the avulsion, any priority assets (built or natural) under threat due to the potential avulsion and the available project budget.

The no intervention approach recognises that avulsion is a natural geomorphological process. Furthermore, if the scale of the avulsion is large, there may be few alternatives other than to allow the avulsion to occur and prepare for the consequences. Avulsion is a self-reinforcing process, and the rate of parent channel abandonment and daughter channel development will naturally accelerate with time. In anticipation of an inevitable avulsion, the waterway manager should use an understanding of the avulsion type, and the best available tools, which may include modelling, expert opinion and monitoring, to estimate:

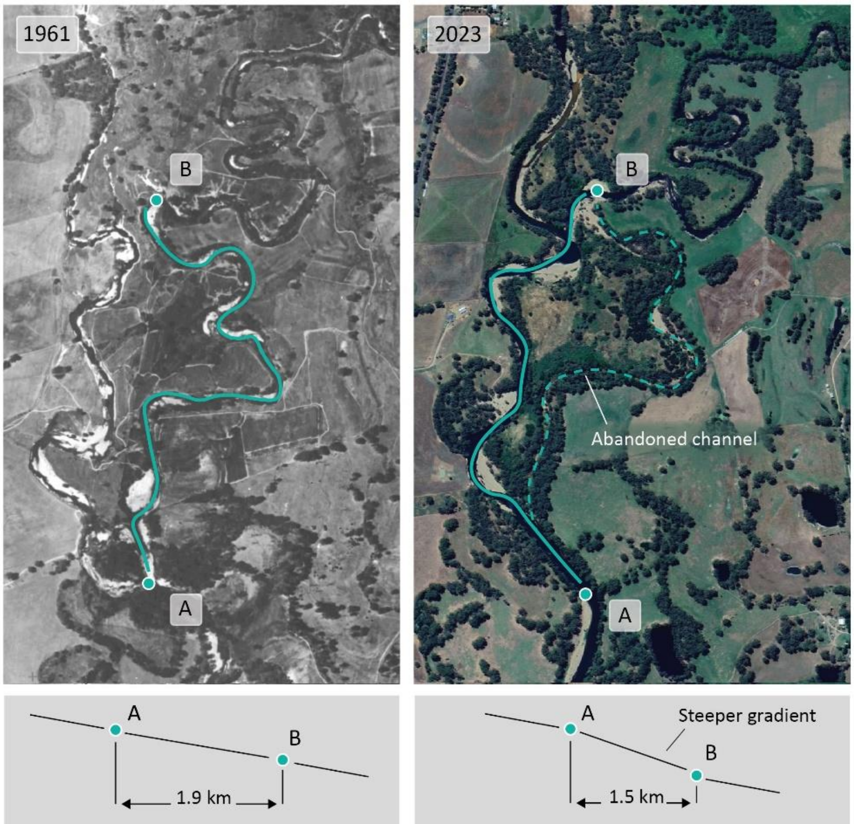
- The likelihood of avulsion within a given planning timeframe.
- The most likely alignment and the dimensions of the developing daughter channel (post avulsion).
- The type and significance of the impacts on waterway condition and other values within the parent and daughter channel, and in upstream and downstream reaches (post avulsion).

The deepening and widening of the daughter channel occurs due to the substantial increase in stream power generated by flood flows, and the eventual capture of all flow from the parent channel. Deepening and widening of the daughter channel can occur rapidly at first, before sediment transported by the parent channel is routed through the newly formed channel, after which channel adjustment slows. Channel scale avulsions may trigger erosion of terraces or inset floodplains that confine the parent channel and were previously stable.

When preparing for an inevitable avulsion, waterway managers should also be mindful of the following impacts in upstream and downstream reaches:

- The steepening of the avulsion reach due to the shortened flowpath in the daughter channel can generate a knickpoint that migrates into upstream reaches of the parent channel (Figure 27). The migrating knickpoint causes impacts associated with channel incision, which may then also generate secondary impacts on downstream reaches.
- Sediment eroded from the daughter channel is delivered as a pulse to downstream reaches, where it can trigger impacts associated with streambed aggradation.

Figure 27. The impact of a meander-scale avulsion (a meander cut off on the overall grade of the reach).



The complicated, cascading sequence of channel changes in upstream and downstream reaches following an avulsion means that the impacts of an avulsion are felt over large distances and potentially long timescales. In preparing for an avulsion, waterway managers should focus on establishing clear objectives and a desired outcome for how the new channel alignment will integrate with future land use and the social, economic and cultural values of the wider valley. Preparations can include:

- Using land use and town planning to identify, and where possible relocate, assets likely to be impacted by the new channel alignment.
- Establishment of suitably wide native riparian vegetation along the likely future alignment of the daughter channel, to ensure that once the avulsion does occur, the daughter channel can function as a healthy waterway.

- Identify future waterway access points for adjacent landholders and community, including those who lose river frontage when the parent channel is abandoned.
- Undertake engagement with relevant Traditional Owners and stakeholders potentially affected by the avulsion. As the geomorphic consequences of an avulsion are felt over large distances and potentially long timescales, so too the human element to avulsion management needs to be addressed with an equivalent scale in mind.

3.3.2 Intervene

3.3.2.1 Identify land status, responsibility and administrative constraints

The Guidelines are designed to assist waterway managers. In considering actions at any given site the waterway manager must be aware of who owns the land, and who is responsible for different aspects of land and waterway management at the site. This knowledge influences much of the four-step process (especially identifying the values of the area). For example, are you on Crown Land or private land? Is the land permanently reserved? Does the land have special status or purposes (such as designated catchments, or Heritage River status, or Native Title, or a fauna or flora reserve)? Do you know the Registered Aboriginal Party (RAP)? There are always rules around what you can and can't do that have to be understood at the start of the process, as well as many classifications that define values and constrain what you can do.

It is always worth checking government files to understand the history of management at the site. For example, there could be a management covenant over the site, or an existing agreement with a past landholder.

It is quite possible that, following some investigation, a waterway manager could conclude that the issue is not their responsibility (for example, it could be the responsibility of another agency, or a water authority, or that the issue is a compliance matter that may require regulatory action). It is prudent to understand this context before investigating management options.

Landholder support is often required for waterway management interventions, especially to establish riparian setbacks, and for ongoing maintenance and monitoring. Additionally, in cases where landholder cooperation and support for appropriate works (e.g. fencing and vegetation) are contingent on a landholder's request for other, inappropriate waterway management works at the site, waterway managers may be better to sacrifice doing works at the site rather than intervene with an overall waterway management approach that would either fail to address the underlying waterway management issue or produce negative consequences.

See section 3.5.3 for additional considerations when implementing on-ground works.

3.3.2.2 Identify common approval requirements

Once the land status, tenure(s), responsibilities and administrative constraints are known, there may be additional approval requirements. Some of these requirements are outlined in Table 2.

3.3.2.2.1 Traditional Owners and waterway management

Waterways are also an extremely important component of the landscape in terms of Aboriginal cultural heritage as reflected in the *Aboriginal Heritage Act 2006* and the *Aboriginal Heritage Regulations 2018* (the Regulations). The Regulations define high impact activities and areas of cultural sensitivity, which includes waterways and land within 200 m of a waterway.

Cultural heritage approvals are required prior to many on-ground projects and penalties apply for harm to cultural heritage. In particular disturbing previously undisturbed ground during the design and implementation stage of waterway projects has the potential to pose a risk to tangible and intangible cultural heritage. Due diligence is required before and during works to avoid impacts to cultural heritage.

Information about cultural heritage and approvals can be found through the Victorian government's First Peoples – State Relations group (formerly Aboriginal Victoria).

Many Traditional Owner corporations have formal agreements with government that relate to the management of public land and waterways. These may provide for Traditional Owners to have a formal say in the approval of works on waterways.

Country plans are an important tool for Traditional Owners and Aboriginal Victorians to help guide partnerships with waterway managers and implement on-ground works. Development of Country plans often involves a series of workshops, site visits and gatherings with Traditional Owners, taking a participatory approach to develop the Plan. Developing Country plans supports Traditional Owner self-determination and increases capacity and involvement in managing landscapes. Actions included in Country plans can range from protecting significant sites to broad scale fire, water and land management activities. Developing the plans provides an opportunity for the waterway manager to foster partnerships with Traditional Owners.

Table 2. Common approvals requirements for waterway projects.

Approvals requirements	Authority	Further information
Works on waterway approvals for many non-CMA project proponents, through a works on waterways permit (or licence), will generally be required for works and activities within or on the bed and banks of waterways.	Melbourne Water and CMAs	Further information can be found on Melbourne Water or each CMA's website.

Approvals requirements	Authority	Further information
Native vegetation removal approvals – A permit is usually required to remove, destroy or lop native vegetation. These regulations are known as the native vegetation removal regulations and are primarily implemented through local council planning schemes.	Local government and DEECA	Regulations and guidelines can be found at Native vegetation removal regulations
Statutory planning approvals – A range of planning permits may be required depending on the scope of works to be undertaken. Examples include removal of native vegetation, flood hazard considerations.	Relevant referral authority, usually local government	Additional guidance on planning permits and the requirements of permits can be found at Permits and applications
Cultural Heritage Permits – Under the *Aboriginal Heritage Act 2006*, a permit is required for many project activities that will, or are likely to, harm Aboriginal cultural heritage. A permit and/or Cultural Heritage Management Plan may be required.	Registered Aboriginal Parties (RAP). If there is no RAP, the application must be made to the Secretary to the Department of Premier and Cabinet.	Application forms and guidance can be found at Cultural Heritage Permits
Sediment extraction approvals – under the *Mineral Resources (Sustainable Development) Act 1990* approvals may be required for sediment extraction activities within a waterway or floodplain. Requirements will vary based on the area and/or depth of extraction and planning scheme requirements for the project area. Sediment extraction from the waterway will also require a works on waterway approval.	Earth Resources Regulation, relevant referral authority (usually local government), DEECA, Melbourne Water and CMAs	Further information can be found at Licensing and approvals

This list of approvals is not exhaustive and there may be other requirements for projects, depending on site and project specifics, for example requirements for landowner consent from DEECA if the project involves Crown land and requirements under the *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth), the *Wildlife Act 1975*, the *Fisheries Act 1995*, and the *Flora and Fauna Guarantee Act 1988* (among others).

It is the responsibility of users of these Guidelines to ensure all and any statutory requirements are met.

3.3.2.3 Halt or modify activities or drivers

In waterways, prevention is better than cure. Preventing, controlling and reducing activities that adversely impact on waterways will have the most direct positive impact on waterway values. The prevention, cessation or modification of such activities should therefore be considered as the highest priority for the protection of waterway values and infrastructure.

Prevention and/or cessation of de-snagging, modification to hydrologic regimes, riparian grazing and direct physical intervention in the waterway will provide immediate benefits to waterway values.

However, in many circumstances, the cessation of the threatening activity will not be an option and modification of the practice will be necessary. For example:

- Adoption of the forest industry code of practice will assist to reduce the impacts of forestry operations on waterways.
- Limiting the scale and location of sediment extraction will minimise adverse impacts on downstream reaches.
- Modification of grazing practice to enable vegetation establishment may be a more realistic outcome with some landholders and regions than permanent and total stock exclusion from riparian land.

3.3.2.4 Intervene to address the geomorphic process

If intervening to prevent, halt or modify a threatening activity is not a viable option, the waterway manager can use interventions to target drivers directly, the geomorphic process generating impacts, or both the driver and the geomorphic process. There is considerable overlap between drivers and processes and many of the on-ground physical interventions can be used to target both the drivers and processes.

For example, grade control works may be required to address channel incision caused by past drainage activities.

3.3.2.5 Intervene to address the impacts

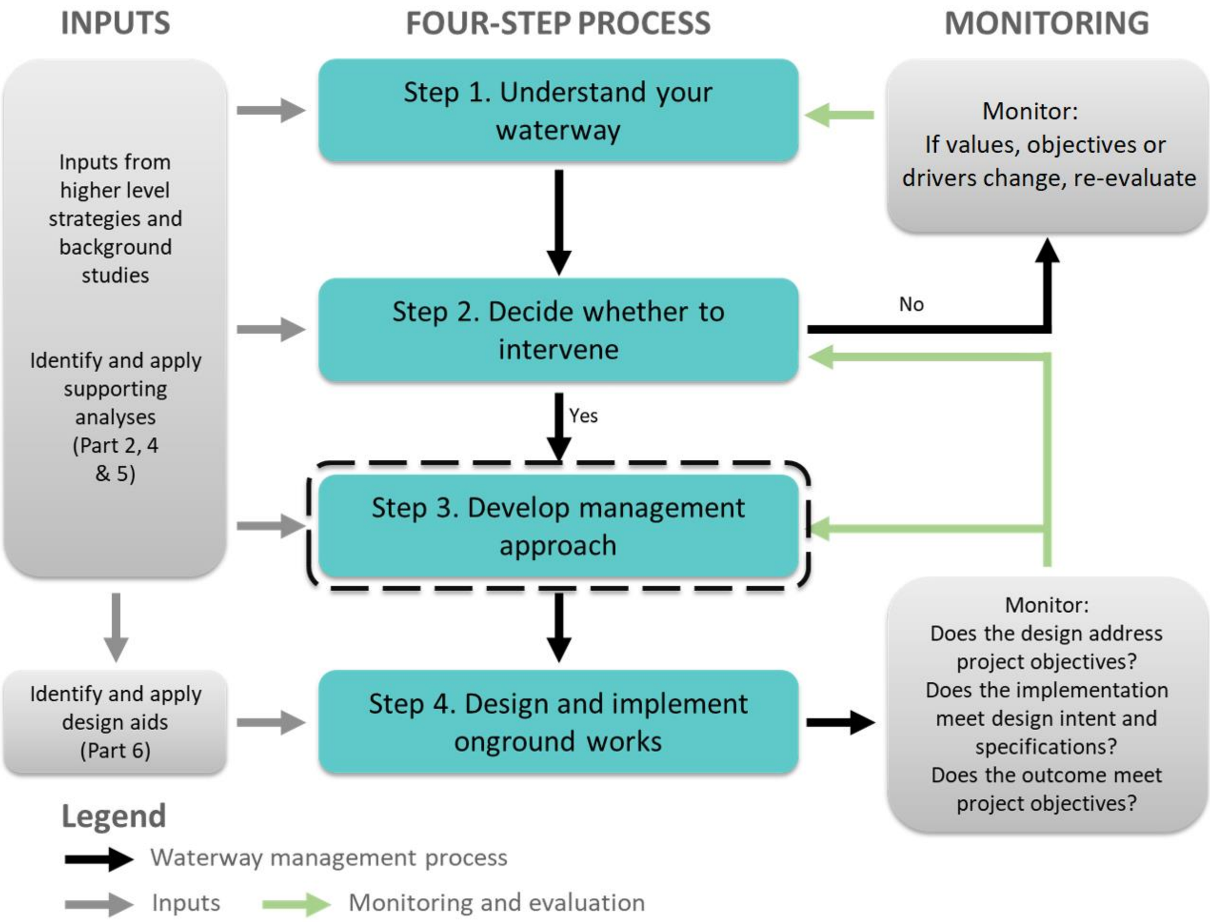
Sometimes intervening to address activities, drivers or geomorphic process is not feasible, or the time taken for such interventions to yield results in the subject reach is too long. For example, when the source of sediment generating streambed aggradation in a reach is a catchment scale disturbance such as fire. In these circumstances waterway managers can intervene to address the impacts of the geomorphic process (i.e., it is necessary to treat the symptoms of the geomorphic process rather than the underlying drivers). Examples of intervening to treat impacts include the limited and site scale re-introduction of large woody debris to generate scour holes for fish habitat in aggrading waterways. Although treating the impacts is sometimes unavoidable, waterway managers should be aware that doing so does risk the objectives of interventions being undermined by the continuation of the underlying geomorphic process.

Often waterway managers will use a combination of the approaches outlined in this section. Simultaneously intervening to cease threatening activities, address drivers and the resulting geomorphic process while also intervening to mitigate the impacts of the geomorphic process in the subject reach (or reaches).

3.4 Step 3: Develop reach scale management approach

After completing Step 2 and identifying that intervention is warranted, the next step is to develop a reach scale management approach. The reach scale management approach provides guidance on the fundamental drivers and processes being addressed by the intervention and provides guidance on the most appropriate interventions available to mitigate the drivers and processes in the waterway. Regional waterway strategies may include management approaches for sites and reaches identified as a high priority for management.

Figure 28. Step 3: Develop management approach.



Note: The Guidelines provide advice on reach scale management approaches and the interventions available to accompany such approaches if waterway managers choose to intervene at a subject reach or site. However, this should not be interpreted that on-ground works are the highest priority for management. Alternate activities such as, regulation, education, capacity building and monitoring (or tailored combinations of approaches) may provide better returns on investment than on-ground works.

When developing a reach scale management approach, regardless of whether on-ground physical works are required or not, the waterway management priority should be to halt or modify the driving activity. Only after the driving activity has been addressed, or if the driving activity cannot be halted or modified, should on-ground physical interventions be considered.

3.4.1 Define reach outcome targets

Identifying objectives should be accompanied by clearly articulating the outcomes targeted for a reach or site. If outcome targets have not already been articulated in the relevant regional waterway strategy, then the waterway manager should clearly define those outcome targets for the subject reach or site. Outcomes, as opposed to outputs, refer to the targeted state of the reach or site following intervention, noting that it may take some time for that target state to be met. A clear outcome target for a reach or site allows the monitoring and evaluation program to learn from the successes, challenges and failures of a particular project and for continuous improvement. Clearly defining a target outcome is an important part of the adaptive management paradigm used in waterway management.

Example of specific criteria suitable for the establishment of outcome targets may include:

- **Physical form:** the presence, size and persistence of scour holes in the bed of the waterway.
- **Ecology:** the presence, size, species composition and abundance of fish and macro invertebrates in the waterway.
- **Hydrology:** the presence of suitable flows for fish passage and habitat.
- **Vegetation:** the presence of suitable shading vegetation, and longitudinal and lateral connectivity.
- **Water quality:** the presence of suitable water quality for consumptive supplies, recreation and instream ecological processes. Note that water quality objectives may already be set for the waterway under the *Environment Protection Act 2017* and the supporting *Environment Reference Standard 2017*.

In addition to the benefit at the site and reach scale, the development and adoption of site and reach scale outcome targets has potential to provide a transparent link between outcomes at the site and the reach scale and the outcomes sought at a larger catchment or regional scale.

Targets should be ‘SMART”. They should be Specific, Measurable, Achievable, Relevant and Time-bound. To determine whether a target is SMART, consider the following:

- Is the target **specific**? i.e. does it clearly define what needs to be done? For example, ‘re-vegetation’ is not specific, but ‘establish a structurally diverse community of native vegetation at site x’ is specific. Ask ‘do I know exactly what I am doing?’
- Is the target **measurable** and reportable? For example, is the target in units such as hectares, metres or in another form of quantitative measurement such as number of deliverables? Ask ‘do I know how much I am doing?’
- Is the target **achievable**? e.g. technically, financially and socially feasible?. Ask ‘can I feasibly achieve this?’
- Is the target **relevant** to achieving the desired project outcomes? Ask ‘is this actually worth doing?’
- Is the target **time-bound**? e.g. does it include a due date? Ask ‘when should the actions be completed by?’

3.4.2 Management of incision

The waterway manager can choose whether to try to reverse the incision process, returning the stream system to Stage 1 of incision, halt the system mid cycle in stages 2, 3 or 4, or accelerate the process through to stage 5 of the incision cycle. These options will require different levels of effort depending on the stage of incision and the objectives of the program.

Ultimately the management of incised systems requires a combination of sediment transport management and the prevention of excess shear on (or armouring by) essential structural elements e.g. rock structures and establishing vegetation. While it may be technically feasible to provide a fully rock armoured response to protect against excess shear across the system, a more economically and ecologically viable response will seek to maximise the use of vegetation that can both armour the system and reduce sediment transport in the reach. Such approaches to incised stream management limit the use of hard structures to the minimum extent necessary to create a system that will enable native vegetation establishment with a level of confidence that is acceptable to the investor and stakeholders.

Where local bed instabilities or head-cuts are migrating upstream, resulting in bed deepening, the incision can be addressed through a grade control program such as rock chutes coupled with revegetation. Rock chutes coupled with revegetation have proved to be one of the most successful techniques for treating incised waterways in Victoria.

The two approaches to the management of incision, which may be used alone or in combination, comprise:

1. Addressing the sediment transport imbalance.
2. Managing erosion thresholds.

3.4.2.1 Addressing the sediment transport imbalance

Imbalances between the sediment supplied to a reach and the sediment transport capacity of the reach is the dominant cause of incision (see Figure 3). When sediment supply is below sediment transport capacity the reach is said to be in a sediment deficit, and the flow energy that would otherwise have been consumed by transporting sediment is instead expended on the exposed channel bed, leading to the potential for incision. The potential for incision will be realised if the erosion forces on the bed of the channel are greater than the resistance forces.

The development of a stable bed grade and / or modifying the channel dimensions to halt the net export of sediment from the reach will only succeed if the supply of bedload sediment to the reach is maintained unless the system can be fully armoured. Thus, addressing any sediment imbalance is key to the success of most stream incision programs.

Waterway managers can address a sediment deficit by either increasing sediment supply to the reach or reducing sediment transport capacity of the reach. The most appropriate approach will depend on what has caused the sediment deficit to arise: a change in sediment supply or a change in sediment transport capacity.

Waterway managers can close a sediment deficit by increasing sediment supply such as:

- Removing upstream instream sediment barriers such as weirs that are trapping sediment and starving downstream reaches.
- Halting or limiting sediment extraction from upstream reaches that are starving downstream reaches.
- Prevent or limit the establishment of invasive weed species in upstream reaches that bind sediment to the channel bed, starving downstream reaches.
- Directly adding sediment to an upstream reach. Directly adding sediment to upstream reaches is seldom feasible and requires repeat interventions for an indefinite period. As soon as sediment replenishment activities cease the sediment deficit will return and incision is likely to recommence.

Further, if a decrease in sediment supply has been caused by a change in flow regime, then waterway managers can use flow management to increase sediment transport and re-supply sediment to the subject reach.

A sediment deficit can also be closed by decreasing the sediment transport capacity within the subject reach. Sediment transport capacity of the subject reach can be decreased by one or a combination of:

- Reducing the bed grade of the reach.
- Altering channel dimensions in the reach (widening the channel).

- Reducing the flow rate in the channel (modifying the catchment hydrology or displacing a proportion of the flow regime from the channel to the floodplain).
- Increasing the roughness of the channel (e.g. by increasing the density of vegetation in the channel).

The interventions that target reductions to sediment transport capacity in an incising reach have the benefit of also reducing the applied shear stress and channel velocity in the reach and hence the potential for such shear stress and channel velocity to exceed the thresholds for the bed and bank material. These interventions are also discussed in section 3.6 below.

3.4.2.2 Managing erosion thresholds

The potential for net erosion to occur, as a result of a sediment deficit, will depend on the potential for sediment transport from the reach (transport capacity) to be realised. Such realisation requires the applied shear stresses to exceed the resisting forces of exposed bed and subsequently bank material.

This approach to management seeks to reduce the occurrence (or likelihood) of in-channel shear stress (and/or velocity) exceeding the threshold for mobilisation (erosion) of bed and bank material.

Reduction is applied shear stress can be achieved through efforts similar to those used to reduce transport capacity including bed (and hydraulic) grade reduction, channel widening and increasing the roughness of the channel.

The shear resistance of the channel can be increased by allowing armour layers to form, introducing new armour layers (e.g. rock chutes) and/ or through the armouring effect of native vegetation.

3.4.2.3 Integration of sediment transport balance and management of erosion thresholds

In rare circumstances a successful incised stream management program will comprise one or the other of the sediment balance and erosion threshold approaches. In most circumstances the effective management of incising systems will be achieved through the integrated management of the sediment imbalance and erosion thresholds. Such integrated management can incorporate:

- Actions to increase the sediment supply to the reach.
- Grade control structures that can armour nick points and / or initiate upstream sediment deposition and aide the development of a stable streambed grade.
- Options to displace a portion of flood flow onto the adjoining floodplain and/or reduce the flow regime delivered to the reach.

- Channel widening (to reduce sediment transport capacity and erosion potential) and/or bank battering to achieve these and to establish a stable platform for native vegetation establishment.
- Additional structures to reduce the mobilisation of bed sediments.
- Native vegetation establishment.

Successful integrated incised stream management programs typically include three core elements:

1. grade control structures to establish a stable streambed grade between structures.
2. channel dimension modification (channel widening and/or bank battering).
3. native vegetation establishment.

In combination these three elements can be used to address the sediment imbalance and erosion thresholds in the incising reach.

Over the long term, establishment of native vegetation will be essential to the success of the incised stream management program. Native vegetation establishment increases the geomorphic stability of the waterway by increasing roughness that reduces the sediment transport capacity of the reach and shear stress applied to the bed and banks and increasing the resistance of the bed and bank material to the applied hydraulic forces. However physical modification of the system through the use of grade control structures and channel cross-section form will often be required to enable vegetation establishment and provide confidence in the long-term success of that vegetation establishment.

A combination of three analysis techniques can be used in the development of an incised waterway management program comprising these three elements (bed grade management, channel cross-section dimensions and vegetation establishment). Additional analysis can be included to explore additional intervention options and/or address more complex systems or systems with elevated risk. The three analysis techniques comprise:

- The identification of a stable (design) bed grade: The stable bed grade can be used to identify whether grade control works are required and if so, the location and height of potential grade control structures.
- The identification in-channel specific stream power: In channel specific stream power can be compared with reference values for (geomorphically) stable waterways and adjoining reaches, and used to identify the extent to which the channel bed grade needs to be further reduced and / or the cross-section modified to reduce the (implied) sediment transport capacity of the reach.
- Shear stress analysis: The use of shear stress thresholds to design individual elements of the grade control program, such as rock chutes and vegetation establishment.

The three analysis techniques are summarised below.

3.4.2.3.1 Identification of a stable (design) bed grade

Control of channel bed grade requires the waterway manager to identify and adopt a stable bed grade for the incising waterway. The supporting analyses described in Part 5 of the Guidelines contain methods for identifying a stable bed grade for a subject reach.

The approach to identifying a stable bed grade relies on first identifying channel bed grades associated with intact and representative stable reaches of stream, and those that are subject to ongoing instabilities. Stable bed grades can be identified via:

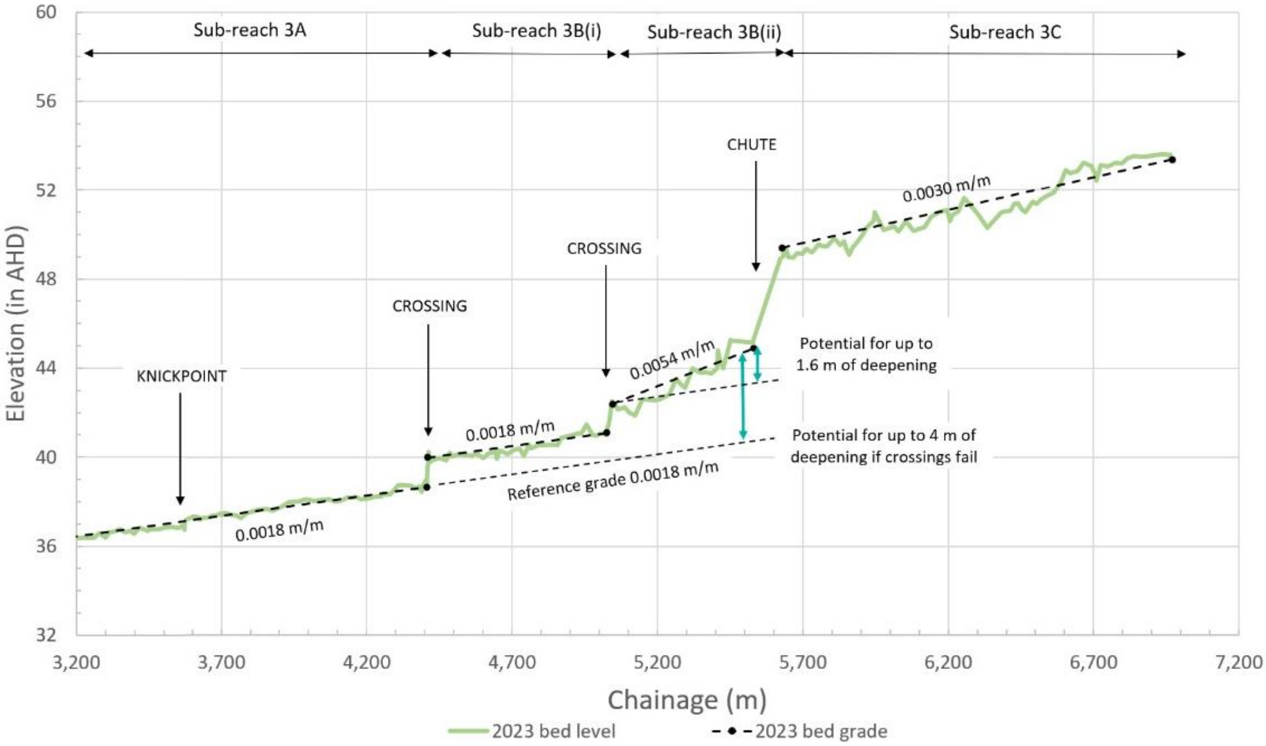
- **Stream bed longitudinal survey**. There should be sufficient survey upstream and downstream of any apparent instabilities to enable identification of stable channel bed gradients for reaches subject to channel recovery.
- **Analysis of the longitudinal channel bed profile data**. The analysis can involve visual or analytical approaches to the identification of representative and stable bed grades for the stream. Analytical procedures may involve techniques such as moving average analysis.
- **Visual identification of knickpoints and/or uncharacteristically steep sub-reaches** – characterised by a sharp increase in bed grade compared to sub-reaches immediately upstream and downstream.

An example of stable bed grade identification is shown in Figure 29. In this example a reference grade of 0.0018m/m has been identified for the channel in sub reaches A and B. Stream bed longitudinal profile inconsistencies are present at the existing crossings at Ch1250m and Ch1850m (approx.). The existing crossings appear to be preventing up to 4 metres of incision. A steep bed grade has been identified between Ch1850m and Ch2400m. An existing rock chute has been identified at Ch 2400m that appears to be preventing approximately 6 metres of channel incision. A grade of 0.0028m has been identified for sub reach D. A potential stable grade of 0.0018m/m may be appropriate for the design (location and elevation) of grade control structures. Based on this assessment the existing rock chute at Ch 2400 may be at risk of being undermined and failing,

Armed with a potential stable (design) bed grade the waterway manager can progress to the identification of the potential location and size of any grade control structures that may be required for the reach.

Once the potential location and size of grade control structures have been identified, the waterway manager can progress the design a streambed stabilisation strategy for the reach. Note several iterations of this analysis and design element may be required based on the outcomes of the subsequent analysis and design elements.

Figure 29. Longitudinal bed profile analysis to identify stable bed grade.



3.4.2.3.2 Reduction of stream power

Stability in the reach requires the sediment transport capacity in the reach to match the sediment supply to the reach, (unless the system can be fully armoured against erosion). In alluvial waterways a sediment discontinuity can in part, and to a large extent, be managed through the establishment of in-channel (bed and bank) vegetation. This vegetation increases the roughness of the channel thereby reducing the sediment transport capacity of the reach. This vegetation has the added benefit of also armouring the bed and banks of the waterway.

Adoption of a stable channel grade when combined with instream vegetation, woody debris, and other techniques increases the roughness of the reach and leads to a reduction in specific stream power, and associated sediment transport capacity.

The estimation of sediment transport capacity into and through a reach can be complex and time consuming. Specific stream power analysis can be used as a simplified means of estimating the sediment transport capacity of a reach. Waterway managers should aim to reduce specific stream power below reference values found for waterways not subject to active incision. Reference stream power values have been established for both the 40% AEP and 2% AEP flow events for waterways in Victoria.

Waterway managers should also ensure that specific stream power values are similar between reaches to ensure sediment transport continuity. Specific stream power analysis can also be used to check that the implied sediment transport capacity in the subject reach matches the sediment transport capacity of the upstream reaches supplying sediment and the downstream reach to which sediment will be supplied.

Refer to the supporting analyses in Part 5 of the Guidelines for further detail on how specific stream power for a subject reach can be estimated, and for the relevant reference values of specific stream power. Note that the reference values for specific stream power have been developed for waterway systems with an ongoing bed load sediment supply and a structurally diverse riparian native vegetation community. Attainment of stable waterway systems using these criteria will require an ongoing bed load sediment supply and establishment of accompanying native vegetation within and downstream of the subject reach.

In addition to the reduction in bed grade through grade control works and increased channel roughness, specific stream power (and hence sediment transport capacity) can be further reduced by:

- Altering the flow regime of the waterway. In many instances, historic alteration of the hydrologic regime may be the driver that triggered incision, and interventions that remove or modify the activities that lead to this driver have potential to aid management. Interventions that alter the hydrologic regime include management of catchment runoff and diversion of reach inflows during some or all flow events (likely only suitable in smaller waterways). However, modification of the flow regime is unlikely to be a viable single approach (even if combined with revegetation) to manage the incision process once the process of incision has commenced and progressed beyond Stage two (see Figure 4).
- Modifying the channel cross-section geometry. This can include channel widening or bank battering.

3.4.2.3.3 Shear stress thresholds for intervention design

The identification of a stable bed grade and the evaluation of specific stream power seeks to establish acceptable applied energy and bed load sediment transport rates. However, the design of individual elements of a grade control program uses a threshold approach based on shear stress values. The threshold approach explicitly quantifies erosion forces (shear stress, units of N/m^2) and resistance forces (shear resistance, units of N/m^2), and adjusts the design of the relevant elements such as grade control structures and bank angles to meet the shear resistance of available materials (e.g. rock on a grade control structure or vegetation on a streambank), for a ‘design’ (flow) event. Details of the approach and values are provided in Part 5 of these Guidelines. As indicated, the shear stress analysis can be applied to any proposed instream stabilising works such as grade control structures and proposed stabilising vegetation.

Vegetation will be most effective in the armouring of the reach in ephemeral gullies where the vegetation can occupy the full cross-section of the channel. Vegetation will be less effective at armouring the bed of the waterway where there is a wide deep channel that cannot be colonised by vegetation. In larger stream systems where vegetated armouring of the bed is not possible, there will be a greater reliance on the formation of an armour layer of resistant bed material (e.g. cobbles) and / or an ongoing source of bed sediment (refer reduction in stream power discussion above).

In some large systems where the waterway lies within an entirely urbanised catchment the incision processes can persist despite the establishment of a flat (horizontal) bed grade between grade control structures and associated bank vegetation. These systems often have limited bed load sediment supply and rely on accompanying rock rip rap armouring of the bed and banks to address the imbalance in bed load sediment transport (high) and supply (low).

3.4.2.4 Secondary consequences

Halting the incision process can lead to a reduction in the sediment supply to downstream reaches. The bed grade and stability of those downstream reaches may have adjusted to the artificially high sediment supply arising from the ongoing upstream incision process. Halting that sediment supply through grade control works has the potential to reduce downstream sediment supply and in the absence of complementary work to reduce downstream sediment transport capacity can result in renewed incision *downstream* of the interventions.

Such renewed incision has the potential to undermine the newly installed grade control structures. There are many examples of this renewed process of incision arising from effective grade control programs including on the Cann River in east Gippsland and Hodgsons Creek in north east Victoria. This risk can be reduced through the provision of measures that reduce the sediment transport capacity or increase the shear stress resistance in the downstream reach. These downstream measures could include vegetation establishment programs and avoiding disturbances (e.g. by stock and machinery) to establishing natural armour layers. In some instances additional grade control structures may be required.

A successful grade control program has the potential to intentionally or as a byproduct of the program, increase the occurrence of overbank inundation. Such inundation should be the subject of discussion and agreement with adjoining landholder and other impacted stakeholders.

3.4.2.5 Common mistakes

There are several errors of management which a careful analysis of the processes at work will help avoid, for example:

- Unnecessarily intervening to address the incision process or intervening at a scale that is not sufficient to halt or aid recovery from the incision process. Significant investment in an incising system is at risk if that investment has not addressed the issue at the scale required.
- Failing to recognise that a waterway is incising or has incised in the past. Addressing bank erosion issues (a symptom of incision) without addressing the route cause incision will result in the loss of those efforts.
- Installing structures that are poorly designed and not capable of resisting the applied forces (particularly being too steep, and so unable to resist the shear stresses in the system).

- Not addressing activities such as grazing by stock, that prevent the establishment of essential native vegetation.
- Not recognising the importance of sediment transport continuity and as a result the potential for ongoing incision following completion of initial grade control and associated erosion control works.

3.4.3 Management of accelerated channel meandering

Waterway managers can use one or a combination of four main approaches to manage meander migration:

1. Don't intervene and let the meander migration continue.
2. Halt meander migration entirely.
3. Reduce the rate of meander migration to natural levels.
4. Relocate assets away from the waterway.

The first option of no intervention is covered in the second step of the four step decision making framework and not further discussed here.

The first priority of the waterway manager should be the establishment of continuous stands of native riparian vegetation, which can be used to both restrain meander migration and provide a host of benefits to waterway values and asset protection over the long term. The choice of approach to meander migration will likely depend on the value of assets impacted by a migrating meander (or meander bends).

Management approaches and techniques that can be used for management meander migration are summarised below.

3.4.3.1 Halt meander migration entirely

Historically, hard engineering interventions, such as rock structures have been used to arrest meander migration and to prevent further loss of floodplain land or infrastructure. While this approach may be appropriate when the value of floodplain land or infrastructure threatened by meander migration is high, halting meander migration at a site has several adverse consequences for waterways:

- The installation of rock, which may be required to eliminate bank erosion, can destroy bank habitat, inhibits the development of riparian vegetation and the ecological function it serves, and degrade waterway amenity.
- Halting meander migration leads to a decrease in local sediment supply, which the waterway compensates for by eroding the channel bed at the toe of the modified bank, or by accelerating migration in adjoining meanders.

Ultimately all structures will reach the end of their design life (even rock) and meander migration will resume if underlying causes have not changed over time or otherwise been addressed. Therefore, intervening to halt meander migration entirely is rarely a permanent solution and should be reserved for situations when a high value asset requires protection (and relocation of that asset is not feasible).

Further, hard engineering delivers little, if any, benefit to reducing reach scale stream power. Such works prevent the development of a meandering channel that matches sediment input with output. Application of “softer” treatments including instream wood and vegetation reduce the sediment transport capacity in the reach and therefore are more able to match the sediment transport from the reach to sediment supply to the reach and hence create a more (geomorphically) stable channel.

3.4.3.2 Reduce the rate of meander migration to natural levels

In cases where threats such as vegetation removal or decline have reduced resistance forces and lead to accelerated meander migration, waterway managers can decrease the rate of meander migration towards natural rates by increasing the resistance of the channel banks. Over the long term, re-establishing native riparian vegetation and permitting natural accumulation of woody debris loads is the most effective means of increasing resistance forces and decreasing the rate of meander migration. In high energy waterway systems, structural works may be required to aid the establishment of native vegetation and a wider area of riparian land vegetated and protected from stock will be required to enable the vegetation to establish. The type and scale of structural work used to support native vegetation establishment will vary between sites and should be based on the purpose of the works and the potential impacts of works. The supporting analyses outlined in Part 5 of the Guidelines can aid the selection and design of works.

Examples of structural works that can be used to support vegetation establishment and long-term bank stability include (individually or in combination):

- Rock beaching at the toe of the bank to prevent erosion undermining the toe and over-steepening the bank.
- Pile fields to increase channel roughness, reduce flow velocity, and promote vegetation establishment.
- Wood revetement and engineered log jams.
- Installation of coir matting or coir logs to shield establishing vegetation from scour. Coir or jute matts/logs are woven matts/logs made from natural coconut fibres (coir) or white jute plant (jute).
- Bank battering and re-profiling to create a stable slope in which native vegetation can be planted.

3.4.3.3 Relocate assets away from the waterway

If the motivation for halting or reducing the rate of meander migration is the protection of assets located on the floodplain, then waterway managers should consider relocation of the threatened asset away from the waterway. Relocating floodplain assets has the advantage that once the asset has been moved, no further intervention in the waterway or ongoing maintenance of on-ground works is required. This approach also has the added benefit that relocated assets may face a decreased likelihood of being impacted by floods.

3.4.3.4 Secondary consequences

As is always the case in waterways, it is not possible to intervene and change the rate of one process, without having consequences elsewhere. This is true of stabilising an eroding bank. Stabilising the bank will reduce the supply of sediment to the channel, as well as altering the deposition on the adjacent point-bar. The typical effect will be an increase in erosion in adjoining reaches.

3.4.3.5 Common mistakes

Interventions aimed at halting meander migration that focus on addressing the scour of the bank face without first addressing scour at the toe of the bank, are inevitably undermined by retreat of the bank toe. The ad-hoc placement of rock against eroding meander bends or failure to batter over-steepened banks so that rock can be properly placed at the bank toe are common examples of such work.

Similarly, the ad-hoc placement or poor construction of bank protection structures that uses material not suited to bank armouring, such as disused machinery or scrap metal, are a common but ultimately futile means of halting meander migration. Such construction also introduces foreign and potentially harmful material into the waterway. Such techniques are not appropriate nor recommended.

3.4.4 Management of aggradation

Often bed aggradation will be a result of upstream sediment release. Strategies for the control of bed aggradation should first look at the source of the sediment and address these if they are still present. If the source of sediment cannot be controlled, or sediment inputs occurred in the distant past but have since ceased, the waterway manager can intervene to deal with the resulting aggradation in downstream reaches or intervene to protect downstream reaches before streambed aggradation occurs. Waterway managers can use one or a combination of three approaches when addressing streambed aggradation:

1. Accelerate the passage of the sediment downstream.
2. Directly extract sediment from the channel bed.
3. Trap and store the sediment in the channel bed.

3.4.4.1 Accelerate the passage of the sediment downstream

If a sediment pulse has formed within a regulated system then waterway managers can modify the flow regime to accelerate the passage of the sediment pulse downstream. This approach requires that waterway managers have some control over the magnitude, duration and frequency of flows that mobilise the sediment pulse. Accelerating the passage of a sediment pulse simply limits the total time that any one reach is impacted by streambed aggradation. However, the tendency for pulses of sediment to disperse as they migrate downstream and the potential for both increased flooding and interaction with bed levels in adjoining tributaries mean that this approach is unlikely to feasible in most cases. This approach is most likely to be feasible only when the size of the sediment pulse (measured as either the volume of sediment or the depth of streambed aggradation) is small relative to the pre-pulse channel capacity and flows are highly regulated.

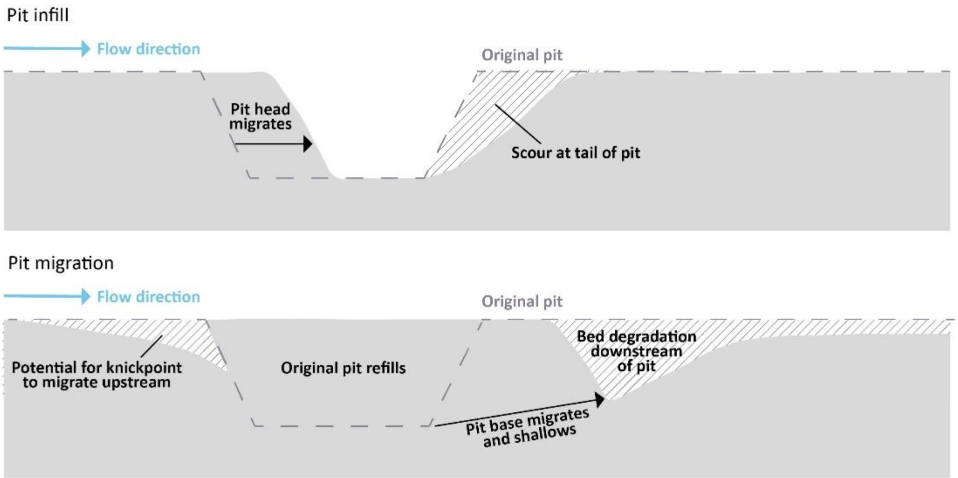
3.4.4.2 Directly extract sediment from the channel bed

The control of bed aggradation may be possible via sediment extraction. Sediment extraction can be used in the pulse peak zone to locally lower bed levels, and to reduce the supply of sediment to downstream reaches. Extraction may also be used in the trailing edge of a sediment pulse to accelerate channel recovery. Extraction in the leading edge zone is not recommended as aggradation has not occurred yet and may lead to destruction of valuable habitat or initiation of unfavourable geomorphic processes.

Note that if the cause of sediment deposition remains, extraction will be ongoing. Further, the volume that must be removed to make a meaningful impact on bed elevation may be extensive, resulting in the establishment of a long-term commitment to ongoing extractions.

The refilling of an extraction pit, and the impact of the pit on downstream reaches is shown conceptually in Figure 30.

Figure 30. The evolution of an extraction pit excavated in the channel bed.



3.4.4.3 Trap and store sediment in the channel bed

When channel bed aggradation is widespread, the downstream movement of sediment is very slow and there is a need to limit the delivery of sediment to downstream reaches, waterway managers can intervene to trap and store accumulated sediment in the channel bed. Trapping and storing sediment in the channel bed can be implemented at both the peak of the sediment pulse and the tail of the sediment pulse as a means of accelerating channel recovery.

Aiding the establishment of instream vegetation is one of the most effective means of trapping and storing sediment on the channel bed. Instream vegetation traps and stores sediment via two mechanisms:

- By increasing channel roughness, which reduces stream power, flow velocity and sediment transport capacity and promotes sediment deposition.
- By increasing the resistance forces on the channel bed, preventing deposited sediment from being re mobilised and available for transport downstream.

Installation of instream structures, such as log sills or pile fields, that span the width of the channel may be required to create initial stability in the mobile environment necessary for vegetation establishment. Instream vegetation can then establish within the sediment deposits and lock sediment into longer term storage on the channel bed. Examples of the use of instream structures to create stability for vegetation establishment in aggrading systems can be seen on the Genoa River downstream of the Genoa township, the Avon River downstream of Stratford and the Glenelg River.

Figure 31. Large woody debris installed in the bed of the Genoa River helping create a stable environment suitable for subsequent vegetation establishment.

Instream vegetation can be established in aggraded waterways by:

- Directly planting vegetation on the channel bed during low flows.
- Natural recruitment: This option requires that nearby patches of suitable vegetation such as macrophytes that can colonise the deposited sediment, or that seedlings of appropriate vegetation are able to be naturally sourced from the waterway.

Stock exclusion fencing will be essential to allow vegetation to establish on the sediment deposits. Similarly control on vehicle and machinery access will also be essential to protect establishing vegetation.

Alternative strategies that help reintroduce channel diversity within an aggrading system can be considered. These might include provision of channel roughness/structure (large wood, engineered log jams and boulder seeding) to induce local scour, or planting of instream vegetation to promote pool development.

Where possible, allowing meander migration to occur, along with the accompanying point bar development, channel lengthening and decrease in stream powers can facilitate sediment storage using the waterways own natural processes, however the release of sediment from the erosion needs to be considered.

Where aggradation is due to a reduction in in-channel flows, consideration should be given to the provision of a suitable flow regime that can transport the bed load in the channel.

3.4.4.4 Secondary consequences

Managing pulses of sediment in a waterway can have secondary consequences upstream and downstream (as summarised in Sims and Rutherfurd 2017) for example:

- Downstream transfer of impacts. If waterway managers intervene to accelerate the passage of a sediment pulse downstream, then the impacts of sediment pulses on channel morphology, such as the smothering of habitat, avulsions and interaction with tributaries are also transferred to downstream reaches.
- Tributary rejuvenation. Mainstem aggradation can block tributaries, and sediment moving down the tributaries is trapped and stored at the junction with the mainstem. As the sediment pulse in the mainstem migrates downstream (perhaps accelerated by interventions such as sediment extraction or trapping and storing sediment in upstream reaches of the mainstem) and the bed deepens, the large volumes of sediment stored in the lower reaches of the blocked tributaries will be released into the river as a second pulse of sediment.
- Enhanced incision. The morphological consequences of a reduction in sediment supply include; incision, channel narrowing, bed armouring and, in some cases, the transition from a braided to a single-threaded sinuous morphology. Incision in downstream reaches can be desirable (and intentional) but depending on the depth and rate of that incision the change may lead to a host of secondary and unintended consequences (see section 2.2.4).

When a pulse of sediment moves through a reach (whether at a rate accelerated by managers or not) there will be consequences. For example, the sand slug that has moved through Bryan Creek a tributary of the Glenelg River. Sims and Rutherfurd (2021) describe how Bryan Creek was an incising stream when it was filled by sand from upstream in the 1940s. The pulse of sand stopped the incision that had been occurring in the channel. But when the sand moved out of the channel (accelerated by commercial sand extraction) the creek returned to where it had left off 80 years before and began incising again.

3.4.4.5 Common mistakes

The use of sediment extraction to reduce the supply of sediment to downstream reaches and manage streambed aggradation requires that the volume of material extracted should be equal to the volume required to trigger removal of excess sediment deposits, but no more. There are many examples in Victoria of over-extraction triggering severe incision and associated impacts in downstream reaches, for example Bryan Creek in the Glenelg River Catchment and the Avon River Gippsland (Davis *et al*, 2000; Sims and Rutherfurd, 2021).

3.4.5 Management of avulsion

Avulsion is a fundamental behaviour of alluvial rivers. Attempts to control this instability by preventing an avulsion occurring can be difficult and requires consideration of the ability to control the process, the level of engineering works required, cost feasibility and broader societal, legal and environmental factors at play.

Avulsion management requires a combination of all the approaches that can be used to address, channel incision and floodplain scour in the daughter channel and bed aggradation and meander migration (and development) in the parent channel.

Considering the above, waterway managers have two options to manage avulsions:

1. Delay or prevent the avulsion.
2. Limit the development of the daughter channel after the avulsion occurs.

Completely halting an avulsion is rarely possible. Regardless of the management approach planning processes will need to be examined that enable the development of social, economic and environmental arrangements in anticipation of the avulsion. The arrangements can include:

- Town planning arrangements to limit development within the corridor of the daughter channel. This width of this corridor should reflect the meander belt of the parent channel.
- Provision of revegetation programs within the meander belt of the daughter channel in preparation for this to become the main stem of the waterway.

The urgency for such planning arrangements will be dependent on the time scale for the avulsion.

3.4.5.1 Delay or prevent the avulsion

While preventing an avulsion may be difficult, the waterway manager can intervene to either delay and/or to some extent, prevent the avulsion. Interventions to delay or prevent an avulsion can treat either the processes driving the decrease in hydraulic efficiency in the parent channel, the processes driving the relative increase in hydraulic efficiency of the daughter channel, or some combination of the two.

Interventions that treat streambed aggradation are the most appropriate means of addressing the decrease in hydraulic efficiency of the parent channel (section 3.4.4. Other, avulsion-specific interventions include:

- Replacement of invasive vegetation (e.g. willow) along the channel bed and banks with appropriate native vegetation. The aim of this intervention is to prevent vegetation from accelerating channel contraction and to decrease channel roughness. Decreasing channel roughness leads to increased flow velocity and higher sediment transport rates, which limits the rate of streambed aggradation and capacity loss.
- The selective removal, or redistribution of channel blockages such as instream wood jams. The purpose of this intervention is to eliminate channel blockages and reduce the likelihood of channel spill and breakout points developing. Only wood that has accumulated in a jam and is blocking the channel should be removed.
- Removal of artificial levees along the channel banks which confine floodwaters and prevent sediment from being transported out of the channel and onto the floodplain.

Waterway managers can address the increase in hydraulic efficiency of the daughter channel by management of the incision process (see Incised Waterways section). This could include the armouring of the bed, banks and migrating head cut of the daughter channel, or terraces confining in-channel avulsions, with riparian vegetation or structural works (Figure 32). The purpose of this intervention is to slow the rate of further channel incision and widening.

Figure 32. Rock work installed at the upstream end of a developing floodplain channel that conveys flow from the Ovens River (parent channel) to Happy Valley Creek (daughter channel).

Reducing floodplain scour is an important element to the strategy of delaying or preventing an avulsion. By increasing the erosion resistance of the floodplain, waterway managers can delay the eventual connection between the parent and daughter channel (and in some cases stop it).

3.4.5.2 Limit the development of the daughter channel after the avulsion occurs

In some instances, such as valley scale avulsions that occur over a sequence of flood events, waterway managers can intervene after the parent channel has connected with the daughter channel, but before the parent channel has been completely abandoned. The aim of such intervention is to delay the development of the daughter channel and to some extent, pause the avulsion process. Interventions that can be used to limit the rate and magnitude of widening and deepening of the daughter channel include:

- Installation of flow regulators that partition flow between the parent channel and the daughter channel. The purpose of regulators is to maintain flows to the parent channel, and to decrease the magnitude and frequency of flows delivered to the daughter channel, to limit the rate of channel expansion. The Cowwarr Weir which partitions flow between the Thomson River and Rainbow Creek is an example of such a structure.
- Undertake a program of grade control in the daughter channel, to limit further channel deepening.
- Establish wide and continuous native vegetation along the daughter channel. The purpose of this vegetation is to increase the erosion resistance of the channel banks and limit further channel widening.

Delaying the development of the daughter channel does not address the fundamental factor driving the avulsion process: the mismatch in hydraulic efficiency between the parent and daughter channel. Any overall gradient that concentrates floodwaters from the parent channel into the daughter channel will also be unaddressed by this management approach. It is therefore inevitable that the avulsion cycle will be completed. Secondary consequences of managing avulsions

The temptation in most situations is to stop avulsions from happening (by blocking effluents or other actions). Experience around the world has shown that this might not be a sustainable option in the long-term. Forcing a channel to stay in one position on the floodplain does not change the underlying processes that have led to the avulsion in the first place. If held in one position, the channel will become increasingly likely to change alignment. This is because the channel will continue to meander, to fill with sediment, to deposit levees. Thus, the forces encouraging avulsions tend to increase with time. This means that managers have to be vigilant for new break-outs and new developing channels.

3.4.5.3 Secondary consequences

Waterway managers must be mindful that interventions in the parent and daughter channel can have a range of secondary impacts within the avulsion reach, and in upstream and downstream reaches. Overall, the most important unintended consequence of interventions that delay avulsion is that they have the potential to increase the elevation difference between the parent and daughter channel. The elevation difference increases because the timeframe over which the processes that build the alluvial ridge and perch the parent channel and those that scour and lower the elevation of the daughter channel is increased due to intervention. Over time, this across-valley gradient makes an avulsion more likely and potentially more energetic once it does occur. A more energetic avulsion is more likely to cause rapid migration and then expansion of the daughter channel.

3.4.5.4 Common mistakes

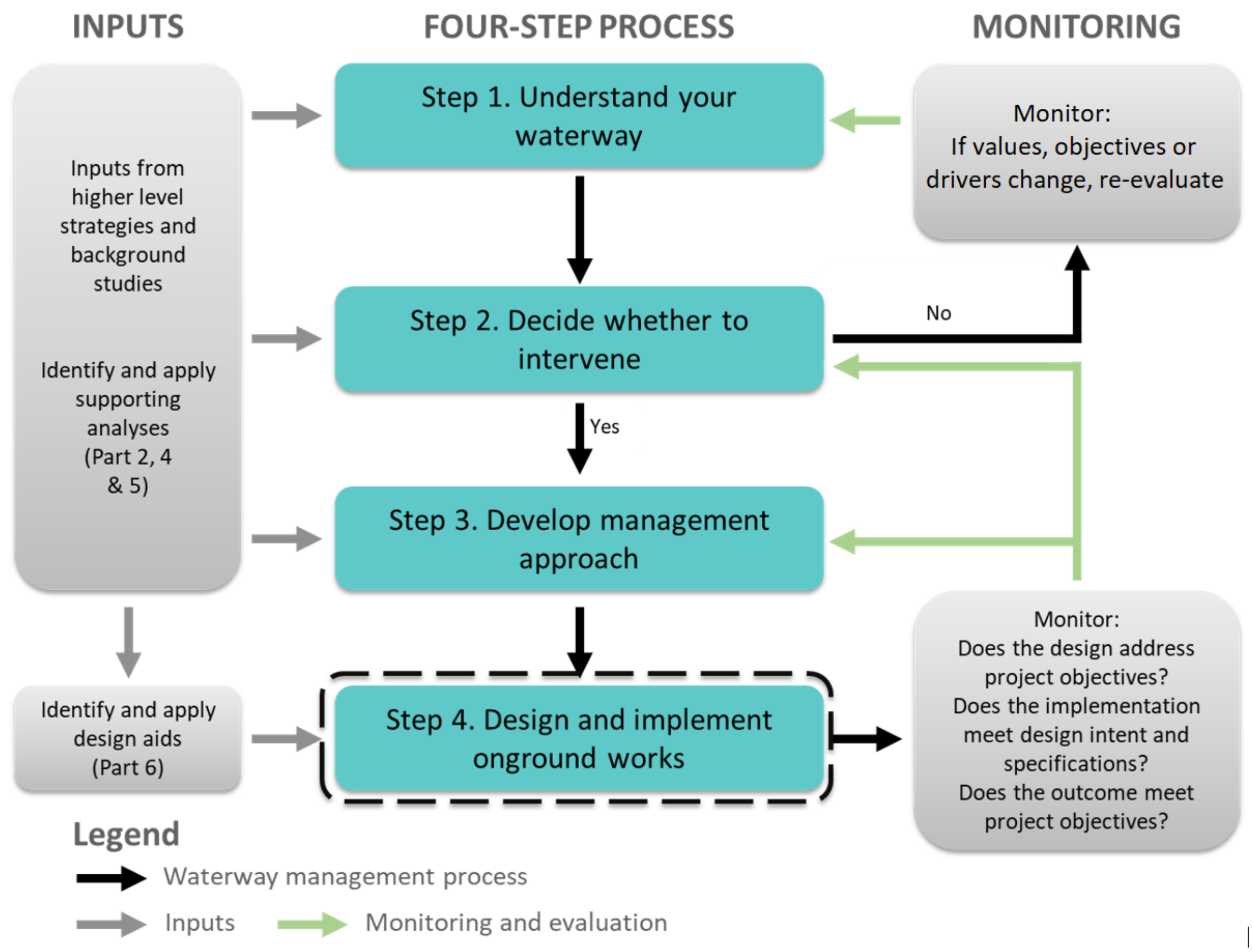
Interventions to manage avulsions commonly focus on addressing spill from the parent channel using on-ground works (such as artificial levees or rock beaching on the outside of meander bends) without also considering the wider avulsion process. An over-reliance on flood control in the parent channel means that the fundamental drivers of avulsion – the reduction in flow capacity of the parent channel and the increase in flow capacity of the daughter channel – remain unaddressed.

Management approaches that aim to prevent the avulsion entirely may be successful in the short term but are likely to fail in the long term. A focus on preventing an avulsion may mean that interventions and associated planning for the consequences of the inevitable avulsion are not undertaken.

3.5 Step 4: Design and implement on-ground works

The final step in the four-step process is to design and then implement on-ground works if and as required. Supporting analyses and design aids to guide the design of on-ground works are provided in Part 5 and 6 of the Guidelines.

Figure 33. Step four: Design and implement on-ground works.



The design and implementation of on-ground works should reflect both the relevant reach scale management approach and the stated project objectives. Key tasks include:

- Identify the required level of service for analysis, design and implementation.
- Design works to appropriate and applicable standards.
- Implement activities and works.
- Monitor and evaluate.
- Document and report.

3.5.1 Levels of service for analysis, design and construction

The level of service (also referred to as the rigour or level of effort) adopted for the analysis, design and implementation of interventions should be a function of the importance of the project and the risks associated with project failure. While the Guidelines can provide guidance, it is not possible to prescribe the most appropriate design standard for any particular project, organisation or circumstance. This is the role and responsibility of the waterway manager.

Projects aimed at protecting waterway assets of greatest value, geomorphic processes posing the greatest threat, projects with the highest level of public profile, or projects with the highest level of expenditure may warrant the highest levels of analysis, design and implementation. Conversely lower levels of analysis and design may be appropriate for those projects with the lowest risks associated with failure.

3.5.2 Design of works

The design of on-ground works requires the assessment of available and appropriate materials and detailed analysis of the selected options. The design process may be aided by software packages and other design aids.

Supporting analyses to aid in the design of on-ground works are outlined in Part 5 of the Guidelines and standard drawings for a selection of intervention options are provided in Part 8 of the Guidelines. A selection of materials commonly used in the design of on-ground works is discussed in section 6.11 of the Guidelines.

3.5.3 Implementation planning

Successful delivery of on-ground works relies on thorough planning. This will require obtaining relevant approvals, development of a construction schedule, engagement of suitable contractors and staff, and the supervision of works.

Site access, including understanding land tenure, both during construction of and for the purpose of ongoing maintenance, will often include private landholder(s) approval. These arrangements will vary in scope and complexity depending on whether the subject reach or site is located within an urban or rural setting, the number of different landholders with properties that adjoin the site, and any history of cooperation or conflict between the waterway manager and landholders. Site access and landholder cooperation are crucial to the success of many on-ground interventions.

It is not the intent of the Guidelines to provide details of construction management techniques and approaches.

Construction works can have temporary and long-term impacts such as:

- Noise.
- Water quality impacts.
- Weed transferral.
- Damage to vegetation.
- Damage to sites of heritage value.

A thorough assessment of potential impacts should be undertaken prior to the implementation of any on-ground works. The assessments should be undertaken to identify whether works should proceed, the appropriate timing of works relative to periods of low or high flow and the associated risk to vegetation establishment or erosion at the site, and to identify whether remedial measures are required to reduce or mitigate potential impacts.

Implementation (output) targets should be developed for the priority activities and works. The implementation targets should set out the timing, location, and extent of works and how these activities and works and the implementation targets will contribute to the attainment of the intended vision and outcome targets.

3.5.4 Monitoring and evaluation

Monitoring and evaluation of works and the impacts those works have on physical waterway form (or the biological process the structures are targeting) is an integral component of reach and site scale interventions and provides feedback on the success or otherwise of projects, activities and works. This feedback will provide information that can improve effectiveness of on-ground works and help “steer” efforts towards those activities that will lead to the desired waterway outcomes for the project and generate information that can be used for similar projects. Further, the monitoring and evaluation may reveal unintended outcomes that necessitate adjustments to the project objectives or to the management approach.

A simple monitoring program that identifies whether works have been implemented and are operating as intended and whether the waterway is moving toward the intended outcomes may be sufficient for many projects. Components of a Monitoring and Evaluation Plan could include, but may not be limited to:

Design monitoring:

Throughout the development of the management approach and subsequent design (Steps 3 and 4), it is critical to monitor and assess the alignment of the design with the project objectives developed in Stage 1. This may include:

- Feasibility: the design is constructable, materials readily available, safety in design has been considered and acceptable, the project is financially feasible considering available budgets.
- Environment values: the design delivers on protection and enhancement objectives for specified plants and animals or whole ecological communities.
- Economic values: the design protects public and private assets that are at risk as a result of ongoing geomorphic processes (e,g. water supply, urban and rural flood security, bridges, roads, telecommunications infrastructure, fences and many more).
- Cultural values: design protects and enhances historic features, and landscape and cultural values.

- Social values: the design addresses recreational use of waterways e.g. fishing and canoeing and the amenity waterways provide to local communities.

Implementation monitoring:

In many cases, waterway management interventions warrant ongoing monitoring to ensure that:

- Works have been undertaken in accordance with the design specifications.
- The ongoing operational performance is in accordance with the design intent.
- Maintenance programs or potential modifications to works are undertaken.

Outcome monitoring:

In addition to implementation monitoring, outcome monitoring and evaluation is generally recommended to assess whether the actions or works are effective. Evaluation of monitoring results includes comparison to baseline conditions and the tracking of progress towards project targets. Evaluation also involves the investigation and analysis of why outcomes may or may not have been achieved. The finding of any monitoring and evaluation can be summarised in a report that is suitable for future reference and for making adjustments to ongoing works that will improve future outcomes. Learnings from this process can often be applied to improve similar projects.

3.5.5 Documentation and reporting

A management unit (waterway reach or site) based plan should be documented within a concise report that sets out:

- A description of the waterway, its condition and processes and its related values.
- Project funding, partners and stakeholders.
- Clear project objectives.
- Drivers impacting on achievement of project objectives.
- Identification of the reach scale management approach, or selection of site scale interventions.
- Details of implementation targets, responsibilities costs and timeframes.

The documentation should clearly detail who will be responsible for implementation of the plan, project partners, funding sources, contributions and the basis for funding of landholder works. Further, the documentation must set out the timeframes over which the plan will be implemented. Details of the proposed ongoing monitoring and evaluation program should be established as a component of the design and implementation phase and documented within a subsequent design and implementation report.

3.6 Management option selection guide

This section provides waterway managers with guidance on the selection of appropriate management options that can be used to address geomorphic processes.

The management option selection guide relates management options to the four dominant geomorphic processes outlined in Part 2 of the Guidelines. The geomorphic processes and corresponding management interventions included in this management option guide are limited to those that are associated with ongoing physical processes that can be addressed through direct management of the driving activity.

In many cases, waterway managers have several different management options at their disposal to address an underlying process, and in many waterways a combination of management options may be required to address a combination of geomorphic processes.

The management option guide comprising Table 4, Table 5, Table 6 and Table 7 provides information to aid the selection of a single, or combination of interventions.

The management options are qualitatively rated in terms of expected performance based on past experience. This rating includes cost, success and adverse impacts. Options with the least cost, greatest likelihood of success and least adverse impacts are afforded the highest rating and management options are ordered in the table to reflect this. The rankings assigned to interventions in the tables below are general, and site-specific factors and costings may make interventions more or less suitable. An option ranking guide is provided in Table 3.

The management option summaries in Part 4 of the Guidelines provide additional detail success factors, potential adverse impacts and monitoring requirements for each management options in more detail.

It should be noted that under certain circumstances the waterway manager may choose to implement multiple management options on the one work site, with a view to addressing multiple processes, or to derive multiple outcomes (e.g. addressing erosion whilst increasing instream habitat). Management interventions to solely increase habitat, considering the geomorphic processes, have also been included in Table 8.

Local knowledge and the target outcomes for the reach will have a major driver on the management options chosen.

Table 3. Option ranking guide.

