Constructed Waterway Design Manual

December 2019

Melbourne Water makes a vital contribution to the famous Melbourne lifestyle through the supply of high-quality water, reliable sewerage services, integrated drainage and flood management services and by enhancing our waterways and land for greater community use.

Enhancing Life and Liveability

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ACRONYMS AND ABBREVIATIONS

TERM	DEFINITION
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ARF	Areal Reduction Factor
ARR	Australia Rainfall and Runoff
ARR2019	Australia Rainfall and Runoff, 2019 revision
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EVC	Ecological Vegetation Class
EY	Exceedances per year
IFD	Intensity-frequency-duration as used to specify design rainfalls
MWC	Melbourne Water Corporation
WSUD	Water Sensitive Urban Design
VPP	Victorian Planning Provisions

INTRODUCTION

INTRODUCTION TO THE MANUAL

Waterways provide a range of environmental, cultural, social, and economic benefits. Waterways provide habitat for flora and fauna and are important in sustaining much of our region's native biodiversity. Socially, waterways are important for our wellbeing. They provide places to escape the busy urban landscape, to bird watch, to actively commute, to meet with friends and family, to exercise, and connect with nature. Culturally, they are places of memories, spiritual connection, and ancestral history. Economically, waterways can provide benefits, through provision of drinking water for towns and cities, water for livestock and irrigation (diversion licence dependent) and protect life and property from flood events.

Melbourne Water is the regional waterway manager for more than 8,000 km of waterways in the Port Phillip and Westernport region. Constructed waterways are created to service urbanising catchments, and Melbourne Water is responsible for delivering these new urban waterways as part of our Development Services Schemes.

Greenfield urban development often requires the construction of a new waterway (or substantial modification of an existing, degraded or undersized waterway) to provide an appropriate drainage level of service. to a new development. In some cases, a waterway will be partially constructed, to preserve high value remnants of the existing waterway, which may also contain associated flora, fauna and cultural heritage values. In other cases, where such values are not present or not significant, waterways may be fully constructed. Waterways are usually constructed in conjunction with surrounding development in order to service that development.

Well designed, constructed and maintained urban waterways integrate with other stormwater management infrastructure such as constructed wetlands and rain gardens and therefore form a key element in both the water sensitive urban design of new developments and the recreational opportunities this infrastructure provides.

Purpose of the manual

The manual is intended primarily for use by members of the land development industry who design, construct, and establish waterways on behalf of Melbourne Water. The manual can also be used by any multi-disciplinary consultant working on constructed waterway design and may also be a useful resource for other professionals working within the stormwater management, waterway management and land development industry, including authority staff and interested community members.

The aim of the manual is to facilitate the consistent delivery of best practice constructed waterways which are sustainable assets to maintain. The manual will improve the experience of customers working with Melbourne Water during the design, construction, and establishment phases. It articulates Melbourne Water's expectations and requirements for constructed waterways and the appropriate waterway design approach to be used by consultants. The manual also sets out the design acceptance process that applies to constructed waterway designs.
The manual:

- Provides detail on fundamental concepts of waterway function
- Defines best practice in constructed waterway design and why it is required
- Describes the design approach and tools necessary to deliver best practice waterway design
- Articulates the requirements of Melbourne Water's constructed waterway design approach and design acceptance process
- Defines Deemed to Comply criteria
- Provides links to relevant guidelines and resources

How to use the manual

The manual is structured in five Parts, each with a distinct purpose:

Part A: Vision, outcomes and criteria
Sets out the vision and desired outcomes for constructed waterways in Port Phillip and Westernport and presents a detailed description of the design objectives and criteria that will deliver the desired outcomes and realize the vision.

Part B: Design approach and fundamentals
Provides an overview of the constructed waterway design approach and the fundamental waterway values and processes

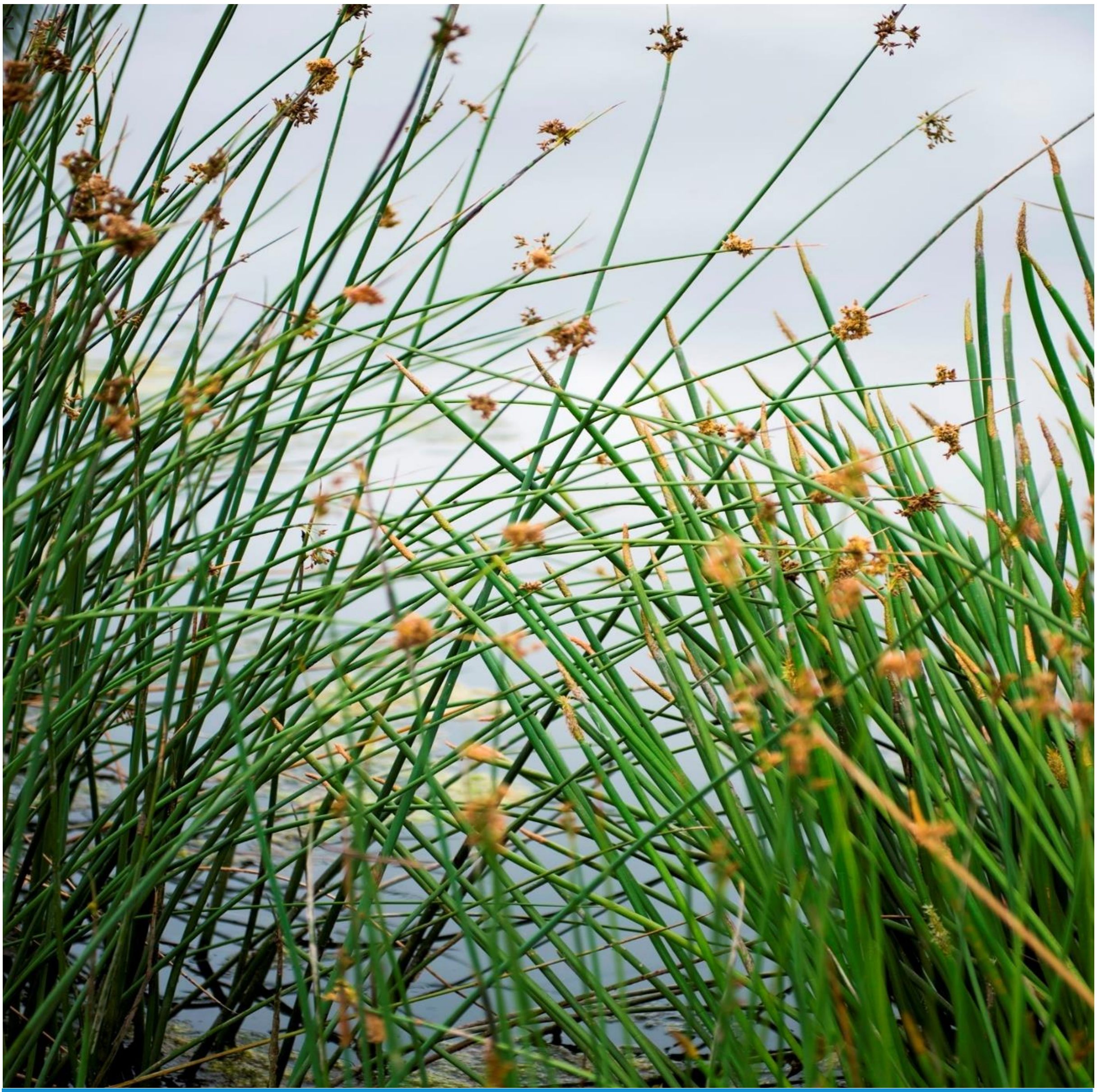
Part C: Design acceptance process and Deemed to Comply
A detailed description of the concept, functional, and detailed design stages and the associated requirements of Melbourne Water's constructed waterway design acceptance process.

Part D: Technical design elements
A detailed guide for preparing a waterway design that meets the requirements of the key stages in the design acceptance process.

Part E: Design tools and resources
Details of the various analytical design tools, information sources and Melbourne Water resources needed to develop constructed waterway design

It is recommended the waterway designers familiarise themselves with the entire document to gain a full understanding of the requirements of Melbourne Water for best practice constructed waterway design. However, the manual has been written in a way that the parts can be used separately if and when required. The manual is intended for use by engineers, landscape architects, urban designers and ecologists.

Image 1: Simmons Creek, Plenty



PART A: VISION, OUTCOMES AND CRITERIA

A1. DESIGN CONTEXT

Constructed waterways should be designed to respond to the opportunities, and constraints at a particular site, which are influenced by the site characteristics (e.g. its topography, existing vegetation, geomorphic character and soils) and the requirements of the urban development. The final form of a waterway will be strongly influenced by the vision and desired outcomes for the waterway.

To assist the designer, a glossary of relevant best practice constructed waterway design terms used in this manual are clearly defined in Table 1.

TERM	DEFINITION	WHO SPECIFIES	EXAMPLE
Desired outcome	The end result that is achieved by preparing a design that meets all design criteria and objectives. Meets Deemed to Comply.	MWC	Neighbouring development and associated built assets are protected from flooding and erosion.
Design objective	A clear requirement of the design that needs to be achieved in order to deliver on the desired outcome that it influences. • Design objectives are descriptive and provide qualitative information regarding the requirement.	MWC	Constructed waterways must contain and safely convey the design flood event.
Design criteria	An explicit technical standard or collection of standards that must be achieved by the design in order to demonstrate that the corresponding design objective can be met. • Design criteria are quantifiable and measurable and provide specific information regarding the requirement.	MWC	The constructed waterway must be designed to: • have a capacity that conveys the 1% AEP flood event. • meet MWC Floodway Safety Criteria in the 1% AEP flood event; and • not cause erosion that threatens built assets adjacent to the waterway in a 1% AEP flood event or otherwise erode the batters or bed of channel in either minor or major events.

Table 1 – Terminology used in the manual and their definition and application.

A2. Vision

A2.1 Healthy Waterway Strategy Vision

The Healthy Waterways Strategy (Melbourne Water 2018) is the guiding resource for waterways, estuaries, and wetlands across the Port Phillip and Westernport region. The Healthy Waterways Strategy is driven by a single regional 50-year vision:

> "Healthy and valued waterways are integrated with the broader landscape, and enhance life and liveability. Waterways connect diverse and thriving communities of plants and animals; provide amenity to urban and rural areas, and engage communities with their environment; and are managed sustainably to enhance environmental, economic, social and cultural values."

Constructed waterways in greenfield urban developments are, by definition, artificial. However, if well designed, constructed, and maintained they will ultimately provide many of the functions set out in the Healthy Waterways Strategy vision. Ensuring that waterways provide for these functions at the level expected by Melbourne Water is a principal driver for applying the *Constructed Waterway Design Manual* to all future constructed waterway designs.

A2.2 Project (Site or Place) Vision

To assist with the design process landscape architects will prepare a Vision that responds to the unique characteristics of a site, the local community who will be living there, and the aspirations held by Melbourne Water and other Agencies for the waterway. Constructed waterways must be integrated into the broader urban landscape and not treated as stand-alone assets.

The vision will demonstrate what the future waterway will look like and the types of experiences visitors could expect to have while visiting it. The design objectives for constructed waterways (Section A3) will accompany the vision. They will articulate the features of the Project Vision that will be delivered as a part of the new waterway. Table 2 outlines the 5 themes that must be explored through the design objectives to accompany the Project Vision.

A3. DESIGN OUTCOMES AND OBJECTIVES

The vision set out in the Healthy Waterways Strategy applies to all waterways in the Port Phillip and Westernport region. To guide the design of constructed waterways in particular, the characteristics of a best practice constructed waterway have been defined as:

Safe and Enjoyable Places

- Provide a safe environment for the community to enjoy the amenity and recreational opportunities provided by the waterway and its corridor
- Provide an appropriate level of flood and erosion protection to public and private assets in the vicinity of the waterway corridor, as well as erosion protection of the waterway itself
- Safely convey stormwater and floodwaters from and through urban developments
- Provide a safe environment for the cost effective, long-term operation and maintenance of the waterway.

Well-designed waterways are attractive places for the community to spend time, connect with nature and interact with other people. They also provide important active transport links between different places in urban areas. It is important that aquatic safety risks are managed appropriately, and that the safety of people around waterways, especially when in flood, is a central focus of any design.

Healthy, resilient and connected waterway environments

- Provide resilient habitat for native flora and fauna within the waterway and its corridor to encourage the presence of native flora and fauna.
- Utilise linear linkages to connect communities and ecosystems through urban areas and, lateral linkages between the waterway channel and the surrounding riparian zones and floodplains.

Places for communities to connect

- Provide opportunities for social gatherings and connections along waterways where suitable
- Provide for a range of experiences along waterways including contemplation, engagement with others and more active uses.
- Design for multiple users who can passively recreate along the waterway or utilise active transport links simultaneously and safely
- Provide connections to nature to deepen user awareness and appreciation of nature without compromising flora and fauna health.

Design objectives for constructed waterways articulate how the desired outcomes should be achieved. These design objectives are summarized in Table 2 according to the outcomes they address and the drivers behind them.

Table 2 – Design objectives for constructed waterways

DESIRED OUTCOMES (WHAT)	DESIGN OBJECTIVES (HOW)	PRINCIPAL DRIVERS (WHY)
Asset protection	• Flood capacity and conveyance • Drainage outfall • Channel stability	• Community health and safety • Risk mitigation • Financial sustainability
Amenity	• Aesthetics • Accessibility	• Community wellbeing • Community safety
Flora and fauna	• Habitat • Connectivity • Diverse vegetation	• Community expectation • Ecosystem function • Biodiversity
Asset Management	• Maintenance • Renewal • Efficient investment	• Legislative requirements • Risk mitigation • Financial sustainability
Community connection	• Sociable settings • Equitable Access	• Mental health and wellbeing • Increase Social Capital

A3.1 Asset protection

Asset protection reduces the risks posed by flooding and erosion in a waterway. This includes risks to the health and safety of the community, the costs imposed on communities, and the risk of damage to public and private assets.

Waterways must meet the following objectives to achieve the asset protection outcome:

Flood conveyance and capacity

- Safely convey large flood events within the waterway corridor. Flood events up to the 1% AEP flow (plus 300mm freeboard) must be accommodated in the waterway corridor in a way that protects public safety.
- Provide an appropriate level of flood protection to existing public and private assets in the waterway corridor. A variety of public and private assets are often present in waterway corridors in new urban developments. The constructed waterway design must ensure these assets are not adversely affected by flooding. Future assets must be designed such that they do not compromise the flood conveyance and capacity of the waterway.

Drainage Outfall

- Provide for free draining outfall of stormwater drainage from the surrounding development. Stormwater drainage systems from adjacent urban development require an outfall to allow stormwater to drain effectively to the waterway and protect the development from minor flooding.
- Integrate drainage outfalls/stormwater connections into the waterway corridor. Stormwater connection points should visually blend into the waterway and avoid negatively affecting the stability, ecology or amenity value of the waterway.

Channel Stability

- Provide an appropriate level of erosion protection to public and private assets in the vicinity of the waterway corridor. Although erosion is a natural process, constructed waterways must be designed with a more limited amount of channel adjustment to provide a high level of protection to public and private assets.
- Use native vegetation as the primary channel boundary material, in preference over rock or other hard engineered materials where modelling shows it will work. Native vegetation supports multiple social and ecological values in waterways and should be used throughout the waterway unless rock armouring is required to meet the design criteria.

A3.2 Amenity

Waterways provide significant amenity value to the community and contribute to the liveability of new urban developments. The amenity value of a waterway to a community largely depends on its aesthetic appeal and accessibility to the community. Research shows that a waterway with a naturalistic, variable form (e.g. varying channel bank slopes, bends, pools and benches) and abundant, healthy and diverse vegetation is valued more by the community than one with an engineered appearance (e.g. a straight channel, or a rock lined or concrete channel). Water quality (including litter) is also an important factor in the amenity value of waterways. Waterways must meet the following objectives to achieve the amenity outcome:

Aesthetics

- Have a naturalistic and variable form. Mimic natural waterway form and provide a range of physical features, which may include a meandering low flow channel, varying bank slopes, pools, riffles and benches. These features are also important habitats for native animals.
- Have abundant and diverse native vegetation. Native vegetation is a key element in achieving both the aesthetics and habitat design objectives. Tree canopy cover can also contribute to a greener, cooler environment.

Accessibility

- Provide a safe and accessible environment for the community to interact with. Safety is a key aspect of waterway design, particularly with respect to landscape features and recreational infrastructure.
- Provide an appropriate level of direct and indirect access to and along the waterway. Many people wish to 'get close' to waterways. They seek out a direct physical and/or indirect visual (line of sight) connection with water. Melbourne Water's shared pathway guidelines provide direction for formal routes along waterways, but the design should consider managing informal access points where people can get close to the waterway.

Pedestrian Connectivity

- Provide an appropriate level of connectivity within and beyond the waterway to the adjoining urban fabric. Pedestrian connectivity relates to the ability of community members being able to move between the waterway to adjoining pedestrian networks, landmarks, activity nodes etc. Barriers to connectivity or poorly designed connections that do integrate with the urban fabric will detract from the amenity of the waterway and possibly its use. Connections between the waterway and adjoining urban landscape must be legible and work to accentuate the values of the waterway.

A3.3 Community Connection

Waterways must meet the following objectives to achieve a community connection outcome:

Sociable Settings

- Provide places that attract a variety of users and support community connection. Safe and attractive places are often highly visible and activated by different user groups engaged in a range of passive and active uses. Flexible spaces can be used in a variety of ways by different users i.e. local community groups, families, individuals etc.
- Provide a variety of well-designed spaces for different user groups to experience the waterway.
- Provide seating that is visible and provides different views and experiences of the waterway

Equitable Access

- Provide public space to local communities who have radically different and changing mobility needs. Waterway corridors provide for those who may have difficulty with mobility such as the elderly and people with disabilities. Waterway corridors provides equitable access for all users.

A3.4 Native flora and fauna

Research shows that the community values the presence of native fauna including: birds, fish, and frogs and other species along urban waterways. The provision and connection of diverse and thriving communities of plants and animals is a central element of the overarching Healthy Waterways Strategy vision. Waterways therefore need to provide appropriate habitat for urban tolerant fauna. In terms of physical form, habitat type diversity is critical to ecosystem health. There are some specific features that may be required in some locations to support threatened species such as ponds for Growling Grass Frogs (DELWP,2017).

Vegetation is also important from a biodiversity and amenity perspective. The diversity of instream and riparian vegetation depends on the shape of the waterway and the wetting and drying regime at different locations in the waterway. Provision of pools, riffles, runs, benches, and other physical features will provide the physical 'template' for a healthy and diverse native vegetation community, that in turn will support a diverse native fauna. The connectivity between habitat features is critical to ensuring native animals can move around the waterway and access different habitats at different times. Waterways must meet the following objectives to achieve a flora and fauna outcome:

Habitat

- Provide for the establishment of abundant and diverse native vegetation species within the waterway. The successful establishment of native vegetation communities in waterways depends on a variety of factors, including the physical form of the constructed channel, the preparation of topsoil, and selection and location of the right species for different locations in the channel.

- Provide suitable physical habitat. An appropriate range of physical habitats for native fauna should be provided, which may include pools, riffles, benches or large wood. Where possible, the amount and diversity of habitat should be maximised.

Habitat and vegetation connectivity

- Provide an appropriate level of connectivity within and beyond the waterway being designed. Connectivity relates to the ability of animals to move from the waterway to the riparian zone, and longitudinally along the waterway. Barriers to connectivity include poorly designed culverts and overly steep rock chutes that fish cannot traverse and breaks in riparian vegetation. Barriers to habitat connectivity should be excluded from the waterway design.
- Constructed waterways should provide passage for transient species to move into and through the constructed waterway where species are known to be present upstream and/or downstream. Waterways are often located upstream, downstream or between reaches of an existing waterway. These waterways may be used as habitat corridors to support populations of native animals. In these instances, the waterway design should ensure the constructed waterway functions as a corridor to facilitate the passage of native animals.
- Provide vegetation connectivity for vegetation. Vegetation connectivity relates to continuous patches of vegetation, which can enhance resilience to weed invasion and other disturbances and enhances the ability to manage the vegetation.

A3.5 Asset Management

Asset management refers to the operation and maintenance of natural and built assets, including waterways. The elements of efficient and effective asset management include:

- Adopting a "whole-of-life" system approach to the planning, design, construction, operation and maintenance of our assets
- Embracing opportunities for innovation in optimising the levels of service provided by our assets to meet Melbourne Water's needs
- Undertaking performance and condition monitoring, and data capture and reporting via knowledge management systems, to continuously improve our asset management approach

To achieve efficient and effective asset management, waterways must meet the following design objectives:

Operation and maintenance

- Ensure sufficient access and space for all required maintenance activities. Appropriate forms of access to the waterway must be provided, as well as room for maintenance vehicles and machinery to maneuver along the waterway outside of the core riparian zone.
- Provide safe environments for Melbourne Water officers and contractors to access and maintain. Maintenance requirements must be incorporated at the design stage to ensure Melbourne Water staff can maintain waterways in a safe and efficient manner.

Renewal

- Meet the expected asset life of 100 years. Constructed waterways have an expected design life of 100 years and should be designed to ensure that they can function without intensive maintenance during this time. Components of the waterway will have shorter design lives.

Efficient investment

- Constructed waterways must be cost effective to design and construct and be cost-effective to operate and maintain

A3.6 Design criteria

Table 3 presents an overview of the design criteria that need to be met in order to achieve the design objectives. Clear links between the design criteria and objectives are illustrated, assisting the designer to check that their design is meeting Melbourne Water's Deemed to Comply requirements. These design criteria are detailed in the relevant sections of **Part D** as part of the technical design elements.

Table 3 – Relationship between the design criteria and design objectives

DESIRED OUTCOMES	DESIGN OBJECTIVES	DESIGN CRITERIA CATEGORIES
Asset protection	Flood capacity and conveyance	• High flow and low flow channel capacity • Freeboard to lots and other infrastructure • Floodway Safety
	Drainage outfall	• Outfall capacity, depth, velocity and angle • Outfall physical interface with waterway
	Channel stability	• Shear stress on/resistance of channel boundary • Hydraulic roughness along and across waterway • Waterway geometry • Engineered stabilisation structures
Amenity	Aesthetics	• Physical form of the waterway and its features • Vegetation in the core riparian zone and buffer • Water quality in the waterway
	Accessibility	• Direct (physical) access to and along the waterway corridor • Indirect (visual) access to and along the waterway corridor
Flora and fauna	Habitat	• Physical form of the waterway and its features • Vegetation in the core riparian zone and buffer
	Connectivity	• Laterally through the core riparian zone • Longitudinally up and down the waterway
Asset Management	Maintenance	• Features supporting efficient maintenance • Safe maintenance access to all functioning features • Safe assets & safe people
	Renewal	• Design life of the waterway (25 years)
	Efficient investment	• Cost-effectiveness of maintenance
Community connection	Sociable settings Equitable Access	• Integration and connections to surrounding area/urban fabric • Safe passage of all user groups, their mobility and speed they travel. • Pedestrian infrastructure to support active and passive uses of the waterway • Encourage people to congregate and / or linger along the waterway • Provide clear view lines to and from areas where people congregate or recreate

PART B: DESIGN APPROACH AND FUNDAMENTALS

B1. DESIGN APPROACH

This part of the manual provides a high-level overview of the waterway design process and the theory that underpins it. The design approach outlined is considered best practice waterway design and is used to translate Melbourne Water's vision and desired outcomes (Part A)into functioning waterways.

There are three stages in the design process: the concept design stage, the functional design stage, and the detailed design stage. Each of these design stages is further divided into steps, and each of these steps is made up of several tasks. The specific inputs, procedures and outputs that are generated by these tasks, and then submitted to Melbourne Water as part of the design acceptance process, are outlined in Part C.

Reference to the more specific, technical details of design is made where necessary in this overview, with more detailed provided in the corresponding section of Part D.

B1.1 Design stages

For the purpose of this manual the design process is defined by three stages:

1. Concept design synthesises and identifies various options potentially meeting the design objectives for the waterway. It will demonstrate to Melbourne Water that the development/subdivisional proposal has made sufficient allowance for the waterway.
2. A functional design addresses Melbourne Water's high-level requirements for any development proposal containing a constructed waterway, including: waterway corridor alignment and width, demonstrating suitability of any Plan of Subdivision which derives from that design. A reach-scale functional design completed to Melbourne Water's satisfaction gives confidence to the designer that they are on the right track and will enable them to proceed to the next level of detailed design. An accepted functional design is required prior to Melbourne Water's issuing of a Works Offer.
3. A detailed design demonstrates that (i) the waterway can incorporate all the desired features from the concept design whilst not compromising waterway function at the reach-scale; and, (ii) all individual features are designed appropriately.

At the end of each of the design stages, the designer will prepare a design package for submission to Melbourne Water (the content of these design packages is described in more detail in Part C).

B1.2 The threshold waterway design method

A central design objective is that the waterway is stable for the design flows. Minor erosion and deposition are fundamental processes in healthy natural waterways, and the goal of a constructed waterway is not to eliminate these processes, but rather to ensure the new waterway does not drastically and rapidly change its course or dimensions over the design life. With this overarching stability criteria in mind, the threshold waterway design method has been adopted for application to constructed waterways in Melbourne Water's Operating Area.

The basic premise of threshold waterway design is that the lateral hydraulic force from flowing water (*shear stress*), at a particular design flow, is less than the hydraulic force needed to mobilise material (*shear resistance*) throughout the cross-section (the bed and banks of the low flow channel, any benches and batter slopes). This equilibrium point is the erosion threshold. This threshold should not be exceeded at any stage of the waterway's intended design life, including immediately post-construction, during vegetation establishment, after five years etc.

The designer has several techniques at their disposal to achieve an acceptable threshold waterway design:

- modification of the channel shape,
- size and slope,
- selecting alternative bed and bank materials to increase erosion resistance
- manipulating flow hydraulics, to create features such as backwaters.

The forces imposed on a channel boundary, and the ability for boundary material to withstand them, varies at different locations in the waterway, and through time. For example, vegetation becomes more resistant to erosion as juvenile plants grow and mature and this should be factored into any modelling. These concepts are illustrated conceptually in Figure 1.

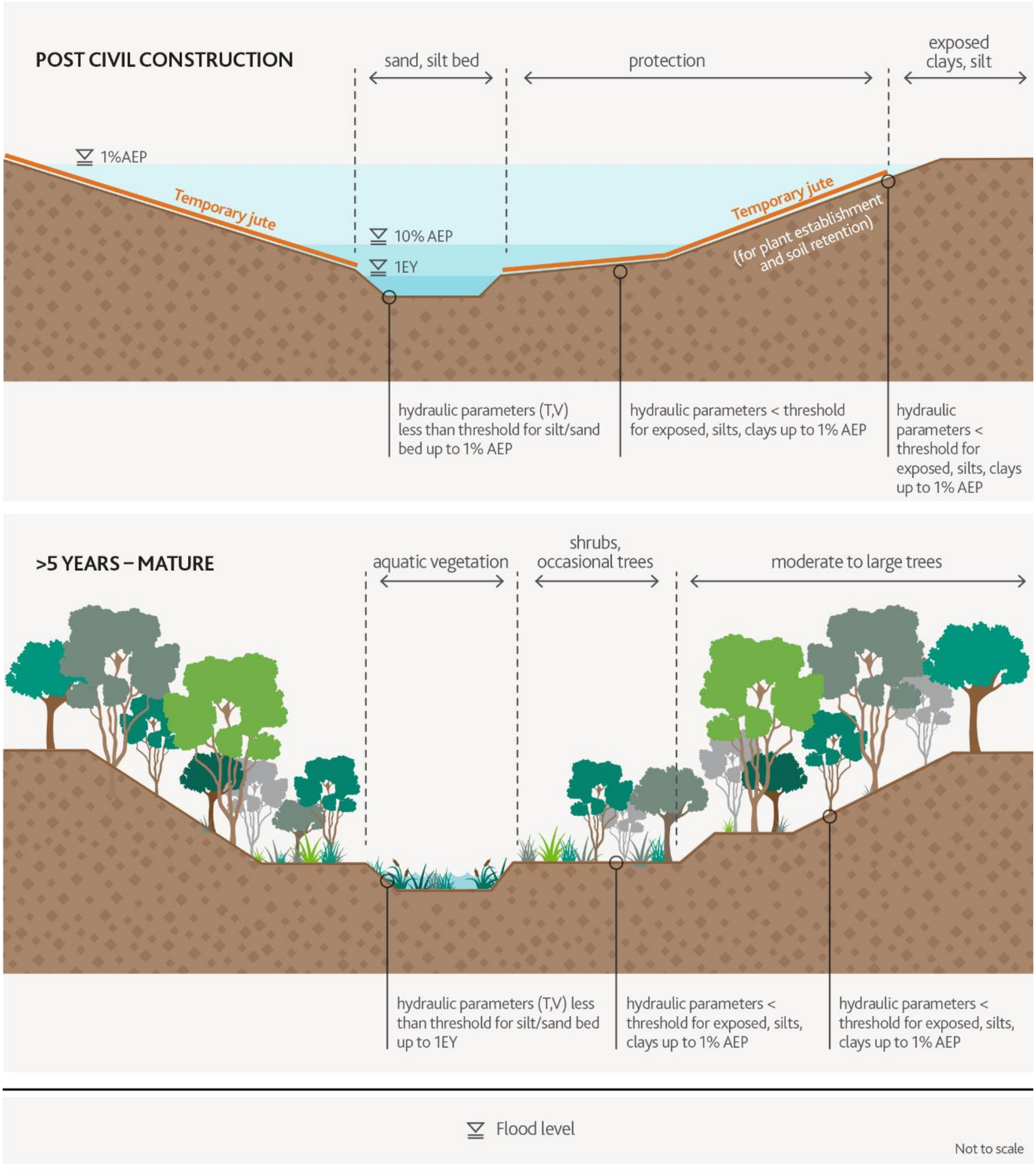


Figure 1 - Spatial and temporal variability of waterways – implications for the threshold design approach (T=shear stress, V=velocity)

Shear stress and resistance

Shear stress is the metric used to describe the hydraulic force applied to a boundary by flowing water. The shear stress equation (DuBoys 1879) is:

$$\tau = \gamma RS \qquad \text{Equation 1}$$

Where τ = shear stress (N/m2), γ = the specific weight of water (N/m3), R = hydraulic radius (m), and S = friction gradient (equal to longitudinal channel bed slope for uniform flow, m/m).

Erosion threshold values for different channel boundary materials have been developed through research over a long time (Shields 1936). The thresholds presented in this manual have been taken from the scientific literature and are specific to the boundary material concerned. Where relevant, they have been tailored to the conditions in Port Phillip and Westernport.

An important consideration when applying the threshold design method is the flow for which shear stress is estimated. Generally, larger flows generate greater shear stress. For example, the 10% AEP flow will normally generate a higher shear stress than the 20% AEP flow. Waterways are designed to convey a variety of flows, so it is important to analyse the range of flows and corresponding shear stresses against erosion thresholds. This will result in a more robust determination of overall channel stability.

The threshold design method does not explicitly consider sediment transport. Design methods that do consider bed sediment transport are much more complex than the threshold design method, and only provide significant additional value when the amount of sediment supplied to a waterway is well understood. Sediment supply is rarely known in most constructed waterway design situations.

For further reading into the concept of threshold channel and open channel hydraulics see:

- United States Department of Agriculture, Natural Resources Conservation Service (2007). National Engineering Handbook, PART 654: Stream Restoration Design - Ch8 Threshold Channel Design http://directives.sc.egov.usda.gov/viewerFS.aspx?hid=21433
- Chang, H (2008). Fluvial Processes in River Engineering
- Chow, V. T. (1959) Open Channel Hydraulics
- Chen, Y. H. and Cotton, G. K. (1988) Design of Roadside Channels with Flexible Linings

Vegetation and waterway stability

Healthy and diverse native vegetation is central to achieving the vision for waterways and native vegetation is an essential component of a naturalistic urban waterway.

During the establishment phase, particularly immediately after planting, juvenile vegetation is more likely to be damaged by flood events and the surrounding channel boundary material is therefore at greater risk of being eroded. Once fully established, the root mass of vegetation strengthens the channel banks, and the above ground mass shields the bed and banks from erosion. Vegetation also accelerates recovery from floods by trapping sediment and ‘repairing’ areas of localised scour. In this way native vegetation provides long-term channel stability as well as visual amenity.

Although native vegetation is robust and resilient, some constructed waterways are subjected to very high shear stresses, and the proximity of the waterway to built assets makes the consequences of failure unacceptable. In these instances, additional erosion protection such as rock beaching or rock chutes is needed.

The designer needs to consider local hydraulic conditions, the proximity of assets and the additional risk of erosion during vegetation establishment phase when developing the waterway design.

B1.3 Waterway design tools

Designing a waterway, evaluating waterway stability, and making iterative changes to a design to improve a waterway functions is done using a suite of modelling tools including:

- **Hydrologic modelling** – using RORB modelling software to establish design flows. Used to provide input to the hydraulic modelling if additional analysis to supplement the Scheme Servicing Advice is required, or the development is not within a DSS.
- **Terrain modelling software (for example 12d)** — used to develop terrain models of proposed waterway designs through the design process, generate the topography that is fed into hydraulic models and input to design drawing production.
- **HEC-RAS hydraulic modelling software** — used to estimate shear stress on the channel boundary and confirm flood levels meet the requirements

Details of each model application for each stage in the design approach are provided in Part D and use of the design tools is described in more detail in Part E, intended as stand-alone resources.

In addition, two river engineering design tools are described in Part D of the manual:

- **CHUTE** - a software design package for designing grade control structures (i.e. rock chutes) and required rock sizes
- **RIRPAP** - a software package for designing rock beaching.

B1.4 Waterway design inputs

There are a wide range of resources available to the waterway designer, including site specific design input data from the relevant Development Services Scheme (such as design flows and waterway corridor widths), regional data sets on existing and desired waterway vegetation (Health Waterways Visions – Vegetation) and existing relevant Melbourne Water design guidelines (e.g. Waterway Corridor Guidelines). Designers are to ensure they are using the current versions of all guidelines. These resources, and how they should be deployed in the waterway design method, are detailed in the various design stages.

Some design resources are required at multiple stages in the design process, and as such sit within Part E of the manual for ease of reference. Other site specific design inputs will be required to be generated by the designer (or project team) using information sourced from the results of due diligence investigations, the assessment of site opportunities and constraints, and consideration of the interface with the proposed urban layout and other infrastructure and services that are required as part of the development.

B1.5 Waterway design outputs

By following the design approach detailed in Part D, the designer will generate a series of outputs. Part C contains information on how these outputs should be presented to Melbourne Water for review, comment, and acceptance as the design moves from concept, through functional, to detailed design. Key outputs are as follows:

- Concept design report and plans
- Functional design report and plans
- Detailed design plans, specifications and schedules
- Maintenance plan and schedule

- Site Management Plan
- As-constructed plans, including flood mapping
- RORB model and associated files
- HEC-RAS model and associated files
- 12D (or similar) model and associated files
- CHUTE, RIPRAP files

B2. WATERWAY DESIGN FUNDAMENTALS

Waterways provide important social and ecological values. The values are influenced by the character and functions of the waterway and its corridor. This section provides an overview of the fundamental theory behind these functions. Details on the design features that help provide these values are discussed in Part D.

Melbourne Water manages waterways (both existing and constructed) throughout the Port Phillip and Westernport catchments to support the social and ecological values important to communities. Research and consultation with the community tells us that these values: community connection, amenity, birds, fish, frogs, macro invertebrates, and vegetation, are the main reasons that the community wants to protect and improve waterways. Constructed waterways must also provide safe passage of floods through new urban areas, facilitate the safe and efficient drainage of stormwater, and be stable enough to protect assets in the waterway corridor.

The size and shape of a waterway is described as its physical form. The designer can adjust the physical form, vegetation and hydraulics to meet the vision and design objectives for the constructed waterway on their site . The physical form is the primary control the designer has because it provides the template for vegetation design and social infrastructure. The physical form controls, to a large degree, flood impacts and the drainage efficiency of the waterway.

B2.1 Hydrology and hydraulics

It is expected the waterway designer will already have a good theoretical understanding of hydrology and hydraulics and experience in applying this knowledge to waterway designs. In this section some important concepts relating specifically to the waterway design approach presented in this manual are introduced.

Constructed waterway hydrology

The flow in permanently flowing waterways fluctuates through a continuous series of normal or baseline flows, larger flows, and cease-to-flow, which are collectively described as the flow regime of the waterway. Because the flow of water in a waterway provides the energy required to shape the channel, and strongly influences the ecology of the waterway, the characteristics of that flow are very important in designing an appropriate channel form.

The flow regime describes the magnitude, frequency, duration, timing, and rate of change of flow across a range of flows in the waterway. These flows are generated by the way rainfall over the urbanised catchment is translated into runoff that then makes its way via a variety of flow paths into the receiving waterway. The flow regime of a waterway that drains a predominantly urban catchment is substantially different from a waterway draining a forested or agricultural catchment.

The flow regime of a waterway can be described in several ways. The metrics most familiar to waterway designers are average recurrence interval (ARI) or Annual Exceedance Probability (AEP) design flows, which describe the probability of peak flows occurring or being exceeded in a particular time period. The flow regime can be estimated using a variety of methods (discussed in Part D and Part E). The adopted terminology and conversion between AEP and ARI are discussed in Part E – Tool 1.

In addition, other elements of the flow regime (called flow components) can be described in terms of their magnitude, frequency and duration, which may have implications for physical and ecological processes in the waterway.

In addition, other elements of the flow regime (called flow components) can be described in terms of their magnitude, frequency and duration, which may have implications for physical and ecological processes in the waterway.

Rainfall and runoff

Rainfall patterns vary across the Port Phillip and Westernport region, from low annual average rainfall observed around the Little River area in the region's south-west, to the highest annual averages seen around Mount St Leonard in the north-eastern region. This is illustrated by Figure 2 below which maps the rainfall characteristics and associated rainfall station across the region.

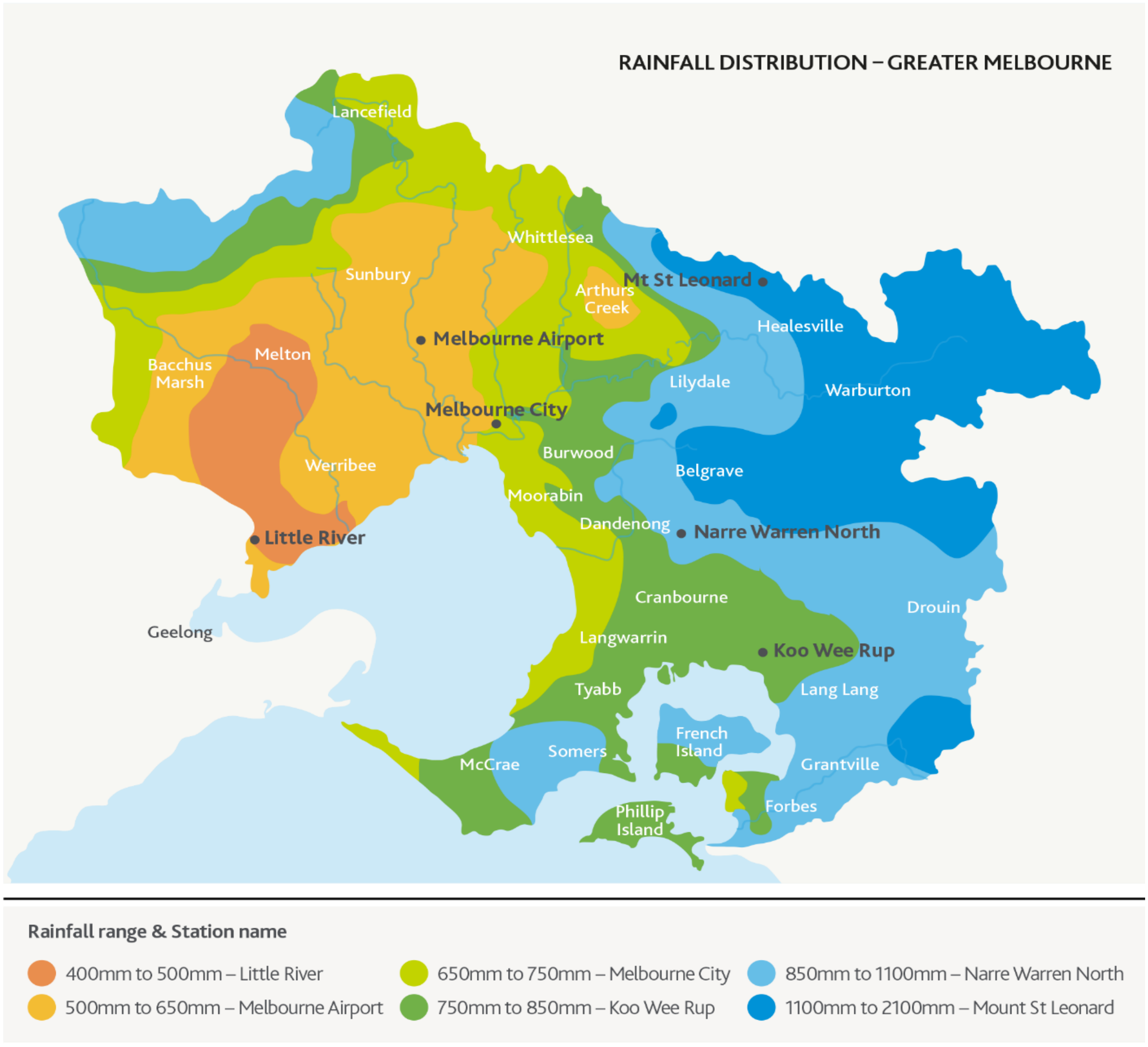


Figure 2 – Regional rainfall distribution (source: Melbourne Water's MUSIC guidelines)

The relationship between rainfall and runoff is influenced by the rainfall event itself (i.e. the intensity, frequency and duration of rainfall) and the physical catchment (the catchment size, topography, underlying geology, and land use). Waterways cover only a very small proportion of the total area of a catchment, so most of the rainfall must make its way to the waterway via a number of pathways. Under natural conditions, these pathways include a range of surface and subsurface hydrologic pathways (Figure 3).

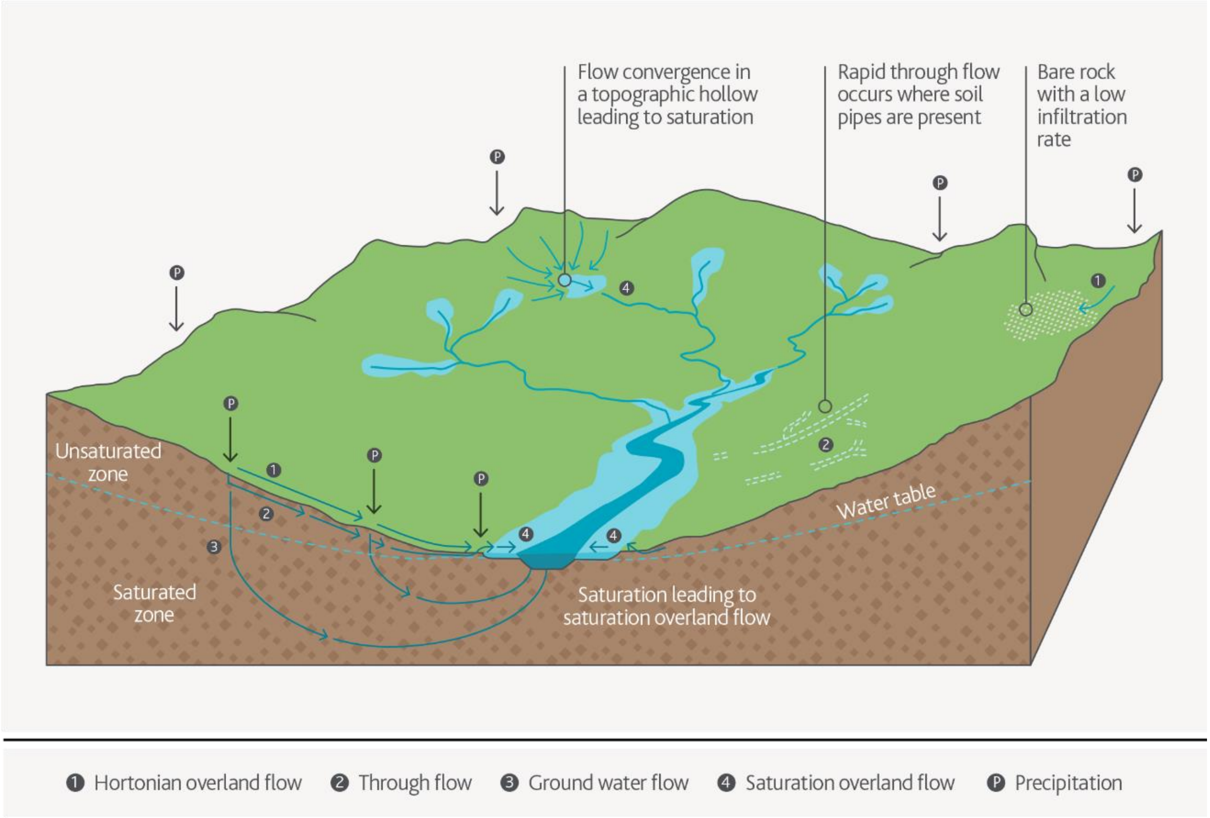


Figure 3 - Hydrologic pathways generating flow in an undeveloped catchment

In a developed catchment the flow paths are substantially modified, with low to moderate flows being conveyed in a piped stormwater drainage system to the waterway, often via stormwater treatment systems such as constructed wetlands. High flows are transferred from the development to the waterway via floodways, which in some cases will be roads (Figure 4). The amount of impervious surface in a developed catchment is much greater than a rural area, so more flow travels overland and reaches the waterway faster compared to a natural catchment.

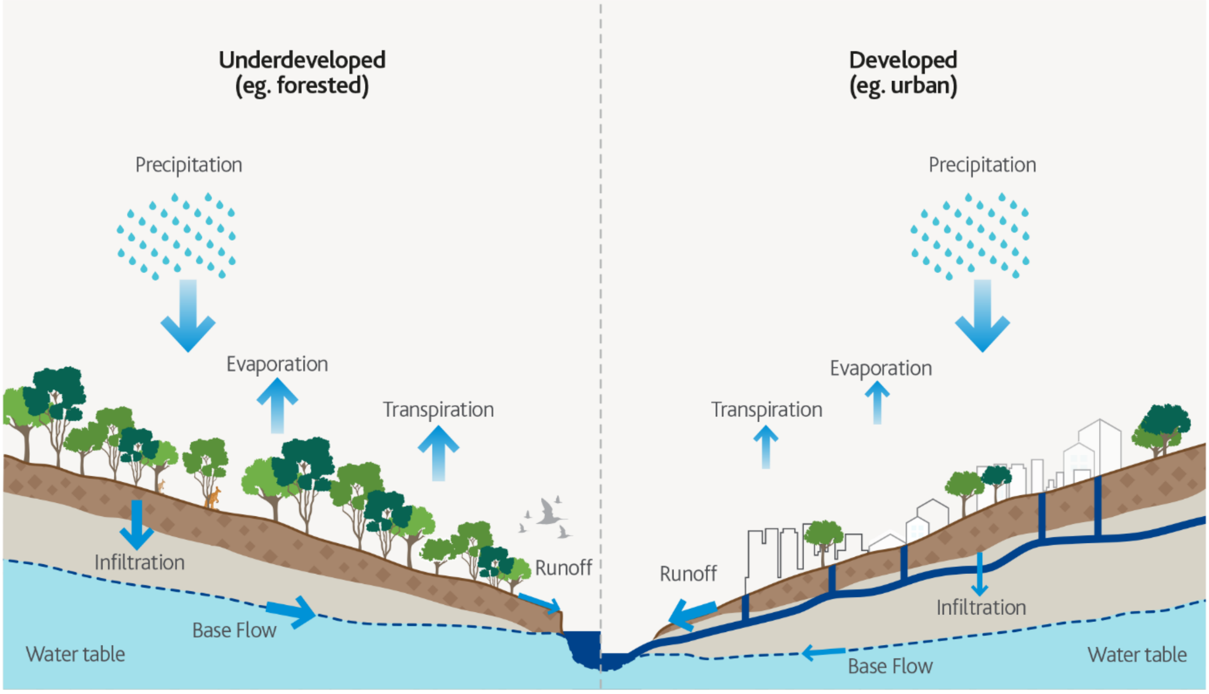


Figure 4 - Comparison of hydrologic pathways generating waterway flow between a developed and an undeveloped catchment.

As the waterway flows downstream it receives additional flows from tributary waterways and additional stormwater pipe connections. These contributions can add significantly to the flow volume at these locations, which in a natural waterway leads the channel capacity to increase (through erosion) to accommodate the larger flows. In urban areas it is important that localised hydraulic disturbance and erosion must be considered and designed for. This is particularly important in the vicinity of pipe outlets/connections to the waterway.

Flow volumes increase from upstream to downstream and so does the required hydraulic capacity of the waterway. Waterways located in the downstream parts of large catchments will receive large flow volumes, which will need to be managed according to the objectives of this manual. These greater flow volumes will have a significant effect on the stream powers and shear stresses the waterway experiences and the waterway will need to be designed accordingly.

Flow components

The flow regime in a waterway comprises a number of different 'flow components' as illustrated below (Figure 5).

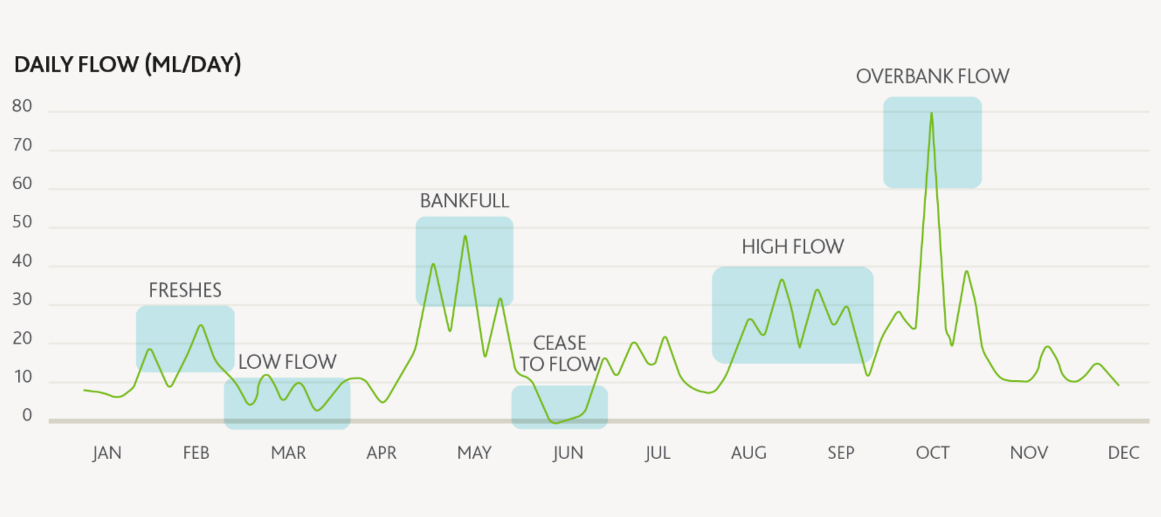


Figure 5 - Illustrative guide to flow components in a natural waterway

Base flows are the flow that occurs during dry periods, when flow in the waterway is supplied by groundwater inflows from regional groundwater systems, leaking infrastructure or infiltration systems. Urban development can reduce the volume of base flows by reducing the infiltration of rainfall to groundwater. Reductions in base flow can lead to extended dry (or cease-to-flow) periods in urban waterways.

Freshes are flow events triggered by rainfall events. The greater impervious areas and higher level of connectivity in urban areas means freshes are likely to occur after every rainfall event. Freshes can have different magnitudes. Some may remain within a defined low flow channel and inundate riffles or runs. Larger freshes will exceed the capacity of any low flow channel and inundate adjacent areas within the waterway corridor. These flows are important for the ecological health of the waterway.

High flows, which occur during and after significant rainfall events, inundate large areas of the waterway corridor within the high flow channel. The magnitude of these events may be controlled by retarding basins, and the design of the waterway must safely convey flows up to the 1% AEP event. The 10% AEP flow is also important as it represents a flood level above which assets intended for public use must to be sited.

Constructed waterways drain a variety of catchment sizes and topography. Most do not generate significant volumes of runoff during dry periods. These waterways are known as ephemeral which means they have significant periods of zero or cease to flow.

Waterway hydraulics

There are two basic principles of flow in open waterways that are important for the waterway design approach set out in this manual: flow continuity (what comes in must come out), and hydraulic resistance to flow.

In the simplest terms, water flows downhill. Flowing water possesses energy, and as it flows through the waterway there is an interaction between the water column and the boundary material, be it clay or sand or vegetation. That is, energy is expended as the water travels over the boundary.

The concept of continuity is important to understand. As a volume of water passes at velocity (V) through any given cross section area (A) it is given a flow rate (Q). The relationship between velocity, area and flow rate is given by:

$$Q(m^3/s) = V(m/s) \times A(m^2)$$

Equation 2

Water can exhibit vastly different behaviour as it passes through different types and shapes of waterways, as well as within different sections of the same waterway. For example, flow can be slow, deep and tranquil in mild gradient sections and in pools. Conversely, water can be fast flowing, choppy and violent in narrow constrictions and steeper sections. Flow in open waterways can be classified according to three general conditions:

- **Uniform or non-uniform flow**. In uniform flow the depth and discharge are constant along the waterway
- **Steady or unsteady flow**. In steady flow there is no change in discharge over time
- **Subcritical or supercritical flow**. Subcritical flow is slow and tranquil, while supercritical flow is fast and turbulent.