Category	**Ranking**	**Ranking**	**Ranking**
Cost of works:	Low = 1	Medium = 2	High = 3
Likelihood of success of addressing geomorphic processes:	Low = 1	Medium = 2	High = 3
Adverse impact on meeting objectives:	Low = 1	Medium = 2	High = 3

Table 4. Management option selection guide – Incision

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Stream incision	Incision stages 2 to 5	Do not intervene	Cost: NA Success: NA Adverse impact: NA	Choosing not to intervene may be based on allowing the incision cycle to complete over time and that any impacts associated with the incision stages (deepening, widening, infilling etc.) are considered in line with project objectives and targets.	Option summary: *Section 3.3.1*
Stream incision	Incision stages 2 to 3	Grade stabilisation: Rock chutes and native vegetation establishment and management	Cost: 3 Success: 3 Adverse impact: 1	Rock chute and vegetation-based grade control programs are one of the most effective means of controlling and managing channel bed incision.	Option summary: *Section 4.2.17* Supporting design aids: *Section 6.2* – page 226*, Section 6.4, Section 6.5*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Stream incision	Incision stages 2 to 3	Grade stabilisation: Reduce stream slope through reinstatement of meanders	Cost: 3 Success: 3 Adverse impact: 1	The reinstatement of meanders within a defined reach can be used to effectively lengthen the stream, reducing the effective stream slope/energy slope and potential for incision to occur.	Option summary: *Section 4.2.8* Supporting design aids: *Section 5.3*
Stream incision	Incision stages 2 to 3	Grade stabilisation: Grass chutes and native vegetation establishment and management	Cost: 2 Success: 2 Adverse impact: 1	Grass chutes can be used to manage incision in ephemeral systems with infrequent, low energy (in line with erosion thresholds of grass) and short duration flow events. They are generally not effective in permanently flowing waterways as they rely on grass coverage for stability.	Option summary: *Section 4.2.10* Supporting design aids: *Section 6.2, Section 6.4* 290 – page 226, Section 6.7.2 – page 290

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Stream incision	Incision stages 2 to 3	Grade stabilisation: Flow modification through best practice management	Cost: 2 Success: 2 Adverse impact: 1	While flow management, through a reduction in flows, may not halt incision once it has been initiated, it can help to slow the rate of the incision process and aid in the recovery stages 4 and 5. This intervention has the potential to trigger adverse impacts on waterway condition and instream ecology, which should be considered when designing flow regimes to reduce rates of meander migration.	External resources: GBCMA, 2022
Stream incision	Figure 33. Step four: Design and implement on-ground works.	Grade stabilisation: Log sills and native vegetation establishment and management	Cost: 2 Success: 2 Adverse impact: 2	Log sills can be less expensive than rock chutes and can be an effective means of controlling and managing channel bed incision where rock supply/delivery to site may be impractical. However, they at risk of being undermined and may adversely impact fish passage.	Option summary: *Section 4.2.12* Supporting design aids: *Section 6.2* – page 226*, Section 6.4, Section 6.6* – page 282

Process and drivers Geomorphic process	**Process and drivers Driving activity**	**Approach to management Intervention option**	**Approach to management Option ranking to address process**	**Approach to management Comment**	**Relevant supporting design method, supporting analyses and external references**
Stream incision	Incision stages 4 to 5	Bank stabilisation: Native vegetation establishment and management	Cost: 1 Success: 2 Adverse impact: 1	The success of vegetation management alone in controlling ongoing widening, is only effective once the degradation phase has halted (ongoing widening can undermine and erode vegetation). Management incorporates native vegetation establishment, management, riparian fencing and weed management.	Incision stages 4 to 5
Stream incision	Incision stages 4 to 5	Bank stabilisation: Pile fields and native vegetation establishment and management	Cost: 2 Success: 2 Adverse impact: 2	Pile fields and vegetation establishment can be an effective means of providing short term and long-term roughness to incised systems. However, these will only be effective if the degradation stage has ceased and the vegetation establishment phase is successful.	Option summary: *Section 4.2.15* Supporting design aids: *Section 6.2* – page 226 Section 6.5 – page 245*, Section 6.4, Section 6.5*

Table 5. Management option selection guide – Accelerated meander migration

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	May include all activities as listed below	Do not intervene	Cost: NA Success: NA Adverse impact: NA	Choosing not to intervene may be based on allowing the channel meander to continue to propagate until a new equilibrium is established and that any impacts associated with the bank migration are considered in line with project objectives and targets.	Option summary: *Section 3.3.1*
Channel meandering	Hydrologic change	Native vegetation establishment and management	Cost: 1 Success: 2 Adverse impact: 1	Hydrologic change can drive an increase in the frequency and/or duration of events that are likely to cause erosion. The establishment of native riparian vegetation on meander bends increases bank strength (resistance forces), shields bank sediment from scour, and increases channel roughness, provided that vegetation extends to the toe of the bank. Once established, native riparian vegetation will decrease, but not eliminate, the rate of meander migration.	Option summary: *Section 4.2.2* Supporting design aids: *Section 6.2, Section 6.4* – page 226

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Hydrologic change	Flow modification (environmental flows)	Cost: 2 Success: 2 Adverse impact: 1	Modification of the flow regime addresses adverse meander migration by decreasing the magnitude, duration and frequency of flows that drive bank erosion and meander migration. This intervention has the potential to trigger adverse impacts on waterway condition and instream ecology, which should be considered when designing flow regimes to reduce rates of meander migration.	External Resources: DEPI, 2013b
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Native vegetation establishment and management	Cost: 1 Success: 3 Adverse impact: 1	Modification of riparian land management practices can provide the most cost-effective means of controlling riverbank erosion and resulting meander migration caused by uncontrolled stock access.	Option summary: *Section 4.2.2* Supporting design aids: *Section 6.2* – page 226*, Section 6.4*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Wood revetment	Cost: 1 Success: 3 Adverse impact: 1	Installation of wood revetment at the bank toe can increase channel roughness and in sufficient density could reduce velocities to have a significant impact on erosion processes including meander migration. It also provides significant habitat opportunities for a range of flora and fauna species.	Option summary: *Section 4.2.14* Supporting design aids: *Section 6.2, Section 6.4, Section 6.6*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Alignment training – Pile Fields	Cost: 2 Success: 3 Adverse impact: 1	Pile fields can be used to either re-align an eroding meander bend, or to decrease the rate of meander migration by supporting vegetation establishment. Pile fields support the establishment of native vegetation by increasing channel roughness and decreasing flow velocity at the bank, which promotes sediment deposition between successive pile alignments. As vegetation establishes and sediment accumulates, channel alignment will shift towards the inward extent of the pile field, and meander migration rate will decline. Pile fields have fewer adverse impacts than rock beaching.	Option summary: *Section 4.2.15* Supporting design aids: *Section 6.2, Section 6.4,* *Section 6.5*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Rock beaching and rock riprap	Cost: 3 Success: 3 Adverse impact: 2	Rock beaching is an effective means of controlling bank erosion and resulting meander migration. However, it is expensive and can destroy undercut bank habitat.	Option summary: *Section 4.2.16* Supporting design aids: *Section 6.8* – page 304
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Alignment training –Rock Groynes	Cost: 2 Success: 2 Adverse impact: 2	Impermeable rock groynes aid native vegetation establishment in the same manner as pile fields and are suited to higher-energy environments where timber piles may have an inadequate design life. Impermeable rock groynes require careful design to prevent scour and failure.	Option summary: *Section 4.2.18* Supporting design aids: *Section 6.9*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering		Bank battering	Cost: 2 Success: 2 Adverse impact: 3	Bank battering can reduce the rate of bank erosion, sediment production and resulting meander migration in incised systems. However, this option can destroy undercut bank habitats, impact on cultural heritage legislation and should only be applied in conjunction with bed and/or bank supplementary actions, or where there is strong confidence that it will not be undermined by returned high flows, such as ephemeral and low energy systems.	Option summary: *Section 4.2.5* Supporting design aids: *Section 5.3*
Channel meandering	Loss of instream wood	Large wood installation	Cost: 2 Success: 3 Adverse impact: 1	Installation of large wood can increase channel roughness and in sufficient density could reduce velocities to have a significant impact on erosion processes including meander migration.	Option summary: *Section 4.2.11* Supporting design aids: *Section 6.6* – page 282

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Physical disturbance of waterway	Channel reconstruction and design	Cost: 3 Success: 3 Adverse impact: 1	An effective means of reducing excess energy in highly modified systems and restoring meander form. This method is expensive however and is usually reserved for situations where re-establishment of a riparian vegetation alone is unlikely to restore natural meander planform and migration rates.	Option summary: *Section 4.2.8* Supporting design aids: Section 5.3

Table 6. Management option selection guide – Aggradation

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel aggradation	May include all activities as listed below	Do not intervene	Cost: NA Success: NA Adverse impact: NA	Choosing not to intervene may be based on allowing the channel to continue to aggrade until a new equilibrium is established and that any impacts associated with the aggradation are considered in line with project objectives and targets.	Option summary: *Section 3.3.1*
Channel aggradation	Riparian and instream vegetation loss (in upstream catchment/ reaches)	Native vegetation establishment and management	Cost: 1 Success: 3 Adverse impact: 1	Addressing the cause of excess sediment supply has a high likelihood of effectively addressing the problem of streambed aggradation over the long term.	Option summary: *Section 4.2.2* Supporting design aids: *Section 6.2* – page 226, *Section 6.4*

Process and drivers Geomorphic process	**Process and drivers Driving activity**	**Approach to management Intervention option**	**Approach to management Option ranking to address process**	**Approach to management Comment**	**Relevant supporting design method, supporting analyses and external references**
Channel aggradation	Soil erosion and runoff (in upstream catchment)	Best practice catchment management e.g. water sensitive urban design, forestry best practice management (other)	Cost: 2 Success: 3 Adverse impact: 1	Catchment management addresses the cause of channel aggradation by effectively addressing sediment production in the upstream catchment.	External Resources: Melbourne Water, 2013; CRC for Water Sensitive Cities, 2020; Melbourne Water, 2020; Melbourne Water, 2021
Channel aggradation	Increase in sediment from upstream reaches (bed and bank erosion)	Bed and bank stabilisation: Pile fields and native vegetation establishment and management	Cost: 2 Success: 2 Adverse impact: 1	Pile fields that span the channel bed and revegetation can be used to limit sediment generation and also trap sediment in place which limits sediment movement into scour holes and decreases sediment supply to downstream reaches.	Option summary: *Section 4.2.15* Supporting design aids: *Section 6.2, Section 6.4,* *Section 6.5*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel aggradation	Increase in sediment from upstream reaches (bed and bank erosion)	Sediment extraction	Cost: 2 Success: 2 Adverse impact: 2	Sediment extraction programs don’t address the supply of sediment to the system. However, sediment extraction can be an effective means of addressing excess sediment once in a stream system.	External Resources: Melbourne Water, 2017 Option summary: *Section 4.2.19* Section 5.4 – page 216
Channel aggradation	Increase in sediment from upstream reaches (bed and bank erosion)	Bed and bank stabilisation: Log sills	Cost: 2 Success: 1 Adverse impact: 1	Provision log sills for both instream timber habitat and to control bed erosion by trapping and holding sediment in upstream reaches.	Option summary: *Section 4.2.12* Supporting design aids: *Section 6.6* – page 282

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel aggradation	Increase in sediment from upstream reaches (bed and bank erosion)	Bed and bank stabilisation: Engineered log jams	Cost: 2 Success: 1 Adverse impact: 1	Engineered log jams have potential to provide habitat and to influence the erosion and deposition of sediment in upstream reaches.	Option summary: *Section 4.2.9* Supporting design aids: *Section 6.6* – page 282
Channel aggradation	Hydrologic change	Flow modification (environmental flows)	Cost: 2 Success: 3 Adverse impact: 1	Addressing the cause of reduced sediment transport has high potential for success. This intervention has the potential to trigger adverse impacts on waterway condition and instream ecology, which should be considered when designing flow regimes to impact sediment transport rates.	External Resources: DEPI, 2013a; DELWP, 2019

Table 7. Management option selection guide – Avulsion

Process and drivers Waterway process	**Process and drivers Driving activity**	**Approach to management Intervention option**	**Approach to management Option ranking to address process**	**Approach to management Comment**	**Relevant supporting design method, supporting analyses and external references**
Channel avulsion	May include all activities as listed below	Do not intervene	Cost: NA Success: NA Adverse impact: NA	Choosing not to intervene may be based on allowing the channel to avulse and that any impacts associated with the avulsion are considered in line with project objectives and targets.	Option summary: *Section 3.3.1*
Channel avulsion	Increase in hydraulic efficiency in daughter channel	Native vegetation establishment and management	Cost: 1 Success: 3 Adverse impact: 1	Modification of riparian land management practices and establishment of continuous native vegetation on riparian land can provide the most cost-effective means of decreasing hydraulic capacity and increasing roughness in the daughter channel, resulting in reduced potential for avulsion development.	Option summary: Section 5 – page 226 *Section 4.2.2* Supporting design aids: *Section 6.2, Section 6.4*
Channel avulsion	Increase in hydraulic efficiency in daughter channel	Wood revetment	Cost: 2 Success: 1 Adverse impact: 1	Installation of wood revetment across the avulsion exit/entry points can increase channel roughness and in sufficient density could reduce velocities in the daughter channel to have a significant impact on erosion processes including avulsion development.	Option summary: *Section 4.2.14* Supporting design aids: *Section 6.6*

Process and drivers Waterway process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel avulsion	Increase in hydraulic efficiency in daughter channel	Pile fields	Cost: 2 Success: 3 Adverse impact: 2	Pile fields can be used to decrease the rate of avulsion development by artificially roughening the daughter channel, decreasing flow velocity, and supporting vegetation establishment.	Option summary: *Section 4.3.10* Supporting design aids: *Section 6.2, Section 6.4,* *Section 6.5*
Channel avulsion	Increase in hydraulic efficiency in daughter channel	Rock groynes	Cost: 2 Success: 2 Adverse impact: 2	Impermeable rock groynes aid native vegetation establishment in the same manner as pile fields by artificially roughening the daughter channel and limiting channel widening.	Option summary: *Section 4.2.18* Supporting design aids: *Section 6.5, Section 6.9.*

Process and drivers Waterway process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel avulsion	Increase in hydraulic efficiency in daughter channel	Rock beaching	Cost: 3 Success: 3 Adverse impact: 3	Rock beaching is an effective means of controlling bank erosion and limit widening of the daughter channel.	Option summary: *Section 4.2.16* Supporting design aids: *Section 6.8* – page 304
Channel avulsion	Decrease in hydraulic efficiency in parent channel	Willow control	Cost: 2 Success: 3 Adverse impact: 2	Willow control/removal is an effective means in improving hydraulic capacity of waterways. Willow removal requires a carefully throughout program of poisoning, removal and subsequent revegetation to provide stability in both the short and longer term.	Option summary: *Section 4.2.4* Supporting design aids: *Section 6.3*- page 231

Process and drivers Waterway process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel avulsion	Decrease in hydraulic efficiency in parent channel	Increase hydraulic capacity of parent channel	Cost: 2 Success: 2 Adverse impact: 3	Increasing the slope of the aggrading reach (through excavation of sediment slugs/fans) or decreasing the roughness (vegetation removal) can help mitigate avulsion potential. However, vegetation removal and/or sediment extraction has potential to have adverse impacts on geomorphic processes and ecology.	Option summary: *Section 4.2.2 and 4.2.3*
Channel avulsion	Decrease in hydraulic efficiency in parent channel	Sediment extraction/ sediment traps	Cost: 2 Success: 2 Adverse impact: 2	Sediment traps don’t address the supply of sediment to the system. However, sediment extraction can be an effective means of addressing excess sediment once in a waterway system and help improve hydraulic capacity.	External Resources: Melbourne Water, 2017 Option summary: *Section 4.2.19 and 4.2.6* Section 5.4 – page 216

Process and drivers Waterway process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel avulsion	Increase in hydraulic efficiency of floodplain	Native vegetation establishment and management	Cost: 1 Success: 3 Adverse impact: 1	Modification of riparian land management practices and establishment of continuous native vegetation across the floodplain can provide the most cost-effective means of decreasing hydraulic capacity and increasing roughness, resulting in reduced potential for floodplain scour and avulsion development.	Option summary: *Section 4.2.2* Supporting design aids: Section 5 – page 226 Supporting design aids: *Section 6.2, Section 6.4*
Channel avulsion	Increase in hydraulic efficiency of floodplain	Pile fields	Cost: 2 Success: 3 Adverse impact: 2	Pile fields can be used to decrease hydraulic capacity and increase roughness of the floodplain, resulting in reduced potential for floodplain scour and avulsion development.	Option summary: Section 4.2.15 Supporting design aids: *Section 6.2, Section 6.4,* *Section 6.5*

Table 8. Management option selection guide – Habitat improvement

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Incision, channel meandering and channel aggradation	Loss of habitat (e.g. de-snagging, aggradation, incision and channel migration)	Large wood installation	Cost: 2 Success: 3 Adverse impact: 1	Large wood installation comprises of single or multiple pieces of wood in the stream system to initiate local scour and establish flow diversity to improve habitat. Alternatively, it may be used in a reach to increase hydraulic roughness, reduce overall velocity and to encourage sedimentation and/or instream vegetation growth within a reach.	Option summary: *Section 4.2.11* Supporting design aids: *Section 6.6* – page 282
Incision, channel meandering and channel aggradation	Loss of habitat (e.g. de-snagging, aggradation, incision and channel migration)	Engineered log jams	Cost: 2 Success: 3 Adverse impact: 1	Engineered log structures comprise the construction of large timber amalgams from individual pieces of timber to create greater hydraulic and habitat influence than that achieved with individual pieces of timber.	Option summary: *Section 4.2.9* Supporting design aids: *Section 6.6* – page 282

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Incision, channel meandering and channel aggradation	Loss of habitat (e.g. de-snagging, aggradation, incision and channel migration)	Boulder seeding	Cost: 2 Success: 2 Adverse impact: 1	Boulder seeding involves the placement of individual large boulders or a formal rock structure forming a riffle/rock chute to increase hydraulic diversity, structural complexity and provide instream habitat for aquatic fauna.	Option summary: *Section 4.2.7* Supporting design aids: *Section 6.8*– page 304
Incision, channel meandering and channel aggradation	Loss of habitat (e.g. de-snagging, aggradation, incision and channel migration)	LUNKERS	Cost: 3 Success: 2 Adverse impact: 1	Installation of lunkers are a means of providing undercut bank habitat in waterway systems modified by bank stabilisation works such as battering and rock beaching.	Option summary: *Section 4.2.13* Supporting design aids: *Section 6.2, Section 6.4, Section 6.6*.

4 Part 4 – Management option summaries

4.1 Introduction

This part of the Guidelines is structured to assist waterway managers with summarised information about options for the management of waterway geomorphic processes. The management options summarised in this part of the Guidelines correspond to those management options identified in the Management option selection guide (Section 3.6), except the option to not intervene which has already been covered above in the management option selection guides (Section 3.6) and in Section 3.3.1

These management options may be applied to influence the inflow of water and sediment, the extent and condition of riparian (and instream) vegetation and the physical characteristics of the channel.

Each option is outlined in a one-page summary including details of the impacts, requirements and factors influencing success. Links to related guidelines and information sources are also provided.

4.2 Management options

The location of each option summary is listed below and is presented on the following pages:

4.2.1 Stock management

Example site

Waterway: Boundary Creek (before and after stock exclusion)

Basin: Barwon River

Contact: Corangamite CMA

Description: Stock management is the act of managing the access of livestock to waterways including riparian land. Stock typically congregates in riparian vegetation as these areas provide water, shade and protection from the wind – this has several adverse impacts on riparian vegetation condition and resultant resistance against erosion forces and sediment transport from the reach. Permanent stock exclusion from riparian land may not be necessary depending on specific vegetation type and management objectives (e.g. well controlled timing, intensity and duration of grazing may be sufficient). Riparian fencing is the simplest and most common form of stock management, although the installation of alternative shaded watering points and/or supplementary feeding stations has been successfully applied in arid to semi-arid regions to the same effect.

Why implement?

Stock management is implemented to retain or enhance the health of riparian vegetation and associated increased resistance against erosion forces and reduced sediment transport from the reach. Importantly stock management can provide additional benefits to waterway health. These benefits can include reduced faecal contamination of water supplies (especially if juvenile stock is excluded from waterways as they contain many more pathogens than adult stock), and the wider benefits of improved riparian vegetation condition such as reduced input of adverse nutrients, reduced downstream flooding, the provision of a long-term source of instream timber, increased floristic diversity and improved aquatic life e.g. increased fish numbers and species composition.

Potential advantages

- Streambank stability
- Improved water quality
- Enhanced riparian and instream vegetation
- Improved terrestrial and aquatic ecosystem health
- Carbon sequestration

Potential disadvantages

- Total stock exclusion without alternate weed management programs can lead to increased weed problems
- Potential to create habitat for pest fauna species (foxes, rabbits etc.)
- Loss of productive land
- Flood damage to fences

Success ranking

- Applications in Victoria: Widely applied successfully across Victoria.
- Success in achieving intended outcome: Very high (the vegetation buffer has a primary function to increase erosion resistance of the channel banks, leading to lower rates of channel change).

Practical considerations

Pre-works considerations

- Weed management: Total stock exclusion without accompanying weed management programs can lead to increased weed problems.
- Riparian width: A sufficient width of structurally diverse vegetation is required to provide ongoing resistance against erosion forces into the future (refer to section 6.2 for example method to determine required buffered width to reduce erosion impacts).

- Stock watering: Placement of stock watering points well away from waterways and drainage lines.
- Consultation: Working with landholders to establish a mutually beneficial outcome and encourage stewardship. This may include agreements about timing, intensity, and frequency of any permitted grazing.
- Flooding: Installation in flood prone areas resulting in damage from flood debris and stock access. Consider flood fencing that drops / lays down or lifts up during flood events. Also ensure high strength end-assemblies.
- Stock bypassing fence lines: Stock bypass low lying fences through gaps. Consider installation of hanging fences across narrow waterways to prevent stock access to channel bed.
- Fence alignment: run parallel to flows and keep fence as straight as possible to minimise damage during floods, avoid ring-lock/mesh fences except where safe from flooding (and they are less problematic in low energy flooding systems), encourage greater offset on outside bends to allow for any channel movement.

Post works monitoring

- Fence maintenance responsibilities need to be clear.
- Fencing should be inspected and assessed for failure points regularly and following high flow events. Debris or fallen tree branches should be removed from the fence line.

Complimentary actions

- Fencing
- Off-stream watering (pumps/tanks/troughs)
- Establishment of alternate shaded areas
- Vegetation establishment
- Instream habitat

Information requirements

- Flood frequency and flooding level
- Catchment context including land use characteristics (type of stocking) and ongoing geomorphic process (e.g. channel meandering)
- Topography and pumping capacity for off stream watering
- Predicted erosion/migration rates (see section 6.2)

Design guidelines and related information sources

- Refer to Part 6.2 —Design Aids of these Technical Guidelines – Riparian buffer width analysis.
- DELWP, (2015a). *DELWP Output Delivery Standards – For the delivery of environmental activities*, accessed DELWP Output delivery standards pdf
- DELWP, (2015b). *Guidelines for riparian fencing in flood-prone areas*, accessed Guidelines for riparian fencing
- DELWP, (2016a). *Juvenile stock in waterways,* accessed Juvenile stock in waterways
- DELWP, (2016b). *Managing grazing on riparian land*, accessed Managing grazing on riparian land
- Staton, J. & O'Sullivan, J. (2019). Stock And Waterways – A practical guide to help New South Wales farmers manage stock and waterways for productivity and environmental benefits, accessed Stock and Waterways website
- Beesley LS, Middleton J, Gwinn DC, Pettit N, Quinton B and Davies PM. (2017). Riparian Design Guidelines to Inform the Ecological Repair of Urban Waterways, Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities.

4.2.2 Native vegetation establishment and management

Example site

Waterway: Genoa River

Basin: Genoa River

Contact: East Gippsland CMA

Description: Native vegetation establishment and management includes the management of both remnant vegetation and the establishment of new plant species growing on or in a site, reach or waterway. Native riparian vegetation establishment increases waterway resistance against erosion forces and can reduce sediment transport from the reach.

The protection of remnant vegetation should be prioritised, followed by natural regeneration, and planting of new vegetation where needed. Management of vegetation type, extent and density may be mechanical, via intermittent grazing or browsing, chemical or more usually a combination. Vegetation management over time is typically decentralised (e.g. through landholder stewardship) and for this reason, as well as the time scale involved, requires addressing issues of capacity to do that work (e.g. maintain revegetated areas).

Native vegetation establishment involves the planting of vegetation in riparian land. The vegetation should preferably consist of indigenous plants representative of the relevant ecological vegetation class (EVC) for that site. Species selection should also consider the ability to adapt with climate change extremes and align with the functional needs for erosion/stability. Native vegetation establishment can also be the result of natural regeneration.

Why implement?

Vegetating riparian land through targeted species selection and placement can improve channel stability and reduce sediment transport. Re-establishing vegetation along riverbanks also provides many other benefits including improved habitat, water quality and aesthetic values.

Fire is less likely to start in riparian land than other parts of the landscape, typically because it is not as prone to lightning strikes, may be remote from access for arsonists, has fuel too moist to burn and is sheltered from the wind and sun. Riparian land therefore poses a lower fire threat to a landholder’s property including to crops, livestock and built assets than other parts of the landscape.

Potential advantages

- Streambank stability
- Habitat provision and enhancement
- Improved water quality
- Shade and shelter provided to the stream to manage water temperature and maintain water quality (e.g. more natural supply of leaf litter and reduction in algae events)
- Provides a long-term source of instream wood

Potential disadvantages

- Clearing of existing exotic vegetation cover and preparing the site for revegetation can allow weed invasion.
- Clearing of existing exotic vegetation cover at the site before revegetation can produce short term decreases in stability, habitat and shading of the waterway.

Success ranking

- Applications in Victoria: Common to successful waterway management projects.
- Success in achieving intended outcome: Very high (the vegetation buffer has a primary function to increase erosion resistance of the channel banks, leading to lower rates of channel change).

Practical considerations

Pre-works considerations

- Providing a diverse range of plant species (in alignment with the appropriate EVC benchmark) will help combat the impact of plant disease and help native species compete with weeds. Genetic diversity within species can also be achieved through provenance mixing to boost resilience.
- Consideration of planting times/seasons that are suitable for the area and watering if needed
- Consideration of protection against pest plant and animal competition during the establishment phase
- Consideration of climate adapted planting for revegetation
- Project objectives (e.g. increased stability or roughness, provision of shade, increased habitat) should be considered when undertaking revegetation works (e.g. species selection).
- Techniques to minimise sedimentation impacts during site establishment should be implemented
- Stock must be excluded from revegetation areas to enable plants to establish
- Community engagement
- Ongoing maintenance arrangements

Post works monitoring

- Develop a revegetation monitoring and maintenance plan
- Maintenance may include watering, weed management, and follow-up planting (failure replacement).
- Monitoring is important for assessing the success or failure of the works and adjusting plans accordingly.

Complimentary actions

- Stock management/fencing
- Weed management and willow control

- Pest animal and over-abundant wildlife control
- Off-stream watering

Information requirements

- Soil type and condition
- Climate and future climate analogue
- Pre-1750s EVC benchmark
- Pest plant and animal control requirements
- Management responsibility
- Determine any landholder requirements

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Probabilistic failure analysis.
- For the future climate analogue for your region go to Climate Analogues webpage
- DELWP, (2020). Biodiversity revegetation with provenance mixing for climate change adaptation, accessed Biodiversity revegetation with provenance mixing for climate change adaptation
- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015
- DELWP, (2017) Riparian land and bushfire: Resource Document, accessed: Riparian land and bushfire
- DELWP, (2017) Riparian Land and Bushfire, accessed: Riparian land and bushfire brochure
- DSE, (2006). Native Vegetation Revegetation planting standards – Guidelines for establishing native vegetation for net gain accounting. Victorian Government, Department of Sustainability and Environment, East Melbourne.
- Greening Australia, (2003). A guide for establishing native vegetation in Victoria, accessed A Revegetation Guide for Temperate Riparian Lands
- Greening Australia, (2017). Revegetation guide for temperate riparian lands, accessed A Revegetation Guide for Temperate Riparian Lands
- Jellinek, S., Bailey, T.G. 2020. Establishing Victoria's Ecological Infrastructure: A Guide to Creating Climate Future Plots. Greening Australia and the Victorian Department of Environment, Land, Water and Planning. Melbourne, Victoria. Version 2.1
- Merri Creek Management Committee, (2013). Trial of Sen-Tree Browsing ™ Deterrent on shrub plantings on escarpments at Bababi Marning Grassland, Campbellfield, accessed Trial of Sen-Tree Browsing

4.2.3 Weed management

Example site

Waterway: Yarrowee/Leigh River
Left – Willow (*Salix)* and Gorse *(Ulex europaeus)* and right – dense blackberry (*Rubus fruticosus*) both prior to revegetation with native species

Basin: Yarrowee/Leigh River

Contact: Corangamite CMA

Description: Weed management involves the control or in some cases eradication of invasive exotic plant species and sometimes non-local native plant species. Weeds are best controlled through long-term and integrated management approaches, some seeds can last in the seedbank for 25 years. Chemical (such as foliar spray, cut and paint) and physical control (such as mowing, grazing, mulching, burning, chipping or pulling by hand) are the most popular methods and usually a combination of methods and repeated efforts will give the best results.

Under the *Catchment and Land Protection Act* 1994 (CaLP Act), weeds that are high risk or have high potential to cause harm to agriculture or the environment are declared as State Prohibited, Regionally Prohibited, Regionally Controlled or Restricted. For weeds declared as Regionally Controlled, land owners have the responsibility to take all reasonable steps to prevent their growth and spread on their land (Agriculture Victoria, 2023).

Why implement?

Weeds are a threat to biodiversity and primary production. Weed management is implemented to eradicate or control the spread of pest plant species. It can also be undertaken to facilitate the re-establishment of native species by reducing competition. The risk of weed invasion, and their impact on farms and the environment dramatically increases during and after a major event such as drought, fire or flood. Weeds are best controlled through a long-term management approach, using several weed management techniques such as biological, cultural, physical and chemical control.

Potential advantages

- Weed removal can improve native vegetation establishment and habitat.
- Subsequent improvements in native vegetation can result in improved structural integrity of the bank and resistance to erosion.

Potential disadvantages

- Chemicals may adversely affect native terrestrial or aquatic flora and fauna.
- The removal of weed species and an absence of other flora may reduce habitat values and shading on streams.
- Poisoning or removal of weeds may increase bank erosion rates with subsequent potential sedimentation and effects on water quality.

Success ranking

- Applications in Victoria: Common to successful stream management projects.
- Success in achieving intended outcome: High (weed management combined with revegetation provides resistance against erosion forces).

Practical considerations

Pre-works considerations

- Sustainability: Requires a planned out, long-term, integrated approach.
- OH&S: Chemicals are correctly applied in line with application standards.

- Regeneration: Seed/propagule sources (e.g. soil seed banks) or adjacent infestations are also considered. Native species may be allowed to naturally regenerate or are planted to compete with weed regeneration and replace minor potential benefits of weeds such as shading and erosion control.
- Invasion by other weeds or neighbouring properties: Considers all weed species that threaten to colonise the area and the appearance of transforming weeds. Weed species need to be detected in the early stage of (re)invasion.

Post works monitoring

- Develop a weed monitoring and maintenance plan.
- By monitoring your weed program, you can determine which control methods have worked best, whether off-target damage has occurred and whether repeated or new treatments are needed.

Complimentary actions

- Fencing and revegetation.
- Stock management.
- Willow control (covered separately in section 4.2.4).
- Pest animal control (see reference below).
- Off stream watering.

Information requirements

- Available/registered chemicals and effect on weeds/waterways.
- Extent of weed problem.
- Effect of weeds on issues such as bank erosion, native and pest animal, stream temperature, etc.

Design guidelines and related information sources

- Refer to Part 6.2 —Design Aids of these Technical Guidelines – Riparian buffer width analysis.
- Agriculture Victoria, (2020). Invasive plant classifications, accessed April 2023, Invasive plant classifications
- Agriculture Victoria, (2023). Invasive animal management, accessed April 2023, Invasive animal management
- DEECA, (2023). Early invader weeds, accessed April 2023, Early invader weeds
- DELWP, (2018). Managing weeds: assess the risk guide

- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015
- DPI, (2007b). Weeds of National Significance – Best practice control manuals, List of Weeds of National Significance.
- Blood, K., James, R., Panetta, F. D., Sheehan, M., Adair, R., and Gold, B. (2019) Early invader manual: managing early invader environmental weeds in Victoria. Department of Environment, Land, Water and Planning, Victoria. ISBN 978-1-76077-317-5 (Print); ISBN 978-1-76077-318-2 (pdf/online/MS word).

4.2.4 Willow management

Example site

Waterway: West Barwon River

Basin: Barwon River

Contact: Corangamite CMA

Description: Under the Catchment and Land Protection Act 1994 (CaLP Act), willows (Salix spp. Sm. (except Salix alba var. caerulea (Sm.),Salix alba x matsudana, Salix babylonica L., Salix X calodendron Wimm., Salix caprea L. 'Pendula', Salix matsudana Koidz 'Aurea', Salix matsudana Koidz 'Tortuosa'., Salix myrsinifolia Salisb., and Salix X reichardtii A. Kern) are declared as restricted, which prohibits the trade, movement and sale of these weeds and their propagules.

Willow control is the physical removal, pruning or poisoning of the above listed willows. Poisoning willows involves the use of herbicide via stem injection, drill and fill, foliar spraying or cutting and painting the stump. Physical methods involve whole of tree removal, lopping and pollarding. Technique selection is dependent on site conditions and available equipment. There are numerous occupational health and safety hazards encountered during willow removal e.g. willows that have been poisoned and allowed to die become brittle and pose a high risk to operators in densely vegetated areas.

Why implement?

Most species of willow in Australia are highly invasive and have significant adverse impacts on waterway health. Willows can spread prolifically, either by fragments or by seed, outcompeting desirable native vegetation. Willow can have an adverse impact on riparian vegetation condition, instream physical form and water quality. Willow management is undertaken to mitigate the adverse impacts that willows have on Australian waterways.

Potential advantages

- Preventing channel change (avulsion, outflanking, channel widening) due to willows colonising the stream channel.
- Removal combined with native revegetation can improve supply of habitat and food for fish.
- Allows light in for other plants to establish.
- Reduces the uptake of significant amounts of water by willows, which can dry out small waterways.

Potential disadvantages

- Willow removal may initiate new instabilities including bank scour and/or incision where willow mats may have previously provided resistance to erosion.
- Willow removal may reduce shading of the stream too much during summer months.
- May result in a reduction in riparian and instream habitat if not done in a staged manner with replacement native vegetation and instream wood.
- Foliar spraying may affect other riparian vegetation.
- Species that spread via vegetative means may be dispersed downstream if physical methods are used.

Success ranking

- Applications in Victoria: Common to successful stream management projects.
- Success in achieving intended outcome: High - provides resistance against erosion forces where willow management and rehabilitation has been achieved.

Practical considerations

Pre-works considerations

- Waterway stability: Identify willow removal’s potential to create instabilities in the system and identify any complimentary stabilisation works where required. Staged removal of willows and revegetation over a number of years may be required.

- Removal technique: Should consider the surrounding environment (e.g. urban, rural, adjacent assets) and employ removal techniques that minimise risks to the community, environment and infrastructure.
- Removal sequence: Removal should ideally be started at the upstream end and working downstream to limit reinvasion.
- Reseeding or vegetative spread: Follow up revegetation with indigenous plants should occur in treated areas as soon as possible after willow removal taking seasonal factors into consideration. Continued monitoring of site allowing quick treatment of re-emerging willow species.
- Habitat considerations: May result in a reduction in riparian and instream habitat if not done in a staged manner with replacement native vegetation and instream wood.

Post works monitoring

- Develop a willow monitoring and maintenance plan.
- Refer to DPI (2007a) Weeds of National Significance – Willows National Management Guide.

Complimentary actions

- Fencing and revegetation.
- Bank stabilisation.
- Instream habitat works.

Information requirements

- Access provision and site conditions.
- Type of willow species.
- Density of willows.
- Equipment availability.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Willow transition methodology.
- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015
- DELWP, (2016b). Managing willows in Victoria.
- DPI, (2007a). Weeds of National Significance—Willows National Management Guide.

4.2.5 Bank battering

Example site

Waterway: Harrisons Creek
(Left) initial works (Right) post works

Basin: Wallagaraugh River

Contact: East Gippsland CMA

Description: Bank battering involves modification of the riverbank to a design bank angle. It can be undertaken to reduce erosion and provide conditions suitable for vegetation establishment. However, there is only a limited range of erosion mechanisms that can be addressed through bank battering.

Failure of bank battering is often a result of the inappropriate application of the technique. This includes failure to consider soil type (i.e. dispersive or sodic soils), appropriate bank angle, flow pathways (including channel flow, overland flow and direct rainfall) and fluvial scour.

Why implement?

Bank battering is implemented to provide a relatively stable surface on which vegetation can be established. Bank battering can be used to accelerate the rate of recovery from past channel incision (where the deepening process has finished and the dominant process is widening). Battering can also be used to increase the safety of a steep bank in the urban environment.

Potential advantages

- Can increase the rate of recovery and reduce the downstream impact of an incised stream system (for example through reduced erosion rates and downstream sedimentation)
- The approach can be applied to reduce lateral rill erosion on banks and increase the success rate for vegetation establishment.

Potential disadvantages

- The approach can remove bank diversity by creating a uniform surface.
- The approach can remove features such as vegetation providing some stability to the riverbanks and initiate erosion, which may destroy undercut banks, overhanging vegetation and other habitat features associated with steep riverbanks.
- Unconsolidated material on a lower bank will in most cases be removed during post-battering flow events increasing sediment loads downstream and further destabilising the bank.
- Impacts on Cultural Heritage due to disturbance of undisturbed ground.

Success ranking

- Applications in Victoria: Estimated to be over 1,000 applications in Victoria over past 20 years.
- Success in achieving intended outcome: Moderate – with appropriate assessment of fluvial and soil properties can provide resistance against erosion forces.

Practical considerations

Pre-works considerations

- Soil profile: Understand soil type and soil dispersity (i.e. sodic soils) and associated risks. Manage sodic/dispersive soils and unconsolidated ground. Does the battering at the toe of the bank consist of existing consolidated material or constructed compacted material?
- Geomorphic processes: Determine ongoing channel bed and bank instabilities i.e. fluvial scour and stability analysis (widening, ongoing deepening and channel meandering). Understand exposure during the vegetation establishment period i.e. the likelihood the site is exposed to a flood event before vegetation has a chance to

establish, in the absence of other structural support. If the likelihood of exposure is deemed unacceptable, consider supporting structural works to aid vegetation establishment or develop mitigation plans in case of damage or loss of vegetation during establishment phase.

- Complementary works: Ensure a stable stream system is present by incorporating other techniques such as biodegradable erosion matting, rock beaching, pile fields or rock groynes. Jute or similar biodegradable matting can be used to improve aid vegetation establishment. Ensure vegetation establishment is successfully implemented as part of works.
- Rill Erosion: Provision of contour drains on banks over 10 metres in elevation. Consider sediment traps upstream of discharge point, and associated maintenance.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events during the vegetation establishment stage. Following this stage, inspections should be event-driven.
- Inspections should assess for indications of loss of bank material and vegetation failure.

Complimentary actions

- Stock exclusion/fencing.
- Revegetation and weed management.
- Biodegradable erosion matting, rock beaching, pile fields or rock groynes.

Information requirements

- Flood estimation of streamflow (hydrology).
- Stream cross-section survey of existing waterway.
- Identification of existing ecological assets.

Design guidelines and related information sources

- Refer to Part 5 of these Technical Guidelines —Waterway stability analysis.
- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015

4.2.6 Bed load sediment retention

Example site (left)

Waterway: Avon River

Basin: Gippsland Lakes

Contact: West Gippsland CMA

Example site (right)

Waterway: Cann River

Basin: Cann River catchment

Contact: East Gippsland CMA

Description: Management of sediment can be used for stabilising and rehabilitating incised streams through bed seeding or alternative sediment trapping. The problem with bed seeding (introducing material to the stream bed) and the reason it is not commonly adopted, is that if the coarse load introduced can be moved to form riffles, it can also be carried through the channel and thus would require material having to be repeatedly added to the stream.

An alternative to adding material to the bed is to retain the bed material being carried through the stream by capturing some of it with sediment trapping devices. Sediment traps could be installed downstream of a headcut or at parts of the stream where natural riffles would normally form. This may include the use of pile fields, vertical pin ramps and other methods aimed at creating depositional zones.

Why implement?

Sediment retention works can be used to capture the sediment load moving downstream. The works typically comprise structures that increase roughness, encourage deposition and reduce ongoing sediment movement. Sediment trapping structures can vary, but often include logs and wire mesh or rows of piles placed perpendicular to flow. The structures act similar to and support the formation of mid-channel bars colonised by vegetation, increasing channel roughness, and promoting sediment retention. The establishment of vegetation along the channel can help provide long term stability to the system beyond the design life of the structures.

Potential advantages

- Promotes deposition and accumulation of sediments and seeds.
- Incision control and sediment retention in aggrading systems.
- Creates favourable conditions for riparian vegetation establishment.
- Provision of direct physical instream habitat for aquatic fauna
- Successful implementation may increase hydraulic roughness and reduce system wide stream power.

Potential disadvantages

- Works can result in riverbank instabilities in the immediate vicinity of the structure through flow redirection.
- Timber elements may be dislodged and mobilised in flood events.
- Potential localised occurrence of overbank flooding may not accord with adjoining landholder’s objectives.

Success ranking

- Applications in Victoria: Multiple examples in Victoria.
- Success in achieving intended outcome: Moderate – where appropriate sediment transport properties have been considered.

Practical considerations

Pre-works considerations

- Geomorphic processes: This approach relies on vegetation establishment to successfully trap and hold sediment on the channel bed. Failure to establish vegetation will result in failure of project as instream structures break down over time. Approach relies on sediment deposition upstream of the structures. Therefore, the approach has only been successful where sediment is being transported through the reach and is off sufficient size to drop out at the sediment retention structure (fine sediment will continue through and past any structures).
- Geomorphic processes: Identify any ongoing channel bed and bank instabilities using fluvial scour and waterway stability analysis (widening, ongoing deepening and channel meandering). Understand the likelihood of successful vegetation establishment in the event of a flood in the absence of other structural support.
- Complementary works: Incorporating other techniques to further aid trapping of sediment including fencing and native vegetation establishment, instream habitat and bank restoration.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events, following construction, for the first 2 years. Following this stage, inspections should be event-driven.
- Inspections should assess structure performance (ability to trap sediment)
- Inspections should assess whether debris has become lodged on the works which may cause accelerated flow and scour.

Complimentary actions

- Instream habitat (large wood, log jams).
- Fencing and revegetation.
- Bank restoration.

Information requirements

- Estimation of streamflow (hydrology).
- Channel hydraulic and scour analysis.
- Longitudinal profile survey.
- Stream cross-section survey or estimate.
- Geomorphic analysis.
- Available timber species and log size.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Scour depth estimation.
- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015
- Rutherfurd, I., Jerie, K. and Marsh, N. 2000, A Rehabilitation Manual for Australian Streams Vol 2, Bed replenishment (pp. 298-299). Land and Water Research and Development Corporation, Canberra

4.2.7 Boulder seeding

Example site (left)

Waterway: Cardinia Creek

Basin: Western Port Bay

Contact: Melbourne Water

Example site (right)

Waterway: Goulburn River

Basin: Upper Goulburn catchment

Contact: Goulburn Broken CMA

(Source: Tonkin, Z., Kearns, J. and O'Mahony, J., 2015)

Description: Boulder seeding refers to the placement of individual boulders (seeding) or boulder clusters as an instream habitat modification. It is not proposed to be used as a management option to address geomorphic processes.

However, their effectiveness in creating habitat may be diminished if they are placed in deposition zones where they become buried in sediment, or changes in river planform such as channel width or alignment make works redundant or in the wrong location.

Boulders may be sourced from the adjacent floodplain, other reaches of the same stream, other streams or from off-stream sources. Note that there is currently little information available on how native fish utilise boulder installations, with most of the supporting research coming from North American projects where salmonids (e.g. trout) are the target species.

Why implement?

Boulder seeding or boulder clusters can provide hydraulic complexity and instream habitat where they may have been previously removed or buried via instream physical disturbance or geomorphic processes (such as incision). Boulder seeding to increase habitat may comprise placement of individual large boulders, a cluster of boulders or a formal rock structure forming a riffle/rock chute (see 4.2.16 Rock Chutes). Boulder installation is particularly useful where large wood installation is not possible or considered risky.

Potential advantages

- Boulder seeding can increase hydraulic diversity, structural complexity and provide instream habitat for aquatic fauna.
- Can be used in conjunction with other stream improvement projects such as rock chutes and fishways.
- Can improve instream aesthetics through riffle creation and aeration of water.

Potential disadvantages

- Boulder placement needs to consider the risk to the safety of boaters and recreational users associated with physical obstructions in the stream and resultant channel hydraulics.
- Potential to impact on flow capacity of the channel and increase the frequency of overbank topping if a large proportion of the channel is blocked.

Success ranking

- Applications in Victoria: multiple applications in Victoria over past 20 years, noting that many of which were targeted at providing beneficial habitat for trout.
- Success in achieving intended outcome: Moderate – dependent on assessment of fluvial processes and appropriate rock sizing (to lock in place) it can provide long term habitat improvement.

Practical considerations

Pre-works considerations

- Sizing: Boulder seeding relies on careful rock selection, boulder configuration and spacings between boulders/clusters to meet stability and habitat needs.
- Materials and transport: Project viability may be dependent on availably of boulders and transportation costs to the site which can be expensive.
- Geomorphic processes: Changes in river planform may make the works redundant. Identify geomorphic processes and associated risk of channel movement (e.g. meander migration) and design works to address this.
- Geomorphic processes: Effectiveness in creating habitat may be diminished if they are placed in deposition zones where they become buried in sediment. Identify geomorphic processes and associated risk of sediment (e.g. aggradation).
- Geomorphic processes: Movement of sediment/rock undermines works. Identify and design works to fit with or address the ongoing geomorphic process (e.g. stream incision).
- Placement: Consider community recreation and uses and locate works to minimise safety risks.

Post works monitoring

- Works should be inspected following high flow events that may dislodge large boulders or bury them with sediment (rendering them ineffective).
- Fish/aquatic surveys to determine ecological response.

Complimentary actions

- Other instream habitat installations (i.e. large wood).
- Rock beaching, rock chutes to help provide stability (where required).

Information requirements

- Flood hydrology of the stream
- Stream survey.
- Location of sediment erosion and deposition zones within the reach.
- Community/stakeholder considerations in recreation areas (i.e. boaters and paddlers).
- Knowledge of instream ecological values.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Scour depth estimation.
- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015
- Kavanagh, R.J., Hoggarth, C.T. Rehabilitation and Enhancement of Aquatic Habitat Guide V. 1.0, April 2023
- Peters, G., (2020). Boulder seeding and boulder clusters: A literature review. Riverness Pty Ltd, Torquay VIC.
- Peters, G., (2020). Discussion Paper. Boulder seeding and boulder clusters – Phase 2. Riverness Pty Ltd, Torquay VIC.
- Rutherfurd, I., Jerie, K. and Marsh, N. 2000, A Rehabilitation Manual for Australian Streams Vol 2, Bed replenishment (pp. 298-299). Land and Water Research and Development Corporation, Canberra
- Tonkin, Z., Kearns, J. and O'Mahony, J. (2015) Assessing the benefits of instream habitat enhancement for fish population in the Goulburn Catchment. Unpublished Client Report for the Goulburn Broken Catchment Management Authority. Arthur Rylah Institute for Environmental Research. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

4.2.8 Channel reconstruction and design

Example site

Constructed stream – Blind Creek (Knoxfield)

Constructed stream – Arnold Creek (Melton).

Description: Channel reconstruction refers to the part or full replacement of an existing (often modified) waterway. The technique comprises major physical intervention to stream systems and requires significant investment in investigations, design and management. The technique is best suited to the replacement of existing modified (piped and concrete lined) waterways in urban environments and to the remediation of waterways within severely disturbed environments such as mine sites. The technique has been used to enable access to open cut mineral resources and may be suited to address major changes to the hydrologic regime associated with river regulation and urbanisation. Alternative, less interventionist approaches to address issues should be considered prior to embarking on channel reconstruction projects.

Why implement?

Channel reconstruction is generally implemented to change the course of a stream for economic development or to improve the health of a constructed stream (e.g. replace a pipe or concrete-lined waterway). The design arrangement is based on consideration of ongoing hydrological and geomorphic processes and ecological needs.

Potential advantages

- The approach, when combined with other appropriate features such as revegetation and large wood installation, can return waterway habitat, connectivity and geomorphic processes of erosion and deposition to degraded stream systems.

Potential disadvantages

- The technique can result in significant reduction in stream condition when used to replace an existing natural waterway. It may take many years to replace the riparian vegetation and stream condition may not fully recover in the long term.
- The technique can result in short term increases in suspended sediment loads if commissioned prior to the establishment of riparian vegetation.
- Adverse outcomes for fish passage if not accounted for in the design, and large wood habitat.

Success ranking

- Applications in Victoria: Multiple urban examples in Victoria and rural examples across Australia
- Success in achieving intended outcome: High where consideration of geomorphic processes is undertaken in channel design and stream features such as large wood, vegetation, and benches have been included.

Practical considerations

Pre-works considerations

- Geomorphic processes: Undertake an appropriate level of design considering geomorphic processes such as incision and meander migration (excess bed and/or bank scour), and streambed aggradation and avulsion.
- Design: The level of detail applied to the investigation and design should align with the level of risk and likely investment at the reach or site.
- Supporting works: The likelihood of structural success is increased with increased vegetative cover. Establishment of vegetation prior to the commissioning of works has potential to reduce construction costs and increase the channel’s robustness.
- Soils: Understand soil type and soil dispersity (i.e. sodic soils) and associated risks. Manage sodic/dispersive soils and unconsolidated ground. Is the waterway constructed of existing consolidated material, or constructed compacted material?

Post works monitoring

- The works should be inspected approximately every six months and following high flow events during the vegetation establishment stage. Following this stage, inspections should be event-driven.
- Inspections should assess for indications of tunnel erosion of bank material and vegetation failure.

Complimentary actions

- Fencing and revegetation.
- Large wood installation.
- Riffle/rock chute, bank armouring construction.

Information requirements

- Estimation of streamflow (hydrology).
- Stream cross-section survey of existing waterway.
- Identification, characterisation and survey of template reach.
- Topographic survey over proposed alignment.
- Geotechnical survey of proposed alignment.
- Identification of existing ecological assets.

Design guidelines and related information sources

- Refer to Part 5 of these Technical Guidelines – Detecting geomorphic change detection and waterway stability analysis
- DELWP, (2015). DELWP Output Delivery Standards – For the delivery of environmental activities. Department of Environment, Land, Water and Planning. Version 2.1 – June 2015
- Federal Interagency Stream Restoration Working Group (1998), Stream Corridor Restoration: Principles, Processes and Practices, by the (FISRWG – 15 Federal agencies of the US government).
- Melbourne Water (2019). Constructed Waterway Design Manual, Melbourne Water Corporation
- Rutherfurd, I., Jerie, K and Marsh, N. (2000). A Rehabilitation Manual for Australian Streams Vol 2, Land and Water Research and Development Corporation, Canberra, ACT

4.2.9 Engineered log jams

Example site

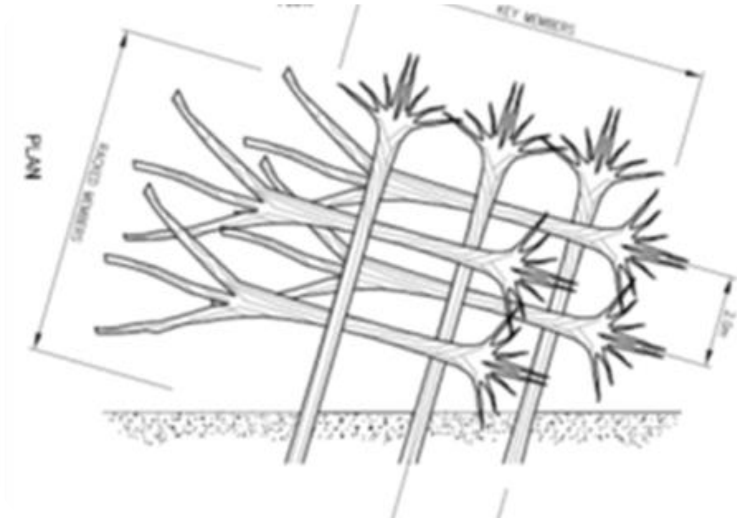
(Left) Engineered log structure schematic sketch

(Right) Glenelg River at Harrow

Basin: Glenelg

Contact: Glenelg Hopkins CMA

(Images courtesy of Earth Tech)



Description: Engineered log structures comprise the construction of large timber amalgams from individual pieces of timber. The purpose of the structures is to create greater hydraulic and habitat influence than that achieved with individual pieces of timber.

Why implement?

Engineered log jams are implemented to provide habitat and to influence the erosion and deposition of sediment (aggradation).

Potential advantages

- Provision of direct physical instream habitat for aquatic fauna.
- Maintenance of bed diversity by causing local scour and deposition.
- Successful implementation can, over time, increase the channel complexity (such as meander geometry and bed diversity).
- Successful implementation may increase hydraulic roughness and reduce system wide stream power.
- Works can result in riverbank instabilities in the immediate vicinity of structure.
- Timber elements may be dislodged and mobilised in flood events.
- Potential localised occurrence of overbank flooding may not accord with adjoining landholder’s objectives.

Success ranking

- Applications in Victoria: Multiple applications across Victoria.
- Success in achieving intended outcome: High where consideration of adequate ballast and embedment to prevent mobilisation has been undertaken.

Practical considerations

Pre-works considerations

- Geomorphic processes: The log jam is correctly designed to interact with the flow and sediment in terms of stability and sites of sediment scour and deposition.
- Geomorphic processes: Understand potential to initiate bank erosion. Provision of suitable complementary erosion protection works (i.e. rock beaching) where required to prevent local scour.
- Geomorphic processes: Understand the potential for aggradation and subsequent burial of log jam. Sediment transport and deposition issues to be addressed as component of assessment and design.
- Materials: Check whether the engineered log jam complements the existing stream environment.
- Materials: Provision of adequate ballast and embedment to prevent mobilisation while timber becomes fully waterlogged.
- Materials: Marine borers in coastal streams will require consideration, including marine borer resistant timbers and or alternative materials.
- Community engagement: To gain acceptance and support of structures. Communicating beneficial outcomes (e.g. generating native fish / recreational fishing outcomes) and potential adverse outcomes (localised overbank flooding), noting that vandalism/burning can be an issue.

Post works monitoring

- Log jams should be periodically inspected (annually or following prolonged wet periods and high flows) to assess whether the logs have moved, additional debris has been trapped and/or whether sediment deposition which may cause accelerated flow and scour.

Complimentary actions

- Fencing and revegetation.
- Bank restoration.

Information requirements

- Available timber species and log size.
- Estimation of streamflow (hydrology).
- Channel hydraulic and scour analysis.
- Geomorphic analysis.
- Longitudinal profile survey.
- Stream cross-section survey or estimate.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Wood stability analysis.
- Brooks, A. *et al*. (2006). Design guideline for the reintroduction of wood into Australian streams, Land & Water Australia, Canberra
- Bureau of Reclamation and U.S. Army Corps of Engineers. 2015. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. 628 pages + Appendix. Available: Bureau of Reclamation
- Herrera Environmental Consultants, Inc. (2006). Conceptual design guidelines – Application of engineered logjams
- Rutherfurd, I., Marsh, N., Price, P. and Lovett, S. (2002), Managing Woody Debris in Rivers, Fact Sheet 7, Land Water Australia, Canberra

4.2.10 Grass chutes

Example site

(Left) Waterway: Bruthen Creek

Basin: Corner Inlet

Contact: West Gippsland CMA

(Right) Waterway: Livingston Creek

Basin: Mitta Mitta

Contact: North East CMA

Description: A grass alternative to rock chute grade control structure. These structures may be preferred from an ecological perspective but are only practicable in ephemeral systems or as floodplain flow re-entry structures. The structures may comprise a combination of low-risk exotic (e.g. sterile ryegrass) and native ground covers to enable satisfactory establishment and operation.

Why implement?

Grass chutes can be used as an alternative to rock chutes within incised systems and to provide for the discharge of overland flow into incised creek systems, where flows are infrequent, of low velocity and short duration (less than 3 days).

Potential advantages

- Acts to reduce the incision of the riverbanks and floodplain by tributary inflows to incised streams, thereby reducing sediment supply to downstream reaches.
- Cheaper to construct compared to rock chutes.
- Relies on rapid successful vegetation establishment to provide stability to chute.
- May be more prone to failure than rock structures and thereby more prone to releasing sediment into the stream system.

Success ranking

- Applications in Victoria: Estimated to be over 100 applications during past 20 years
- Success in achieving intended outcome: High where flow duration, vegetation establishment and geomorphic processes such as scour potential have been considered in the design.

Practical considerations

Pre-works considerations

- Vegetation design: Understand the potential for flow during the vegetation establishment phase
- Vegetation design: Appropriate vegetation selection that provides sufficient shear resistance to flow
- Soils: Understand soil type and soil dispersity (i.e. sodic soils) and associated risks. Manage sodic/dispersive soils and unconsolidated ground. Is the location of the chute on existing consolidated material, or constructed compacted material?
- Positioning: Grass chutes should be located on minor tributaries with low stream power only and avoid significant flow paths where debris and high stream power can damage the structure.
- Hydrology: Will the duration and frequency of flow kill the grass or reduce the performance of the grass
- Geomorphic processes: Jute matting/geotextile reinforcement, design of structure such that maximum velocity does not exceed the threshold of vegetation stability.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events during the vegetation establishment stage. Following this stage, inspections should be event driven.
- Inspections should look to identify indications of vegetation failure, lining material tears (where used), outflanking of flows and any new signs of incision downstream of the chute.

Complimentary actions

- Fencing and revegetation.
- Weed management.
- Levee/bund construction.
- Lining materials (prior to vegetation establishment)
- Rock riprap.
- Bank battering.

Information requirements

- Longitudinal profile survey.
- Stream cross-section survey or estimate.
- Estimation of streamflow (hydrology).
- Soil type, proposed vegetation type and related non scour velocities.

Design guidelines and related information sources

Refer to Part 5 of these Technical Guidelines – Waterway stability analysis.

Information on threshold shear stress and velocity for a range of vegetation types are provided within:

- Fischenich, C. (2001b). Impacts of stabilization measures. U.S. Corps of Army Engineers, Engineer Research and Development Center. Vicksburg
- Chow, V. T. (1959). Open-channel hydraulics, McGraw-Hill, New York.

4.2.11 Large wood installation

Example site

(Left) Waterway: Ovens Creek

Basin: Ovens

Contact: North East CMA

(Right) Waterway: Genoa River

Basin: Genoa River

Contact: East Gippsland CMA

Description: Large wood installation, comprises the installation and management of single or multiple pieces of wood in the stream system to create habitat and flow diversity, reduce sediment transport (by increasing hydraulic roughness) and/or create scour holes and aid in vegetation establishment.

Why implement?

The purpose of the large wood installation is to initiate local scour and establish flow diversity to improve habitat. Alternatively, it may be used in a reach to increase hydraulic roughness, reduce overall velocity and to encourage sedimentation/aggradation and/or instream vegetation growth within a reach. Additionally, it can be used to help promote scour of narrow shallow sand bed streams where a narrowing and deepening of the channel is preferred within the existing over-widened channel.

Potential advantages

- Provision of stable instream structure in mobile bed systems.
- Establishment of habitat and flow diversity for aquatic fauna.
- Reduced sediment transport through a reach
- Aids establishment of instream vegetation.

Potential disadvantages

- Works can result in riverbank instabilities in the immediate vicinity of structure.
- Timber elements may be dislodged and mobilised in flood events.
- Potential localised occurrence of overbank flooding.

Success ranking

- Applications in Victoria: Widely applied across Victoria in multiple jurisdictions.
- Success in achieving intended outcome: High – dependent on many other factors (i.e. flows, water quality, instream barriers, pinning, geomorphic processes).

Practical considerations

Pre-works considerations

- Positioning: Placement of large wood should consider location with waterway plan form and desired project objectives (inside of bend, outside of bend, or instream bench).
- Geomorphic processes: Are the geomorphic processes amenable to the introduction of timber? (e.g. is there potential for burial by sediment?).
- Hydrology and sediment transport: Assess likelihood of scour hole formation, size and persistence through time series analysis coupled with identification of target fish species requirements for hole depth, timing and persistence.
- Hydrology: Mobilisation of the timber in flood events. Provision of additional anchoring if and as needed.
- Materials: Use of Australian hardwood timber to help minimise decomposition time. Maintenance of timber moisture by ensuring timber is partially buried in the channel bed.
- Materials: Wood selection is project dependent. Ideally native wood and from near to the site. The amount and size of wood depends on the waterway characteristics and the structure being built. For example, where no single pieces of large wood are available, smaller branches of the tree crown can be bundled together to create habitat. Consideration of timber resistance to marine borer in coastal waterways.

- Materials: Marine borers in coastal streams will require consideration, including marine borer resistant timbers and or alternative materials.
- Community acceptance: Community engagement to gain acceptance of structures through investigation and communications of beneficial (e.g. generating native fish / rec fishing outcomes) and potential adverse outcomes (localised of overbank flooding).
- Other stream health issues limiting habitat utilisation: Assess waterway health and address all limitations on stream health.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events to assess for log movement. Following this stage, inspections should be event driven.
- Inspections should assess log movement or pinning failure and whether debris has become lodged on the works which may cause accelerated flow and scour of adjacent banks.
- Fish or macroinvertebrate monitoring to demonstrate ecological outcomes.

Complimentary actions

- Fencing and revegetation.
- Bank protection (such as rock beaching).

Information requirements

- Flood Longitudinal profile and stream cross-section survey.
- Design flow rates.
- Channel hydraulic and scour analysis.
- Timber size and species availability.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Wood stability analysis.
- ARI. (2021) Timber for fish: Repurposing timber (removed from road projects) for waterway rehabilitation, Arthur Rylah Institute
- Brooks, A. *et al*. (2006). Design guideline for the reintroduction of wood into Australian streams, Land & Water Australia, Canberra
- Bureau of Reclamation and U.S. Army Corps of Engineers. 2015. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. 628 pages + Appendix.
- DEECA (2021). Arthur Rylah Institute – Instream Woody Habitat

- Kavanagh, R.J., Hoggarth, C.T. Rehabilitation and Enhancement of Aquatic Habitat Guide V. 1.0, April 2023
- Rutherfurd, I., Marsh, N., Price, P. and Lovett, S. (2002), Managing woody debris in rivers, Fact Sheet 7, Land and Water Australia, Canberra
- Saddlier, S. (2008). Techniques for reinstating instream habitat. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria

4.2.12 Log sills

Example site

Waterway: Wattle Creek

Basin: Wimmera River

Contact: Wimmera CMA

(Left image curtesy of Earth Tech).

Description: Log sills are single or multiple pieces of large wood anchored to the channel bed and bank most commonly for the purpose of creating pool habitat, trapping sediment or as a grade control structure. Consisting of large logs usually larger than 600 mm in diameter, they are usually placed perpendicular to the flow and across the channel.

Why implement?

Log sills are used to create pool habitat, assist fish migration through the provision of a range of flow velocities, provide instream woody habitat and to control bed erosion by trapping and holding bedload sediment. Alternatively, it may be used in a reach as a bed grade control tool to help mitigate incision.

Potential advantages

- Provision of stable instream structure in incising bed systems.
- Create physical and hydraulic diversity in uniform channels.
- Collect and retain gravel and sand.
- Create pool habitat.

Potential disadvantages

- Outflanking, erosion and sediment generation may become a problem if logs are not keyed into riverbanks correctly.
- Prone to undermining and outflanking without appropriate rock beaching.
- They have the potential to become barriers to fish migration at low flows.

Success ranking

- Applications in Victoria: Estimated to be less than 50 applications in Victoria.
- Success in achieving intended outcome: High where consideration is given to stream incision, outflanking and ecological needs.

Practical considerations

Pre-works considerations

- Positioning: Placement of log sill should consider location of the structure along the longitudinal bed profile (i.e. the grade of the reach in which the sill is constructed) so that the role of the sill in controlling incision can be understood.
- Geomorphic processes: Are the geomorphic processes amenable to the introduction of log sill? Are the log sills likely to be buried by sediment or undermined by knickpoints located downstream that are migrating towards the structures? An assessment of bed instabilities and sediment transport processes is required to address these possible threats to the structures.

- Geomorphic processes: Assess potential for undermining and outflanking of sill. Key an adequate distance into the riverbank. Provide rock beaching to protect each bank at the point of key in. Do you need to provide a low point in the sill to direct low flows away from the riverbank, and does the downstream side of the low point need rock beaching?
- Hydrology: Mobilisation of the timber logs in flood events. Provision of additional anchoring/keying in as needed.
- Materials: Use of Australian hardwood timber to help minimise decomposition time. Maintenance of timber moisture by ensuring timber is partially buried in channel bed.
- Materials: Wood selection is project dependent. Ideally native wood and from near to the site. The amount and size of wood depends on the waterway characteristics and the structure being built.
- Materials: Marine borers in coastal streams will require consideration, including marine borer resistant timbers and or alternative materials.
- Ecological needs: Assess potential to become a fish barrier.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events for the first 2 years. Following this stage, inspections should be event driven.
- Inspections should assess for log movement, outflanking, bank and bed scour and for whether debris has become lodged on the works which may from a barrier, reduce the effective flow area and cause accelerated flow and scour through outflanking.

Complimentary actions

- Fencing and revegetation.
- Rock beaching.

Information requirements

- Longitudinal profile survey.
- Stream cross-section survey or estimate.
- Available timber species and log size.
- Estimation of streamflow (hydrology).
- Fish passage requirements.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Wood stability analysis.
- Rutherfurd, I., Jerie, K. and Marsh, N. (2000), A Rehabilitation Manual for Australian Streams Vol 2, Full width structures (pp. 268-277). Land and Water Research and Development Corporation, Canberra

4.2.13 LUNKERS

Example site

Waterway: Acheron River

Basin: upper Goulburn catchment

Contact: Goulburn Broken CMA

(Source: Tonkin, Z., Kearns, J. and O'Mahony, J., 2015)

Description: LUNKERS (Little Underwater Neighbourhood Keepers Encompassing Rheotactic Salmonids) are a form of constructed undercut bank. The term and technique were developed in the USA. Undercut banks are an important habitat component of meandering stream systems, however riverbank stabilisation works (such as rock riprap and bank battering) can result in the destruction of undercut banks.

Why implement?

LUNKERS are a means of providing undercut bank habitat in waterway systems modified by bank stabilisation works such as battering and rock beaching.

Potential advantages

- Provision of instream undercut bank habitat for fish and other aquatic species in modified system, such as urban streams and regulated streams with extensive rock beaching, and sites with battered and otherwise "stabilised" banks.
- Can work with traditional rock beaching bank stabilisation works.

Potential disadvantages

- Construction works can involve significant bank disturbance and may result in vegetation damage and/or removal.
- Bank disturbance can result in a short term increase in turbidity and potential longer term bank instabilities
- Localised channel bed and bank scour where construction of LUNKER has resulted in encroachment into the stream channel.

Success ranking

- Applications in Victoria: Multiple sites within Victoria including by GBCMA and NECMA.
- Success in achieving intended outcome: High. Recent (2015) surveys indicate an increase in abundance of fish at sites with LUNKERS.

Practical considerations

Pre-works considerations

- Positioning: Placement of LUNKERS should consider location within waterway plan form and desired project objectives (desired habitat locations). High potential for success subject to any structural works and vegetative plantings to stabilise the upper bank and ensure a regenerative source of riverbank vegetation.
- Positioning: Adopt suitable design of LUNKERS to maintain normal/base flow water level above structure.
- Geomorphic processes: Are physical instream processes amenable to the introduction of LUNKERS? e.g. they won't be buried by sediment. Most successfully used in streams with gravel-cobble beds.
- Geomorphic processes: Estimation of scour depth and provision of suitable protection of the structure to prevent collapse.
- Hydrology: Mobilisation of the LUNKERS in flood events. Provision of additional anchoring as needed.
- Materials: Use of Australian hardwood timber to help minimise decomposition time. Maintenance of timber moisture by ensuring timber is partially buried in channel bed.
- Materials: Marine borers in coastal streams will require consideration, including marine borer resistant timbers and or alternative materials.

- Other stream health limitations: Assess whether LUNKERS are likely to limit habitat utilisation.

Post works monitoring

- LUNKERS should be periodically inspected (annually or following prolonged wet periods and high flows) to assess whether the overlying bank has collapsed, or whether sediment deposition has filled the engineered cavity.

Complimentary actions

- Fencing and revegetation
- Bank restoration

Information requirements

- Estimation of streamflow (hydrology)
- Bank and where possible channel survey (cross-sections, LiDAR or estimate).
- Stream bed scour estimate
- Ground conditions (to determine anchor requirements).
- Identification of targeted aquatic species likely to inhabit undercut banks and details of body size and their habitat preferences.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Wood stability analysis.
- Natural Resources Conservation Service, (2005). Technical Supplement 140 – Stream Habitat Enhancement Using LUNKER
- Bureau of Reclamation and U.S. Army Corps of Engineers. 2015. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. 628 pages + Appendix
- Tonkin, Z., Kearns, J. and O'Mahony, J. (2015) Assessing the benefits of instream habitat enhancement for fish population in the Goulburn Catchment. Unpublished Client Report for the Goulburn Broken Catchment Management Authority. Arthur Rylah Institute for Environmental Research. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

4.2.14 Wood revetment

Example site

(Left) Waterway: Ovens River

Basin: Ovens

Contact: North East CMA

(Right) Waterway: King River

Basin: Ovens

Contact: North East CMA

Description: Wood revetments are protective structures used to stabilise riverbanks, they are designed to maintain the bank slope or to protect it from erosion. Typically consisting of hardwood logs and driven timber piles they are founded on the bed of the stream and generally extend up the portion of the bank threatened by erosion. Similar to rock beaching, this technique provides localised protection of riverbanks and does not address system wide processes.

Why implement?

Wood revetment is used as a form of armouring of riverbanks against erosion. This technique is often undertaken as an alternative to hard engineering and is based on bioengineered approaches to streambank protection and in reshaped banks. Logs with rootballs attached provide a more natural approach to toe protection. They may provide greater habitat value than rock for all life phases of fish and other aquatic organisms.

Potential advantages

- Reduces near bank velocity and shear stress (and riverbank erosion) by increasing hydraulic roughness along the lower bank.
- Promotes sediment depositions and provide favourable conditions for vegetation establishment.
- Increased habitat value, through creation of complex hydraulic diversity and enabling burrowing animals to easily access the bank.

Potential disadvantages

- The approach may not address the cause of erosion and as a consequence excess energy within the system may still cause erosion elsewhere.
- Approach is not sympathetic to the planform evolution of meandering rivers. Hence, has potential to cause planform instabilities and continuing erosion in the long term.

Success ranking

- Applications in Victoria: Widely applied across Victoria in multiple jurisdictions
- Success in achieving intended outcome: High – dependent on many factors (i.e. flows, water quality, instream barriers, pinning, geomorphic processes)

Practical considerations

Pre-works considerations

- Positioning: Application of sound engineering judgement regarding suitability of bank material (foundation) and keying into bed of toe logs to ensure no undermining or outflanking.
- Geomorphic processes: The wood revetment is designed to fit within the existing planform of the stream. The stream is not subject to ongoing deepening which has potential to undermine the logs. Make provision for bed scour at the toe. Address any ongoing degradation of the channel bed.
- Design considerations: Key logs into the bank and avoid significant voids between logs and the bank face.
- Loss of logs: Installation of driven piles to help lock logs in place and prevent floating/dislodgment during floods.

- Materials: Use of Australian hardwood timber to help minimise decomposition time. Maintenance of timber moisture by ensuring timber is partially buried in channel bed.
- Materials: Wood selection is project dependent. Ideally native wood and from near to the site. The amount and size of wood depends on the waterway characteristics and the structure being built. For example, where no single pieces of large wood are available, smaller timber elements (e.g. branches) can be arranged to create the desired revetment.
- Materials: Marine borers in coastal streams will require consideration, including marine borer resistant timbers and or alternative materials.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events during the vegetation establishment stage. Following this stage, inspections should be event driven.
- Inspections should assess for vegetation failure and whether debris has become lodged on the works which may cause accelerated flow and scour.

Complimentary actions

- Fencing and revegetation
- Weed control
- Rock beaching
- Instream large wood

Information requirements

- Longitudinal profile.
- Bank and where possible channel survey (cross-sections, LiDAR or estimate).
- Estimation of streamflow (hydrology)
- Available log size
- Access arrangements

Design guidelines and related information sources

- Refer to 6 of these Technical Guidelines – Wood stability analysis.
- Bureau of Reclamation and U.S. Army Corps of Engineers. 2015. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. 628 pages + Appendix.
- Rutherfurd, I., Jerie, K. and Marsh, N. (2000), A Rehabilitation Manual for Australian Streams Vol 2, Incorporating vegetation into bank protection (pp. 290-297). Land and Water Research and Development Corporation, Canberra

4.2.15 Pile fields

Example site

(Left) Waterway: Thowgla Creek

Basin: Upper Murray

Contact: North East CMA

(Right) Waterway: Wimmera River

Basin: Wimmera River

Contact: Wimmera CMA

Description: Pile fields, comprise several individual lines (groynes), comprising timber piles. Each timber pile is driven vertically (or near vertically) into the stream bed and / or bank. Pile fields have replaced the use of timber pile and rail structures. Pile fields and their individual groynes are permeable, allowing water to flow through the structures at a reduced velocity, resulting in deposition and accumulation of sediments. These structures are typically designed to occupy a portion of the channel width on the outside of a meander to control erosion. However, pile fields can also be designed to occupy the full channel width to collect and retain sediment across the channel.

Why implement?

Pile fields mitigate bank erosion by reducing near-bank flow velocity and increasing fine and coarse sediment deposition. Reduction of flow velocity within pile field promotes sediment deposition and accumulation of seeds, creating favourable conditions for riparian vegetation establishment. The establishment of vegetation along the lower bank can help provide long term stability to the bank beyond the design life of the pile fields.

Potential advantages

- Stream bank erosion control.
- Promotes deposition and accumulation of sediments and seeds.
- Creates favourable conditions for riparian vegetation establishment.
- No long term visual evidence of channel intervention works.

Potential disadvantages

- Approach requires access to the riverbank and channel bed by machinery and field crews and associated instream and riverbank disturbance that will take some time to recover.
- Not suited to cobble bed streams where driving timber piles may not viable.

Success ranking

- Applications in Victoria: Widely applied across Victoria in multiple jurisdictions
- Success in achieving intended. outcome: High – where consideration to plan form, outflanking, vegetation establishment and pile sizing has been considered in the design.

Practical considerations

Pre-works considerations

- Geomorphic process: Ensure an adequate sediment supply to the site to promote deposition within the pile field.
- Positioning: Placement of pile fields should consider location within the channel and desired project objectives (alignment training, sediment capture etc.).
- Positioning: Selection of an alignment that promotes the desired waterway planform.
- Design consideration: Inclusion of scour depth analysis in design. Provision of rock beaching at toe of piles. Provision of pile tails (short rows of piles placed at the riverward edge of each row, perpendicular to the main pile row and extending in a downstream direction). Provision of rock partly embedded into the bank and channel on

either side of the most upstream rows of piles to prevent scour in the event of out flanking.

- Materials: Use of Australian hardwood timber to help minimise decomposition time. Approach relies on vegetation establishment to succeed timber piles. Failure to establish vegetation will result in failure of project as timber piles break down over time.
- Materials: Wood selection is project dependent. Ideally native wood and from nearby to the site. The amount and size of piles depends on the waterway characteristics and the embedment depth required.
- Materials: Marine borers in coastal streams will require consideration, including marine borer resistant timbers and or alternative materials.
- Hydrology: Consideration of debris impacts on the piles in flood events. Provision of additional thickness if and as needed.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events to assess for pile movement or failure. Following this stage, inspections should be event-driven.
- Inspections should also assess for indications of outflanking/erosion of bank material, and vegetation failure and/or establishment.

Complimentary actions

- Fencing and revegetation
- Rock beaching (upstream and at pile tie ins to bank).

Information requirements

- Bank and where possible channel survey (cross-sections, LiDAR or estimate).
- Longitudinal profile.
- Estimation of streamflow (hydrology).
- Shear stress assessment.
- Target sediment size and settling velocity.
- Available timber.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Pile field design.
- Rutherfurd, I., Jerie, K. and Marsh, N. (2000), A Rehabilitation Manual for Australian Streams Vol 2, Partial Width Bank Erosion Control Structures (pp. 278-289). Land and Water Research and Development Corporation, Canberra

4.2.16 Rock beaching

Example site

(Left) Waterway: Barongarook Creek

Basin: Lake Colac

Contact: Corangamite CMA

(Right) Waterway: Ovens River

Basin: Ovens

Contact: North East CMA

Description: Rock beaching involves the placement of quarried rock on riverbanks. The rock is founded on the bed of the stream and generally extends up the portion of the bank threatened by erosion. The technique provides localised protection of riverbanks and does not address system wide processes. The technique is also known as rock revetment or rock riprap.

Why implement?

Rock beaching is used as a form of armouring of riverbanks against erosion. This technique is often undertaken to protect economic assets such as bridges. It is also often used in conjunction with techniques such as alignment training and rock chutes to reduce the risk of these structures failing due to bank erosion.

Potential advantages

- Provides instant protection (not reliant on short term vegetation establishment).
- Streambank erosion control and associated reduction in sediment loads (particularly important when riparian areas are still maturing).
- Can provide some instream habitat for aquatic fauna (particularly native fish) in waterways that lack alternative instream structures (such as large wood).

Potential disadvantages

- The approach may not address the cause of erosion and as a consequence excess energy within the system may still cause erosion elsewhere.
- Approach is not sympathetic to the planform evolution of meandering rivers (due to halting of meander migration at treated sites). Hence, has the potential to cause planform instabilities and continuing erosion in the long term.
- Potential to destroy undercut bank habitat and bank diversity.

Success ranking

- Applications in Victoria: Widely applied across Victoria in multiple jurisdictions.
- Success in achieving intended outcome: High where appropriate rock sizing is determined through modelling and design and construction consider and mitigate common failure mechanisms.

Practical considerations

Pre-works considerations

- Soil profile: Understand soil type and soil dispersity (i.e. sodic soils) and associated increased risks. Manage sodic/dispersive soils and unconsolidated ground. Does the beaching at the toe of the bank consist of existing unconsolidated material, or constructed compacted material?
- Geomorphic processes: Determine ongoing channel bed and bank instabilities present i.e. fluvial scour and stability analysis (widening, ongoing deepening and channel meandering). Understand potential for outflanking - key rock into bank. Key in toe rock to a suitable depth allowing for provision for bed scour at the toe. Address any ongoing degradation of the channel bed. Assess plan form development of the stream.

- Sizing of rock: Size and grading of beaching should be designed to withstand shear stress for adopted design event. Analysis to determine appropriate rock size using RIPRAP software and / or site-specific hydraulic modelling.
- Sliding failure of rock mass: Failures associated with use of geotextile under rock riprap. Application of sound engineering judgement regarding suitability of bank material (foundation) and placement of filter material between bank material and rock.
- Complementary works: Vegetation establishment is successfully implemented as part of works.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events over the first 2 years. Following this stage, inspections should be event-driven.
- Inspections should assess points where rock settlement has occurred, potential undermining at toe and erosion at edges of the beaching, and for significant voids or loss of rock.

Complimentary actions

- Fencing and revegetation.
- Weed control.
- Off stream watering.
- Large wood and/or LUNKERS can be installed to offset adverse impacts arising from rock beaching.

Information requirements

- Longitudinal profile survey.
- Stream cross-section survey or estimate.
- Available rock size.
- Estimation of streamflow (hydrology).

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Rock beaching design.
- CRC for Catchment Hydrology 2005, Guidelines for the Design of River Bank Stability and Protection using RIP-RAP, CRC for Catchment Hydrology. Water Toolkit documentation
- Price, K. (2021) Advancing Australian Riprap Sizing Approaches, Hydrology and Water Resources Symposium 2021, ISBN: 978-1-925627-53-4.:
- Melbourne Water, Rockwork construction: general notes

4.2.17 Rock chutes

Example site

(Left) Waterway: Livingston Creek

Basin: Mitta Mitta

Contact: North East CMA

(Right) Waterway: Ovens River

Basin: Ovens

Contact: North East CMA

Description: Rock chutes generally involve the excavation/reshaping of the bed and banks of a stream and the placement of graded (quarried) rock, often forming a small weir in the stream. Rock chutes provide a hardened, rough surface where flow energy and erosive forces can dissipate.

Why implement?

Rock chutes are constructed to control the gradient of channel beds. However, with careful design they can be used to address other stream management issues such as the provision of fish passage, diversion weirs, sediment stabilisation, flow control structures within constructed wetlands or the creation of riffle and pool habitat.

Potential advantages

- Reduction in incision, more stable bed substrate and banks.
- Provision of fish passage through existing weirs.
- Establishment of pool habitat and pool-riffle sequences by using multiple chutes.
- Gully head erosion control.
- Storage of eroded sediment thereby reducing sediment inputs downstream.

Potential disadvantages

- Successful implementation will result in reduction in downstream sediment supply, potentially starving downstream reaches. In the absence of a complementary downstream vegetation establishment program, sediment starvation can initiate incision in downstream reaches.
- Poorly designed and constructed structures can have an adverse impact on fish passage by creating high velocities that are impassable for some fish species or life stages.

Success ranking

- Applications in Victoria: Widely applied across Victoria in multiple jurisdictions.
- Success in achieving intended outcome: High where appropriate rock sizing through modelling has been undertaken and construction undertaken considering common failure mechanisms.

Practical considerations

Pre-works considerations

- Soils: Understand soil type and soil dispersity (i.e. sodic soils) and associated increased risks. Manage sodic/dispersive soils and unconsolidated ground. Is the location of the chute on existing consolidated material, or constructed compacted material?
- Geomorphic processes and chute positioning:
  - Vertical: Consider incision and aggradation processes and ensure structure is not undermined by incision or buried by sediment.
  - Horizontal: Consider potential for meander migration and/or channel widening by providing appropriate abutment protection.

- Design consideration: Ensure that hydraulic jump occurs on the chute or apron for all flows – use CHUTE program.
- Stream power: Consider use of a sequence of rock chutes along a reach to maintain a stable grade and reduce overall stream power, reducing the potential for incision that can undermine the rock chutes.
- Rock sizing: Limit potential for rock movement arising from high shear stress, poor rock grading, poor foundation material and/ or development of failure planes between rock and either bed material or filter fabric. Mitigate failure through design of rock size for chute – use CHUTE program, provision of appropriate foundation materials and preparation, supply of rock of suitable size and grading and cautious use of filter fabric (filter fabric should only be used based on sound engineering judgement regarding suitability of bed material (foundation) and placement of filter material between the bed material and rock).
- Complementary works: Ensure that revegetation and maintenance programs are effective. In particular, reeds and sedges such as *Phragmites australis* are used to assist in stabilising bed material.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events over the first 2 years. Following this stage, inspections should be event-driven.
- Inspections should assess points where rock settlement has occurred, and for significant voids or loss of rock.
- Inspections should assess vegetation/debris build up within chutes and whether it is redirecting flow inappropriately.

Complimentary actions

- Fencing and revegetation.
- Levee/bund construction.
- Inclusion of fish passage.

Information requirements

- Longitudinal profile survey.
- Stream cross-section survey or estimate.
- Available rock size, grading and density.
- Estimation of streamflow (hydrology).

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Rock chute design.
- CRC for Catchment Hydrology (2003), Guidelines for the Design of Rock Chutes using CHUTE, CRC for Catchment Hydrology. Documentation | CHUTE | Tools | eWater Toolkit
- Keller, R.J. and Winston, F.B., (2004). Design of Rock Chutes for the Stabilization of Channel Beds. In Protection and Restoration of Urban and Rural Streams (pp. 329-338).
- Price, K. (2021) Advancing Australian Riprap Sizing Approaches, Hydrology and Water Resources Symposium 2021, ISBN: 978-1-925627-53-4.
- Melbourne Water, Rockwork construction: general notes

4.2.18 Rock groynes

Example site

(Left and right images) Waterway: Tambo River

Basin: Tambo

Contact: East Gippsland CMA

Description: Rock groynes are largely impermeable deflectors placed into waterways to prevent bank erosion, create deposition and alter the local planform of the stream. Rock groynes provide some erosion protection and can result in some deposition. However, the impermeable nature of the structures can lead to local scour associated with over topping of the structures. Rock groynes can be used to alter the alignment of the stream thalweg where this is desired and alternative permeable structures are not viable. Complementary rock beaching is typically required to prevent local scour between groynes.

Why implement?

Rock groynes have been used for both erosion control through the deflection of water away from an eroding bank (alignment training) and for initiation of scour through the acceleration and deflection of flow.

Potential advantages

- Can be used for riverbank erosion control in some circumstances.
- Can create localised instream scour and accompanying habitat formation.
- Can provide instream habitat for aquatic fauna in waterways or reaches without alternative structural habitat.
- Can be used in bedrock-controlled and cobble bed reaches where pile fields cannot be installed.

Potential disadvantages

- Rock groynes are generally not well suited to erosion control works. Rock beaching is a better application for erosion control of streambanks. Permeable structures are preferred over rock groynes for alignment training style erosion control projects.
- Poorly designed and/or constructed rock groynes might exacerbate bank erosion.

Success ranking

- Applications in Victoria: Limited applications across Victoria.
- Success in achieving intended outcome: Moderate where appropriate rock sizing and alignment has been considered.

Practical considerations

Pre-works considerations

- Soils: Understand substrate, soil type and soil dispersity (i.e. sodic soils) and associated increases in risks. Manage sodic/dispersive soils and unconsolidated ground. Is the location of the groynes on existing consolidated material/bedrock, or constructed compacted material?
- Positioning: Consider planform development of the stream, ongoing geomorphic processes, local flow patterns and align groynes appropriately.

- Geomorphic processes: Consideration of scour depth analysis into design. Key in suitable toe rock to a depth allowing for provision for bed scour at the toe.
- Rock sizing: Loss of rock that can occur from high stream power/shear stress, undersized rock. Mitigate structure failure through design of rock groynes using RIPRAP, and / or site-specific hydraulic modelling. Explicitly assess expected shear stresses during design.
- Complementary works:
  - Inclusion of necessary associated works i.e. provision of adequate rock keyed into bank to prevent outflanking at the bank edge and rock beaching between structures.
  - Revegetation and maintenance programs.

Post works monitoring

- The works should be inspected approximately every six months and following high flow events over the first 2 years. Following this stage, inspections should be event-driven.
- Inspections should assess points where rock settlement has occurred, and for significant voids or loss of rock.
- Inspections should assess vegetation/debris build up within groynes and whether it is redirecting flow inappropriately.

Complimentary actions

- Fencing and revegetation.
- Rock beaching.

Information requirements

- Target sediment size and settling velocity.
- Estimation of streamflow (hydrology).
- Estimation of design water levels (hydraulics).

Design guidelines and related information sources

- Refer to sections 6.5 and 6.8 of these Technical Guidelines – Pile field design and Rock beaching design.

4.2.19 Sediment extraction

Example site

(Left) Waterway: Reedy Creek

Basin: Ovens

Contact: North East CMA

(Right) Waterway: Glenelg River

Basin: Glenelg

Contact: Glenelg Hopkins CMA

Description: Sediment extraction involves the removal of bed load sand and gravel sediments from the channel bed. It should only be used in rare circumstances and in streams that have been aggraded with slugs of sediment from outside of the reach resulting from human disturbance. Sediment extraction may involve removing sediment from the full width of the bed or from bars of accumulated material.

Why implement?

Sediment extraction is undertaken to remove accumulated sediment from within the channel and hence encourage channel rejuvenation by reducing sediment supply to downstream reaches leading to increase instream habitat diversity via bed deepening, pool/scour hole formation and exposure of previously buried large wood.

Potential advantages

- Can be used to help implement accelerated channel recovery by removing sand in an environmentally sensitive manner.
- Protection of downstream reaches from excess sediment transport and deposition.
- Initiation of channel rejuvenation through channel bed deepening, pool/scour hole formation, and associated increase in bed habitat diversity.

Potential disadvantages

- Can result in substantial responses and changes to physical form (incision and widening) both upstream and downstream.
- Instream and floodplain assets such as wetlands may be destroyed by channel deepening resulting from sediment extraction.
- Sediment extraction may reduce habitat diversity, destroy the channel bed and associated habitat and may cause a decline in local fauna populations.
- Extraction may cause re-suspension of sediment with consequent adverse downstream impacts.

Success ranking

- Applications in Victoria: Multiple examples applied across Victoria.
- Success in achieving intended outcome: High – when undertaken in an environmentally sensitive manner and where the current distribution and transport rate of sediment is understood.

Practical considerations

Pre-works considerations

- Sediment re-suspension: Timing and duration of operation needs to be governed by the need to minimise the effects of turbidity on downstream values. Sediment is extracted from the downstream face of the bar not exposed to current, or from the dry channel bed during low flows.
- Geomorphic process: Sediment extraction can cause deepening and therefore bank collapse upstream and downstream of the extraction site. Consider the rate of extraction and target an extraction rate that balances sediment transport supplied to the reach with sediment transported downstream.

- Geomorphic process: Ensure that implementation is sympathetic to waterway health e.g. minimising impacts on water quality and benthic and riparian habitat, preserve instream vegetation, avoid disturbance of bank toe.
- Damage to habitat: Only work and stockpile sediment on one bank. Deep or repeated excavation at one site is preferable to minor excavations over a long stretch of waterway. Depth of excavation should consider channel deepening response, turbidity and impact on instream habitat.
- Habitat improvement: Introduce diversity into the excavated channel bed by leaving some areas of shallow channel among the deeper areas (noting that this initial diversity may be a short term features as ongoing deposition occurs); Reinstate snags after excavation is complete.

Post works monitoring

- Monitoring should concentrate on reaches immediately upstream and downstream of extraction sites and be used to guide the extent and frequency of extraction. Note: extraction pits may refill overtime and is not necessarily a sign that more extraction is required.
- Downstream reaches should be monitored for signs of excessive loss of instream depositional features and bed incision that either undermines the toe of adjacent banks or begins to undermine instream vegetation.
- Monitoring upstream of extraction sites should concentrate on identifying bed incision that can undermine channel banks.
- Over the long term, downstream reaches should be monitored for signs of persistent erosion triggered by the sediment deficit caused by extraction.

Complimentary actions

- Fencing and revegetation
- Large wood installation

Information requirements

- Depth of sediment.
- Sediment supply to extraction reach.
- Hydrology.
- Annual bedload transport rates.
- Stream bed longitudinal profile.
- Channel cross-section survey, access to channel bed for plant, and site for spoil stockpile.

Design guidelines and related information sources

- Refer to Part 6 of these Technical Guidelines – Sediment budget analysis.
- Rutherfurd, I., Jerie, K. and Marsh, N. (2000), A Rehabilitation Manual for Australian Streams, pp. 326-27, Land and Water Research and Development Corporation, Canberra

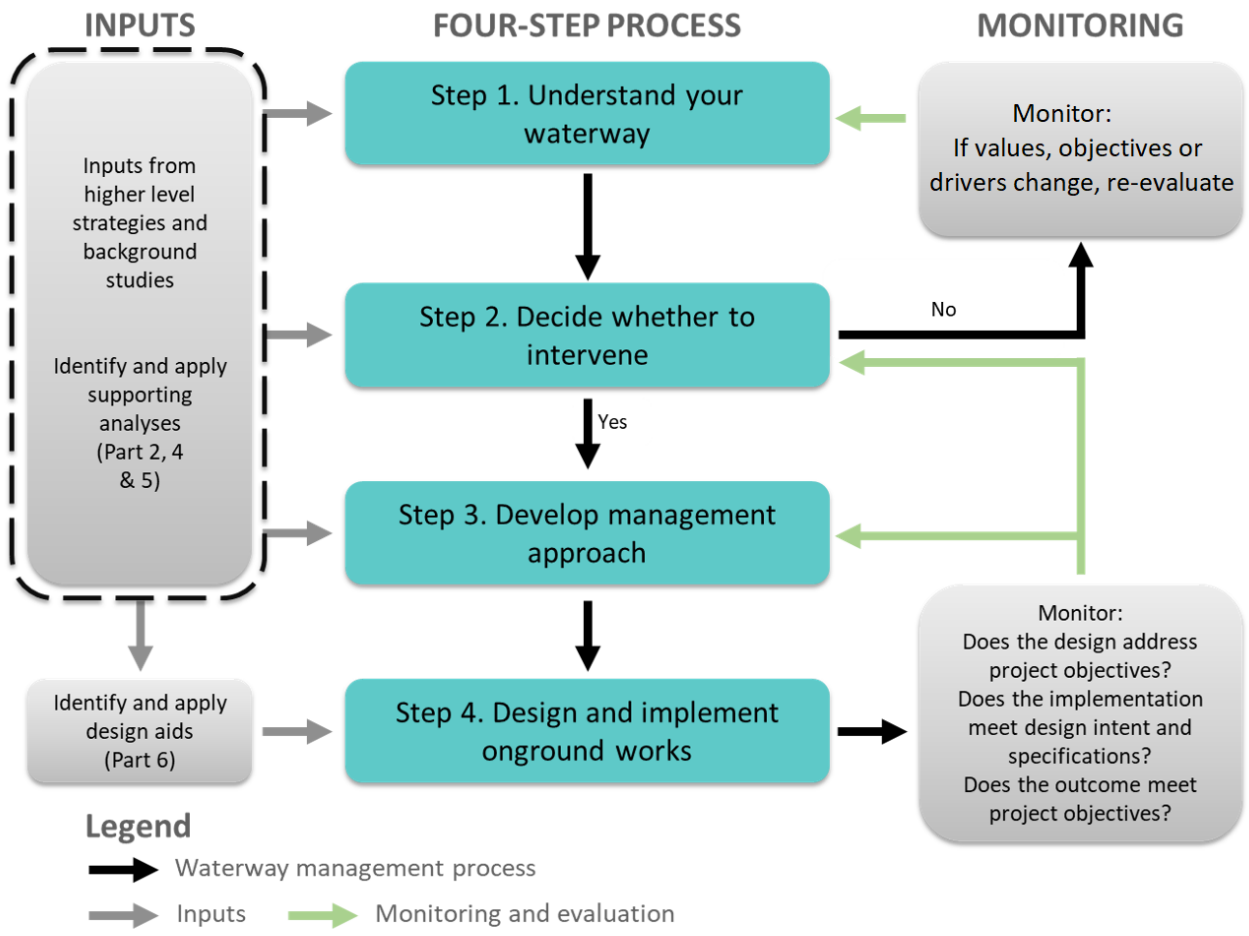
5 Part 5 – Supporting analyses

5.1 Introduction

This section of the Guidelines provides access to supporting analyses that may assist with the understanding of geomorphic processes, applicable management approach and inform the design of a selection of waterway management techniques. Included in this section are design approaches for both larger temporal and spatial scale programs, and more discrete site-based projects.

The identification and application of the supporting analyses is highlighted in the four-step process (Figure 34) and is to be used to help guide the identification of threatening process through to the design of intervention options to enable construction.

Figure 34. Supporting Analyses input into the four-step process.



5.2 Detecting geomorphic change using historic and contemporary aerial imagery and repeat LiDAR survey

5.2.1 Overview

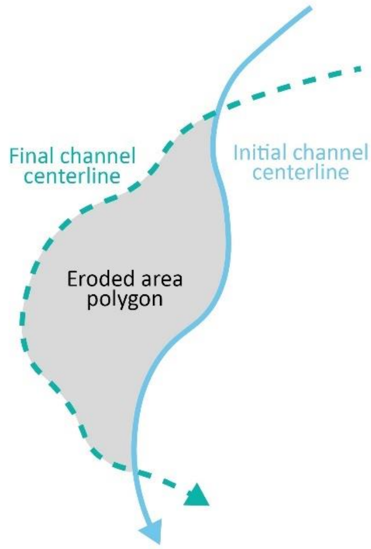
Understanding historical rates of channel change can assist in predicting the future channel change and the trajectory of the system. An analysis of historical aerial imagery and repeat LiDAR enables changes in vegetation condition, channel width, and planform to be assessed.

5.2.2 Summary of the method

Multi-temporal aerial imagery and LiDAR data analysis captures waterway dimensions and alignment and how those change over time. LiDAR and aerial imagery are distinct (but complementary) datasets that have their own strengths and weaknesses. LiDAR data is best used where changes in elevation or volume must be calculated or where dense vegetation coverage may otherwise obscure changes in a waterway (as properly processed LiDAR data is able to generate a ‘bare earth’ elevation model). Aerial imagery, which has often been captured more regularly than LiDAR data, is best used when there is a need to identify the extent and type of vegetation present and to provide context (for example by revealing roads and buildings on the floodplain). Ideally, both LiDAR and aerial imagery datasets captured at the same time are used together to provide a more robust dataset.

Sequences of aerial imagery can be used to quantify the lateral shift of a stream channel over time (Brewer and Lewin, 1998). Stream meander migration can be measured by mapping channel centrelines and quantifying the ‘eroded-area polygon’ as the centreline shifts over successive years (Micheli *et al.*, 2004). The ‘eroded-area polygon’ is created by superimposing channel centrelines mapped at two different points in time (Figure 35). The average rate of migration is then given by the polygon area divided by the average polygon stream length (i.e. half of the polygon perimeter) and the length of the time period (Micheli *et al.*, 2004). At a site scale the average rate of meander migration is often determined based on top of bank retreat and time period of retreat.

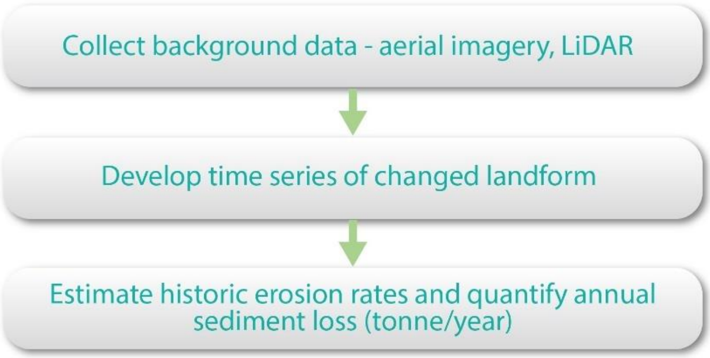
Figure 35. Eroded-area polygon (adapted from Micheli *et al.*, 2004).



More recently, the availability of high-resolution LiDAR topographical data, used in combination with aerial imagery, has improved accuracy in the mapping and prediction of riverbank erosion rates (Marcus and Fonstad, 2008). The horizontal and vertical accuracies of LiDAR, and its ability to filter vegetation, enables accurate measurement of riverbank position and elevation (De Rose and Basher, 2011). The method is useful in determining riverbank erosion due to individual flood events (i.e. comparison of data pre- and post-flood data).

Key tasks in this approach are shown in Figure 36 and outlined below.

Figure 36. Comparison of historical data – key steps to estimate annual erosion rates.



1. Collect background data – aerial imagery, LiDAR
2. Develop time series of changed landform
3. Estimate historic erosion rates and quantify annual sediment loss (tonne/year)

5.2.3 Repeat aerial imagery analysis

Multi-temporal analysis of aerial imagery can be used to estimate sediment loss from bank erosion.

Estimation of historical sediment loss using multitemporal aerial imagery analysis involves:

- Collecting aerial imagery from a given time period (e.g. 10 years) which experienced high flow events.
- Developing a time series of bank erosion. Assess aerial imagery to identify a section of the bank which is actively retreating. Measure the length of the active bank, and the average lateral bank retreat over a given period in order to calculate the eroded area. A corresponding average bank height for the eroded area can be determined through field survey or estimated using a digital elevation model (DEM) if available.
- Calculating the estimated sediment loss volume (m^3) over the given period and the average sediment loss per year (m^3/yr):

$$Estimated\ sediment\ loss\ (m^3/yr) =$$

$$\frac{lateral\ bank\ retreat\ (m) \times average\ active\ bank\ length\ (m) \times average\ bank\ height\ (m)}{time\ period}$$

An example site scale comparison of historical imagery is shown in Figure 38. Figure 37 The temporal analysis of aerial imagery at the site indicates there has been major meander migration since 1967. The outside of the meander bend has shifted approximately 90 metres north-west between 1967 and 2018. Based on arial imagery analysis an estimated 295,800 m^3 of sediment was mobilised over a 51-year period; this corresponds to an estimated annual sediment loss of 5,800 m^3/yr.

Figure 37. Site scale comparison of historical imagery.

5.2.4 Repeat LiDAR survey analysis

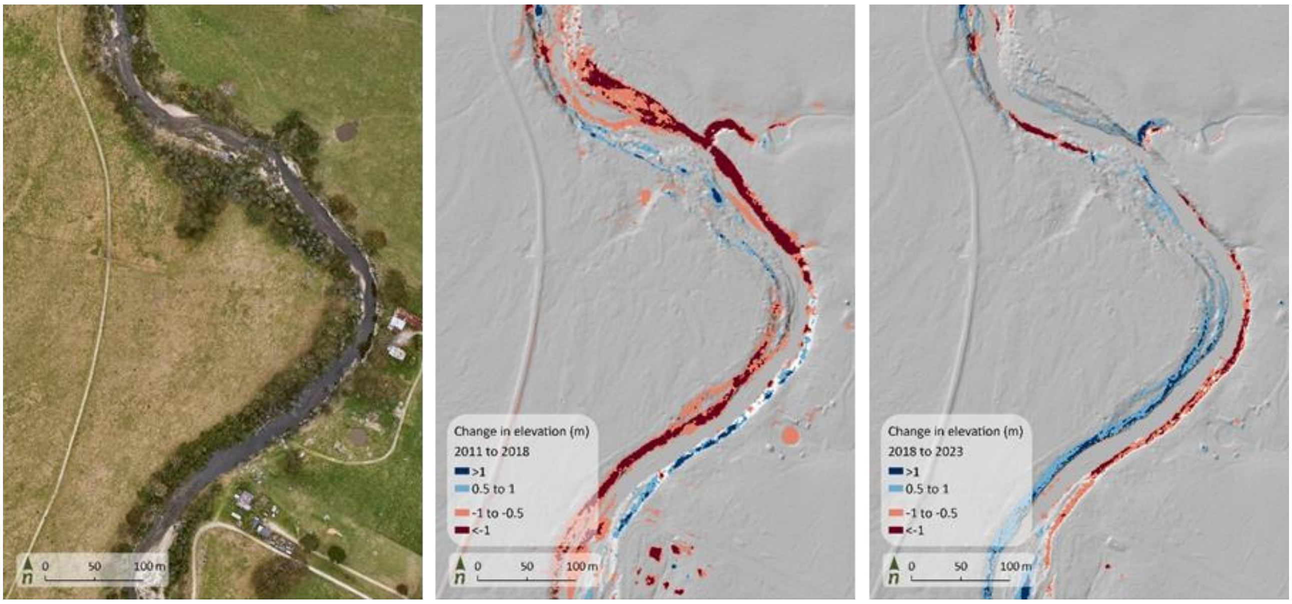
Multi-temporal analysis of LiDAR can be used to assess dominant erosional process (i.e. meander migration, channel widening), and estimate sediment loss over a given time period. Cross-sections through the waterway system can be extracted from LiDAR and used to assess channel morphology and lateral bank retreat.

Estimation of historical sediment loss using multi-temporal LiDAR analysis involves:

- Collect LiDAR data sets from two different time periods.
- Create Digital Elevation Models (DEMs) with a one metre cell size. DEMs are rasters files with elevation data assigned to each cell.
- Quantify volumetric change between successive DEMs. Produce a DEM of Difference (DoD) by subtracting the DEM from the earlier time-period from the more recent DEM. The DoD would provide a pixel level (1m2) evaluation of the amount of erosion or deposition that has occurred. Vertical and spatial variability across component DEMs should be assessed as part of error analysis to ensure DoDs are reliable and accurate.

An example site scale comparison of LiDAR imagery is shown in Figure 38 with red, orange, yellow and green displaying a drop in elevation indicating erosion has occurred. Blue displays an increase in elevation. The temporal analysis indicates that major meander migration and subsequent erosion occurred at the site between 2009 and 2014, resulting in up to 30 metres of bank retreat and mobilisation of over 50,000 m^3 of sediment (7,780 m^3/yr). Further downstream meander migration occurred between 2014 and 2018, resulting in 25 metres of bank retreat and over 20,000 m^3 of sediment mobilisation.

Figure 38. Change in elevation of a meander bend on the Cann River between 2011 and 2018 (middle), and 2018 and 2023 (right).



5.2.5 Extent of application

Over the last 50 years multi-temporal aerial imagery has been used extensively by geomorphologists to assess channel change and erosion rates. The use of LiDAR data has become more prevalent in recent years. Multi-temporal LiDAR analysis is widely used in geomorphic studies in Australia. With the LiDAR data becoming more cost effective, this method enables estimates of historical bank erosion rates at both reach and catchment scales. LiDAR has previously been collected for many major waterways in Victoria as part of the Index of Stream Condition (ISC) and the State-wide Riparian Rivers Projects.

5.2.6 Limitations

This method is useful in determining historical rates of erosion. If using retrospective observations to forecast future events, an underlying assumption is that the conditions under which the observations were made are applicable to future events. Increases in the severity and frequency of extreme weather events due to climate change, and/or changed catchment conditions (i.e. land clearing), are likely to impact the accuracy of predictions made using this method. Additionally, erosion rates can wane over time. Often there is rapid erosion due to disturbance (i.e. urbanisation) and over time as the channel widens erosion rates reduce.

The method is further limited by the availability of data at a given site and the geomorphic processes occurring at the time of data collection. Where flood events, resulting in significant channel change, have occurred since collection of aerial imagery and LiDAR, data used for comparison may not be representative of the current waterway state.

The ability of this approach to accurately predict bank erosion rates is dependent on the quality and accuracy of LiDAR data. Advances in LiDAR have significantly improved the accuracy and resolution of topographic data it is able to generate. However, LiDAR is still unable to penetrate the water surface, therefore where there is water in the channel at the time of data collection an accurate estimation of bed level, and therefore change in bed level, cannot be determined.

5.3 Waterway stability analysis

5.3.1 Overview

A waterway stability assessment is a combination of qualitative and quantitative methods that can be used to help predict whether a waterway reach is undergoing, or is primed to undergo, incision. Stability in this sense refers to gradual rates of channel change, as opposed to the rapid rates of channel change often associated with incision.

Quantifying ongoing geomorphic processes through modelling and survey analysis (including bed grade analysis, stream power analysis and shear stress analysis) is an effective means of designing the scale and location of on-ground works used to manage incised waterways.

This section summarises the methods used in the quantitative analysis described above. The intent of waterway stability analyses is to identify whether a target reach is currently undergoing or is likely to undergo, incision.

5.3.2 Bed grade analysis

The purpose of bed grade analysis is to assist the development of an understanding of the threatening processes to be managed. The analysis enables identification of bed grades associated with intact reaches of a waterway (that serve as a representative target grade), and those that are subject to ongoing instabilities. When undertaking bed grade analysis waterway managers should identify (through field assessment) which stage/s of incision the study reach is in (see section 2.2.1).

The process of channel bed grade analysis comprises three key steps.

1. Collection of channel bed longitudinal data. There should be sufficient LiDAR or field-based survey data upstream and downstream of any apparent instabilities to enable identification of stable channel bed gradients for intact reaches or reaches subject to channel recovery.
2. Analysis of the longitudinal channel bed profile data. The analysis can involve visual or analytical approaches to identify representative and stable bed grades (reference bed grades – see below) for the stream. Analytical procedures may involve techniques such as moving average analysis. Knickpoints and over steep reaches should also be identified on the longitudinal profile.

3. Field assessment to identify reaches/sub-reaches where the bed is stable. A stable bed may be indicated by the presence of in-channel vegetation, and/or instream physical diversity (e.g. pools, riffles, point bars). In the field waterway managers should also identify knickpoints and over steep reaches. Field assessment should be used to verify longitudinal profile assessment.

5.3.2.1 Reference Bed grade

A reference data set of bed grades for a set of incised stream reaches in north east Victoria has been developed based on Hardie (1993) and can be expressed as a function of the lesser of bankfull flow and the 40% AEP (i.e. 2-year ARI) for the system. The reference bed grade provides an indication of a potentially stable grade in the subject reach. The stable reference bed grade (Hardie, 1993) is calculated as:

$$S = 0.016 \times Q^{-0.58}$$

Where, S = reference bed grade

Q = the lesser of bankfull flow and the 40% AEP (2-year ARI) design event for the system

Hardie (1993) compiled data for approximately 40 sand and gravel bed waterways in north east Victoria. The data set was largely based on incised waterways with an ongoing source of bed load sediment. The investigation sought to identify a stable or design bed grade downstream of active incision or within reaches of active incision between identified knickpoints.

When determining a design bed grade, waterway mangers should firstly identify a stable (reference bed grade) within the study reach (or an adjacent representative reach). The Hardie (1993) equation may then be used as an additional or complementary approach to inform identification of design bed grades from longitudinal profile surveys using the bed grades found for other waterway systems in Victoria. Design bed grades identified from channel bed longitudinal profile surveys can be used for incised waterway management programs and the geomorphic design of waterway systems.

An example reach scale bed grade assessment is shown in Figure 39. Indicative bed grades for each sub-reach compared to the reference bed grade is provided in Table 9. As shown in the table, although the bed-grade for sub-reaches C and D are much higher than the reference bed grade, the grade is currently stabilised by the presence of willows and rock protection.

Figure 39. Longitudinal bed grade assessment. Showing indicative bed grades for the study reach, with potential for up to 1.6 m deepening (potential for up to 4 m of deepening if crossings fail).

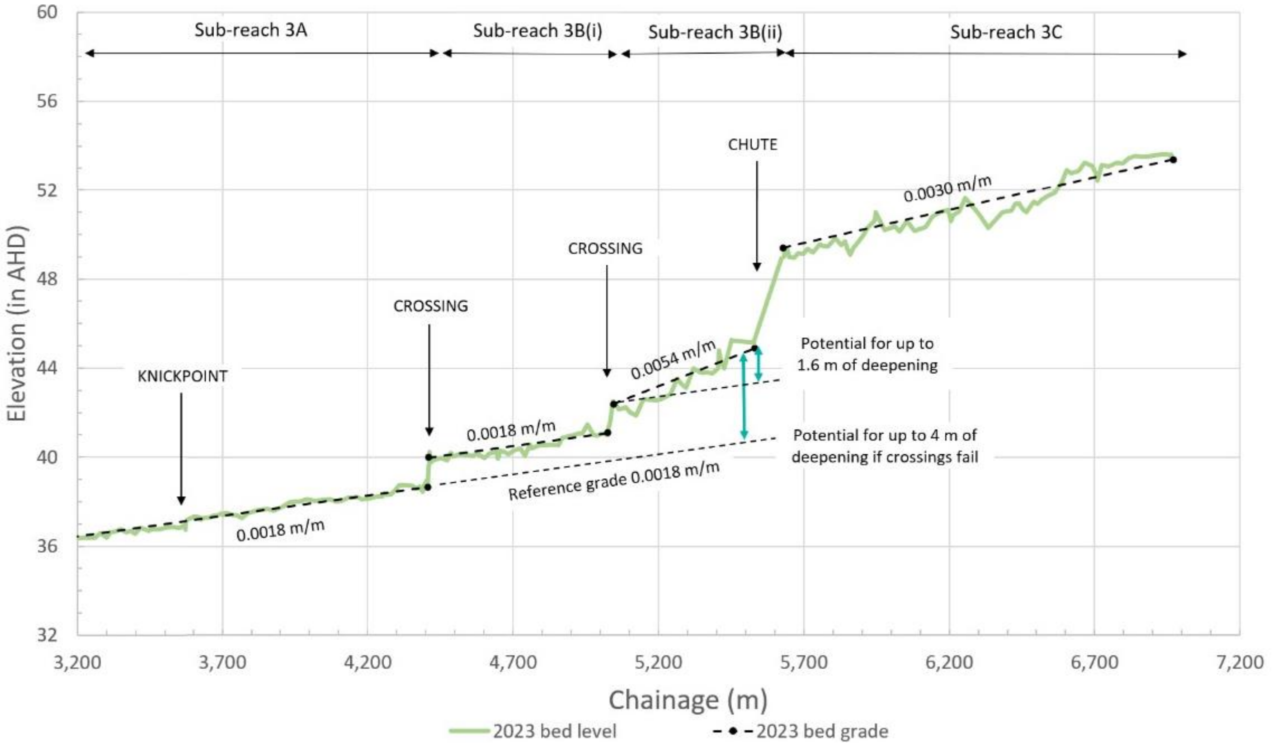


Table 9. Comparison between indicative bed grades and reference bed grades.

Sub-reach	**Chainage**	**Stage of incision**	**Bed grade (m/m)**	**Reference bed grade (m/m)**	**Acceptable?**
Sub-reach A	CH0 – CH1230	Stage 5	0.0018	0.0018	Yes
Sub-reach B	CH1230 – CH1850	Stage 4	0.0018	0.0018	Yes
Sub-reach C	CH1850 – CH2400	Stage 2-3	0.0054	0.0018	No
Sub-reach D	CH2400 – CH3790	Stage 1	0.0028	0.0018	Yes

The indicative bed grades are approximate to the reference bed grades in Sub-reaches A and B. The bed grade of Sub-reach 3 (0.0054 m/m) is much steeper than the reference bed grade, there is potential for up to 1.6 m of deepening. Grade control works may therefore be required in Sub-reach C. The most upstream Sub-reach D consists of a relatively shallow, narrow channel which is not incised, therefore the bed grade of 0.0028 m/m has potential to be relatively stable.

5.3.3 Hydraulic analysis

Hydraulic analysis can be undertaken to identify the velocity, shear stress and specific stream power within the subject waterway and its reaches for a range of flow events.

The analysis can be used to compare stream power, shear stress and velocity parameters for the study reach with refence values for adjoining stable reaches and for other stable alluvial systems.

The process for hydraulic analysis typically comprises the following steps.

1. Hydrologic analysis using either a rainfall runoff approach (e.g. Rational method or RORB Model), or flood frequency analysis. Flood frequency analysis is preferable where stream gauging data is available. Flood frequency analysis should be undertaken using the approach set out in *Australian Rainfall and Runoff* (Commonwealth of Australia, 2019).
2. LiDAR and/or longitudinal and cross-sectional survey of the study reach.
3. Development of a hydraulic model of the stream system. This could comprise a one-dimensional (1D) (e.g. HEC-RAS) or two-dimensional (2D) hydraulic model (e.g. TUFLOW). A more sophisticated modelling package may be appropriate depending on the complexity of the system.
4. Testing the size and composition of sediment in the stream banks and on the floodplain. Such soil testing may incorporate either:
    - Visual soil assessment.
    - Analytical soil properties analysis, i.e. sediment size and dispersion analysis.
5. Analysis of the reach scale hydraulic parameters (e.g. stream power and shear stress outputs from TUFLOW) and comparison with reference values for alluvial systems and/or key design parameters (e.g. critical shear stress of channel boundary material).

Key hydraulic parameters relevant to analysis and design of stream systems (from Tilleard, 2001) are defined below.

Energy loss, stream power and shear stress

Water can have potential energy by virtue of its elevation. As water flows within a channel this potential energy is converted into kinetic energy of moving water and any debris and sediment load that is carried. Energy is dissipated as the result of turbulence within the flow and by friction between the flow (and any load) and the channel boundaries. **Stream power** is the rate of energy expenditure per unit channel length.

In a channel, at least part of the energy expenditure occurs as a result of the **velocity gradient** in the flow close to the boundaries. This shearing of flow close to the boundary occurs as a result of the force exerted on the flow by the irregularities associated with the boundaries at a particle and a bedform scale. Per unit area of boundary, this force is the **average boundary shear stress.**

5.3.3.1 Stream power analysis

Stream power is an indicator of the amount of work or energy expended on the bed and banks of a waterway by flowing water. Equilibrium and/or channel recovery usually involves a balance of depositions and erosion. If the stream power is too high, then the channel banks will typically erode. Alternatively, if the stream power is too low, aggradation may occur (also dependent on sediment transport discontinuities).

Specific stream power (ω) refers to the stream power per unit width of a defined channel (m^2). Specific stream power reduces the scale effects of wide and narrow channels, and is therefore useful for making comparisons between waterways, or different reaches within a waterway (Charlton, 2008).

Specific stream power (in W/m^2) is given by the equation:

$$\omega\ (W/m^2) = \frac{\rho g Q S}{w}$$

Where,

ρ = density of water (kg/m^3)

g = acceleration due to gravity (m/s^2)

Q = flow in the channel (m^3/s)

S = hydraulic gradient (i.e. bed slope of channel) (m/m) energy slope?

w= water surface top width (m)

Upper limit specific stream power reference values of 60 W/m^2 and 150 W/m^2, for 2- and 50-year ARI (i.e. 40% and 2% AEP) events respectively, have been identified for geomorphically stable systems with visually observed ongoing bed load sediment supply and good vegetation cover (Fisher Stewart, 2002) (Table 10). Unconfined alluvial systems with stream powers above these reference values may experience channel instabilities during flood events. These reference limits are a guide only and will vary for different systems depending on channel characteristics (i.e. substrate, sediment supply, vegetation condition etc.). Crucially these limits will be highly dependent on the riparian vegetation condition and an ongoing bed load sediment supply. These reference limits can be used to assess system stability and are most commonly applied to the analysis of incised streams and the development of incised stream management programs.

Table 10. Stream power reference values for 2-year and 50-year ARI events – for use in sand bed stream (adapted from Fisher Stewart, 2002).

Stream type	**Approximate stream power (W/m^2) 2-year ARI event (40% AEP)**	**Approximate stream power (W/m^2) 50-year ARI event (2% AEP)**
Incised Bankfull ARI > 5 years	20 < stream power < 60	Typically, 50 < stream power < 150
Limited capacity Bankfull ARI < 5 years	Typically stream power < 60	Stream power < 100
Bedrock controlled As identified in field	50 < stream power < 110	100 < stream power < 220

Notes:

It is not recommended that the information drawn from this investigation be extrapolated to streams with a bed sediment size larger than approximately 1mm.

The reference values above were derived from analysis of a range of ephemeral sand bed streams in the Bowen Basin coal field of central Queensland. Stream bank material comprised mud drapes with dense grass cover.

Importantly, the stated stream power reference values are not erosion thresholds and are not intended to be used in the design of a waterway completely free of the erosion and deposition to be expected in natural waterways, nor for the design of individual design elements, such as rock chutes.

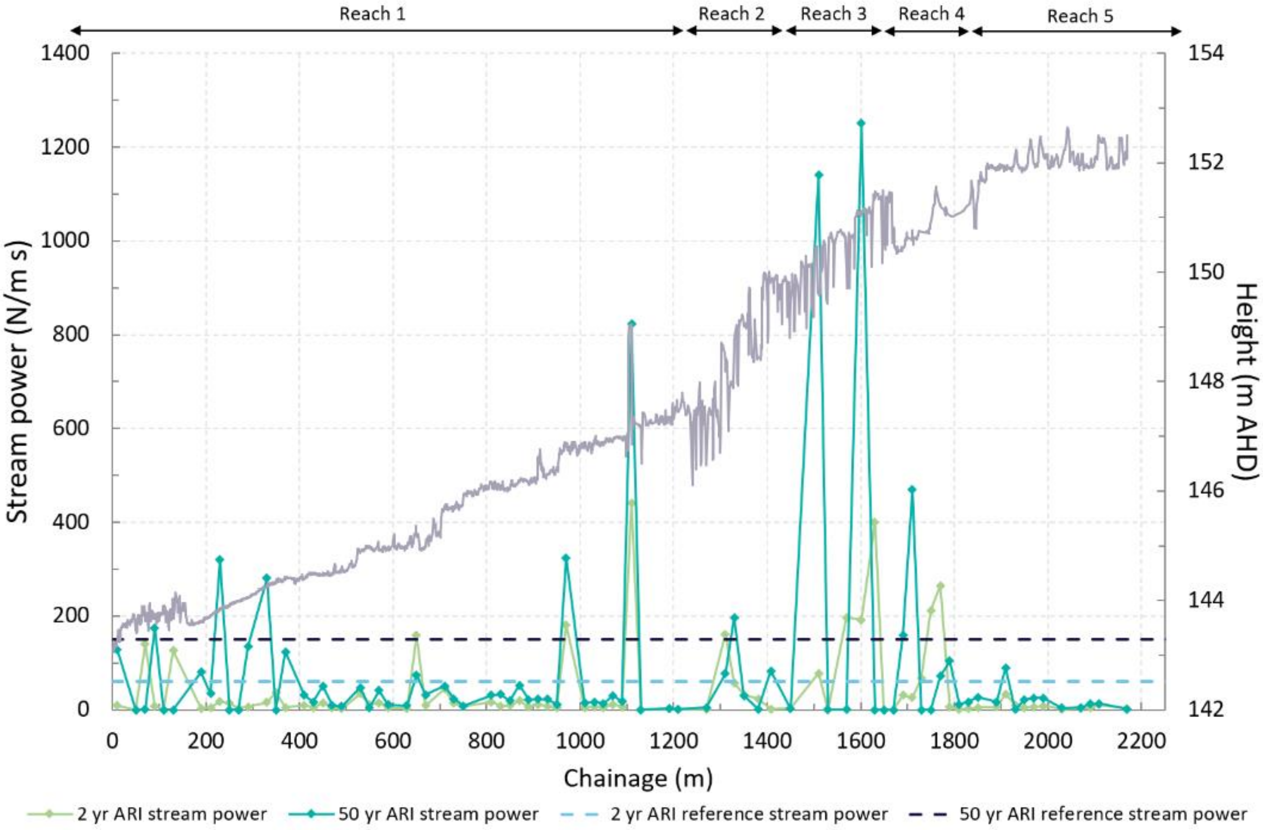
In waterways with specific stream power values below the reference values ongoing, limited rates of meander migration is likely and scour in flood events is likely in these systems. However, such scour will be short term and not result in broad scale changes in the stream systems. The use of the 2-year and 50-year ARI events is intended to capture the range of flow events and stream power encountered by the stream system.

5.3.3.1.1 Example stream power analysis

The results of an example stream power assessment for the 2- and 50-year ARI events are shown in Figure 40. The results show that for the existing channel conditions, during the 2- and 50-year event stream powers are mostly below reference conditions in sub-reaches 1 and 5, with some anomalies at various culverts. However, in sub-reaches 2, 3 and 4 the 2- and 50-year ARI stream power are above reference values for alluvial systems. The results indicate that reaches 2, 3 and 4, in the absence of structural controls, may experience ongoing accelerated channel instability.

The stream power analysis in concert with the bed grade analysis can be used to design an incised stream management program, that seeks to stabilise the system by establishing a stable bed grade and reference stream power (between grade control structures) and consistent with adjoining (upstream and downstream) reaches.

Figure 40. Stream power within an example study reach for the design flows. Showing 2-year and 50-year ARI reference stream power.



5.3.3.2 Shear stress analysis

Shear stress is the force exerted per unit area against the channel and floodplain boundary (i.e. land cover such as alluvial soil or native grass) by the action of water during flow events. Once a critical shear stress value (for sediment mobilisation) is reached the channel boundary material may begin to erode (mobilise). Shear stress is given by the following equation:

$$\tau\ (N/m^2) = (\rho g R S)$$

Where, ρ = density of water (kg/m^3)

g = acceleration due to gravity (m^2/s)

R = hydraulic radius – the ratio of the cross-sectional area of flow to the wetted perimeter (can be approximated by depth is some systems – see note below) (m)

S = energy slope (which can be approximated by bed slope of the channel) (m/m)

Note: Depth can be used an approximation for hydraulic radius is some systems, such as wide shallow channels. In entrenched (incised) systems, however, hydraulic radius should be use as the application of depth (in the above equation) can result in inaccurate shear stress estimations.

The critical shear stress at which mobilisation of the boundary layer occurs for various boundary layers is provided in Table 11. Shear stress outputs from hydraulic modelling can be compared with the critical shear stress threshold of the boundary layer at the study site to assess the likelihood of erosion, and the system trajectory.

Table 11. Shear stress thresholds for various boundary layers (adapted from Fischenich, 2001a).

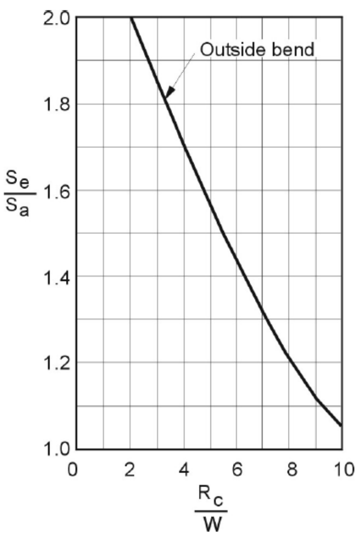
Boundary layer (land cover)	Shear stress threshold range (N/m^2)
Cohesive alluvial soil with occasional gravel	12-20
Sand (1mm)	1.44
Gravel (25 mm)	16
Gravel (50 mm)	32
Gravel (150 mm)	95
Jute mat (matting over soil)	22
Short native and bunch grass	34 – 45

Boundary layer (land cover)	Shear stress threshold range (N/m²)
Long native grasses	57 – 81
Coconut fibre with net	108
Mature trees, shrubs and grasses (structurally diverse vegetation)	80 – 120

One dimensional (1D) hydraulic models capture the impact of changes in successive channel cross-sections (such as channel constrictions) but are unable to model variation in flow across individual cross-sections. The inability to model changes in depth and velocity across a channel means that 1D models reproduce flow through meander bends poorly. Therefore, shear stress results extracted from one dimensional hydraulic modelling must be adjusted to account for the meander. This can be achieved by:

- Measuring the radius of curvature of the meander bend, where the radius of curvature is the radius of a circle that touches the channel centreline at the apex of the bend and at the ‘straight’ section of the channel at the entry to the bend.
- Measuring the base width of the channel.
- Extracting the average energy slope of the reach.
- Using the relationship shown in Figure 41 to estimate the effective energy slope on the outside of the meander bend.

Figure 41. Effect of channel bend on effective energy slope (Adapted from US Soil Conservation Service, 1971).



$\frac{S_e}{S_a}$ = Ratio of effective energy slope on the outside of a bend relative to the average energy slope for a reach

$\frac{R_c}{W}$ = Ratio of the radius of curvature of the channel centreline of the bend to the base width of the channel

5.4 Sediment budget analysis

5.4.1 Overview

Imbalances between sediment supply and sediment transport capacity can lead to degradation (incision) or aggradation of the streambed. This relation and the drivers of aggradation and degradation are captured conceptually by Lane's (1955) balance model (Figure 3). Sediment budgets are a quantitative tool used to predict whether a given reach or site will undergo degradation or aggradation, given some time period and flow regime.

A sediment budget analysis can be used at the reach scale to understand how the net volume of sediment stored in a reach is expected to change over time. The length of the reach for which a sediment budget is calculated depends on the scale of interest to the waterway manager, but sediment budgets are generally not suited to detailed site scale analysis, such as erosion and deposition around individual logs on the streambed. Waterway managers can use a sediment budget analysis to:

- Predict how changes in catchment sediment supply or flow regime may impact downstream reaches. For example, waterway managers can use a sediment budget analysis to build a geomorphic trajectory for a reach, to understand what will happen to a reach if the waterway manager does not intervene.
- Predict how physical disturbance of a waterway, such as sediment extraction or channel realignment, will impact downstream reaches. For example, the magnitude of erosion that can be expected in reaches downstream of a sediment extraction site.

A sediment budget analysis can be undertaken for any time interval and any spatial scale. Whether a sediment budget analysis is applied to a single event, annually or over decades will depend on the questions the analysis is intending to answer. In most applications, a sediment budget analysis will be used for timescale of years to decades. Constructing a sediment budget often involves detailed hydrologic, hydraulic and sediment transport modelling. Detailed instruction on how to perform each of these tasks is beyond the scope of the Guidelines and instead this section summarises the overall steps in the process. There are a variety of methods and combinations of software that can be used to construct a sediment budget, with each method more suited to a particular spatial or temporal scale. Two examples of more detailed and software-specific instructions on constructing sediment budgets are:

- Sediment Impact Analysis Methods (SIAM). Implemented in the open source1D hydraulic modelling software HEC-RAS.
- SedNet. A regional scale sediment budgeting tool available as part of the eWater toolkit. Software documentation can be found at: SedNet

5.4.2 Components of a sediment budget

Calculation of a sediment budget has three components:

- **Sediment inputs** include sediment delivered from the catchment, from upstream reaches, and sediment fed to the reach from tributaries that flow directly into the reach.
- **Sediment output** from the reach is controlled by the sediment transport capacity of the reach. Sediment transport capacity is discharge dependant, so as discharge fluctuates over time, so too does the expected volume of sediment that can be transported through the reach.
- **Sediment storage** is the net difference between sediment inputs and sediment outputs. Change in storage is:
  - Positive when the input of sediment is greater than the transport capacity of the reach. A positive change in sediment storage means sediment accumulates within the reach. For example, channel bed aggradation.
  - Negative when the transport capacity of a reach exceeds the sediment inputs. A negative change in storage means that all sediment supplied to the reach is transported downstream, and providing local erosion forces exceed resistance forces in the reach, sediment already within the reach is eroded and then also transported downstream.

  Calculation of the change in sediment storage in a reach is expressed via the equation:

$$Sediment\ input - sediment\ output = change\ in\ sediment\ storage$$

5.4.3 Define sediment reaches

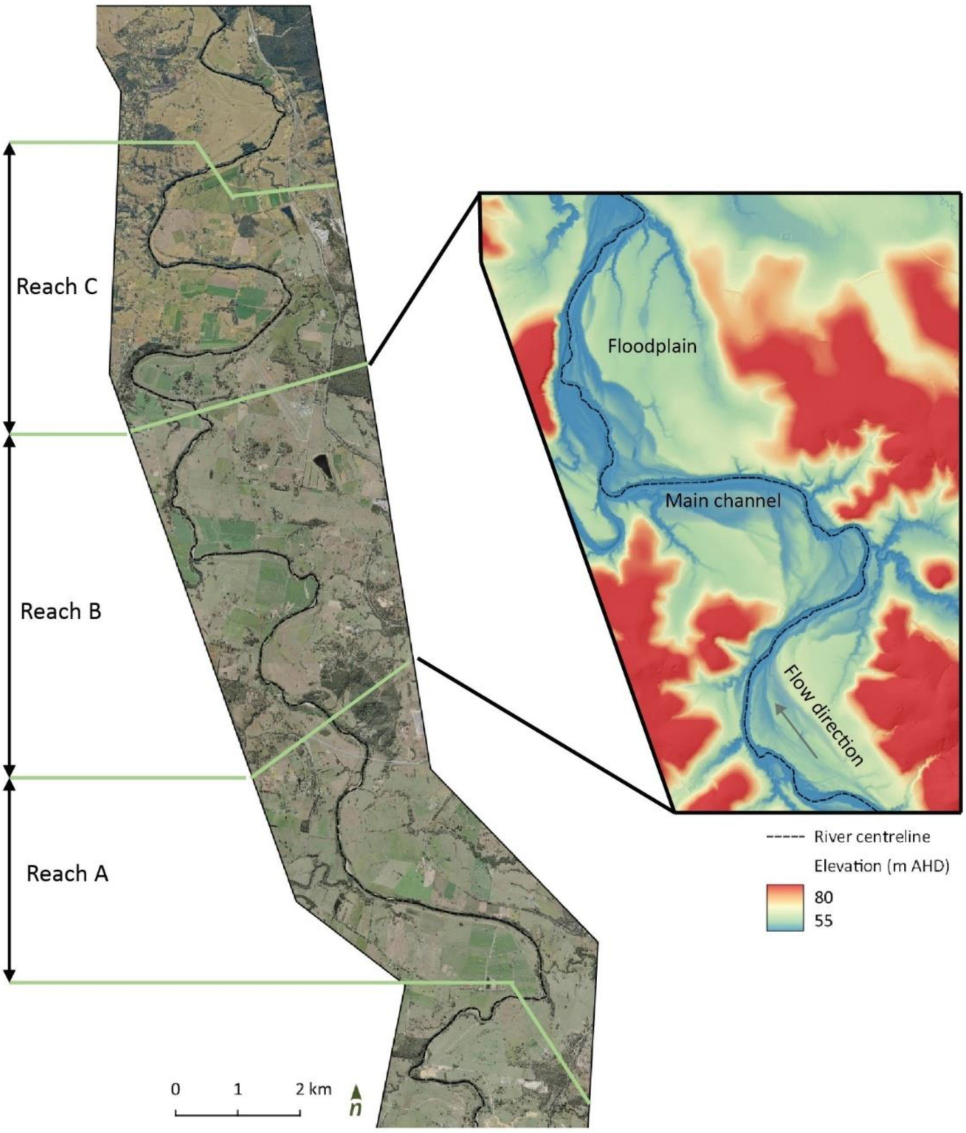
A sediment budget is best applied at the reach scale and as many reaches as needed can be defined. Sediment reaches are lengths of waterway with a relatively uniform channel planform, channel dimensions, geomorphic processes, and sediment transport capacity. The length of the sediment reach will be determined by the processes being investigated using a sediment budget. For example, changes in catchment flow regime may be investigated by defining relatively long sediment reaches because the interaction between reaches over long time periods is of most interest. Conversely, if waterway managers are using a sediment budget to understand how more localised modification of channel dimensions by direct intervention will influence aggradation or incision in the modified reach, sediment reaches may be relatively short. In defining sediment reaches, the aim is to segment the waterway into units that are expected to respond to changes in sediment supply in a relatively uniform manner.

Waterway managers can use available data to map sediment reaches, for example:

- High resolution elevation data such as LiDAR.
- Historic or contemporary aerial imagery or cadastral maps.
- Field observations of geomorphic processes shaping the reach or observed changes in the depth and distribution of sediment in a reach.

Often, there is no clear-cut distinction between sediment reaches and defining the boundary between reaches requires some subjective assessment. Overall, waterway managers should keep the ultimate goal of the sediment budget in mind when defining reaches, so that the output from the sediment budget is straightforward to interpret and at the most useful scale. An example of sediment reach definition is shown in Figure 42. The reaches were defined primarily based on the degree of channel confinement. The degree of channel impacts a channel’s ability to laterally adjust within contemporary timeframes. Reach A and C are partly confined by terraces, whereas Reach B is unconfined (the channel abuts floodplains).

Figure 42. Example sediment reach definition.



5.4.4 Catchment hydrology and sediment supply

Task two is to estimate the hydrology and sediment inputs for each reach. At a minimum, flow time series and sediment inputs must be defined for the most upstream reach, with each downstream reach receiving the sediment exported from the reach immediately upstream. Flow and sediment inputs from tributaries entering each reach are also defined during this step.

The resolution of the hydrology and sediment data input to the sediment budget will depend on the timescale being considered, and the types of data available. Estimating the sediment supplied to the most upstream reach can be especially challenging, and field measurements and long-term data records are seldom available. Waterway managers have several options when generating hydrology inputs, for example:

- Using measured discharge data from nearby gauge stations.
- Using hydrologic modelling to generate a time series of streamflow.

Generating estimates of sediment supply to the most upstream reach is often more challenging than generating hydrologic inputs, waterway managers can use one of the following methods to estimate sediment inputs:

- Using measurements of sediment transport rate, taken at a range of flows to construct a sediment rating curve (see step 3).
- Using sediment yield calculations, which relate land use or land cover in the upstream catchment to annual or seasonal sediment supply.
- Assuming that the sediment supply is infinite and use sediment transport modelling to estimate sediment inputs. This approach assumes that the transport capacity of the most upstream reach determines sediment inputs. This approach is often most appropriate when no data on sediment supply is available.

5.4.5 Reach sediment transport capacity

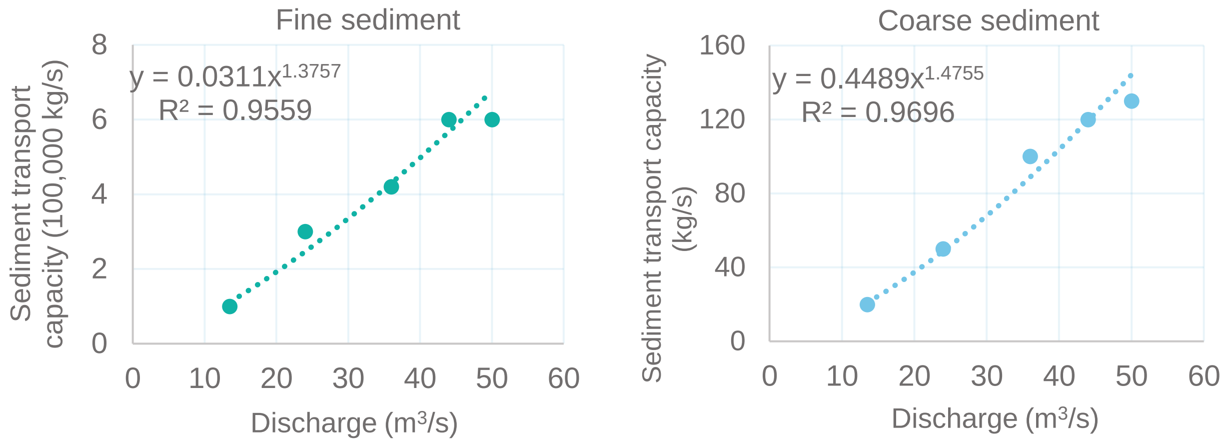
Task three is to estimate the sediment transport capacity of each reach for a range of flows and to construct a sediment transport rating curve for each reach.

The hydrologic, hydraulic and sediment transport modelling implemented in the sediment reaches will be determined by the scale and type of sediment transport processes of interest. For example, catchment scale sediment budgets may employ models that use the simplifying assumption of uniform channel hydraulics (for example, SedNet) while more detailed analyses of sediment movement through successive meander bends will employ 1D or 2D hydraulic models that accommodate such variations in geometry (for example, HEC-RAS or TUFLOW).

Sediment transport capacity is a theoretical (rather than a measured) value and is defined as the maximum volume (or mass) of sediment that can be transported by a waterway at a given discharge, per unit time (for example, the units can be expressed as kg/s, or T/yr). A range of sediment transport equations have been developed to estimate sediment transport capacity. Each of the widely available sediment transport equations were developed under, and should only be applied to, a specific set of flow and sediment conditions. For example, typically this includes a well-defined range of flow depths, flow velocities or using a particular size of sediment grains. The waterway manager and designers should select the sediment transport equation that was developed under conditions most similar to the waterway of interest. Where possible, field measurements of sediment transport can be used to calibrate the predictions output by sediment transport equations.

Estimates of sediment transport capacity are used to build a sediment rating curve, a relationship between discharge and sediment transport capacity (Figure 43). The waterway manager can then apply the sediment rating curve to the hydrology data and generate a time series of sediment transport. This time series of sediment transport also serves as a time series of sediment inputs for each reach downstream.

Figure 43. Example sediment rating curves completed for the fine and coarse sediment fractions of a reach (Alluvium, 2021).



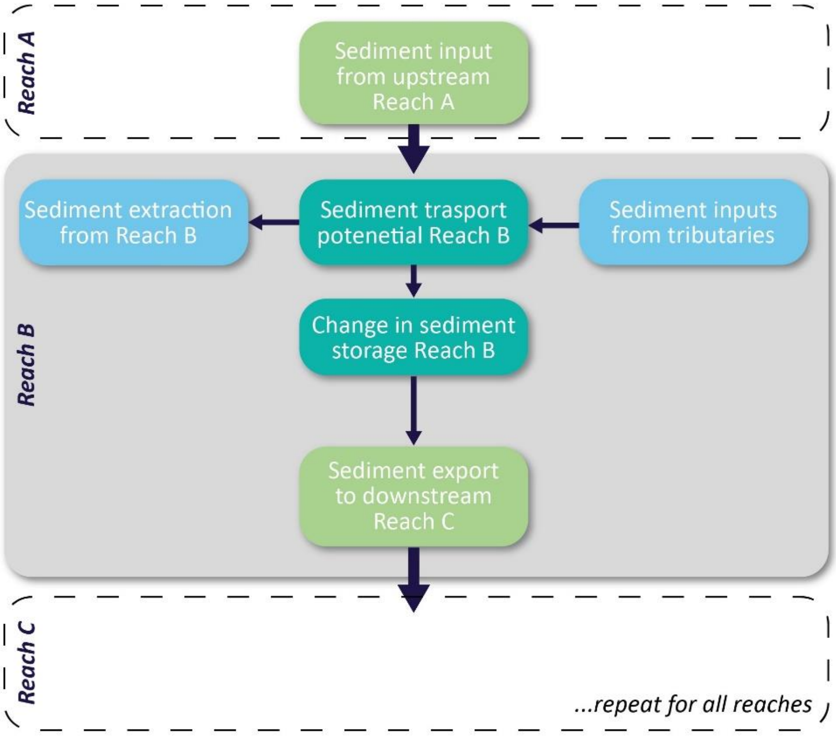
5.4.6 Calculate change in sediment storage

Task four is the calculation of change in sediment storage in each reach, for each timestep. With the sediment inputs and sediment transport potential (and therefore the sediment outputs) calculated for each timestep, for each reach in step 3, the change in sediment storage within a reach is calculated using the formula:

$$Sediment\ inputs - sediment\ outputs = change\ in\ sediment\ storage$$

The formula above is applied to each timestep. In each timestep, the change in sediment storage will either be positive (sediment accumulates in the reach), negative (sediment is removed from the reach) or zero. Change in sediment storage is calculated for each reach, and the outputs from one reach generate the sediment inputs to the next reach. The calculation of change in sediment storage and the linking of sediment reaches from upstream to downstream is shown in Figure 44.

Figure 44. Diagram illustrating how the sediment inputs and sediment outputs are used to calculate change in sediment storage in each reach.



The output of the sediment budget analysis can be used to predict how the volume (or mass) of sediment stored within a reach will change over time in response to changes in the wider catchment, and in upstream reaches. There are many ways to analyse the output of a sediment budget analyses. For example:

- Examining the year-to-year variation in sediment stored within a reach, which can help contextualise observed bed level changes.
- Predicting the longer-term consequences of management interventions that alter sediment inputs or change the sediment transport potential of a reach.

Estimates of change in sediment storage can be validated by comparing predicted changes in sediment storage (and bed level) to those captured by:

- Geomorphic change detection (see Section 5.4.6).
- Persistent changes in bed level recorded during successive inspections of infrastructure, such as bridges.
- Anecdotal observations.

6 Part 6 – Design aids

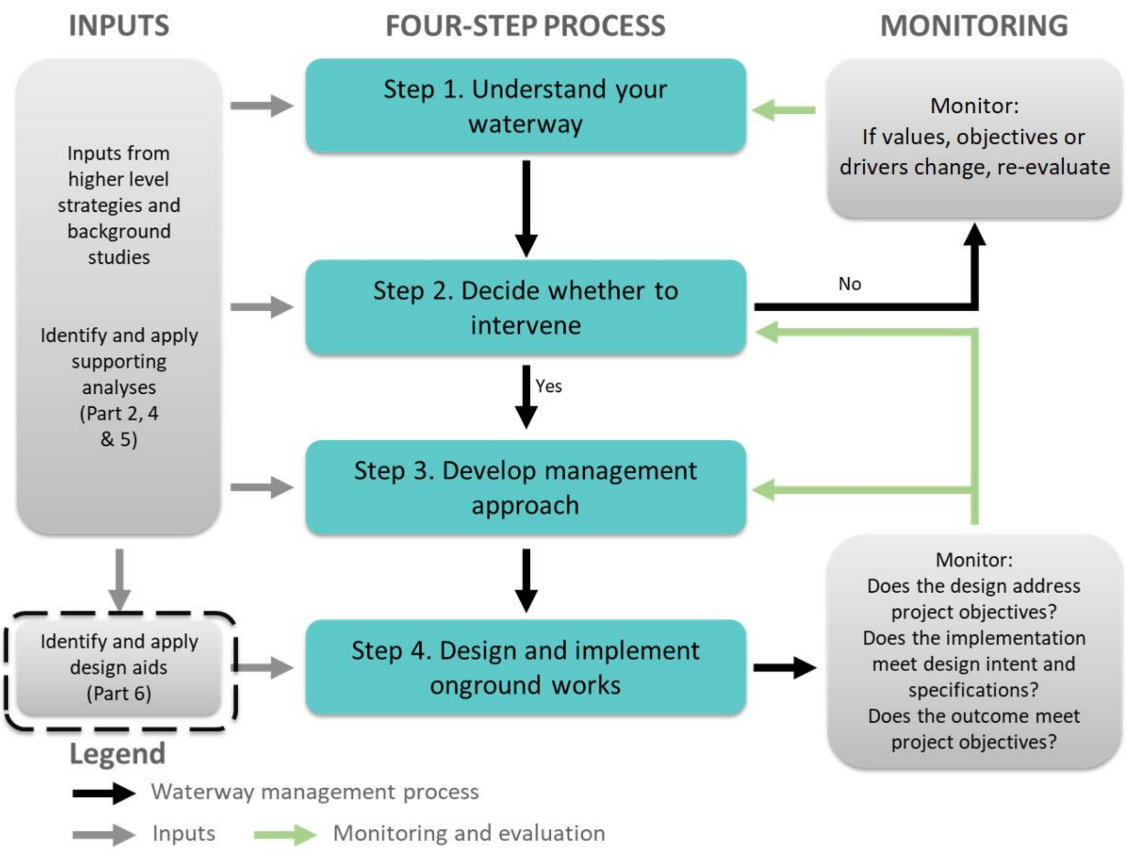
6.1 Introduction

This section of the Guidelines provides access to design aids that may assist with the design of a selection of waterway management techniques. Included in this section are design approaches for reach scale programs and more discrete individual projects.

The identification and application of the design aids is highlighted in the four-step process (Figure 45), which extends across Step 4 and is to be used to help guide the design of intervention options to enable construction.

Reference to the design aids and their applicability to the management options is included in section 3.6, Table 4- Table 7.

Figure 45. Design aids input into the four-step process.



The design aids outlined in this section have been categorised as follows:

- Vegetation
  - Section 6.2: Riparian buffer width determination for geomorphic stability.
  - Section 6.3: Willow transition methodology.
  - Section 6.4: Probabilistic failure analysis.

- Wood structures
  - Section 6.5: Pile field groyne design.
  - Section 6.6: Wood stability analysis.
- Rock structures
  - Section 6.7: Rock chute design
  - Section 6.8: Rock beaching design.
  - Section 6.9: Method for estimating rock size and grading.
- Scour depth estimation
  - Section 6.10: Scour depth estimation.

This part also includes a materials selection guide Section 6.11 to provide waterway managers with access to information that may assist with the selection and use of materials employed in the design and implementation of waterway management projects.

A selection of software design tools that may assist with the design of activities and works is provided in the Table 12. This selection is not a complete listing. Alternate software tools may be available and be more suited to the individual program or project. It is the responsibility of the waterway manager to assess the validity and usefulness of software and design tools for their intended purpose.