Open channel hydraulics is a complex subject, and the designer must be familiar with a number of concepts. A brief overview is presented in this section, but the following texts are recommended further reading on open channel hydraulics:

- Chang, H (2008). Fluvial Processes in River Engineering
- Chow, V. T. (1959) Open Channel Hydraulics
- Chen, Y. H. and Cotton, G. K. (1988) Design of Roadside Channels with Flexible Linings

The uniform depth equation

As stated above the flow behaviour through waterways can vary according to channel shape, types of boundary material, and flow rate. This makes the task of computing flow parameters such as depth and velocity somewhat problematic.

Several assumptions are required to apply these theories to practical waterway design. By assuming uniform and steady flow conditions the Manning's equation can be used to relate the flow rate with the hydraulic roughness coefficient (n, an estimate of the relative resistance of the boundary material), flow area, the hydraulic radius (R, a measure of the perimeter of boundary that is in contact with the water column), and the bed slope (S) (Figure 6):

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

Equation 3

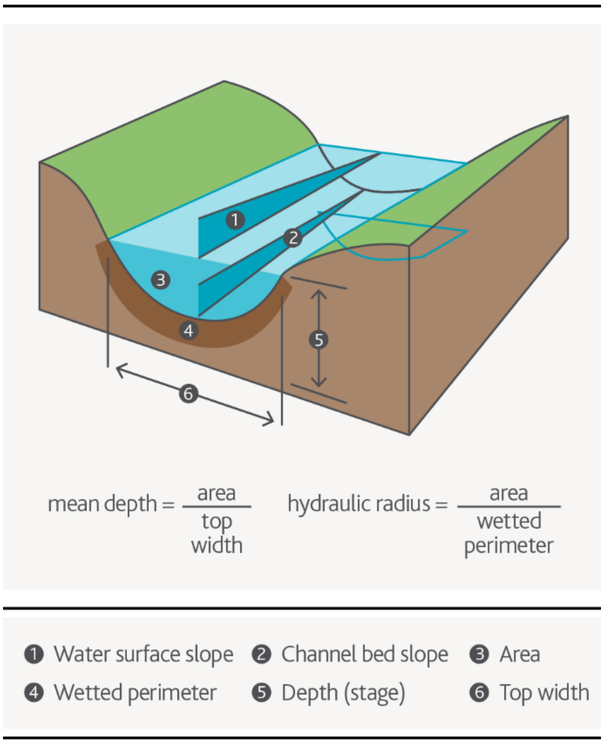


Figure 6 - Illustration of parameters in the Manning equation

Measuring flow resistance

Most people are familiar with different responses by waterways to the force of water that flows through them. Some waterways move and change, by way of erosion and subsequent deposition of boundary material, while other waterways remain relatively static. To inform the design it is important to be able to measure the amount of energy being produced at the water-channel boundary interface, which is referred to as the 'hydraulic force'.

Shear stress is the hydraulic metric used to describe hydraulic force, and was introduced by DuBoys in 1879 (see Equation 1).

There are a number of drivers of shear stress that the designer can take advantage of in the design process (Figure 7):

- Longitudinal slope
- Hydraulic radius
- Cross section shape – base width and batter slope
- Hydraulic resistance (Manning's n)
- Design flow

Greater shear stress amounts to greater ability for the water to do work on the waterway boundary (erode the waterway boundary). Waterway design, as detailed in Part D of the manual, must ensure that the applied shear stress is within tolerable limits for the boundary material in question (bare earth, vegetation, or rock beaching, etc.). This is the fundamental principle behind the threshold channel design approach and is explained in detail in Section B1.2.

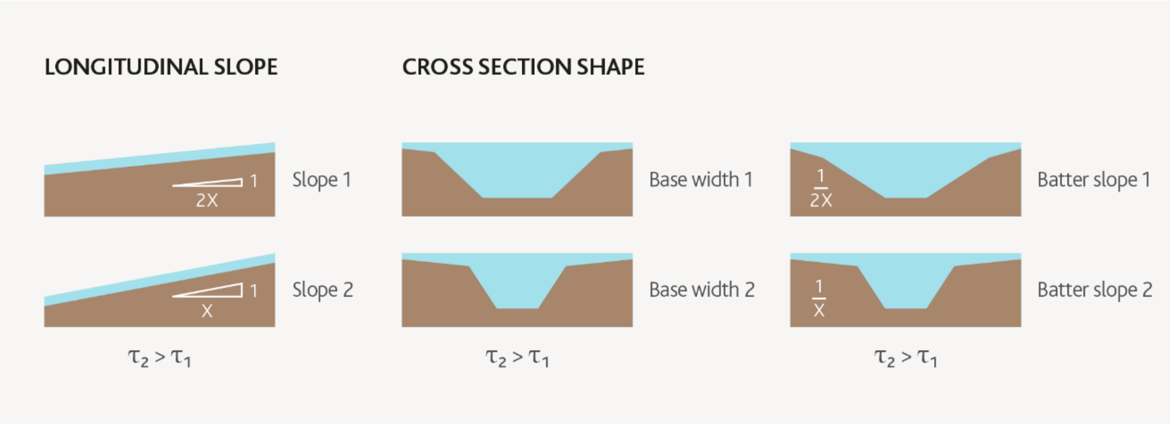


Figure 7 – Concept of average shear stress as a function of various channel parameters

B2.2 Physical form, processes and stability

The size, shape and pattern (in plan view) of a waterway are collectively referred to as its physical form. The physical form of a constructed waterway, expressed ultimately in the civil construction plans, is one of the primary outputs from a constructed waterway design process. Other outputs such as vegetation design, landscape design, and stormwater management infrastructure design depend (to a varying extent) on the physical form of the waterway.

The concept design should take into account where existing landscape features could be incorporated into the overall design of the waterway corridor so that the local character and identity of the area is retained.

Perspectives for visualising and describing waterways

Three perspectives are typically used to describe the physical form of a waterway:

- **Planform.** The physical form of a waterway when viewed in plan (from vertically above). This view is used to understand the sinuosity of the waterway and the low flow channel in the corridor.
- **Longitudinal section (or long-profile)**. The long-profile describes the longitudinal grade (channel slope) and any features that have a vertical dimension (e.g. pools)
- **Cross-section.** The cross-section of a waterway is used to describe the attributes that have both a lateral and vertical dimension (e.g. the width and depth of the low flow and high flow channel).

These perspectives are used throughout the manual and form the basis of much of the information required by Melbourne Water through the design process. It is important that the waterway designer clearly understands their definition. Simple illustrations of each are presented in Figure 8.

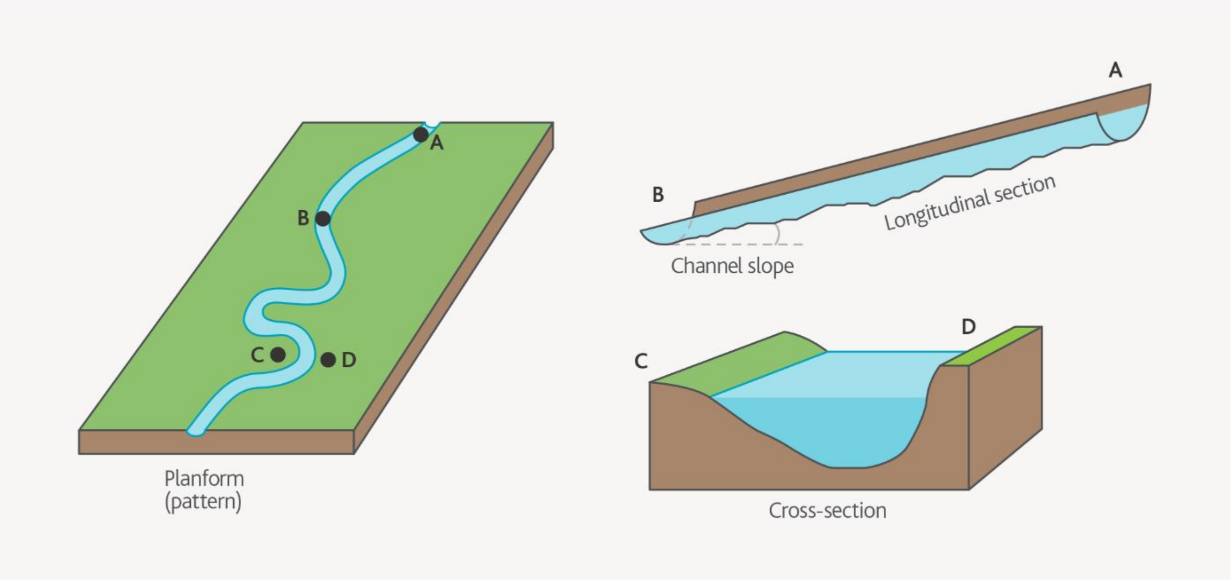


Figure 8 - The three waterway perspectives used: planform, longitudinal and cross section

Waterway types

The diversity of natural waterways is illustrated by the range of physical features and forms. The physical form of a particular waterway is influenced by factors such as climate, geology, landscape setting, and vegetation cover. The wide range of physical features and forms, and their variability within and between waterways combine to create a large number of types of waterways.

Understanding waterway types is important for waterway design – they provide the basic physical 'template' for the design of a waterway that will meet the vision and design requirements for a particular site. Although constructed waterways will generally not exhibit the same degree of physical variability as natural waterways, it is important to recognise that as a broad type, they generally look the same but different reaches of constructed waterway at different locations in a catchment or across the region will look subtly different depending on their landscape setting (geology, soils, topography and vegetation), upstream catchment area, existing features being incorporated and the objectives for that reach of waterway that are required to be met. The variety of landscapes being developed across the Port Phillip and Westernport catchments therefore necessitates the consideration of landscape setting reflected in the form of constructed waterways via three different predominant types, being bedrock, linear pools and compound channels. The decision-making for the type of waterway selected is detailed in Part D1. Further details are provided in Part E, – Waterway Types, which is intended to be a standalone resource for a designer.

Physical processes

The interaction between flow and the channel boundary material in a waterway creates physical processes that can be broadly classified as either erosion (including transport) or sedimentation. These processes result from the way in which the waterway expends the energy from the flow on the boundary material.

- **Erosion**. A group of natural processes where material is worn away from the earth's surface (Thomas and Goudie 2009). In constructed waterways, the principal cause of erosion is the scouring of the channel boundary material by flows and its subsequent transport downstream by those flows.

- **Sedimentation.** Any sediment eroded from the waterway or introduced to the waterway from its catchment has the potential to be deposited within the waterway downstream of the source. Depending on the volume and type of sedimentation it can have beneficial or negative effects on the waterway.

Erosion and sedimentation are expected to occur in waterways, and will depend on the balance of hydraulic force (shear stress) exerted by flow and the resistance of the channel boundary (shear resistance) from the boundary materials.

Natural waterways continuously shape and reform their channels through erosion of the channel boundary (the bed and banks) and the reworking and deposition of sediments. These are natural processes, and in rural systems best practice management is often based on the principle of 'working with natural waterway processes' (e.g. Brierley and Fryirs 2005) and allowing erosion and deposition unless its rate is too high or specific assets are threatened.

However, in urban waterways where the space available for channel adjustment is constrained by infrastructure such as houses, bridges, roads, culverts, and services such as sewers, it is often necessary to limit the rate and magnitude of erosion and deposition.

Constructed waterways are the urban waterways of the future, so they are subject to the limits on erosion common to urban waterways. Constructed waterways are therefore not expected to change significantly over time, having been designed to maintain a relatively 'static' trajectory once they have settled after construction.

Waterways can be managed at various spatial scales, from the individual site scale through to reach, sub-catchment, whole-of-catchment and regional scale planning. There are two spatial scales of importance to waterways in the context of this manual:

- A section of waterway with similar physical character and behaviour, known as the **reach scale.**
- At the level of individual waterway, features such as a pool or riffle are known as the **feature scale**

A waterway can be made up of one or several reaches, and in turn each reach may include any number of individual features. Important aspects of the physical form of constructed waterways at the reach-scale and feature-scale are introduced in the following sections.

Reach-scale physical form

This section describes physical form at the reach-scale and identifies important aspects of reach-scale physical form that links with the waterway design elements set out in Part D2 of this manual.

Sinuosity expressed through planform

Waterways are naturally sinuous (i.e. winding). A straight waterway rarely forms naturally, and artificially straightened channels will tend to develop sinuosity over time through erosion of some parts of the channel bank and deposition in others. Series of bends in waterways are called meanders.

Why is sinuosity important for waterways?

Although it is possible for constructed waterways to be designed with a very low sinuosity, there are several reasons why it is beneficial for some sinuosity to be incorporated into the design:

1. Channel stability - Straight channels are inherently unstable and will usually adjust to reach a more stable form. One of the central design principles in this manual is that the waterway should be stable for all design flows. A waterway that is constructed with an appropriate degree of sinuosity is less likely to undergo major channel adjustment, and consequently will require less maintenance over the long-term (in the form of revegetation or bank stabilisation works);
2. In-stream ecology - Sinuous waterways have a wider range of flow conditions (e.g. faster flows on the outside of bends, slower on the inside of bends). A diversity of flow conditions contributes to the range of habitats needed to support the target species of animals and plants;
3. Amenity - The community highly values waterways with a 'naturalistic' visual appearance, rather than an engineered artificial appearance. Amenity value is a central component of a well-designed constructed waterway so sinuosity should be integrated. Sinuosity will also enable elements that facilitate access to more easily be incorporated e.g. places for viewing/seats etc.

The sinuosity ratio gives an indication of how sinuous a waterway is and can be worked out by measuring the length of a waterway reach and dividing this by the straight line distance along the valley (Figure 9). Waterways with a sinuosity ratio of less than 1.05 are described as straight, those between 1.05 and 1.5 are sinuous, and meandering waterways have a ratio of more than 1.5.

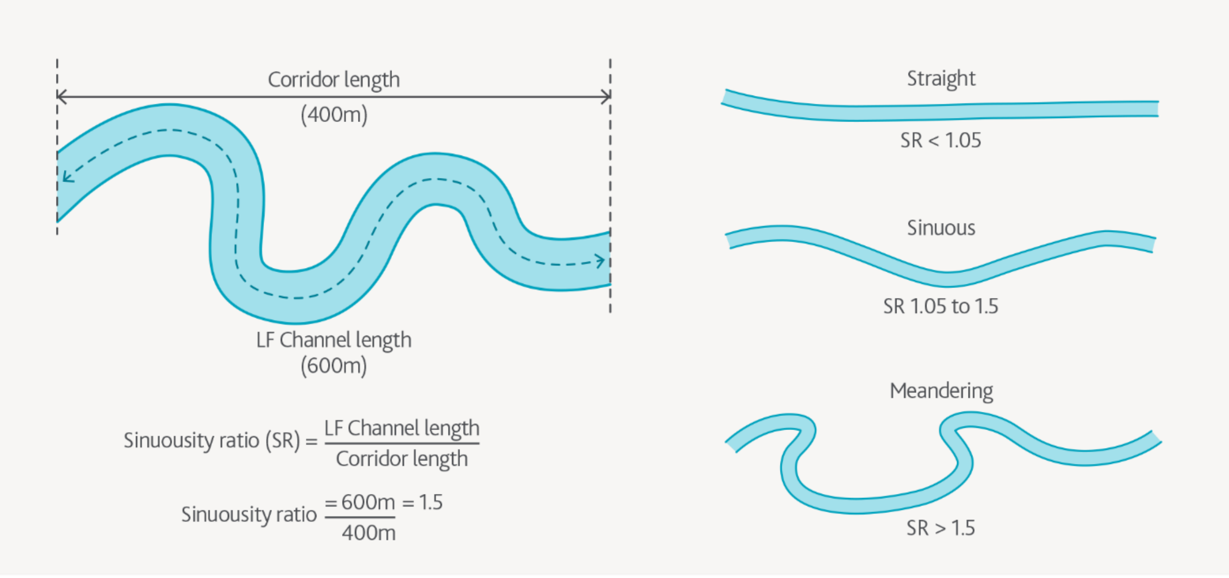


Figure 9 - Sinuosity ratio definition (from Charlton 2008)

There is a tendency for the ***thalweg***, or line of deepest and fastest flow, to shift from side to side along the channel, which is the process that leads to bank erosion and sinuous channel development in straightened channels. This shift in the position of the thalweg is driven by the helicoidal nature of the flow through the channel.

Various methods are used to quantify the geometric characteristics of meandering waterways. These metrics are used to describe natural rivers and are important design parameters for constructed waterways. It is important the waterway designer is familiar with these metrics. The spacing of meander bends, or ***meander wavelength (λ)***, can be determined by measuring the straight-line distance from one bend to the next (Figure 10). Since the distance between successive meander bends generally varies, a mean wavelength is calculated for several meander bends along the reach of interest.

The 'tightness' of individual meanders is expressed by fitting a circle to the centre line of a meander (Figure 10). The radius of this circle is called the ***radius of curvature (r_c)***. To allow comparison between waterways of different sizes, the tightness of bends is usually expressed as the ratio between the radius of curvature and the waterway base width at the bend (r_c/w). This ratio is relatively small for tight bends and increases for bends that curve more gradually. Observations have shown that many bends develop an r_c/w ratio of 2 to 3. For bends that are tighter than this, flow separation leads to increased energy losses (Bagnold, 1960). This observation provides a distinction between bends that are likely to be 'stable' i.e. maintain low rates of erosion and migration versus those that are likely to be 'unstable', i.e. erode and migrate rapidly. The design approach to achieve an appropriate level of sinuosity is set out in Part D2 - sinuosity. In some waterways it will not be appropriate to design significant sinuosity.

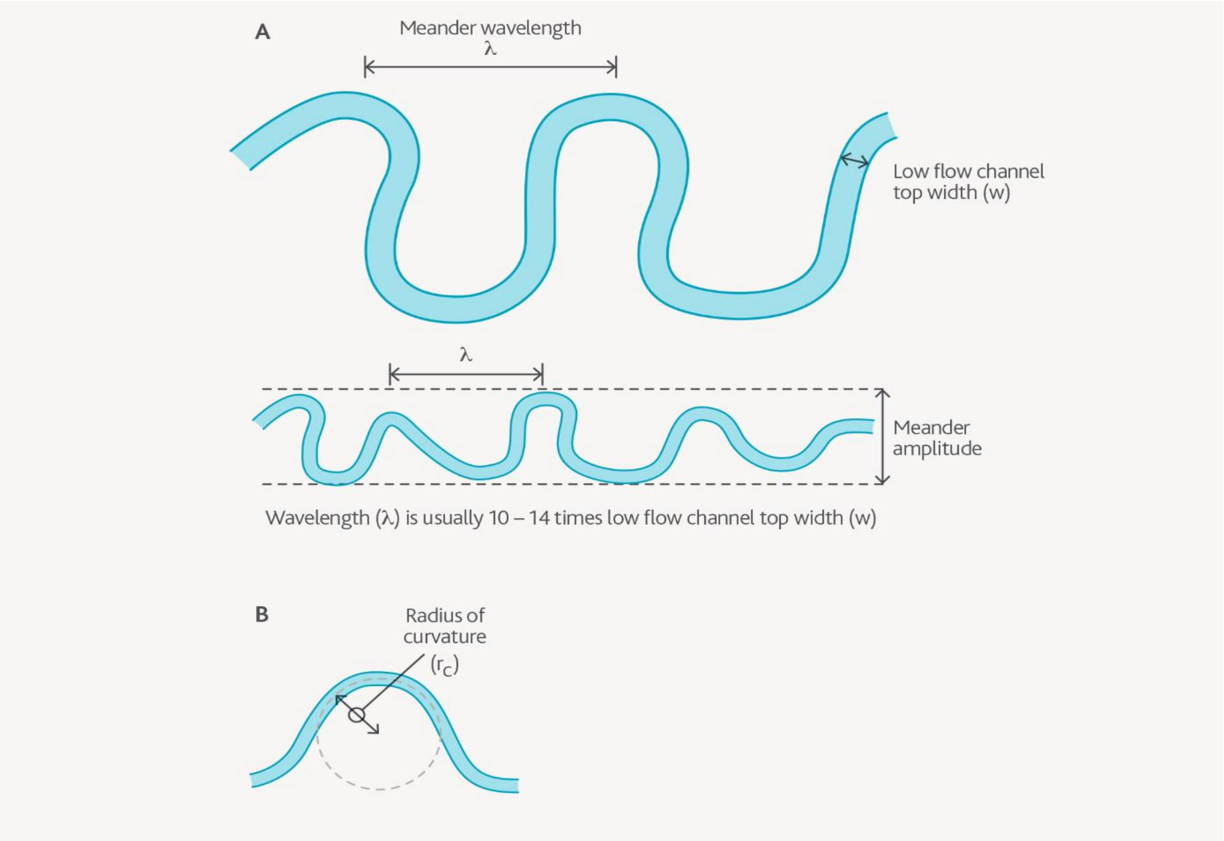


Figure 10 - Aspects of meander geometry (a) Meander wavelength. (b) Radius of curvature

Depth variability expressed through the long-section

An important link between physical form and ecology is the provision of variability in flow depth and refugia for fauna to live in during dry periods. In constructed waterways, variability in depth is provided by the construction of pools and connecting shallower riffle or run zones (see below for details on these features) (Figure 11).

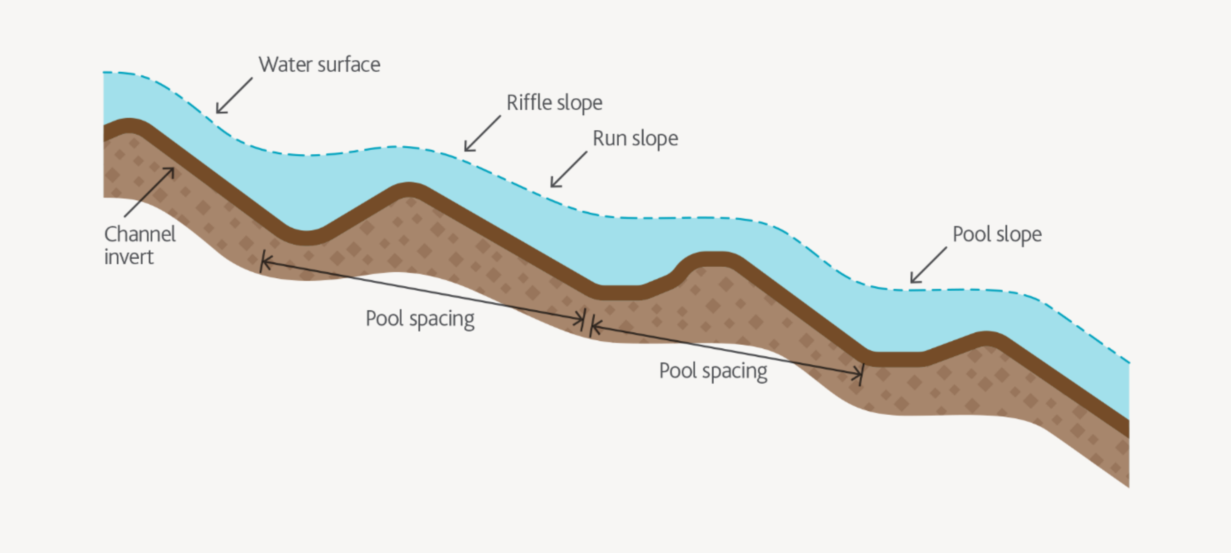


Figure 11 – Example waterway long-section (longitudinal profile)

Waterway shape expressed through the cross-section

Variability in the cross section of the waterway provides a range of flow conditions and habitats that support different ecological communities. In natural waterways the cross section is rarely symmetric or consistent along its length. Moving along the waterway the width contracts and expands with corresponding change in the depth. The slope of its banks (otherwise known as the batter slope) also changes, with steep batter slope prevalent on the outside bank around meander bends, and more mild slopes expected at the inside bank. These features should be represented in constructed waterways by varying the size and shape of the channel through any particular reach (accounting for all other design criteria), by altering width, depth, batter slopes, and incorporating benches into the cross sections. Waterway geometry criteria is detailed in Part D2 of this manual.

Feature-scale physical form

This section describes the physical features that are available to the waterway designer. Details of the feature-scale design elements are set out in Part D3 of this manual.

Floodplains, benches and low flow channel

Interactions between waterways and floodplains support important ecosystem functions in many natural waterways. In constructed waterways, and existing urban waterways more generally, the floodplain connectivity is limited or absent because urban development occurs in areas that would previously have been inundated in large flow events. To avoid flooding these developments, constructed waterways are generally designed to efficiently convey flood flows within a waterway corridor that is substantially narrower than the area that would previously be inundated under natural conditions.

In many natural and constructed waterways, a defined ***low flow channel*** conveys base flow and small flow events, before flow exceeds the capacity of the low flow channel and inundates adjacent areas on the floodplain or riparian area. The purpose of the low flow channel is:

- Convey low flows in a relatively narrow, defined channel to maximise available habitat in features like pools
- Provide the physical diversity that creates a ‘naturalistic’ rather than engineered appearance, which is an important factor in the amenity of the waterway
- To provide sufficient flow velocity to prevent stagnation in the relatively narrow low flow channel
- Create hydrologic diversity across the width of the waterway corridor. The low flow channel will be significantly wetter than areas adjacent to it, hence supporting a different range of flora and fauna
- Provide sufficient depth for stormwater pipes to drain freely to the waterway

In constructed waterways with a low flow channel form, flows above the capacity of the low flow channel (usually 4EY to 1EY flow) up to the 1% AEP flow are conveyed in a larger ***high flow channel*** (Figure 12).

Although true floodplains are not present in constructed waterways, some of their function can be provided by having small off-channel areas that are periodically inundated, and support plant species that are adapted to intermittent inundation. These areas, called ***benches***, form in natural channels through sediment deposition along the edges of the waterway. They are intermediate height features, located between the low flow channel and the batters of the high flow channel. In constructed waterways, benches can be designed into the channel cross section at different flow levels to create habitat niches for the establishment of different vegetation assemblages. They also provide greater visual interest in the channel cross section. Thus, in constructed waterways these features are not intended to be depositional and self-formed but pre-formed, with their level and areal extent pre-determined according to the functional requirements of the waterway being designed.