Table 12. Selection of available software design tools

Category	Design aid	Description	Supplier	Web site
Hydrologic modelling	RORB	Industry Standard event based hydrologic software	Monash University	RORB
Hydrologic modelling	RAFTS	Event based hydrologic software	XP Software	Innovyze
Hydrologic modelling	AWBM/ MUSIC	Time series hydrologic software	CRC for Catchment Hydrology/ eWater	eWater Toolkit
Hydrologic modelling	Source	Time series hydrologic software	CRC for Catchment Hydrology/ eWater	Source - public version

Category	Design aid	Description	Supplier	Web site
Hydraulic modelling	HEC-RAS	Industry Standard hydraulic modelling software	US Army Corps of Engineers	Hydrologic Engineering Center
Hydraulic modelling	TUFLOW	Industry Standard hydraulic modelling software	BMT Commercial Australia Pty Ltd	TUFLOW
Rock beaching design/sizing	CHUTE	Software for the design of rock chute style grade control structures and fish ladders	eWater	CHUTE
Rock beaching design/sizing	RIPRAP	Software for the design of rock riprap beaching	eWater	RIPRAP
Rock beaching design/sizing	HEC-RAS	Industry Standard hydraulic modelling software	US Army Corps of Engineers	Hydrologic Engineering Center
Rock beaching design/sizing	TUFLOW	Industry Standard hydraulic modelling software	BMT Commercial Australia Pty Ltd	TUFLOW
Sediment transport	HEC-RAS	Reach-based hydraulic analysis of sediment transport capacity	US Army Corps of Engineers	Hydrologic Engineering Center

Category	Design aid	Description	Supplier	Web site
Sediment transport	SedNet	Catchment based sediment source and transport analysis	eWater	SedNet
Flow statistical analysis	RAP	Hydrologic and hydraulic viewing, manipulation and interrogation software	eWater	RAP
Flow statistical analysis	FLIKE	Flood frequency analysis toolkit	BMT Commercial Australia Pty Ltd	FLIKE

6.2 Riparian buffer width analysis

6.2.1 Overview

Management practices in Australia such as land clearing, removal of riparian vegetation, and uncontrolled grazing (that limits reestablishment of vegetation) has resulted in ongoing degradation of riparian lands and accelerated rates of waterway erosion (Figure 46).

Riparian vegetation is critical to the healthy ecological functioning of waterways (Rios and Bailey, 2006; Ghermandi *et al.*, 2009; Vidon *et al.*, 2010). Riparian vegetation provides several ecosystem functions such as improving:

- Physical form (incision stages 3-4 and channel meandering).
- Water quality.
- Carbon sequestration.
- Terrestrial and aquatic biodiversity.

Figure 46. Examples of poor quality riparian vegetation (left) and good quality riparian vegetation (right).

6.2.2 Riparian buffer width based on management objectives

The width of the structurally diverse vegetation should be sufficient to provide resistance of the channel boundaries (bed and banks) against erosion forces through time. The width of the vegetation buffer should be sufficient to meet the requirements sought from the vegetation into the future, based on expected rates of channel migration.

6.2.3 Riparian buffer width analysis for geomorphic stability

An approach to riparian buffer width analysis approach (for geomorphic stability) is outlined in *Guidelines for stabilising stream banks with riparian vegetation* (Abernethy and Rutherfurd, 1999). The approach in this section is formed around the Abernethy and Rutherfurd 1999 method and is based on assessing expected bank migration/erosion during the vegetation establishment phase (Establishment Allowance Zone) and then ensuring sufficient structurally diverse vegetation remains to provide ongoing resistance against erosion forces and meets any other demands sought from that vegetation into the future.

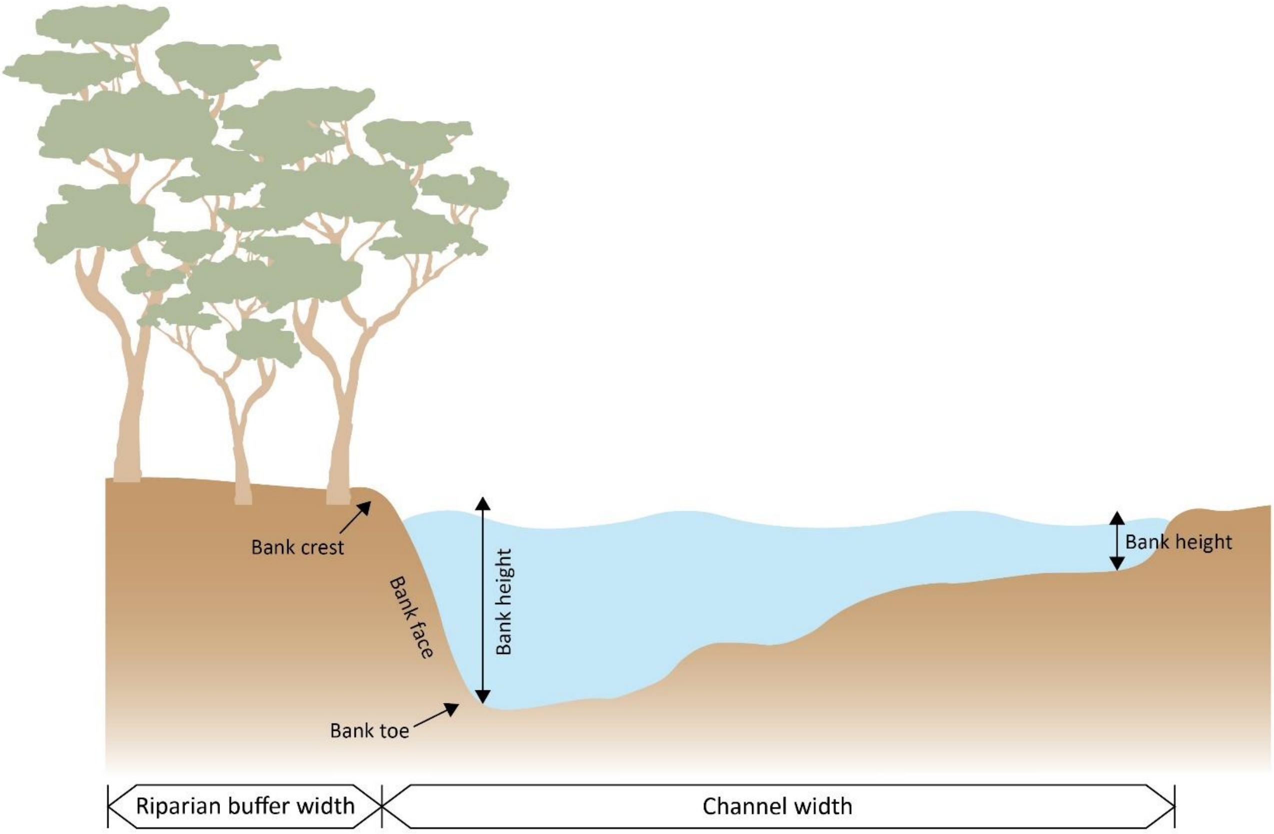
This analysis outlines the recommended minimum riparian erosion control buffer width to achieve long term stability. This analysis does not include allowance for additional objectives such as ecology, water quality or Crown frontage management. Where required, the buffer width should be adjusted to meet any additional objectives. In cases where there are multiple management objectives (e.g. geomorphic stability and water quality improvement) the larger of the recommended buffer widths should be applied.

The riparian buffer width for geomorphic stability is defined as “the minimum width of riparian forest required for ongoing bank stability. It is measured from the bank crest away from the channel. The minimum width of riparian land varies with bank height and bank erosion rate” (Abernethy and Rutherfurd 1999) (Figure 47).

The riparian buffer width for geomorphic stability is determined based on Abernethy and Rutherfurd (1999):

Riparian buffer width = bank height (m) + bank erosion/mitigation over establishment phase (m) + ongoing riparian buffer width required to maintain a suitable structurally diverse vegetation community (m)

Figure 47. Riparian land feature description (from Abernethy and Rutherfurd, 1999).



The four tasks towards calculating the riparian buffer width for geomorphic stability are:

1. Define the suitable riparian buffer width to sustain a structurally diverse suite of vegetation.
2. Determine the time required to establish a structurally diverse suite of vegetation.
3. Estimate the erosion/migration rate using repeat aerial photography, LiDAR or method outlined in Section 5.2.
4. Calculate the riparian buffer width for geomorphic stability.

6.2.3.1 Task 1: Define the suitable riparian buffer width to sustain a structurally diverse suite of vegetation

A sufficient buffer of structurally diverse vegetation is required to provide ongoing resistance against erosion forces. The width of the vegetation buffer should be sufficient to meet the erosion resistance requirements sought from the vegetation into the future, based on expected rates of channel migration. This buffer width does not consider other management objectives such as water quality and terrestrial habitat. Additional width will be required to meet additional management objectives.

To achieve this the planting buffer width needs to be wide enough to provide for a diverse range of understory, mid and canopy species. A range of species should be selected to shield the soil from moving water, provide structural reinforcement to the soil and to reduce the velocity of the moving water. In addition, the vegetation should be selected to meet complementary biodiversity outcomes. Species selected for revegetation should be informed by the site's bioregion (suggested source: local vegetation records from the DEECA NatureKit).

There are a number of methods available to help guide waterway managers in choosing a suitable riparian buffer width. Waterway managers should review these guides and select a method most appropriate to the project setting and objectives for management. A selection of these guides include:

- Guidelines for stabilising stream banks with riparian vegetation. Abernethy and Rutherfurd (1999)
- Riparian Setback Widths: A review of recommendations for guidelines (Ecology Australia, 2018) – refer to section 6.2.
- Waterway Corridors. Guidelines for greenfield development areas within the Port Phillip and Western Port Region (Melbourne Water, 2013).
- Minimum width requirements of riparian zones to protection flowing waters and to conserve biodiversity: a review and recommendations (Hansen B.D., Reich P., Lake P.S., Cavagnaro T., 2010)

6.2.3.2 Task 2: Determine the time required to establish a suitable riparian vegetation community

Success of the revegetation program is dependent on the time required to reach a suitable vegetation maturity (to withstand erosive forces) and the likelihood for flow events to scour vegetation within this period. Rapid vegetation establishment reduces the risk of scour during the vegetation establishment phase. Thus, the duration of the vegetation establishment phase, and potential for scour during this period, needs to be considered.

Abernethy and Rutherfurd (1999), suggest plantations in the wet tropics can reach maturity within ten years, but this could take up to 50 years in drier areas. The adopted vegetation establishment period is not necessarily linked to full maturity, but at which point vegetation provides resistance to erosion, which can also be informed by review of previous revegetation programmes in the region (using multi-temporal aerial imagery analysis – see Section 5.2.3).

An example 10-year establishment timeline, based on a shrubby woodland vegetation community, is outlined below:

1. Initial plantings of the disturbed bank areas should be planted at 2-4 grasses/sedges per m^2 with 1 bank shrub per 4 m^2. The grasses are expected to establish and provide a uniform cover within 3 years at which they will provide moderate resistance to erosion.
2. The shrubs and trees will begin to compete with the grasses from the 3rd year and should begin to dominate the vegetated riparian land by year 5.
3. The trees and shrubs will dominate the vegetated riparian land by year 10 with spaces for natural regeneration in the ground-layer developing as they shade out the initial grass layer.

The success of the establishment period will be dependent on climate conditions and weed control support for the establishing shrubs and trees, which needs to be provided to enable them to develop and stabilise the site. Without ongoing weed management and substitute planting the vegetation establishment period would be expected to extend beyond 10 years.

6.2.3.3 Task 3: Estimate the erosion/migration rate

The width of the final riparian buffer is dependent on the historic rate of bank migration/erosion. Until the vegetation is suitably established to withstand expected erosive forces for the subject reach the bank will continue to migrate. Historic migration rates can be identified using either multi-temporal aerial imagery analysis (Section 5.2.3), repeat LiDAR analysis (Section 5.2.4) or the method outlined within the Abernethy and Rutherfurd (1999) (see below).

> Abernathy and Rutherfurd (1999) suggests **yearly erosion rates can be estimated to be 1.6% of the stream width**, where existing evidence is insufficient to measure site-specific rates. This is the median value from an unpublished dataset of 100 waterways.

6.2.3.4 Task 4. Calculate the riparian buffer width for geomorphic stability

The total riparian buffer width for geomorphic stability is calculated as:

> Width = bank height (m) + bank erosion/mitigation over establishment phase (m) + ongoing riparian buffer width required to maintain a suitable structurally diverse vegetation community (m)

6.2.4 Additional considerations

Geomorphic stability is just one consideration of for determining a suitable a riparian buffer width. Considering the objectives of the project and the funding source requirements for riparian works, the final total riparian buffer width may be larger than that calculated in section 6.2.3 above. The total width should be the larger of:

- The buffer width riparian buffer width for geomorphic stability, calculated above.
- The buffer widths for other relevant management objectives, outlined in Section 6.2.3.1.

Additional considerations also include:

- A fencing strategy should be developed to maintain the required buffer distance from the bank crest.
- The *Victorian Waterway Management Strategy* (Policy 9.7) outlines requirements for the management of fence riparian land when the Victorian Government contributes to the costs of fencing and revegetation:
  - Riparian land fenced for riparian management purposes will aim to be at least 20 metres wide on average from the top of the bank and must not be narrower than 10 metres in any one place.
  - With an exception, riparian land fenced for riparian management purposes on dairy farms will not be less than 10 metres wide on average from the top of the bank. It is recognised that setbacks less than 10 metres may be required in some circumstances for practical purposes (e.g. bends in the waterway, placement of strainers, paddock design, obstructions from existing vegetation, etc.).
- The final revegetated riparian width and subsequent fencing alignment should be developed in consultation with landholders and where possible adjusted to maximise environmental benefits while considering benefits to the landholders (e.g. riparian shelter and improved stock health). Refer to the DEECA Benefits of riparian land to landholders webpage (DEECA, 2023) https://www.water.vic.gov.au/waterways/riparian-land/benefits-of-riparian-land-to-landholders).

6.3 Willow transition methodology

6.3.1 Overview

Most types of willows in Victoria are considered Weeds of National Significance (WoNS) (DPI, 2007a) and are recognised as one of the most serious riparian weeds in Australia. Willows were originally planted along waterways for erosion control and aesthetic purposes but have since spread and now cover thousands of kilometres of riparian land in south east Australia (DELWP, 2016b). Willows impact waterways by:

- Blocking waterways and initiating erosion via outflanking resulting in channel widening.
- Competing with native vegetation.

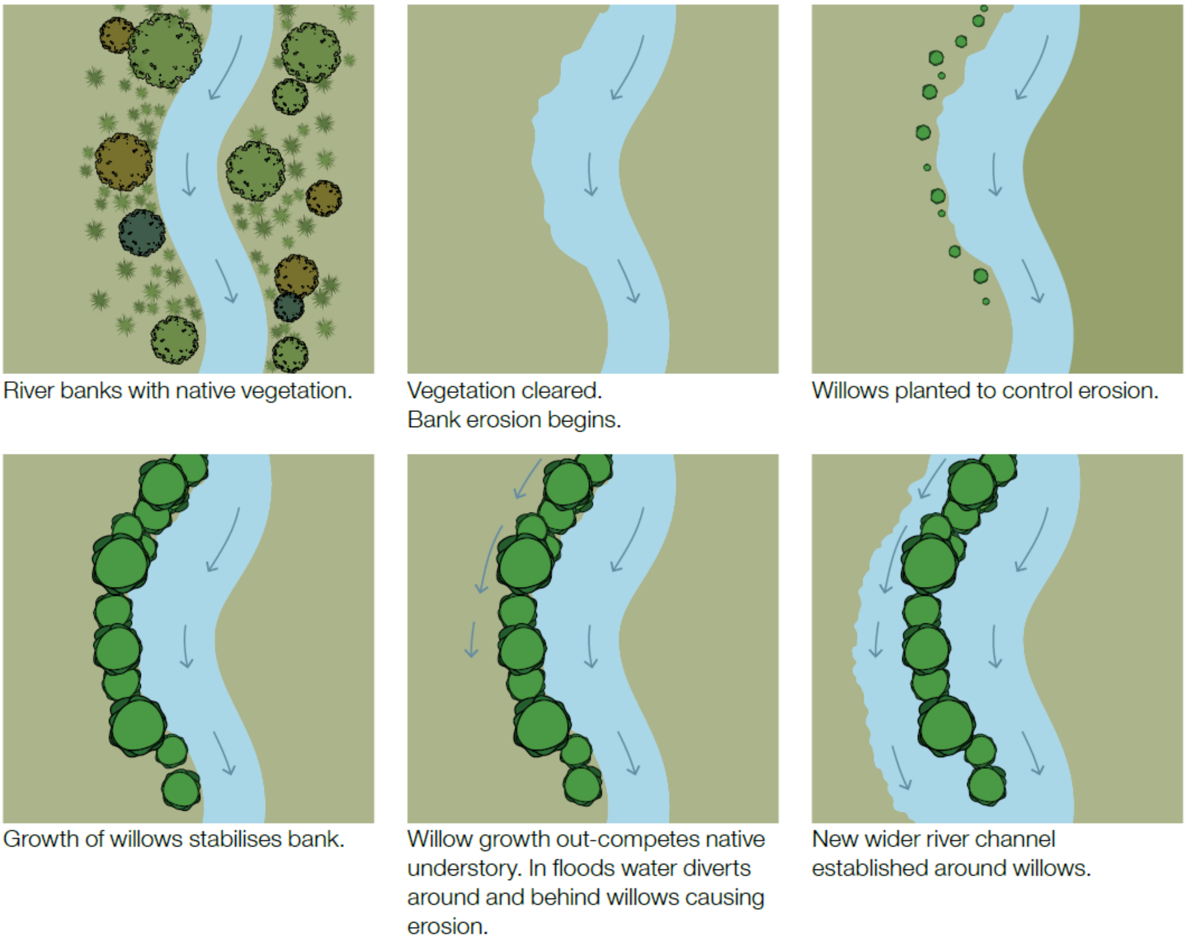
- Reducing supply of habitat and food for fish.
- Consuming large amounts of water.
- Obstructing waterway recreation e.g. obstructing watercraft and access to the waterway.
- Threatening public infrastructure.

Although willows provide temporary erosional stability to a riverbank, over time, they can encroach into the centre of a waterway, forcing water laterally (Figure 48). Silt and debris will gather around the dense roots of the willows, with waterways tending to become wider and shallower, with reduced capacity.

Figure 48. Willows growing in the centre of the East Barwon River channel (Alluvium, 2019b).

Increased lateral erosion and flooding can cause channel avulsion or altered courses of the channel to develop. Along a narrow waterway, willows can cause shallow, braided channels to develop with a series of mid-stream islands. This process is described further in DPI (2007a) and Figure 49 below.

Figure 49. Impacts of willows on Australian waterways (Adapted by NECMA from DPI, 2007a).



6.3.2 Willow management principles

Principles for willow management can be based on those set out in 'Managing invasive riparian weeds in Victoria – Willows (DELWP, 2016b), including:

- Managing willows as part of a broader waterway health program.
- Setting priorities at the regional level. These priorities include:
  - First priority: Protecting intact vegetation communities from willow colonisation.
  - Second priority: Prevent the spread of highly invasive species and in particular seeding species including black willow and pussy willow.
  - Third priority: Prevent the spread of highly brittle willow species including crack willow.
- A successful approach to the transition of willow dominated waterways to waterways supported by structurally diverse native vegetation follows.

Note: The management of willows should consider the context and location of willows such as rural, urban and proximity to public infrastructure. This may include consideration of where willows are cut and stump poisoned (i.e. willow removed) or poison and leave (willows breakdown in place). While poison and cut are the preferred approach and helps to manage risk of debris blockages and falling limbs (such as in urban areas and adjacent to public infrastructure), poison and leave may be appropriate in headwater or forested streams where decaying willows pose minimal safety risk.

6.3.3 Willow transition management

Complete removal of willows without careful management can leave banks exposed to flood flows, causing bank erosion and other instabilities. Complete removal of willow without careful consideration and management of resultant willow debris can lead to subsequent downstream willow debris blockages. Therefore, willow management programs should be undertaken in a cautious and coordinated manner to avoid initiating channel instability, protect banks from accelerated erosion, manage willow debris and establish revegetated native riparian land. An approach for willow replacement, management of willow debris and bank stabilisation, that has been successfully applied within Victoria, is detailed in Figure 49. Such a phased willow removal program is illustrated in Figure 51.

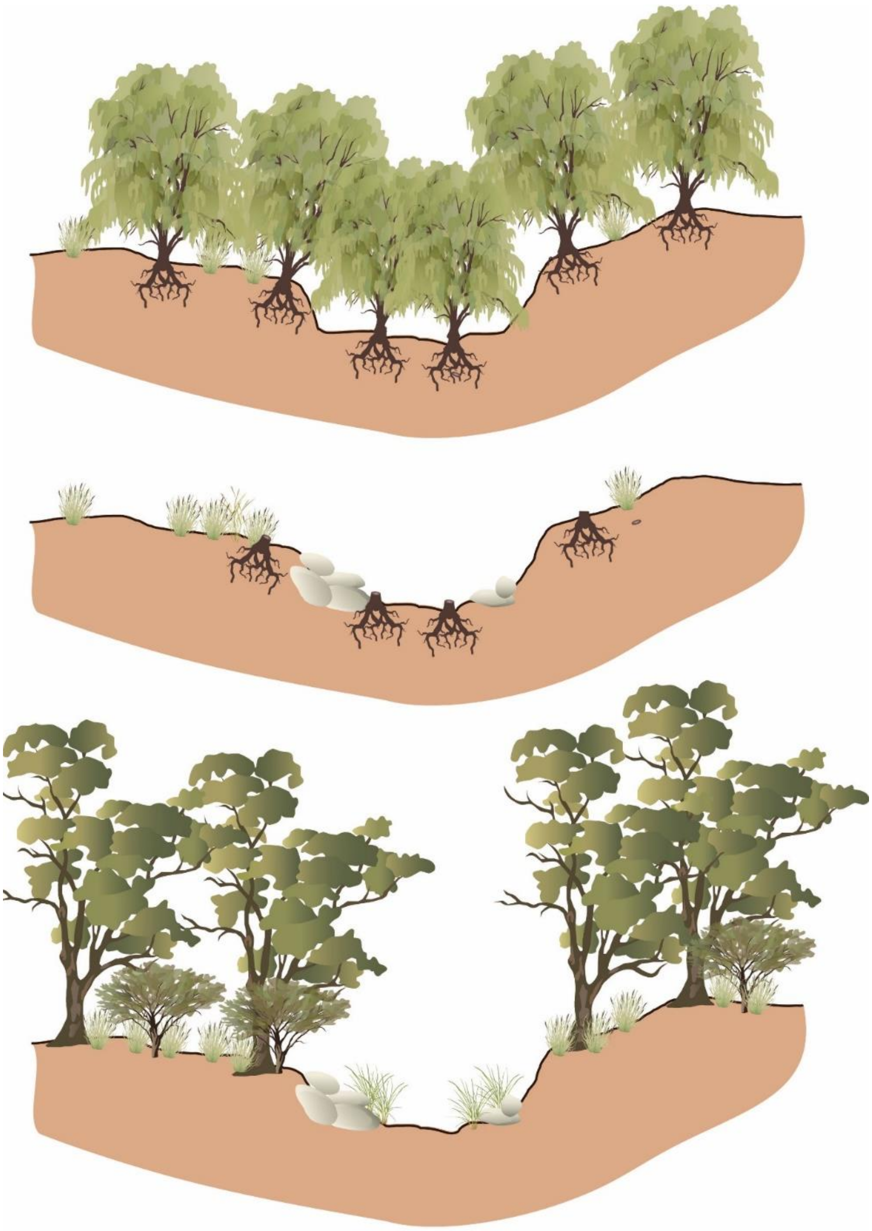
Figure 50. Approach for approach for willow replacement, management of willow debris and bank stabilisation.

Undertake willow removal in a downstream direction if possible. Stage works to prevent extended length of waterway without shade. Poison willow prior to any physical works to limit spread of live/viable material.

Mechanically remove poisoned willow, retain willow roots on *banks* to assist with riverbank protection. Remove willow roots from the channel *bed* if and as necessary to meet management objectives. Stockpile willow debris out of the channel for subsequent disposal e.g. bio char.
Provide additional structural protection of riverbanks, where required (subject to further analysis and design). Structural protection could include rock beaching and/or pile fields and include revegetation with native rhizomatous littoral and aquatic species, and/or smaller shrubs (e.g. *Leptospermum*, *Melaleuca*, *Callistemon*[2]) which can provide a soil stabilising root structure without the tendency to colonise and then block the channel bed.
Secure riparian land from stock access. Undertake additional revegetation activities including weed control and native vegetation tube stock planting on riverbanks and adjoining floodplain within 12 months of willow removal.
Willow removal sites to be maintained in an effective willow free condition via intense site-based management and broader scale willow maintenance program. Activities include maintenance of stock management, weed control and vegetation replacements as required.

[2] If consistent with the appropriate EVC for that site.

Figure 51. Phased willow management program.



6.4 Probabilistic failure analysis for vegetation loss

The probabilistic failure analysis is an approach that can be used to assess the likelihood of scour that could cause the loss of revegetation efforts during the critical vegetation establishment phase. The analysis is based on the critical shear stress for the mobilisation of riverbank material in the critical period between exposure of bare banks (e.g. willow removal) and native vegetation establishment.

Quantitative analysis of bank erosion processes is an area of active research and the likelihood of vegetation establishing on a given reach is subject to uncertainty. This probabilistic failure analysis outlined here is a tool waterway managers can use to address some of that uncertainty and to better understand the scale of work that may be required to aid vegetation establishment.

6.4.1 Overview

A probabilistic failure analysis can be used by waterway managers in two ways:

- To estimate the likelihood of vegetation successfully establishing at a site.
- To identify the type and scale of supporting structural works required to provide an acceptable likelihood of vegetation establishing at a site.

At its core, the probabilistic failure analysis relies on quantifying erosive forces (shear stress caused by streamflow) and resistance forces (provided by the bed and bank sediment and by vegetation) and how the balance between these forces changes as vegetation establishes, or as discharge varies. Users define a success criterion (e.g. a minimum probability of 80% that establishing vegetation will not be destroyed by high flows over a defined period of time) and then use the method to identify parts of a reach or site where this criteria is/is not met, and the scale of works required for this criteria to be met (e.g. whether rock beaching or pile fields are required to protect establishing vegetation).

This quantitative approach to the planning and design of on-ground interventions assesses the probability that fluvial scour will destroy vegetation on the banks or floodplain. The method does not account for other bank failure mechanisms, such as undercutting of the bank toe by incision. Although this approach only considers fluvial scour, it has several advantages:

- Flow forces are explicitly calculated using either 1D or 2D hydraulic modelling, and resistance forces are estimated based on sediment properties or vegetation type and age. As hydraulic modelling capabilities increase, and the type of sediment and vegetation along waterways is better understood, the method can be used with increasing confidence.
- In using the notion of probability, the method accounts for the inherent uncertainty of waterway discharge and the geomorphic processes of fluvial scour, sediment transport and channel change.
- The analysis is flexible and can be used to plan where within a reach an intervention will be most effective, the scale and type of works required to prevent erosion with an acceptable level of confidence, and to compare different intervention options.

The method requires four inputs, which can be calculated or replaced with assumptions. The inputs are:

- A clearly defined success criterion. For example, an 80% probability that establishing vegetation will not be destroyed by a flood over the vegetation establishment phase e.g. the next 10 years.
- Measurements or estimates of both the magnitude and frequency of flow events. For example, the magnitude (m^3/s or ML/Day) of the 50%, 20%, 10% 5% 2% and 1% AEP discharge events.

- Estimates of the magnitude and distribution of the bed shear stress generated by the defined flow events. For example, 1D or 2D hydraulic modelling can be used to estimate the peak bed shear stress (N/m^2) flow exerts on the channel banks during each of the defined flow events, and how this peak shear stress varies along a reach or across a channel.
- Measurements or assumptions about the erosion resistance of the channel bed, bank or the floodplain. For example, published studies (such as Fischenich, C., 2001a) can be used to predict the resistance (also measured in N/m^2) provided by sediment of different size, by different types of vegetation, or by vegetation at different stages of establishment. Note that published estimates of erosion resistance of bed, bank and floodplain material are highly variable and often have high uncertainty.

The probabilistic failure analysis has five steps, which are outlined below:

6.4.2 Task 1: Define success criteria

A success criterion defines the minimum likelihood of vegetation establishment acceptable to waterway managers or project stakeholders. For example, the waterway manager may be unwilling to invest in revegetation of a site if that vegetation has less than an 80% probability of successful establishing within ten years, or if the structural works required to increase the probability of successfully vegetation establishment above 80% are too great. Defining a success criterion may be an interactive process, in which the waterway manager:

1. Defines a success criterion.
2. Moves through the remaining steps and identifies the scale and cost of any structural works required to support vegetation establishment.
3. Evaluates the scale and cost of works against the project objectives and project resources.
4. If necessary, re-evaluates the success criteria in light of the above, either accepting a lower probability of success for the project, expanding the level of investment to support vegetation establishment at the site (erosion control), or choosing not to invest at the site.

6.4.3 Task 2: Determine the magnitude of flow events

Large flow events are more likely to generate bed shear stress that undermines establishing vegetation. This step calculates the peak discharge (m^3/s or ML/Day) for a range of increasingly rare flow events, expressed as the event’s Annual Exceedance Probability (AEP). Peak discharges can be calculated using:

- Flood frequency analysis applied to flow records from nearby gauges
- Hydrological modelling

The waterway manager should ensure that the full range of flows likely to be experienced at the site are calculated. The greater the number of flow evens modelled, the more accurate the final probability calculations. Peak discharges are commonly calculated for the 50%, 20%, 10%, 5%, 2% and 1% AEP events.

6.4.4 Task 3: Hydraulic modelling

Hydraulic modelling is used to estimate the erosive forces (bed shear stress – N/m^2) for each flow event. The aim of this step is to estimate the peak bed shear stress generated by each flow event, so that those bed shear stress values can be compared to shear resistance values in task four.

Hydraulic modelling can be either 1D, in which case each channel cross-section will be assigned a single value of bed shear stress, or 2D, in which case each cell in the model will be assigned a single value of bed shear stress (refer to Section 5.3.3.2 for guidance). The choice between 1D, 2D or some combination of the two approaches will depend on:

- The topographic and bathymetric elevation data available
- The level of spatial detail required, whether that be at the reach or site scale

6.4.5 Task 4: Shear resistance

The resistance provided by sediment and vegetation is quantified by shear resistance, also measured in N/m^2. The presence of silt and clay in the channel bed or banks, which provides cohesion, increases the resistance provided by sediment. Instream and riparian vegetation both increase shear resistance and decrease erosive forces via three mechanisms:

1. Increasing roughness, which decreases flow velocity and erosive power.
2. Increasing the strength of the sediment via a network of plant roots.
3. By shielding the bed and banks from fluvial scour.

Because vegetation can increase roughness and reduce erosion forces, hydraulic modelling undertaken in step three may need to be adapted to include this effect through modification of roughness parameters (e.g. manning's roughness coefficient (n)).

Different vegetation types will increase resistance via the above three mechanisms in different ways. For example, short dense shrubs with a dense network of fibrous roots will increase bank strength to a greater degree than shallow, sparse root systems, while tall dense stands of emergent vegetation will increase roughness (and reduce bed shear stress) to a greater degree than the widely spaced stems of establishing seedlings. For this reason, a structurally diverse, mosaic of vegetation that includes ground cover, mid-storey and canopy vegetation will ultimately prove to be most robust in the long term.

Vegetation is most vulnerable during the establishment phase, which is in the order of ten years (assuming supporting maintenance such as weed and pest management). Once established, vegetation enters the maintenance phase and erosion resistance is maximised. Typical shear resistance values provided by establishing vegetation, with and without vegetation maintenance, are provided in Table 13 (based on Fischenich, C., 2001a).

Shear resistance values are directly compared with bed shear stress values. Therefore, shear resistance values are defined for each year post-planting, for each cross-section in the case of 1D hydraulic modelling, and for each model cell when 2D hydraulic modelling is used.

Table 13. Example shear resistance values and the number of years before values are attained with and without vegetation maintenance for a riparian revegetation program.

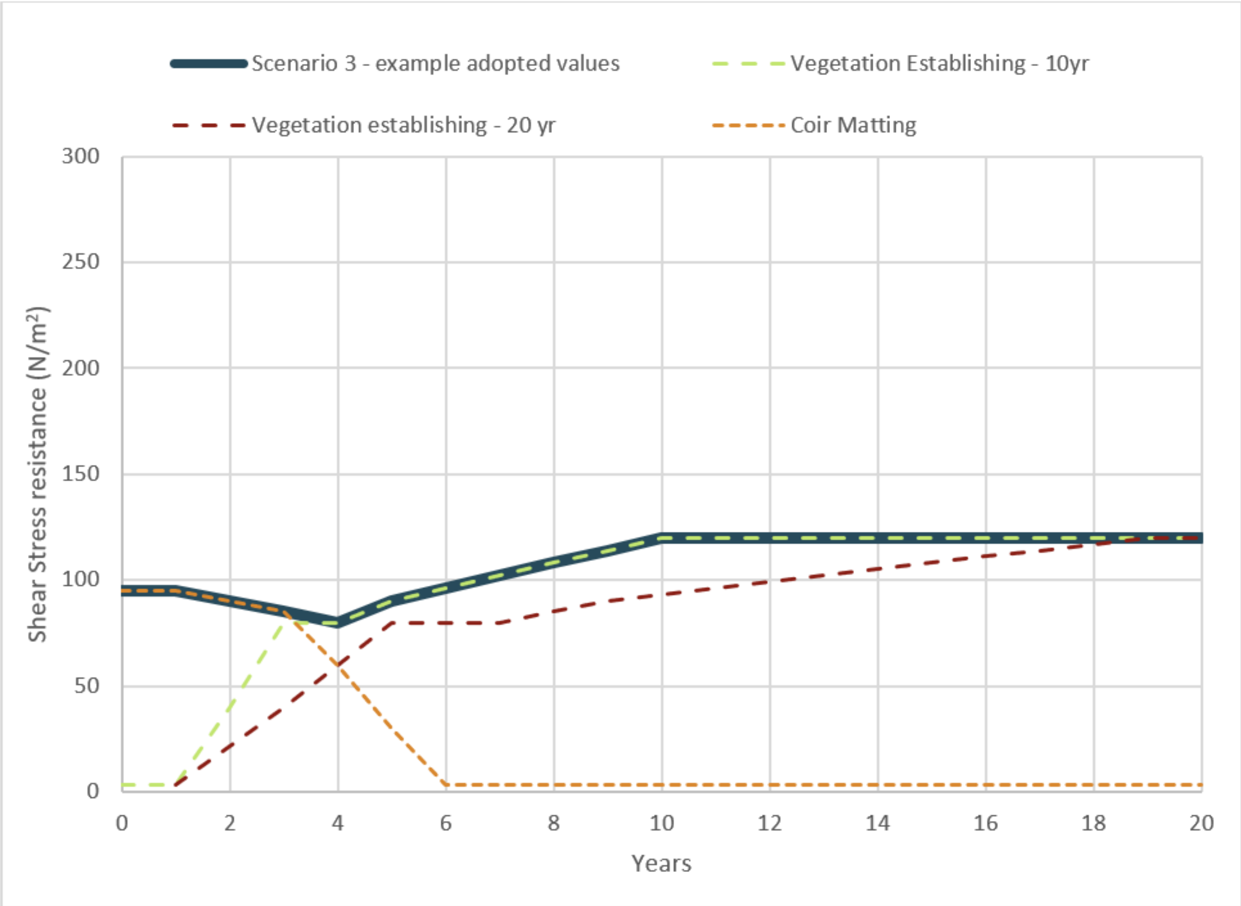
Shear stress threshold (N/m^2)	Year achieved (No maintenance)	Year achieved (with maintenance)	Comment
2 – 3.6	1	1	Soil shear stress resistance (firm loam)
20 – 30	3	2	Ground covers established (sterile rye)
30 – 45	5	3	Short and long native grasses establishing, rye grass dying
45 – 80	7	4	Short and long native grasses established and some shrubs establishing
58 – 90	9	5	Short and long native grasses and shrubs established, tree layer establishing
58 – 96	11	6	Short and long native grasses and shrubs established, tree layer establishing
80 – 102	13	7	Structurally diverse vegetation establishing
80 – 108	15	8	Structurally diverse vegetation establishing

Shear stress threshold (N/m^2)	Year achieved (No maintenance)	Year achieved (with maintenance)	Comment
80 – 114	17	9	Structurally diverse vegetation establishing
80 – 120	20	10	Structurally diverse vegetation established

At this stage the waterway manager may also choose to include the additional shear resistance provided by structural works that aim to protect establishing vegetation and therefore increase the probability of vegetation establishing. For example, coir matting can be used to protect establishing seedlings. Such works are not intended to provide long term erosion protection for vegetation and the erosion resistance provided by supporting works will decline over time (for example as coir matting deteriorates). The simultaneous increase in shear resistance provided by establishing vegetation and the decreasing shear resistance provided by deteriorating structural works leads to u-shaped profile of shear resistance over time. An example is shown in Figure 52 which shows four scenarios for erosion control:

1. Vegetation establishing over a 10-year period
2. Vegetation establishing over a 20-year period
3. Coir matting
4. Combined coir matting with vegetation establishing over a 10-year period

Figure 52. Example of the change in total shear resistance at a site over time.



6.4.6 Task 5: Calculate probability of success

Task five is to calculate the probability of successful vegetation establishment, or the type and scale of structural works needed to meet the success criteria defined in step one.

Probability of failure is defined as the probability the shear stress applied by flows will exceed the shear resistance values defied for the cross-section or 2D model cell during each of the vegetation establishment years. This step uses the output of the 1D or 2D hydraulic model to assign a shear stress value (N/m^2) to each cross-section (1D), or cell (2D) for each design event.

The probability of successful vegetation establishment in any one year is the inverse of the probability of failure (where failure is erosion that removes vegetation):

$$Probability\ of\ success\ (\%) = 100 - probability\ of\ failure.$$

Using the shear resistance value for each cross-section or model cell, for each year, the smallest flow event which exceeded the shear resistance (for each cell) is identified. The probability of failure then simply corresponds to that events AEP. For example, a critical shear stress of 5 N/m^2 (bare soil) is exceeded by a 50% AEP flow event. Therefore, the probability of failure *in that year*, is 50%. This process is completed for each year of the vegetation establishment phase, and for any shear resistance scenarios (for example, to compare the probability of success with and without vegetation maintenance). Probability of failure values are then simply converted to a probability of success.

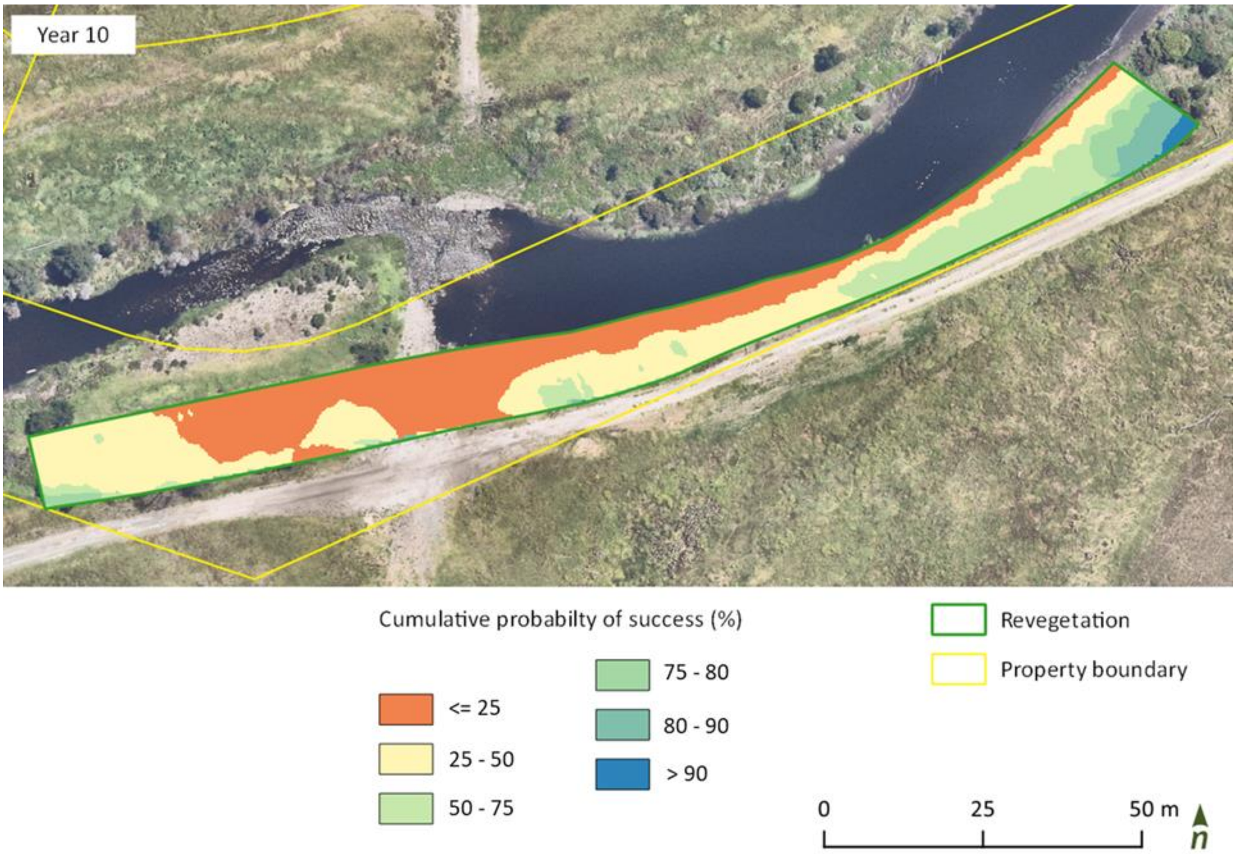
The cumulative probability of successful vegetation establishment is calculated by multiplying the probability of success in each year. In some cases, the shear resistance of structural works (e.g. pile fields) is greater than the shear stress during the largest event modelled (for example a 1% AEP event). In those cases, the calculation is 'cut short', as the event that causes failure is never reached and thus no need to calculate chance of failure. In such cases, the probability of success is determined using those years for which the calculation could be completed. Example calculations for a single cross-section, where vegetation establishment is aided by coir matting, are shown in Table 14 and an example illustrating outputs of the method using 2D modelling are shown in Figure 53.

Table 14. Example calculations of cumulative probability of successful vegetation establishment for a single cross-section.

Year	Shear stress resistance, vegetation, and coir (refer to Figure 52)	Probability of event occurring in any year (AEP%)	Probability of event not occurring (success) each year	Cumulative probability of success
1	95	10	90	90
2	90	10	90	81
3	85	20	80	65
4	80	20	80	52
5	90	10	90	47
6	96	10	90	42
7	102	5	95	40
8	108	2	98	39
9	114	1	99	39
10	120	1	99	38

* Year 1 example, a critical shear stress of 95 N/m^2 (coir) is exceeded by a 10% AEP flow event. Therefore, the probability of failure *in that year*, is 90%. Year 1 a critical shear stress of 90 N/m^2 (coir starting to break down and some vegetation establishment) is exceeded by a 10% AEP flow event, the probability of failure *in that year*, is 90%. However, the cumulative probability for the first two years is then 81%.

Figure 53. Cumulative probability of successful vegetation establishment without supporting structural works and assuming a 10-year vegetation establishment phase.



6.5 Pile field design for streambank stabilisation

6.5.1 Overview

Pile fields are placed in sequence along streambanks to disrupt near bank flow and reduce bank erosion. A pile field comprises individual timber poles which are embedded vertically into the streambed (Figure 55). Pile fields are spaced to optimise shear stress reduction and are oriented and angled slightly downstream, directing flow away from the eroding bank and assisting debris shedding.

A primary function of pile fields is to mitigate bank erosion by increasing flow resistance, decelerating flow, and reducing sediment transport capacity in the space between the pile fields (Alauddin, 2011 and Carling, *et al*. 1996). The space between two pile fields is referred to as an embayment. Establishing vegetation within the embayment's is an essential element of the design technique. Vegetation increases the hydraulic roughness within the embayment's, assists in reducing the flow velocity, stabilises sediment, and provides for the replacement of timbers piles as they degrade over time.

Pile fields can be used to:

- Prevent formation of undesirable alignments that place waterway and related values at risk.
- Limit sediment and nutrient generation through ongoing accelerated rates of bank erosion.
- Create desirable (and prevent loss) of important bank habitat.
- Trap and store sediment.

Pile fields achieve this by:

- Increasing the resistance of a streambank to erosion forces by interrupting flow lines adjacent to the bank and creating a zone of decelerated flow.
- Creating a depositional environment to allow vegetation establishment (natural recruitment or revegetation).

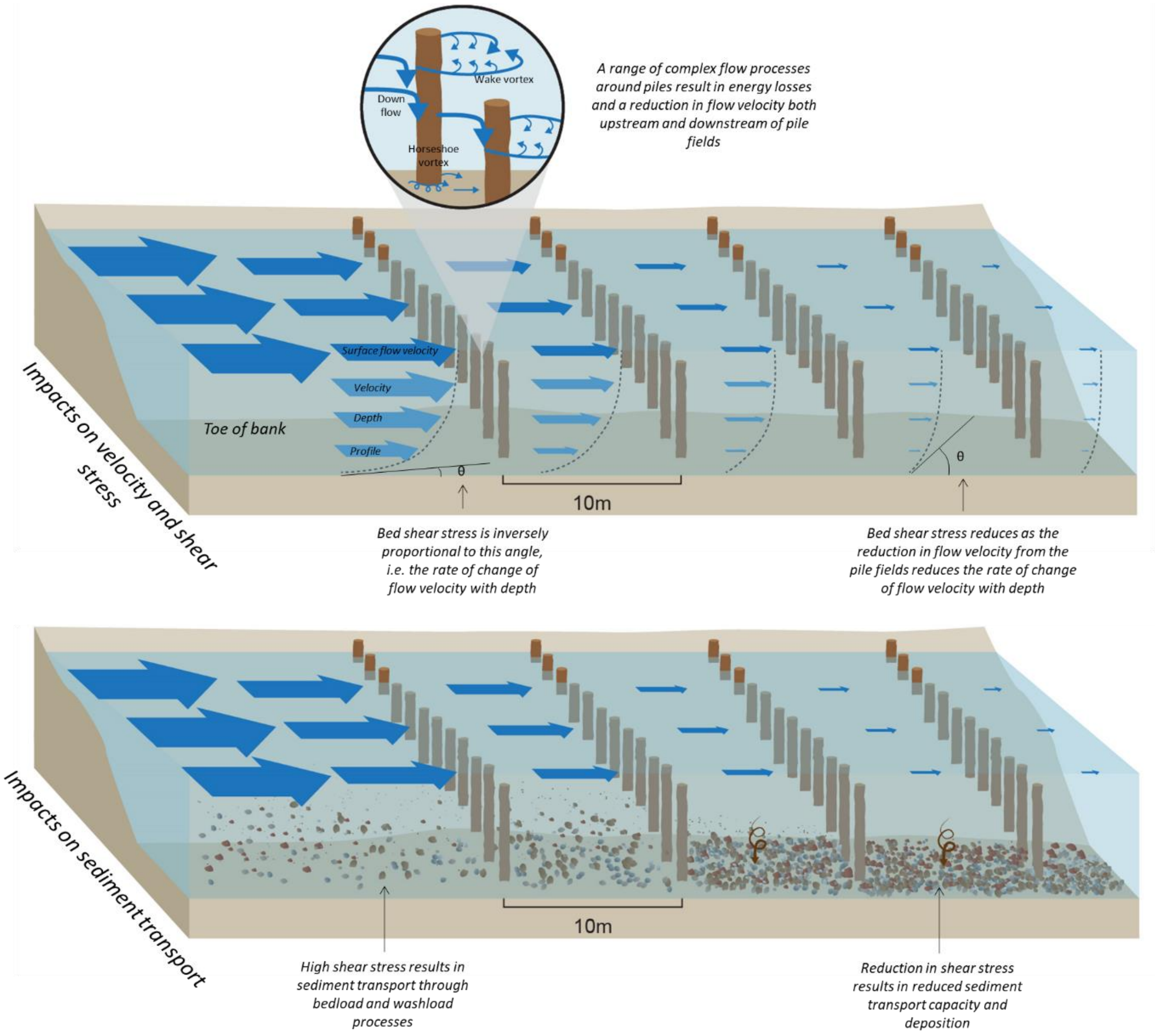
6.5.1.1 Flow processes around pile fields

The complex flow, turbulence, and sediment transport processes which occur through and around pile fields are illustrated in Figure 54.

The turbulent flow processes around piles include the down flow immediately upstream of the pile, the associated horseshoe vertex at the base of the piles, and the subsequent formation of wake vortex (oscillating circular flow) downstream of the piles (Yang, et. al, 2021). These flow processes result in energy losses, and reduction in flow velocity (and bed shear stress), both upstream and downstream of the pile fields.

High bed shear stress results in sediment transport through bedload and wash load processes. Reduction in bed shear stress, due to pile fields, results in reduced sediment transport capacity. Therefore, if there is sufficient sediment supply in the system sediment deposition will occur within the pile field embayment’s.

Figure 54. Flow processes around pile fields. Impacts on velocity and shear stress (top), impacts on sediment transport (bottom) (from Alluvium, 2022).



The impacts of pile fields on waterway hydrodynamics and morpho-dynamics are outlined in Table 15, mitigating effects of pile fields on bank erosion are detailed in Table 16, and key factors which impact on pile field performance are summarised in Table 17.

Table 15. The impacts of pile fields on waterway hydrodynamics and morpho-dynamics.

Impact	Description
Modification of velocity distribution across the waterway channel	Pile fields impact velocity distribution across the waterway channel. Flow velocities are reduced when flow approaches and passes through permeable pile fields (Zhang 2009). Conversely, flow velocities in the main channel are significantly increased. Pile fields also disrupt the erosive helical flow pattern characteristic of meander bends (Abad *et al.*, 2008; Jia *et al.*, 2009)

Impact	Description
Local scour near groynes	Pile fields are used to reduce flow energy and consequently fluvial scour in the near bank zone; converting sites of scour to depositional environments. However, pile field structures themselves are also subject to scour. Pile fields restrict flow, creating a backwater effect which influences the pressure distribution around the structure. This change in pressure distribution can result in the formation of eddies and consequently local scour near individual piles.
Deposition within embayment’s	Pile fields mitigate bank erosion by reducing near bank flow velocity and increasing sediment deposition (if there is sufficient sediments supply) (Alauddin, 2011). Reduction of flow velocity within pile field embayment’s results in deposition and accumulation of sediments and seeds, creating favourable conditions for vegetation establishment (Carling, *et al.*, 1996).

Figure 55. Example of vegetation establishment within the embayment’s of pile fields at Black Range Creek in north east Victoria.

Table 16. Mitigating effects of pile fields on bank erosion.

Impact	Description
Reduces shear stress along toe of bank	Shear stress increases with depth, therefore higher forces are exerted on the channel bed and toe of bank compared to areas higher on the bank profile. Fluvial scour along the toe of a bank can lead to a steepening of the bank profile and associated mass failure of the riverbank. Pile fields function by reducing flow velocity and applied shear stress along the toe of the bank; mitigating undercutting and steepening of banks due to fluvial scour.

Impact	Description
Promotes vegetation establishment	The establishment of vegetation along the lower bank can help provide long term stability to the system via the following mechanisms • The establishment of vegetation increases hydraulic roughness within the pile field embayment's, which results in a reduction in near bank flow velocity and therefore a reduction in shear stress acting upon the bank (Blackham, 2006). • Vegetation and root reinforcement can add geotechnical stability by increasing the effective cohesion of the bank material; the level of reinforcement is dependent on root strength and density (Abernethy & Rutherfurd, 1999). • By providing extensive coverage of bank surface area shrubs and grasses can limit entrainment of bank sediment.

Table 17. Key factors which impact pile field performance

Impact	Description
Flow regime	Water level, flow velocity, and consequently flow discharge, influence pile field performance. In most waterway systems, discharge varies throughout hydrological seasons. The seasonality of flows and flood frequency can have significant impact of pile field stability. Pile field performance has been found to be sub-optimal in reaches with prolonged sustained flow periods and low sediment supply (Rutherfurd *et al.,* 2007). This is due to prolonged periods of low to moderate flow where the critical shear stress of the boundary sediment within the embayment's is slightly exceeded. Over extended periods this can result in significant sediment mobilisation within pile field embayment's. In addition, high flow velocities increase the dynamic force on pile fields, this force acts to overturn individual piles. Stability is achieved by ensuring lateral earth pressure acting on the pile exceeds the dynamic flow force (Abam, 1995). The lateral earth pressure relates to the embedment depth.

Impact	Description
Sediment supply regime	Sediment supply and transport within waterway systems is key to pile field performance. Pile fields reduce sediment transport capacity such that if there is sufficient sediment supply, deposition will occur within permeable pile field embayment’s. In turn, aggregation of sediments creates favourable conditions for the establishment of vegetation (Carling, *et al.* 1996). In conditions of low sediment supply there will be limited deposition within embayment’s, and vegetation may struggle to establish. Timber piles have a finite design life (typically 10-15 years). Therefore, without the establishment of vegetation along the bank the works will be unable to provide long-term bank stability.
Bioregion	Bioregion characteristics including climate, soil type and vegetation influence pile field performance. Climatic conditions and soil type influence the ability of vegetation to establish, and subsequently support the structural works by increasing critical shear strength of the channel boundary and structural stability of the bank. The establishment of vegetation is a critical component of pile field performance in the long term. Without vegetation establishment the pile fields are unlikely to perform their design intent of reducing long term erosion. As a result, these environmental factors can impact on the long-term success of the works regardless of the hydraulic and geomorphic performance of the works.
Revegetation effort	Vegetation is a critical component of riverbank stabilisation works. The timber piles making up the pile field will decay. Vegetation is required to replace the timber piles. The revegetation effort should commence immediately following pile field installation and the design life of the timber piles should exceed the establishment period for native vegetation. Without the appropriate investment in revegetation design, monitoring, and maintenance the pile fields are unlikely to perform their design intent of reducing long term erosion.

A note on terminology: Pile fields are comprised of multiple permeable groynes. Within a pile field, permeable groynes comprise lines of piles. Most commonly these are timber piles.

6.5.2 Design considerations

Design considerations should ensure the construction of pile fields, the individual groynes and piles which:

- Are of a length and height above the channel bed to maximise their effectiveness.
- Are located and oriented to maximise their effectiveness.

- Are able to withstand bed scour adjacent to the structures.
- Have sufficient structural strength to withstand hydraulic and debris forces without catastrophic failure.

The spacing and length of pile fields does not conform to a pre-set formula but accounts for items such as stream width and depth, the radius of curvature of the bend, direction of maximum flow velocity, velocity of approach, and desired velocity in the pile field embayment’s.

Rigid design rules for pile fields do not exist. The range of conditions, functions and construction materials means that design becomes a judgemental process which must rely heavily on the experience and judgement of the designer. The design guidance provided in the Guidelines must not be interpreted as a strict code of practice. Flexibility in the design process can lead to innovative implementations and major cost savings without sacrificing effectiveness, providing the major principles are recognised and incorporated.

Seven key design considerations are summarised below.

6.5.2.1 Permeability of groynes

Pile fields, constructed from timber piles, are one example of permeable groyne structures which have been used extensively in riverbank stabilisation projects in Australia. Permeable pile fields are generally preferred to impermeable structures for bank erosion mitigation; having less impact on downstream and adjacent waterway hydraulics. Permeable structures increase the resistance to flow through the pile field, without completely blocking the flow. This has considerable advantages with respect to the hydraulic characteristics of the structure; enabling flow through the structure reduces turbulence and scour at the tip of the structure.

In contrast, impermeable pile fields are commonly used to create bed scour for the purpose of river training, navigation, or instream habitat creation. By modifying flow distribution and pushing the thalweg away from the bank, impermeable pile fields can be used to protect the riverbank and improve navigational conditions (i.e. increase water depth) (Przedwojski *et al.*, 1995; Kang *et al.*, 2011).

For the range of applicable waterway types, the pile field porosity (% open) is typically 50%. Increasing the ratio of the solid area (i.e. the timber piles) to the open area (i.e. the gaps between the piles) in a pile field, leads to a less permeable structure which is prone to:

- Significantly greater head loss across the pile field with correspondingly greater hydraulic forces on the structure itself.
- Weir type overtopping which can lead to significant scour on the downstream side of the structure.
- Severe acceleration of flow at the riverward end of the structure which can lead to major vortices and scour adjacent to and under the structure.

- Acceleration of flow along the upstream face of the groyne which may cause scour along the upstream length of the structure.
- Abutment failure (at the bank end) associated with scour from overtopping eroding the bank.
- Structural failures associated with these scours.
- Collecting debris which further decreases the porosity and exacerbates the above effects.

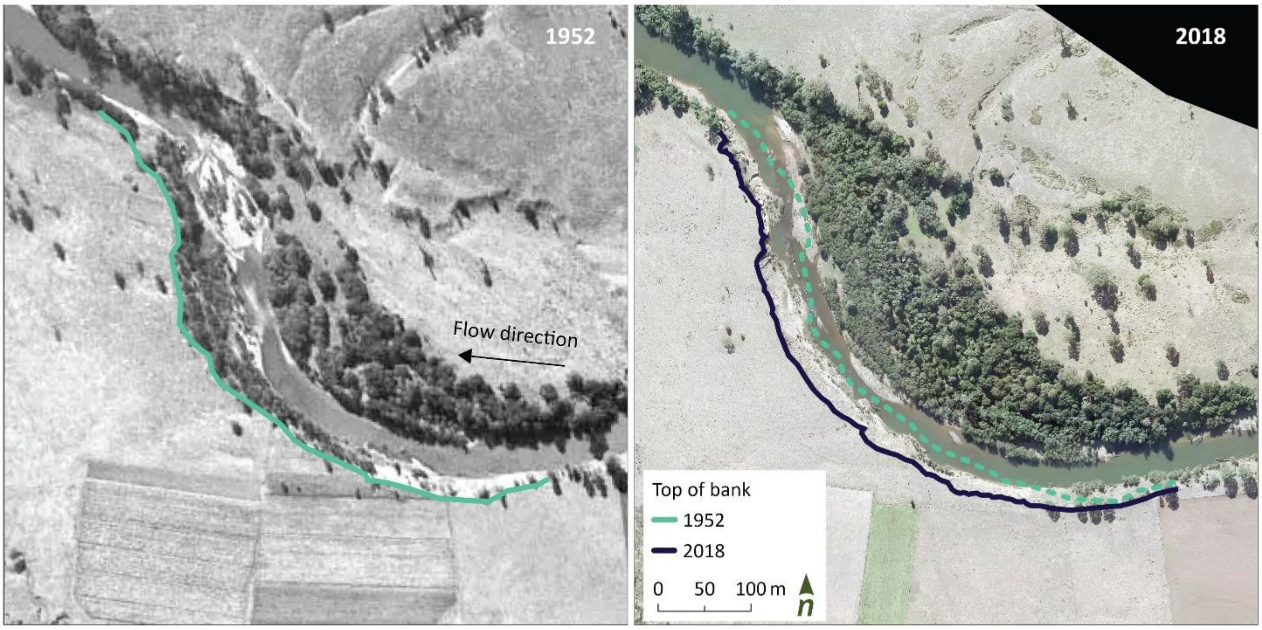
6.5.2.2 Pile field positioning

The positioning of the pile field groynes (i.e. from the most upstream location and to the most downstream location) is a critical decision in the design process. One of the most common failure mechanisms for pile fields is outflanking. Outflanking occurs when bank retreat and associated bend migration upstream of the pile fields results in erosion of the bank surrounding the structural works.

Positioning of the pile fields requires a detailed understanding of the bank substrate, erosion processes and bend migration trajectory. Many bank erosion sites are the result of a down valley meander migration process (Figure 56). As a result, retreat rates at the upstream end of the site wane over time until they are negligible. In some instances, deposition may occur as part of a concave bench formation process. Therefore, position of pile fields is crucial for project success. If pile fields are not positioned far enough upstream the works can be outflanked. Conversely if pile fields are positioned too far upstream it may result in a significantly more expensive project, as structural works are installed in areas where they are not required.

The use of multi-temporal spatial analysis (see Section 5.2) should be used to assess bend migration trajectory and help the positioning of pile fields.

Figure 56. Example of a down valley meander migration processes.



6.5.2.3 Position of the design toe of the bank

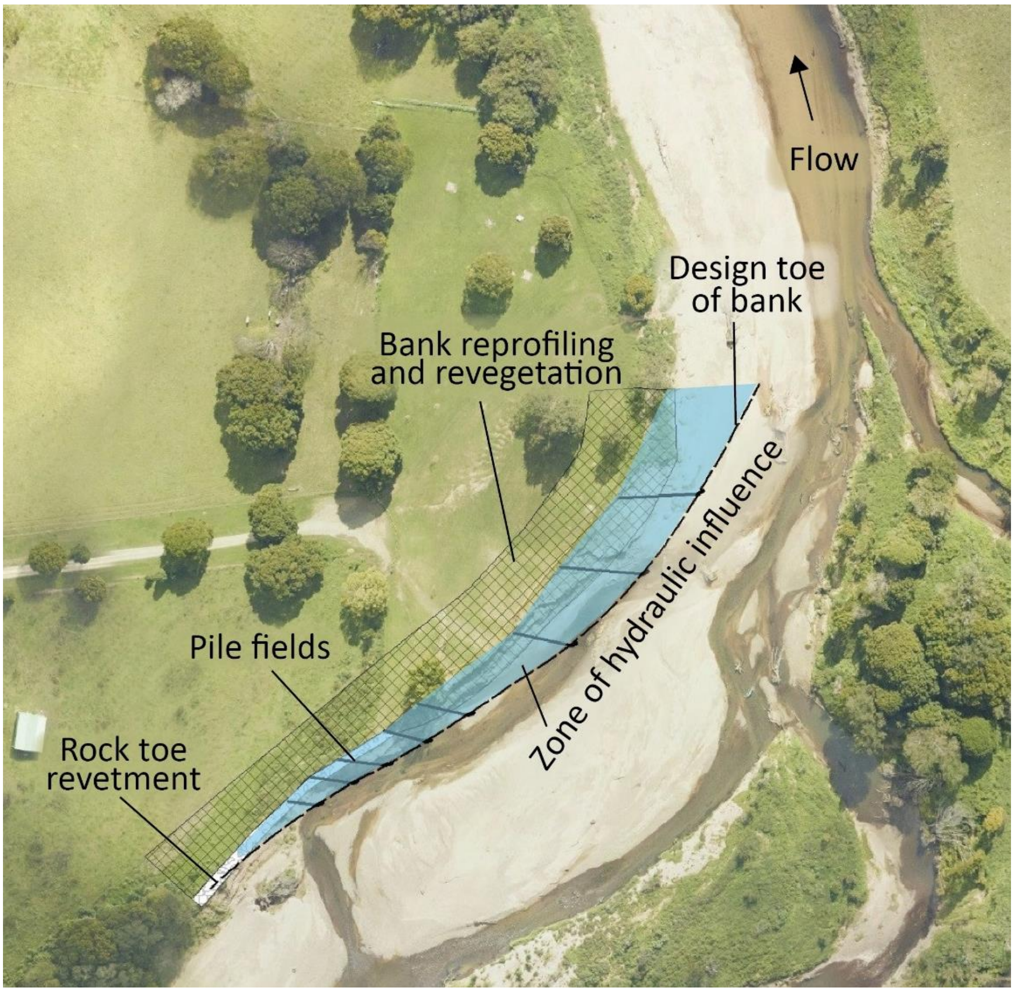
The positioning of pile fields requires that the new position of the toe of the bank is identified (Figure 57). The pile fields then extend up the bank from the new toe of the bank (design toe of bank). The zone of hydraulic influence (i.e. where there is significant reduction in velocity and shear stress) is controlled by the location of the design toe of bank. If the design toe of bank is extended out in the riverward direction from the existing toe of bank a more significant zone of hydraulic influence is created.

Extending the design toe of bank out in the riverward direction can have a range of unintended consequences including:

- Redirection of flow towards the centre of the waterway can reduce the flow sinuosity and increase velocity. This process could result in increased flow energy being exerted on adjacent bank areas and is analogous to ‘waterway straightening’.
- Creating excess scour on the riverward side of pile fields by extending the pile fields into the higher flow velocity areas of the channel.
- Impacts on instream habitat values such as changes to benthic habitat and infilling of pools.

As a result, the positioning of the design toe of bank needs to balance shear stress reductions with these broader geomorphic and waterway health implications. Where bank reprofiling is proposed as part of the stabilisation strategy the design toe of bank should extent at least 1 metre from the toe of the bank batter to limit the risk of toe scour.

Figure 57. Example pile field design showing the design toe of bank set out from toe of the bank and the zone of hydraulic influence (blue).



6.5.2.4 Pile field groyne spacing

The pile field groyne spacing requires the judgement of the designer based on an understanding of the processes occurring in the waterway system and the objective of the works. This judgement can be informed by analysis, modelling and experience. The spacing between groynes does not conform to a pre-set formula but should account for items such as waterway width, direction of maximum flow velocity or attack, velocity of approach, desired velocity in the pile field embayment’s, and the radius of curvature of the bend.

6.5.2.5 Pile field angle

Increasing or decreasing groyne angle relative to upstream flow has marginal impact on near-bank shear stress. As a result, a more cost-effective design may be achieved by implementing a groyne angle almost perpendicular to flow. However, the designer will need to consider other factors including bend curvature and debris shedding processes as part of the design.

6.5.2.6 Height of piles

The exposed pile height has significant impact on shear stress reduction across the bank area (Alluvium, 2022). The height of the pile should be related to the expected range of flow conditions. As a guide, minimum pile height is expected to be the lesser of one third of the annual flood stage, and one third of the annual bankfull stage.

The exposed height is limited by the embedment depth of the pile. An approach for determining pile diameter and depth of embedment based on the estimated drag, impact, and resistant forces applied to a pile within a waterway is outline in Section 6.5.9.

6.5.2.7 Elevation of pile field on the bank side

A probabilistic cumulative risk of erosion analysis can be used (see Section 6.2) to determine the optimal elevation up the bank that the piles, groynes and pile field extend.

The aim of pile fields is to increase flow resistance, decelerate flow, and create favourable conditions for vegetation establishment. Structurally diverse, remnant vegetation will typically be able to resist erosion on many riverbank areas (i.e. critical shear stress of approximately 120 N/m^2). However, vegetation takes time to establish and there is a risk high flow events will erode the bank prior to the vegetation reaching maturity. The probabilistic cumulative risk of erosion analysis can help designers determine the optimal height of bank protection works to provide a low likelihood of bank scour which may undermine any revegetation works.

The probabilistic cumulative risk of erosion analysis requires:

- An understanding of the variation of shear stress across the site for different flood magnitudes. Variation in velocity across the site for different flood magnitudes could also be assessed.
- An understanding of the temporal variation in bank boundary resistance as the vegetation establishes (i.e. from post construction to full maturity).
- Flood frequency analysis to determine critical scour events for each temporal period.

6.5.3 Design alignment

This section applies to the use of pile fields to achieve a modified stream alignment. The section describes the choice of a design stream alignment to form the basis of a pile field layout.

Alignment design requires detailed planimetric information over the site and less detailed information up and downstream for a total distance of at least 2.5 meander wavelengths or 25 channel widths.

Suitable planimetric information is available from aerial imagery, LiDAR, and field survey.

Field survey information can complement aerial imagery and LiDAR data. Survey planimetric information may include the:

- Location of all man-made features and controls.
- Bank line.
- Water line.
- Areas of vegetation.
- Areas of erosion or scour.
- Limits of floodplain.
- Longitudinal bed profile and cross-sections (these are used in determining the elevation of the pile fields).

6.5.3.1 Alignment design

Selection of an appropriate design alignment is essentially an exercise in compromise between a number of aims and constraints including:

- Removing flow lines of attack from vulnerable banks.
- Aligning or constricting flow in a bridge approach to reduce attack on abutments.
- The need to use bend radii which are large enough to be stable.
- A recognition of the severe adverse effects of over straightening a waterway reach.
- The requirement to match entry and exit angles of the realigned reach to existing conditions.
- Limitations on cost.

For a realigned section to achieve long term stability without major heavy engineering work, the realigned waterway should depart as little as possible from the characteristics of the waterway in stable reaches upstream and downstream. Major straightening must be avoided.

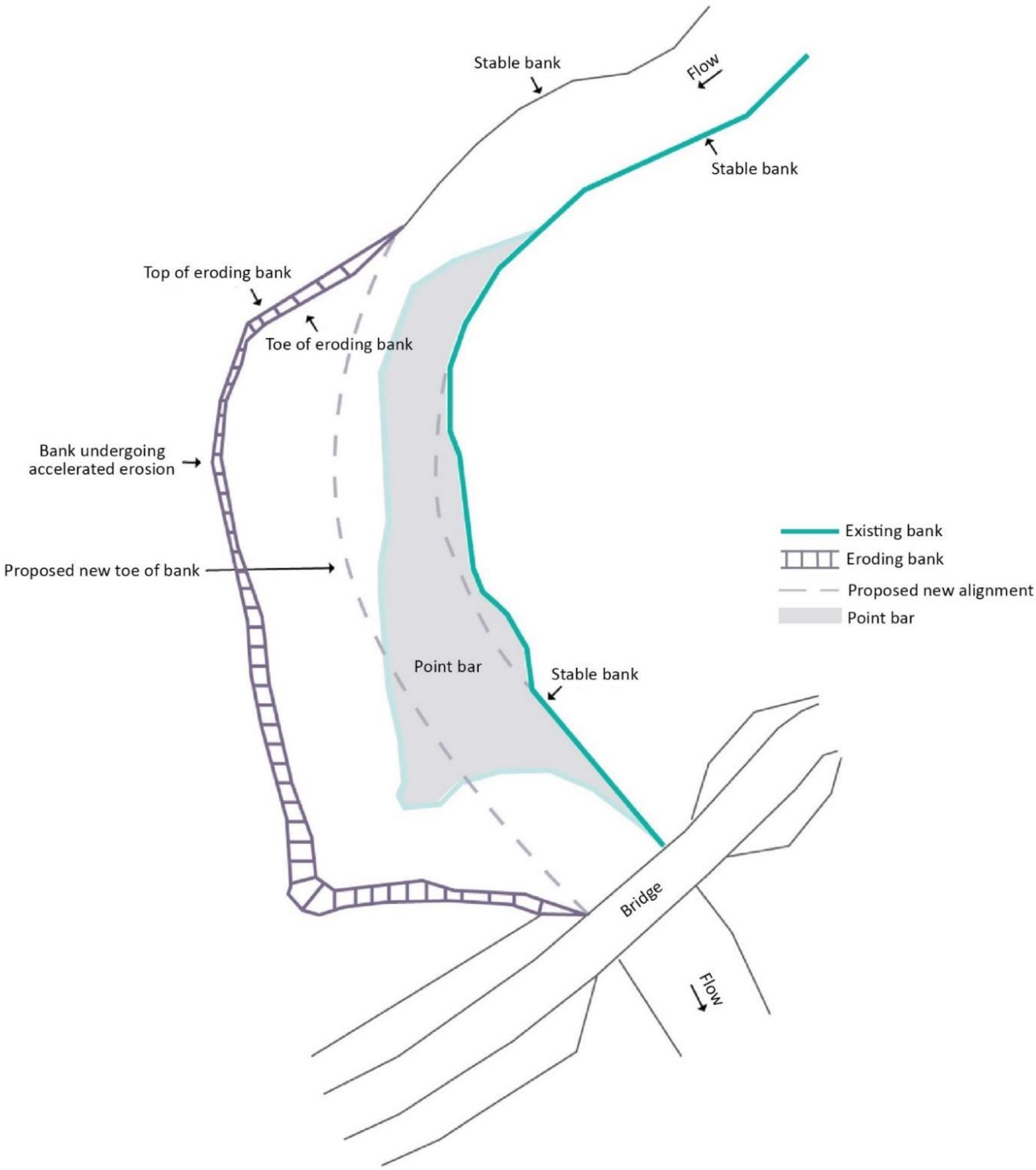
The following guidelines are given to assist in selecting an appropriate design alignment through a trial-and-error procedure:

- Establish basic constraints on the alignment (e.g. bridge orientation, natural rock outcrops).
- Choose a range of suitable bend radii from an overview of stable bends upstream and downstream or on similar waterways.
- Choose a design width on the basis of width in stable reaches upstream and downstream.
- Using circular curves for convenience, attempt trial fits of curves within the constraints already established.

- Ensure curves are tangent to existing alignment or to bridge abutments, at upstream and downstream limits.
- In general try to move bends back upstream to counteract the tendency for bends to migrate downstream and crowd natural channel controls or bridge sites.
- Review proposals by comparisons upstream and downstream.

Development of proposed new bank toe alignment is illustrated in Figure 58.

Figure 58. Pile field design – existing site layout.



6.5.3.2 Hydraulic considerations

Hydraulic, and other design factors, that are of assistance to the design engineer are outlined below.

- *Stage recurrence interval relationship*. A relationship between stage and flood recurrence interval. Preference is for the use of a calibrated hydraulic model. Local knowledge from landholders can be of considerable assistance in determining this relationship. This information is useful in determining the height of the top of bank and the height of the pile fields.
- *Velocities at different points through the section*. This can be determined from the hydraulic model or measured in flow events.
- *Sediment size information*. Visual inspection or sieve analysis of the bed and deposited material will allow the designer to determine suitable velocities within the pile field. When considering sediment, it is also worth considering sediment loads. If the sediment load is low then the embayment’s will fill slowly and it may be necessary to give greater consideration to the construction of a berm to retain the low flow channel away from the area to be rehabilitated and provide a location on which revegetation can commence.

The hydraulic information can be used to determine the annual exceedance probability of the failure flood and hence obtain an estimate of the risk of failure associated with a given design.

6.5.4 Pile field groyne spacing and orientation

This section applies to the use of pile fields to shift high velocity and high shear stress flow away from the toe of an eroding bank. This section outlines possible steps which can be used to determine pile field groyne spacing and orientation. How far a waterway manager progresses through these steps, for a particular site, is dependant on available data (i.e. survey, LiDAR), level of risk at the site (i.e. value of assets threatened, complexity of channel erosion/deposition processes), and value of the project (i.e. construction costs).

Design can be undertaken via two steps:

1. The notional line of attack approach.
2. Hydraulic modelling of pile fields (2D or 3D modelling).

These approaches are summarised below.

Note: Pile field design in this section is underpinned by hydraulics. The design steps focus on protecting the lower bank from scour by reducing velocity and bed shear stress (rather than explicitly settling sediment). It is assumed that reducing shear stress (below the threshold as which mobilisation of channel boundary material occurs) will:

- Protect the lower bank from scour and allow vegetation to establish.
- Reduce the sediment transport capacity such that, if there is sufficient sediment supply, deposition will occur within pile field embayment’s.

6.5.4.1 Design steps

The Guidelines are not intended as a prescriptive set of procedures, rather key recommendations, and factors for designers to consider. Designing waterway restoration works requires detailed understanding of site characteristics including hydraulics, sediment transport processes, bed and bank substrate, and riparian and watering ecology (including presence/absence of wood borers). As a result, designers need significant expertise beyond the advice that can be provided within this guideline document.

The steps used for the design of pile fields depends on the level of risk at the site and/or with the proposed works. For example, the value of the project (i.e. construction cost), value of assets threatened, and the complexity of channel erosion/deposition processes can all impact the level of risk associated with a design. A range of design steps with varying degrees of rigour are outlined in Table 18.

Table 18. Design steps recommended based on the level of risk

Design step	Suitability
Engineering judgement (suitable experience and geomorphic understanding) with limited modelling or quantitative geomorphic analysis. Design to be informed by the Notional Lines of Attack approach (likely results in a conversative design).	Suitable for **low to moderate risk** sites, where the cost of works is relatively low (i.e. small – medium site) and erosion processes are relatively well understood, and no high value assets are threatened.
Engineering judgement coupled with quantitative geomorphic analysis and detailed 2D or 3D modelling of differing design arrangements to optimise the design.	Suitable for **moderate to high risk** sites, where the cost of works is relatively high (i.e. medium to large site), and/or a high value asset is under threat. Also, may be appropriate where there are very high velocity and shear stress values across the site which increases the erosion risk. For example, if shear stress across the site is greater than 100 N/m² for the existing condition then modelling of different configuration may be required to determine if a suitable reduction can be achieved.

6.5.4.2 Probability and risk of failure

The reduction in shear stress arising from the installation of a pile field can be identified using hydraulic modelling. The modelling can be used by designers to determine the probability of failure over the vegetation establishment phase and beyond (see Section 6.2).

A detailed understanding of the cumulative probability of failure over a defined period (e.g. vegetation establishment phase) can be used by waterway engineers and waterway managers to predict whether or not a project is likely to be successful (i.e. whether vegetation is likely to reach a level of maturity such that it can provide the long-term erosion protection) before the occurrence of a flood event that has the potential to erode the material on which the vegetation is being established. The designer will need to identify an appropriate probability of success commensurate with the consequence of failure and an acceptable level of risk, over the bank vegetation establishment phase, for the works and site. The level of shear stress reduction afforded by the pile fields, and hence the porosity, height, and spacing of pile fields, should be adjusted such that the probability of failure creates an acceptable risk of failure.

6.5.4.3 Notional Lines of Attack

The Notional Line of Attack approach can be used as a first step to determine spacing and orientation requirements.

The Notional Line of Attack approach is detailed in the *Guidelines for Stabilising Waterways* (Standing Committee on Rivers and Catchments, 1991). This approach was developed based on the authors knowledge and experience. While there is strong anecdotal evidence of the success of the notional lines of attack approach, the method is not explicitly based on waterway hydraulics.

The approach leads to the design of pile fields which are angled relative to downstream flow direction. Increasing the angle relative to direction of downstream flow (i.e. from 100º to 145º) leads to increased pile field length (and therefore a higher cost) for a given top- and toe-of-bank alignment. There is limited theoretical justification for significantly angled pile fields (Dyer, 1995 & Alluvium, 2022). However, there is some anecdotal evidence that increasing the pile field angle with the angle of flow assists in shedding flood debris from the pile fields (preventing blockages and increased turbulent flow). The shedding of debris has potential to reduce such blockages.

The Notional Lines of Attack approach has been found to provide an economical and successful solution in moderate to steep gravel and sand bed rivers. It involves an iterative process which relies on the judgement of the designer and an understanding of the processes occurring in the waterway system. The results from the research by Dyer (1995) may be of use to the designer in determining the effect of a given pile field and how its response will vary for different flow conditions.

Pile fields and their associated groynes are seldom uniform in length through a waterway reach. They are spaced such that the flow passing around and downstream from the riverward end of the structure intersects the next pile field prior to intersecting the eroding bankline. Realistically, the spacing and length of reach groyne making up the pile field does not conform to a pre-set formula but should account for items such as waterway width, direction of maximum flow velocity or attack, velocity of approach, desired velocity in the pile field embayment’s, and the radius of curvature of the bend.

The estimated critical line of attack is a matter of judgement for the designer. It incorporates many factors including width and radius of curvature, existence of point bars, vegetation or channel controls.

The following procedure is provided as a guideline to establishing length and spacing requirements given a proposed new alignment:

1. Establish the progression of critical attack lines around the bend or through the reach, as indicated in Figure 59. A review of aerial photos or plans supplemented by information gained from a full reconnaissance of the site during various flow conditions is necessary to establish the notional lines of attack.
2. Locate the landward end of the first pile field groyne just downstream of the start of the re-aligned section. Additional direct bank protection will often be needed upstream of the first pile field. Determine if the influence of a single pile field will be sufficient to provide suitable hydraulic conditions for stable sediment.
3. If more than one pile field groyne is required to obtain suitable downstream hydraulic conditions, then the minimum distance between the pile fields groynes is to be at least 5 times the height of the upstream pile field groyne. This is to minimise the scour, resulting from the turbulence from the upstream pile field, undermining the downstream pile field.
4. If one pile field groyne is sufficient to provide suitable hydraulic conditions for stable sediment, then identify the worst-case flow line or the critical line of attack on the first pile field groyne. The angle of the pile field groyne can then be set based on this critical line of attack. The pile field groynes should be angled 5 degrees to 15 degrees downstream of the perpendicular to this line of critical attack. The angle does not affect the hydraulic performance of the pile field and thus the angle may be varied to suit the design conditions. However, the pile field groyne should not be angled upstream as the pile field could become blocked with debris. The pile field is then located along this angle from the bank to the desired flow alignment. This concept is illustrated in Figure 58 to Figure 62.
5. The second pile field groyne should be located such that the landward end of the second pile field is located upstream of the intersection of the critical line of attack from the first pile field and the eroding bank line.
6. The remaining pile field groynes should be located and spaced as described in step 3. The last pile field groyne is often awkward to place. In addition to the last pile field, a complementary form of bank protection can be utilised to further stabilise the downstream limit.
7. Figure 59 illustrates placement of the remaining pile fields and illustrates the completed pile field.
8. It is rare that the procedures described above will result in the best geometry for a given site during the first attempt. An iterative technique is required where the geometry is re-evaluated in upstream and downstream directions. The purpose of the iterations is to select the layout which best arranges the pile field to the upstream and

downstream boundary conditions and takes into account site specific irregularities in the channel bank.

Figure 59. Pile field design – notional lines of attack.

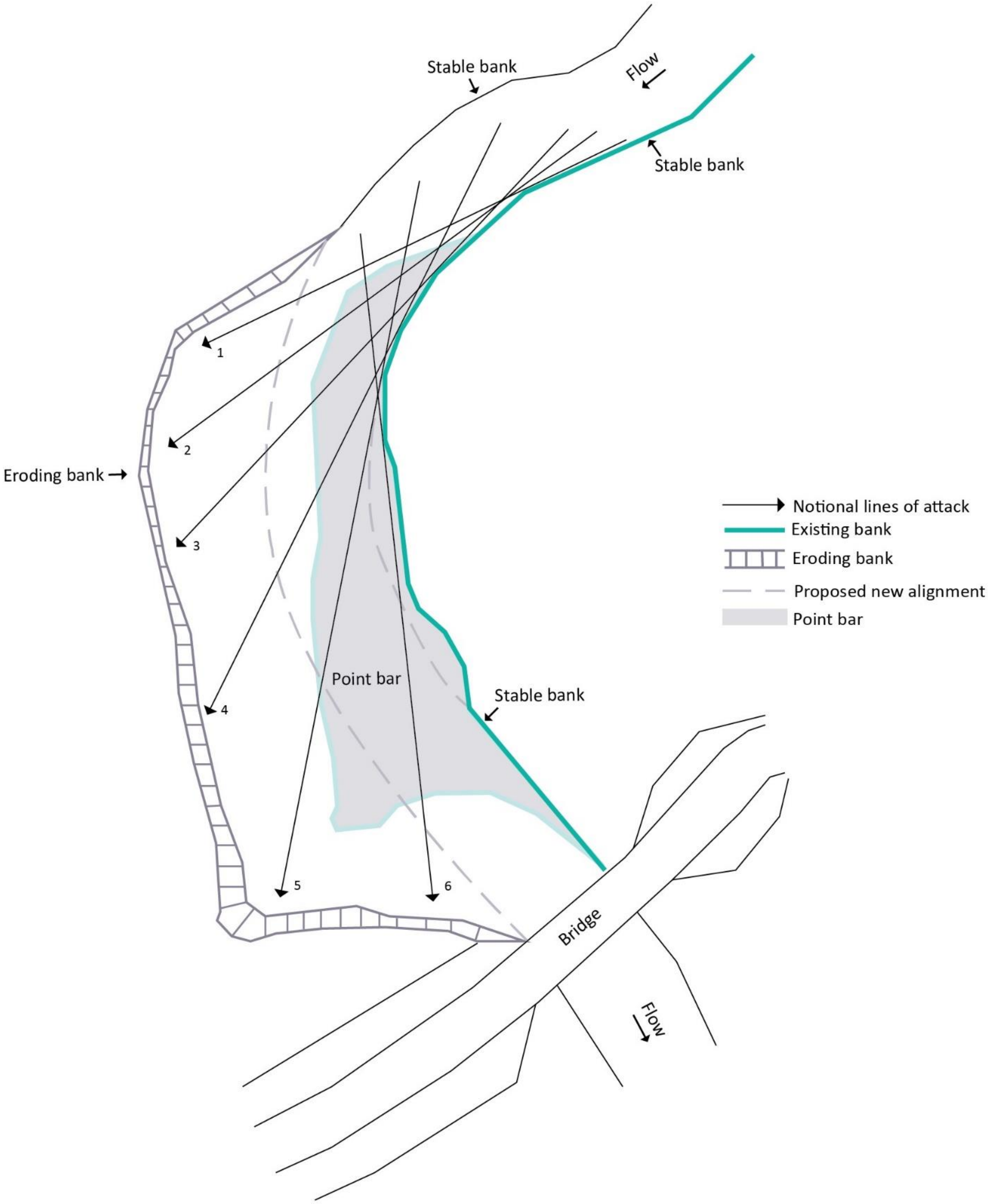


Figure 60. Pile field design – 1 to 3 layout.

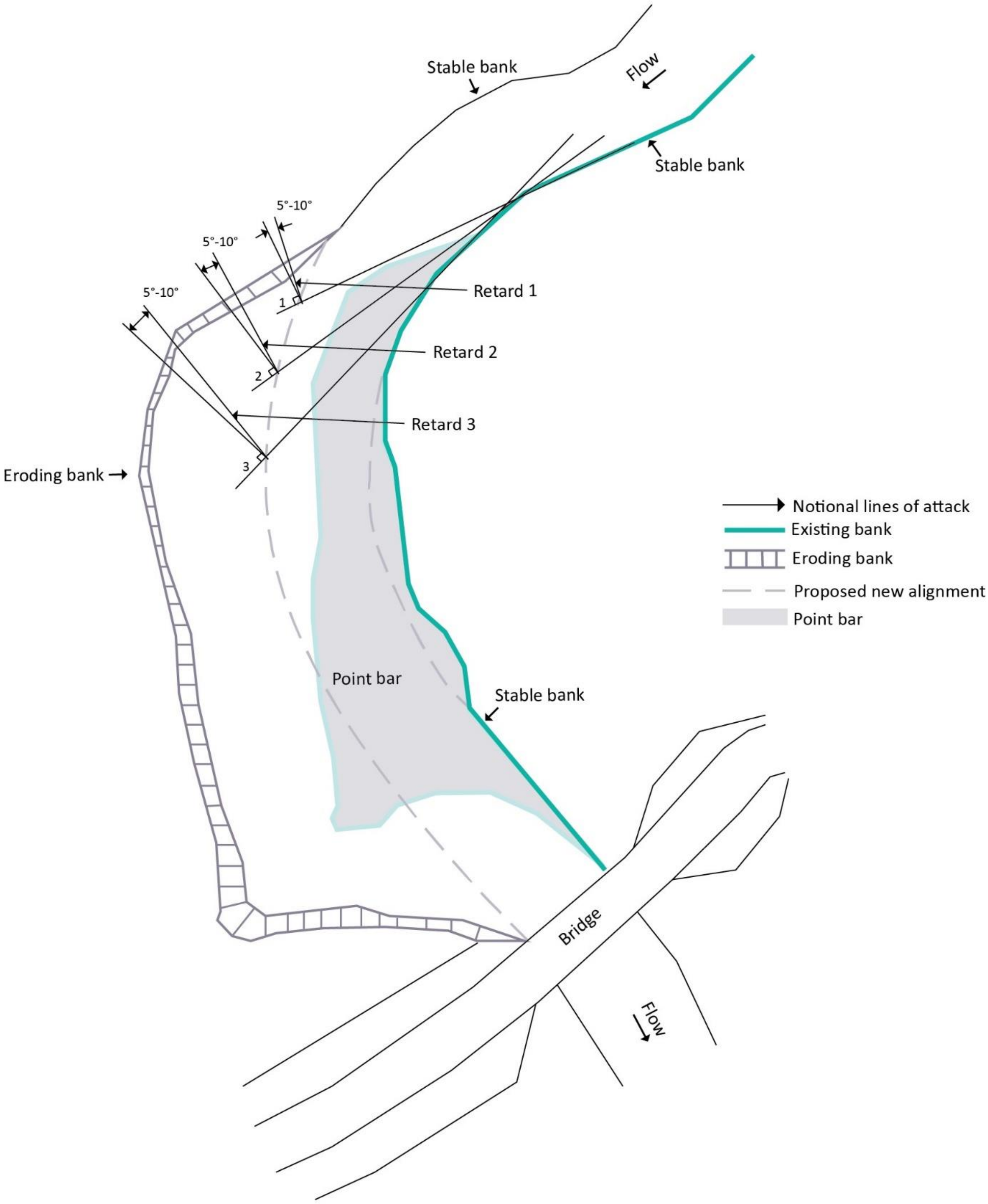


Figure 61. Pile field design – 4 to 6 layout.

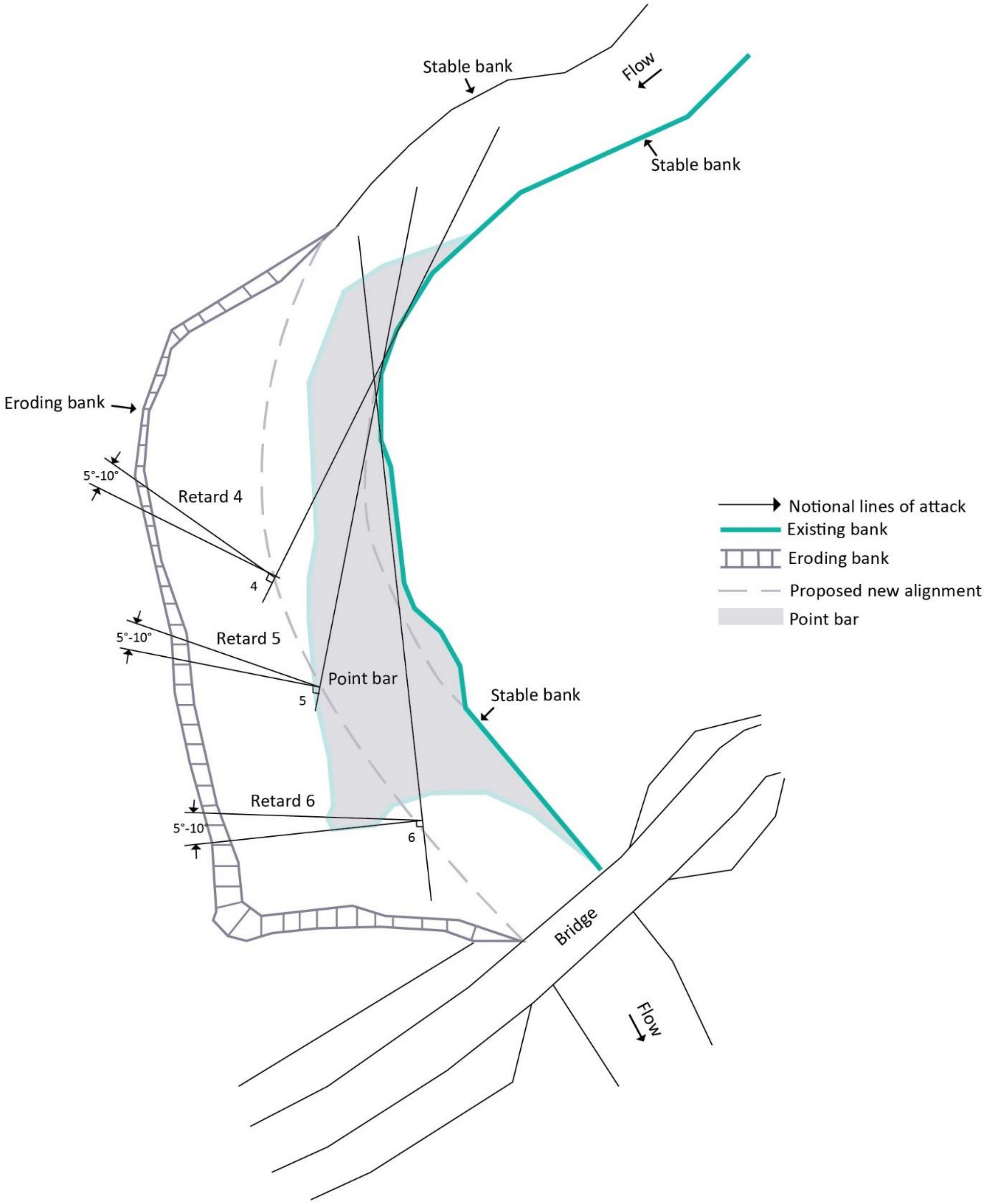
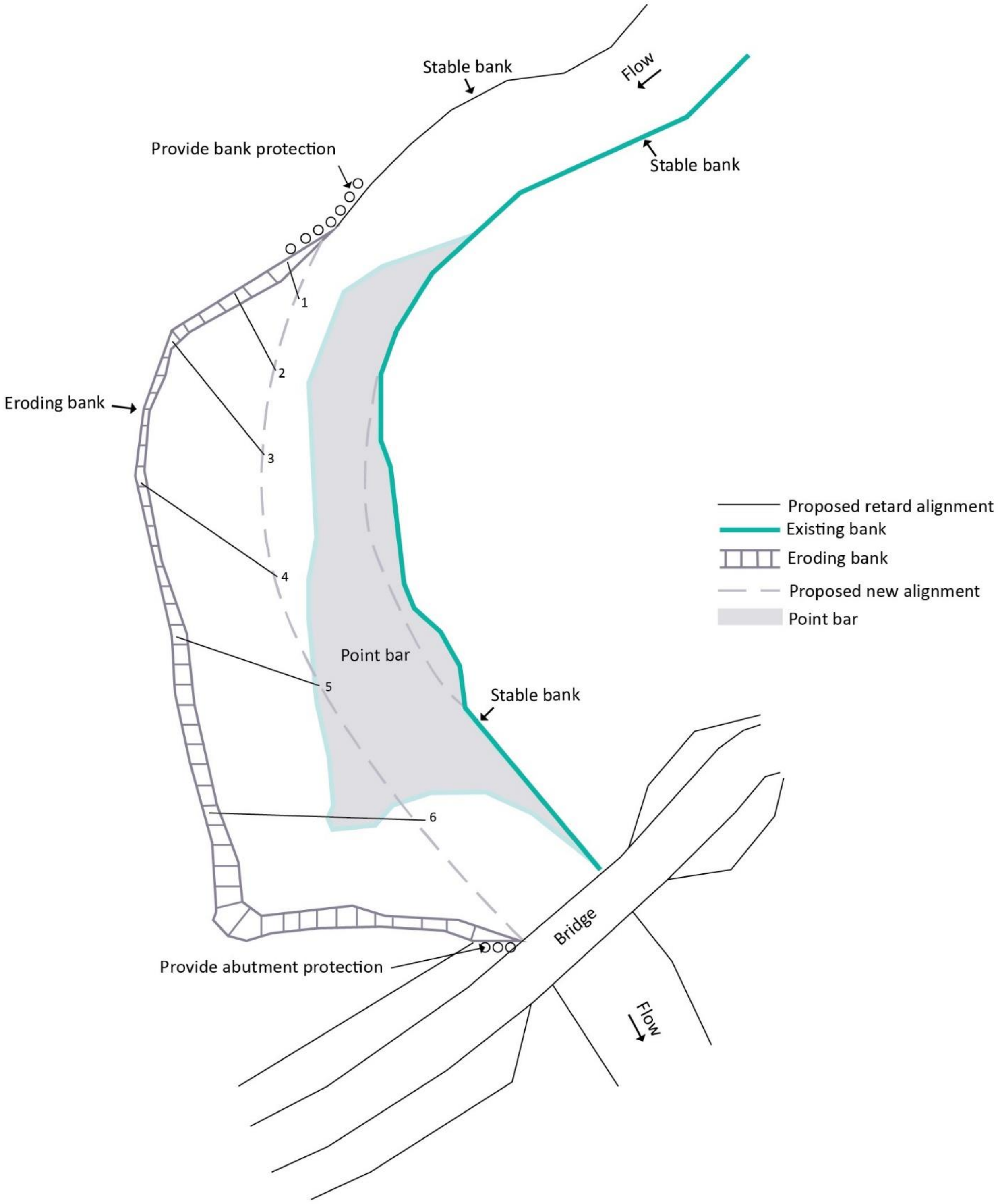


Figure 62. Pile field design – proposed site layout.



6.5.4.4 Hydraulic modelling of pile fields

Hydraulic modelling can be undertaken as a second step where refinement of pile field spacing is required. Modelling may be used in conjunction with the Notional Angle of Attack approach to produce a more refined design arrangement.

Key hydraulic modelling steps are outlined below:

1. Develop initial pile field configuration. Initial pile field groyne positioning and spacing, design toe, height of exposed piles, and height of pile on the bank side to be informed by design considerations (outlined in Section 6.5.3).
2. Develop a 2D or 3D hydraulic model of the waterway system (see Section 5.3.3). Represent the pile field configuration in the design scenario model.
3. Identify target shear stress. This should be based on the critical shear stress for the bank sediments. A sediment size and composition analysis should be undertaken incorporating either:
    a. visual sediment assessment; or
    b. analytical sediment properties analysis (i.e. sediment size and dispersion analysis).
4. Analyse the shear stress model outputs within the pile field works (i.e. near bank zone). It is suggested that as a minimum the 40% AEP, 20% AEP, 5% AEP, and 2% AEP events be analysed. Assess design shear stress against the critical shear stress of the design conditions channel boundary. Critical shear stresses appropriate for a range of sediment sizes are provided in Table 19.

Table 19. Critical shear stress for a range of sediment sizes.

Particle size mm	Particle size m	Critical shear stress N/m^2
0.1	0.0001	0.08
0.2	0.0002	0.15
0.5	0.0005	0.38
1	0.001	0.76
2	0.002	1.52
5	0.005	3.80
10	0.01	7.61
20	0.02	15.22
50	0.05	38.04
100	0.1	76.08

Note: Critical shear stress based on shields entrainment factor of 0.047 and sediment density of 2.65 tonnes m^3.

5. Iteratively refine pile field configuration (i.e. positioning and spacing of groynes, design toe, height of exposed piles) should until target shear stress is achieved.
6. Design shear stress results can be used by designers to determine the probability of failure over the vegetation establishment phase (Section 6.4). Pile field configuration should be adjusted until an acceptable risk of failure is achieved.

Note: Two-dimensional (2D) models are depth-averaged and ignore (or simplify) the complex three-dimensional (3D) aspects of flow through pile fields These flow characteristics are key drivers of scour and riverbank erosion and have a significant impact on pile field performance.

Complex flow patterns can be explicitly represented in 3D models. However, 3D models are time intensive to establish and run and their use is pile field design is seldom feasible. Further research is required to derive 3D correction factors that can be used to correct for the simplifications inherent in 2D modelling.

6.5.5 Structural design of piles used in pile fields

Pile fields must resist the following main loads:

- Dynamic load: direct impact from waterborne debris.
- Hydraulic load: pressure forces resulting from hydraulic head across the pile fields (static and dynamic).
- Hydrodynamic load: drag of flowing water on components of the pile fields.

Of the three, the dynamic load and hydraulic load are the most important. Hydrodynamic loads are always relatively insignificant. For the design conditions investigated for the Guidelines, dynamic loads are generally more significant than hydraulic loads. The resistance of the pile field to dynamic loads depends on its flexibility, or its capacity to absorb shock loadings by temporary deformation.

Structural design of pile fields must consider:

- Pile height.
- Size of timber piles and embedment depth.
- Scour at riverward end of piles.

These design elements are discussed below.

6.5.5.1 Pile height

Pile fields for alignment training and bank protection, as described in the Guidelines, are generally low structures about 1 to 2 metres high (above the streambed). They function, not by providing direct protection to the entire profile of a vulnerable bank, but by stabilising the toe of that bank, preventing failure by undermining and encouraging sediment deposition. Correctly designed pile fields will, over time, collect sediment within the embayment's and hence form a new bank line. The long-term stability of this new bank line is dependent upon some form of mechanical protection, either by maintained pile fields or vegetation.

6.5.5.1.1 Height of an individual pile field

The following guidelines are provided to assist in determining appropriate structure height:

- For the range of applicable waterway types, the exposed height of the pile (above the riverbed) is typically 1.5 m.
- The height of the pile should be related to the expected range of flow conditions. As a guide, pile height is expected to be the lesser of one third of the annual flood stage, and one third of the annual bankfull stage.
- The elevation of the top of the pile field may be level or angled or stepped slightly downward toward the waterway. There should be no high or low spots along the pile field.
- Minor excavation may be necessary to install piles of a more or less constant height on an uneven bed or bar.
- The height of the pile may increase toward the bank to provide some additional protection and prevent premature overtopping adjacent to the bank.
- If the pile field is constructed on a berm then the pile field should be driven into the berm to allow for localised scour due to the high velocity flow between the piles. At the riverward end, the pile field needs to be driven deeper into the berm to allow for scour at the tip.

6.5.5.1.2 Gradient across a series of pile fields

Over a study reach the top of the pile fields should form a line of constant gradient from the most upstream pile field to the most downstream pile field. The top of pile elevation (across a series of pile fields) should reflect the expected hydraulic grade of the channel. The gradient is best determined by considering the longitudinal section of the bed. This allows the gradient to reflect the overall topography of the reach and not be unduly influenced by the location of pools, riffles, or scour holes; providing a uniform slope across the pile fields within the waterway reach.

Some additional notes to assist the design and layout of pile fields include:

- Their function is not to provide direct protection to the entire bank but to provide toe protection by reducing flow velocity.
- Excessive height increases vulnerability of structure to damage by debris and undermining by overtopping.
- Opportunities for concentrated overflows at any point must be avoided to reduce risk of scour and/or outflanking of works.

6.5.5.2 Size of timber piles and embedment

Pile field structures should be designed to resist dynamic and hydraulic loads based on design flow conditions. The designer must choose an appropriate design debris loading condition for the waterway in question. These criteria must remain flexible, with the final selection of design conditions dependent on the designer’s assessment of site-specific conditions.

A design method for the estimation of timber pile size and embedment is provided in Section 6.5.9.

6.5.5.3 Scour at riverward end of pile fields

The riverward end of a pile field is subject to scour. However, the magnitude of that scour is difficult to predict. Two methods for estimating scour depth are summarised in Section 6.10. To account for scour, and optimise the structural integrity of pile fields, the following design recommendations are made:

- Design and construct tails on pile fields to reduce the extent of scour, and hence the depth of embedment and length of pile required.
- Calculate likely scour depths for the design flow event (see Section 6.10). Pile fields with a tail, are likely to have scour depths of approximately half that for structures without a tail.
- If scour depths are such that structural criteria become difficult to meet, then consider provision of a rock riprap apron at the riverward end of the groyne may be used. If the rock riprap apron is used, it can be assumed that scour is effectively prevented at the end of the pile field.

Where scour depths of greater than two metres are predicted, the unsupported structure height will be greater than 3 metres (assuming a minimum 1 metre high pile above bed level) and the structural integrity of the pile field is uncertain. It is a question of the designer’s judgement as to what course of action is chosen. One of the main advantages of pile fields is that localised undermining of the riverward end of the structure can occur without rendering the whole structure ineffective. The designer will need to consider the material that the pile field is constructed on and its angle of repose under saturated conditions to determine how much of the berm may be removed by the formation of a scour hole at the end of the pile field. For example, for a material with an angle of repose of 30 degrees and a 2 metres deep scour hole, the hole will extend (horizontally) 3.5 metres into the berm. This design scour hole size and shape should be used to design embedment depths and pile stability within the groyne.

6.5.5.4 Design approach

An iterative design approach is required for the design of the pile height, diameter, and embedment. Iterations must be undertaken with pile field location and orientation discussed within the shear stress approach to pile field design. Design steps include:

1. Estimate scour depth at the riverward end of the pile field (refer Section 6.10 Scour depth estimation).
2. Select trial pile diameter based on available timber (typically 200mm dia.).
3. Check pile stability and embedment depth based on design velocity and impact loads (refer Section 6.6 for design of pile stability).
4. Identify total pile length required (exposed pile height above channel bed + scour depth + embedment) (Section 6.5.9).
5. Modify pile field arrangement, if necessary, based on available timber.

6.5.6 Vegetation design

Native vegetation plays an essential role in the success of pile field strategies. The establishment of vegetation along the bank, through revegetation and natural regeneration, can help provide long term stability to the system, beyond the design life of the piles.

The timber piles will decay through time and depending on their size and species and the local environment can have a useful life of between 10 and 20 years. Beyond this time, the stability of the site will be wholly reliant on the vegetation established within the pile field embayment’s.

Therefore, the pile field based approach to sediment and erosion management should not be undertaken without a complementary vegetation establishment and management program. Information on native vegetation establishment can be found in the DEECA output delivery standards (DELWP, 2015a). Information on what plants to use can be found in regional revegetation guides.

6.5.7 Other design considerations

Emphasis has been given in the Guidelines to the most common uses of groynes. The principles described will have application to other situations. However no definitive guidance can be given for aspects such as spacing of pile fields to prevent point bar cut-off. In these circumstances the best guide to practice is experience.

Additional considerations in pile field design include:

- Where pile fields are likely to become impermeable through debris accumulation, consideration may be given to constructing the pile field so that it is angled downstream of the vertical. This has the effect of moving any plunge pool, resulting from weir type overtopping, away from the foundation of the structure.

- Where the pile field abuts the existing bank line, it should be excavated into the bank to a distance at least twice the pile field height. The excavation should be backfilled with selected material and compacted. Where practical, rock protection upstream and downstream is desirable.
- Rock or other means of direct bank protection may also be required at the upstream and downstream limits of the pile field to ensure stability of the approach or departure alignment.
- Situations will exist where pile driving is difficult or impossible, although this will not be common in most waterways suited to alignment training. Where pile driving is not a realistic possibility other forms of anchorage could be installed or an alternative method used such as rock groynes. Remember that the loads being designed for are typically horizontal and not vertical.
- Native vegetation is a vital aspect in the long-term stabilisation of the channel bank and area protected by the pile fields. Appropriate steps must be taken to promote vegetation in conjunction with pile field implementation. The faster the vegetation becomes established the lower the likelihood of failure of the pile fields.

6.5.8 Field notes

6.5.8.1 Construction

Excavation of a pilot channel may be the first stage of construction to divert water away from the works area.

To minimise turbidity downstream:

- Commence near the downstream end excavating a pilot channel to form an island. Leave downstream intact, and work upstream as to not engage the pilot channel. Before making upstream cut to engage the channel, remove the downstream block and finally upstream section to allow flow down the pilot channel.
- Bund flow between island and bank at most convenient place and complete building of construction platforms.
- Try not to shift material in flowing water.
- Use the material excavated from the pilot channel to form a berm.
- Piles are often driven from the top of the bank.
- Benches of bed material (berms) may be constructed along or adjacent to the line of a pile field to facilitate access during construction. Upon completion these should be modified to have some minor topography as this will assist in the revegetation of the embayment’s. Small hollows of 0.3 metres are recommended. These should be isolated hollows and not form a line which might concentrate flow during an event.

Set out requirements include:

- Riverward (toe) and landward coordinate of each pile field; and
- Riverward (toe) and landward coordinates for bank reprofiling (if applicable).

6.5.8.2 Maintenance and monitoring

- Check for accumulation of debris which may either overload the structure or reduce its permeability. Clear debris if necessary.
- Check for evidence of scour at the structure which may indicate that the structure is not sufficiently permeable. Adjust if necessary or place scour protection.
- Check for signs of abutment failure and correct as necessary.
- Encourage vegetation in embayment's between structures. This should take the form of planting or direct seeding upon completion of construction with follow up planting to fill areas where the vegetation did not become established initially.
- Check the structural integrity of the pile fields. This includes broken piles and scour holes. These have proven to be areas that require a systematic check at regular intervals.

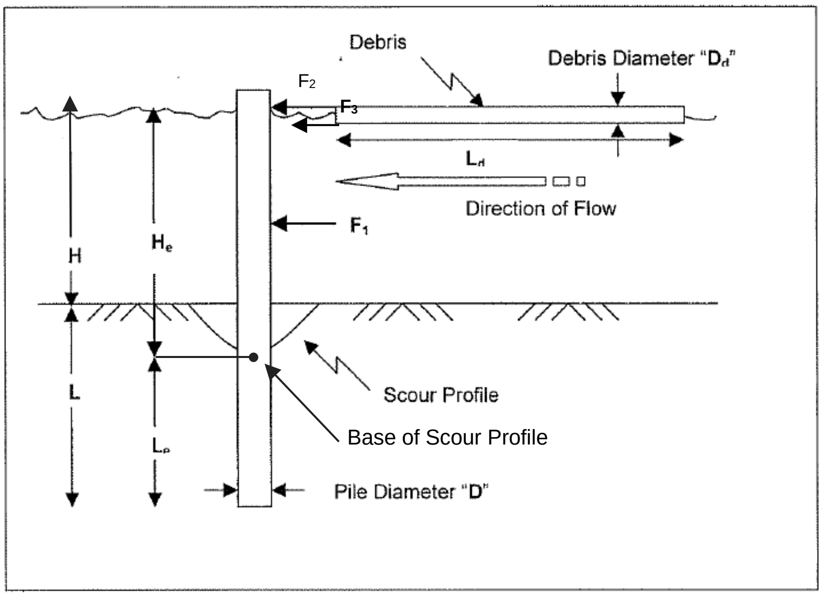
6.5.9 Supporting computations: pile stability analysis

This design method enables the determination of pile diameter and depth of embedment based on the estimated drag, impact and resistant forces applied to a pile within a waterway. It is suitable for the design of short, unrestrained piles in cohesionless soil used in waterway management applications.

This method does not allow for dissipating factors including deflection, impact load applied to multiple piles, shock absorption by the bed material and cushioning by smaller trapped debris. This method also assumes that failure will occur when the soil yields along the total length of the pile and the pile rotates as a unit, such that the selected timber material will not rupture due to its loadings. However, these should be acknowledged and could be accommodated into the analysis by the designer.

The forces acting on a timber pile are shown in Figure 63. The method is adapted from the simplified Broms method (Broms 1964) that is provided in *Bridge Design Specifications* (NAASRA 1976).

Figure 63. Forces acting on a timber pile (from NAASRA, 1976).



Where:

Symbol	Parameter	Notes
H	Pile height above ground	Before scouring occurs
H_e	Effective pile height	Allows for exposure due to scour
L	Pile embedment	Minimum required length
L_e	Effective pile embedment	Minimum required length allowing for scour
D	Diameter of pile	Minimum required diameter
V	Velocity of water	Design velocity
L_d	Length of debris	Estimated
F_1	Drag force on pile	No accumulation or impact
F_2	Debris impact force on pile	Assumed debris mass
F_3	Drag due to accumulated debris	
D_d	Diameter of debris	Debris assumed to be circular

Broms method (Broms 1964) assumes that the lateral soil reaction is equal to zero to a depth of 1.5D below the ground due to a decrease in soil shear strength from repetitive loads, however this is intended to be accommodated for in the base of scour profile estimation. A method for the estimation of scour depth is provided in Section 6.10.

Equations and parameters relevant to determination of pile diameter and depth of embedment are summarised below.

6.5.9.1 Load due to river flow – F_1

Determine the horizontal force F_1 due to the velocity of the water in the waterway. The calculation assumes that the water velocity is constant irrespective of water depth.

$$F_1 = \frac{C_d A \rho V^2}{2} \quad \text{N} \qquad \textbf{Eq. 1}$$

Where:

C_d	=	Coefficient of Drag (1.2 for a cylinder)	
A	=	area over which the force acts. In this case it acts along the entire exposed length of the pile H_e*D H_e = initial height of pile above the soil = H + estimated scour depth	m^2
ρ	=	Unit weight of water 1,000	kg/m^3
V	=	Velocity of flow	m/s

Note: It is assumed that head loss at the pile is negligible, and water deflects at 45° to the flow around either side of the pile.

6.5.9.2 Load due to impact from debris – F_2

Pile design should allow for impact due to debris where anticipated and has been based on the National Association of Australian State Road Authorities (1976). The equation assumes elastic deformation of a pile on debris impact and is described below. The greater the flexion, the greater the stopping distance of the debris and therefore the lesser the force experienced by the pile and the supporting bed material.

$$F_2 = \frac{m V^2}{2 S} \quad \text{N} \qquad \textbf{Eq. 2a}$$

Where:

S	=	Stopping distance (maximum pile deflection)	m
m	=	Mass of debris	kg
V	=	Velocity of debris Assume to be the same as the velocity of the water	m/s

In conjunction with the calculation for Maximum Deflection (**Eq. 10**), the load due to impact from debris can therefore be given by

	F_2 =	$\sqrt{\frac{3mV^2EI_{xx}}{2 * {H_e}^3}}$	N	**Eq. 2b**
Where:	m =	Mass of debris	kg	
	V =	Velocity of debris Assume to be the same as the velocity of the water	m/s	
	E =	Modulus of elasticity of the pile material Refer to Table 21. Minimum Mpa values for Australian unseasoned and seasoned hardwood timber for relevant Standards Australia timber code for strength group for Australian hardwood timber.	Mpa	
	D =	Assumed diameter of pile	m	
	I_{xx} =	Second moment of inertia	m^4	**Eq. 9**
	H_e =	Effective Pile Height	m	

6.5.9.3 Load due to drag from trapped debris – F_3

Flow conditions and pile height and spacing may encourage debris to become trapped and an additional drag force to be imposed. For design purposes, debris may be assumed to become trapped to create a near impervious barrier to flow within the top 1 metre of an exposed pile. Pile spacing (gap between piles) may be assumed to be equal to the pile diameter. The resulting equation is outlined below:

	F_3 =	$\frac{C_d A \rho V^2}{2}$	N	**Eq. 3**
Where:	C_d =	Coefficient of drag (1.2 for a cylinder)		
	A =	area over which the force acts. In this case it is assumed to act only on the top 1 m of the pile A = 1*2*D	m^2	
	ρ =	Unit weight of water 1,000	kg/m^3	
	V =	Velocity of flow	m/s	

6.5.9.4 Resulting load

The resulting load is the combined force acting upon the exposed effective pile height.

	$\mathbf{P}$ =	$F1 + F_2 + F_3$	N	**Eq. 4**
Where:	F_1 =	Load due to river flow	N	**Eq. 1**
	F_2 =	Load due to impact from debris	N	**Eq. 2**
	F_3 =	Load due to drag from trapped debris	N	**Eq. 3**

6.5.9.5 Moment at base of scour profile – M_{He}

The moment is taken along the effective pile height, from the point at which the effective pile is first exposed after expected scouring has occurred.

	$\mathbf{M_{He}}$ =	$\frac{F1*H_e}{2} + F_2*H_e + F_3*(H_e - 0.5)$	N.m	**Eq. 5**
Where:	F_1 =	Load due to river flow	N	**Eq. 1**
	F_2 =	Load due to impact from debris	N	**Eq. 2**
	F_3 =	Load due to drag from trapped debris	N	**Eq. 3**
	H_e =	Effective Pile Height	m	

6.5.9.6 Eccentricity of total force above the base of scour profile

Determine the eccentricity of the combined lateral loads above the base of scour profile.

	$\mathbf{E}$ =	$\frac{M_{He}}{P}$	m	**Eq. 6**
Where:	M_{He} =	Moment at base of scour profile	N.m	**Eq. 5**
	P =	Resulting load	N	**Eq. 4**

6.5.9.7 Embedment depth

The simplified Brom's Method provided in *The Civil Engineering Handbook* (Chen and Liew 2002) can be used for determining the required pile embedment of a short, free-headed pile in cohesionless soil. Typical values for internal angle of friction and material are provided in Table 20.

The result is obtained by taking the moment about the base of scour profile to determine L_e.

	P =	$\frac{GDL_e^3 \tan^2((\frac{\pi}{4}+\frac{\varphi}{2})°)}{2(e+L_e)}$	N	**Eq. 7**
Where:	P =	Resulting load (N)	N	**Eq. 4**
	G =	Saturated density of the foundation soil Typical dry density values are provided in Table 20 Increase these by 40% for saturated density	kg/m^3	
	D =	Assumed diameter of pile	m	
	L_e =	Effective length of pile embedded in the river after expected scouring has occurred See Figure 63	m	
	φ =	Angle of internal friction of soil Typical values in Table 20	°	
	e =	Eccentricity of total force above base of the scour profile	m	**Eq. 6**

The required initial pile embedment is therefore calculated by accommodating for the estimated scour depth determined at the beginning of computations.

	L =	$L_e + (H_e - H)$	m	**Eq. 8**
Where:	L_e =	Effective length of pile embedded in the river after expected scouring has occurred	m	**Eq. 7**
	H_e =	Effective Pile Height	m	
	H =	Height of pile before scouring occurs	m	

Table 20. Typical values of soil internal friction angle and densities (from Merritt *et al.*, 1995).

Typical Values	**Material condition**	**Angle of internal friction $\Phi°i$**	**Density kg /m^3**
Coarse sand or sand and gravel	Compact	40	2242
Coarse sand or sand and gravel	Loose	35	1441
Medium sand	Compact	40	2082
Medium sand	Loose	30	1441
Fine silty sand or sandy silt	Compact	30	2082
Fine silty sand or sandy silt	Loose	25	1361
Uniform silt	Compact	30	2162
Uniform silt	Loose	25	1361
Clay-silt	Soft to medium	20	1440-1922
Silty clay	Soft to medium	15	1440-1923
Clay	Soft to medium	0-10	1440-1924

6.5.9.8 Second moment of inertia – I_{xx}

It is assumed that generally the piles will have circular cross-sections.

6.5.9.8.1 Circular Section

$$I_{xx} = \frac{\pi D^4}{64} \quad \text{mm}^4 \qquad \textbf{Eq. 9}$$

Where: D = Estimate diameter of pile m

6.5.9.9 Maximum deflection

Determine the maximum deflection, assuming the pile is a cantilevered structure loaded at the end by the debris and in the middle by the river. The upper part of the pile deflects from the base of the scour profile.

Given that the pile is not acting as a structural member, there are no recommendations for maximum deflection so long as the deflection does not render the pile ineffective.

$$S = \frac{F H_e^3}{3 E I_{xx}} \quad \text{m} \qquad \textbf{Eq. 10}$$

Where:	F =	Force causing the deflection	N
	I_{xx} =	Second moment of inertia	m^4
	H_e =	Effective pile height above base of scour profile	m
	D =	Assumed diameter of pile	m
	E =	Modulus of elasticity of the pile material Refer to Table 21. Minimum Mpa values for Australian unseasoned and seasoned hardwood timber for relevant Standards Australia timber code for strength group for Australian hardwood timber.	Mpa

Table 21. Minimum Mpa values for Australian unseasoned and seasoned hardwood timber

Minimum values (Mpa) for green (unseasoned) timber

Strength group	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Rupture modulus	103	86	73	62	52	43	36
Elastic modulus	16,300	14,200	12,400	10,700	9,100	7,900	6,900

Minimum values (Mpa) for seasoned timber

Strength group	**SD1**	**SD2**	**SD3**	**SD4**	**SD5**	**SD6**	**SD7**	**SD8**
Rupture modulus	150	130	110	94	78	65	55	45
Elastic modulus	21,500	18,500	16,000	14,000	12,500	10,500	9,100	7,900

(Source: Strength groups and stress grades)

6.5.9.10 Embedment depth calculation method

Determining to what depth the selected timber must be buried to withstand the loading of the waterway is an iterative calculation. It is recommended that a spreadsheet is set up so that results are automatically updated as different lengths are trialled for suitability.

6.5.9.11 Example table of minimum pile diameter and embedment depths

Example pile diameters and embedment depths have been developed for a range of exposed pile lengths, stream velocity and impact loads, approximated to the nearest half-metre (Table 22). The following values were assumed for the estimation of pile diameter and embedment depth given in Table 22.

- Factor of safety of 1.5 on embedment depth analysis (following calculation of L).
- Factor of safety of 1.4 (bed grade) on initial pile diameter estimation.
- Dry bed material density of 1,450 kg/m^3.
- Bed material internal angle of friction of 35°.
- Modulus of elasticity of timber pile of 12,000 Mpa.
- Assumed scour depth of 1.5D.
- Minimum pile embedment (after scour) of 1 m.
- Minimum pile diameter of 100 mm (excluding sapwood).

Table 22 is a guide only under the conditions listed above. Where these conditions vary, site specific design should be undertaken.

Table 22. Minimum pile diameters (MPD, mm) and embedment depths (MED, m) for given loadings, exposed pile height and flow velocities.

Load on pile	**Exposed pile height, H (m)**	**Flow Velocity (m/s) 1**	**Flow Velocity (m/s) 1.5**	**Flow Velocity (m/s) 2**	**Flow Velocity (m/s) 3**
Flow only	**1**	100 MPD	100 MPD	100 MPD	100 MPD
Flow only	**1**	1.0 MED	1.5 MED	2.0 MED	2.5 MED
Flow only	**2**	100 MPD	100 MPD	100 MPD	100 MPD
Flow only	**2**	1.5 MED	2.0 MED	2.5 MED	3.5 MED
Flow only	**3**	100 MPD	100 MPD	100 MPD	100 MPD
Flow only	**3**	2.0 MED	2.5 MED	3.0 MED	4.5 MED

Load on pile	**Exposed pile height, H (m)**	**Flow Velocity (m/s)** **1**	**Flow Velocity (m/s)** **1.5**	**Flow Velocity (m/s)** **2**	**Flow Velocity (m/s)** **3**
Flow + Debris	**1**	100 MPD	100 MPD	100 MPD	100 MPD
Flow + Debris	**1**	1.5 MED	2.5 MED	3.0 MED	4.0 MED
Flow + Debris	**2**	100 MPD	100 MPD	100 MPD	150 MPD
Flow + Debris	**2**	2.0 MED	3.0 MED	3.5 MED	5.0 MED
Flow + Debris	**3**	100 MPD	100 MPD	100 MPD	150 MPD
Flow + Debris	**3**	2.5 MED	3.0 MED	4.0 MED	5.5 MED
Flow + Debris + 100 kg debris impact	**1**	100 MPD	150 MPD	200 MPD	350 MPD
Flow + Debris + 100 kg debris impact	**1**	1.5 MED	2.5 MED	3.5 MED	5.0 MED
Flow + Debris + 100 kg debris impact	**2**	100 MPD	150 MPD	200 MPD	300 MPD
Flow + Debris + 100 kg debris impact	**2**	2.0 MED	3.0 MED	4.0 MED	5.0 MED
Flow + Debris + 100 kg debris impact	**3**	100 MPD	150 MPD	200 MPD	300 MPD
Flow + Debris + 100 kg debris impact	**3**	2.5 MED	3.5 MED	4.5 MED	6.5 MED
Flow + Debris + 1,000 kg debris impact	**1**	350 MPD	500 MPD	600 MPD	NA* MPD
Flow + Debris + 1,000 kg debris impact	**1**	3.0 MED	4.0 MED	5.0 MED	NA* MED
Flow + Debris + 1,000 kg debris impact	**2**	250 MPD	400 MPD	550 MPD	700 MPD
Flow + Debris + 1,000 kg debris impact	**2**	3.0 MED	4.0 MED	5.5 MED	7.5 MED

Load on pile	Exposed pile height, H (m)	Flow Velocity (m/s) 1	Flow Velocity (m/s) 1.5	Flow Velocity (m/s) 2	Flow Velocity (m/s) 3
Flow + Debris + 1,000 kg debris impact	**3**	200 MPD	400 MPD	450 MPD	650 MPD
Flow + Debris + 1,000 kg debris impact	**3**	3.0 MED	4.5 MED	5.5 MED	8.0 MED

(* Exceeds practical design limits)

6.6 Wood stability analysis

This section of the Guidelines provides a method for the stability analysis of large wood and engineered log structure installations. The method outlined below has been broken up to into two methods:

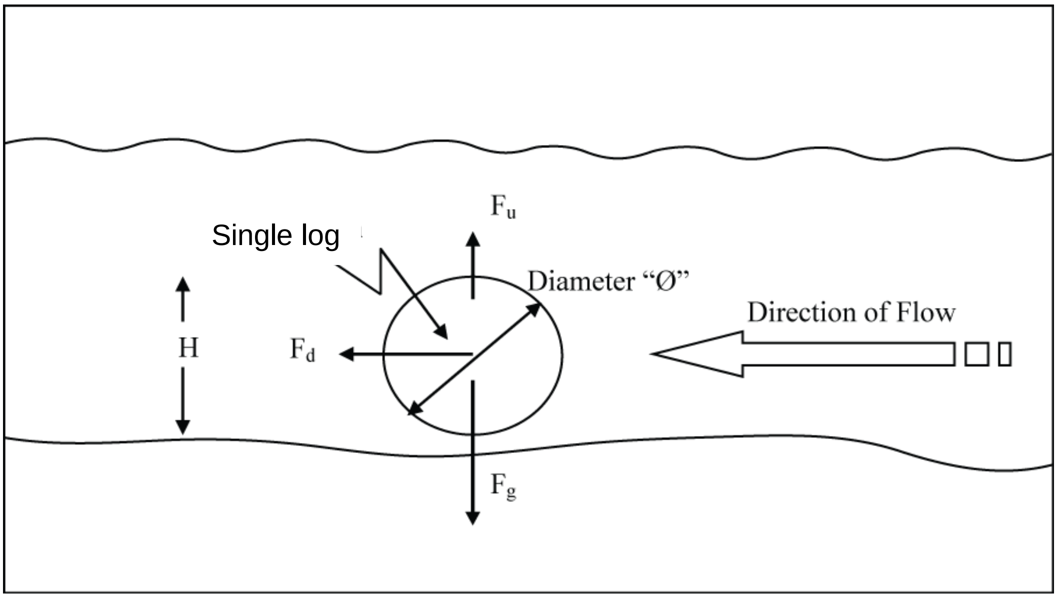
1. Single log configuration.
2. Engineered log jam configuration.

The calculation method for each of these is similar and is described below. The method identifies the load on the timber and when combined with the pile stability analysis provided in Section 6.5.9 can be used to identify the depth of embedment of timber elements necessary to prevent movement of the timber.

6.6.1 Single log

The various forces acting on a single log are shown in Figure 64 and can be used to calculate the resultant force, which can be used to determine the sizing and embedment of piles for the pining the logs in place.

Figure 64. Forces acting on a single log.



Ø	Diameter of log	Use the average diameter
A	Area of log	Where the log is less circular
L	Length of log/log jam	
H	Height of log jam	
V	Velocity of water flow	
F_g	Force due to gravity	
F_u	Force due to uplift	
F_d	Force due to drag	

In these calculations it is assumed that while the log is resting on the channel bed, water can still flow underneath it as well as above it.

6.6.1.1 Drag force

To calculate the drag force acting on the log the following equation is used.

$$F_d = \frac{C_d V^2 L\varnothing}{2} \qquad \textbf{Eq. 13}$$

Where:

C_d = Co-efficient of drag (refer to typical values in Table 23)

Assume 1.2 for field timber

V = Velocity of flow

$L\varnothing$ = Area of the log jam perpendicular to the flow.

If the logs are not round, but more oval, this equation should become length x height where height refers to the height of the log or log jam.

Table 23. Typical values for coefficient of drag (from Streeter and Wylie, 1979)

Shape	**Value C_d**
Circular cylinder	1.2
Elliptical cylinder 2:1 4:1	0.6-0.46
Elliptical cylinder 2:1 4:1	0.23-0.29
Triangular cylinders (With Apex =120^o)	2.0
Triangular cylinders (With Apex =120^o)	1.72
Square (Solid Square)	2.0
Square Square Lattice	1.2

6.6.1.2 Uplift force

To calculate the uplift force acting on the log the following equation is used:

$$F_u = \frac{C_u V^2 L\text{Ø}}{2} \qquad \textbf{Eq. 14}$$

Where: C_u = Co-efficient of uplift (Assume a worst case value of 1.0)

V = Velocity of flow

$L\text{Ø}$ = Area of the log jam parallel to the flow.

If the logs are not round, but more oval, this equation should become L*W (where W is the width of the log)

6.6.1.3 Force of gravity

To calculate the force of gravity acting on the log the following equation is used:

$$F_g = G*A*L \qquad \textbf{Eq. 15}$$

Where: G = Saturated density of timber (Typical values in Table 24)

A = Cross-sectional area of log

For circular logs

$$= \frac{\pi\phi^2}{4}$$

L = Length of log

Table 24. Typical density of material

	Density (kg/m^3) Green
York Gum	1185
Stringybark	1100
Sugar Gum	1105
Spotted Gum	1150

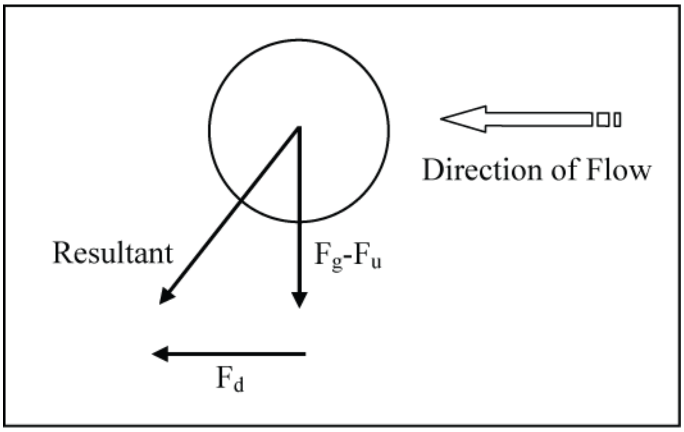
Assume that the saturated density of the timber is about 20% greater than the selected density. If the log is Stringybark (green) then density = 1.2*1100.

6.6.1.4 Calculation of resultant force

Calculated resultant force (Figure 65) can be used in the pile stability analysis provided within 6.5.9 to determine the depth of embedment required to restrain the timber log in place.

It is anticipated that no additional restraint will be required for individual pieces of timber that remain wet and partially buried within most waterway systems.

Figure 65. Calculation of resultant force.



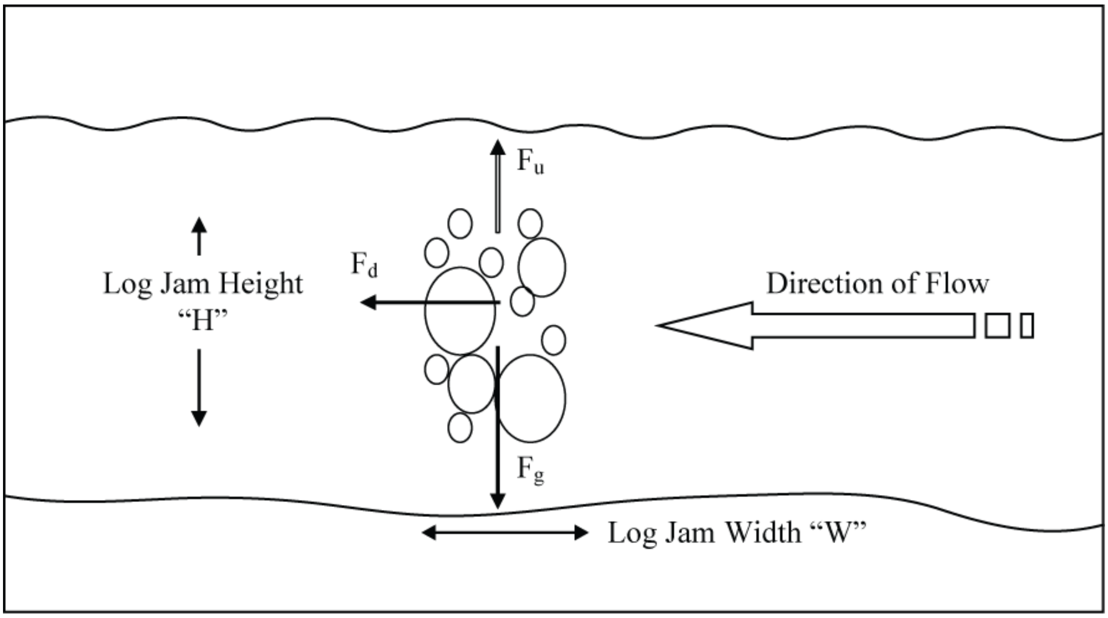
Where:

Resultant force = $\sqrt[2]{\{F_d^2+(F_g-F_u)^2\}}$ **Eq. 16**

6.6.2 Engineered log jam

When multiple logs are used to construct an engineered log jam, they may not always be keyed into the bank. This calculation determines the depth of piles required to restrain an engineered log jam. Forces acting on log jam are illustrated in Figure 66.

Figure 66. Forces acting on log jam.



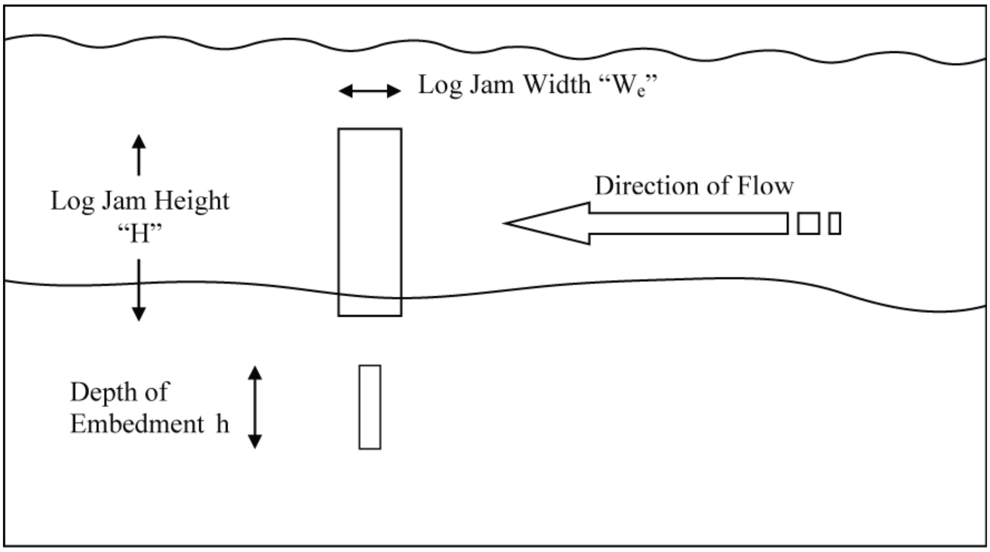
W	Width of log jam	Use the average width
H	Height of log jam	
A	Area of log jam	This is the total area occupied by logs and does not include the voids
L	Length of log jam	
V	Velocity of water flow	
F_g	Force due to gravity	
F_u	Force due to uplift	
F_d	Force due to drag	

In this case an equivalent structure should be determined with:

- Equivalent height of the log jam.
- Equivalent cross-sectional area.

The resulting structure for calculation purposes is shown in Figure 67.

Figure 67. Resulting structure for calculation purposes.



W_e	Equivalent width of log jam	Determine the actual cross-sectional area of the log jam and create an equivalent structure such that $A=H*W_e$
H	Height of log jam	
L	Length of log jam	
h	Depth of embedment	
V	Velocity of water flow	

6.6.2.1 Horizontal force due to water

Determine the horizontal force (F_d) due to drag of retaining the water behind the engineered log jam.

If a scour profile is assumed, substitute the effective length and height of the pile for the actual in all of the calculations.

F_d is the horizontal force on the log jam per lineal metre of log-jam.

$$F_d \text{ equals } \frac{C_d V^2 H}{2} \text{ (kN/m)} \qquad \textbf{Eq. 17}$$

Where:

C_d equals Co-efficient of drag

Typical values in Table 23

V equals Velocity of flow

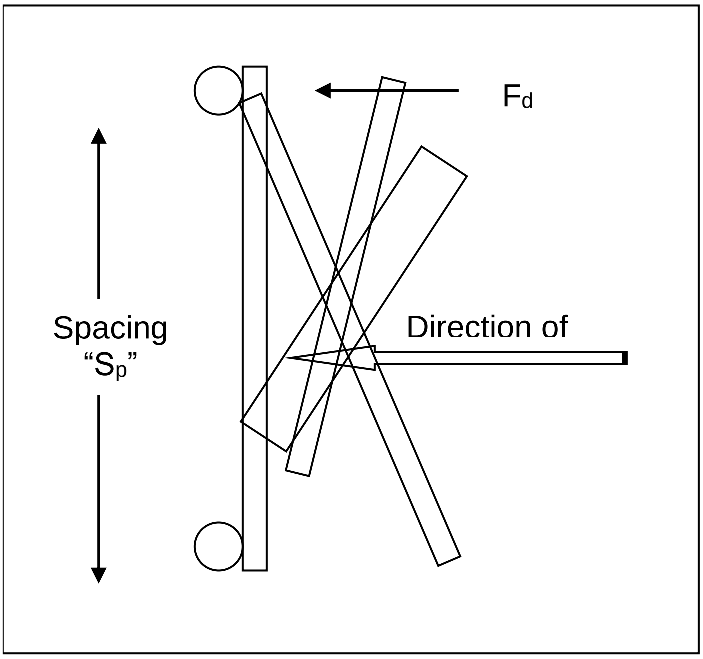
H equals Area of the log jam perpendicular to the flow.

6.6.2.2 Force due to uplift

While there will be an uplift force associated with an engineered log jam, for simplicity it is assumed to be negligible.

6.6.2.3 Horizontal force per pile

Figure 68. Horizontal force per pile holding the log jam in place.

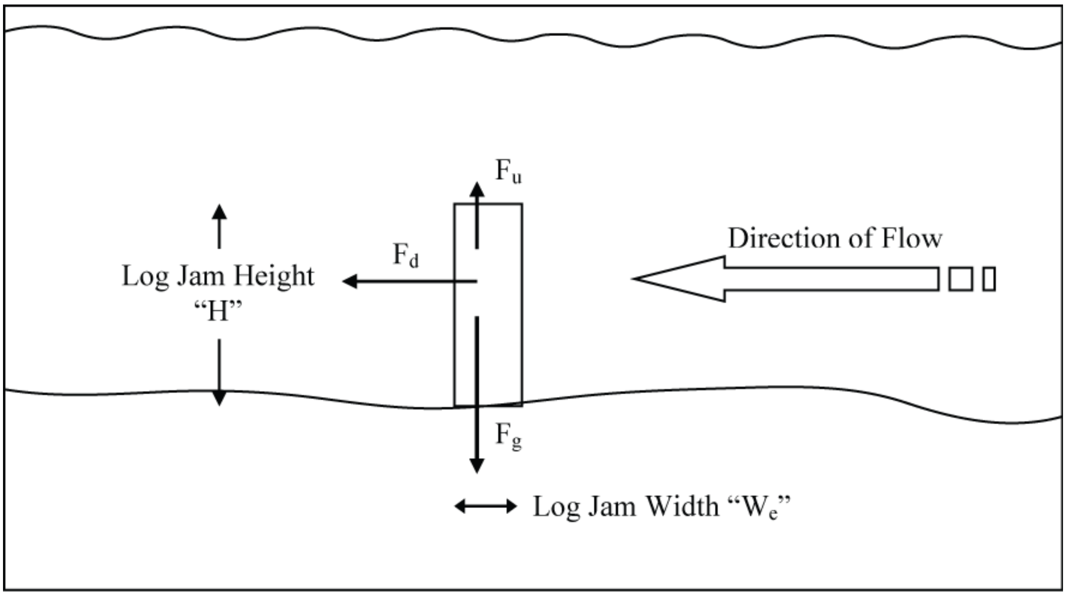


$$F_h = \frac{F_d * L}{\text{(number of piles)}} \qquad \textbf{Eq.18}$$

6.6.2.4 Calculation method

This calculated horizontal force can be used in the pile stability analysis provided in Section 6.5.9. Design of Timber Piles to determine the depth of embedment required to restrain the engineered log jam.

Figure 69. Horizontal force used in the pile stability analysis to hold the log jam in place.



6.7 Rock chute design

6.7.1 Overview

A rock chute is a relatively short and steep section of the bed of a channel which has been armoured with rock. It is normally intended to either stabilise a headcut and prevent it from moving upstream in the channel, or to reduce the overall bed grade of a channel.

A rock chute offers a form of drop structure that can provide for fish passage, and minor channel adjustments without complete failure. Rock chutes are a preferred means of grade control within incising waterway systems. An application is illustrated in Figure 70.

A recommended approach to the design of a grade control program for an incised channel using rock chutes is set out below. The strategy design is based on inclusion of native vegetation within the system to provide for the long-term stability of the system. The design approach includes the assessment and design of system stability based on channel bed gradient and a selection of hydraulic parameters.

Figure 70. Barwidgee Creek, north east Victoria, six months (left) and 10 years (right) after rock chute construction and revegetation (Images courtesy of T. McCormack, North East CMA).

6.7.2 Design considerations

6.7.2.1 Objectives

Grade control structures are sometimes necessary to address incision, and reaches with bed grades steeper than the design bed grade. Structures could comprise rock chutes, log sills, grass chutes and other drop structures. These options are discussed in Part 3 of the Guidelines. However, the rock chute structure is considered the most robust structure for grade control programs and the remainder of this discussion is based on this technique.

The objectives of individual rock chute design are to ensure that:

- Positioning addresses current bed grade instabilities and hydraulic parameters.
- Chute geometry and rock size are matched with expected flow conditions so that the rock remains stable under the design conditions.
- Abutment treatment prevents the chute failing by outflanking at the crest.
- The grading of sizes within the rock mixture minimises the presence of voids and minimises the area of individual rocks exposed to forces from the flow.
- Chutes are located where they can serve their function most efficiently and effectively.

Rock chute design must consider the stable bed grade, hydraulic parameters, design flow event/s, rock chute dimensions, and fish passage. These design elements are discussed below.

6.7.2.2 Bed grade

A design bed gradient (grade) for the waterway can be identified by:

- Reviewing bed grades in adjoining stable reaches (i.e. reaches not subject to ongoing erosional instabilities).
- Comparison with other channel bed grades found for similar waterways (refer Section 5.3.2).