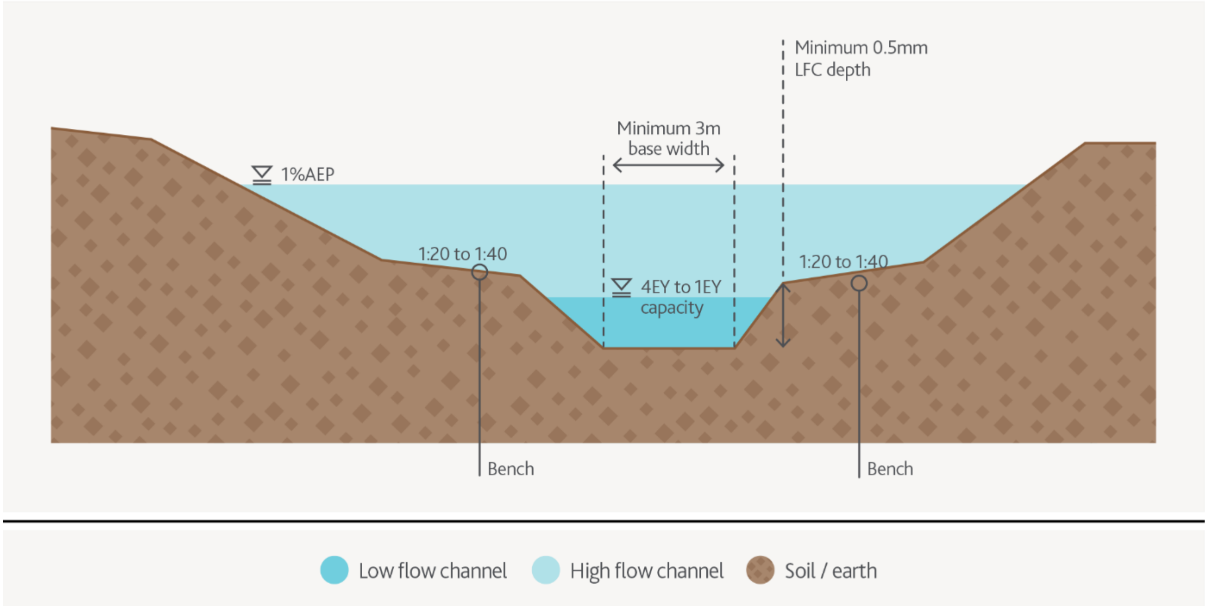


Figure 12 - Typical compound waterway section example

Pool-riffle and pool-run sequences

In natural rivers longitudinal variations in depth and bed slope are often associated with periodic features called ***pools and riffles***. Pools and riffles can provide important habitats: certain species of fish lay their eggs in the spaces between the coarse gravels in riffles, while pools provide shelter and a suitable habitat for rearing young. Pools also provide critical habitat and refuge during periods of lower flow.

Pools are generally located on the outside bends of meanders between riffles. The pool has a flat water surface slope and is deeper than the average channel depth. Riffles are bed features with larger bed material. Riffles are typically found between meanders and control the streambed elevation, ponding water into the pool upstream (Figure 13 and Figure 14). Flow depth is relatively shallow over the riffles and the local bed slope is steeper than the average slope of the channel.

The difference between riffles and pools is most obvious at low flows, when the flow moves rapidly over coarse sediment in the relatively steep riffle sections and more slowly through the deeper pools (Figure 13). The turbulence caused by water moving faster over riffles provides oxygen to the water. Runs intersperse pools in the same way as riffles, but flow is deeper, and the bed material may not be as large.

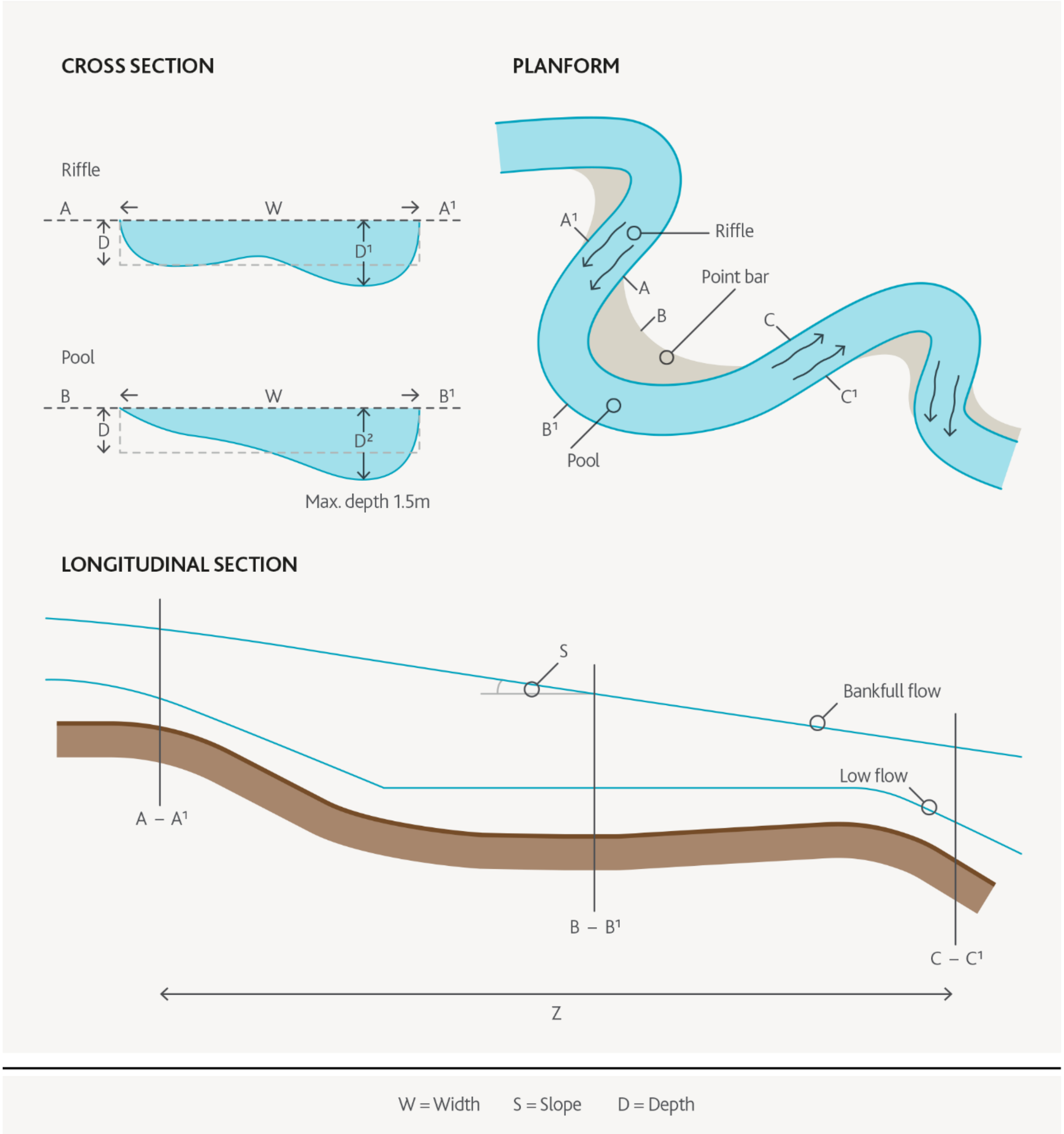


Figure 13 – A typical pool-riffle sequence[1]

[1] North Carolina Stream Restoration Handbook. Features of natural streams From Hey, R.D. and Heritage, G.L. (1993). Draft guidelines for the design and restoration of flood alleviation schemes. National Rivers Authority, Bristol, UK, R&D Note 154

Figure 14 - Example of a constructed pool-riffle sequence

Large wood

Community perceptions regarding the benefits of both retaining and reintroducing wood into rivers and streams have fundamentally changed since the early 1990s. The role that large wood plays in aquatic ecosystem health is now well established: Brooks (2006) noted that, 'in many respects wood in rivers is akin to the coral reefs in our oceans, as it provides substrate for invertebrates and biofilms, and provides complex habitat that supports a wide range of aquatic species.' Waterway management authorities across Victoria actively promote the reintroduction of large wood into their waterway systems. Large wood can assist in reducing flow velocities and increasing channel stability.

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.

Bed grade control structures (rock chutes)

Rock chutes are also known as rock riffles and rock ramps. They generally involve the excavation 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 are largely constructed to control the gradient of stream beds to address system-wide change. However, 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 wetlands, or the creation of riffle and pool habitat.

Bank stabilisation structures (rock beaching)

Rock beaching involves the placement of quarried rock on stream banks. 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 stream banks and does not address system wide erosion. The technique is also known as rock revetment or rock riprap.

Rock beaching is used as a form of armouring of stream banks 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.

Technical details on bank stabilisation can be found in Section D3.1.

B2.3 Ecological values in waterways

The ecology of waterways depends on complex interactions between physical, chemical and biological factors. At a broad level, there are two major influences on a waterway that determine the types and suitability of habitats for animals and plants:

- The catchment setting (geology, soil, land use, altitude and topography), which controls the physical form of the waterway, as well as influencing water quality and vegetation types
- The flow regime, which describes the characteristics of the hydrology in a waterway

Waterway ecosystems rely on the relationship between communities of flora, fauna, and micro-organisms. Different vegetation communities within a waterway corridor combine to form the waterway ecosystem and contribute to ecosystem health. Species distribution within a waterway corridor is dependent on the presence of water, which influences a series of vegetation zones across the profile of a waterway.

In urban areas the waterway ecology is negatively influenced by increased pollution and changes in hydrology caused by changes from rural to urban land use. Rainwater that once soaked into the ground before reaching the waterway now flows over impervious surfaces, collecting contaminants and increasing the volume and flashiness of flows in the waterway. The rate and magnitude of bed and bank erosion is increased, in-channel habitat niches are destroyed, and large wood is removed from the system. The changes in the physical form of the waterway lead to significant degradation of waterway and riparian habitat, and consequently the diversity of animals and plants reduces.

In addition to increased erosion during floods, small rainfall events that would normally infiltrate entirely into the ground are delivered to the waterway, resulting in more frequent flows than flora and fauna have adapted to. Animals that are tolerant of these conditions are more likely to be found in urban waterways, and are the target species for constructed waterways. Between rainfall events, base flows in urban waterways are lower than would be expected because of the limited infiltration into the groundwater, which would have historically supplied base flows: this again favours biota that are tolerant of those conditions.

The ecology of constructed waterways

Providing habitat for flow-dependent fauna depends on a combination of physical form, water quality, flow regime, and vegetation. Research carried out on waterways in Port Phillip and Westernport catchments indicated only a limited range of native species (see Table 4) will colonise urban waterways (either constructed or existing). This is due to changes in the flow regime and reduction in water quality compared to pre-development conditions, regardless of best practice stormwater treatment. Table 4 is not a comprehensive list, but provides some examples that align with Melbourne Water's key values as outlined in the Healthy Waterways Strategy. Possums, lizards and snakes may also reside within an urban waterway corridor. The management of stormwater water quality and flow regimes are outside the scope of this manual, but it is assumed that stormwater from urban areas draining to the waterway will be treated to the current best practice standards before entering the waterway (see Best Practice Environmental Management Guidelines for more details).

Table 4 – Some Urban tolerant fauna species expected in constructed waterways

FISH	FROGS	BIRDS	
• ***Anguilla australis*** (Short-finned eel) • ***Galaxias maculatus*** (Common galaxias) • ***Galaxias truttaceus*** (Spotted galaxias) • ***Galaxias brevipinnis*** (Climbing galaxias)	• ***Litoria ewingi*** (Southern brown tree frog) • ***Crinia signifera*** (Common froglet) • ***Limnodynastes dumerilii*** (Pobblebonk) • ***Limnodynastes peroni*** (Striped marsh frog) • ***Limnodynastes tasmaniensis*** (Spotted marsh frog)	• ***Ardea pacifica*** (White-necked heron) • ***Egretta novaehollandiae*** (White-faced heron) • ***Cygnus atratus*** (Black swan) • ***Nycticorax caledonicus*** (Nankeen night heron) • ***Porphyrio porphyrio*** (Purple swamphen) • ***Fulica atra*** (Eurasian coot) • ***Gallinula tenebrosa*** (Dusky moorhen) • ***Phalacrocorax melanoleucos*** (Little pied cormorant)	• ***Phalacrocorax varius*** (Pied cormorant) • ***Phalacrocorax sulcirostris*** (Little black cormorant) • ***Phalacrocorax carbo*** (Great cormorant) • ***Anhinga melanogaster*** (Darter) • ***Todiramphus sanctus*** (Sacred kingfisher) • ***Acrocephalus australis*** (Australian reed-warbler) • ***Cisticola exilis*** (Golden-headed cisticola)

Many of the factors influencing ecology are heavily modified in constructed waterways. The artificial nature of constructed waterways means the designer has considerable control over its physical form and vegetation community. Through implementing high quality waterway designs a reasonable amount of ecological function can be provided.

An overview of the characteristics of a waterway that can be designed to maximise its ecological value is provided below:

- **Habitat structure.** One of the major advances in waterway design supported by this manual is a structured method of designing a range of physical habitat features to support native animals and plants. Almost any habitat feature that can be found in natural systems can be constructed, but there a subset of features that are relatively straightforward to design and construct including:

  pools (of different sizes and capacity)

  shallow riffle or run sections

  small off-channel benches or wetlands (not stormwater treatment systems).

  instream wood features provide habitat and protection for fish and macro invertebrates, and also perching habitats for birds

  benches are flatter, vegetated features next to the low flow channel that provide habitat for frogs.

- **Flow regime.** The larger and more frequent peak flows and reduced base flows from urban catchments creates difficult conditions in a constructed waterway for native flora and fauna. The practical implications for waterway design are that the ecological objectives are to provide habitats suitable for flora and fauna that are tolerant of the hydrology and water quality in urban areas, rather than for the species that require less disturbed hydrology and water quality.

- **Food and energy resources.** Like all ecosystems, the fundamental basis of food chains and webs in waterways comes from primary production. The presence of different instream and riparian vegetation will dictate the potential to support other life forms within the waterway and its corridor.
- **Habitat connectivity between waterway reaches.** The vegetation corridor that surrounds the waterway provides a complex role of protecting the waterway by providing habitat support, facilitating connections to existing habitat and remnant vegetation, and strengthening habitat corridors between existing waterway systems. The unidirectional nature of the flow introduces longitudinal links between points within the waterway system. Water, sediments, nutrients, chemicals and biota are transported downstream throughout the waterway to lower areas and eventually to a receiving natural waterway or the sea. While most of this movement is downstream with the flow, many fish migrate upstream at some stage in their life cycle. Terrestrial and amphibious animals can move up and downstream in the riparian zone.

The animals and plants supported by a waterway depend on the physical form of the waterway. The various aspects of physical form are described in Section B2.2. Details on how to incorporate them as part of a constructed waterway design (for the various stages) are provided in Part D.

Vegetation in constructed waterways

Vegetation is vital to the ecological health and function of waterways, both within the waterway (instream vegetation) and alongside the waterway (riparian vegetation). The health, diversity and structure of vegetation is important for providing food, shelter and habitat for animals, improving soil and water quality, stabilising waterway banks, and providing shade and temperature control within waterways.

The successful use of vegetation in a waterway depends on several factors:

- A diversity of physical form in the waterway, which provides a range of hydrologic conditions to support a diversity of plants (e.g. aquatic, ephemeral, terrestrial etc.).
- An appropriate vegetation design involves planting the right plant species in the right location in the waterway corridor. For example, plants that are adapted to wetter conditions should be planted closer to the centre of the channel rather than on higher banks.
- Effective planting and establishment of vegetation using plants of an appropriate maturity, planted at the right time of year, with the appropriate erosion protection and at the right density.
- Effective maintenance and weed and pest control, particularly through the pre-planting and establishment phases.

Birds in constructed waterways

Birds are one of the most visible, studied and monitored classes of animal in the Port Phillip and Westernport catchments, and their presence has a positive influence on how people feel about the health of waterways. Well-designed constructed waterways can provide substantial benefits to bird populations, primarily through the provision of healthy, diverse and well-structured native vegetation in the waterway and its corridor.

Habitat features important for birds are:

- Exposed large wood pieces in the riparian zone, along the edges of the waterway and pools, and extending from pools to act as roosts
- Gentle edge batters around the low flow channel and pools (above and below the normal waterline) to permit wading
- Flowering shrubs are particularly beneficial for small native birds as habitat and a food source.

- Spikey shrubs which provide cover from predators can also limit public access

Fish in constructed waterways

Waterways in the Port Phillip and Westernport catchment contain a diverse variety of fish, with 36 species of freshwater fish (native and introduced) found in rivers, lakes and wetlands across the region. Due to declines in abundance, several of these species are of national conservation significance (such as dwarf galaxias and Australian grayling).

Fish use waterways as habitat in several ways. They rely on variations in natural water flows, including flooding, to trigger breeding, spawning and migration. The structure of waterways is also vital to fish because they need a diversity of physical features (such as deeper pools, shallow runs and occasionally inundated benches) to rest, feed and spawn. Instream and riparian vegetation are also an important food source for fish. The shade provided by larger riparian plants controls instream temperature variations, which is important for native fish.

The range of fish species that a constructed waterway can support is limited, compared to undisturbed rural waterways, by poorer water quality and the modified flow regime generated by urban areas. However, there are a range of urban tolerant fish species that well-designed constructed waterways can support. Features important for fish are:

- High quality, diverse native aquatic and riparian vegetation
- A variety of appropriate physical habitats in the waterway, in particular deep pools that retain water during dry periods
- Waterway crossings (i.e. bridges and culverts) that fish can pass through
- Submerged large wood pieces in pools in the low flow channel.

Frogs in constructed waterways

Frogs can be found at many locations within the Port Phillip and Westernport region, and are an integral part of waterway ecology. Frogs are amphibians, meaning that they spend some time in the water as well as on land. Most species of frog breed and lay eggs in or around wetlands and waterways. Waterways therefore provide important habitats for frogs.

Features important for frogs are:

- Provision of suitable physical habitats for frogs within the waterway corridor—generally areas that are regularly inundated, have high quality vegetation, and are connected to the waterway by high quality vegetation.
- High quality, diverse native aquatic and riparian vegetation that connects breeding habitats.
- Waterway crossings that encourage movement through the waterway corridor. Areas that are identified as Growling Grass Frog (GGF) conservation areas require crossings to be designed in accordance with the GGF Crossing Design Standards.

Macroinvertebrates in constructed waterways

Dragonflies, beetles and freshwater crayfish are among a diverse group of animals called macroinvertebrates. These are animals without a backbone that live or spend some of their lifecycle (eggs, larval stage) in waterways. Most freshwater macroinvertebrates can be seen with the naked eye but are generally smaller than 30mm. There are thousands of macroinvertebrates and several types of worms, snails, mites and flies belong to this group.

Macroinvertebrates are a critical part of the aquatic, ephemeral and riparian zones, providing a food source for frog, fish and birds. The diversity of macroinvertebrates is closely linked to the management of stormwater from urban areas, but there are several important features in waterways:

- High quality, diverse native aquatic and riparian vegetation, particularly fringing and overhanging riparian vegetation
- Ensure erosion and sedimentation is not excessive so as to smother riffles
- Large wood in pools in the low flow channel.

B2.4 Social Values

There are five broad areas where high quality constructed waterways provide services to the community:

- Amenity
- Community Connection
- Recreation
- Flood protection
- Erosion protection.

These are described in the follow sections.

Amenity in constructed waterways

As introduced in Chapter A3, amenity is defined as 'the pleasantness of a waterway to visitors and the ability of the waterway to provide a restorative escape from the urban landscape.' Waterways and their corridors provide opportunities for many recreational pastimes and activities. Well-designed waterways within new urban environments are highly valued by our communities.

The attributes that contribute to the way people appreciate and value waterways can be tangible, such as paths and natural vegetation, or intangible such as vistas, links to places or people, or the knowledge that wildlife is present (Figure 15).

Collectively referred to as landscape values, in a waterway they are largely addressed through a combination of these elements:

- Naturalistic physical form
- Vegetation
- Access and circulation
- Sensory access
- Recreational facilities
- Areas for respite/ contemplation/ meeting

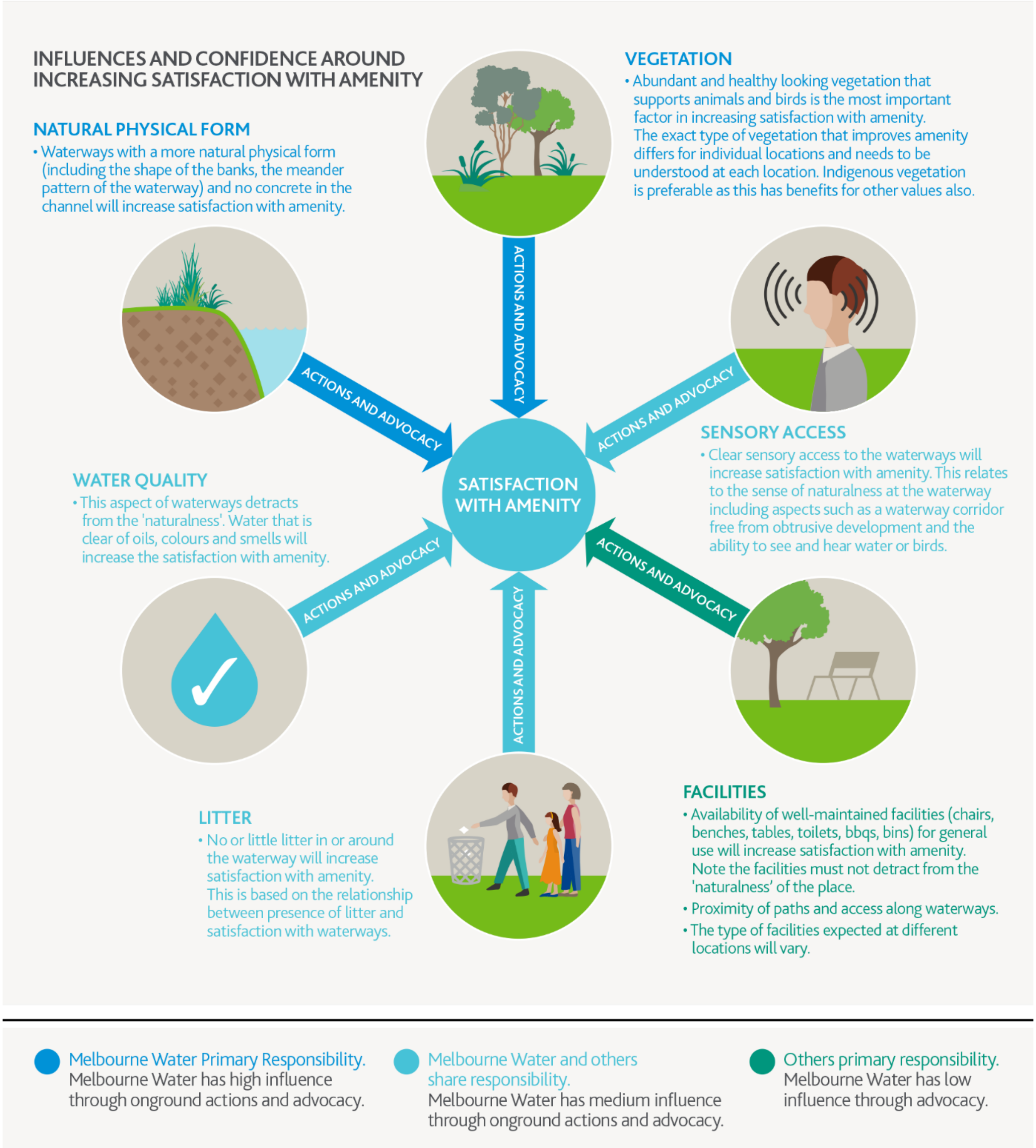


Figure 15 - Amenity conceptual model: actions and influences to protect and improve amenity

Community connection

Constructed waterways offer new communities places they can use to connect with others in their community. Waterways provide valuable public open space opportunities and connections to biodiversity to support good mental and physical health. Providing community gathering places along waterways close to homes and workplaces supports the opportunity to build connections within community to support greater personal health and resilience.

The overall path and road network within a future urban structure will also need to be considered so that, wherever possible, connections are provided to connect people to parkland destinations and the waterway corridor.

Flood protection and drainage services in constructed waterways

Urbanisation leads to a significant increase in the area of impervious surfaces such as roofs, driveways and road, which decreases water infiltrating soil and increases the volume and frequency of stormwater runoff. In response to this hydrologic change urban development planning adopts a major/minor approach to stormwater management.

Drainage systems in urban developments consist of a minor drainage system with sufficient capacity to contain flows up to the 20% AEP event. The pipelines do not always follow the natural drainage path and are usually aligned along property boundaries and the roadway kerb and channels. The major drainage system caters for the runoff from storms producing higher peak flows than the capacity of the minor drainage system. The major drainage system is designed to handle overland flows resulting from storms with a 1% AEP. This may take the form of a pipeline and roadway, however once the safe flow capacity of the roadway is exceeded a drainage reserve and constructed waterway is required to cater for the flood flows and maximise the social and ecological values of the waterway corridor.

Constructed waterways play two key flood protection and drainage roles:

- To provide the minor drainage system with a free draining outfall
- To safely manage flood flows within the urban built form and to provide flood protection to properties

Erosion management for asset protection in constructed waterways

Excessive erosion in constructed waterways poses risks to the waterway itself, and built assets including roads and pedestrian bridges, drainage outfalls, walking and cycling paths, and access and maintenance tracks.

Constructed waterways offer a variety of means to address the risk of excessive erosion. For example, through careful design of the physical form of the waterway the designer can ensure that drainage outfall points merge into the waterway, minimising forceful and erosive flow conditions and constructing rock protection. Strategic layout and design of native vegetation communities can also reduce flow velocities, protecting the asset (pedestrian bridge, viewing platform, etc.) and nearby bank from excessive erosion. In some cases, additional vegetated buffer may be necessary to respond to these more vulnerable locations.

PART C: DESIGN ACCEPTANCE PROCESS AND DEEMED TO COMPLY

C1. DESIGN ACCEPTANCE APPROACH

Melbourne Water and/ or council are the ultimate client for almost all waterways in Port Phillip and Westernport catchments. Once constructed, these waterways become Melbourne Water or council assets to own and maintain.

This part of the manual summarises the three stages in the design process, the steps involved in each stage, and how Melbourne Water review and provide feedback on the waterway design. It details what a designer can expect from the process. Part D of this manual provides the key technical design elements for each stage in the design process, and the standard that should be adhered to when providing material to Melbourne Water. The purpose of this alignment was to provide clarity and efficiency for Melbourne Water's land development customers working through the design process.

The waterway designer must ensure they meet the requirements of Melbourne Water through the design process in the same way they meet the requirements of the developer client for the subdivision/development adjacent to the waterway. Waterway designers therefore play a pivotal role in ensuring the waterway design interfaces with the surrounding development to the satisfaction of all parties.

Under Melbourne Water's Quality Assurance system (ISO 9001: Quality Management), developers, engineering consultants, sub-consultants and contractors have defined roles and responsibilities with respect to the delivery of Melbourne Water assets, such as waterways. Further information can be found on Melbourne Water's Planning and Building website[2]

The flow chart below (Figure 16) sets out the interactions between the design approach—undertaken by the waterway designer—and the steps in the design acceptance process. The waterway designer will work through three key design stages: concept, functional and detailed.

[2] http://www.melbournewater.com.au/Planning-and-building/land-development-process/policy/Pages/Quality-management.aspx

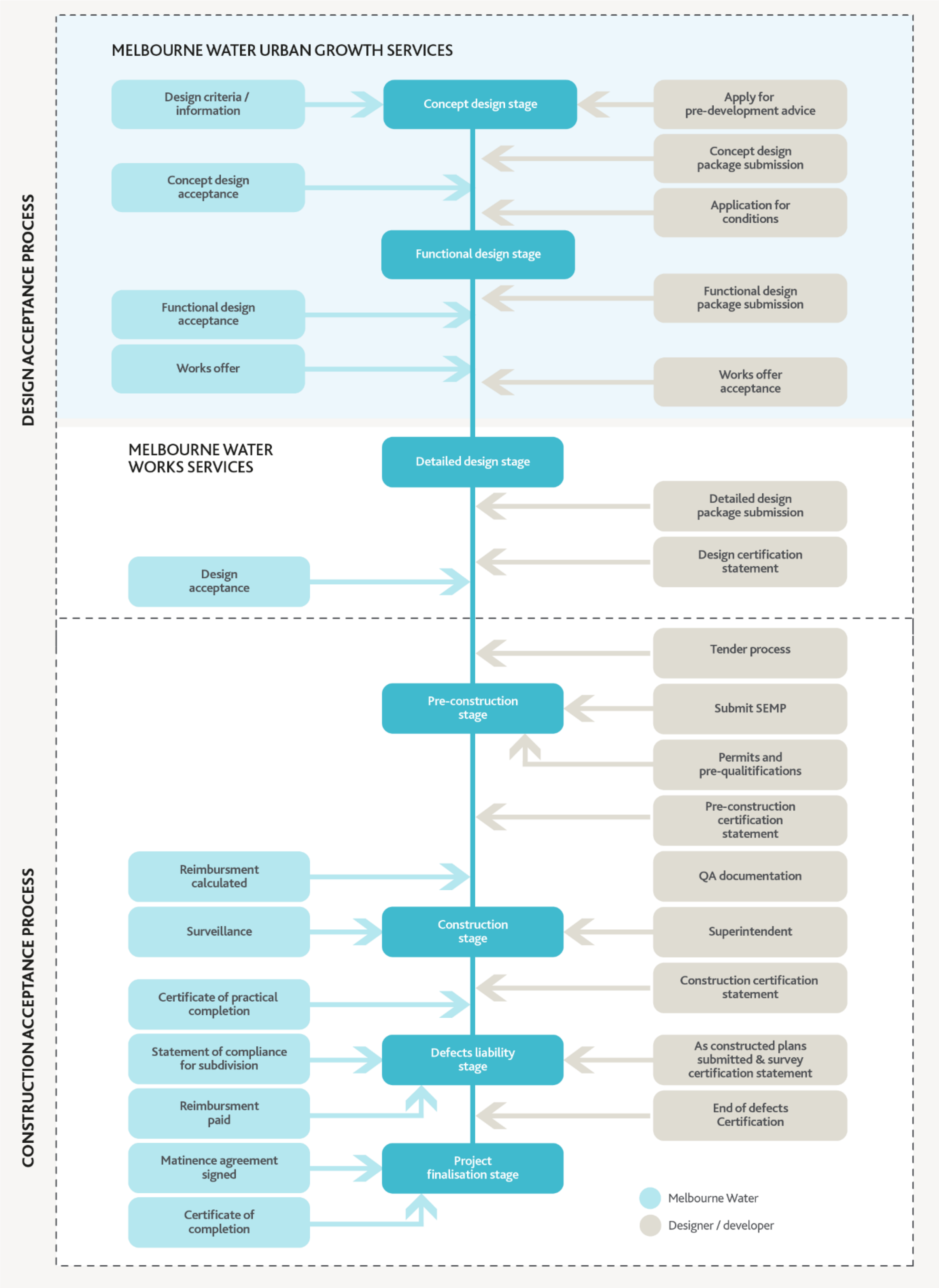


Figure 16 - *Overview of design acceptance process*

The developer/ consultant may choose to apply for the following approvals or consents in conjunction with the corresponding design acceptance (as a minimum) from Melbourne Water:

- An application for a Planning Permit should be accompanied by a Stormwater Management Strategy;
- An application for Certification of a Plan of Subdivision showing the creation of a Reserve and/or Easement over a constructed waterway/waterway corridor should be accompanied by an accepted functional design;
- An application for conditions (Works Offer) should be accompanied by an accepted functional design.

Completion of the following forms is a key administrative part of the design acceptance process under Melbourne Water's Quality Assurance program:

- Request for Scheme Servicing Advice
- Application for Conditions
- Acceptance of Conditions
- Design Certification
- Pre-Construction Certification
- Construction Certification
- As-Constructed Certification
- End of Defects Certification

Further assistance is provided to the consultant via a series of checklists, which can also be found on Melbourne Water's Planning and Building website.

C1.1 Design acceptance options

Melbourne Water has adopted two review/acceptance approaches for submitting waterway design proposals to Melbourne Water rather than attempting to define one set that applies to all situations. The two options are:

- Deemed to comply approach
- Alternative approach

After consultation with the development industry it is clear that developers and waterway designers want a clear understanding of Melbourne Water's requirements for waterways and request a prescriptive set of design criteria. It was decided that a Deemed to Comply design acceptance approach, with a prescriptive set of design criteria, would be most beneficial and useful for the industry to use. Melbourne Water also acknowledges that not all waterways and development sites are the same and it is difficult to have one set of prescriptive design criteria to suit all types and topography. As a result, an alternative design acceptance approach is available for designers, which allows developers and waterway designers to submit designs that do not entirely achieve all the design criteria but still achieves the required core outcomes.

Deemed to Comply approach

The Deemed to Comply approach requires designers to demonstrate compliance with a prescriptive set of design criteria. Deemed to Comply waterway designs have an estimated review (not acceptance) timeframe of a maximum of 28 calendar days per the Melbourne Water customer service charter.

Provided that designers demonstrate compliance with the design criteria they will have a high level of confidence that their designs will be accepted by Melbourne Water. The Deemed to Comply design criteria are included in the design checklists, provided on the Planning and Building website.

Alternative approach

The Alternative approach provides designers with the option of submitting an approach that differs from the prescriptive Deemed to Comply approach, but still delivers the required core outcomes for waterways. Part D provides a set of key design considerations and minimum standards when considering an appropriate waterway design and when the alternative design approach is sought.

> If any of the Deemed to Comply criteria are not complied with, the design will be considered an Alternative approach.

The designer is responsible for providing Melbourne Water with evidence that the “Alternative approach” achieves equivalent or better performance than the “Deemed to Comply” approach.

The review timeframe for “Alternative approach” designs will be longer than Deemed to Comply designs. Designers should be aware that there is no certainty that their design will be accepted by Melbourne Water. This provides the opportunity for developers and their designers with tight time constraints and/or those that are risk averse to pursue the Deemed to Comply approach.

The review process for the Alternative approach will be the same as the Deemed to Comply approach, with a concept, functional and detailed design package required for each stage of the process. This ensures a transparent and consistent process for internal and external stakeholders. When an Alternative approach design is submitted, Melbourne Water’s review involves input from various internal departments and expertise in waterway design and operation, including hydrology, hydraulics, ecology, constructability, and maintenance.

For unusual design applications, or where internal resources are not available, Melbourne Water may choose to seek expert opinion from independent peer reviewers about whether the information submitted demonstrates that Melbourne Water’s core outcomes and design objectives will be achieved. Note: The cost associated with this will be borne by the developer not Melbourne Water.

C1.2 Working with Melbourne Water

Melbourne Water’s Development Services team is the principal point of contact for all customers undertaking land development within catchments covered by Development Services Schemes.

To find out if your development is located within a Development Services Scheme, and for more information on working with Melbourne Water, please visit Melbourne Water’s Planning and Building website.

The following diagram represents the structure of the Development Services team as it relates to the planning and delivery of key assets in Development Services Schemes.

STRATEGY DEVELOPMENT	**Catchment Strategies Team** • Implementation of Development Services Schemes • Review of Precinct Structure Plans • Assessment of catchment models including RORB, hydraulic models and MUSIC in greenfield areas
CONCEPT DESIGN	**Urban Growth Services Team** • Scheme servicing or feasibility advice • Review and assessment of Greenfield planning permit applications and subdivision applications • Review of surface water management strategies • Review of concept design package • Confirmation of wetland location and indicative footprint • Review of core outcomes associated with wetland proposal
FUNCTIONAL DESIGN	**Urban Growth Services Team and Developer Works Services Team** • Combined team review and assessment of functional design package • Preparation of internal business case for the delivery (timing and funding) of projects • Preparation of Non-Works and Works Offer • Review of MUSIC and flood models • Review of Certification of Plan of Subdivision and consent to the issue of a Statement of Compliance
DETAILED DESIGN	**Developer Works Services Team** • Assessment of detailed design packages • Issue design acceptance • Contractor tender assessment • Calculation of reimbursement for scheme works • Review of maintenance agreement
PRE-CONSTRUCTION AND CONSTRUCTION	**Developer Works Services Team** • Pre-constriction meeting onsite • Issue of permit to work • Surveillance of on-ground works • Issue certificate of practical completion
AS-CONSTRUCTED	**Developer Works Services Team** • Reimbursement paid • Maintenance agreements reviewed • Certificate of completion issued

Figure 17 – Development Planning team (high level structure)

C2. CONCEPT DESIGN STAGE

The concept design stage provides a chance to consider the opportunities and constraints of the subject site in relation to waterway design and construction, and to understand Melbourne Water's requirements and aspirations for the waterway that any design must address.

Providing a site responsive design that maximises the site's natural values and characteristics while balancing liveability outcomes for the future community is central to the concept stage. To achieve this Melbourne Water requires project proposals to have clear design objectives and a project Vision.

Design objectives establish the broad design priorities being sought for a project. Chapter A3 includes guidance for designs through the provision of design objectives for constructed waterways.

Design objectives should respond to the site's strengths as they have been identified through the context and site analysis. For example a site with biodiversity values may include a design objective such as *Protect and enhance habitat of the Baw Baw Frog* or if active transport is an important feature of the future adjoining urban development, a design objective might be *Provide a shared pedestrian and cycle pathway along the waterway that integrates with the broader neighbourhood active transport network.*

The vision will combine knowledge of the site (obtained from the context and site analysis) with expectations and aspirations for the future. It will articulate the priority elements of this future state and establish who it is for. The concept plan will be a reflection of the vision and design objectives and should include Melbourne Water's aspirations (i.e. Healthy Waterway Strategy) and the aspirations of other key agencies as outlined in key documents (i.e. PSPs).

The land developer and the local government authority may also have design specifications for the waterway and surrounding open space. The designer is tasked with the job of preparing a concept that meets each of these combined design objectives.

The concept design stage in this manual is concerned with the process of synthesising and identifying various options that could potentially meet the design objectives for the waterway. It does not just determine the layout but how the waterway will be incorporated into the landscape design and marry with the other design considerations associated with a development. A Development Services Scheme is a catchment masterplan and does not provide the necessary information required for a concept design of a waterway.

It is at the functional design stage where these options and ideas are tested to determine their feasibility. The outcome is the preferred design scenario. This underlines the **importance of iteration** during the evolution of the concept and functional design as different options are explored and refined.

Refer to Part D for more information on technical design elements to assist with this stage.

Concept design steps

The concept design stage consists of six steps (Figure 18).

Step 1
Submit request for Pre-Development Advice (feasibility)

The consultant submits the relevant form to Melbourne Water requesting pre-development advice. The form should include the following information:

- Catchment plan for the waterway clearly defining the property boundaries
- Overall estate plan (if available)
- Any baseline due diligence

It should be noted that this is not an application for conditions (i.e. the Works Offer), but a request for Pre-Development Advice.

Step 2
Receive Pre-Development Advice (feasibility)

Melbourne Water will provide the designer with advice regarding the scheme objectives and intent, including highlighting components (physical form, vegetation, etc.) of the waterway that need to be protected or modified, the waterway corridor width, design flows, identifying relevant plans and strategies, design parameters for Scheme infrastructure (such as outfall pipes), and any available background studies (flora, fauna, cultural heritage, etc.).

Step 3
Prepare initial concept design package

It is strongly recommended that the concept design package is jointly prepared by the landscape architect and waterway designer. The concept design package will clearly link to the overall development landscape masterplan (which is generally a permit requirement for a development). This is to ensure the waterway integrates with the greater development context, provides connections, and is responsive to the surrounding development. It is envisaged that once the concept package is developed for the waterway, a summary of this can be included in the development landscape masterplan (thus not duplicating work).

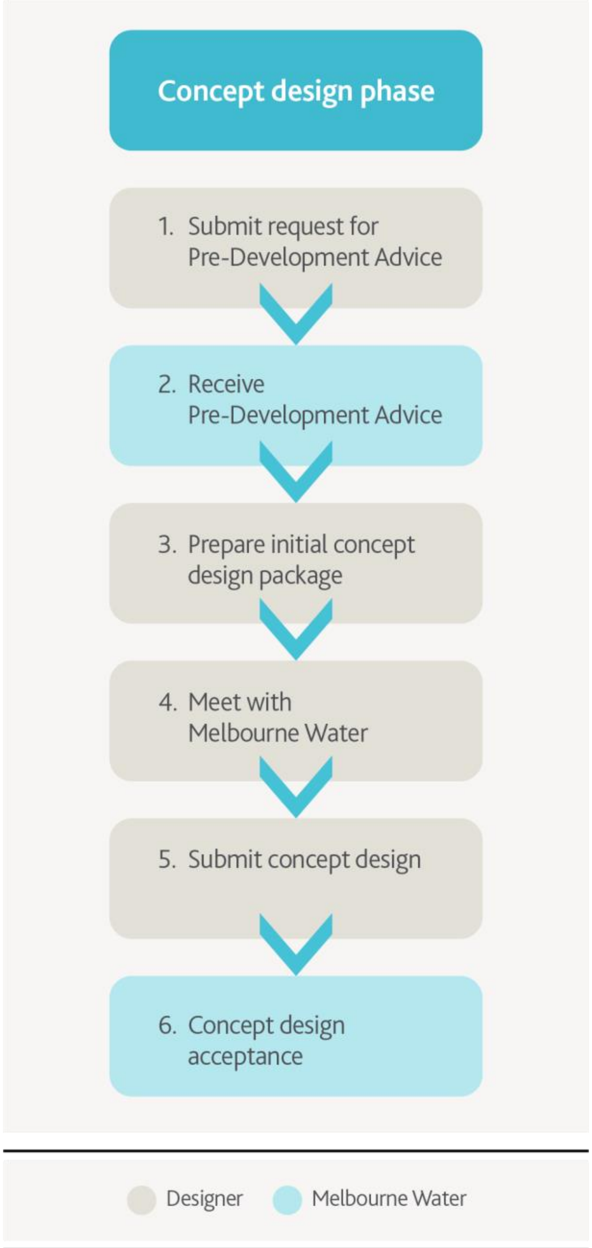


Figure 18 - *Steps in the concept design phase*

The designer's role is to:

- Co-ordinate the input from the design team;
- Assemble the design package; and
- Present it in the required format.

Tasks include:

1. Undertake context and site analysis (existing conditions)
2. Resolve issues from site analysis (opportunities and constraints)
3. Prepare site Vision and Design Objectives
4. Undertake a desktop soil assessment
5. Set the waterway type
6. Confirm the preliminary waterway corridor width
7. Set the preliminary waterway alignment
8. Establish preliminary maintenance requirements and delegation (MWC and Council)
9. Prepare a preliminary cost estimate
10. Prepare the concept design package

The above information should be used to produce a two-dimensional concept design plan that captures and articulates all the constraints, features and expectations associated with the waterway.

The initial concept design package should provide sufficient detail to demonstrate that the intent of the design specifications objectives and criteria and performance objectives provided required by Melbourne Water can be met, subject to further design (i.e. functional design). The package consists of a single report and concept design plans.

The concept design package includes:

- Context Plan
- Site location and background
- Opportunities and Constraints plan to inform the Design Response
- Project Vision and Design Objectives and demonstrate the planned connections within the broader open space network to and from the constructed waterway utilising a master planning approach
- Waterway type
- Description of the waterway corridor width, alignment and grade
- Any specific required outcomes for the waterway (e.g. specific habitats or recreational linkages, key species such as GGF)
- Landscape setting (from desktop study)
- Summary of the key opportunities and constraints for waterway design (including landscape and urban design opportunities)
- Where there is no road separation, cross sections and other information will need to be provided to show built form controls and performance measures to achieve a positive interface between public and private realm.
- Options, maintenance delegations and recommendations

The various elements contributing to a concept design plan are shown in Figure 19

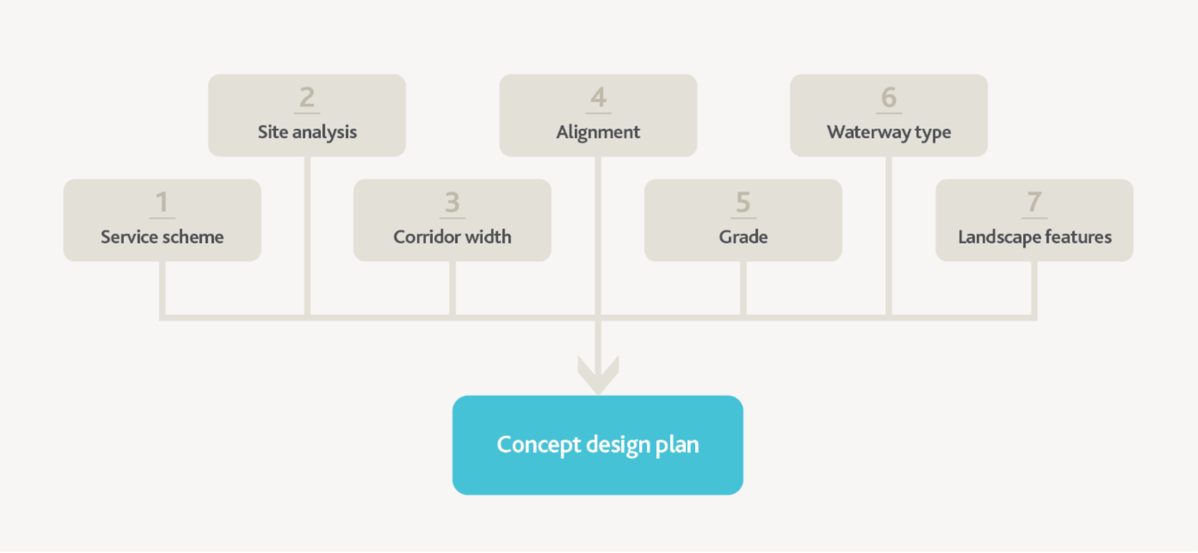


Figure 19 - Concept design plan elements

The plans to be included in the concept design package must include a layout plan and typical cross-section views of the proposed waterway and corridor features including as much detail as possible, such as:

- Land use plan including open space networks highlighted
- Indicative pedestrian and cycle networks and key connections between the waterway and adjoining urban development
- Existing waterway/channel location, size and shape
- Proposed road reserves
- Civil services (either existing or major proposed services)
- Proposed waterway corridor width and alignment
- Proposed low flow channel alignment (based on the waterway typology)
- Proposed maintenance access points, tracks and areas
- Indicative locations of proposed channel features (e.g. pools, riffles)
- Indicative locations of pathways, crossings and other social infrastructure
- Indicative pipe outfall/surcharge locations
- Indicative locations of proposed storm water quality treatment systems within the urban layout and/or waterway corridor based on the Stormwater Management Strategy for the development.
- Existing areas of flora, fauna, geomorphic and cultural heritage values
- Nodes at intervals within the corridor of the waterway that provide points of interest or places to gather; with sufficiently modified spatial layout
- An indicative cross-section for the waterway, based upon the consideration of future drainage connection invert levels and the nominated waterway corridor width. Indicate likely batter slopes, flood levels and vegetation plantings.

> **Important Note:** Reports and plans are to be submitted in .PDF format and Reports are to be submitted in .doc or .docx format (to permit track changes). The package should be submitted in full as one package; not individually.

Step 4
Meet with Melbourne Water

The designer must submit the draft Concept Design package to Melbourne Water prior to the meeting via DevConnect.

The aim of this step is to seek feedback that the concept is generally to Melbourne Water's satisfaction and to give direction to the designer so that they can continue on the right track or make changes to design as required.

The designer then collates the feedback from Melbourne Water, relevant stakeholders, and incorporates this into the next iteration of the concept design.

> **Important note:** Sometimes, it may be worthwhile submitting the revised draft concept design for further review and comment to check that the iteration adequately addresses the feedback, before making the final formal submission for acceptance.

Step 5
Submit concept design

Update the concept design as per the feedback from the previous Step and submit the concept design package to Melbourne Water for review and acceptance.

It is important that the designer highlights in their accompanying report:

- Any conflicts that arose from undertaking the iteration in attempting to address all parties' comments.
- How each comment has been addressed and what components of the design have changed accordingly.
- Any significant changes from the original concept design that may not otherwise be obvious to the reviewers.

Step 6
Concept design acceptance

Melbourne Water will provide concept design comments following receipt of the *completed* package.

- If the package is incomplete or is not to Melbourne Water's satisfaction, then there is no guarantee that the above review timeframes will be met.
- Melbourne Water does not accept any liability for delays caused by incomplete or inaccurate information submitted for review.

Melbourne Water's concept design acceptance will take the form of an 'in-principle acceptance subject to', with the 'subject to' being the further feasibility analysis that needs to be undertaken through the functional design phase.

Outcome of concept design stage

- At the end of the concept design phase three key parameters should have been generally agreed upon (subject to functional design):
- The design objectives (including landscape design outcomes) the concept design will aim to achieve.
- The waterway corridor width.
- The waterway type and corridor alignment.

There is an understanding between Melbourne Water and the developer at this stage that **nothing is 'locked-in'** and some changes to waterway reserve width and alignment, and possibly some of the objectives, may need to be made according to the results of the feasibility analysis undertaken during the functional design.

Note:
A concept design is a **great communication tool** that will assist in explaining the intent of the design response to Melbourne Water, Councils and other interested parties.

C3. FUNCTIONAL DESIGN STAGE

The aim of the functional design stage is to test and evaluate the options identified in the concept stage, at a reach-scale, to ensure the proposed design meets the objectives for the waterway. The functional design is a *proof of concept* that provides confidence that the proposed waterway will function appropriately.

The proposed reach-scale design will:

- Meet free drainage outfall, public safety and flood protection requirements
- Be stable within the tolerable limits at a reach-scale
- Fit within the waterway corridor width
- Meet the objectives agreed to in concept design stage

Important note:

The Developer must work with Melbourne Water to arrive at a functional design that meets Melbourne Water's requirements *before* seeking Melbourne Water's consent to Certification of a Plan of Subdivision showing the creation of a Reserve and/or Easement over a constructed waterway/waterway corridor or subdivisional stages abutting or surrounding a proposed waterway corridor.

Functional design steps

The functional design stage consists of five steps (Figure 20)

Step 1
Prepare functional design package

The functional design package is prepared by the designer using the design elements and modelling detailed in Part D2. Tasks carried out to prepare the functional design package include:

1. Undertake geotechnical assessment and soil contamination investigation
2. Identify locations of non-waterway assets
3. Establish design flows
4. Set the waterway planform
5. Set the waterway cross section geometry
6. Develop the digital terrain model (DTM)
7. Estimate the hydraulic roughness
8. Specify hydraulic structures and interface elements
9. Develop the hydraulic model
10. Test the design for flooding, public safety and channel stability
11. Set the location of engineering and habitat features (as required by key species identified in the concept stage)
12. Incorporate geotechnical findings (e.g. clay, topsoil, rock etc)
13. Establish maintenance requirements and delegation
14. Revised cost estimate and proposed construction timeframe
15. Prepare the functional design package

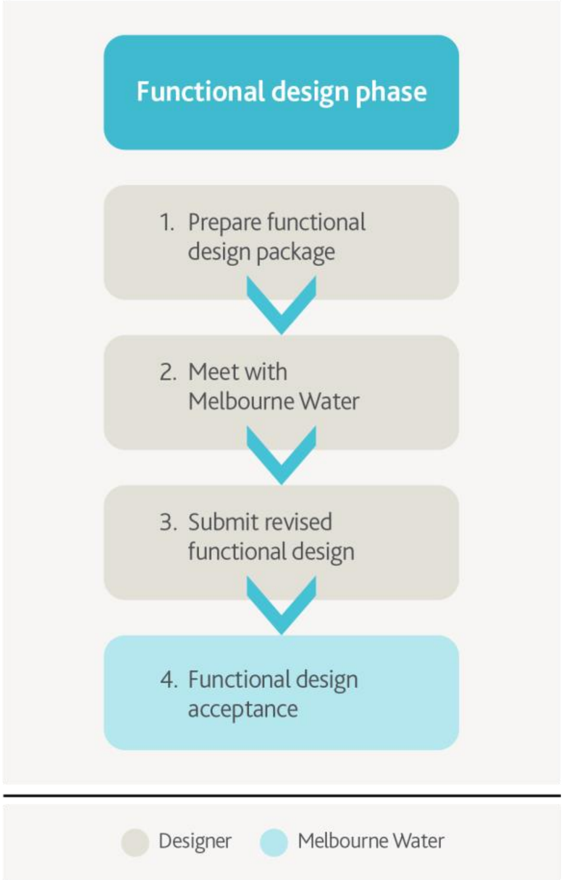


Figure 20 – Steps for designer in the functional design phase

Table 5 - Acceptable file formats for the functional design package

TASK	NOTES	FORMAT
Functional design checklist	Deemed to comply checklist	.pdf or .docx
Functional design report	Contents outlined in Part D	.pdf or .docx
Hydrological modelling summary	Approach, assumptions, input parameters and design flows	.pdf or .docx
Hydraulic modelling summary	Approach, assumptions and input parameters. Longitudinal profile of shear stress at each cross section showing comparable thresholds	.pdf or .docx
Cost estimate	Preliminary cost estimate according to the standard schedule of costs presented in Part D.	.pdf
Proposed construction timeframe	Preliminary construction timelines	.pdf or .docx
Functional design plans	Location of all interface elements, location of proposed features, long section, cross sections, landscape plans	.pdf
Constructed waterway strings	Boundary and design strings of constructed waterway for use in ArcMap/MapInfo	.shp or .tab (with associated files)
RORB hydrologic model	Catchment file, storm file, and data file Only if user defined: IFD file, pluviograph data, and temporal patterns	.cat, .stm, and .dat .map, .dat, and .pat
Catchment boundary strings	Delineated catchment boundary spatial data (for use in ArcMap/MapInfo)	.shp or .tab (with associated files)
HEC-RAS hydraulic model	HEC-RAS project file and associated plan file, geometry file and steady flow file	.prj (with associated .p*, .g* and .f*)
Geotechnical report	Report – findings to be summarised in functional design report	.pdf

Step 2
Meet with Melbourne Water

The designer must submit the draft functional design package to Melbourne Water prior to the meeting. The aim of this step is to:

- Seek feedback that the functional design is generally in accordance with the agreed design objectives, Melbourne Water's and the stakeholder/approval authority expectations.
- Give the designer an opportunity to demonstrate that the design will work, providing 'proof of concept'.
- Give certainty to the designer so that they can continue on the right track.