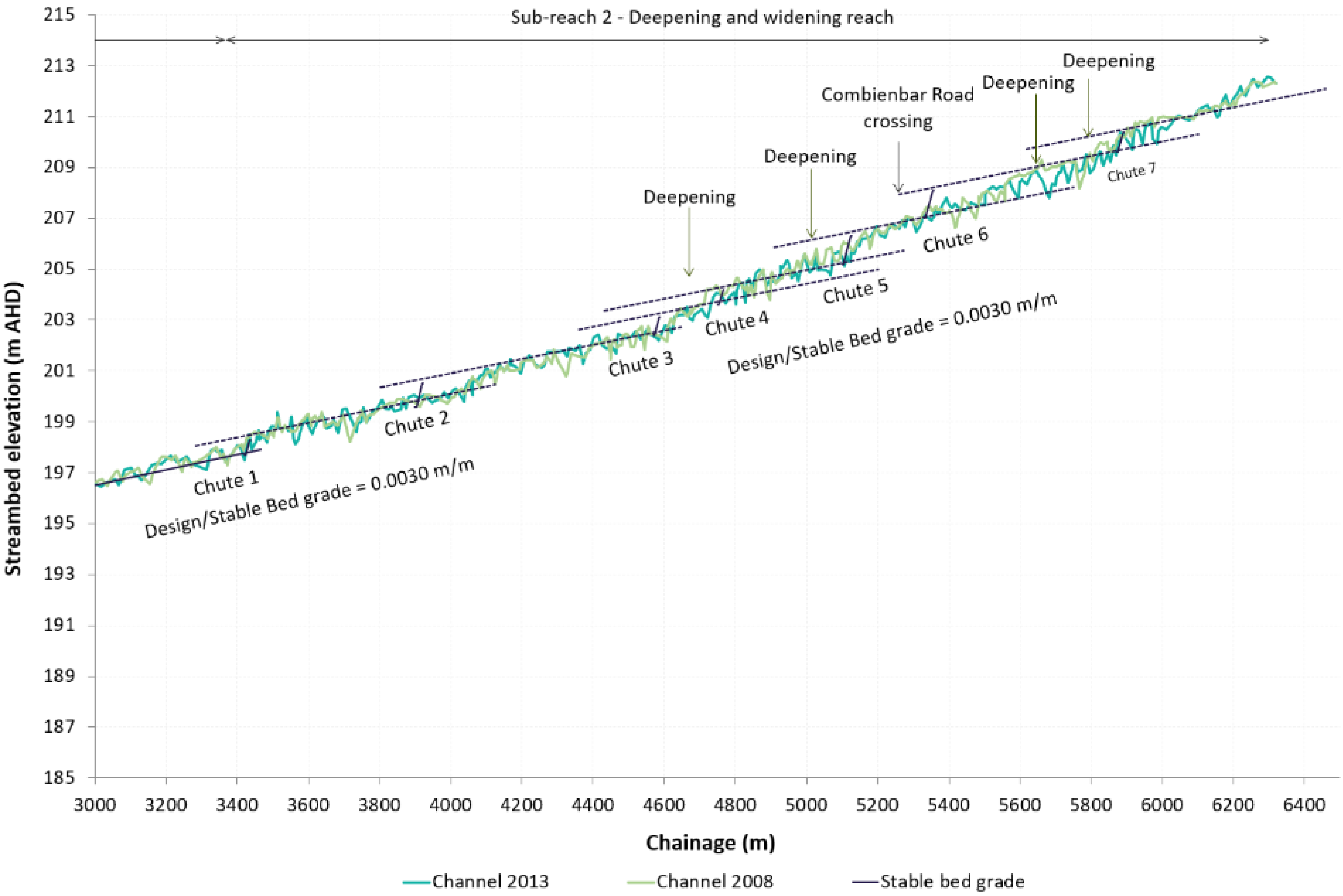
This analysis relies on the results of the channel bed grade longitudinal analysis undertaken for the stream (See Section 5.3.2.)

Once a design bed grade has been adopted a range of chute height and location options can be explored to identify the most economical solution. The site selection and arrangements for structures should include consideration of the following:

- As a minimum, individual structures should be located and sized such that the grade between the crest of one structure and the apron of the next upstream structure is at or below the design bed grade.
- Avoid chute heights (or drops) greater than 2 m.
- Preferably structures should not be located on bends.
- Avoid structures in wide cross-sections as they may attract additional expense of embankments to confine flow.
- Avoid structures in narrow cross-sections as they may require greater excavation volumes and may present design challenges due to the size of rock required for the hydraulics in such narrow waterways.
- Suitable abutment conditions must be available to allow secure abutment construction.
- Access and other construction considerations may significantly increase costs at some sites.
- Bridges, crossings, pump sites and existing vegetation may place further restrictions on sites.
- Location of tributaries and overland flow paths must be considered.
- Sites must allow provision of bypass for flows which exceed the design flow event.

An example chute layout for an incised waterway system is shown in the Figure 71.

Figure 71. Longitudinal profile showing design bed grades, and proposed chute locations.



6.7.2.3 Hydraulic parameters

Grade control structures are intended to provide a level of stability for low flow events; enabling the establishment of native vegetation to provide stability in larger events and in the long term.

A specific stream power analysis can be undertaken to increase the level of confidence in the design approach and shear stress analysis undertaken to assess the resistance of specific features to erosion forces.

The stream power analysis can be used to assess whether the system is likely to achieve sediment continuity and the shear stress analysis to design individual features. Both analysis can be used to provide confidence that vegetation establishment is achievable and to ensure that establishing vegetation is not undermined in more extreme flood events. Further information on the stream power and shear stress analysis and their application to the development of an incised management strategy can be found in Section 3.4.2 of these Guidelines. Further information on undertaking such analysis can be found in Section 5.3.3 of the Guidelines.

The final stage of the design approach comprises the design of individual elements such as rock chutes, vegetation establishment and channel roughness. Some iteration of the design steps may be required to meet rock size limitations and other constraints identified through the design of the individual elements.

6.7.2.4 Design flow event

The flow event adopted for the design of the chute will be a function of the level of security required against rock movement and chute failure. Higher design flow events may be adopted where failure has a high consequence, such as in urban areas with difficult access for reconstruction and with high public visibility. It is not uncommon for chutes with high consequence of failure being designed for all flow events up to the 1% AEP event. A lower design flow event may be adopted for structures of lower consequence of failure. It is not uncommon for rock chutes in rural areas to be designed for flows up to and including the 5% AEP event.

However, it is worthwhile noting that the design flow event may be governed by the upstream channel capacity. A limited upstream channel capacity may limit the maximum flow in the subject waterway and over the subject grade control structure to a flow considerably less than the 5 or 1% AEP design event. In such circumstances it may be appropriate to design the grade control structure for the maximum capacity of the upstream channel.

Care should also be taken to ensure that overland flows that bypass the grade control structure do not create scour at any points of re-entry to the main channel. Additional grade control or gully control structures may be required to assist control of scour at entry points for overland flow.

6.7.2.5 Rock chute sizing

The hydraulic design program CHUTE has been developed for the design of rock chute structures used for stabilising waterways (CHUTE). The program provides a means to determine the rock chute dimensions (length, width and drop), bank angle and D_{50} rock size required for a stable structure. Design is based on maintaining a hydraulic jump on the structure for all events up to, and preferably beyond, the design event. The design input parameters for the software package include:

- Rock density and angle of repose.
- Factor of safety for design.
- Hydrology.
- Trial dimensions of the chute (width, length and drop) and apron (length and rise).
- Downstream channel depth.

Achieving appropriate tailwater conditions is a critical element of rock chute design. Rock chutes should be designed with tailwater conditions to ensure, in design event flows, the chute is either drowned out, or the hydraulic jump is contained on the chute (i.e. on the hardened erosion resistant rock boundary). Failure to achieve appropriate tailwater conditions will cause the hydraulic jump to occur downstream of the chute, which will result in bed and bank scour, and ultimately, failure of the chute. CHUTE provides four options for downstream boundary depth calculation including rating table, normal depth, y crit +10%, and average normal and y crit. Where possible, it is recommended that the rating table depth calculation approach is used, as this is considered the most accurate approach.

An example of CHUTE input data, input rating table, and results is shown in Table 25 to Table 27.

Table 25. Example CHUTE input table.

CHUTE - Input Table

About

A design program for rock chutes for stabilisation of river grade and prevention of headward erosion

Input Table			
Variable Name	Allowed range	Value	Units
Chute Drop	0.1-20	1.6	m
Chute Length	1-200	40	m
Apron Rise	0-10	0	m
Apron Length	1-100	3	m
Flowrate (minimum)		0.1	m^3/s
Flowrate (maximum)		8.73	m^3/s
Chute Width		3	m
Rock Angle of Repose	30-44	42	degrees
Specific Gravity of Rock	1.5-3.0	2.65	
Factor of Safety	1.0-3.0	1.3	
Critical Depth (min)	calculated	0.048	m
Critical Depth (max)	calculated	0.952	m
Chute Slope	calculated	0.040	
Apron Slope	calculated	0.000	

Input Warnings	Ok
	Ok
	Ok

Downstream Channel Input Table			
Variable Name	range	Value	Units
Bed Slope		0.0034	
Roughness (mannings n)	0.01-0.1	0.05	
Downstream Width (if known)		3	m

Choices for downstream boundary depth calculation

- (●) Rating Table
- ( ) normal depth
- ( ) y crit +10%
- ( ) average normal and ycrit

RUN

Table 26. Example CHUTE input rating table to guide tailwater depths

Rating Table Information for Channel Downstream of Chute

Input Table

Enter rating table data as (Q, h) pairs

Flowrate Q m³/s	Water level h m	q m³/s/m	h m
0.1	1.74	0.033333	1.74
1.1	1.74	0.366667	1.74
2.1	1.74	0.7	1.74
3.1	1.75	1.033333	1.75
4.1	1.75	1.366667	1.75
5.01	1.77	1.67	1.77
5.86	1.89	1.953333	1.89
6.27	2.17	2.09	2.17
6.68	2.35	2.226667	2.35
7.09	2.45	2.363333	2.45
7.5	2.53	2.5	2.53
7.91	2.58	2.636667	2.58
8.32	2.65	2.773333	2.65
8.73	2.78	2.91	2.78
9.14	2.86	3.046667	2.86
9.55	2.95	3.183333	2.95
9.96	3.03	3.32	3.03
10.37	3.11	3.456667	3.11
10.78	3.19	3.593333	3.19
11.19	3.24	3.73	3.24
			0
			0
			0
			0
			0
			0
			0
			0
			0
			0
			0
			0

Output table

Flow Range for Testing

q	h
0.03	1.74
0.32	1.74
0.61	1.74
0.90	1.74589
1.18	1.75
1.47	1.75692308
1.76	1.80783529
2.05	2.08190244
2.33	2.42902439
2.62	2.5747561
2.91	2.78

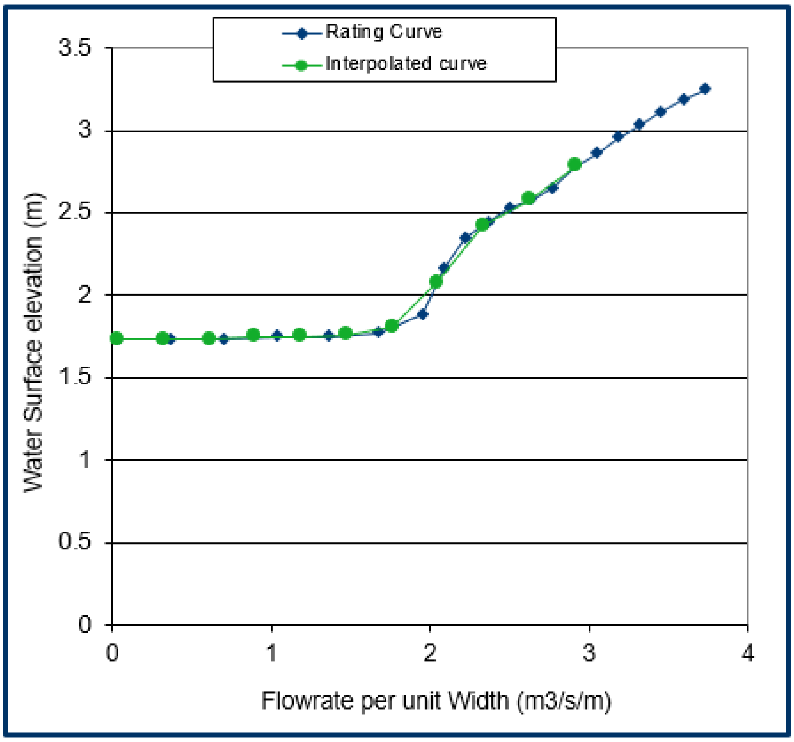


Table 27. Example CHUTE results.

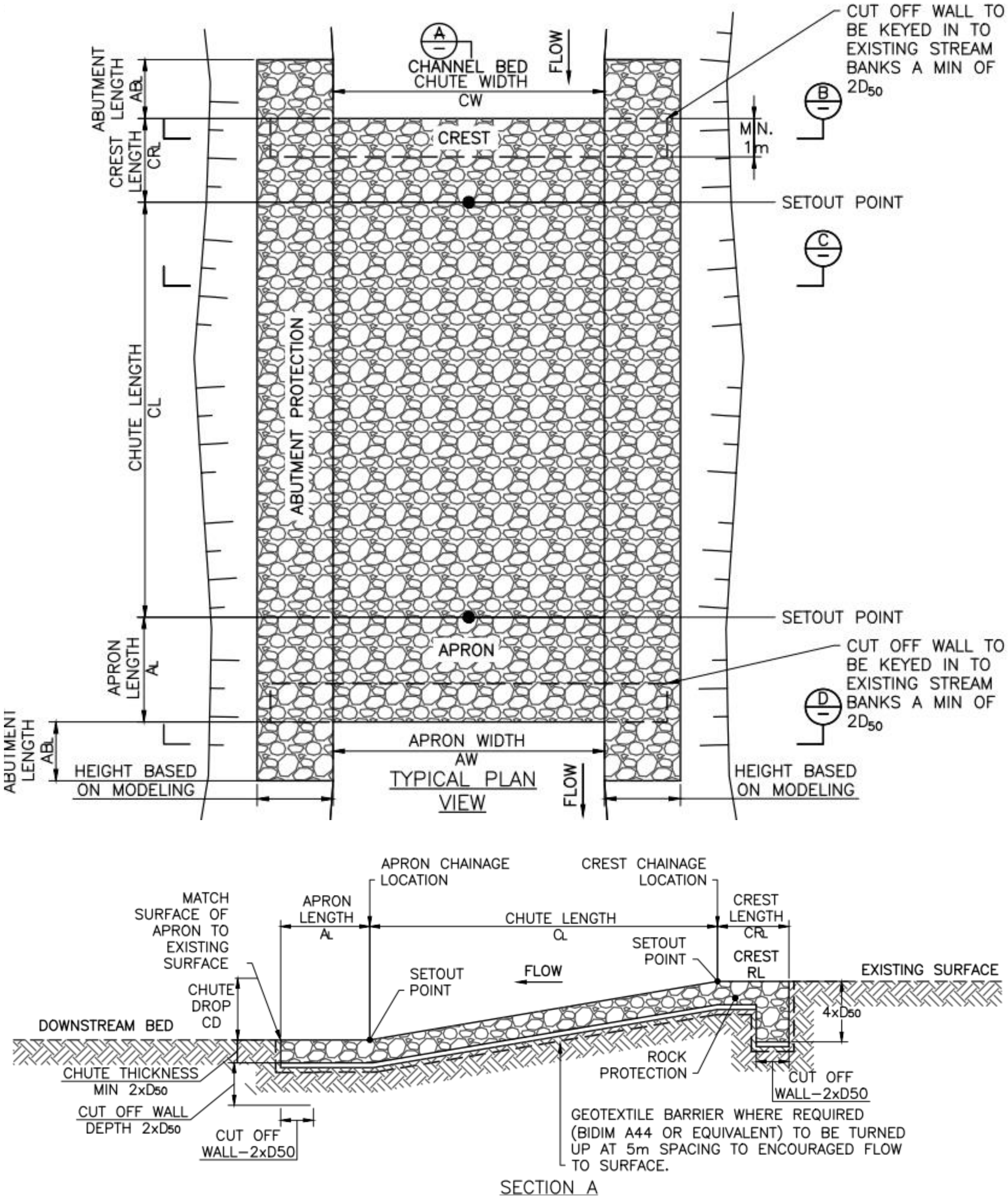
Results																	
Calculations for range of flows				d/s boundary depths			Specific Energy			Jump Conditions							
Q	d50 Normal	d50 Calc.	Bank Angle	used	rating tbl.	critical	u/s	d/s	extra	scenario	description	Location	depth	y conj.	Loss	friction loss
0.10	22	0	21	1.740	1.74	0.0484	0.14	1.74	0	1	chute drowned	0.000	0.000	0.000	0.000	0.000
0.96	99	95	21	1.740	1.74	0.2190	0.329	1.742	0	2	jump in chute; OK	5.136	0.155	0.299	0.016	0.171
1.83	152	149	21	1.740	1.74	0.3355	0.503	1.746	0	2	jump in chute; OK	9.654	0.236	0.460	0.026	0.331
2.69	197	193	21	1.746	1.7459	0.4343	0.651	1.759	0	2	jump in chute; OK	13.282	0.305	0.596	0.034	0.458
3.55	237	233	21	1.750	1.75	0.5228	0.784	1.773	0	2	jump in chute; OK	16.481	0.367	0.718	0.041	0.570
4.42	274	270	21	1.757	1.7569	0.6044	0.907	1.793	0	2	jump in chute; OK	19.275	0.424	0.830	0.048	0.666
5.28	309	303	21	1.808	1.8078	0.6808	1.021	1.856	0	2	jump in chute; OK	20.760	0.478	0.934	0.053	0.712
6.14	342	326	21	2.082	2.0819	0.7531	1.13	2.131	0	2	jump in chute; OK	16.641	0.533	1.026	0.055	0.544
7.00	373	323	21	2.429	2.429	0.8221	1.233	2.476	0	2	jump in chute; OK	10.360	0.598	1.096	0.047	0.310
7.87	403	332	21	2.575	2.5748	0.8883	1.332	2.628	0	2	jump in chute; OK	8.976	0.656	1.171	0.045	0.260
8.73	432	310	21	2.780	2.78	0.9522	1.428	2.836	0	2	jump in chute; OK	5.674	0.732	1.213	0.031	0.161

Typical plan and section views of a rock chute are shown in Figure 72. Considerations for design include:

- Specification for rock quality and grading.
- Thickness of the rock layer.

- Possible incorporation of a fixed crest within the rock structure.
- Details of filters required.
- Details of cut offs.
- Treatment of abutments.

Figure 72. Typical rock chute plan and sections.



6.7.2.6 Fish passage

Rock chutes should typically be designed and constructed to provide fish passage. Rock chutes should be constructed at a grade no steeper than1:25 to enable fish passage where required. In addition, chutes should be constructed with a low flow channel within which deeper flow depth and resting pools can form to enable fish passage. Relevant documents include:

- *Guidelines for the design, approval and construction of fishways* (O'Connor *et al.,* 2017a) – provides specific advice on the design of rock chutes for fish passage.
- *Performance, Operation and Maintenance Guidelines for Fishways and Fish Passage Works* (O'Connor *et al.* 2015) – provides fishway and fish passage performance, operation and maintenance guidelines, including a framework for developing site-specific guidelines.
- *Monitoring the performance of fishways and fish passage works* (Jones and O'Connor 2017) – provides methods for monitoring fishway performance, including consistent methods allowing fishways to be benchmarked against each other.

6.7.3 Rock specifications

6.7.3.1 Rock gradation

Rock used in chute construction should be a well graded mixture designed to ensure that all interstices between large rocks are filled with rock of a progressively smaller size. This has the combined effect of:

- Ensuring that no significant voids occur in the chute through which underlying material could be washed out.
- Ensuring an interlocking mass of rock in which no individual rock is free to move by itself.
- Creating a shielding effect on the surface of the riprap to avoid high drag forces that occur when individual rocks protrude into the flow.

An example rock gradation is summarised in Table 28 (Source: Guidelines for the Design of Rock Chutes using CHUTE, CRC for Catchment Hydrology 2003).

Table 28. Suggested rock chute rock gradation.

Equivalent spherical diameter*	Percent (by weight) smaller size
1.5 – 2.0 times D_{50} **	100%
D_{50}	50%
0.3 – 0.4 D_{50}	10 – 20%
0.1 D_{50}	< 5%

* The diameter of a sphere with an equivalent volume to the individual rock.

** D_{50} is the median riprap diameter of the rock mix (i.e. 50% (by weight) is smaller and 50% (by weight) is larger).

The above grading has been found to produce a rock matrix within rock structures which enables the interlocking of individual rocks, reducing mobilisation during flow event. Furthermore, the grading has been found to work well with granular filter materials, preventing the loss of such filter material through the rock matrix.

When specifying rock gradation to field staff and contractors, it has been found helpful to convert this grading by weight into an equivalent grading by number. This greatly assists in visualising and testing the rock mixture to be achieved. Methods for the identification of rock size are provided in Section 6.9.

6.7.3.2 Rock quality and shape

Rock for chute construction should be hard, tough and durable. It should have a crushing strength of a least 25 Mpa. The rock should be free of defined cleavage planes and should not be adversely affected by repeated wetting and drying.

Rock should preferably be predominantly angular in shape with not more than 25% of rocks, distributed through the gradation, having a length more than twice the breadth or thickness. No rock should have a length exceeding 2.5 times its breadth or thickness. Where rock fails to meet this specification, it may still be used in some cases at the designer’s discretion provided allowance is made in the design for its shortcomings.

Rock to meet size and strength criteria will normally be won from a hard rock quarry by drilling and blasting. If available, a hydraulic rock breaker mounted on a hydraulic excavator provides an excellent means of producing rock to design size gradation.

A material guide for rock is provided in Section 6.8.

6.7.3.3 Rock placement

The placement of rock during construction has been found to be an important determinant in the structural integrity of rock chutes. Tightly packed rock structures built through the careful and selected placement of individual rocks have been found to be more robust than structures built through mass rock dumping and spreading. Further discussion on the robustness of a trial rock chute can be found in ID&A (1996a).

6.7.4 Filter layer

Filter materials may be necessary to stabilise the rock chute over fine material and where the presence of soil soils may pose a risk to long term subgrade stability. The filter layer prevents material being washed from behind the chute structure through residual interstices in the rock layer.

It is common practice in rural Victoria for rock riprap, graded and sized in accordance with the Guidelines to be placed directly onto bed/bank surfaces. These have been built with high levels of success where sound engineering judgement has been applied. If well graded riprap is designed according to the procedures outlined in the Guidelines then filter material should only be necessary where:

- The underlying material is largely non-cohesive such as a uniform sand.
- The underlying material comprises fill.
- There is evidence of high groundwater levels or seepage areas in the bank profile.
- An unusually high factor of safety is required.

Where one or more of these conditions exists, the need for a filter layer can be further tested using the following criteria:

For stability:

$$\frac{D_{15}\ riprap}{D_{85}\ bank\ material} \leq 5$$

and

$$\frac{D_{50}\ riprap}{D_{50}\ bank\ material} \leq 25$$

For permeability:

$$\frac{D_{15}\ riprap}{D_{15}\ bank\ material} \geq 5$$

Note that the importance of the filter layer will be far greater if the rock grading exhibits a tighter range of sizes than that recommended herein. Design of a granular filter layer is based on the above three conditions applied twice: once between the bed/bank material and the filter layer; and once between the filter layer and the rock.

Where the bank and riprap materials do not satisfy the above criteria the use of a granular or geotextile filter layer may be justified. Note that the importance of the filter layer will be far greater if the design riprap grading exhibits a tighter range of sizes than that recommended herein.

6.7.4.1 Geotextile

Geotextile fabric has been used as an alternative to the use of a granular filter layer and help prevent tunnelling under the chute crest and along the batters. However, several failures including partial failures have been observed where rock has slid on the geotextile. This occurs where the friction between the rock and the filter cloth is less than the internal friction of the rock mix. The most vulnerable designs will be those in which hydraulic forces are not particularly great, allowing the bank angle or chute to be steep, probably close to the natural angle of repose of the rock riprap.

For designs where a flat batter or chute is required to ensure riprap stability against hydraulic forces, then the risk of failure by sliding of the rock on the filter cloth is diminished.

In addition to the above some geotextiles have been found to inhibit vegetation establishment through the rock matrix and into the underlying soil.

The failure mechanism and inhibitor to vegetation establishment have rendered geotextiles to be a less robust and a less desirable filter layer than the granular material. As a consequence, geotextile-based filter layers should be avoided and only used in exceptional circumstances.

However, there will be applications where geotextiles are appropriate. In such circumstances care must be taken to ensure maximum resistance is developed between the riprap and the cloth. This can be achieved by:

- Avoiding preparation of the bank/bed to a smooth and even batter before placing the cloth.
- Not stretching cloth tightly over the underlying bank/bed.
- Avoiding cloths with low friction surfaces.

Engineering judgement should be applied to ensure maximum resistance is developed between the rock matrix and the filter material.

6.7.5 Field notes

6.7.5.1 Construction

- Chutes can be constructed in wet conditions, but construction is simpler if water can be diverted around the site or by-passed using a pump or syphon.
- Excavation by hydraulic excavator is generally favoured.
- Set out requirements include crest location, crest level, apron location, apron level, or batter pegs.
- Spoil from excavation can be spread in the upstream channel, used to form guide banks, or disposed of off-site.
- Variation in rock quality and size must be monitored and compensated for.
- Rock is best placed by hydraulic excavator or equivalent, with care taken to avoid excessive segregation of size fractions, and with the larger rocks at the surface interlocked and bedded with the smaller rock.
- Geotextile will be difficult to handle in wet conditions. Ample spare cloth must be allowed for folding into abutment keys and cutoff trenches where required.
- Ensure that care is taken with abutment treatment.
- The entire works area should be fenced against stock and revegetated with native species.

6.7.5.2 Maintenance and monitoring

- Initial high flows will remove some of the smaller material from the chute surface. Ensure that no significant voids, surface irregularities or loose rocks concentrate flow and threaten the integrity of the rock layer.
- Place additional rock where necessary.
- Some settlement of the rock mass sometimes occurs. Excavate and replace additional rock if the integrity of the rock layer is threatened or where differential settlement creates rills or low areas.
- Guard against vegetation establishing in the chute itself where it may cause acceleration of flow around the obstruction or dislodge rock if it is dragged out during a flood.
- Inspect the chute during high flows to ensure it is performing according to design expectations.
- Carefully inspect abutments for any sign of tunnelling or piping of bank material. Excavate and repair if necessary.
- Regularly inspect the chute face and crest for loss of material and potential unintended channelisation or concentration of flow.

- Monitor bed levels immediately downstream of the chute for scour at the end of the apron. Place additional rock as required.
- Ensure stock are excluded from the site and from reaches of stabilising channel.

Encourage a range of vegetation including grasses, sedges, reeds, together with shrub and upper storey species to assist in ultimate stability of channel.

6.8 Rock beaching design

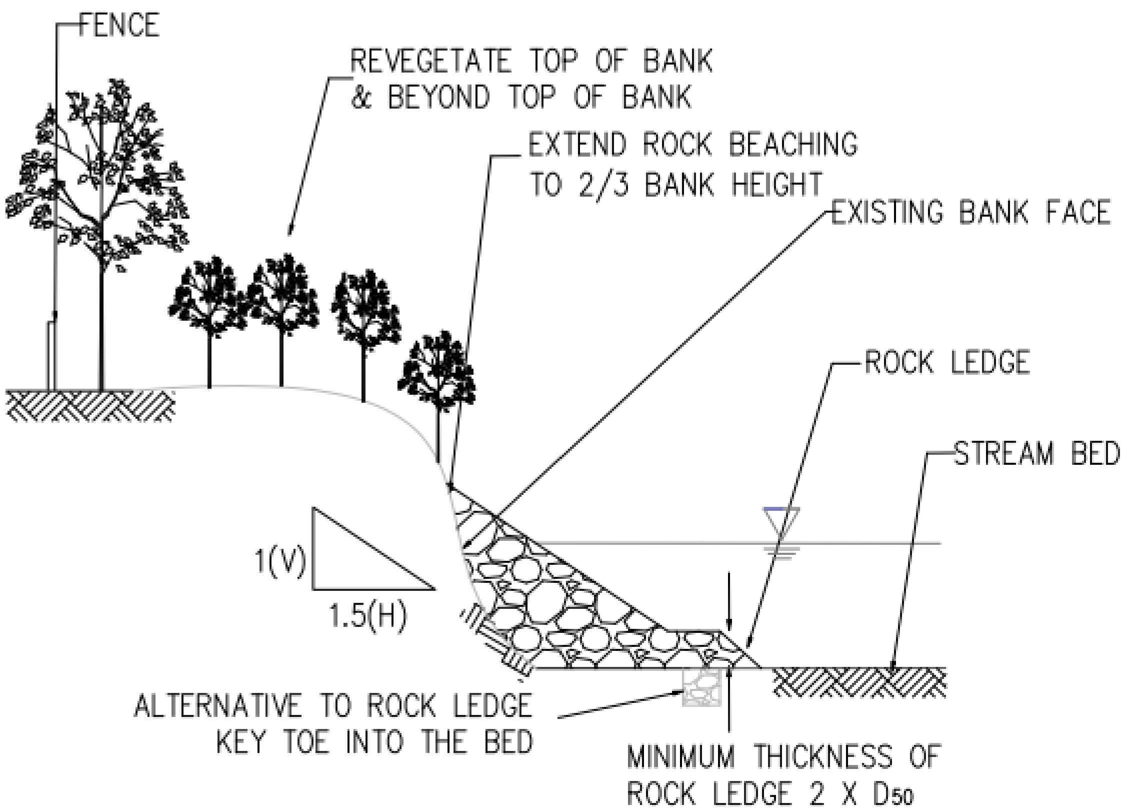
6.8.1 Overview

For the purpose of the Guidelines rock beaching is a layer of sized and graded rock which is placed on a riverbank to protect it from erosion. A typical rock beaching application of the type covered by the Guidelines is illustrated in Figure 73.

Rock beaching is not the preferred method for bank stabilisation in most waterways and should be used only when alternative options such as revegetation or pile fields are unsuitable (for example when a high-value asset lies adjacent to the bank and no bank retreat or meander migration is acceptable, or in very high energy systems where ‘softer’ engineering options are unlikely to succeed).

A recommended approach to the design of riverbank erosion control using rock beaching is set out below. The approach comprises the use of blasted quarry or field rock. The design approach is based on inclusion of vegetation within the system to provide for complementary outcomes and reduce the total cost of works.

Figure 73. Typical rock beaching arrangement.



6.8.2 Objectives

The objective of rock beaching design is to ensure that:

- The rock is of sufficient size to resist movement by the action of flowing water.
- The grading of sizes within the rock mix minimises the presence of voids within the protective layer and minimises the area of individual rocks exposed to forces from the flow.
- A filter layer is provided where necessary to prevent bank material washing out through the protective rock layer.
- The rock extends a distance upstream and downstream which is appropriate to the acceptable level of risk, and the cost of the protection.
- The rock covers a proportion of the bank height (typically 2/3 of the bank height) which is appropriate to the acceptable level of risk, and the cost of the protection.
- The rock extends below estimated scour depth.
- The rock is of suitable quality.

6.8.3 Applicability of design technique

These design guidelines apply to protection of the bank against removal of bank material by the action of flowing water i.e. fluvial scour. They do not apply to protection of banks against mass failure of the bank material as the result of soil processes occurring within the bank material. Mass failure mechanisms may need to be analysed to assist identification of appropriate stabilisation measures to address the mass failure modes. Once mass stability is confirmed, the procedures described herein may be applied to prevent erosion due to flowing water.

Experience has shown that in most riverbank applications, once the stability of the toe of the bank is ensured by rock or other means, catastrophic slip circle failure is unlikely. Notable exceptions are very high banks, and saturated bank conditions such as in a draw down condition associated with the recession limb of floods and regulated waterway operations, or where water ponds on the top of the bank or in the adjacent floodplain. These design guidelines provide general rules for economical design of rock beaching as a measure against bank erosion based on experience principally in rural areas. They will be in conflict with some practices which have been developed for treatments in special situations. For instance, Melbourne Water has historically adopted bank treatment techniques using individually placed, predominantly single sized rock, which will demand far more rigorous attention to filter layers than is suggested herein.

6.8.4 Size of rock

The size distribution of rock riprap can be determined through the application of the RipRap software package. The software package and users guide (CRC for Catchment Hydrology, 2005) are available as a download from RipRap. The users guide provides a background to the software, the theory for rock movement, and design examples.

Input parameters for the software package include rock density, rock riprap angle of repose, maximum depth of flow, energy gradient and factor of safety for design. Critical among these is the estimation of the energy gradient.

6.8.4.1 Design hydraulic energy slope

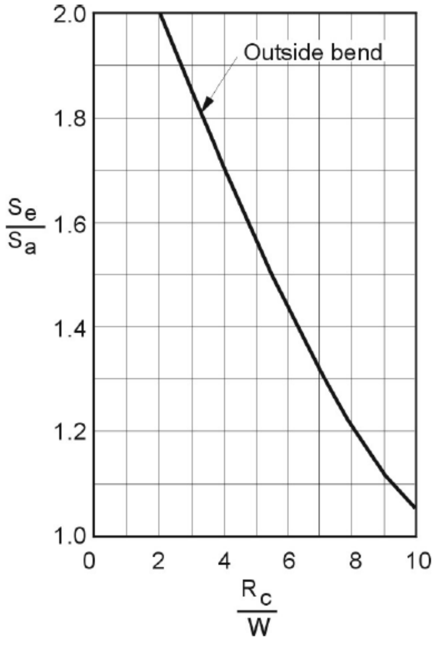
The design hydraulic energy slope or energy gradient is crucial to the determination of the required rock size. The theoretical basis for the computation of the D_{50} rock size provides for a direct proportional relationship between rock size and the adopted energy gradient.

The adopted value must represent the local energy gradient adjacent to the rock beaching. The local slope will vary significantly from the reach-averaged energy gradient at constrictions, bridges, other in-waterway structures and at channel bends. Only in straight channels of reasonably consistent cross-section will the local energy gradient approximate the reach-averaged value. One dimensional hydraulic backwater modelling such as HEC-RAS can be used to assist the determination of the local energy gradient.

The accuracy of the estimate will be dependant on the accuracy of model input. While such modelling may provide for increased energy gradient associated with local constrictions such as bridges it may not be appropriate for increases in energy gradient associated with channel bends.

One dimensional models are unable to model the hydraulic effect of changes in cross-sectional geometry and meander bends. Therefore, on channel bends, a multiplying factor (Se/Sa) should be applied to the reach-averaged energy gradient (estimated as a function of the ratio of the bend radius of curvature (centreline radius) to the channel base width) (Figure 74).

Figure 74. Effect of channel bend on effective energy slope (Adapted from US Soil Conservation Service 1971).



$\frac{S_e}{S_a}$	= Ratio of effective energy slope on the outside of a bend relative to the average energy slope for a reach
$\frac{R_c}{W}$	= Ratio of the radius of curvature of the channel centreline of the bend to the base width of the channel

For the river-end of pile fields and at bridge abutments, work by Maynard (1978) suggests that a design energy gradient of 4 times the reach-averaged value in the channel is appropriate.

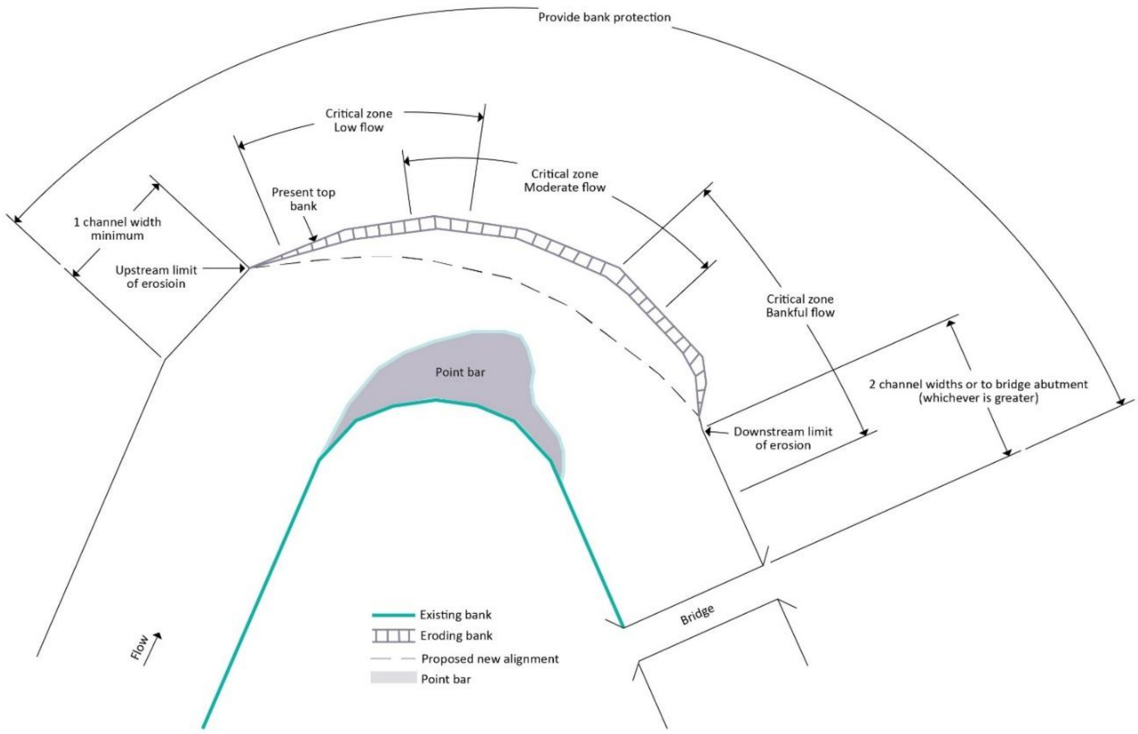
6.8.5 Length of bank to be protected

There are no universally applicable rules to determine the extent of bank protection appropriate to a particular site. It is the responsibility of the designer to assess such factors as cost of protection, acceptable degree of risk, and consequences of failure, for each design case.

A site inspection and an understanding of the mechanisms causing erosion will assist in determining the appropriate length of bank to be treated. Aerial photographs will assist in understanding alignment development at the site. The following guidelines should also assist:

- Flow lines and corresponding points of attack will vary significantly with the flow level. In a meandering waterway the main current lines tend to straighten with increasing flow, and the point of attack on a bend moves downstream. Braided waterways are less predictable.
- Aerial photographs or local knowledge will often assist in determining the history of erosion at the site. A knowledge of past erosion episodes is a valuable indicator of likely future developments (see Section 5.2).
- Erosion on the outside of bends will also move downstream with time. It is desirable to continue erosion protection downstream beyond the limit of existing erosion. As a guide, for treatment of major meander developments, erosion protection should extend by at least two channel widths downstream of any existing instability (where channel width is the distance between banks, not the low flow channel).
- The upstream extent of erosion protection is generally easier to locate. As a guide, for treatment of major meander developments, erosion protection should extend at least one channel width upstream of any existing instability.
- Guidelines for treatment of major meander developments are illustrated in Figure 75. Note that minor meander developments may not require the same extent of bank protection shown here.

Figure 75. Typical upstream and downstream limits to bank protection.



6.8.6 Proportion of bank height to be protected

It is generally not necessary to extend rock beaching protection to the top of the bank unless dictated by special considerations such as the presence of strong over bank flows, upper bank erosion by action of standing waves or prolonged high flows, or high consequences of failure. Experience has shown that protection of the lower two thirds of a bank generally offers optimum protection. The upper one third of the bank can, if appropriate, be treated by less resistant and less expensive techniques (e.g. native vegetation).

However, the proportion of bank height to be protected should always be reviewed in the light of local knowledge and conditions. For instance, if a riverbank is very high, relative to the 50% AEP flow, and flows rarely reach bankfull (i.e. less than once every second or third year), then the height of protection may be reduced. Conversely a very low bank relative to the annual flood may need full protection. An understanding of the mode of failure will also assist in this assessment. For example, if the bank is failing through undermining of the toe and subsequent collapse, then protection of the toe is crucial. However, if the mode of erosion is by fretting at high water levels, then protection at that water level is the most important. In designing major rock beaching works it will be desirable to supplement this guideline with a consideration of the stream longitudinal profile. This will give the designer the additional options of either:

- Ensuring that the height of rock beaching protection represents an average bank profile through the reach; or
- Allowing rock beaching height to vary along the reach to reflect variations in the water surface profile.

6.8.7 Allowance for scour at toe

Many rock beaching failures are caused by undermining of the toe, by scour of the channel bed during high flow events. A method for the estimation of scour depth is provided in Section 6.10.

Rock beaching design can allow for bed scour either by:

- Extending rock beaching protection below the bed level by placing rock in an excavated trench; or
- Providing extra rock at the toe of the bank which can drop down and provide necessary protection following local scour (i.e. self-launching toe).

These techniques are illustrated in Figure 73.

Care must be taken in using the self-launching toe. The response of the rock to settling is unpredictable and is not covered in the theory used for determining rock size. If a graded rock source is being used (as is recommended), the finer material will be susceptible to loss during settlement and allowance should be made for at least 50% loss of rock if this technique is considered.

The importance of allowing for bed scour in rock beaching design varies with the type of waterway. The designer must rely on judgement of the likely severity of bed scour in the particular design situation. This judgement may be aided by using the techniques for estimating scour depths (Section 6.10). The following guidelines may also assist:

- In meandering gravel bed waterways in Victoria, allowance for scour on the outside of bends would generally be made by ensuring generous provision of rock at the toe of the protection works. Additional scour depths beyond the deep holes typical of this situation are likely to be reasonably small.
- In sand bed waterways, scour depths can be several metres in magnitude, particularly if the channel is steep. Allowance for scour is fundamental to successful design.
- Deep scour requiring particular attention will also occur at constrictions, groynes, bridge abutments or other areas of flow disturbance.
- The importance of scour (and the scour depth) increases with increasing channel grade and with increasing depth of flow. It also increases with decreasing bed material size.
- In severe cases, in-channel scour control techniques may be an alternative means of providing rock beaching security.

6.8.8 Rock specifications

6.8.8.1 Thickness of rock protection

The thickness of rock beaching should be at least twice the median rock diameter or equal to the largest rocks in the rock mix, whichever is the greater (Figure 73).

6.8.8.2 Rock gradation and filter

Refer to Section 6.7.3.

6.8.9 Native vegetation establishment

While native vegetation establishment is not required to achieve the structural intent of the rock beaching at the toe of the bank, native vegetation can be used to provide protection to the upper bank. Further vegetation can be incorporated into the design to achieve important ecological outcomes from the works. Information on native vegetation establishment can be found in the DEECA output delivery standards (DELWP, 2015a) and EVC benchmark guides. Information on what plants to use can be found in regional revegetation guides. Vegetation (grasses, sedges, rushes and small shrubs) can generally be successfully established in the voids in rock beaching. This may be further assisted by placement of topsoil over the top of the rock shortly after placement.

6.8.10 Field notes

6.8.10.1 Construction

- Do not tip rock directly over the bank from dump trucks unless a flat batter is required. Rock should normally be carefully pushed over the bank or placed by the bucketful with a front-end loader or excavator.
- Placing rock from the waterway side of the bank from a barge or by loader gives very successful results for the protection of the lower bank and toe.
- Rock should be handled and placed to avoid segregation of size fractions.
- Variations in rock quality and size must be monitored and compensated for.
- If banks which are very uneven can be battered before rock is placed, major savings in rock volumes can be achieved. Be sure to place rock on cut surfaces only, fill must be removed from channel.

6.8.10.2 Maintenance and monitoring

- Check regularly for excessive settling of rock along the rock beaching.
- Check regularly for evidence of scour along the toe of the rock beaching.
- Pay particular attention to the stability of the bank at the downstream end of the riprap.
- Check for evidence of bank slumping associated with overbank flood waters re-entering the channel.
- Encourage a range of vegetation including grasses, sedges, reeds, together with shrub and upper storey species to assist in ultimate stability of channel and to achieve some ecological outcomes from the works.

6.9 Methods for estimating rock size and grading

6.9.1 Overview

It will often be necessary for waterway managers practitioners to estimate the size of rock for waterway management projects. There are three methods used in the estimation of rock sizes in stockpiles and structures. They are:

- Ring grading – commonly used in a quarry.
- Visual guide – used once rock is delivered to site.
- Walk over method – applicable when rock is already placed in a structure or still in rock piles.

6.9.2 Ring grading

Ring grading as a method for determining rock sizes and grading involves categorising rocks according to size by passing them through metal rings of fixed diameters.

The test procedure involves:

1. **Selection of a suitable stockpile of rock for testing.** Rock sample is selected for test that is representative of that proposed for or has been supplied for construction.
2. **Loading and transporting of 16 to 18 m^3 of rock to the test site.** The test sample is photographed in the truck and trailer and the loaded combination is taken to a weighbridge. After weighing, each sample is tipped onto the ground at the site and the mass of the empty truck and trailer checked on the weighbridge.
3. **Sorting of the rock into size ranges.** Samples are then broken into their component size rages with the assistance of an excavator. Eight size ranges are commonly used. Rock would be classified and sorted into size range by comparing their size to a set of standard sized steel test rings.
4. **Determining the mass of rock in each of the size ranges.** Once sorted, each rock size range is heaped, photographed and its mass determined by transporting it over a weighbridge.
5. **Determining overall rock grade.** At the conclusion of each test, all of the rock sample would be re-loaded into the truck and trailer and run over the weighbridge to check the total mass of the rock.

Some difference between initial and final total mass values will most likely occur. For each sample, the final or corrected mass is used as a basis for calculation of mass distribution and size grading. Ring sizes adopted for rock size ranges are detailed in Table 29:

Table 29. Ring sizes adopted for rock size ranges

Rock size ranges	Ring size
Less than 90 mm	90 mm
90 to 145 mm	145 mm
145mm to 190 mm	190 mm
190mm to 300 mm	300 mm
300mm to 450 mm	450 mm
450mm to 600 mm	600 mm
600mm to 900 mm	900 mm
Larger than 900 mm	900 mm

6.9.3 Other methods

Other methods for estimating rock size and grading can be found in:

- *Rock Size Grading 'A Visual Guide'* (ID&A 1996b) which provides photographs of rock from a number of quarries in Victoria.
- *Investigation into Sampling Methods for the Measurement of Rock Riprap in Rock Chutes* (Balshaw 1999) which provides a field-based method for the estimation of rock size on an existing chute.

6.10 Scour depth estimation

6.10.1 Overview

This section provides procedures for the estimation of scour depth. Scour depth is a function of channel bed degradation or aggradation, general scour and local scour.

Numerous approaches to the estimation of scour depth have been developed by researchers, including Farraday and Charlton (1983) and Blench (1969). Many of the approaches have been built into hydraulic modelling software packages enabling their use for scour estimation. These hydraulic packages include HEC-RAS, Mike 11 and Mike 21. In addition, three-dimensional (3D) hydraulic modelling packages have become available, and at some cost, can be used to estimate scour depth. These packages can be used by designers to estimate scour depth for the purpose of design of large wood installations, engineered log jams and pile fields. However, scour depth can also be estimated "long hand" based on an understanding of geomorphic processes and using the original equations, now contained within some of these software packages.

6.10.2 Degradation/aggradation

Degradation and aggradation are the lowering and raising of the bed, respectively over relatively long reaches and long time periods. Quantification of the degradation and aggradation component of the estimated scour depth relies on estimating the sediment supply or transport capacity of the upstream reach and is beyond the scope of this manual.

Refer to Section 5.4 for sediment supply analysis.

6.10.3 General and local scour

General scour refers to a more localised vertical lowering of the channel bed over relatively short time periods. For the purpose of the Guidelines, general scour will be restricted to scour resulting from the contraction of the channel due to the encroachment of bridges or protection works. Local scour results from local disturbances in the flow such as the scour occurring at bridge piers, and abutments.

Two methods are presented for estimating general and local scour:

- Method 1: Farraday and Charlton, 1983
- Method 2: Blench, 1969

Both methods compute the total scour resulting from the summation of general scour and local scour. These methods are restricted to the scour which occurs along banks, abutments and alignment training structures. No methods have been presented for estimating the scour adjacent to bridge piers or piles. HEC-RAS includes a module for the estimation of scour depth at bridge piers.

6.10.3.1 Method 1: Faraday and Charlton equation

Basic equations:

$$y_s = y_2 - y_1$$

$y_1 = A_1 / T_1$ (design depth)

$y_2 = 0.38\ (V_1 y_1)^{0.67}\ D_{50}^{-0.17}$ (Sand bed channels)

$y_2 = 0.47\ (V_1 y_1)^{0.8}\ D_{90}^{-0.12}$ (Gravel bed channels)

$y_2 = 51.4\ n^{0.86}\ (V_1 y_1)\ 0.86\ T_c^{-0.43}$ (Cohesive bed channels)

where:

y_2 is the average depth of general scour measured from the water surface, in metres

y_1 is the design depth equal to A_1 / T_1, in metres

V_1 is the design flow velocity, in metres/second

D_{50} is the size of the bed material, in metres, such that 50% of the stones by weight are smaller

D_{90} is the size of the bed material, in metres, such that 90% of the stones by weight are smaller

n is Manning's roughness coefficient

T_c is the critical tractive stress for scour to occur, in Newtons/square metres, as indicated in Table 30.

T_1 is the average top width for the design flow, in metres

A_1, is the average bankfull flow area for the design flow in square metres.

Procedure:

1. Determine the nature of the bed material as either sand bed, gravel bed or cohesive bed.

2. Select the appropriate equation and compute y_2 may be obtained by factoring the depth y_2 by the multiplier in Table 31.

3. The depth of total scour (y_s) below the channel bed is given by:

Table 30. Critical tractive stress for cohesive bed material.

Voids ratio	**2.0 – 1.2**	**1.2 – 0.6**	**0.6 – 0.3**	**0.3 – 0.2**
Dry bulk density (kg/m^3)	880 – 1220	1200 – 1650	1650 – 2030	2030 – 2210
Saturated bulk density (kg/m^3)	1550 – 1740	1740 – 2030	2030 – 2270	2270 – 2370

Critical tractive stress N/m^2

Types of soil	**2.0 – 1.2**	**1.2 – 0.6**	**0.6 – 0.3**	**0.3 – 0.2**
Sandy clay	1.9	7.5	15.7	30.2
Heavy clay	1.5	6.7	14.6	27.0
Clay	1.2	5.9	13.5	25.4
Loam clay	1.0	4.6	10.2	16.8

Table 31. Multipliers for estimating total local scour.

Nature of Location	**Multiplier**
Nose of groynes and abutments	2.0 – 2.75
Flow impinging at right angles on bank	2.25
Flow parallel to bank	1.5 – 2.0

6.10.3.2 Method 2: Blench equation

Basic equation:

$$y_2 = \left(\frac{q^2}{F_b}\right)0.33$$

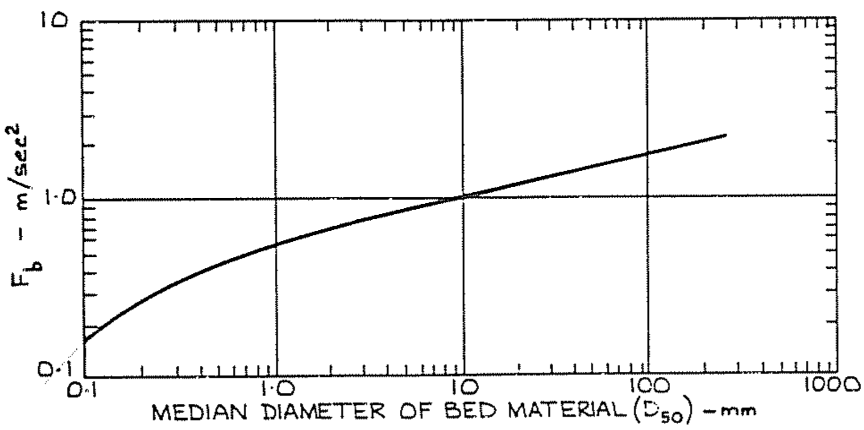
where:

Y_2 is the average depth of scour measured from the water surface, in metres

q is the average design unit discharge, in cubic metres/second/metre adjacent to the subject section

F_b is the Blench’s “zero bed factor” determined from Figure 76

Figure 76. Relationship between Blench zero bed factor and bed material size.



Procedure:

1. Given the channel cross-sectional geometry, determine the average depth of flow y1 for the design discharge by $y_1=A_1/T_1$.
2. Determine the design velocity.
3. Determine $q = V_1 y_1$.
4. From a sieve analysis of the bed material, determine the D50 (mm).
5. Determine F_b using Figure 76.
6. Determine y^2 using the Blench equation.
7. Estimate the maximum scoured depth by multiplying y_2, by the appropriate factor in Table 31.
8. The depth of total scour (y) below the channel bed is given by:

$$y_s = y_2 - y_1$$

6.10.3.3 Summary

It is advisable to compute the total scour by both methods and compare the results. When large differences are obtained, knowledge of the erosion characteristics of the waterway and engineering judgement will be the determining factor. In extreme conditions, scour depths may be excessive as computed by the methods discussed above. Nevertheless, the computed scour depths should be used as the guide. Scour depths in excess of 2 to 5 metres are not uncommon in alluvial waterways.

6.10.4 Safety margins against scour

The equations provided in the preceding section are considered to provide conservative estimates of scour. However, because of the inherent uncertainty of scour estimates and the complex considerations involved, it is difficult to give general guidance on safety margins against scour. Hence, the following factors should be considered in the final analysis:

- Long term trend in aggradation or degradation.
- Reliability of the basic data, especially hydrologic and geotechnical.
- Probability that extreme flows might exceed limits selected for design estimates.
- Seriousness of the consequence of total or partial failure of the protection measures.
- Experience of the designer in comparable situations.
- Additional cost of providing more security.

6.10.5 Natural armouring as a limit to scour

Natural armouring may limit the scour in a gravel bed waterway. The armouring process begins as the non-moving coarser particles segregate from the finer material in transport. The coarser particles are gradually worked down into the bed, where they accumulate in a sub-layer. Fine bed material is leached up through this coarse sub-layer to augment the material in transport. As movement continues and degradation and scour progresses, an increasing number of non-moving particles accumulate in the sub layer. Eventually enough coarse particles accumulate to shield or “armour” the entire bed surface. When fines can no longer be leached from the underlying bed, degradation and scour is arrested.

The potential for the development of an armour layer can be assessed using a representative bed material composition and Shield’s criteria for incipient motion:

$$D_c = \frac{T_c}{0.047\ (Ò_s - Ò)}$$

where:

D_c	is the diameter of the sediment particles in metres for conditions of incipient motion
T_c	is the critical boundary shear stress
Ò and $Ò_s$	are the specific weights of sediment and water.

Assuming a specific gravity of 2.65, the above equation reduces to:

$$T_c = 77.6D_c$$

To determine the size of the armouring particle for a given set of conditions, the critical shear stress is determined by:

$$T_c = \frac{V^2 n^2}{y^{\frac{1}{3}}}$$

where:

V is the design flow velocity in metres/second

n is Manning's roughness coefficient

y is the design flow depth in metres.

6.11 Material selection

6.11.1 Overview

This materials selection guide provides waterway managers with access to information that may assist with the selection and use of materials employed in the implementation of waterway management projects.

Key materials used in waterway management projects include:

- Native vegetation.
- Timber (and large wood).
- Rock.
- Geotextiles.

6.11.2 Native vegetation

Native vegetation is the most useful and effective material available to the waterway manager. Native vegetation is also an essential component of riparian habitat and assists in the provision of instream habitat. Vegetation management can include but may not be limited to livestock management, revegetation, and weed management. Vegetation establishment and management are essential components of all waterway management projects. Further information on native vegetation establishment and management can be found in Section 4.2.2.

Further information on native vegetation establishment can be found in the DEECA output delivery standards (DELWP, 2015a). Information on what plants to use can be found in EVC benchmarks and regional revegetation guides. It is recommended that the EVC benchmarks should be used as an initial guide for species that could occur, but is not a considered a definitive list or planting list. Final selection of plants should be based on site knowledge and the objectives of the work (e.g. increased stability or roughness, provision of shade, increased habitat etc.), which should be considered foremost when selecting species or undertaking revegetation works.

6.11.3 Timber/large wood specification guide

Timber can be successfully used in a number of waterway management applications. However a clear understanding of the issues and of the success factors for the proposed design arrangements are necessary to ensure a successful outcome.

Timber can be used in waterway systems to:

- Induce sedimentation, by increasing roughness.
- Induce channel bed scour by local flow acceleration.
- Provide a stable stream substrate.
- Provide instream, riparian and floodplain habitat.

Applicable techniques include:

- Pile Fields– Pile fields are used to reduce energy in a range of flow events converting sites of scour to create depositional environments suitable for vegetation establishment.
- Large Wood – Single pieces of large wood can be used to increase channel roughness in a similar manner to pile fields.
- Engineered Log Jams – Engineered log jams work in a similar manner to single pieces of large wood. The difference lying in the large hydraulic impact and potential scour holes that can be created through the installation of the log jam.
- Log Sills – Log sills are a form of grade control structure that can be applied to small waterway systems. Log sills are less robust than other forms of grade control (e.g. rock chutes) and may present a barrier to fish passage. Log sills should be used with caution.

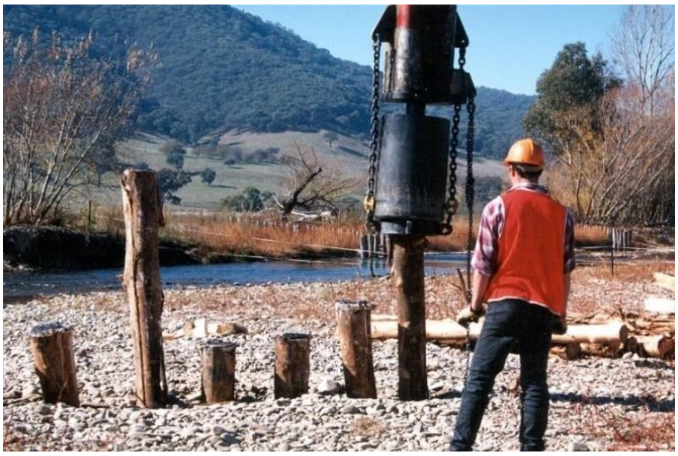
Example specifications to help guide the selection of wood material are provided below:

6.11.3.1 Plantation Timber

Applicable instream intervention techniques

- Pile fields
- Large wood
- Engineered log jams

Figure 77. Timber piles in north east Victoria (Photo courtesy of North East CMA).



Purpose

Plantation timber is used where uniform timber shape is required. This typically comprises piles and pile fields.

Materials selection criteria

Design life of timber

Diameter

Density (hardwood)

Resistance to borer.

Specification

The minimum diameter of the timber poles used in pile fields (without bark) should be 150 mm.

Timber poles shall taper naturally and uniformly. Deviations from straightness may be suitable provided that a line adjoining the mid-point of the butt and of the head should not depart from the centre of the timber pole at any point by more than 50 mm.

The timber poles should be free from live insects that would cause deterioration of the timber (e.g. termites), short crooks, kinks, shakes of all descriptions, fractures, splits at the head, and decay pockets.

The following individual defects can be acceptable:

- grub holes, unless clustered.
- borer holes, provided the sapwood is not extensively damaged.
- termite galleries, provided that the total area at the butt does not exceed 50 mm^2. Enclosed termite galleries shall not be permitted.

- bull end splits not exceeding 3% of the length, provided they extend in one direction only.
- sound knots, in the third nearest the head.
- knot holes in the third nearest the head, less than 10 mm in diameter.

Related information sources

ARI. (2021) Timber for fish: Repurposing timber (removed from road projects) for waterway rehabilitation, Arther Rylah Institute

Brooks, A., Abbe, T., Cohen, T., Marsh, N., Mike, S., Boulton, A., Broderick, T., Borg, D. and Rutherfurd, I. (2006). Design guideline for the reintroduction of wood into Australian streams, Land & Water Australia, Canberra,

Bureau of Reclamation and U.S. Army Corps of Engineers. (2015). *National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure*. 628 pages + Appendix, available Large Wood Design Guidelines - National Manual.

Saddlier, S. (2008). *Techniques for reinstating instream habitat*. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria

6.11.3.2 Large wood

Applicable instream intervention techniques

- Large wood (instream woody habitat)
- Engineered log jams, Snags, Large Woody Debris

Figure 78. Large wood for installation at Harrow, Victoria. (Photo courtesy of Earth Tech).

Purpose

Wood is used for the establishment of instream diversity, creation of habitat and channel bed scour holes.

Materials selection criteria	Design life of the wood Diameter Density (hardwood) Resistance to borer Handling and transport constraints.
Specification	ARI (2021) provides good guidance. Large, green, wood pieces should have the root ball attached where possible and branches should be retained where practicable. Hollow and broken wood is suitable for use as instream woody habitat and engineered log jams, subject to anchorage by embedment as discussed below. Preference should be given to the use of larger debris where possible as it is more stable, more durable and provides generally better habitat but this should not preclude the use of branches down to approximately 150 mm diameter. Native species are to be used as they provide many benefits in addition to their ecological benefits. They are more dense (especially when green), less likely to move and have a much longer life span than that of exotic wood. Exotic species should not be used. They may only be used when the supply of native species is exhausted and there is a significant shortfall in field timber supply. Willows, poplars and declared weed species shall not be used as large wood and engineered log jams. Note that excellent sources of large wood are trees killed by fires, and trees removed for infrastructure projects. Note that 19 different agencies (such as VicRoads) have signed a Memorandum of Understanding about providing wood cleared for road projects for use in rivers (see ARI, 2021). An important consideration is stability. It is possible for large wood to be transported downstream and jam up on bridges, exacerbating flooding. There is a great deal of new literature on this topic (and it is covered in Bureau of Reclamation (2015) as well).

Related information sources	ARI. (2021) Timber for fish: Repurposing timber (removed from road projects) for waterway rehabilitation, Arther Rylah Institute Brooks, A., Abbe, T., Cohen, T., Marsh, N., Mike, S., Boulton, A., Broderick, T., Borg, D. and Rutherfurd, I. (2006). Design guideline for the reintroduction of wood into Australian streams, Land & Water Australia, Canberra Bureau of Reclamation and U.S. Army Corps of Engineers. (2015). *National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure*. 628 pages + Appendix, available Large Wood Design Guidelines - National Manual. Saddlier, S. (2008). *Techniques for reinstating instream habitat*. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria

6.12 Rock

Rock is one of the most common and widely used materials in waterway management projects. Rock can be used in bank erosion control and rock chute grade control structures. However, rock can also be used for the provision of localised instream habitat and flow diversity through boulder seeding. Both quarry rock and field rock can be used for a range of applications. A discussion on the type of rock and its applicability is provided in this section.

6.12.1 Field rock

Applicable instream intervention techniques	Boulder seeding Particularly used in urban areas where a higher aesthetic outcome is required.
Purpose	Field rock can be used for rock structures where a more natural “look” is required. The rounded shape of field rock provides less interlocking than quarry rock and as a result may be subject to movement at lesser forces than that applied to structures comprising quarry rock.

6.12.2 Quarry rock

Applicable instream intervention techniques

- Rock chutes
- Rock beaching
- Rock groynes

Figure 79. Everton Quarry in north east Victoria.

Purpose

Quarry rock is used in the construction of rock structures.

Quarry material may also be used as a filter material.

Materials selection criteria

Rock used for rock chutes, bank protection and abutment protection should be hard, durable, angular in shape, and free from cracks, overburden, shale and organic matter. Thin, slab-type stones, rounded stones, and flaking rock should not be used.

Rock used for abutment protection should meet the durability requirement listed below, when tested in accordance with the specified procedures. Service records of the proposed material may also be useful in determining the acceptability of the rock.

Classifications and gradations for the rock are shown below. The maximum stone size shall not be larger than the thickness of the designed rock layer. Neither breadth nor thickness of a single stone should be less than one third its length.

Specification

Rock durability requirements

Test	Requirements
Relative density (density of dry solid rock relative to water)	Minimum of 2.6
Abrasion (Abrasive Grading A) Los Angeles Abrasion Test (AS 1141.23)	Less than 40% loss of weight after 500 revs

Size specification for rock

Equivalent “sieve” size	Percentage smaller (by weight)
2 times D_{50}	90%
D_{50}	50%
0.3 D_{50}	10%

D_{50} = Median particle size (50% of the mass shall consist of stones with an equivalent spherical diameter equal to or larger than this dimension)

6.12.3 Geotextile – Filter fabric

Applicable instream intervention techniques

Figure 80. Application of geotextiles (Source: S. Cleven).

Purpose

Rock chutes on fine stream bed materials

Geotextile is used as a filter layer to prevent the movement of fine soil materials through the rock matrix.

Materials selection and placement criteria

Geotextiles should be 100% insect, rodent, mildew and rot resistant.

Geotextiles should meet the physical requirements specified below.

Geotextiles should be loosely laid (not stretched) in such a manner to avoid rupture of the cloth.

The Geotextiles should be anchored in place with “U” shaped securing pins placed at 2 metre intervals.

Overlaps of the Geotextiles should be 500 mm and have the upstream layer on top of the next layer downstream.

Full rolls of Geotextiles should be used wherever possible in order to minimise overlaps.

Specification

Physical requirements for non-woven, needle punched polyester geotextile fabric used in rock chute construction:

Test	Unit	Standard	Minimum requirement
Wide strip tensile strength	KN/m	AS3706.2	
Elongation	%	AS3706.2	50%
CBR burst strength	N	AS3706.4	
Trapezoidal tear strength	N	AS3706.3	200
Pore size	Micron	AS3706.7 EOS	130
Flow rate	$L/m^2/s$	AS3706.9	200
Grab tensile strength	N	ASTM4632.86	600
Mullen burst	Kpa	AS2001.2.4	2,100
Drop cone	mm	AS3706.5$H_{50}D_{500}$	1,900
G rating		AS3706.4	2,000

Related information sources

Geotextile Supplies and Engineering

Geofabrics Australasia Pty Ltd

7 Part 7 –Worked example of the four-step decision making process

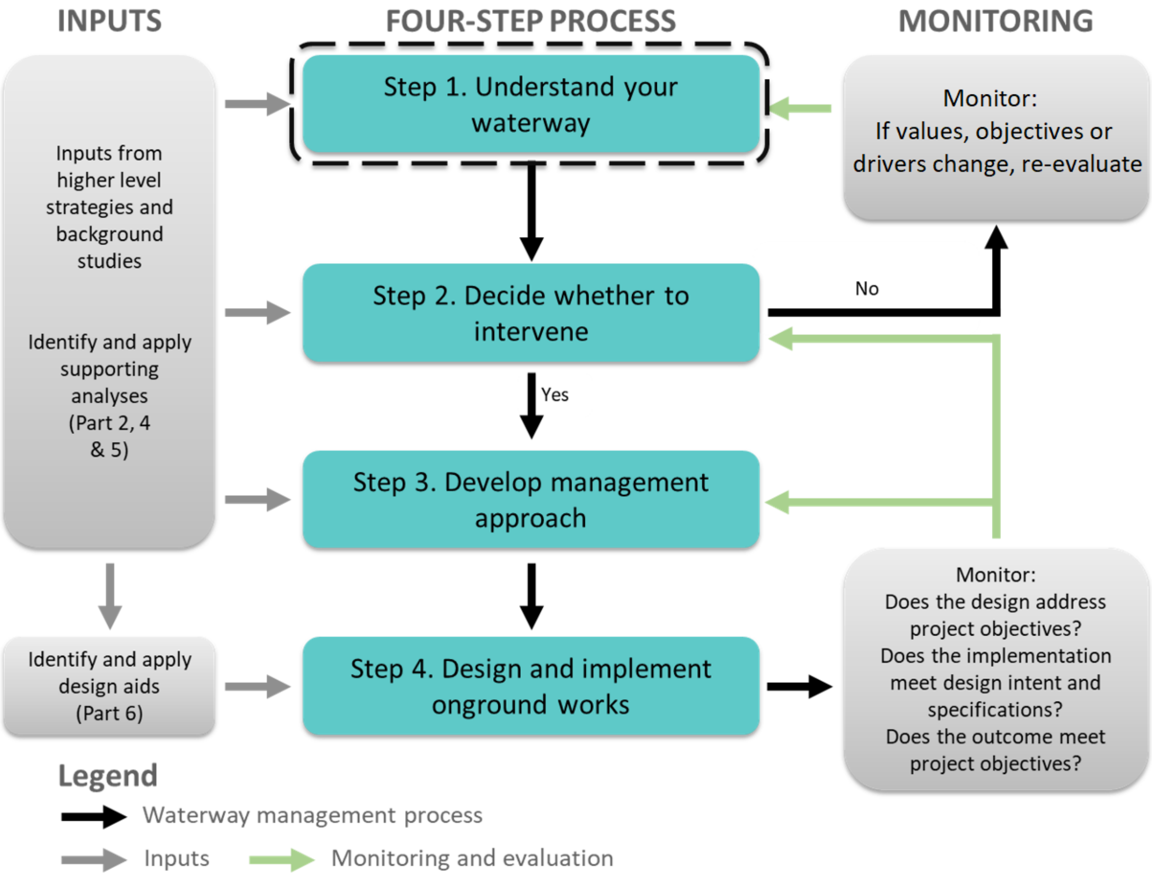
This section of the Guidelines illustrates the application of these four-step process thorough a worked example.

The worked example does not illustrate all necessary components in the development and delivery of a waterway management project. Components, such as the methods for the communication of the project, have not been detailed. Similarly, the example does not include details of relevant legislation and policy that may impact on the development and delivery of the project.

7.1 Step 1: Understand your waterway

The first step in the four-step process is to identify the waterway values at the reach or site, derive agreed objectives to protect these values, understand the geomorphic processes operating within the waterway reach and the threats these pose to the agreed objectives (Figure 81).

Figure 81. Worked Example – Step 1: Identify values at the reach or site.



7.1.1 Project context

Like many projects, the example project has been brought to the attention of a Victorian CMA (herein referred to as the CMA) by a concerned landholder, who has observed that streambank erosion on the Errinundra River is leading to the loss of valuable grazing land. Investigations undertaken in support of the regional waterway strategy have identified that the surrounding floodplain was cleared of vegetation and converted to pasture following colonisation. All floodplain land adjacent the waterway is currently within private property. The waterway at the subject reach has been mapped and classified as a meandering gravel bed river. This stream form is expected to exhibit the behaviour of meander migration as part of natural channel processes (Figure 82, Figure 83 and Figure 84).

Figure 82. Study reach on Errinundra River; showing the six priority sites.