The designer then collates the feedback from Melbourne Water and the relevant stakeholders and authorities and incorporates this into an iteration of the functional design (if required).

Important note:
Submit the revised functional design for further review and comment. This provides an additional check that the iteration has correctly interpreted feedback before making the final, formal submission for acceptance.

Challenging and complex designs may require several iterations, therefore may need an allowance for multiple iterations and meetings with Melbourne Water and council to discuss and refine the design before submitting the package for formal acceptance.

Step 3
Submit revised functional design

Submit the functional design as per the feedback from the previous Step and update the functional design package for submission to Melbourne Water for formal review and acceptance.

It is important that the designer highlights in their accompanying report:

- any conflicts that arose from undertaking the iteration in attempting to address all parties' comments.
- how each comment has been addressed and what components of the design have changed accordingly.
- any significant changes from the original design objectives or the concept/functional design that may not otherwise be obvious to the reviewers.

Step 4
Functional design acceptance

Melbourne Water will provide functional design comments/acceptance following receipt of the *completed* package.

- If the package is incomplete or not to Melbourne Water satisfaction then there is no guarantee that the above review timeframes will be met.
- Melbourne Water does not accept any liability for delays caused by incomplete or inaccurate information submitted for our review.
- The review timeframe is contingent on the designer having followed the design acceptance process, including the submission of the draft package, attending meetings with Melbourne Water and stakeholders to discuss the design and the completion of any design iteration required to address comments to the satisfaction of the relevant parties, prior to submission of the final package for formal acceptance.

Important note:
Please refer to Planning and Building section of the Melbourne Water website for information on the functional design acceptance.

C4. DETAILED DESIGN STAGE

The aim of the final design stage is to finalise individual features within the waterway and produce detailed design documentation. This stage ensures the design of individual features meets specific requirements, and that the incorporation of the proposed features does not have an adverse impact on the function of the waterway. Design elements for the detailed design are covered in Part D3 of this manual.

Ultimately the aim of the detailed design stage is to document the design for construction. Key steps in this stage are gaining final design acceptance from Melbourne Water and the lodgement of design certification paperwork to Melbourne Water.

Completion of the detailed design stage will provide:

- Detailed civil design plans suitable for public tender (excluding set out).
- Detailed landscape plans suitable for public tender.
- Specifications suitable for public tender.
- Schedules suitable for public tender.
- Confirmation that construction and maintenance requirements can be met (MWC and Council).
- Addition of set-out information to the drawing set.
- Draft maintenance agreement

Detailed design steps

The detailed design stage consists of five steps (Figure 21).

Step 1
Finalise feature-scale design waterway elements

The feature-scale design elements are prepared by the consultant in accordance with the approach detailed in Part D3. Tasks carried out to prepare all information required as part of the detailed design package include:

1. Incorporate comments from the previous Stage
2. Confirm waterway features and locations
3. Size features (e.g. pools, rock work etc.)
4. Incorporate features into DTM
5. Update hydraulic model
6. Test design for flooding, stability and fish passage
7. Post-construction risk assessment
8. Revise maintenance schedule and budget

Step 2
Prepare detailed design package

The detailed design package is prepared by the designer. Tasks carried out to prepare all of the information required as part of the package include:

1. Prepare detailed design drawings (civil and landscape) suitable for public tender
2. Finalise the specifications
3. Finalise the maintenance plan and schedule
4. Finalise the cost estimate
5. Draft the Site Management Plan (to be finalised by appointed contractor)

Table 6 outlines the file formats and supplementary information requirements of the detailed design package

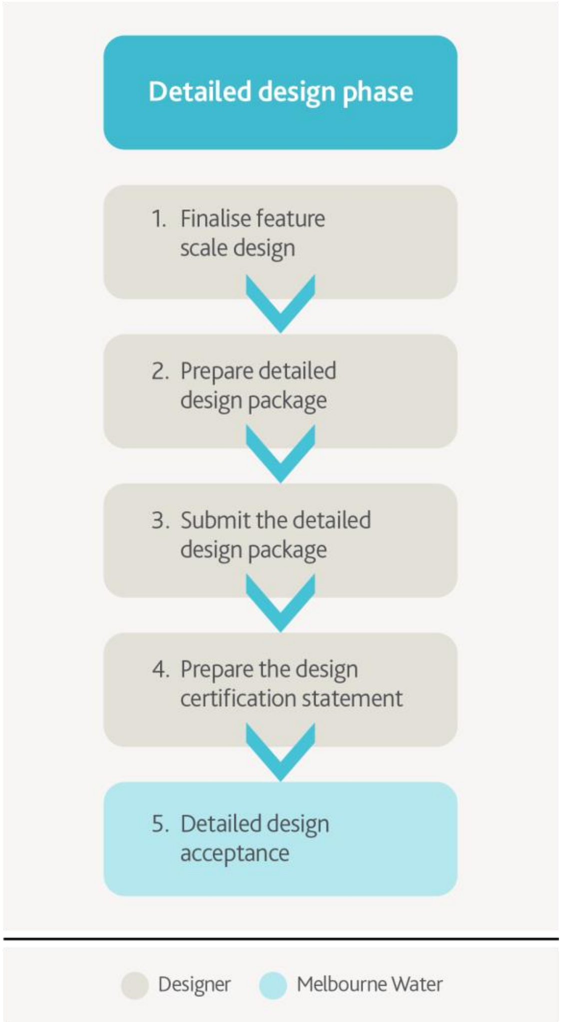


Figure 21 - *Steps in the detailed design phase*

Table 6 - Accepted file formats for the detailed design package

TASK	NOTES	FORMAT
Detailed design checklist	Deemed to comply checklist	.pdf or .docx
Detailed design report	Contents outlined in Part D	.pdf or .docx
Hydrological modelling summary	Approach, assumptions, input parameters and design flows	.pdf or .docx
Hydraulic modelling summary	Approach, assumptions and input parameters. Longitudinal profile of shear stress at each cross section showing comparable thresholds	.pdf or .docx
Detailed design plans	Location of all interface elements, location of proposed features, long section, cross sections, civil details, landscape plans, planting schedule, and landscape details	.pdf
Technical specification	Civil and landscape specifications for all design details, construction and establishment elements, Cultural Heritage Management Plan requirements	.pdf or .docx
Cost estimate	Final cost estimate according to the standard schedule of costs presented in Part D.	.pdf
Service alterations/ relocation approval	Written approval from service authorities for any service alterations/relocations.	.pdf or .docx
Operation and maintenance agreement	An asset operation plan and maintenance agreement.	.pdf or .docx
Draft Site Environmental Management Plan	Draft Site Environmental Management Plan	.pdf or .docx
Constructed waterway strings (output from DEM)	Boundary and design strings of constructed waterway for use in ArcMap/MapInfo	.shp or .tab (with associated files)
RORB hydrologic model	Catchment file, storm file, and data file Only if user defined: IFD file, pluviograph data, and temporal patterns	.cat, .stm, and .dat .map, .dat, and .pat
Catchment boundary strings	Delineated catchment boundary spatial data (for use in ArcMap/MapInfo)	.shp or .tab (with associated files)
HEC-RAS hydraulic model	HEC-RAS project file and associated plan file, geometry file and steady flow file	.prj (with associated .p*, .g* and .f*)
DEM/Terrain Model	DEM model and associated files	Grid as.txt

Important note:
Consultation with Melbourne Water will be required for any design changes that may be proposed/required during the preparation and/or review of the detailed design (civil or landscape) to ensure they will not have an adverse impact on waterway function.

Step 3
Submit the detailed design package

The designer must submit the Detailed Design package to Melbourne Water. Melbourne Water will review and provide comment on the detail design of a *completed* package. Melbourne Water may require some amendments prior to the finalisation of the detailed design and lodgement of design certification and package.

Important note:
If Melbourne Water has significant comments on the detailed design, a meeting will usually be required to discuss and resolve these comments prior to finalisation of the detailed design.

Step 4
Prepare the design certification statement

Once the design has been amended as per comments from Step 3 (if required), and the designer is confident that their design is acceptable, the Developer must submit the following documents to Melbourne Water:

- The Design Certification Statement.
- The finalised Detail Design package.

Step 5
Detailed design acceptance

Melbourne Water will provide detailed design comments/acceptance following receipt of the *completed* package.

- If the package is incomplete or not to Melbourne Water's satisfaction then there is no guarantee that the view timeframe will be met and timelines may be extended.
- Melbourne Water does not accept any liability for delays caused by incomplete or inaccurate information submitted for our review.
- The review timeframe is contingent on the designer having followed the design acceptance process, including the submission of the draft package, attending meetings with Melbourne Water and stakeholders to discuss the design and the completion of any design iteration required to address comments to the satisfaction of the relevant parties, prior to submission of the final package for formal acceptance.

C5. PRE-CONSTRUCTION STAGE

The objective of the pre-construction phase is to ensure that all stakeholders associated with the project are aware of their responsibilities, and that the contractor has all of the information relevant to the construction works. The pre-construction stage incorporates the tender process and the lodgement of pre-construction certification paperwork to Melbourne Water.

Pre-construction steps

The pre-construction stage consists of six steps (Figure 22).

Step 1
Tender process

The tender interview process should include design related questions so that the contractor's understanding of the project can be determined. It is recommended that the process include a site walk where the designer can communicate the design intent to the contractor and the field staff. The tender review process is to be conducted by the developer or their representative. Melbourne Water is not generally involved in the tender review process. Refer to Melbourne Water's Planning and Building website for further information.

Note: for tenders expected to be >$450k please follow the Victorian Government tendering process (Tenders Vic).

Important note:
When preparing the schedule of quantities that will form the basis of the tender documents, the developer's consultant is to itemise those components of the works that Melbourne Water is to pay for. This will allow for a prompt and accurate assessment of the value of Melbourne Water's reimbursement for the works.
Tendering of works

Reimbursements

Step 2
Submit SEMP

The designer, in consultation with the contractor, is to finalise and submit the Site Environmental Management Plan (SEMP) to Melbourne Water.

Step 3
Contractor assessment & reimbursement calculated

The actual reimbursement amount will be calculated and Melbourne Water will advise the Developer of the proposed reimbursement. An owner who is required to build Melbourne Water assets in conjunction with the development is reimbursed an amount towards the cost of the works by Melbourne Water.

Refer to Melbourne Water's land development policies on reimbursements for further information.

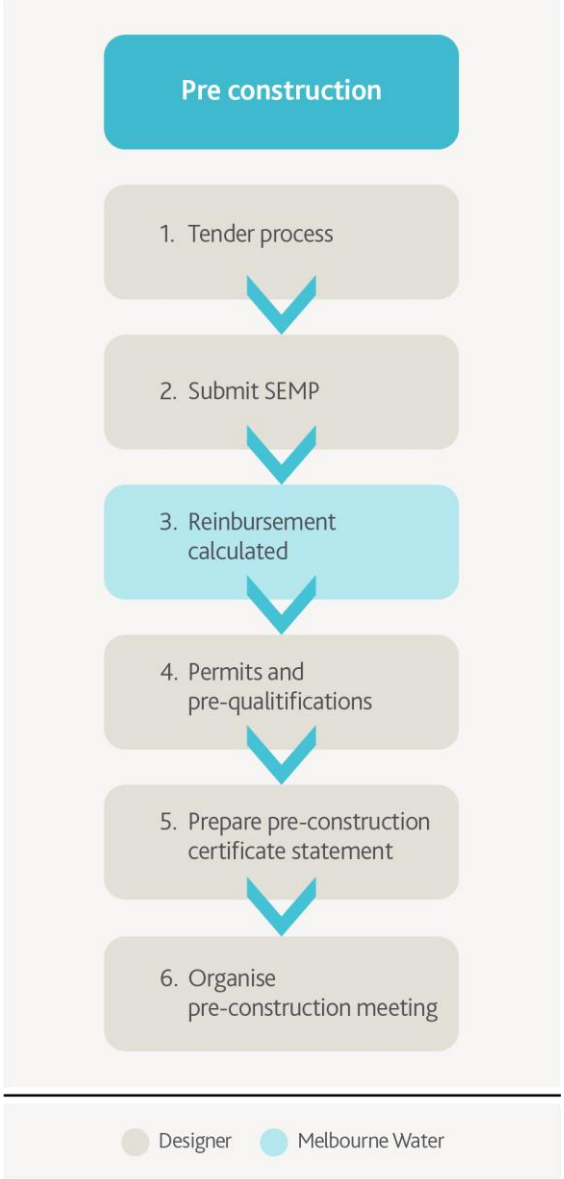


Figure 22 - *Steps in the pre-construction phase*

Step 4
Permits and pre-qualifications

Before works commence, the contactor is to obtain all permits and complete all pre-qualification processes:

- The contractor must obtain a Permit to Work for any projects that involve connections to an existing Melbourne Water asset including a waterway if required. The Permit to Work will be issued by the Project Surveillance Office at the Pre-commencement meeting. The contractor must have completed a Permit recipient training course in order to obtain a Permit to Work.
- While civil works are being carried out, the contractor must have someone on site that has obtained a Melbourne Water green card (i.e. attended the Site Environmental Awareness Training course).

Step 5
Prepare pre-construction certification statement

Before commencing construction, the Developer must submit the following documents to Melbourne Water:

- The Pre-Construction Certification List in the Construction Specifications section of Melbourne Water's website in accordance with Commencement of Works.
- Evidence that insurance requirements set out in the Insurance Conditions have been complied with.

Important note:
Melbourne Water must have at least two working weeks' notice of intention to start construction by submission of a Pre-Construction Certification Statement and Checklist.

You must give Melbourne Water at least two working days' notice from the start date if construction is going to be delayed. Melbourne Water also needs to know your new start date at least two working days before you begin.

Note: The manual does not cover the details of the construction components of the asset delivery process and the reader is encouraged to review this information as presented on Melbourne Water's Planning and Building website.

Step 6
Organise a pre-construction meeting

Once you have completed all the necessary pre-construction activities, you must organise a project pre-construction meeting with Melbourne Water to review your plan.

By this stage you should have:

- design acceptance
- lodged your pre-construction certification checklist and statement;
- lodged your site environmental management plan;
- had your reimbursement calculated;
- selected a contractor; and

  paid or lodged the necessary bonds if there is no reimbursement associated with the works

> **Important Note:**
> Consultation with the Melbourne Water Project Officer and Surveillance Officer **will be required** for any **design changes during construction** to ensure they will not have an adverse impact on waterway function.
> Works must match the accepted design, unless Melbourne Water provides acceptance of any changes. If the contractor's works do not match the design or meet Melbourne Water's construction standards, the principal/developer may be asked to rectify them at their own cost.

During construction, the Melbourne Water Project Officer and Surveillance Officer will:

- visit your site to make sure the work complies with our standards;
- monitor your Site Environmental Management Plan, and amend the plan where necessary; and
- undertake water quality testing of some sites plus if necessary require modifications to the Site Environmental Management Plan and/or provide liaison and cooperation with the Environmental Protection Authority on serious pollution matters.

If unforeseen issues occur during construction that impact on and/or require a variation to the accepted design, it may be necessary to resubmit the new design to Melbourne Water for formal review and acceptance.

C6. AS-CONSTRUCTED AND ESTABLISHMENT STAGE

Submitting accurate documentation of what has been constructed to Melbourne Water is an essential part in (i) demonstrating that the construction process has met the intent of the design and (ii) in providing critical information to Melbourne Water for future use.

As-constructed and establishment steps

The as-constructed phase consists of seven steps (Figure 23)

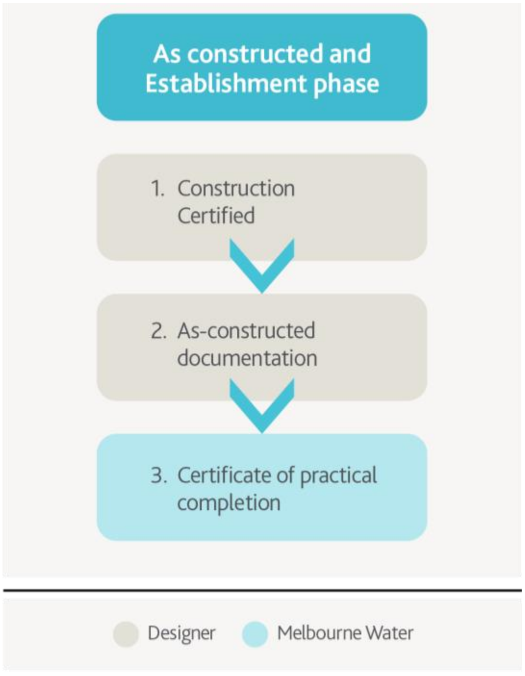


Figure 23 – Steps in the as-constructed phase

Step 1
Construction certification

At the end of construction, the designer must submit a Construction Certification Statement. Melbourne Water will consider the Works as completed when they have reviewed and accepted the Construction Certification Statement.

Check that you are ready to lodge your Construction Certification Statement by using the Construction Certification Checklist. See Melbourne Water's construction website for more details. Be sure to review all conditions in the Works Offer before submitting the Construction Certification Statement. If the works are not completed to Melbourne Water's satisfaction by the due date:

- The agreement may be terminated at the discretion of Melbourne Water;
- The developer must pay any reasonable additional costs incurred by Melbourne Water.

If the Agreement terminates, money paid by the Developer under the Agreement will be forfeited or refunded at the discretion of Melbourne Water. Melbourne Water will deduct any reasonable costs incurred, before determining any refund amount.

Melbourne Water will not accept the Construction Certification Statement if it has reason to believe that there are discrepancies between the works as certified and as constructed. As-constructed feature surveys should be undertaken by the consultant/owner to validate the construction/design process and be 're-input' into DEM and hydraulic models. Rather than compare isolated cross-sections the constructed DEM should be compared to the design DEM. The results should be provided to Melbourne Water.

Step 2
As-constructed documentation

All *As-constructed* documentation (plans, survey and flood mapping results) must be submitted to Melbourne Water. When the documentation is ready, submit the 'as-constructed' plans and complete the following forms:

- As-constructed Survey Certification Checklist
- Submission of digital data

Of significance for constructed waterways, this information must include:

- As-constructed drawings (plan layout, cross sections and long section) in electronic format (.PDF and MapInfo or AutoCAD) of the constructed waterway clearly showing:
- 1% AEP flood levels
- 1% AEP flood extents.
- 10% AEP flood levels and extents
- Low flow channel design flow flood levels and extents
- As-constructed survey data showing finished surface levels and other feature information in accordance with the specifications.
- Any other information required by and in accordance with the specifications on the checklist.
- An as constructed summary report completed by the designer that highlights that the design meets or does not meet the design intent, including the as-constructed hydraulic modelling results.

Important Note:
If the *As-constructed* survey is significantly different from the *for-construction* plans, hydraulic modelling should be re-run to generate as-constructed flood levels and extents using the as-constructed survey.
The creation and submission of accurate as-constructed flood mapping data to Melbourne Water is critical in that it facilitates:

- Melbourne Water's ability to demarcate new lots as being flood free via an automated system that relies on electronic flood mapping data to provide responses to requests for Information Statements issued by Water Retailers to future home owners;
- The Owner's ability to demonstrate that they have achieved sufficient freeboard from the 1% AEP flood levels in the constructed waterway in order to satisfy this requirement as part of receiving Melbourne Water's Consent to Statement of Compliance.

Step 3
Certificate of Practical Completion

Following receipt of the Construction Certification Statement and supporting information, and providing there are no discrepancies between the condition of the works as certified and as constructed, Melbourne Water will:

- issue the Certificate of Practical Completion;
- pay the reimbursement, less the amount held until the defects liability period finishes.

Step 4
Submit End of Defects Liability Period Statement

The defects liability period starts on the date of the Certificate of Practical Completion. The Developer must submit an End of Defects Liability Period Certification Statement at the end of the defects liability period.

The defects liability period differs depending on the asset. The following periods apply and take effect from when the Certificate of Practical Completion is issued:

- pipes and structures – three (3) months
- earthwork and rockwork – twelve (12) months
- plantings – three (3) month establishment period and twenty-four (24) month maintenance period (27 months total)

The Developer's nominated representative must certify that all works still comply with the Construction Certification Statement and that the construction of the development's roads and other services is complete.

Use the End of Defects Liability Period Certification Checklist to make sure that all the necessary steps are completed, and then submit the End of Defects Liability Period Certification Statement.

- End of Defects Liability Period Certification Checklist
- End of Defects liability Period Certification Statement

Once Melbourne Water has accepted your End of Defects Liability Period Certification Statement, Melbourne Water will organise for the remainder of the reimbursement to be paid and provide a Certificate of Completion provided the asset is defect free.

Melbourne Water will not accept the End of Defects Liability Period Certification Statement if it has reason to believe that there are discrepancies between the condition of the Works as certified and as existing.

Step 5
Certificate of Completion

A Certificate of Completion will be issued by Melbourne Water when all the requirements of the agreement have been satisfied. The requirements (if applicable), include:

1. The Certificate of Practical Completion issued by Melbourne Water
2. All contributions have been paid
3. All other money required by Melbourne Water has been paid
4. Downstream outfall works have been certified complete or the Developer has made alternative arrangements which are acceptable to Melbourne Water
5. Any other information, notices or documents required by Melbourne Water have been provided
6. The defects liability period has ended to the satisfaction of Melbourne Water
7. An endorsed maintenance agreement is in place (if required).

Step 6
Final reimbursement

Melbourne Water reimburses for works after the issue of a Certificate of Practical Completion and a Certificate of Completion as per the schedule outlined in the works offer and Melbourne Water's Planning and Building website:

- Reimbursements – Planning and Building website

C7. DEEMED TO COMPLY

C7.1 Introduction

This section presents an overview of the design criteria that need to be met to satisfy the Deemed to Comply assessment pathway. Please refer to Section C1.1 for more information on the Deemed to Comply approach and the Alternative Approach as part of the design acceptance process. Clear links between the design criteria and core outcomes are illustrated, assisting the designer to check that their design is meeting Melbourne Water's requirements.

These design criteria are expanded upon in this part of the manual and are also included in the relevant sections of Part D as part of the technical design elements. The Deemed to Comply conditions are also included in the design checklists available on Melbourne Water's Planning and Building website.

Please refer to the right-side column in the tables provided in this part for the various stages of design that relate to the Deemed to Comply criteria:

- Concept design deemed to comply checklist
- Functional design deemed to comply checklist
- Detailed design deemed to comply checklist

Where applicable, crosslinks have been provided to Melbourne Water standard drawings relevant to specific Deemed to Comply design criteria to assist with detailed design documentation.