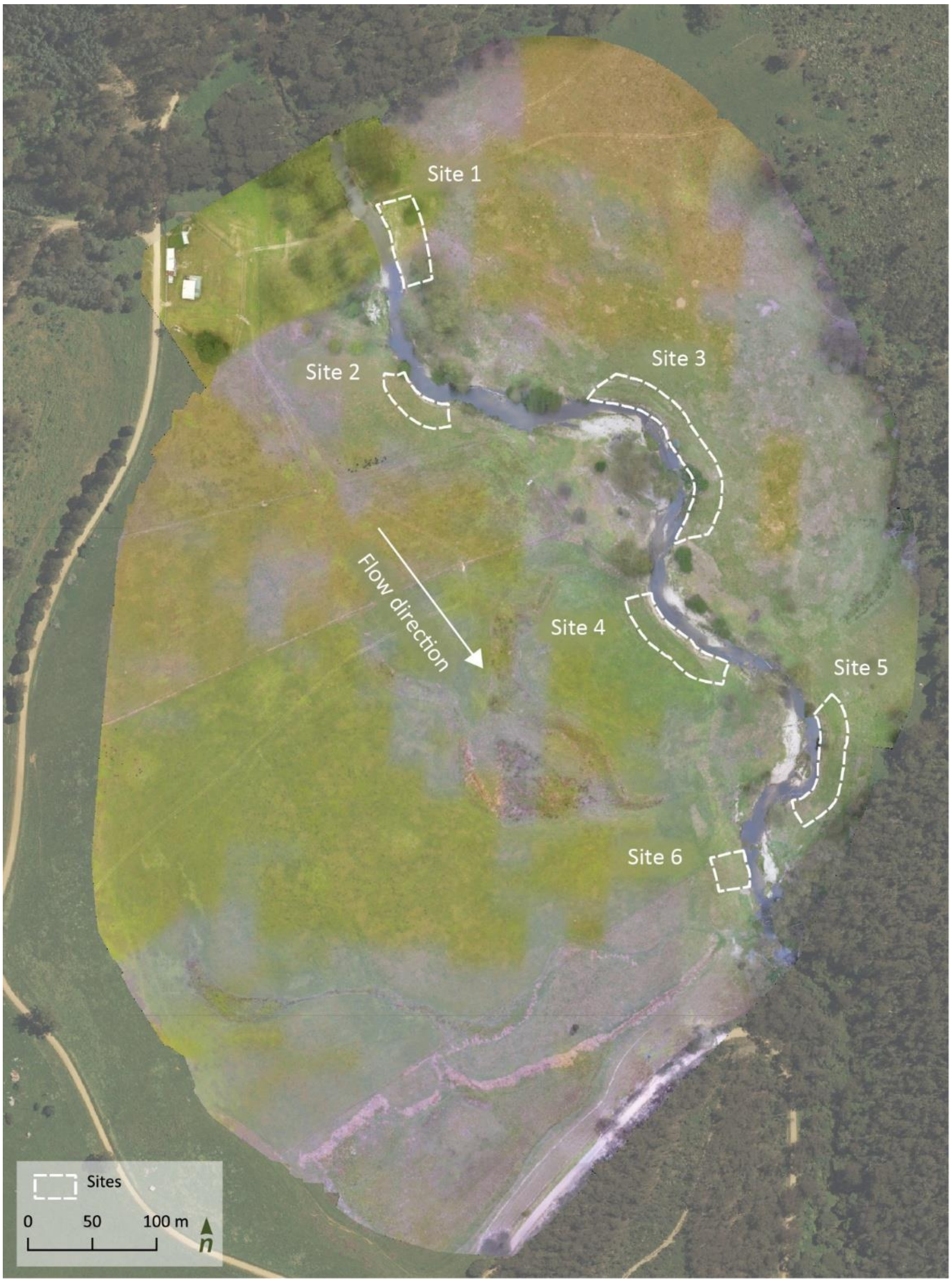


Figure 83. Example site meander bend showing bank erosion on outside of meander, and gravel point bar on inside meander on Errinundra River.

Figure 84. Example site meander bend showing near vertical bank comprised of unconsolidated sands. The fence has been undermined due to bank retreat on Errinundra River.

In considering the potential costs of intervening at the subject site, in light of competing waterway management priorities, the CMA first consults the relevant regional waterway strategy to:

- Ensure that any intervention in the subject site, either via on-ground works or other supporting management actions, would either give effect to, or not conflict with, the broader aims and priorities of the regional waterway strategy and the *Victorian Waterway Management Strategy*.
- Identify potential funding sources, including ongoing capital works programs, riparian vegetation establishment or restoration programs and flood or bushfire recovery grants.

A key priority of the East Gippsland Waterway Strategy is to:

Improve the resistance and resilience of waterways within cleared land to reduce the risk of bed and bank instabilities, for public benefit

Upon consulting with the relevant regional waterway strategy, the CMA identifies that intervention at the study site is appropriate as it is a priority for action due to the threats to the values (see below) at the site and that the CMA's existing capital works budget will be the source of funding for any on-ground works and supporting investigations.

The vision and priorities outlined in the higher-level strategies are used to establish the following aim for the subject reach of Errinundra River:

East Gippsland's rivers, estuaries and wetlands are valued and well-managed, so that communities can enjoy the current and future benefits that healthy waterways provide.

The relevant stakeholders identified for the project are:

- The CMA.
- Traditional Owners.
- The local landholder.

7.1.2 Identifying project objectives

Like many sites, intervention at the subject waterway is intended to protect or enhance multiple, and sometimes competing, waterway values. The values, objectives and assets being managed for at the site are:

- Economic: Productive grazing land is being lost to erosion; reducing the rate of erosion will translate into an increase in economic output from the property. No public or private infrastructure was identified as being threatened by observed meander migration. Restoration of an intact riparian buffer will improve stock health, increase stock productivity, and increase the land value.
- Environmental: Restoration of an intact riparian buffer along the reach will provide benefit to instream fauna, reconnect part of what is currently a fragmented riparian buffer and would reduce the rate of sediment delivery to the high value waterway; which is currently thought to be elevated above natural levels and may be contributing to the loss of pool habitat downstream.
- Cultural: Traditional Owners of the Country through which the subject reach passes have expressed to the CMA that restoration of waterways in the region to a state that more closely resembles the natural, pre-colonisation waterway condition is of high importance.

Having identified the relevant stakeholders and waterway values being managed for in the subject reach of the Errinundra River, the CMA reassesses and slightly modifies the aim for the reach:

To return Errinundra River to a condition that supports an abundance of instream indigenous flora and fauna, provides a habitat corridor between the forested upper catchment and lowland plains, realises the aspirations of Traditional Owners for the regions waterways, and supports the economic values of the reaches floodplain.

The project objectives are informed by the waterway values being managed for in the subject reach.

The waterway values for which Errinundra River is to be managed:

- Environmental: Improve instream habitat, longitudinal connectivity and water quality
- Cultural: Traditional Owner values.
- Economic: Productive land

Project objectives:

- Establish structurally diverse native vegetation along both banks of the study reach of Errinundra River. Restoring Errinundra River to a state that more closely resembles the natural, pre-colonisation waterway condition.
- Reduce the rate of meander migration in the subject reach of Errinundra River to approximate those expected in this type of waterway under pre-colonisation conditions
- To reduce, over the long term, the rate of sediment delivery to the waterway from rapidly eroding channel banks.

7.1.3 Identify drivers

The first step is to identify the activities, either in the catchment or along the subject reach, that may be generating the drivers. The CMA identified the following drivers:

- Loss of riparian and instream vegetation due to grazing of the riverbanks and channel bed by stock.
- Loss of large instream wood due to some historic but limited de-snagging of the subject reach.

Some of these drivers were undertaken in the past (de-snagging and riparian vegetation removal), and some are ongoing (grazing of the channel bed and streambanks within fenced riparian zones). The CMA's first priority is to cease any ongoing activities inline with the above objective for restoration of an intact riparian buffer along the reach. In the case of Errinundra River, the CMA has chosen to require stock exclusion from the channel bed and banks as a condition of any on-ground works. I.e. the cessation of this activity.

The values impacted by these drivers are:

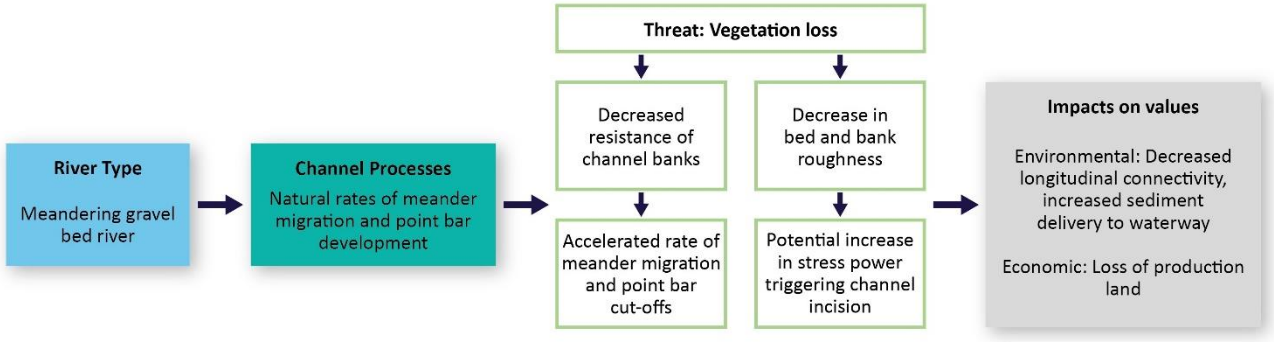
- Economic: the loss of valuable grazing land due to accelerated meander migration.
- Environmental: The loss of habitat provided by riparian and instream vegetation and large instream wood and a decrease in longitudinal connectivity between reaches.
- Cultural: A further deterioration in waterway condition compared to the waterways pre-colonisation state.

7.1.4 Build an impact logic

The loss of riparian and instream vegetation, and historically, of instream wood, has led to a reduction in the resistance forces of the channel bed and banks, which has accelerated the meander migration process in the subject reach. The decrease in bed and bank resistance due to vegetation and instream wood loss also has the potential to trigger channel incision, although whether the process of incision is underway in the reach is not known without more detailed investigations (see next section – geomorphic trajectory).

A impact logic was developed for Errinundra River (Figure 85). The impact logic provides a high-level summary of processes in the study reach that can be used a communication tool and refined by practitioners for individual sites.

Figure 85. Impact logic for Errinundra River.



7.1.5 Build trajectory of change without intervention

Additional studies are required to build a geomorphic trajectory for the study reach, and to predict how the reach will evolve if the CMA does not intervene. The additional studies utilise site inspection and a variety of the supporting analyses outlined in Part 5 of the Guidelines, including:

- Geomorphic change detection (refer to Section 5.2).
  - Multi-temporal aerial imagery analysis (refer to Section 5.2.3) was used to quantify the rate of meander migration.
  - Multi-temporal LiDAR imagery analysis (refer to Section 5.2.4) was used to quantify the volume of sediment liberated by bank erosion and delivered to the subject reach.

A stream stability analysis was used to assess whether the subject reach is currently, or is likely to, undergo incision. The stream stability analysis included:

- Bed grade analysis (refer to Section 5.3.2)
- Hydraulic analysis (refer to Section 5.3.3) of:
  - Stream power
  - Shear stress

Application of each of the supporting analyses to Errinundra River is described in more detail below.

7.1.5.1 Site Inspection

The purpose of the site inspection was to characterise the geomorphic processes shaping the reach, assess the reach for signs of channel incision, and to obtain additional data to inform geomorphic change detection. Key observations at the site included:

- Through the study reach the Errinundra River is a coarse-grained gravel bed waterway meandering through unconsolidated sandy floodplain deposits.
- The floodplain, which is used for grazing, is poorly vegetated and the bank is largely devoid of vegetation.
- The banks consist of unconsolidated sands with some embedded gravel lenses. Despite the unconsolidated nature of the floodplain sediments, several of the upper exposed banks on the outside of meander bends are near vertical (average height 3–4m) (Figure 86).
- Stock exclusion fencing is present in some segments of the reach but not others, but much of the fencing has been undermined by erosion and subsequent riverbank retreat (Figure 87).
- There are six major sections of eroding bank with a combined length of approximately 490 metre (Figure 88).
- Point bars are comprised of gravels with some sand. Scour channels, which range from early stages of formation at bar heads, to cut-off channel that span the entire point bar, have developed on all point bars.
- Some large woody debris has accumulated in the channel bed; generally stranded on the crest of riffles.
- The gravel bed and the presence of a bedrock step at the downstream extent of the site appear to be limiting channel incision.

Figure 86. Example of a near vertical upper bank within the study reach (Site 3). Large woody debris is situated along the toe of bank.

Figure 87. Site 2 – looking downstream, showing near vertical upper bank largely devoid of vegetation. The fence has been undermined due to bank retreat (2021).

7.1.5.2 Geomorphic change detection

Geomorphic change detection was used to assess the extent and rate of meander migration, and to quantify the total volume of sediment delivered to the reach from bank erosion between 2010 and 2021.

Repeat aerial imagery analysis (refer to Section 5.2.3)

Comparison of 2010 and 2021 aerial images indicates that active meander migration has occurred since 2010 (Figure 88). Bank erosion is concentrated on the outside of meander bends but also occurs to a lesser degree along relatively straight segments of channel at the upstream and downstream ends of the study reach. The average meander migration rate for the reach based on repeat aerial analysis is 1 m/yr.

Repeat LiDAR analysis (refer to Section 5.2.4)

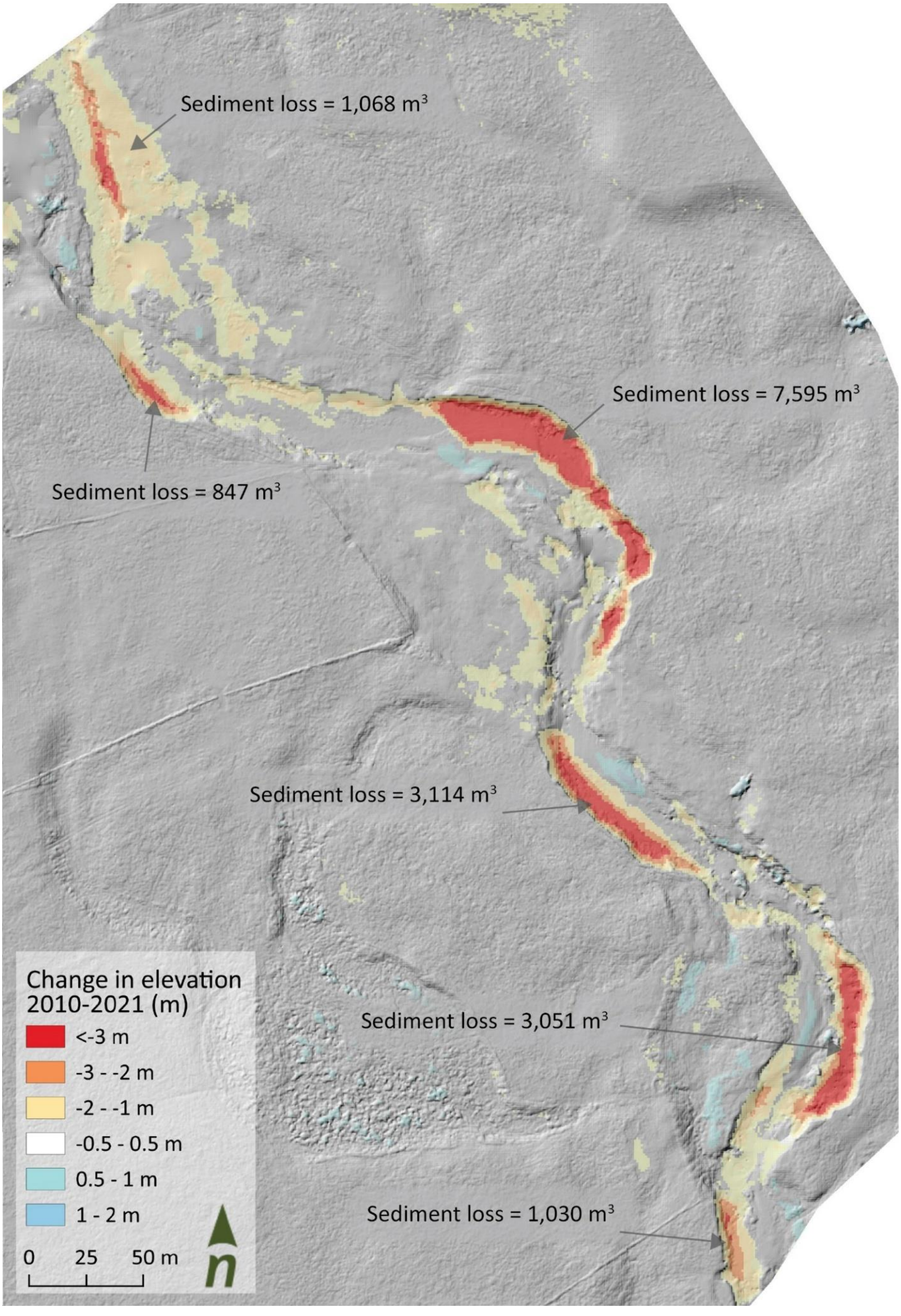
A high-resolution DEM created for this project (2021) was compared with an existing LiDAR DEM captured in 2010. The resulting DEM of difference (DoD) was used to quantify the changes in sediment storage in the study reach between 2010 and 2021.

The DoD analysis shows that erosion has removed approximately 16,700m^3 of sediment from the banks of the study reach since 2010 (Figure 89). The dominant mechanism of erosion was meander migration and included the removal of inset floodplains that were present at the toe of steep banks in 2010. Site 2 was the most significant site of erosion; with an active bank length of 165 metres and lateral bank retreat of up to 18 metres between 2010 and 2021.

Substantial erosion of the point bar on the inside of the mender at Site 2 shows that point bar growth (a depositional process) has not kept pace with meander extension. The mismatch implies that on average, between 2010 and 2021, the energy available to remove sediment from the reach is greater than the volume of sediment entering the reach from upstream.

Figure 88. Aerial imagery analysis showing bankline retreat between 2010 (left) and 2021 (right).

Figure 89. Change in elevation between 2010 and 2021 at the study site. Yellow and orange displays a drop in elevation indicating erosion has occurred. Blue displays an increase in elevation.



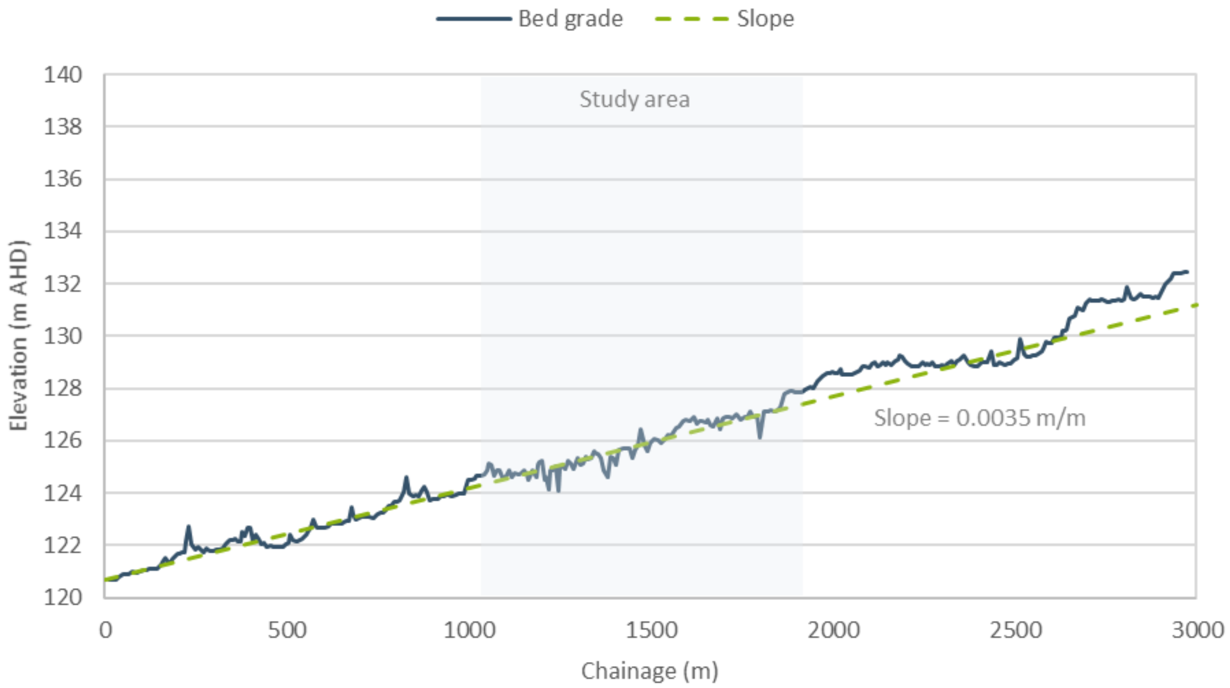
7.1.5.3 Stability assessment

While a site inspection did not reveal evidence for channel incision, a stream stability assessment was undertaken to quantify whether channel incision is occurring or likely to initiate in the future.

Bed grade analysis (refer to Section 5.3.2)

The longitudinal channel bed profile (derived from 2021 imagery within the study reach and 2010 at the upstream and downstream extent) of the Errinundra River study site is shown in Figure 90. The average bed grade through the study reach is 0.0035 m/m. The overall bed grade of the study reach is similar to upstream and downstream reaches, which are not incising and are surrounded by intact, native riparian vegetation.

Figure 90. Longitudinal profile of the Errinundra River study site.



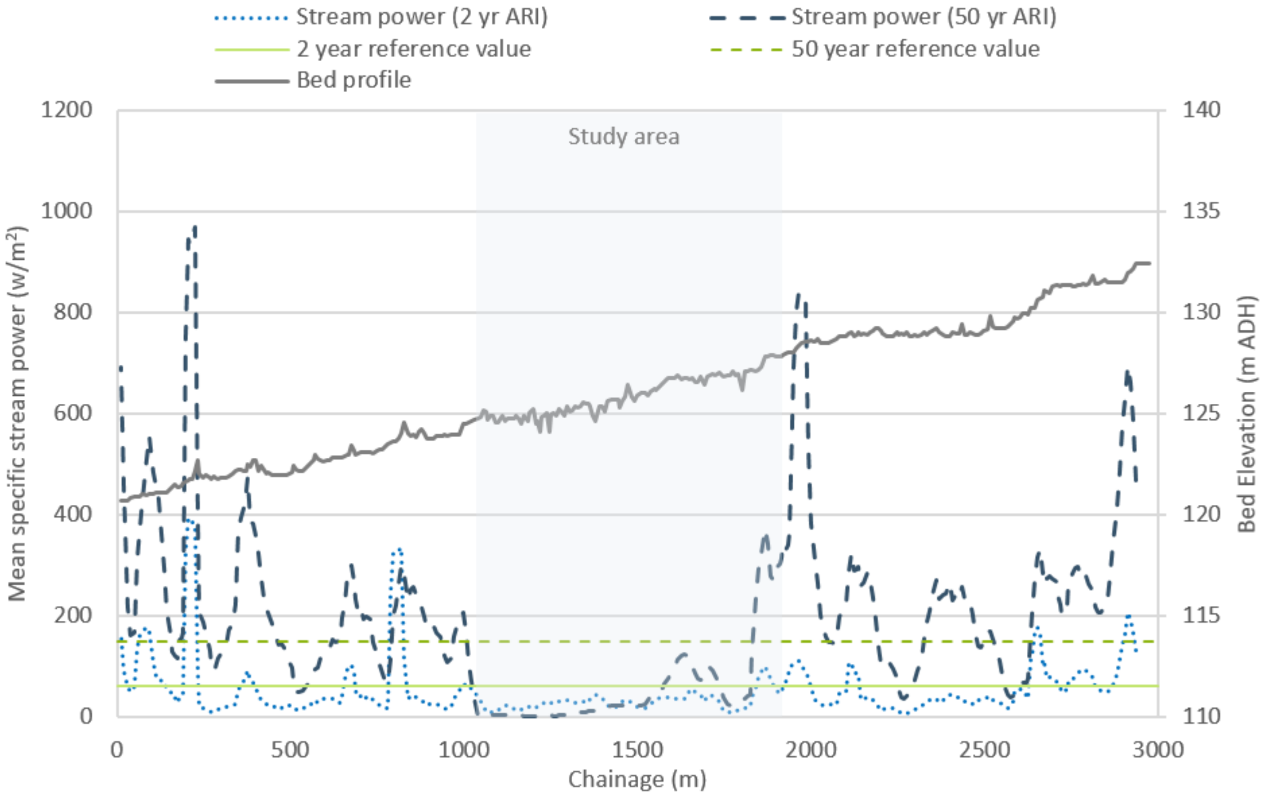
The 2021 average bed grade (0.0035 m/m) is marginally steeper than the average reference bed grade for stable alluvial waterways (approx. 0.0021 m/m). However, no significant bed grade discontinuities (such as migrating knickpoints) were observed during the site inspection or appear in the 2021 longitudinal bed profile. Furthermore, there has only been a slight change in average bed grade between 2010 and 2021 (0.0033m/m in 2010 vs.0.0035 m/m in 2021), and the coarse gravel bed appears to be limiting bed incision through the reach. As such, no interventions to manage streambed incision are proposed.

Hydraulic analysis (refer to Section 5.3.3)

One-dimensional hydraulic modelling was undertaken to quantify stream power and bed shear stress during two flow events. Model results were then checked against reference values for stable waterways (refer to Section 5.3.2).

The results of the stream power assessment for the 2- and 50-year ARI events (40% and 2% AEP events) are shown in Figure 91. Through the study reach the 2- and 50-year stream power are close to, or above, reference values for alluvial systems. The results indicate that in the absence of a suite of high quality and structurally diverse native vegetation, this waterway has a high potential for incision.

Figure 91. Stream power within the study reach for the design flows.



Shear stress is the force exerted against the channel and floodplain boundary during flow events. Once a critical shear stress value is exceeded the channel boundary material may begin to erode. The critical shear stress at which mobilisation of the boundary layer occurs for a range of shear stresses is provided in Table 32.

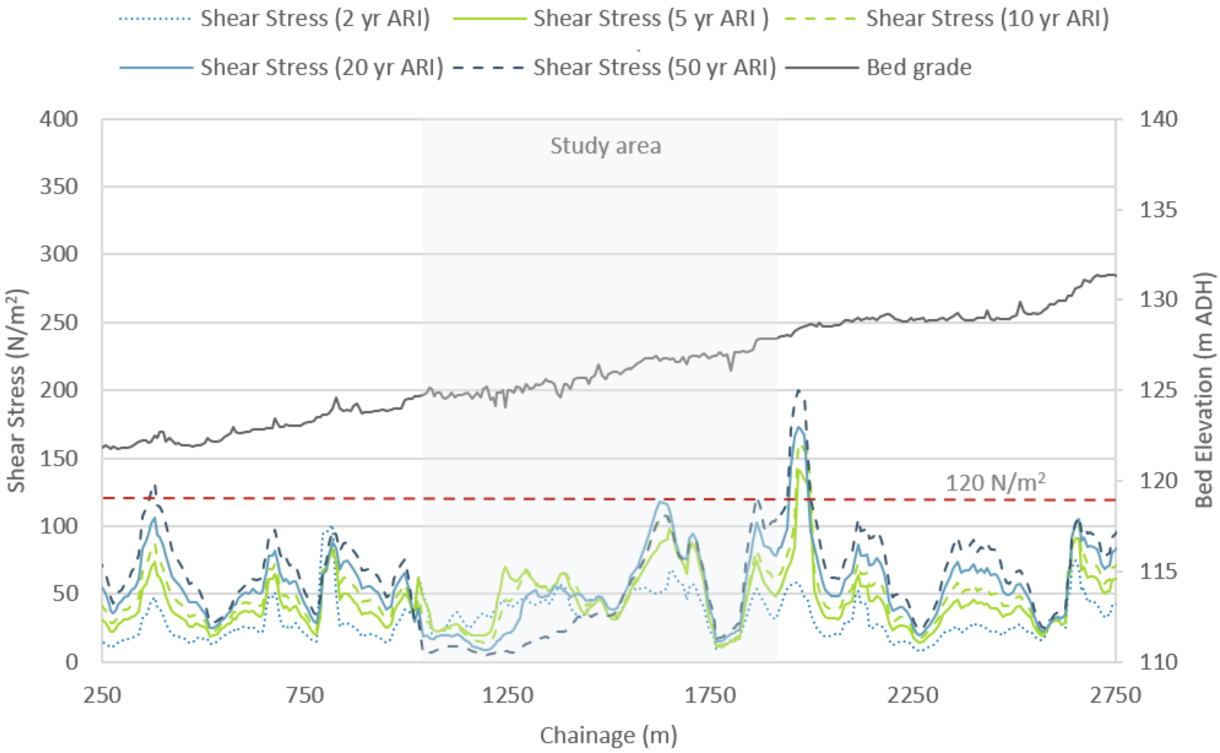
Table 32. Shear stress thresholds for various boundary layers (from Fischenich 2001a).

Boundary layer	Shear stress upper threshold (N/m²)
Cohesive alluvial soil with occasional gravel	12–20
Sand (1mm)	1.2
Gravel (10 mm)	10
Cobbles (100 mm)	100
Jute mat (matting over soil)	22

Boundary layer	Shear stress upper threshold (N/m²)
Short native and bunch grass	34–45
Long native grasses	57–80
Mature trees, shrubs and grasses (structurally diverse vegetation)	80–120

The modelled shear stress results through the study site for a range of design events are shown in Figure 92. The figure shows the shear stress from the one-dimensional model has been adjusted to account for the radius of curvature within the study reach (Department of Sustainability and Environment, 2007). The adopted shear stress threshold of structurally diverse native vegetation is indicated by a red dashed line. The site assessment identified that the bank largely consists of consolidated sands. The erosion threshold for these sediments is approximately 1.2 N/m^2. The results indicate that during the 2-year ARI event shear stresses at the study site exceed the erosion threshold of the exposed soils (increasing in severity upstream), but that structurally diverse suite of good quality established native vegetation (shear stress threshold 120 N/m^2) would be sufficient to limit erosion at the site during major flood events e.g. the 2% AEP (50-year ARI) event.

Figure 92. Shear stress within the study reach for the design flows.



7.1.5.4 Geomorphic trajectory of the study reach

The outcomes of the supporting analysis above were used to build a geomorphic trajectory for the study reach – a prediction of how the channel will evolve if the CMA does not intervene. The geomorphic trajectory for Errinundra River is as follows:

- The overall grade of the study reach is similar to upstream and downstream reaches indicating waterway incision is not an ongoing process of concern.
- Thick sandy floodplain deposits have been built up by waterway meandering over thousands of years as sediment from upstream is stored in the low energy floodplain.
- Errinundra River is a gravel bed waterway that transports appreciable quantities of sand during higher flows. Sand is deposited on the channel bed during floods and is easily mobilised, re-worked and transported downstream by lower flows. This removal of fine sediment from the channel bed (winnowing) has formed a gravel armour layer on the channel bed. The armour layer is coarse and resistant to incision, which causes excess stream energy to be instead exerted on the stream banks.
- Removal of vegetation from the floodplain and riparian land has exposed the consolidated sand channel banks, which are now highly sensitive to erosion. The combination of the armoured bed and the exposed streambanks has triggered accelerated meander migration in the study reach.
- Accelerated meander migration will continue until the slope of the study reach decreases enough to cause sustained sediment deposition.
- As long as accelerated meander migration continues, larger volumes of sand sized sediment will continue to be delivered to downstream reaches.

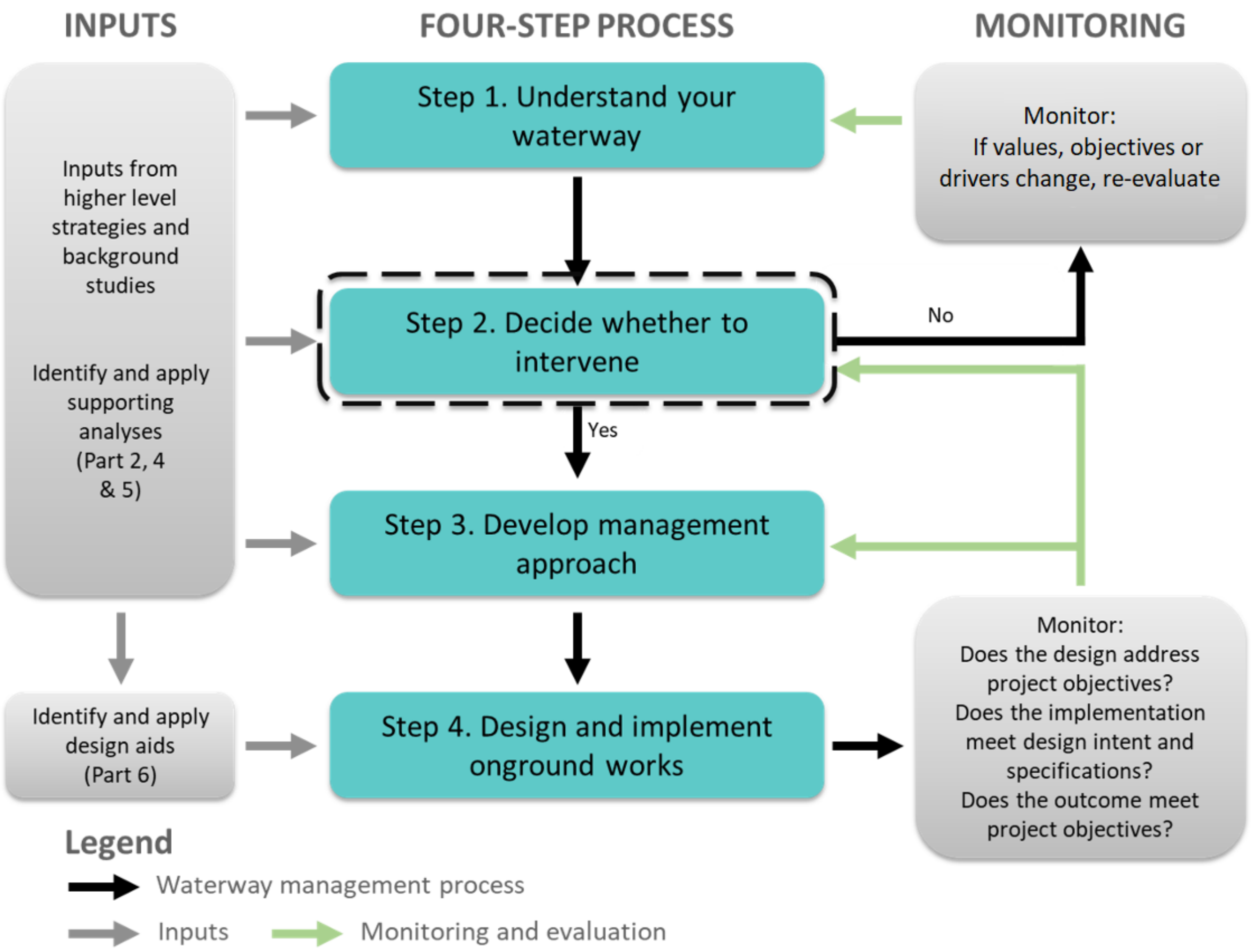
Based on this assessment it is likely that meander development will continue to progress. This will result in ongoing erosion of the outside bends of the subject reach and significant sediment liberation. The erosion is the result of excess energy in the system. This excess energy is the result of a loss of in-channel, streambank and floodplain vegetation.

7.2 Step 2: Decide whether to intervene

The second step in the four-step process is to decide whether to intervene. A key step in deciding whether to intervene at a reach or site is to consider the identified impacts and geomorphic processes and decide whether the no intervention option is acceptable or not (Figure 93).

The CMA will seek to understand the cause-and-effect relationship between activities, drivers, processes and impacts in Errinundra River in order to build a geomorphic trajectory for the reach.

Figure 93. Worked Example – Step 2: Decide whether to intervene.



7.2.1 Decide whether to intervene

Are the identified drivers likely to adversely impact waterway values and project objectives without intervention?

Key **threats** to the waterway arising from riparian vegetation removal, de-snagging, and grazing include:

- Loss of riparian and instream vegetation due to grazing of the channel bed and banks by livestock.
- Loss of large instream wood due to some historic but limited de-snagging of the subject reach which would otherwise assist in trapping be sediments and reduce the bed grade.
- The potential for streambed aggradation in downstream reaches due to the elevated sediment supply generated by bank erosion.

Based on the geomorphic trajectory of the reach these drivers are likely to adversely impact **project objectives** in Errinundra River including:

- Restoration of an intact riparian buffer along the reach and improved longitudinal connectivity, instream habitat, and water quality.

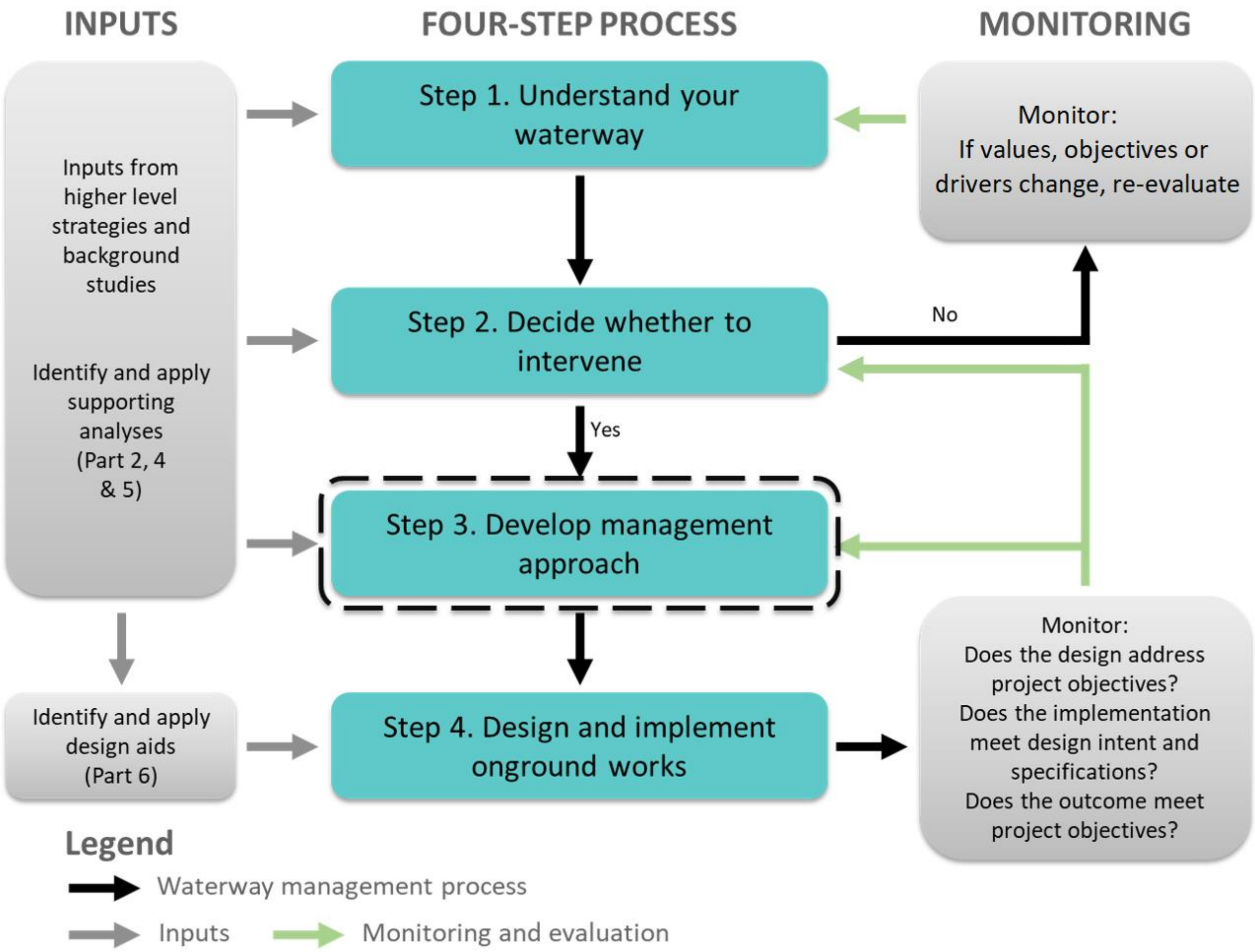
- Restoration of waterways in the region to a state that more closely resembles the natural, pre-colonisation waterway condition.
- Productive grazing land is being lost to erosion.

Action: Based on the above assessment the CMA has decided to intervene to address the threats and the process of accelerated meander migration.

7.3 Step 3: Select intervention option

The CMA has decided to intervene in the subject reach with on-ground works. Step 3 is to define the reach or site outcome targets and to then select appropriate on-ground intervention options (Figure 94). The approach to managing meander migration (section 3.4.3) and an understanding of the drivers of accelerated meander migration (section 2.4.3) can be used to identify the most appropriate interventions available to treat the threats and processes in the waterway.

Figure 94. Worked example – Step 3: Develop management approach.



7.3.1 Define reach outcome targets

The aim for the subject reach is:

To return Errinundra River to a condition that supports an abundance of instream indigenous flora and fauna, provides a habitat corridor between the forested upper catchment and lowland plains, realises the aspirations of Traditional Owners for the region's waterways, and supports the economic values of the reach's floodplain.

Based on this aim the following outcome targets have been established:

- Vegetation: the presence of structurally diverse native vegetation along both banks of the study reach of Errinundra River.
- Physical form: the presence, and persistence of pools and instream habitat in the bed of the creek and the reduction in the rate of meander migration to levels experienced in upstream undisturbed reaches.
- Traditional Owner cultural heritage: the presence of culturally appropriate vegetation and an improvement in waterway condition so that the reach more closely resembles the condition of upstream, intact reaches.

7.3.2 Reach scale processes and management

All erosion control measures identified for the study reach should be aimed at establishing structurally diverse, native vegetation along the channel banks. In addition to increasing the erosion resistance of streambanks, vegetated riparian buffers provide habitat for terrestrial fauna, shading for the channel (which limits spikes in water temperature that adversely impact fish) and in the long-term, provides a source of instream wood to the study reach.

A range of alternate management approaches have been considered for the site. The options assessed comprised of:

1. Halt meander migration entirely.
2. Reduce the rate of meander migration.

Based on the potential to meet reach outcome objectives, option two "reduce the rate of meander migration'' was considered the most appropriate management approach.

7.3.3 Intervention option selection

Several different intervention options can be used to address meander migration within Errinundra River. The intervention option guide in Table 33 (adapted from Section 3.6) provides information to aid the selection of a single, or combination of, interventions. Based on Table 33, the CMA has four types of intervention (which can be used alone or in combination) to treat the process of meander migration in the study reach of Errinundra River. Those intervention options are:

1. Vegetation establishment. This option includes a suite of vegetation related activities aimed at establishing a buffer of structurally diverse native vegetation. Vegetation management includes, permanent stock exclusion measures such as stock-proof fencing, the provision of alternate stock watering points for stock, weed and pest management at the site and revegetation at appropriate densities.
2. The use of structural works to increase the likelihood of successful vegetation establishment. Structural works intervention options identified in Table 33 are:
    a. Bank battering
    b. Alignment training – pile fields or rock groynes
    c. Rock beaching
    d. Wood revetment
    e. Large wood

When evaluating which option (or options) is most suitable for Errinundra River, the CMA considers:

- The waterway values and objectives, which include establishment of riparian native vegetation, and to return the reach to a geomorphic state that more closely resembles its pre-colonisation condition; and
- The cost of each intervention option, which is increased due to the remote location of the site, compared to the project budget.

In considering the points above, the CMA decided that the most effective combination of intervention options is:

- Bank battering to a recommended grade of 1V:3H, the installation of pile fields, and vegetation establishment.

While each option has potential to address the geomorphic processes, the above works provide a more cost-effective solution compared to that of rock beaching or rock groynes, where the purchase and transportation of rock to the remote site far outweighs the costs of piles which can be sourced locally. Additionally, the source of sufficient suitable large wood to line the banks was not available.

This combination of intervention options is deemed most likely to achieve the project objectives, while also meeting the project budget and avoiding the adverse impact of rock beaching may have on meandering waterways, such as:

- Preventing the development of undercut bank habitat in the long term once the rate of meander migration has slowed; and
- The tendency for the point of maximum erosion to shift from the treated meander bends to downstream meander bends.

Table 33. Intervention selection guide – Accelerated meander migration.

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	May include all activities as listed below	Do not intervene	Cost: NA Success: NA Adverse impact: NA	Choosing not to intervene may be based on allowing the channel meander to continue to propagate until a new equilibrium is established and that any impacts associated with the bank migration are considered in line with project objectives and targets.	Option summary: *Section 3.3.1*
Channel meandering	Hydrologic change	Native vegetation establishment and management	Cost: 1 Success: 2 Adverse impact: 1	Hydrologic change can drive an increase in the frequency and/or duration of events that are likely to cause erosion. The establishment of native riparian vegetation on meander bends increases bank strength (resistance forces), shields bank sediment from scour, and increases channel roughness, provided that vegetation extends to the toe of the bank. Once established, native riparian vegetation will decrease, but not eliminate, the rate of meander migration.	Option summary: *Section 4.2.2* Supporting design aids: *Section 6.2, Section 6.4* – page 226

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Hydrologic change	Flow modification (environmental flows)	Cost: 2 Success: 2 Adverse impact: 1	Modification of the flow regime addresses adverse meander migration by decreasing the magnitude, duration and frequency of flows that drive bank erosion and meander migration. This intervention has the potential to trigger adverse impacts on waterway condition and instream ecology, which should be considered when designing flow regimes to reduce rates of meander migration.	External Resources: DEPI, 2013b
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Native vegetation establishment and management	Cost: 1 Success: 3 Adverse impact: 1	Modification of riparian land management practices can provide the most cost-effective means of controlling riverbank erosion and resulting meander migration caused by uncontrolled stock access.	Option summary: *Section 4.2.2* Supporting design aids: *Section 6.2* – page 226*, Section 6.4*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Reduction or loss of instream and riparian vegetation (Interventions that aid vegetation establishment as a means of increasing erosion resistance)	Wood revetment	Cost: 1 Success: 3 Adverse impact: 1	Installation of wood revetment at the bank toe can increase channel roughness and in sufficient density could reduce velocities to have a significant impact on erosion processes including meander migration. It also provides significant habitat opportunities for a range of flora and fauna species.	Option summary: *Section 4.2.14* Supporting design aids: *Section 6.2, Section 6.4, Section 6.6*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	vegetation establishment as a means of increasing erosion resistance)	Alignment training – Pile Fields	Cost: 2 Success: 3 Adverse impact: 1	Pile fields can be used to either re-align an eroding meander bend, or to decrease the rate of meander migration by supporting vegetation establishment. Pile fields support the establishment of native vegetation by increasing channel roughness and decreasing flow velocity at the bank, which promotes sediment deposition between successive pile alignments. As vegetation establishes and sediment accumulates, channel alignment will shift towards the inward extent of the pile field, and meander migration rate will decline. Pile fields have fewer adverse impacts than rock beaching.	Option summary: *Section 4.2.15* Supporting design aids: *Section 6.2, Section 6.4,* *Section 6.5*

Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	vegetation establishment as a means of increasing erosion resistance)	Rock beaching and rock riprap	Cost: 3 Success: 3 Adverse impact: 2	Rock beaching is an effective means of controlling bank erosion and resulting meander migration. However, it is expensive and can destroy undercut bank habitat.	Option summary: *Section 4.2.16* Supporting design aids: *Section 6.8* – page 304
Channel meandering	vegetation establishment as a means of increasing erosion resistance)	Alignment training –Rock Groynes	Cost: 2 Success: 2 Adverse impact: 2	Impermeable rock groynes aid native vegetation establishment in the same manner as pile fields and are suited to higher-energy environments where timber piles may have an inadequate design life. Impermeable rock groynes require careful design to prevent scour and failure.	Option summary: *Section 4.2.18* Supporting design aids: *Section 6.9*

Process and drivers Geomorphic process	**Process and drivers Driving activity**	**Approach to management Intervention option**	**Approach to management Option ranking to address process**	**Approach to management Comment**	**Relevant supporting design method, supporting analyses and external references**
Channel meandering	vegetation establishment as a means of increasing erosion resistance)	Bank battering	Cost: 2 Success: 2 Adverse impact: 3	Bank battering can reduce the rate of bank erosion, sediment production and resulting meander migration in incised systems. However, this option can destroy undercut bank habitats, impact on cultural heritage legislation and should only be applied in conjunction with bed and/or bank supplementary actions, or where there is strong confidence that it will not be undermined by returned high flows, such as ephemeral and low energy systems.	Option summary: *Section 4.2.5* Supporting design aids: *Section 5.3*
Channel meandering	Loss of instream wood	Large wood installation	Cost: 2 Success: 3 Adverse impact: 1	Installation of large wood can increase channel roughness and in sufficient density could reduce velocities to have a significant impact on erosion processes including meander migration.	Option summary: *Section 4.2.11* Supporting design aids: *Section 6.6* – page 282

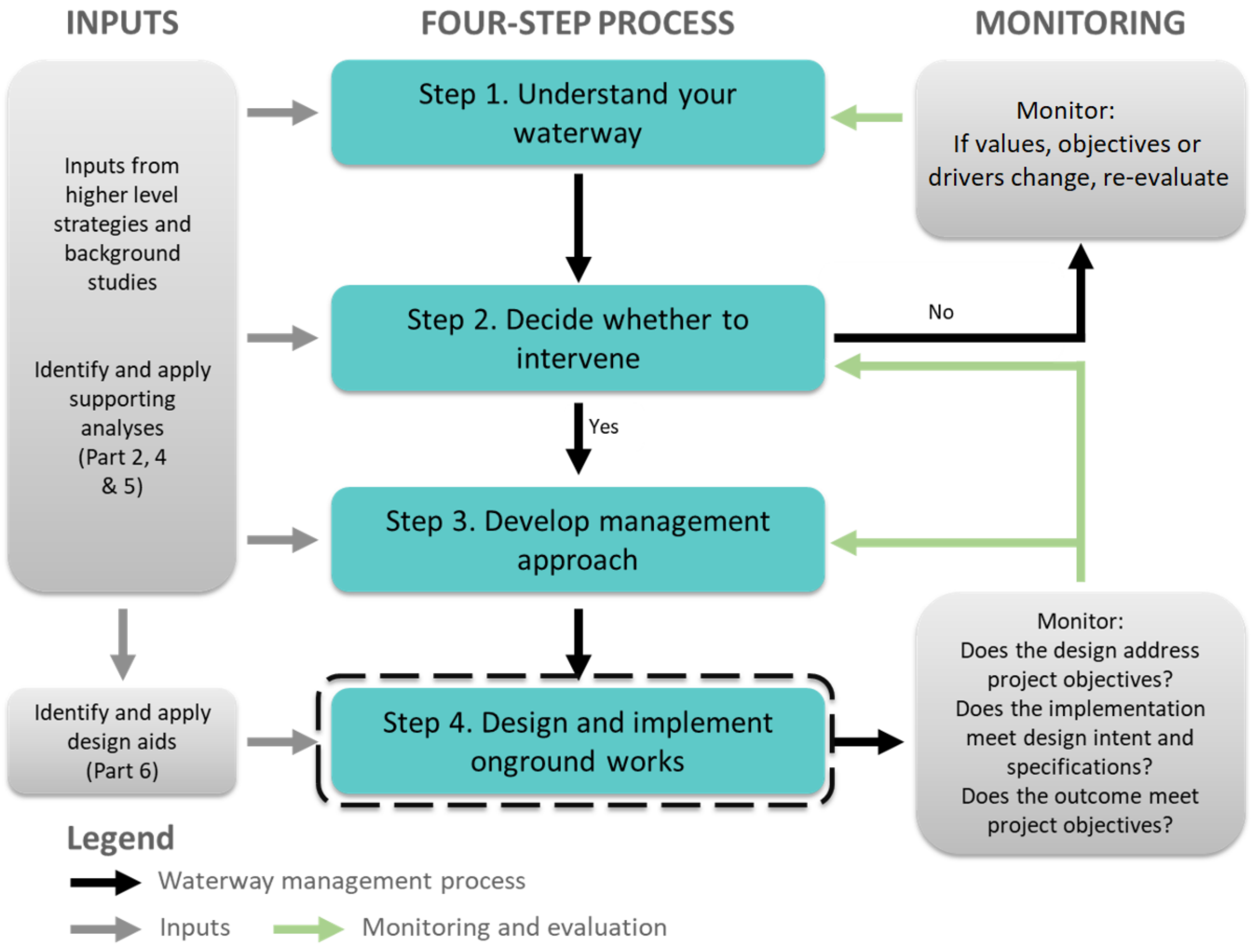
Process and drivers Geomorphic process	Process and drivers Driving activity	Approach to management Intervention option	Approach to management Option ranking to address process	Approach to management Comment	Relevant supporting design method, supporting analyses and external references
Channel meandering	Physical disturbance of waterway	Channel reconstruction and design	Cost: 3 Success: 3 Adverse Impact: 1	An effective means of reducing excess energy in highly modified systems and restoring meander form. This method is expensive however and is usually reserved for situations where re-establishment of a riparian vegetation alone is unlikely to restore natural meander planform and migration rates.	Option summary: *Section 4.2.8* Supporting design aids: Section 5.3

7.4 Step 4: Design and implement on-ground works

The final step in the four-step process is to design and then implement on-ground works if they are required. Supporting analyses to aid in the design of on-ground work are provided in Part 5 of the Guidelines.

The following section provides an example design process for one of the subject Errinundra River meanders.

Figure 95. Worked Example – Step 4: Design and implement on-ground works.



7.4.1 Design of on-ground works

The selected intervention involves reprofiling the bank to a recommended grade of 1V:3H, the installation of pile fields and revegetation.

- The bank is to be reprofiled to form a stable slope (1V:3H) that is less vulnerable to gravitational mass failure and more suitable for vegetation establishment.
- The pile fields should be designed to prevent scour of the adjacent bank and aid in vegetation establishment. The reduction in scour and sediment accumulation in this zone will promote vegetation establishment along the toe of the bank. To assist in vegetation establishment along the reprofiled bank erosion matting could be used to provide additional protection during the establishment phase.

The design process is summarised below.

7.4.2 Pile field design – notional line of attack method

The notional line of attack approach was used to establish the pile field length and spacing requirements based on the proposed alignment for Errinundra River (see Section 6.5.4) (Figure 97). Key design steps in the notional line of attack method are detailed below and illustrated in Figure 97.

- Establish the progression of notional lines of attack around the bend.
- Locate the landward end of the first pile fields just downstream of the start of the re-aligned section. The angle of the pile field is set based on the critical line of attack. The pile fields were angled 5 degrees to 10 degrees downstream of the perpendicular to this line of critical attack.
- The remaining pile fields were located such that the landward end of the downstream pile field was located upstream of the intersection of the critical line of attack from the upstream pile field and the eroding bank line.

The shear stress analysis was used to determine the required height of toe protection up the bank (see Section 6.4.5). To assist in vegetation establishment along the reprofiled bank, erosion matting could be used to provide additional protection; jute matting has a critical shear stress of 22 N/m^2. Shear stress results indicate that the piles should extend approximately 2 metres up the bank from the channel invert (Figure 96) in order to protect the jute matting from excess shear stress in flood events. Rock should be placed around the two most upstream piles fields at each site, to reduce the risk of outflanking scour. A typical pile field plan and cross-section drawings is provided in

.

Figure 96. Average shear stress with depth within the Errinundra River study reach for the 0.5EY, 0.2EY, 10% to 2% AEP events.

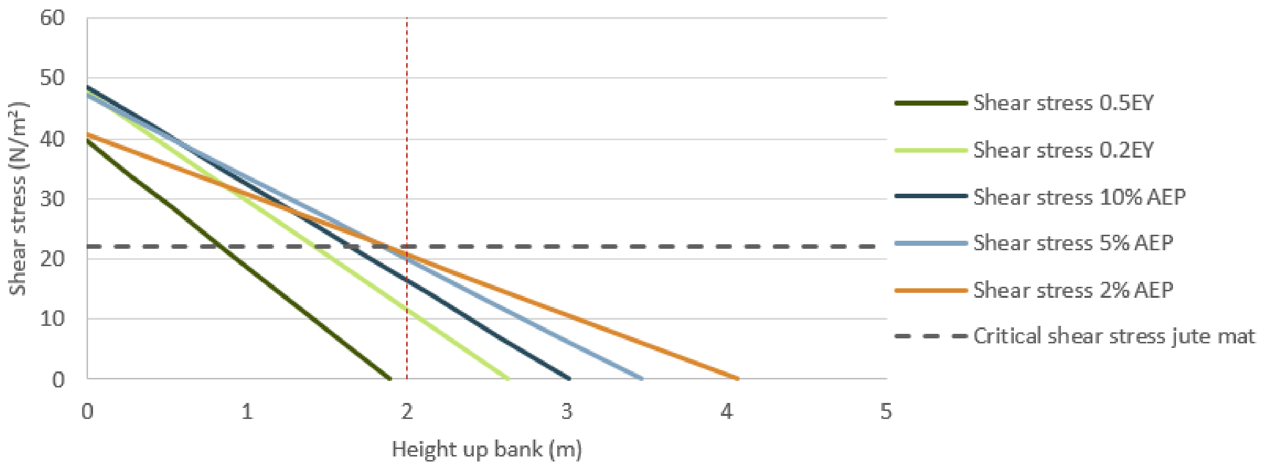


Figure 97. Angle of attack method for alignment – Site 4.

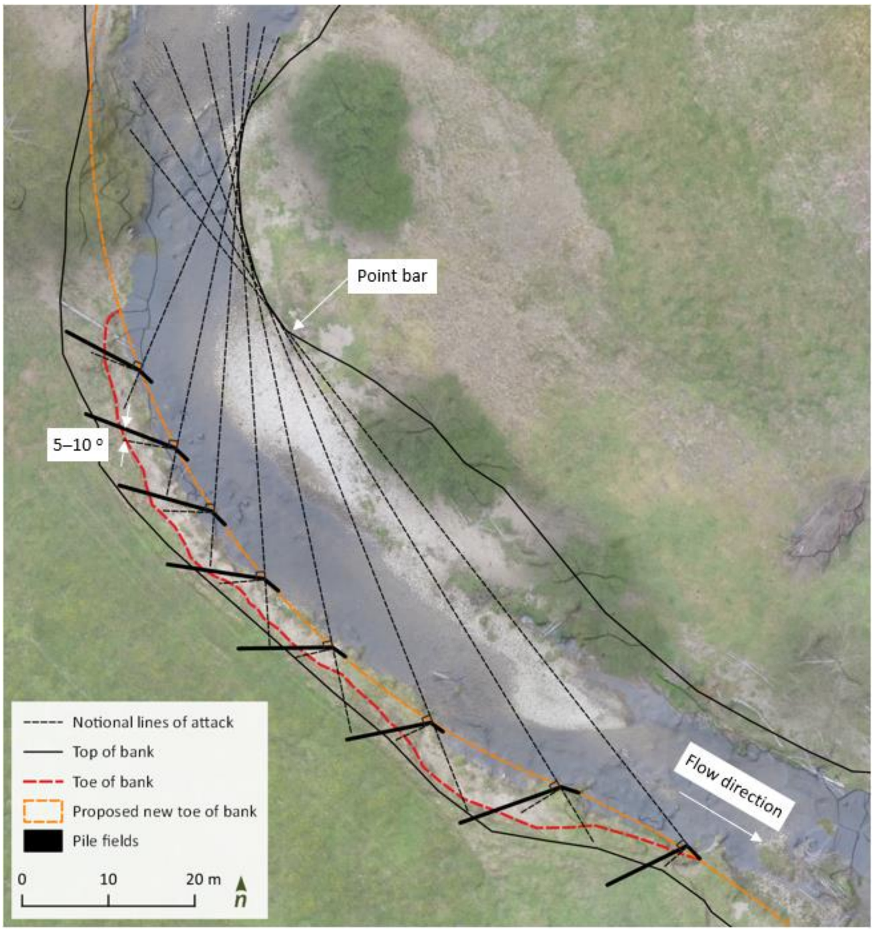
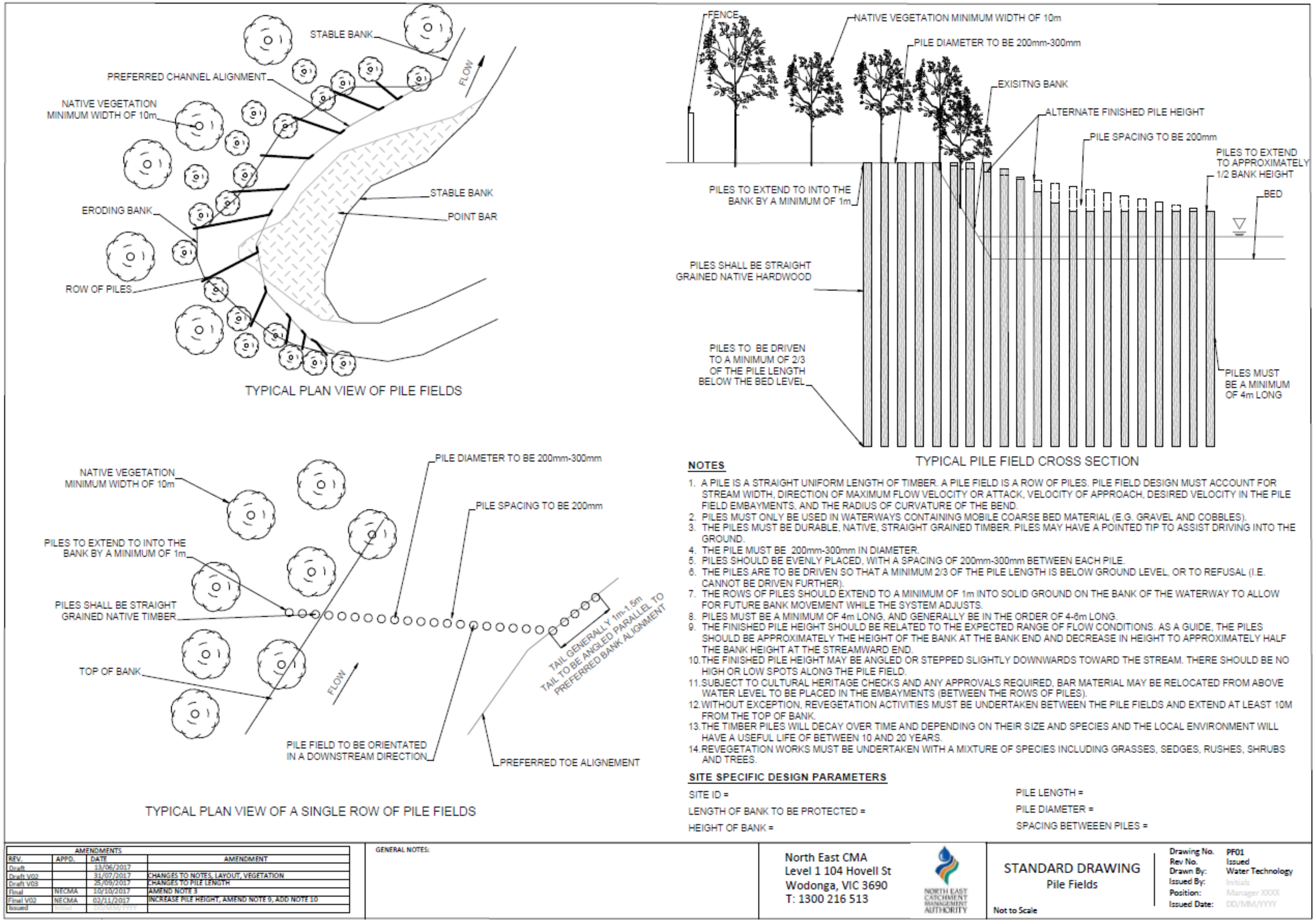


Figure 98. Standard pile field plan and cross-section drawing (Source NECMA).



7.5 Monitoring

As outlined in Section 3.5.4 monitoring and evaluation of works and the impacts those works have on physical waterway form (or the biological process the structures are targeting) is an integral component of reach and site scale interventions and provides feedback on the success or otherwise of projects, activities and works.

A simple monitoring plan for the Errinundra River could include, but may not be limited to:

- Design monitoring:
  - The proposed design falls within the allocate budget available, materials readily available and construction is feasible and safe.
  - The proposed design addresses the geomorphic processes of meander migration.
  - The proposed design meets ecological objectives to help create structurally diverse native vegetation.
- Implementation monitoring:
  - Pile fields have been installed in accordance with the design specifications including: pile alignment, pile thickness, pile timber material, pile embedment depth, pile tie in with bank, pile spacing etc.
  - Bank battering has been installed in accordance with the design specifications including: extent of battering, batter slope, tie in with exiting bank profile, batter toe alignment, batter top of bank alignment, topsoil or finishing where required.
- The ongoing operational performance is in accordance with the design intent:
  - No movement or failure of pile fields.
  - Vegetation establishment on battered banks.
  - No damage to stock exclusion fencing.
  - maintenance programs or potential modifications to works are undertaken.
- Outcome monitoring:
  - Improved longitudinal riparian buffer connectivity, instream habitat, and water quality – measured as increased vegetation coverage, number of large wood/logs located within waterway, repeat water quality monitoring.
  - Waterway is now in a state that more closely resembles the natural, pre-colonisation waterway condition – measured through.
  - No productive grazing land is being lost to erosion – measured as area of land retained or reduced post works.

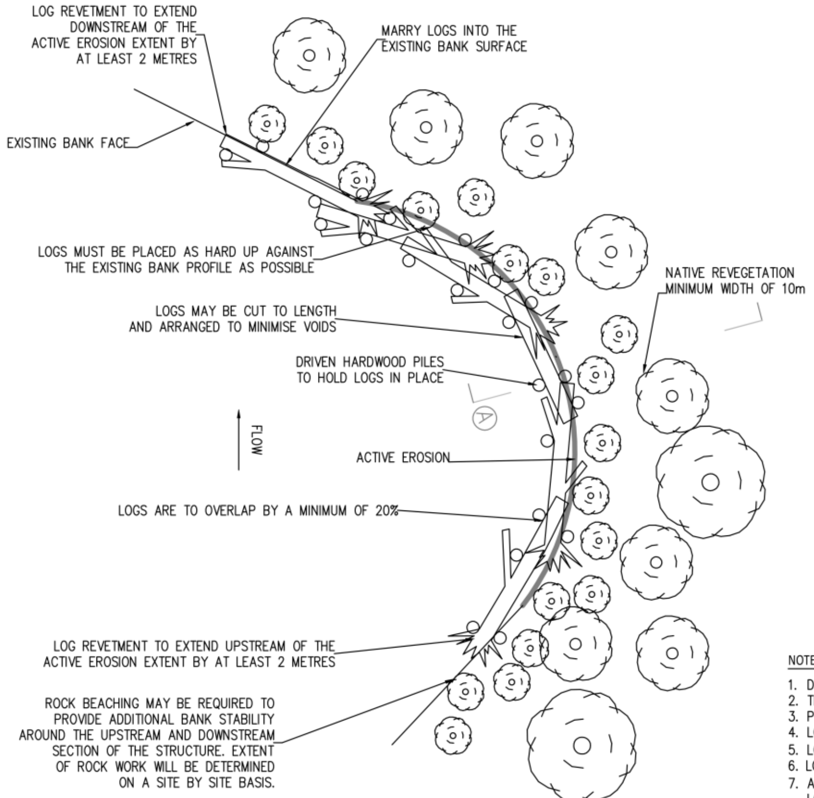
8 Part 8 – Standard drawings

The standard drawings provided below have been prepared to help guide waterway practitioners. The purpose of these drawings is to provide typical details for a range of commonly applied intervention options. These drawings should be used as a guide only and changes to the designs are to be made to suit site-specific geomorphic processes and conditions.

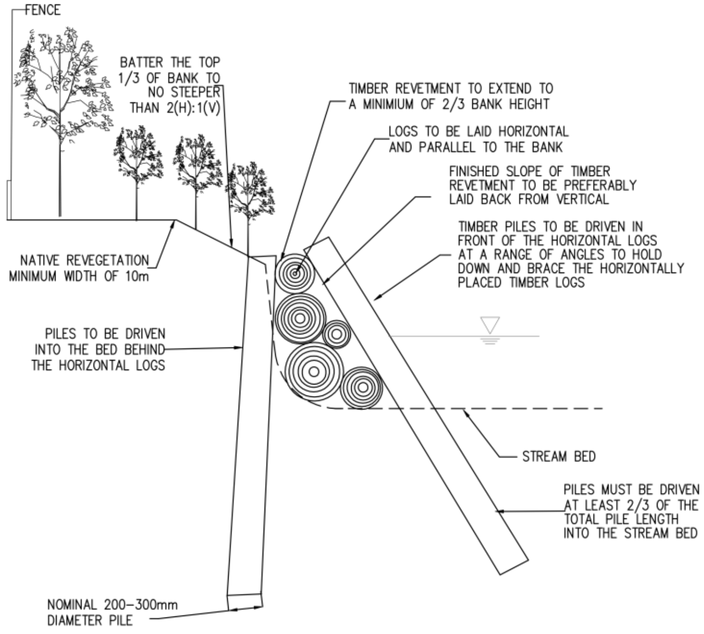
The fitness for purpose of these drawings for a specific project shall be determined and certified by a suitably qualified engineer.

The following drawings are provided:

- Log revetment/brushing.
- Log jam.
- Pile anchor and large wood.
- Log groyne.
- Pile field.
- Rock chute.
- Rock beaching.
- Rock beaching with log toe.



PLAN VIEW



CROSS SECTION 'A'

NOTES

1. DURABLE NATIVE TIMBER MUST BE USED FOR THE INSTREAM LOGS AND PILES.
2. TIMBER LOGS FOR REVETMENT WORK MUST HAVE A MINIMUM TRUNK DIAMETER OF 300mm, WITH A RANGE OF SIZES TO MINIMISE VOID SPACE.
3. PILES MUST HAVE A DIAMETER BETWEEN 200 AND 300mm, AND A MINIMUM LENGTH OF 4.5m.
4. LOGS MUST BE PLACED HARD UP AGAINST THE EXISTING BANK PROFILE.
5. LOG REVETMENT MUST BE PLACED TO AT LEAST 2/3 BANK HEIGHT SO THAT THE TOE OF THE BANK IS PROTECTED.
6. LOGS MAY BE CUT TO LENGTH AS REQUIRED TO MATCH THE BANK PROFILE AND MINIMISE VOIDS BETWEEN PLACED LOGS AND THE BANK FACE.
7. AS A GENERAL RULE LOGS SHALL BE PLACED WITH THE ROOT BALL (BUTT) FACING UPSTREAM. HOWEVER, IT IS ACCEPTABLE TO PLACE SOME LOGS ROOT BALL TO ROOT BALL IF THIS ARRANGEMENT LEADS TO GREATER ELIMINATION OF VOIDS, CONTACT WITH THE ORIGINAL BANK PROFILE, DISRUPTION OF FLOW ENERGY AND/OR TRAPPING OF SEDIMENT.
8. THE PILES ARE TO BE DRIVEN SUCH THAT 2/3 OF THE PILE IS BELOW THE BED LEVEL.
9. THE PILES ARE TO BE DRIVEN AT A RANGE OF ANGLES TO HOLD DOWN AND BRACE THE HORIZONTAL PLACED TIMBER LOGS.
10. A MINIMUM OF FOUR PILES ARE TO BE DRIVEN FOR EACH ROW OF HORIZONTALLY PLACED TIMBER LOGS, TO PREVENT DISPLACEMENT AS A RESULT OF FLOTATION OR HYDRAULIC FORCES.
11. TIMBER REVETMENT MUST EXTEND LONGITUDINALLY PAST THE EXISTING EROSION EXTENT, BOTH UPSTREAM AND DOWNSTREAM BY A MINIMUM DISTANCE OF TWO METRES.
12. ATTENTION NEEDS TO BE PAID TO ENSURING THAT THERE IS A SMOOTH TRANSITION FROM THE TIMBER REVETMENT TO THE BANK PROFILE AT EITHER END OF THE WORKS.
13. ALL TIMBER LOGS SHALL OVERLAP PREVIOUS LOG BE APPROXIMATELY 20% OF IT'S LENGTH.
14. BRANCHES AND LEAF LITTER ON TIMBER LOGS IS ENCOURAGED TO BE LEFT. LOPPING OF BRANCHES ON THE LOGS CAN BE UNDERTAKEN WHERE REQUIRED TO ASSIST WITH PLACEMENT OR TO REDUCE THE RISK OF THE TREE CATCHING FLOOD DEBRIS.
15. WITHOUT EXCEPTION, REVEGETATION ACTIVITIES MUST BE UNDERTAKEN BEHIND THE TIMBER REVETMENT WORKS.
16. INSTALLATION OF TIMBER REVETMENT SHOULD CORRESPOND AS CLOSE AS POSSIBLE WITH THE TIMING FOR OPTIMAL GROWTH OF REVEGETATION TO ENSURE FOLLOW UP REVEGETATION RAPIDLY COLONISES THE SURROUNDING AREA.