C7.2 Deemed to Comply criteria

General

GN1	Designer must request for Pre-development Advice. The application should include the following information: • Catchment plan for the waterway clearly defining the property boundaries • Overall estate plan (if available) • Any baseline due diligence and topographic survey information	Concept
GN2	The waterway designer must acquire the Healthy Waterways Visions for Vegetation (Species and Quality) for the site.	Concept
GN3	The following site specific investigations have been completed: • Feature survey • Geotechnical assessment • Cultural heritage assessment • Flora and fauna assessment	Concept Functional
GN4	Obtain the minimum waterway corridor width from the approved site Stormwater Management Strategy (SWMS), the Precinct Structure Plan (PSP) and/or the Development Services Schemes (DSS) (if applicable). Undertake design to confirm this minimum	Concept

	specified corridor width is sufficient to meet the waterway design objectives.	
GN5	The waterway designer and landscape architect must prepare a concept package which includes a Vision with supporting Design Objectives for the site. Utilising the findings from the site specific investigations the designer must establish a Vision for the site that considers the existing features of the site in the context of the adjoining urban development, the future community who will be living near to and using the waterway and the broader strategic goals and aspirations for the waterway. The plans should consider: • Pedestrian and cycle connections along the waterway, and to the waterway from the adjoining urban development • Connections/ bridges across the waterway • Landmarks or other nodes that will support wayfinding along the waterway • Seating or unique character areas informing local sense of place • Key view lines to be protected • Other features that support the experience of users	Concept
GN6	Designer to establish whether the site is within a Growling Grass Frog (GGF) strategic area. The Growling Grass Frog Crossing Design Standards should be followed in the site falls in a GGF conservation area to meet the design criteria required. This applies to other protected fauna area (e.g. golden sun moth or legless lizard).	Concept
GN7	The waterway corridor alignment incorporates the existing low point at the upstream and downstream property boundary extents. Otherwise written agreement with the adjoining landowner/developer will be required for an alternative interface at the property boundary.	Concept

Waterway type

WT1	In areas with a natural longitudinal bed grade flatter than 1 in 800, a linear pool system waterway type should be selected	Concept Functional Detailed
WT2	Bedrock channels should be the selected waterway type should bed rock be located <1.5m below surface	Concept Functional Detailed

WT3	A compound waterway (i.e. a low flow channel within a high flow channel) should be selected for areas with natural longitudinal grades steeper than 1 in 800, and where bed rock is not located.	Concept Functional Detailed

Planform

P1	Waterway alignment to follow low point of the valley and through the landscape	Concept Functional Detailed
P2	Waterway alignment must integrate and consider upstream and downstream constraints and requirements to ensure it matches in with existing or proposed sections of waterway.	Concept Functional Detailed
P3	The developer and or their consultant is to negotiate with any downstream property owners with regard to outfall design and construction (temporary or permanent), not Melbourne Water. The developer must own and maintain any temporary outfalls until the permanent asset is constructed, not Melbourne Water.	Concept Functional Detailed
P4	Compound waterways must meet the following sinuosity criteria: • at least 1.05 (low sinuosity) • no greater than 1.25 (moderate sinuosity)	Functional Detailed
P5	For compound waterways the reach average meander wavelength should be around 10-14 times the low flow channel top width. To avoid the artificial appearance of a sequence of regular bends (i.e. non-uniform planform), the following break-down should be used as a guide for meander wavelength: • 50% at 10-14 times the low flow channel top width • 25% at 6-10 times the low flow channel top width • 25% at 14-20 times the low flow channel top width	Functional Detailed
P6	In compound waterways, bends should have a sharpness ratio of greater than 2 to 3. Bends in the range 2 to 3 represent the upper limit of the acceptable range. Bend sharpness less than 2 to 3, which include right-angled bends, are not acceptable; regardless of the waterway type. The waterway corridor reserve boundary may have a tighter angle (e.g. 90 degree bend) as long as the overall corridor is of sufficient width to transition the low and high flow channel around the bends in the corridor at an acceptable bend radius.	Functional Detailed
P7	To avoid significant increases in shear stress (and therefore the need for extensive rock work), bend sharpness ratio along a meander reach should desirably be greater than about 7. Therefore, the minimum desirable radius of curvature is about 20 metres for a low flow channel with a bottom width of 3 metres.	Functional Detailed

P8	Wholly straight waterways are not acceptable. Straight sections are permissible but the straight section of a high flow channel must not be greater than eight times the high flow channel top width and the straight sections of the low flow channel not greater than eight times the low flow channel top width.	Functional Detailed
P9	Diversity provided through physical form and alignment	Functional Detailed

Longitudinal grade

LG1	Design grades must be proposed within the acceptable 'stable' range, being flatter than 1 in 200 (dependant on shear stresses being within the acceptable thresholds). Rock chutes are likely to be required for longitudinal grades steeper than 1 in 200. The following chute grade are acceptable: • For longitudinal grades between 1 in 200 and 1 in 60: 1 in 20 rock chute (max) • For longitudinal grades between 1 in 60 and 1 in 40: 1 in 12 rock chute (max) • For longitudinal grades between 1 in 40 and 1 in 35: 1 in 10 rock chute (max) • For longitudinal grades steeper than 1 in 35: rock lined waterway Note: any fish passage requirements need to be established and if this cannot be met (i.e. chutes steeper than 1 in 20 are required) a discussion must take place with Melbourne Water.	Concept Functional Detailed
LG2	All graded rock chutes are to have a height no greater than 1.2m.	Functional Detailed
LG3	Compound channel waterways must have a maximum rock chute coverage of 25% of the waterway (from a plan view perspective)	Concept Functional Detailed

Modelling

MD1	Peak design flows must be estimated in accordance with methods in Australian Rainfall and Runoff 2019. RORB hydrologic modelling software should be used.	Concept Functional Detailed
MD2	A hydraulic model of the waterway with various flood events is developed using HEC-RAS or similar as approved by Melbourne Water. All geometry, flow constrictions, roughness values, and terrain inputs must be consistent with the design plans. Models are to be provided to Melbourne Water and model inputs and results documented in design reports.	Functional Detailed

MD3	Flood modelling should adopt hydraulic roughness coefficients (Manning's n) to represent the mature phase of the vegetation community that will be created in the waterway (conservative flood conveyance analysis) considering vegetation plantings take 2 years to establish.	Functional Detailed
MD4	The designer must select the appropriate hydraulic roughness to best represent the constructed waterway at various time scales – at ultimate and during establishment phase (for the relevant bed and bank materials/vegetation).	Functional Detailed

Cross section geometry

CS1	All constructed waterway types are required to safely convey the 1% AEP flow event	Functional Detailed
CS2	Compound waterway types must be sized such that the low flow channel has a bankfull capacity to convey flows somewhere in the range of a 4EY (minimum) to 1EY (maximum) event (3m minimum base)	Functional Detailed
CS3	Compound waterway types are required to have a high flow channel with sufficient capacity to convey the 1% AEP flow event	Functional Detailed
CS4	Compound waterway types are to have a high flow batter slope of typically 1V:5H to 1V:8H (no steeper than 1V:3H)	Functional Detailed
CS5	Minimum 300mm freeboard to be provided from 1% AEP flood level to top of high flow channel	Functional Detailed
CS6	Minimum 600mm freeboard to be provided from 1% AEP flood level to adjacent lot floor levels	Functional Detailed
CS7	Compound waterway types are to have a low flow channel batter slope of typically 1V:3H	Functional Detailed
CS8	Typically 1V:8H batter for waterways holding water at all times (e.g. linear pools type).	Functional Detailed
CS9	Compound waterway types are to have a low flow channel minimum base width of 3m. * Need to check that the low flow channel capacity is not >1EY given the minimum base width and depth requirements. If so discuss with Melbourne Water to get permission to have a reduction in base width.	Functional Detailed
CS10	Compound waterway types are to have a low flow channel minimum depth of 0.5m.	Functional Detailed

CS11	Low flow channel base to be flat (no 'U' shaped or V shaped)	Functional Detailed
CS12	Benches to have a 1 in 20 to 1 in 40 cross-fall grade towards low flow channel	Functional Detailed

Waterway stability

WS1	The designer must demonstrate that the shear stresses exerted on the waterway do not exceed the threshold shear stress for the boundary material or substrate. • Vegetated low flow channel shear stress threshold of 80 N/m2 (for the 1% AEP event thresholds should not be exceeded) • Vegetated high flow channel shear stress threshold of 45 N/m2	Functional Detailed
WS2	The applied (average) shear stress calculated by using Equation 1 (DuBoys 1879) or HEC-RAS needs to be factored up to estimate the maximum shear stresses occurring on the bed and sides of the cross section.	Functional Detailed
WS3	The applied shear stress at waterway bends has been "factored up" to determine maximum shear stress. Refer to Waterway Stability.	Functional Detailed
WS4	The designer must present tabulated shear stress values along the waterway length. The table should include the cross section chainage, the cross section average shear stress, and where applicable the multiplication factors. This should be done for the low flow channel and the high flow channel (maximum section distances 50m).	Functional Detailed

Features

F1	**Benches** Benches must not sit above the 10% AEP flood inundation level otherwise they will be too dry to perform the required habitat and ecological function.	Functional Detailed
F2	**Stormwater connections** The proposed design must integrate any drainage outfalls without causing unfavourable hydraulic conditions such as: • Inappropriate freefall from drainage outfalls or lack of rock armouring • Velocities greater than 1.5m/s (maximum) from drainage outfalls • Drowning of outfalls causing flows to be backed up and potentially flood the local drainage network upstream of the outfall The stormwater connection should be to a pool or direct to the low flow channel. There should be no bench at this point (i.e. the low flow channel is an extension of the high flow channel batter). Outfalls should also consider: • Configuration to facilitate access and maintenance requirements. • Protection, such as additional rock or vegetation, where flows are likely to cause scour due to increased turbulence or shear stress • Free draining	Functional Detailed
F3	**Rock chutes** • Rock chutes are to be designed using the CHUTE spread sheet. • Rock chutes, or rock riffles, must be designed to facilitate fish passage where required (1V:20H longitudinal grade). • D50 600mm is generally recommended as the upper limiting median rock size in any rock chute design (excluding toe and edge rock)	Functional Detailed
F4	**Fish passage** The default (deemed to comply) position is that fish passage is provided. This is achieved if a "drop cell culvert" (with a pool upstream and downstream) is provided at road crossings and rock chutes have a drop of less than 1.2m and chute grades are no steeper than 1 in 20.	Detailed

F5	**Crossings (bridges, culvert crossings)** Waterway crossing design details are set out in Melbourne Water's Constructing Waterway Crossings Guidelines. The guideline provides design criteria for single span and culvert crossings as well as pedestrian crossings. Design criteria include: • Minimum 5m abutment offsets from bank (for single span structures) • Shared pathways • Rock work configuration • Minimum safety criteria for culvert crossings • Pedestrian crossings should not adversely impact the functioning of nearby assets (e.g. road crossings) by increasing the flood height or flow velocity • There should be no crossings in the upstream or downstream general vicinity of critical culverts or bridges, except where the proposed crossing is above the 1% AEP flood level (this minimises potential impacts to critical culvert functions during flood events) • The underside of the pedestrian bridge should be set at least 600mm above the 1% AEP flood level • Rock armouring for scour protection is required under bridges and decks where vegetation cannot grow due to lack of sunlight • Crossings must be designed to facilitate fish or frog passage. This is achieved by providing a "wet drop cell culvert". • Box culvert crossing with a wet and dry cell culvert required for ecological purposes (fauna passage).	Functional Detailed
F6	Pools are to be located upstream and downstream of culvert crossings.	Detailed
F7	There must be a 1 in 20 rocked longitudinal bed grade transition from the waterway bed grade into the pool	Detailed
F8	Rock work should extend 400mm below the normal water level of the pool	Detailed
F9	Pool spacing approximately 20 – 30 times the low flow channel top width	Detailed
F10	Maximum pool width extends to the outer extent of the benches	Detailed
F11	Intermediate pools typically 600mm deep. Culvert pools typically 900mm deep below the "dry cell culverts".	Detailed
F12	Pool length is typically 3 to 4 times the maximum pool width	Detailed

Safety

S1	Floodway Safety Criteria for grassed floodways' in drainage reserves must be applied to the proposed waterway corridor. The safety criteria are appropriate for the safety of children. Full child safety is to be maintained to a depth of 0.4m on both banks wherever free access is available: For d≤0.4 m, V×d≤0.35 m^2/s	Functional Detailed
S2	Fencing must be provide around steep grades and vertical drops (e.g. culverts, culverts)	Detailed

Vegetation

VG1	At least 200mm of topsoil must be provided in all planted areas accordance with Melbourne Waters Topsoil Specification.	Detailed
VG2	Topsoils used (in situ or imported) must comply with Melbourne Waters Topsoil Specification which is sub set of AS 4419 Soils for landscaping and garden use. Testing must be carried out by a NATA accredited laboratory. If required, amelioration to the topsoil must be undertaken to achieve compliance with Melbourne Waters Topsoil Specification.	Detailed
VG3	Minimum vegetation quality to be category 3 as per Healthy Waterways Visions.	Detailed
VG4	Vegetation diversity provided via a mixed palette of species	Detailed
VG5	Mulch located above the 1% AEP flood level	Detailed

Landscape design

LD1	Assets that are to be sited within the waterway corridor and are intended for public use (e.g. paths) must be located above the level of a 10% AEP flow event.	Functional Detailed
LD2	Boardwalks and viewing platforms must: • Sit above the 10% AEP flood level. • Not obstruct the capacity and hydraulic functioning of the waterway up to and including the 1% AEP flood level.	Functional Detailed

LD3	All boardwalks, piers, bridges and/or structurally treated edges installed and maintained by others are to meet Melbourne Waters below guideline requirements and also have heights and/or railings in accordance with relevant design codes and satisfy inundation and safety criteria. - Constructing waterway crossings guideline - Shared pathways guideline	Functional Detailed

Maintenance

MN1	Maintenance activities and responsibilities are documented in a schedule and indicated on a plan that will ultimately form part of the Maintenance Agreement.	Detailed
MN2	Access tracks for maintenance must be at least four (4) metres wide	Functional Detailed
MN3	Any grassed areas that Melbourne Water must maintain are to meet one of the below options. Councils batter grade requirements should be sought for areas they are to maintain as each council has a different requirement prior to construction: • 1 in 5 or flatter with a 3m run out area at the bottom of the slope is to be provided so MW can mow up and down if necessary. Run out area is to be a maximum grade of 1:12 and be clear of rocks, trees, fences etc. • Maximum grade of 1:12 to allow for safe grass cutting (horizontal and vertical cutting method). No run out area is required, area must be clear of rocks, trees, fences, drops etc. Note: For mowing around vegetation MW requires a 3m gap between vegetation to allow mower access. Overhanging vegetation can be an access issue. Slopes steeper than 1 in 5 to be densely vegetated.	Functional Detailed
MN4	Melbourne Water and council have the ability to safely access the waterway and its corridor to undertake the range of activities required to maintain the proposed structures and features that they will become responsible for via access tracks/roads.	Concept Functional Detailed
MN5	Removable bollards installed at the commencement of any vehicle access tracks into the waterway reserve	Detailed

Landscape contractor selection, plant supply, installation & maintenance

The landscape consultant must be engaged by the developer to supervise and approve the entire landscape construction process from the pre-commencement meeting through to achieving the end of defects period (a minimum of 27 months), ensuring the fellow requirements are met:

LC1	The landscape contractor awarded the waterway project is suitably qualified and experienced and has completed work on Melbourne Water waterways historically and the work is of a high quality.	Construction
LC2	The landscape contractor awarded the waterway project must be the contractor undertaking the plant installation. Melbourne Water will not accept sub-contracting to another contractor without written approval to ensure the sub-contractor is suitably qualified, experienced and has completed work of this nature previously.	Construction
LC3	The landscape contractor awarded the waterway project must be the contractor maintaining the planting once installed. Subcontracting of the maintenance activity must be approved by Melbourne Water in writing to ensure the sub-contractor is suitably qualified and experienced and has completed work of this nature previously.	Construction
LC4	The landscape contractor awarded the waterway project must order stock from an accredited nursery that grows plants to the specifications outlined within this manual (no wild stock or cutting up of planting clumps is to be installed).	Construction
LC5	Check the planting contractor's delivery docket to ensure the number of plants and format of plants ordered and delivered matches the landscape plan and requirements of this manual.	Construction
LC6	Audit the quality of stock delivered to site prior to the installation occurring accepting and/or rejecting any unacceptable stock that doesn't meet the requirements of this manual.	Construction
LC7	Ensure the contractor is undertaking regular weed runs (aquatic, ephemeral and terrestrial) of the site to ensure a weed seed bank doesn't develop.	Construction
LC8	Undertake random audits of the accredited nurseries they regularly source stock from to ensure the stock they are growing and supplying is of a high quality and meets the requirements of this manual.	Construction
LC9	Make Melbourne Water aware of any accredited nurseries growing and supplying poor quality stock that doesn't meet the requirements of this manual.	Construction

LC10	Make Melbourne Water aware of any landscape contractor not sourcing, installing and maintain planting to the requirements of this manual. See: Aquatic Plant Supply Standard Aquatic Plant Installation Standard Ephemeral & Terrestrial Plant Supply Standard Ephemeral & Terrestrial Plant Installation Standard Plant Selection and Provenance Standard	Construction
LC11	Make Melbourne Water aware of any topsoil installation that doesn't meet the requirements of Melbourne Waters topsoil specification whether installed by the civil or planting contractor.	Construction

Note:
Should Melbourne Water feel the quality or quantity of sourced plants delivered to and installed on site do not meet the requirements of this manual, we reserve the right to engage an independent auditor to assess and make a recommendation as to the quality of the landscape planting. Any required rectification works resulting from this audit would be at the expense of the developer, not Melbourne Water.

PART D: TECHNICAL DESIGN ELEMENTS

This part of the manual covers the technical aspects of the three stages in waterway design: concept design, functional design, and detailed design and the technical information that underpins each stage in the design process.

Part D is structured as a series of design elements that lead the designer through the design process. Design iterations are often required during the design process, and the designer may be required to review and repeat some design steps until the design meets the required criteria and design intent to Melbourne Water's satisfaction. Part D is broken into the following sections:

- D1 – Concept design
- D2 – Functional design
- D3 – Detailed design

D1. CONCEPT DESIGN

The concept design phase is likely to include the tasks shown in Figure 24.

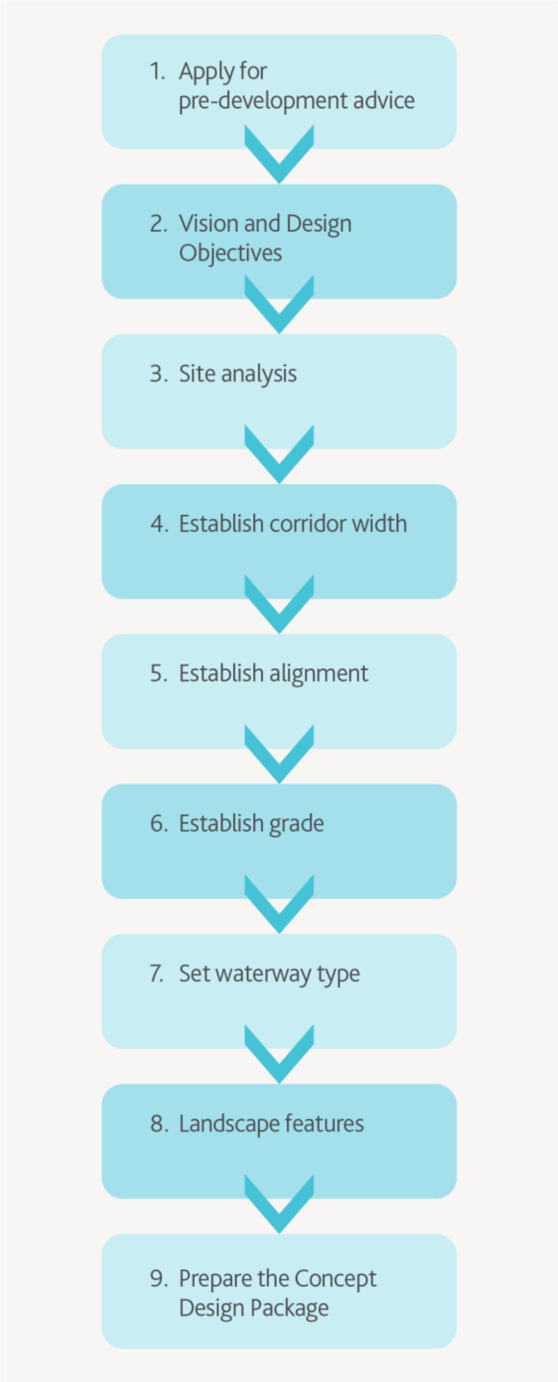


Figure 24 - *Tasks to prepare the concept design package*

D1.1 Background Information

The designer should contact Melbourne Water to request Scheme Servicing Advice for the property or properties being proposed for land development.

It is often valuable to undertake a site visit with Melbourne Water to walk the waterway alignment to gain an appreciation of the existing topography, soil type, flora and fauna, cultural heritage, and geomorphic values.

Melbourne Water will provide the designer with advice regarding the scheme objectives and intent, including highlighting environmental conditions (habitat, flows, physical form, etc.) of the waterway that need to be protected, the waterway hydraulic corridor width, design flows, relevant plans and strategies, Scheme infrastructure such as outfall pipes and sizing, and any available background studies (flora, fauna, cultural heritage, whether catchment is charged etc.). The existing information that the designer should acquire are summarised in Table 7.

Continuity of design

Not all developments occur in a linear upstream-downstream sequence (or vice-versa). Sections of waterway are frequently constructed out-of-sequence, by different developers and designed by different consultant teams. In these instances, **the developer** will need to **build a temporary outfall at their expense and maintenance**. A key requirement of implementing the manual is to support greater consistency in the approach to planning and design of constructed waterways to result in an integrated waterway system in each DSS.

Table 7 - Resources available for concept constructed waterway design development

RESOURCE	DETAILS	APPLICATION IN DEVELOPING A CONSTRUCTED WATERWAY DESIGN	SOURCE
Healthy Waterways Visions	Vegetation species and quality	Used as template vegetation planning and design. Implications for hydraulic modelling procedure (functional design).	Melbourne Water
	Stream form	Overarching template for constructed waterway form. Refer discussion on waterway types (next Task).	Melbourne Water
Plans and strategies	Development Services Scheme	Sets the corridor width (including core riparian zone and vegetated buffer widths) and includes initial hydrologic information	Melbourne Water
	Landscape master plan	Location of various land uses interacting with waterway corridor must be incorporated into functional and detailed design stages. For example sets out location of shared pathways, public open space, pedestrian crossings over the waterway, and so on.	Developer
	Servicing strategy	Location of infrastructure services such as sewer main, electricity, gas, telecommunications, some of which will interact with the waterway corridor and must be incorporated into functional and detailed design stages	Developer
	Stormwater management plan	Location of stormwater infrastructure such as outlet locations and elevation, as well as flows, must be incorporated into hydraulic modelling in the functional and detailed design stages	Developer
	Road layout	The constructed waterway corridor is often bounded by roads. The road layout will show the location of road crossings through the waterway corridor.	Developer
Planning and Building website		Engineering details of infrastructure in the waterway corridor	Melbourne Water
Site specific surveys	Topographical feature survey	Survey of waterway corridor and existing features informs the hydrological and hydraulic modelling carried out in functional and detailed design stages	Developer
	Geotechnical	Locations and extent of various soil types and the presence or not of bedrock informs the placement and sizing of the constructed waterway in all stages of design	Developer
	Geomorphic	The presence and condition of waterway forms and features of geomorphic interest and value inform the design of the constructed waterway given Melbourne Water's requirement to protect intact geomorphic waterway forms and features	Developer
	Cultural heritage	Identifies culturally sensitive areas and informs, at all stages of design, the alignment and extent of the constructed waterway, features. Continues beyond design phase to construction process.	Developer
	Flora and fauna	Survey of historical and existing flora and fauna values through the waterway corridor informs the vegetation planning and feature design processes. For example, using the flora study in conjunction with the vegetation visions in the vegetation design task, or using the fauna study as the basis for design of particular waterway features in the detailed design stage.	Developer
	Services search	Carry out a dial before you dig survey to locate any existing services	Developer
Other guidelines	GGF crossing guidelines	Informs design requirements crossing through GGF conservation zones.	DELWP
	GGF Master Plan and associated design standards (Habitat & Crossing)	Informs the design of particular waterway features such as on-line pools or benches for the provision of habitat	DELWP
	Waterway Corridor Guidelines	Informs the required width of the waterway corridor that will apply to the constructed waterway being designed. Width is scaled according to hydraulic width and maintenance requirements.	Melbourne Water

D1.2 Context and site analysis

Undertake a context and site analysis to ensure the waterway is well integrated with the adjoining urban edge and maximises active transport opportunities. Prepare a contextual and site analysis plan that establishes the opportunities and constraints of the site.

Context analysis to include:

- (Where relevant) Cultural heritage and biodiversity values on a site
- Protect view lines to natural landmarks and other key features
- Neighbourhood land use plan highlighting active and community uses that may influence the activation of the waterway
- Priority pedestrian connections and opportunities for nodes/ destinations along the waterway
- Neighbourhood pedestrian and cycle network and links to the waterway
- Neighbourhood open space

Site specific investigations are likely to include:

- Feature survey
- Geotechnical assessment and geomorphic assessment
- Soil contamination assessment
- Cultural heritage assessment
- Flora and fauna survey

It is important the designer is aware of and can identify all potential interface issues associated with the waterway corridor and urban development. In many cases the structure planning or development planning process will have prepared servicing reports and plans, road and traffic layouts, stormwater management plans and a landscape masterplan. The site analysis should therefore consider:

- Interface with upstream and downstream properties, including drainage outfall
- Interface with adjacent properties, land uses and the broader landscape
- Bike/pedestrian paths and connectivity
- Road crossings and pedestrian crossings of the waterway
- Subdivisional stormwater drainage connections to the waterway
- Stormwater treatment assets
- Landowner consultation and approval
- Alternative service crossings of the waterway (i.e. sewer, water, gas, electricity, telecommunications)

Liaise with Melbourne Water to discuss any significant issues arising from the site analysis. Significant issues are those that have the potential to have a major impact on the ability to construct the waterway and/or achieve the design intent/objectives. Examples of significant issues could be (but are not limited to):

- Presence of EPBC listed flora and fauna species along the proposed waterway corridor
- Presence of sites of geomorphological significance or intact or valuable geomorphic forms along the proposed waterway alignment
- Waterway requires permanent pools to support urban tolerant migratory fish species
- Waterway requires connectivity for fish passage to support urban tolerant migratory fish species

- Presence of cultural heritage values triggering the need for a cultural heritage management plan (CHMP) along the proposed waterway alignment
- The existing waterway is severely eroded and incised into unstable soil and rock types
- Logistical issues restricting access to the proposed waterway alignment (such as existing overhead power cables, underground services)
- Landscape/topographical constraints restricting the ability to construct the waterway in a cost-effective manner, such as the presence of bedrock close to the surface or steeply sloping terrain creating confined waterway corridors (which also presents issues for maintenance access) or sodic soils
- Soil contamination restricting the ability to construct the waterway in a cost-effective manner

Geotechnical Advice

The selection of bore locations is critical in contributing to waterway design. The bores should be located within the asset footprint and provide good coverage of the waterway bed. Spacing of the bores needs to be based on the confidence of uniformity or otherwise of base conditions. This information would contribute to the design by providing location of rocky outcrops and soft spots, thereby allowing designers to use in situ rock to provide natural shallow weirs and the softer spots to open up the channel and create shallow pools which can be shallow pools. The geotechnical report should also provide information on the local soils and what amelioration is required. For example for highly dispersible soils, a clay liner may be required particularly within the low flow channel. The report should identify high water table and its influence on a potential waterway design.

D1.3 Place-making considerations

The following considerations are relevant to the concept design stage objectives.

Comfort

The length of time people choose to stay in a place will depend on how comfortable it is. The **landscape architect** will work with the waterway designer to ensure:

- Pathway design must meet the needs of all users, taking care to separate users with different mobility needs. Shared pathway widths must be a minimum of 3m or meet local council’s footpath width requirement, whichever is the widest.
- Pathways provide clear viewlines ahead to manage possible conflict between different users
- Signage supports wayfinding along the waterway.
- Bicycle parking is provided at recreation node to facilitate the option to cycle to the waterway to go walking, meet friends etc.
- Passive spaces for respite are not exposed to unpleasant heat, noise, wind, traffic or other elements that may cause discomfort.
- Agreement is made with MW as to the areas along the waterway that will be shaded when trees have fully matured
- Areas with amenities such as toilets and seating include lighting to enhance public safety
- The alignment and design of the waterway provides good surveillance of pathways and seated areas
- Access and facilities comply with the relevant standards and codes related to the Disability Discrimination Act.

Safety

The **landscape architect** will work with the waterway designer to ensure:

- Crime Prevention Through Environmental Design (CPTED) principles in all waterway design, acknowledging safety is a key factor in achieving comfortable places that are inviting
- Clear visibility and surveillance of areas where people congregate

Activation

The **landscape architect** will work with the waterway designer to ensure:

- Safe, active pedestrian and cycle links along the waterway with clear connections and regular access points to the wider cycle and pedestrian networks.
- Walkability is encouraged by providing regular pedestrian connections to the waterway, clear entry points to the waterway and pedestrian crossings over the waterway every 800m.
- The waterway facilitates a range of different activities in a safe environment that manages conflict between users

Legibility

- The **landscape architect** will work with the waterway designer to ensure:
- Consider incorporating landmarks to assist people to orientate themselves when walking or cycling along or to the waterway. To assist with creating a local sense of place the landscape architect is encouraged to use natural features or other distinctive forms (i.e. historical artefacts etc.) to support the wayfinding along a waterway. Landscape architects will be able to advise how to strengthen the sense of place by increasing the legibility of the waterway in a number of ways.
- Interest and variety in the landscape is provided by meandering pathways where possible to replicate a more natural waterway
- Consideration of wayfinding elements such as signage, maps, and landmarks to increase access to and legibility of the waterway.