SITE SPECIFIC DESIGN PARAMETERS

SITE ID =

LENGTH OF BANK TO BE PROTECTED =

HORIZONTAL LOG LENGTH =

HORIZONTAL LOG DIAMETER =

HEIGHT OF BANK =

HEIGHT OF REVETMENT =

VERTICAL PILE DIAMETER =

VERTICAL PILE LENGTH =

FENCE OFFSET FROM TOP OF BANK =

AMENDMENTS			
REV.	APPD.	DATE	AMENDMENT
Draft		13/06/2017	
For Approval		10/07/2017	CHANGES TO NOTES, LAYOUT, LOGS, VEGETATION
Final	NECMA	12/07/2017	AMENDMENTS TO NOTES AND ANNOTATIONS
Revised Final	NECMA	18/01/2018	AMENDMENTS TO NOTES, ANNOTATIONS, SECTION A
Revised Final	NECMA	29/01/2018	AMENDMENTS TO NOTES
Revised Final	NECMA	05/03/2018	AMENDMENTS TO NOTES
Issued	Initials	DD/MM/YYYY	

GENERAL NOTES:

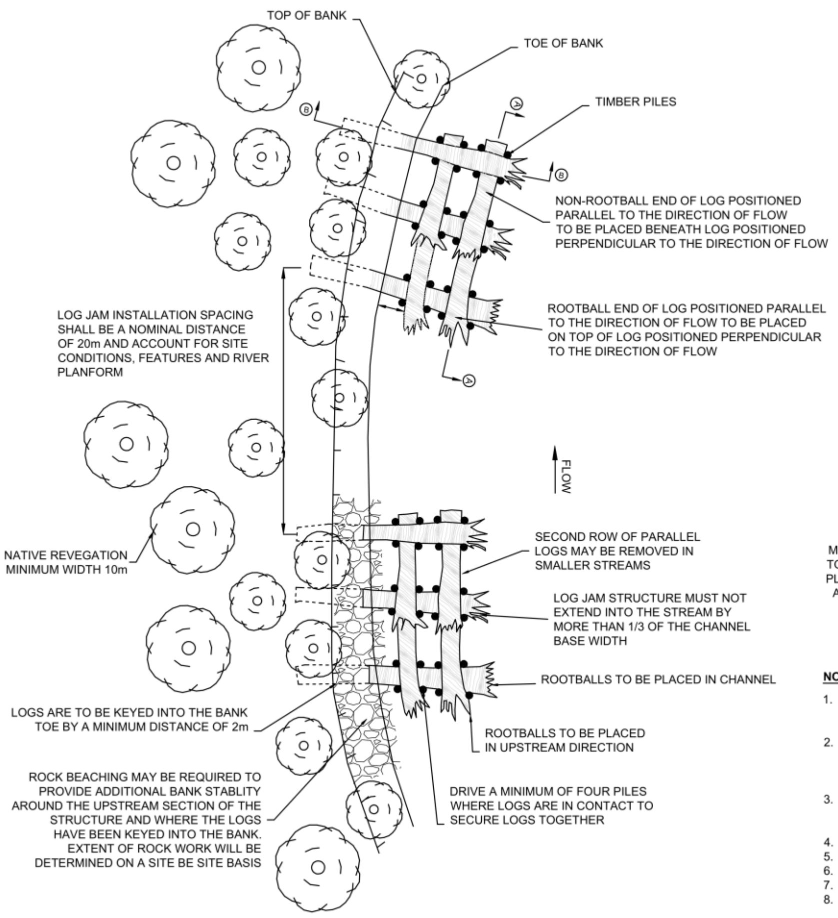
North East CMA
Level 1 104 Hovell St
Wodonga, VIC 3690
T: 1300 216 513

NORTH EAST CATCHMENT MANAGEMENT AUTHORITY

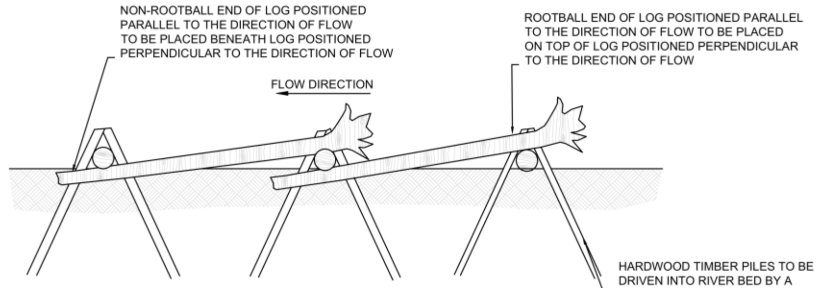
STANDARD DRAWING
LOG REVETMENT / BRUSHING

Not to Scale

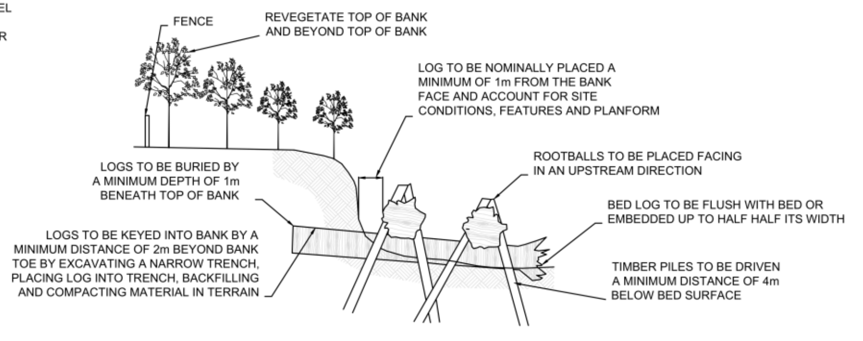
Drawing No. LR01
Rev No. Issued
Drawn By: Water Technology
Issued By: Initials
Position: Manager XXXX
Issued Date: DD/MM/YYYY



PLAN VIEW - STANDARD LOG JAM STRUTURE



SECTION A



SECTION B
FLOW DIRECTION INTO PAGE

NOTES

1. DRAWINGS ARE FOR A STANDARD DESIGN ARRANGEMENT FOR LOG JAMS CONSISTING OF 7 ROOTBALL-HARDWOOD LOGS. THIS PATTERN CAN BE REPEATED DOWNSTREAM IF THE SITE CALLS FOR A GREATER DISRUPTION OF ENERGY OR LENGTH OF BANK TO BE PROTECTED (IE 7, 10, 13 LOG CONFIGURATIONS).
2. A TYPICAL LOG JAM STRUCTURE WILL COMPRISE OF THREE LOGS PERPENDICULAR TO FLOW AND FOUR LOGS PARALLEL TO FLOW. IN LARGE WATERWAYS, OR WHERE THE EROSION EXTENDS FOR 50m+, THE SAME PATTERN OF 2-3 PARALLEL LOGS LAID OVER 1 PERPENDICULAR BED LOG CAN BE EXTENDED IN A RUNNING BIND DOWNSTREAM UNTIL THE DESIRED EFFECT OF BREAKING UP HYDRAULIC FORCES IS ACHIEVED.
3. OVERALL WIDTH OF THE LOG JAM SHALL BE NO GREATER THAN 1/3 OF THE TOTAL STREAM WIDTH. ACCORDINGLY, THE NUMBER OF PARALLEL LOGS USED MAY VARY TO SUIT SITE AND MATERIAL DIMENSIONS IN ORDER TO ACHIEVE THE DESIRED OVERALL WIDTH OF THE STRUCTURE.
4. LOGS USED FOR THE WORKS ARE TO CONTAIN THE TRUNK AND ROOT BALL.
5. LOGS SHOULD HAVE A DIAMETER OF APPROXIMATELY 400mm-800mm.
6. DRIVEN PILES ARE TYPICALLY 6m IN LENGTH AND DRIVEN A MINIMUM OF DISTANCE OF 4m BELOW THE CHANNEL BED.
7. DRIVEN PILES ARE TO HAVE A DIAMETER OF 200mm TO 300mm AND BE SOURCED FROM NATIVE STRAIGHT GRAINED HARDWOOD TIMBER.
8. THE PLACEMENT AND SPACING OF EACH STRUCTURE WILL NEED TO TAKE INTO ACCOUNT SITE SPECIFIC CONDITIONS, FEATURES, AND RIVER PLANFORM.
9. LOGS PLACED PARALLEL TO THE FLOW IS TO BE NOMINALLY PLACED A MINIMUM OF 1m FROM THE BANK FACE AND ACCOUNT FOR SITE CONDITIONS, FEATURES AND PLANFORM.
10. LOGS PLACED PARALLEL TO THE FLOW IS TO HAVE ROOT BALLS FACING UPSTREAM.
11. LOGS PLACED PERPENDICULAR TO THE FLOW ARE TO BE KEYED INTO THE BANK BY A MINIMUM OF 2m.
12. LOGS PLACED PERPENDICULAR TO THE FLOW ARE TO HAVE ROOT BALLS FACING AWAY FROM THE BANK.
13. THE DOWNSTREAM END OF THE LOGS PARALLEL TO THE DIRECTION OF FLOW ARE TO BE PLACED BENEATH LOG POSITIONED PERPENDICULAR TO THE DIRECTION OF FLOW.
14. A MINIMUM OF FOUR PILES ARE TO BE DRIVEN WHERE LOGS CROSS EACH OTHER. .
15. WHERE THE RISK OF OUTFLANKING OF THE STRUCTURE IS UNACCAPTABLE, ROCK ARMOURING ON THE LEADING EDGE AND ADJACENT BANK OF THE LOG JAM SHOULD BE CARRIED OUT WITH A NOMINAL ROCK SIZE OF 300-500mm HARD, ANGULAR ROCK APPROPRIATE TO THE SIZE OF THE WATERWAY. SEE THE STANARD DESIGN FOR ROCK BEACHING.
16. WITHOUT EXCEPTION, REVEGETATION ACTIVITIES SHOULD BE UNDERTAKEN BEHIND THE LOG JAMS.

SITE SPECIFIC DESIGN PARAMETERS

SITE ID =
LENGTH OF EROSION =
NUMBER OF LOG JAMS =
NUMBER OF LOGS PER STRUCTURE =

HORIZONTAL LOG LENGTH =
HORIZONTAL LOG DIAMETER =
VERTICAL PILE DIAMETER =
VERTICAL PILE LENGTH =

AMENDMENTS			
REV.	APPD.	DATE	AMENDMENT
Draft		13/06/2017	
Draft V02		24/07/2017	CHANGES TO NOTES, LAYOUT, DRAWING
For Approval		18/01/2018	AMENDMENT TO NOTES AND ANNOTATIONS
Final	NECMA	29/01/2018	AMENDMENT TO NOTES
Issued	Initials	DD/MM/YYYY	

GENERAL NOTES:

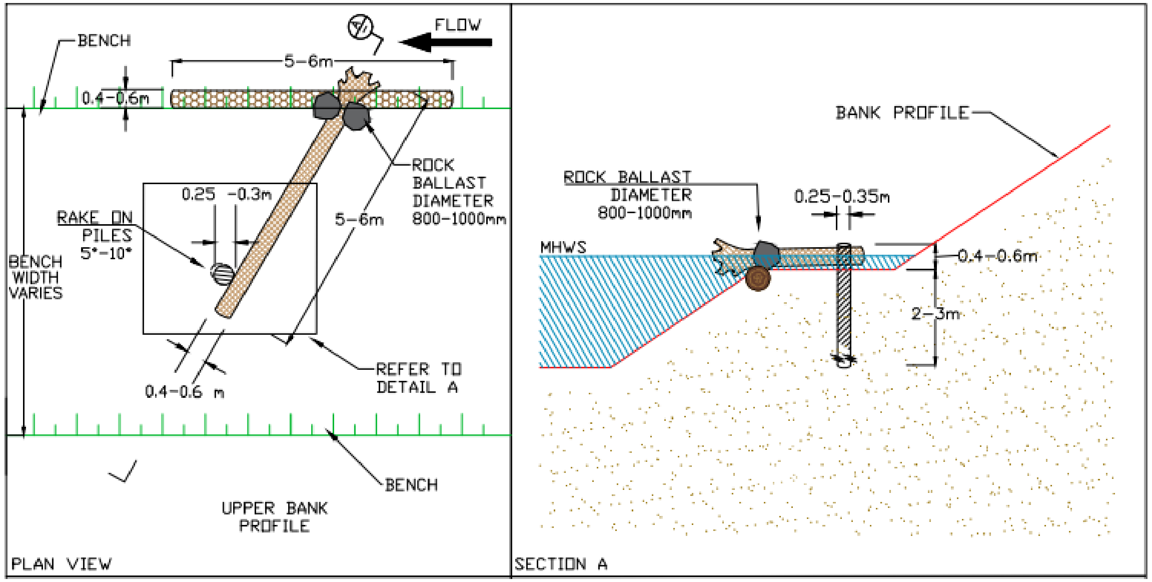
North East CMA
Level 1 104 Hovell St
Wodonga, VIC 3690
T: 1300 216 513

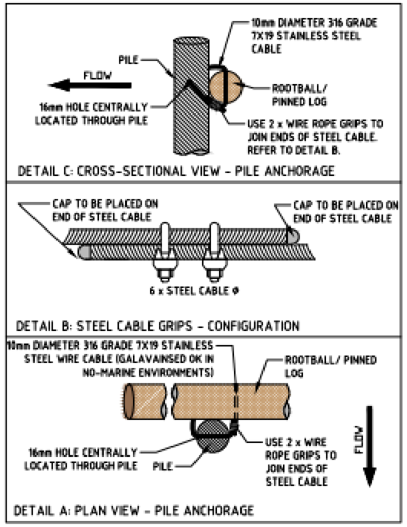
NORTH EAST CATCHMENT MANAGEMENT AUTHORITY

STANDARD DRAWING
Log Jam

Not to Scale

Drawing No. LJ01
Rev No. Issued
Drawn By: Water Technology
Issued By: Initials
Position: Manager XXXX
Issued Date: DD/MM/YYYY





LEGEND

- ROOTBALL LOG
- FOOTER LOG
- PILING TIMBER
- BALLAST BOULDER
- MEAN HIGH WATER SURFACE (MHWS)
- FLOW — RIVER FLOW DIRECTION

DIMENSIONS		
	PILE	LOG
DIAMETER	250–350 mm	400–600 mm
LENGTH	2–3m	5–6m

PILE ANCHOR AND LARGE WOOD SPECIFICATIONS

1. ALL LOGS TO BE AUSTRALIAN HARDWOOD
2. ROOTBALL LOG ALIGNMENT TO BE ON A RAKE 5-10 DEGREES TO FLOW
3. FOOTER LOGS TO BE SECURED BELOW WATER LEVEL SO THEY REMAIN SATURATED
4. ROOTBALL LOGS TO BE PLACED ON FOOTER LOGS AND SECURED IN PLACE WITH PILE AND ROCK BALLAST
5. ONCE LOGS HAVE BEEN SECURED WITH PILE/BOULDERS DISTURBED SOIL/BANK PROFILE TO BE REINSTATED
6. EROSION MATTING SHOULD BE PLACED ON FINISHED BANK SLOPE PRIOR TO REVEGETATION (WHERE REQUIRED)

REV	DESCRIPTION	DATE	INTL
B	FOR APPROVAL	17/07/23	SC
A	ORIGINAL ISSUE	30/06/22	SC

REVISIONS

	NAME	DATE
DESIGNED:	S.CLEVEN	17/07/2023
DRAWN:	M.TOZER	17/07/2023
CHECKED:	S.CLEVEN	17/07/2023
APPROVED:	S.CLEVEN	17/07/2023

SCALE: NOT TO SCALE

VICTORIA State Government — Energy, Environment and Climate Action

WWW.DEECA.VIC.GOV.AU

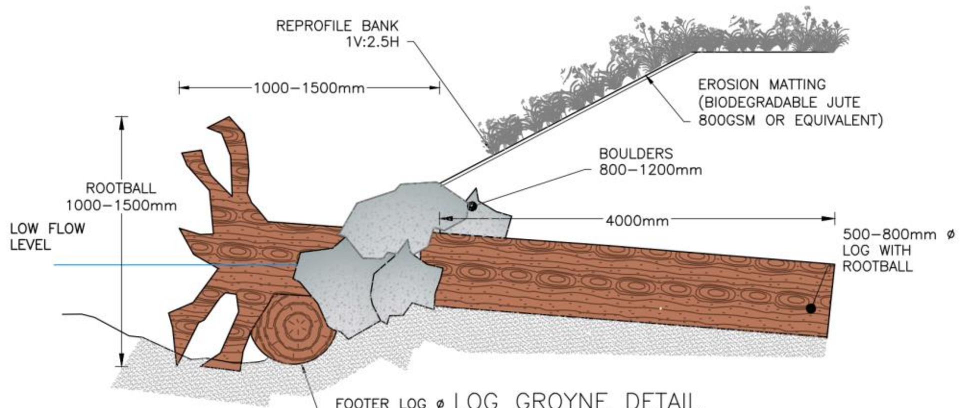
DRAWN: alluvium

STANDARD DRAWING
PILE ANCHOR AND LARGE WOOD

Drawing No. SHEET 001 — Revision No. A
Sheet No. 001 — File Name: 0121073_001.dwg
 — ABN 45 653 522 596
A3

STREAM BANK LOG PROTECTION

1. ALL LOGS TO BE AUSTRALIAN HARDWOOD
2. LOGS MAY BE PLACED ON GEOTEXTILE FILTER WHERE REQUIRED
3. FOOTER LOGS TO BE SECURED BELOW WATER LEVEL SO THEY REMAIN SATURATED
4. LOGS WITH ROOTBALLS TO BE PLACED ON FOOTER LOGS AND SECURED IN PLACE WITH LARGE BOULDERS
5. ONCE LOGS HAVE BEEN SECURED WITH BOULDERS AREA IS TO BE BACK FILLED
6. EROSION MATTING SHOULD BE PLACED ON FINISHED BANK SLOPE PRIOR TO REVEGETATION



LOG GROYNE DETAIL

EXAMPLE INSTALLATION

REV	DESCRIPTION	DATE	INTL
B	FOR APPROVAL	17/07/23	SC
A	ORIGINAL ISSUE	30/06/22	SC

REVISIONS

	NAME	DATE
DESIGNED:	M.IVEZICH	17/07/2023
DRAWN:	M.TOZER	17/07/2023
CHECKED:	S.CLEVEN	17/07/2023
APPROVED:	S.CLEVEN	17/07/2023

SCALE A B C NOT TO SCALE

VICTORIA State Government | Energy, Environment and Climate Action

WWW.DEECA.VIC.GOV.AU

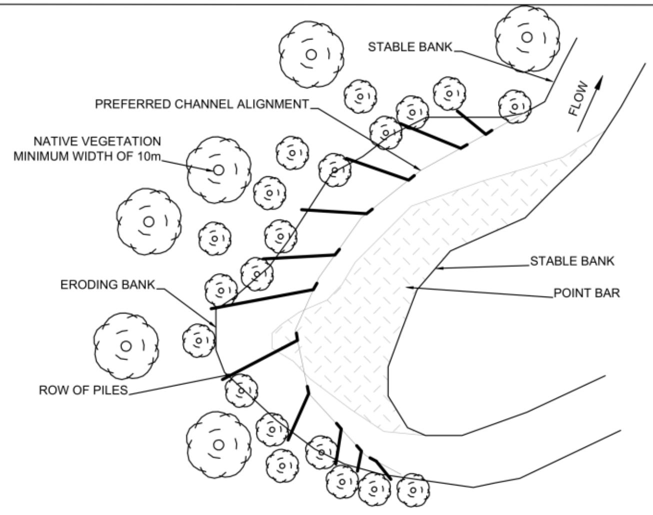
DRAWN: alluvium

STANDARD DRAWING
LOG GROYNE PLAN AND TYPICAL DETAIL

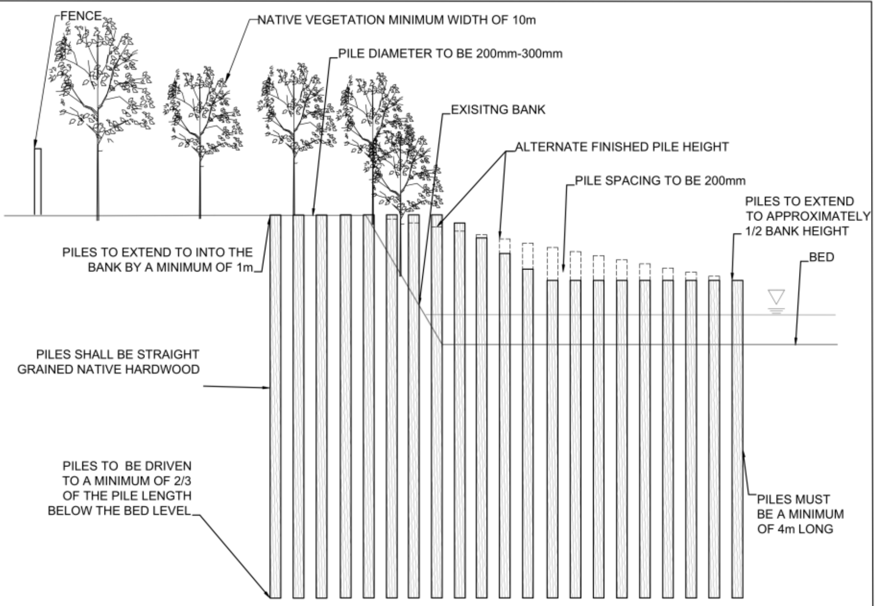
Drawing No. SHEET 001 | Revision No. A
Sheet No. 001 | File Name: 0121073_001.dwg

 | ABN 45 653 522 596

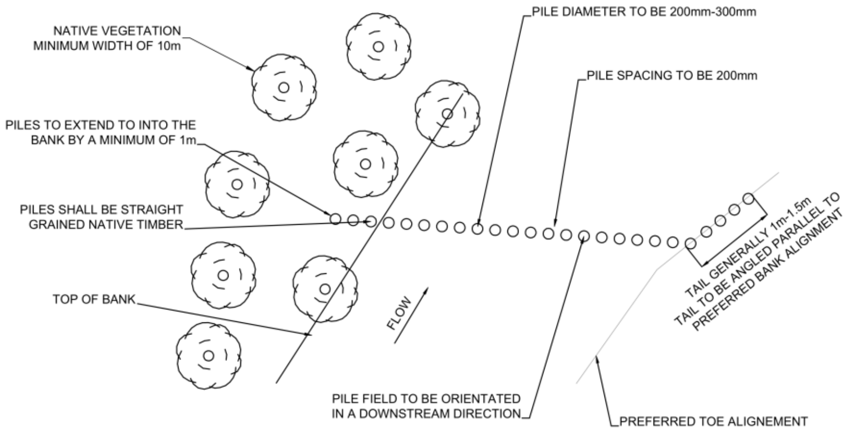
A3



TYPICAL PLAN VIEW OF PILE FIELDS



TYPICAL PILE FIELD CROSS SECTION



TYPICAL PLAN VIEW OF A SINGLE ROW OF PILE FIELDS

NOTES

1. A PILE IS A STRAIGHT UNIFORM LENGTH OF TIMBER. A PILE FIELD IS A ROW OF PILES. PILE FIELD DESIGN MUST ACCOUNT FOR STREAM WIDTH, DIRECTION OF MAXIMUM FLOW VELOCITY OR ATTACK, VELOCITY OF APPROACH, DESIRED VELOCITY IN THE PILE FIELD EMBAYMENTS, AND THE RADIUS OF CURVATURE OF THE BEND.
2. PILES MUST ONLY BE USED IN WATERWAYS CONTAINING MOBILE COARSE BED MATERIAL (E.G. GRAVEL AND COBBLES).
3. THE PILES MUST BE DURABLE, NATIVE, STRAIGHT GRAINED TIMBER. PILES MAY HAVE A POINTED TIP TO ASSIST DRIVING INTO THE GROUND.
4. THE PILE MUST BE 200mm-300mm IN DIAMETER.
5. PILES SHOULD BE EVENLY PLACED, WITH A SPACING OF 200mm-300mm BETWEEN EACH PILE.
6. THE PILES ARE TO BE DRIVEN SO THAT A MINIMUM 2/3 OF THE PILE LENGTH IS BELOW GROUND LEVEL, OR TO REFUSAL (I.E. CANNOT BE DRIVEN FURTHER).
7. THE ROWS OF PILES SHOULD EXTEND TO A MINIMUM OF 1m INTO SOLID GROUND ON THE BANK OF THE WATERWAY TO ALLOW FOR FUTURE BANK MOVEMENT WHILE THE SYSTEM ADJUSTS.
8. PILES MUST BE A MINIMUM OF 4m LONG, AND GENERALLY BE IN THE ORDER OF 4-6m LONG.
9. THE FINISHED PILE HEIGHT SHOULD BE RELATED TO THE EXPECTED RANGE OF FLOW CONDITIONS. AS A GUIDE, THE PILES SHOULD BE APPROXIMATELY THE HEIGHT OF THE BANK AT THE BANK END AND DECREASE IN HEIGHT TO APPROXIMATELY HALF THE BANK HEIGHT AT THE STREAMWARD END.
10. THE FINISHED PILE HEIGHT MAY BE ANGLED OR STEPPED SLIGHTLY DOWNWARDS TOWARD THE STREAM. THERE SHOULD BE NO HIGH OR LOW SPOTS ALONG THE PILE FIELD.
11. SUBJECT TO CULTURAL HERITAGE CHECKS AND ANY APPROVALS REQUIRED, BAR MATERIAL MAY BE RELOCATED FROM ABOVE WATER LEVEL TO BE PLACED IN THE EMBAYMENTS (BETWEEN THE ROWS OF PILES).
12. WITHOUT EXCEPTION, REVEGETATION ACTIVITIES MUST BE UNDERTAKEN BETWEEN THE PILE FIELDS AND EXTEND AT LEAST 10M FROM THE TOP OF BANK.
13. THE TIMBER PILES WILL DECAY OVER TIME AND DEPENDING ON THEIR SIZE AND SPECIES AND THE LOCAL ENVIRONMENT WILL HAVE A USEFUL LIFE OF BETWEEN 10 AND 20 YEARS.
14. REVEGETATION WORKS MUST BE UNDERTAKEN WITH A MIXTURE OF SPECIES INCLUDING GRASSES, SEDGES, RUSHES, SHRUBS AND TREES.

SITE SPECIFIC DESIGN PARAMETERS

SITE ID =

LENGTH OF BANK TO BE PROTECTED =

HEIGHT OF BANK =

PILE LENGTH =

PILE DIAMETER =

SPACING BETWEEEN PILES =

AMENDMENTS			
REV.	APPD.	DATE	AMENDMENT
Draft		13/06/2017	
Draft V02		31/07/2017	CHANGES TO NOTES, LAYOUT, VEGETATION
Draft V03		25/09/2017	CHANGES TO PILE LENGTH
Final	NECMA	10/10/2017	AMEND NOTE 3
Final V02	NECMA	02/11/2017	INCREASE PILE HEIGHT, AMEND NOTE 9, ADD NOTE 10
Issued	Initial	DD/MM/YYYY	

GENERAL NOTES:

North East CMA
Level 1 104 Hovell St
Wodonga, VIC 3690
T: 1300 216 513

NORTH EAST CATCHMENT MANAGEMENT AUTHORITY

STANDARD DRAWING
Pile Fields

Not to Scale

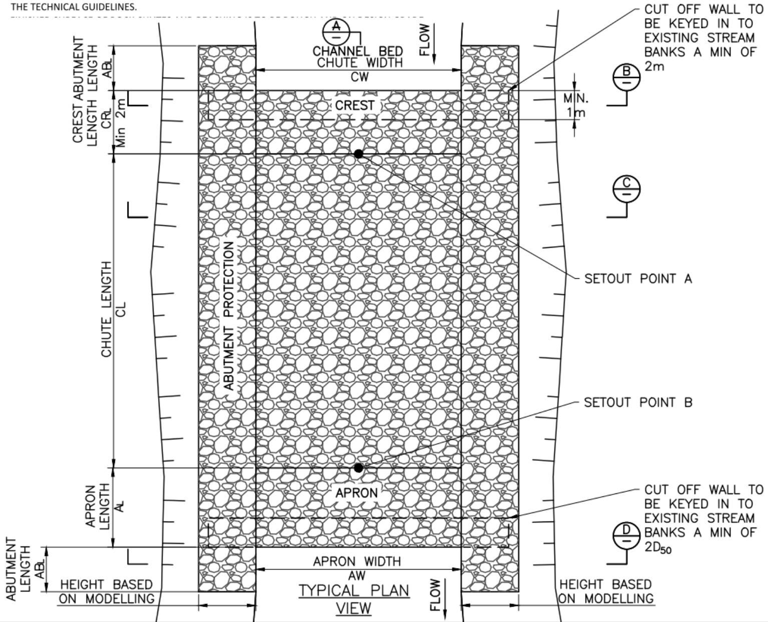
Drawing No. PF01
Rev No. Issued
Drawn By: Water Technology
Issued By: Initials
Position: Manager XXXX
Issued Date: DD/MM/YYYY

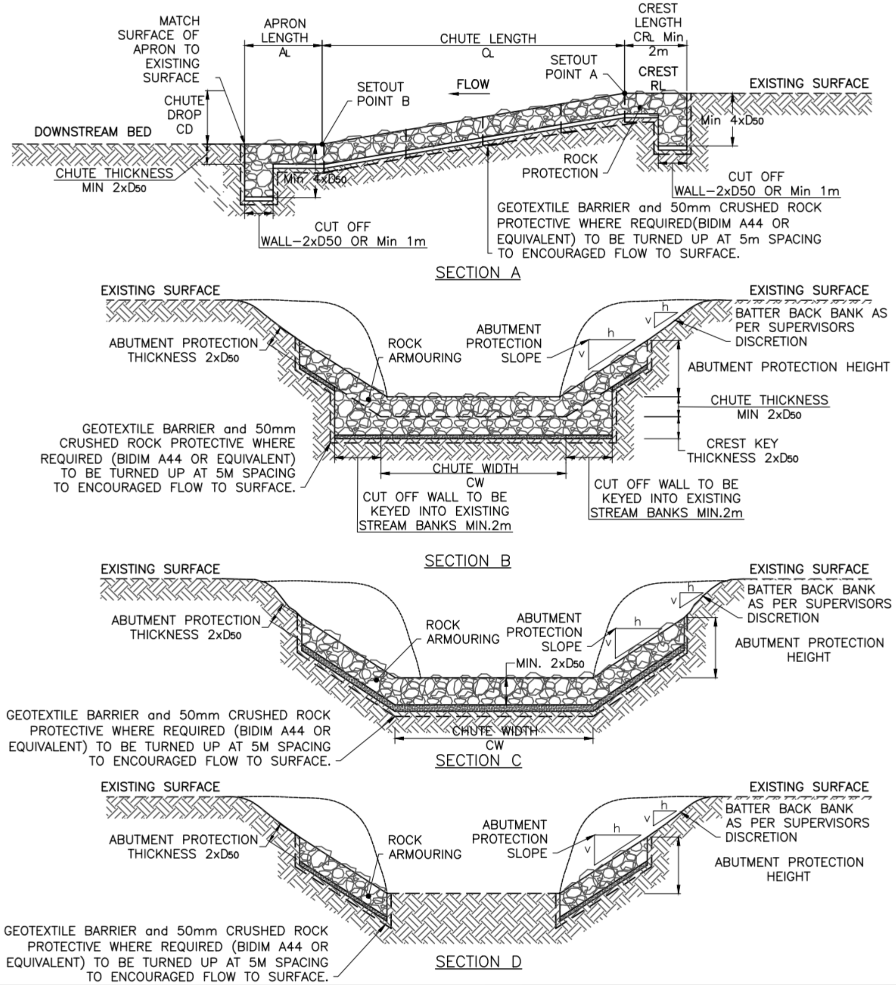
ROCK CHUTE

1. ROCK CHUTE DIMENSIONS/POSITIONING TO BE DETERMINED AS PER SECTION 6.7 ROCK CHUTE ANALYSIS
2. CREST CUTOFF WALL IS TO EXTEND THE TOTAL CHUTE WIDTH
3. CREST OF CHUTE AND START OF APRON TO BE CLEARLY DEFINED BY CHANGE IN GRADE.
4. ABUTMENT PROTECTION HEIGHT TO BE SPECIFIED DURING DESIGN OR TO TOP OF BANK (WHICH EVER IS THE LOWER)
5. ABUTMENT PROTECTION TO EXTEND A MINIMUM OF 3 m UPSTREAM OF CHUTE CREST AND 3 m DOWNSTREAM OF APRON AND TOP DRESSED WITH LOCALLY EXCAVATED MATERIAL. FINAL EXTENT OF ABUTMENT PROTECTION TO BE DETERMINED ON SITE BY SUPERINTENDENT.
6. BANK BATTERS ABOVE ABUTMENT PROTECTION TO BE AT THE SAME SLOPE OR FLATTER THAN ABUTMENT PROTECTION SLOPE.
7. ROCK USED FOR ROCK CHUTES AND STREAM BANK PROTECTION MUST MEET THE FOLLOWING SIZE SPECIFICATION:
8. ROCK SHOULD NOT BE ADVERSELY AFFECTED BY REPEATED WETTING AND DRYING AND SHALL HAVE A CRUSHING STRENGTH OF NOT LESS THAN 25 MPa.
9. CHUTE MATERIAL TO COMPRISE WELL-GRADED ANGULAR ROCK, FREE OF CRACKS AND FOREIGN MATERIAL.

ROCK SUPPLY AND PLACEMENT FOR ROCK CHUTE WORKS:

10. SUPPLY AND PLACEMENT OF ROCK TO BE IN ACCORDANCE WITH SECTION 6.11.4 - ROCK OF THE TECHNICAL GUIDELINES AND ONSITE DIRECTION BY DESIGN ENGINEER OR SITE SUPERVISOR.
11. ROCK PLACEMENT SHALL NOT COMMENCE UNTIL THE PREPARED SURFACE AND GEOTEXTILE PLACEMENT HAS BEEN APPROVED BY THE SITE SUPERVISOR.
12. ROCK SHALL BE CAREFULLY PLACED BY BUCKET FROM A LOADER OR EXCAVATOR FROM NO GREATER THAN 1.0 m ABOVE THE MATERIAL ONTO WHICH IT IS TO BE PLACED.
13. ROCK SHALL BE WORKED INTO PLACE SO AS TO PRODUCE A BLANKET OF INTERLOCKING ROCK THAT HAS NO SIGNIFICANT VOIDS AND DOES NOT MOVE UNDER FOOT.
14. GRADING SHALL PRODUCE A CONSISTENT MIX OF ROCK SIZES IN ACCORDANCE WITH SECTION 6.11.4 - ROCK OF THE TECHNICAL GUIDELINES.





REV	DESCRIPTION	DATE	INTL
B	FOR APPROVAL	17/07/23	SC
A	ORIGINAL ISSUE	30/06/22	SC

REVISIONS

	NAME	DATE
DESIGNED:	S.CLEVEN	17/07/2023
DRAWN:	M.TOZER	17/07/2023
CHECKED:	S.CLEVEN	17/07/2023
APPROVED:	S.CLEVEN	17/07/2023

SCALE
A
B
C
NOT TO SCALE
mm

VICTORIA State Government | Energy, Environment and Climate Action

WWW.DEECA.VIC.GOV.AU

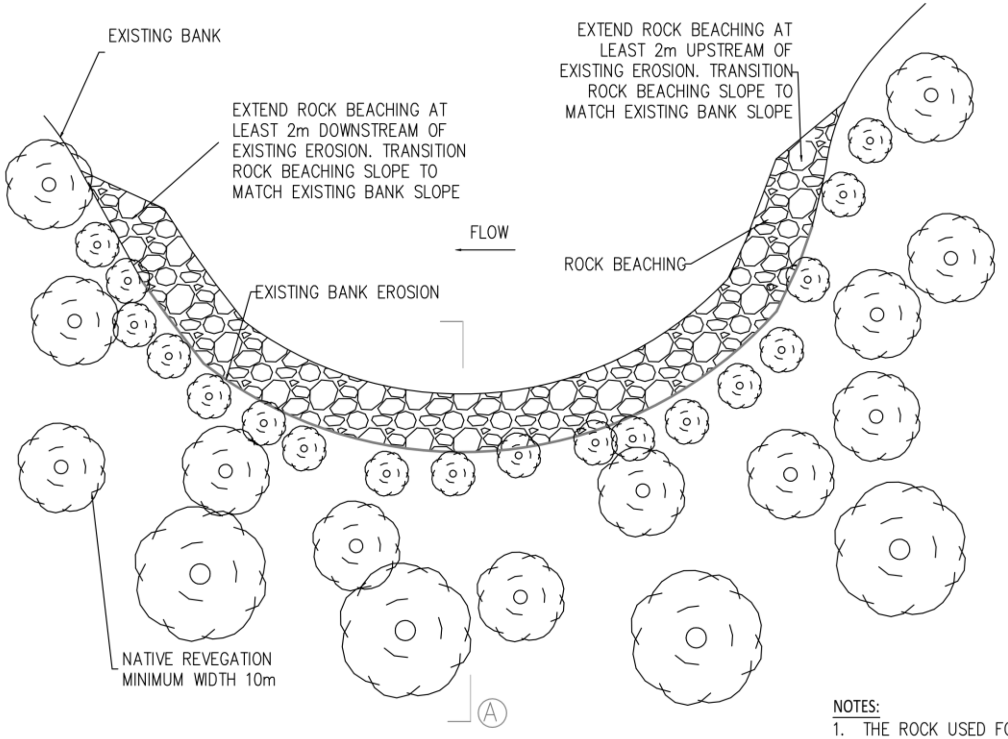
DRAWN:

alluvium

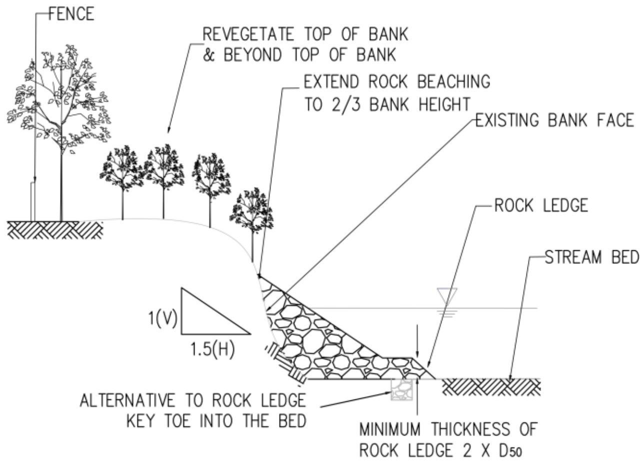
STANDARD DRAWING
ROCK CHUTE

Drawing No. SHEET 001
Revision No. A
Sheet No. 001
File Name: 0121073_001.dwg

ABN 45 653 522 596
A3



STANDARD PLAN VIEW



CROSS SECTION 'A'

NOTES:

1. THE ROCK USED FOR THE BANK STABILISATION MUST BE CLEAN, HARD, WELL-GRADED (A MIXTURE OF SIZES TO ALLOW INTERLOCKING AND MINIMISE VOIDS), ANGULAR ROCK.
2. THE MEDIAN SIZE OF THE ROCK USED MUST BE BETWEEN 300mm - 500mm. THIS ROCK SIZE IS REFERRED TO AS D_{50}, BY DEFINITION 50% OF THE MASS MUST CONSIST OF ROCKS WITH AN EQUIVALENT SPHERICAL DIAMETER EQUAL TO OR LARGER THAN THIS DIMENSION.
3. ROCK SHALL BE PLACED ON A SLOPE THAT DOES NOT EXCEED 1.5 HORIZONTAL WITH 1 VERTICAL.
4. THE ROCK IS TO BE KEYED INTO THE BED AT THE TOE OF THE BANK, OR A LEDGE OF ROCK SHALL BE PLACED ON THE STREAM BED, AT LEAST 2 X D_{50} TO MITIGATE UNDERMINING ALONG THE LENGTH OF THE SITE.
5. ROCK SHALL BE PLACED TO APPROXIMATELY TWO THIRDS BANK HEIGHT.
6. ROCK BEACHING SHALL EXTEND LONGITUDINALLY PAST THE EXISTING EROSION EXTENT, BOTH UPSTREAM AND DOWNSTREAM BY A MINIMUM DISTANCE OF TWO METRES.
7. ROCK SHOULD BE PLACED ON THE BANK TO A MINIMUM THICKNESS OF TWICE THE MEDIAN DIAMETER (D_{50}) OF THE ROCK MATERIAL.
8. THE FINISHED ROCK BEACHING SHALL BE FULLY KEYED INTO THE BED AND BANKS OF THE RIVER AND NOT LEFT PROUD OF THE RIVER BED AND BANKS.
9. ALL ROCK SHOULD BE PLACED ON THE BANK RATHER THAN TIPPED OVER THE BANK, AND WHERE POSSIBLE LARGER ROCKS SHOULD BE PLACED ALONG THE TOE OF THE BANK TO PROVIDE A SOLID FOUNDATION.
10. SOME SETTLEMENT OF THE ROCK MAY REQUIRE THE PLACEMENT OF ADDITIONAL MATERIAL ON THE SLOPE.
11. WITHOUT EXCEPTION, REVEGETATION ACTIVITIES SHOULD BE UNDERTAKEN BEHIND THE ROCK BEACHING.

SITE SPECIFIC DESIGN PARAMETERS

SITE ID =

D_{50} OF ROCK =

LENGTH OF BANK TO BE PROTECTED =

HEIGHT OF BANK =

HEIGHT OF ROCK ARMOURING =

FENCE OFFSET FROM TOP OF BANK =

AMENDMENTS			
REV.	APPD.	DATE	AMENDMENT
Draft		13/06/2017	
For Approval		10/07/2017	Update notes, change layout, change to bank profile
Final	NECMA	12/07/2017	Amend note 2
Final v02	NECMA	25/09/2017	Amend note 2
Issued	Initials	DD/MM/YYYY	

GENERAL NOTES:

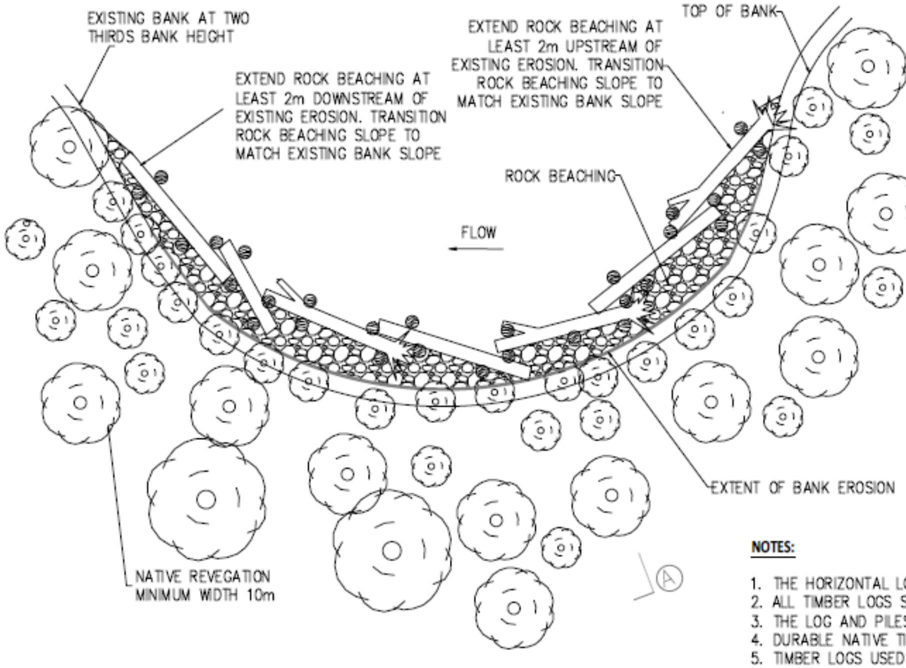
North East CMA
Level 1 104 Hovell St
Wodonga, VIC 3690
T: 1300 216 513

NORTH EAST CATCHMENT MANAGEMENT AUTHORITY

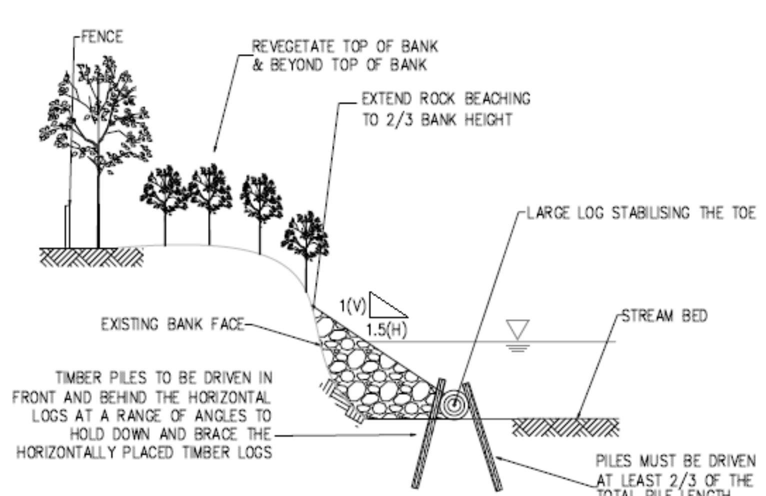
STANDARD DRAWING
ROCK BEACHING

Not to Scale

Drawing No.	RB01
Rev No.	Issued
Drawn By:	Water Technology
Issued By:	Initials
Position:	Manager
Issued Date:	DD/MM/YYYY



STANDARD PLAN VIEW



CROSS SECTION 'A'

NOTES:

1. THE HORIZONTAL LOG IS TO BE PLACED FLUSH ON THE STREAM BED.
2. ALL TIMBER LOGS SHALL OVERLAP PREVIOUS LOG BY APPROXIMATELY 20% OF ITS LENGTH.
3. THE LOG AND PILES MUST BE PLACED AND SECURED PRIOR TO PLACING THE ROCK.
4. DURABLE NATIVE TIMBER MUST BE USED FOR THE INSTREAM LOGS AND PILES.
5. TIMBER LOGS USED TO SUPPORT THE TOE OF THE ROCK WORK MUST HAVE A MINIMUM DIAMETER OF 300m.
6. PILES MUST HAVE A DIAMETER BETWEEN 200 AND 300mm, AND A MINIMUM LENGTH OF 4m.
7. PILES MUST BE DRIVEN SO THAT AT LEAST TWO THIRDS OF THE PILE LENGTH IS BELOW THE STREAM BED.
8. TIMBER MAY BE CUT TO LENGTH AS REQUIRED TO MATCH THE DESIRED ROCK BEACHING TOE ALIGNMENT.
9. THE PILES ARE TO BE DRIVEN AT A RANGE OF ANGLES TO HOLD DOWN AND BRACE THE HORIZONTAL PLACED TIMBER LOGS.
10. A MINIMUM OF FOUR PILES ARE TO BE DRIVEN FOR EACH ROW OF HORIZONTALLY PLACED TIMBER LOGS, TO PREVENT DISPLACEMENT AS A RESULT OF FLOTATION OR HYDRAULIC FORCES.
11. BRANCHES AND LEAF LITTER ON TIMBER LOGS IS ENCOURAGED TO BE RETAINED. LOPPING OF BRANCHES CAN BE UNDERTAKEN WHERE REQUIRED TO ASSIST WITH PLACEMENT OR TO REDUCE THE RISK OF THE TREE CATCHING FLOOD DEBRIS.
12. ROOTBALL LOGS SHOULD ONLY BE USED IF THE ROOTBALL DOES NOT IMPACT THE PLACEMENT OF LOGS AND ROCK.
13. IF ROOTBALL LOGS ARE TO BE USED THEN THE ROOTBALL IS TO FACE IN AN UPSTREAM DIRECTION.
14. THE ROCK USED FOR BANK STABILISATION MUST BE CLEAN, HARD, WELL–GRADED (A MIXTURE OF SIZES TO ALLOW INTERLOCKING AND MINIMISE VOIDS) ANGULAR ROCK.
15. THE MEDIAN SIZE OF THE ROCK USED MUST BE BETWEEN 300 –500mm. THIS ROCK SIZE IS REFERRED TO AS D_{50}, BY DEFINITION 50% OF THE MASS MUST CONSIST OF ROCKS WITH AN EQUIVALENT SPHERICAL DIAMETER EQUAL TO OR LARGER THAN THIS DIMENSION.
16. ROCK SHALL BE PLACED ON A SLOPE THAT DOES NOT EXCEED 1.5 HORIZONTAL WITH 1 VERTICAL.
17. ROCK SHALL BE PLACED TO APPROXIMATELY TWO THIRDS BANK HEIGHT.
18. ROCK BEACHING SHALL EXTEND LONGITUDINALLY PAST THE EXISTING EROSION EXTENT, BOTH UPSTREAM AND DOWNSTREAM BY A MINIMUM DISTANCE OF TWO METRES.
19. ROCK SHALL BE PLACED ON THE BANK TO A MINIMUM THICKNESS OF TWICE THE MEDIAN DIAMETER (D_{50}) OF THE ROCK MATERIAL.
20. THE FINISHED ROCK BEACHING SHALL BE FULLY KEYED INTO THE BED AND BANKS OF THE RIVER AND NOT LEFT PROUD OF THE RIVER BED AND BANKS.
21. ALL ROCK SHOULD BE PLACED ON THE BANK RATHER THAN TIPPED OVER THE BANK, AND WHERE POSSIBLE LARGER ROCKS SHOULD BE PLACED ALONG THE TOE OF THE BANK TO PROVIDE A SOLID FOUNDATION.
22. SOME SETTLEMENT OF THE ROCK MAY REQUIRE THE PLACEMENT OF ADDITIONAL MATERIAL ON THE SLOPE.
23. WITHOUT EXCEPTION, REVEGETATION ACTIVITIES SHOULD BE UNDERTAKEN BEHIND THE ROCK BEACHING.

SITE SPECIFIC DESIGN PARAMETERS

SITE ID =

LENGTH OF BANK TO BE PROTECTED =

HEIGHT OF BANK =

HORIZONTAL LOG LENGTH =

HORIZONTAL LOG DIAMETER =

VERTICAL PILE DIAMETER =

VERTICAL PILE LENGTH =

D50 OF ROCK =

HEIGHT OF ROCK ARMOURING =

FENCE OFFSET FROM TOP OF BANK =

AMENDMENTS

REV.	APPD.	DATE	AMENDMENT
Dra		31/08/2017	
For Approval			
Final			
Issued	Inials	DD/MM/YYYY	

GENERAL NOTES:

North East CMA
Level 1 104 Hovell St
Wodonga, VIC 3690
T: 1300 216 513

NORTH EAST CATCHMENT MANAGEMENT AUTHORITY

STANDARD DRAWING
ROCK BEACHING WITH LOG TOE

Not to Scale

Drawing No.	RB02
Rev No.	Dra
Drawn By:	Water Technology
Issued By:	Inials
Posion:	Manager
Issued Date:	DD/MM/YYYY

9 References

Abad, J.D., Rhoads, B.L., Güneralp, İ., and García, M.H. (2008). Flow Structure at Different Stages in a Meander-Bend with Bendway Weirs, *Journal of Hydraulic Engineering*, pp. 1052-1063

Abam, T.K.S. (1995) Factors affecting performance of permeable groins in channel bank erosion control, *Environmental Geology*, Vol. 26., pp. 53-56

Abernethy, B. and Rutherfurd, I.D. (1999). *Guidelines for stabilising streambanks with riparian vegetation*, Technical Report 99/10, Cooperative Research Centre for Catchment Hydrology

Alauddin, M. (2011) *Morphological Stabilization of Lowland Rivers by Using a Series of Groynes*, A dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Engineering

Alluvium (2011). *An assessment of the impact of riparian revegetation on stream erosion during floods in Victoria*

Alluvium (2019a). *Defining waterway setbacks for river health benefits: a Melbourne Water Perspective*, Discussion Paper prepared for Melbourne Water, P118215.

Alluvium (2019b). *East Barwon transfer and remediation project – technical assessment*. Final report by Alluvium Consulting Australia for Barwon Water, Geelong, P119053.

Alluvium (2021). *Impacts of GPTs on the geomorphology of Gwawley*, report prepared for Sutherland Shire Council, Sutherland, NSW.

Alluvium (2022). *Hydraulic modelling of pile field groyne, bank stabilisation, to inform design guidelines*. Report P420065_R01 by Alluvium Consulting Australia for Great Barrier Reef Foundation.

Balshaw, D. (1999). *Investigation into Sampling Methods for the Measurement of Rock Riprap in Rock Chutes*, unpublished thesis, The University of Melbourne.

Blackham, D. (2006). *The resistance of herbaceous vegetation to erosion: implications for stream form.* PhD thesis, The University of Melbourne.

Blench, T. (1969). *Mobile bed fluviology*, University of Alberta Press, Edmonton, Canada

Brewer, P.A. and Lewin, J. (1998). Planform cyclicity in an unstable reach: complex fluvial response to environmental change. *Earth Surface Processes and Landforms*, Vol. 23, Is. 11, pp. 989-1008

Broms, B.B. (1964). Lateral resistance of piles in cohesive soils, *Journal of the soil mechanics and foundations division: Proceedings of the American Society of Civil Engineers*.

Brooks, A., Abbe, T., Cohen, T., Marsh, N., Mike, S., Boulton, A., Broderick, T., Borg, D. and Rutherfurd, I. (2006). *Design guideline for the reintroduction of wood into Australian streams*, Land & Water Australia, Canberra

Carling, P.A., Kohmann, F., Golz, E. (1996). River hydraulics, sediment transport and training works: their ecological relevance to European rivers. *Archiv. Hydrobiol. Suppl*., Vol. 113, Is.10., pp. 129-146.

Charlton, R. (2008). *Fundamentals of fluvial geomorphology*. London: Routledge. 234 pp.

Chen, W.F., & Liew, J.Y.R. (Eds.). (2002). *The Civil Engineering Handbook (2nd ed.)*. CRC Press.

CRC for Catchment Hydrology (2003), *Guidelines for the Design of Rock Chutes using CHUTE*, CRC for Catchment Hydrology

CRC for Catchment Hydrology (2005). *Guidelines for the Design of River Bank Stability and Protection using RIP-RAP,* Prepared by Associate Professor R.J. Keller for CRC for Catchment Hydrology, Australia

CRC for Water Sensitive Cities (2020). *Designing for a cool city: Guidelines for passively irrigated landscapes*, Victoria: Cooperative Research Centre for Water Sensitive Cities

Crossman, M. and Simm, J. (2004), *Manual on the Use of Timber in Coastal and River Engineering*, Wallingford, England.

Davis, J., Bird, J., Finlayson, B. and Scott, R. (2000). The management of gravel extraction in alluvial rivers: a case study from the Avon River, southeastern Australia. *Physical Geography*, Vol. 21, Is. 2, pp.133-154

DEECA (2023). Benefits of riparian land to landholders webpage, The State of Victoria Department of Energy, Environment and Climate Action, https://www.water.vic.gov.au/waterways/riparian-land/benefits-of-riparian-land-to-landholders

DELWP (2015a). *DELWP Output delivery standards For the delivery of environmental activities*, The State of Victoria Department of Environment, Land, Water & Planning

DELWP (2015b). *Guidelines for riparian fencing in flood-prone areas*, The State of Victoria Department of Environment, Land, Water & Planning

DELWP (2015c). Effective engagement: Building relationships with community and other stakeholders. Book 1: An introduction to engagement (4th ed.). Melbourne: State Government of Victoria.

DELWP (2016a). *Managing grazing on riparian land*, State of Victoria Department of Environment, Land, Water and Planning, East Melbourne

DELWP (2016b). *Managing Willows in Victoria Factsheet*, State of Victoria Department of Environment, Land, Water and Planning, East Melbourne

DELWP (2018). *Managing weeds: assess the risk guide*

DELWP (2019). *Environmental Water*, State of Victoria Department of Environment, Land, Water and Planning, East Melbourne

DELWP (2020). *Biodiversity revegetation with provenance mixing for climate change adaptation*

DELWP (2022). *Water is Life: Traditional Owner Access to Water Roadmap*, State of Victoria Department of Environment, Land, Water and Planning, East Melbourne

DEPI (2013a). *Victorian Waterway Management Strategy*, Victorian Government Department of Environment and Primary Industries

DEPI (2013a) *FLOWS – a method for determining environmental water requirements in Victoria: Edition 2*, Victorian Government Department of Environment and Primary Industries.

De Rose, R.C. and Basher, L.R. (2011). Measurement of river bank and cliff erosion from sequential LIDAR and historical aerial photography. *Geomorphology*, Vol. 126, Is. 1-2, pp. 132-147

DPI (2007a). *Willows National Management Guide: current management and control options for willows* (Salix spp.) in Australia, Victorian Department of Primary Industries, Geelong

DPI (2007b). *Weeds of National Significance – Best practice control manuals*, New South Wales Department of Primary Industries, List of Weeds of National Significance, NSW WeedWise

DSE (2006). *Native Vegetation Revegetation planting standards – Guidelines for establishing native vegetation for net gain accounting.* Victorian Government, Department of Sustainability and Environment, East Melbourne.

DSE (2012). *Monitoring, evaluation and reporting framework: Land, water and biodiversity*, Victorian Government Department of Sustainability and Environment

Dyer, B. (1995). *Retards and Groynes Design Guidelines, Guidelines for Stabilising Waterways*, Victoria.

Ecology Australia (2018) Riparian Setback Widths: A review of recommendations for guidelines. Report prepared for Melbourne Water by M Le Feuvre, F Sutton, C Maloney (Ecology Australia Pty Ltd: Fairfiled)

Farraday, R.V. and Charlton, F.G. (1983). *Hydraulic factors in bridge design*, Hydraulics Research Station Limited, Wallingford, England.

Federal Interagency Stream Restoration Working Group (1998), *Stream Corridor Restoration: Principles, Processes and Practices,* by the (FISRWG – 15 Federal agencies of the US government).

Fischenich, C. (2001a). *Stability Thresholds for Stream Restoration Materials*, EMRRP Technical Notes Collection (ERDC TNEMRRP-SR-29), U.S. Army Engineer Research and Development Center, Vicksburg, MS

Fischenich, C. (2001b). *Impacts of stabilization measures*. U.S. Corps of Army Engineers, Engineer Research and Development Center. Vicksburg.

Fisher Stewart (2002). *Bowen Basin River Diversions, Design and Rehabilitation Criteria*, Report for Australian Coal Association Research Program (ACARP), Queensland.

Fryirs, K. A., & Brierley, G. J. (2012). *Geomorphic analysis of river systems: an approach to reading the landscape*. John Wiley & Sons.

GBCMA (2022) *Waterway and Floodplain Management Resources*, Goulburn Broken Catchment Management Authority

Ghermandi, A., J.C.J.M. van den Bergh, L.M. Brander, H.L.F. de Groot, and P.A.L.D. Nunes. (2009). *The Values of Natural and Constructed Wetlands: A Meta-Analysis.* Tinbergen Institute Discussion Paper.

Grant G.E., O'Connor J.E., and Wolman M.G. (2013). A River Runs Through It: Conceptual Models in Fluvial Geomorphology. In: John F. Shroder (ed.) *Treatise on Geomorphology*, Volume 9, pp. 6-21. San Diego: Academic Press

Greening Australia (2003). *A guide for establishing native vegetation in Victoria*

Greening Australia (2017). *Revegetation guide for temperate riparian lands*

Hansen B.D., Reich P., Lake P.S., Cavagnaro T. (2010) *Minimum width requirements of riparian zones to protection flowing waters and to conserve biodiversity: a review and recommendations*. Report to Department of Sustainability and Environment (Monash University: Clayton).

Hardie, R. (1993). *Review of Stream Profile Information for Catchments of North East Victoria.* Masters Thesis, University of New England, New South Wales

Hicks, D. and Mason, P. (1991). *Roughness Characteristics of New Zealand Rivers*, New Zealand National Institute of Water and Atmospheric Research, Auckland, 329 Pages.

Jia, Jia, Y., Scott, S., Xu, Y., & Wang, S. S. Y. (2009). Numerical study of flow affected by bendway weirs in Victoria Bendway, the Mississippi River. J. Hydraul. Eng., 135(11), 902-916.

ID&A Pty Ltd. (1996a). *Improvements in the design and construction of rock chutes*, Unpublished report prepared by Ian Drummond and Associated Pty Ltd to Department of Natural Resources and Environment and the Mitchell River Management Board Victoria.

ID&A Pty Ltd. (1996b). *Rock Size Grading 'A Visual Guide'*, prepared by Ian Drummond and Associated Pty Ltd to Department of Natural Resources and Environment and Mitchell River Management Board, Victoria.

Jia, Y., Scott, S., Xu, Y., & Wang, S. S. Y. (2009). Numerical study of flow affected by bendway weirs in Victoria Bendway, the Mississippi River. *Journal of Hydraulic. Engineering*, Vol. 135, Is. 11, pp. 902-916

Jones, M.J. and O'Connor, J.P. (2017). *Monitoring the performance of fishways and fish passage works.* Arthur Rylah Institute for Environmental Research. Technical Report Series No. 257. Department of Environment, Land, Water and Planning, Heidelberg, Victoria

Kang, J., Yeo, H., Kim, S., Ji, U. (2011). Permeability effects of single groin on flow characteristics, *Journal of Hydraulic Research*, Vol. 49, Is. 6, pp. 728-735

Keller, R.J. and Winston, F.B., (2004). Design of Rock Chutes for the Stabilization of Channel Beds. In *Protection and Restoration of Urban and Rural Streams* (pp. 329-338).

Kondolf, G. M., H. Piégay, and N. Landon. (2002). Channel response to increased and decreased bedload supply from land-use change: contrasts between two catchments. *Geomorphology* Vol. 4, pp.35-51.

Ladson, A., Gerrish, G., Carr, G., Thexton, E. and Brizga, S. (1997), *Willows along Victorian Waterways – Towards a willow management strategy*, Waterways Unit, Department of Natural Resources and Environment Victoria.

Ladson, A., Lang, S., Abderson, B. and Rutherfurd, I. (2003). *An Australian Handbook of Stream Roughness Coefficients,* 28th Hydrology and Water Resources Symposium, Wollongong, The Institute of Engineers, Australia, Lane, E.W. (1955). The importance of fluvial morphology in hydraulic engineering. *Proceedings (American Society of Civil Engineers),* Vol. 81 paper no. 745, pp. 1–17

Marcus, W.A. and Fonstad, M.A. (2008). Optical remote mapping of rivers at sub-meter resolutions and watershed extents. *Earth Surface Processes and Landforms*, Vol. 33. Is. 1, pp. 4-24

Maynard, S.T. (1978). *Practical Rip Rap Design*, U.S. Army Corps of Engineers, Vicksburg, Mississippi.

Melbourne Water (2013). *Water Sensitive Urban Design Guidelines: South Eastern Councils,* Melbourne Water Corporation

Melbourne Water (2013) *Waterway Corridors – Guidelines for greenfield development areas within the Port Phillip and Westernport Region*. Melbourne Water Corporation

Melbourne Water (2017). *Sediment management measures*, Melbourne Water Corporation

Melbourne Water (2019). *Constructed Waterway Design Manual*, Melbourne Water Corporation

Melbourne Water (2020). *Biofiltration systems in Development Services Schemes Guideline*, Melbourne Water Corporation

Melbourne Water (2021). *Stormwater Harvesting*, Melbourne Water corporation

Merritt, F.S., Loftin, K. and Ricketts, J.T. (1995). *Standard handbook for civil engineers (4th ed.)* New York: McGraw-Hill.

Micheli, E.R., Kirchner, J.W., and Larsen, E.W. (2004). Quantifying the effect of riparian forest versus agricultural vegetation on river meander migration rates, central Sacramento River, California, USA. *River Research and Applications*, Vol. 20, pp. 537-548, http://seismo.berkeley.edu/~kirchner/reprints/2004_66_Micheli_riparian.pdf

Natural Resources Conservation Service, (2005). *Technical Supplement 14O – Stream Habitat Enhancement Using LUNKER*, https://directives.nrcs.usda.gov//sites/default/files2/1720623416/Technical%20Supplement%2014%20O%20-%20Stream%20Habitat%20Enhancement%20Using%20LUNKERS.pdf

NAASRA (1976). *NAASRA Bridge Design Specification, Fifth edition*. National Association of Australian State Road Authorities.

Newson (2022). Geomorphological concepts and tools for sustainable river ecosystem management, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12, 365–379.

O'Connor, J., Stuart, I. and Jones, M. (2017a). *Guidelines for the design, approval and construction of fishways.* Arthur Rylah Institute for Environmental Research. Technical Report Series No. 274. Department of Environment, Land, Water and Planning, Heidelberg, Victoria

O'Connor, J., Stuart, I. and Campbell-Beschorner, R. (2017b). *Guidelines for fish passage at small structures.* Arthur Rylah Institute for Environmental Research. Technical Report Series No. 276. Department of Environment, Land, Water and Planning, Heidelberg, Victoria

O'Connor, J., Mallen-Cooper, M. and Stuart, I. (2015). *Performance, operation and maintenance guidelines for fishways and fish passage works.* Arthur Rylah Institute for Environmental Research Technical Report No. 262 for the Water and Catchments Group, Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria

Osman, A.M. and Thorne, C.R. (1988). Riverbank Stability Analysis. I: Theory, *Journal of Hydraulic Engineering*, Vol. 114, Is. 2

Chow, V. T. (1959). *Open-channel hydraulics*, McGraw-Hill, New York.

Przedwojski, B., Blazejewski, R., and Pilarczyk, K.W. (1995). *River training techniques*, Balkema, Rotterdam, The Netherlands.

Rios, S.L. and Bailey, R.C. (2006). Relationship between Riparian Vegetation and Stream Benthic Communities at Three Spatial Scales. *Hydrobiologia*, Vol. 553, pp. 153-160

Roberts, J., Casanova, M.T., Morris, K. and Papas, P. (2017). *Feasibility of wetland recovery: Decision Support Tool, version 1.0.* Arthur Rylah Institute for Environmental Research Technical Report Series No. 283, Department of Environment, Land, Water and Planning, Heidelberg, Victoria

Rutherfurd, I., Jerie, K. and Marsh, N. (2000), *A Rehabilitation Manual for Australian Streams*, Land and Water Research and Development Corporation, Canberra

Rutherfurd, I., Marsh, N., Price, P. and Lovett, S. (2002), *Managing Woody Debris in Rivers, Fact Sheet 7*, Land Water Australia, Canberra.

Rutherfurd, I.D., Vietz, G., Grove, J., Lawrence, R. (2007). *Review of erosion control techniques on the River Murray between Hume Dam and Lake Mulwala*, Draft Report prepared for the NSW Department of Natural Resources

Rutherfurd, I., Gower, T., Vietz, G., Arrowsmith, C. (2020). *Geomorphological assessment of the Nariel and Corryong creeks in the Upper Murray*. Report by Streamology for the North East Catchment Management Authority, 2020.

Standing Committee on Rivers and Catchments (1991). *Guidelines for Stabilising Waterways, Rural Water Commission*, Victoria.

Simon (1989). A model of channel response in disturbed alluvial channels. *Earth Surface Processes and Landforms*, Vol. 14, Is. 1, pp.11-26

Sims, A.J. and Rutherfurd, I.D. (2017). Management responses to pulses of bedload sediment in rivers. *Geomorphology*, Vol. 294, pp. 70-86

Sims, A.J. and Rutherfurd, I.D. (2021). Local scale interventions dominate over catchment scale controls to accelerate the recovery of a degraded stream. *PLoS ONE* 16(6): e0252983.

Staton, J. & O'Sullivan, J. (2019). *Stock And Waterways – A practical guide to help New South Wales farmers manage stock and waterways for productivity and environmental benefits*, Australian River Restoration Centre

Streeter, V.L. and Wylie, B. (1979). *Fluid dynamics*: *7th Edition,* New York: McGraw Hill.

Stout, J. (2017). *The geomorphic impact of large in-stream wood on incisional avulsions* (Doctoral dissertation, Doctoral dissertation). University of Melbourne, Parkville, Victoria, Australia)

Sydney Water (2014). *Stormwater connections. to natural waterways*.

Tonkin, Z., Kearns, J. and O'Mahony, J. (2015) *Assessing the benefits of instream habitat enhancement for fish population in the Goulburn Catchment*. Unpublished Client Report for the Goulburn Broken Catchment Management Authority. Arthur Rylah Institute for Environmental Research. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Tilleard, J.W. (2001). *River channel adjustment to hydrologic change*, PhD thesis, University of Melbourne.

U.S. Soil Conservation Service (1971). *Design of Open Channels*, USSCS.

Vidon, P., Allan, C., Burns, D., Duval, T.P., Gurwick, N., Inamdar, S., Lowrance, R., Okay, J., Scott, D., Sebestyen, S. (2010). Hot Spots and Hot Moments in Riparian Zones: Potential for Improved Water Quality Management, *Journal of the American Water Resources Association*, Vol. 46., Is. 2., pp.278-298

White, M., Cheal, D., Carr, G. W., Adair, R., Blood, K. and Meagher, D. (2018). *Advisory list of environmental weeds in Victoria*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 287. Department of Environment, Land, Water and Planning, Heidelberg, Victoria

Yang, Y., Qi, M., Li, J., & Ma, X. (2021). Experimental study of flow field around pile groups using PIV. *Experimental Thermal and Fluid Science*, *120*, 110223

Zhang, H., Nakagawa, H., Kawaike, K., Baba, Y. (2009). Experiment and simulation of turbulent flow in local scour around a spur dyke, *International Journal of Sediment Research*, Vol. 24., pp. 33-45

9.1 Useful web Links

An Australian Handbook of stream roughness coefficients

Arthur Rylah Institute

AUSRIVAS: https://ausrivas.ewater.org.au/index.php/home/introduction

Before You Dig Australia

Bureau of Meteorology

eWater Cooperative Research Centre

eWater Cooperative Research Centre Toolkit

CSIRO, Climate Change in Australia

CSIRO Natural Environment Division

Department of Climate Change, Energy, the Environment and Water

Department of Climate Change, Energy, the Environment and Water, Building Victoria's Climate Resilience

Department of Climate Change, Energy, the Environment and Water, Climate Action

Department of Climate Change, Energy, the Environment and Water, Environment Protection and Biodiversity Conservation Act home page

Department of Energy, Environment and Climate Action

Department of Environment, Land, Water and Planning, Bioregions and EVC benchmarks

Department of Environment, Land, Water and Planning, Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria

Environment Protection Authority Victoria

Environmental Water: https://www.vewh.vic.gov.au/water-for-the-environment/what-is-water-for-the-environment

First Peoples – State Relations

Flora and Fauna Guarantee Act Threatened List

Greening Australia

Guidelines for the Design of Riverbank Stability & Protection using Rip Rap

Index of Stream Condition Victoria

Melbourne Water

Murray Darling Basin Authority

NatureKit

New South Wales Department of Primary Industries Fishing

Queensland Department of Agriculture and Fisheries, Fisheries

SILO Australia climate data (1889 to current)

US Geological Survey, Water Resources

United States Environment Protection Agency

United States Army Corps of Engineers Hydrologic Engineering Centre

Vic Catchments

Victorian Catchment Management Authorities

Victorian Environmental Water Holder

Victorian Government open data

Water Measurement Information System