D1.4 Establish the waterway corridor width

A waterway corridor is defined as the waterway channel and its associated riparian zones. An appropriate waterway corridor width is essential for healthy waterways of all types. In urban environments, where the waterway is often the primary habitat area and a critical ecological and social link, it is particularly important to provide sufficient waterway corridor width.

In many cases Melbourne Water Development Services Schemes (DSS), especially those established from 2010/11 onwards, will provide information on both the overall waterway corridor width required and the hydraulic width required. The hydraulic width is the width of the 1% AEP flood extent. The DSS will generally also provide an indicative alignment for the waterway, which usually follows the alignment of any existing waterway through the site, or the low point of the valley floor where an existing waterway is poorly defined. Any Development Services Scheme established prior to 2010/11 shows only Melbourne Water's hydraulic width requirements and a conceptual alignment.

All Precinct Structure Plans (PSP) established since 2010/11 have waterway corridor widths and alignments shown, which were based on input from Melbourne Water regarding waterway management requirements for these corridors, in accordance with Melbourne Water's Waterway Corridor Guidelines (2013). It is important to note that in the guideline, these widths are referred to as 'standard' widths, meaning that they are intended to represent a **minimum** not a maximum width requirement. Where there are local or site-specific values that require additional corridor width it will be increased.

If the development falls outside of an area with a PSP, which may or may not have a Structure Plan (SP) or Local Area Plan (LAP), or an Outline Development Plan (ODP), the waterway corridor width and alignment will most likely need to be determined. Figure 25 provides an example schematic

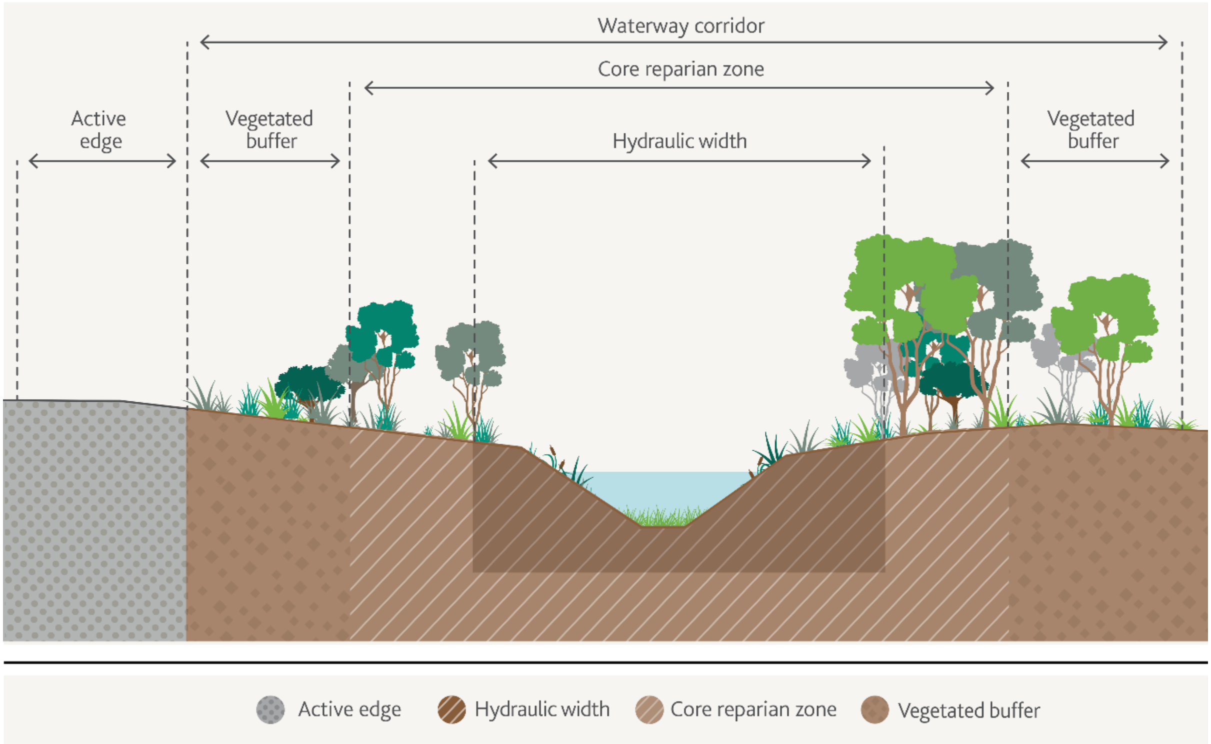


Figure 25 - Example water corridor section for a constructed waterway (*Waterway Corridor Guidelines* (2013).

Collaborating with the landscape architect

It is important to begin collaborating with the landscape architect when setting the corridor width and alignment to consider, at the conceptual level, the proposed location and details of:

- Engineered structures within the waterway such as waterway crossings (culverts and bridges), stormwater outfalls, grade control structures and bed and bank strengthening materials (such as vegetation and rock beaching)
- Vegetation design and layout within the waterway
- Habitat features such as pools and riffles, benches and bars, and large wood
- Landscape features such as shared paths, viewing platforms, pedestrian bridges, cultural interpretation/signage, and seating nodes, within the waterway and broader corridor (maintained by council)
- Other peripheral landscape features within the waterway corridor such as BBQ and picnic facilities, playgrounds, passive open space, and sporting facilities to be maintained by council
- Stormwater quality treatment systems in the waterway corridor
- Connections to and along the waterway corridor.

D1.5 Establishing the waterway alignment

The DSS and/or PSP will nominate an alignment for the waterway (Figure 26). Generally, the rationale for the alignment is that it follows the low point in the landscape valley.

Where possible the constructed waterway should follow the path of an existing waterway that needs to be modified to enhance hydraulic capacity for developed conditions.

In some parts of the Port Phillip and Westernport catchments with very flat topography, there could be options to vary the alignment of the waterway to better suit the proposed development layout. In these instances, guidance is required from Melbourne Water as to what an acceptable alternative waterway alignment would be.

Key aspects the designer should consider are:

- The waterway alignment is retained in the low point of the valley and through the landscape; i.e. is not proposed to be aligned into hillsides
- The waterway alignment considers upstream and downstream constraints and requirements to ensure it matches in with existing or proposed sections of waterway (continuity of design)
- The resulting waterway alignment does not have unnaturally tight bends (e.g. close to 90 degrees, unless the overall corridor is of sufficient width to transition the low and high flow channel around the bends in the corridor at acceptable bend radii. This design issue is discussed further in the functional design stage.

If the developer/designer seeks approval for an alignment that does not follow the low point, the developer/designer needs to consider the additional cost of the extra earthworks that will be required. These additional costs will need to be borne by the developer. Any issues introduced by not following the low point will need to be resolved to Melbourne Water's satisfaction through the design process.

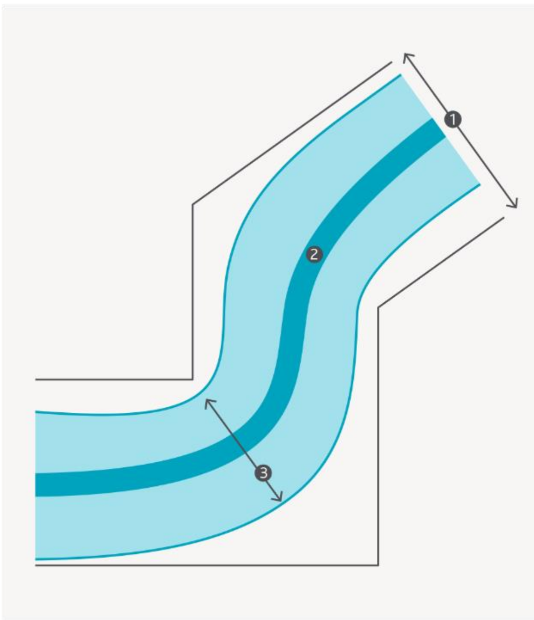


Figure 26 – Example waterway width and alignment

D1.6 Establish the initial waterway grade

Grade in a waterway context means the longitudinal slope of the channel bed along its thalweg or deepest point (i.e. a line connecting the invert of cross-sections throughout the reach (Figure 27). The DSS nominates two parameters that can be used to derive an initial waterway grade.

- Upstream and downstream invert levels for the DSS waterway
- Waterway length based on the DSS alignment

The designer should review this information in the context of the conceptual waterway alignment they are preparing to establish the initial grade of the waterway. This is an important step in selecting the constructed waterway type and informs:

- The potential for a low flow channel if working with a compound channel type.
- The grade of the high flow channel, which in is an important input parameter for selecting the range of low flow channel design parameters.

Longitudinal grade is a fundamental design criterion for constructed waterways, as it is for many other types of civil engineering infrastructure (e.g. roads). It is essential that the designer is aware of the contextual differences between waterway grades and grades appropriate for other infrastructure. For example, a road with a longitudinal grade of 1 in 100 is generally considered to be of relatively mild or gentle slope, whereas a longitudinal grade of 1 in 100 in a waterway is considered "steep" and likely to erode.

Grade is an important factor in controlling flow conveyance and waterway stability. For example, waterways with grades flatter than 1 in 800 will require the linear pools waterway type for drainage outfall and flow conveyance. Waterways with natural grades steeper than 1 in 200 will typically require the bed grade to be stabilised with a series of rock chutes to manage higher shear stress and prevent channel incision.

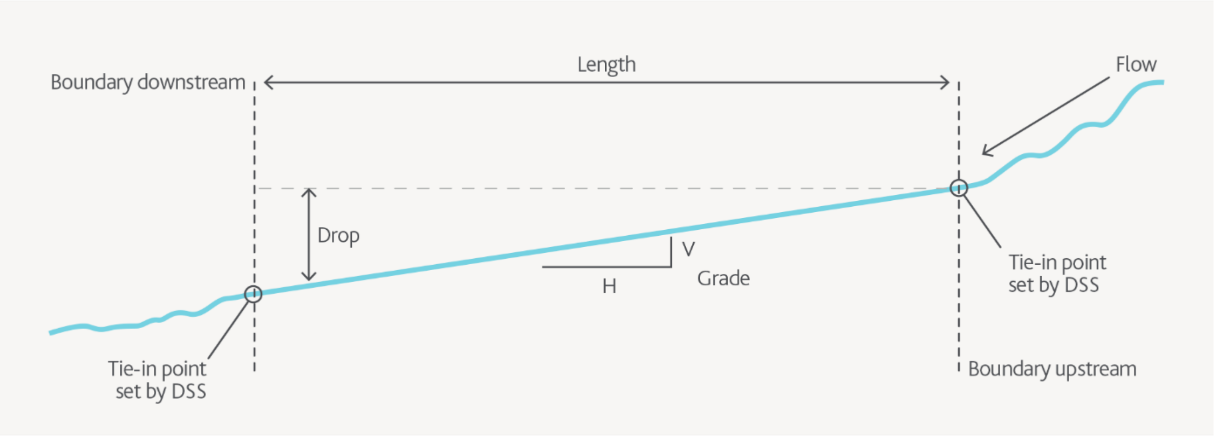
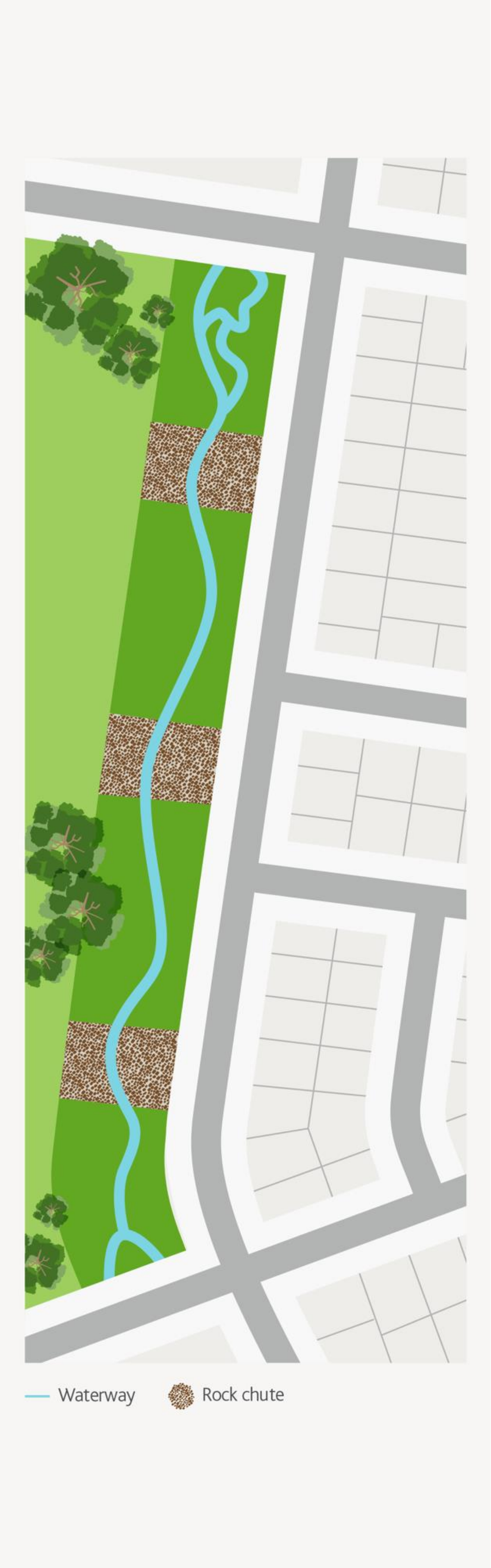


Figure 27 - Parameters used to determine the longitudinal bed grade of a waterway

It is Melbourne Water's preference to create waterways with minimal rockwork. A decision tree has been developed to help guide designers with when grade control structures should be considered, and the maximum allowable steepness of the chutes (Figure 28). This is particularly important in naturally steep areas where a standard 1 in 20 chute would result in extremely long chutes to chase the grade – an outcome Melbourne Water does not wish to see. If chutes are required, designers should aim for a maximum rock chute coverage of 25% of the waterway (



). These details should be confirmed with Melbourne Water during the concept stage.

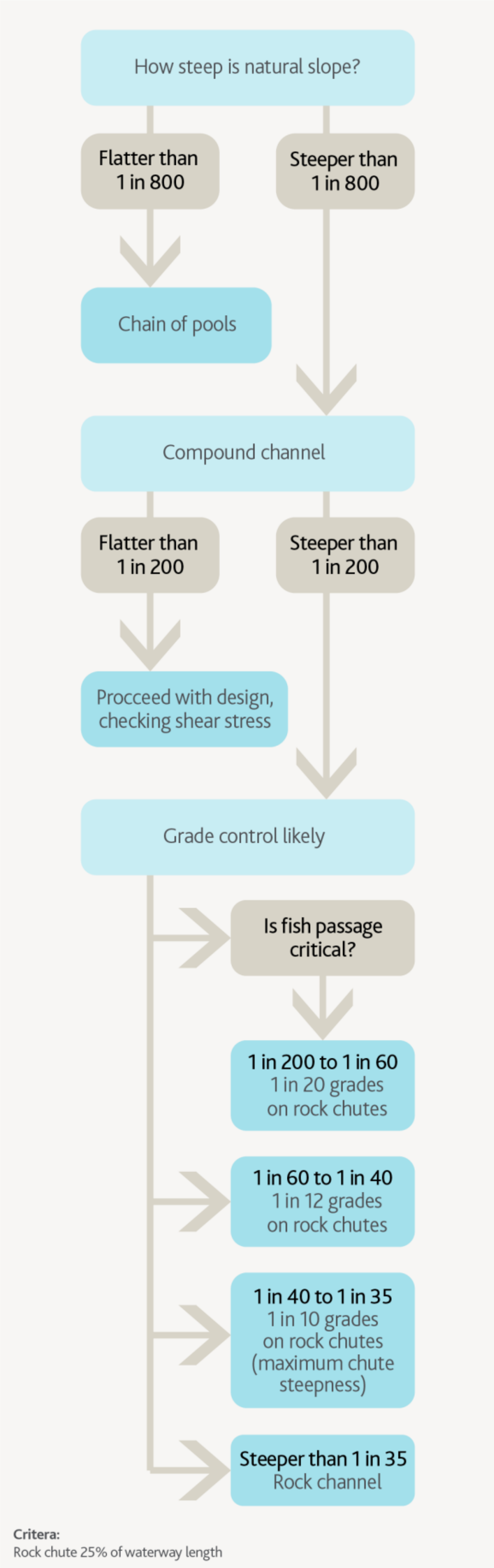


Figure 28 - Decision tree for longitudinal grade (existing grades shown)

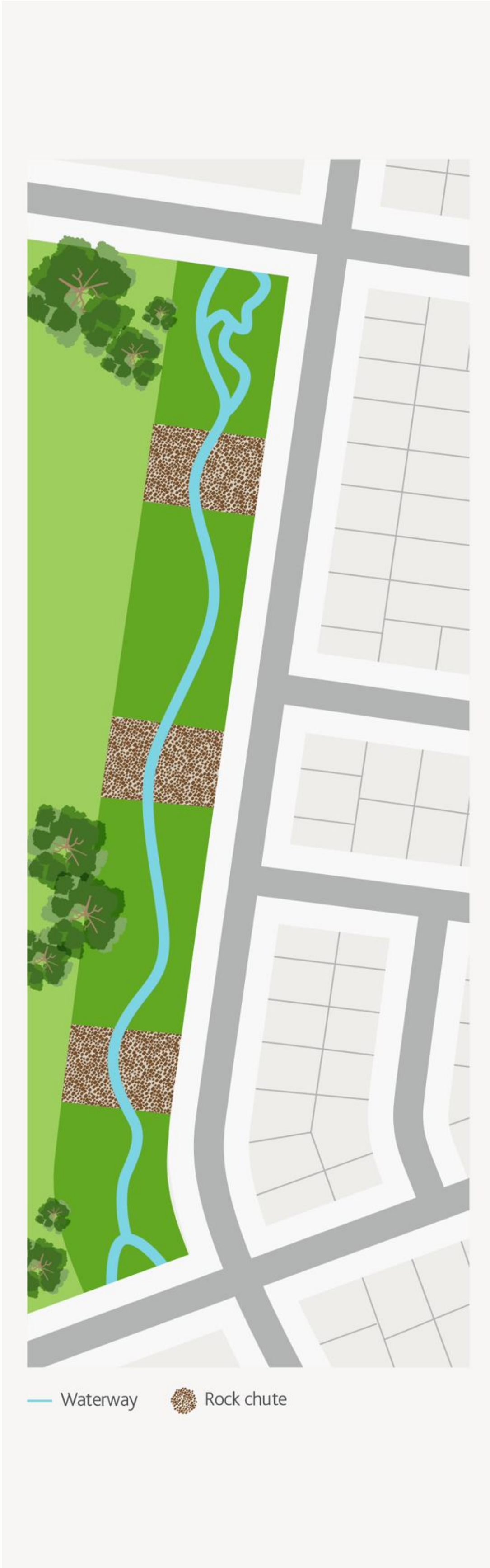


Figure 29 - Plan view schematic of 25% rock chute coverage on a waterway

It is critical that design grades are proposed within the acceptable 'stable' range, being **flatter than 1-in-200** wherever possible, and are able to incorporate bed depth variability.

D1.7 Determining the waterway type

A central component in designing a waterway to meet the required outcomes is to identify the appropriate waterway type for the site (as introduced in Waterway design fundamentals - Waterway Types). The size, shape and character of constructed waterways will vary across the region. To assist the waterway designer, these variations have been grouped into three waterway types. It is important that an appropriate waterway type is selected as the basis for the constructed waterway design at an early stage in the design process.

There are three broad constructed waterway types available to the designer:

- **Bedrock channel** –the channel bed and banks, are constructed directly into solid bedrock (<1.5m deep)
- **Compound waterway** - a low flow channel within a high flow channel that conveys larger, infrequent floods (up to the 1% AEP). Constructed in alluvial sediments (i.e. clay, loam)
- **Linear pool systems** – in sites where the longitudinal bed slope is very flat (grades less than 1:800) and effective drainage is difficult the waterway can take the form of a series or chain of large pools that flow during rainfall events.

Examples of the waterway types are presented below (Figure 30). Additional resources on waterway types and the factors influencing which to select can be found in Part E2.2 – Waterway Types which is intended to be used as a stand-alone resource.

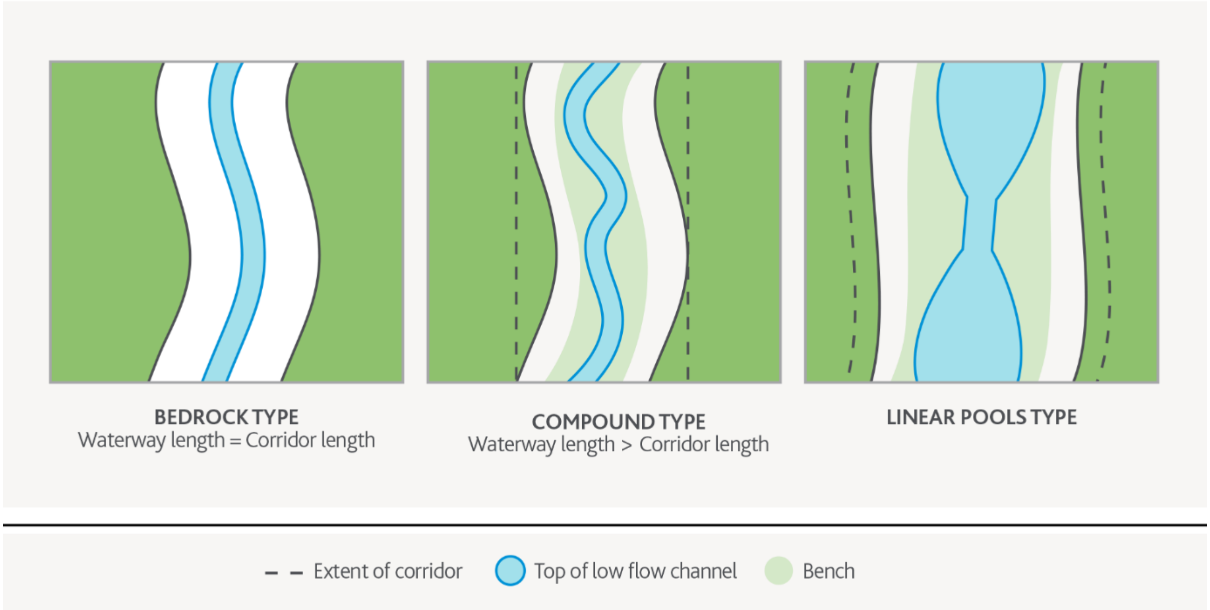


Figure 30 - Examples of the three constructed waterway types

In some areas in the northern and western growth corridors the construction of a compound type waterway will not be appropriate due to geological constraints (e.g. solid bedrock close to the surface). In these situations bedrock channels will be the preferred waterway type. Bedrock should not be topsoiled and planted. Linear pools are only recommended for sites where the bed slope is very flat, predominantly located in the South East. Most sites will not require a linear pool design response.

The criteria that distinguish between the three waterway types include:

- the soil profile
- the proposed longitudinal grade
- the presence of bedrock as identified within geotechnical reports.

The criteria are used to select an appropriate waterway type using a decision tree (Figure 31) by answering these questions:

- Is there bedrock present on the waterway alignment at a depth less than 1.5m?
- Is the longitudinal grade of the proposed alignment greater or less than 1V:800H?

Where longitudinal grade is steeper than 1V:200H the designer will need to consider grade control as part of the design response for the site.

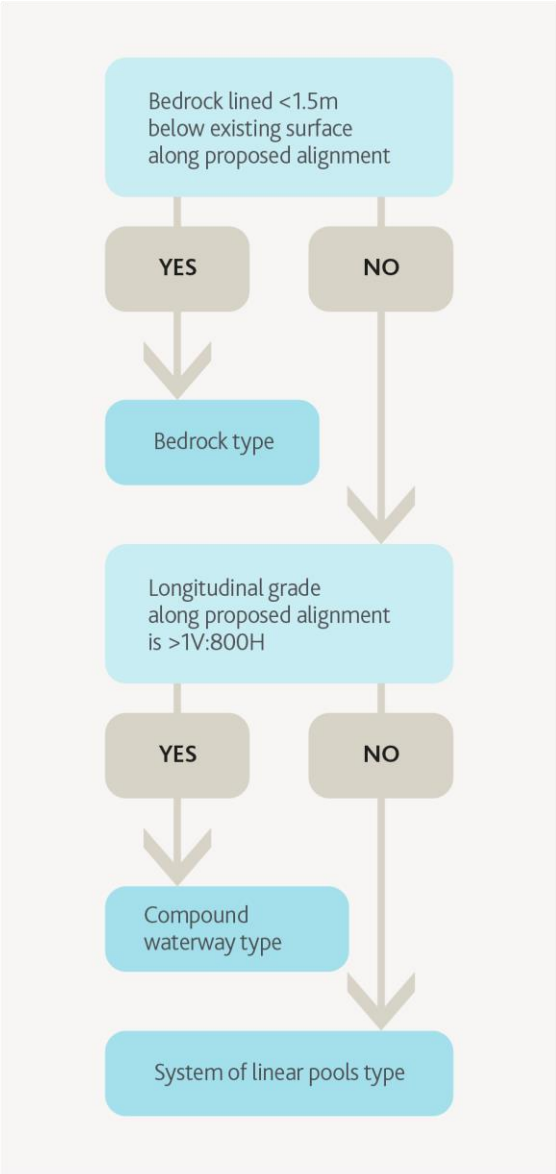


Figure 31 - Constructed waterway type decision tree

Image 2 – Constructed waterway with landscape feature

D1.8 Landscape features and waterway structures

Once an indicative corridor width and alignment has been established the designer can incorporate structures and features within the waterway and its corridor. These details will assist in meeting the design objectives and desired outcomes described in Part A.

Some of these features (mainly the engineered structures) are configured at the functional design stage. Detailed sizing and configuration of all features occurs at the detailed design stage. Table 8 provides guidance on the kind of features to be included in the waterway design.

It is important that collaboration between the waterway designer and landscape architect continue through the concept design stage. This ensures that all waterway landscape and maintenance requirements integral to the design can be accommodated. Some amendment to the waterway corridor width and/or alignment may be required to accommodate all the necessary features.

The designer should conceptually propose the location of engineered, habitat and landscape features which will be further refined during the functional and detailed design stages.

Table 8 – Matrix of features contributing to achievement of design objectives

DESIGN OBJECTIVES (HOW)	ENGINEERED STRUCTURES	VEGETATION	HABITAT	LANDSCAPE	OTHER LANDSCAPE	WATER QUALITY TREATMENT
	Waterway crossings (culverts and bridges), stormwater outfalls, grade control structures and bed and bank strengthening materials	Native grasses, shrubs and trees. Instream and riparian communities	Pools and riffles, benches, large wood	Shared paths, viewing platforms, pedestrian bridges, cultural interpretation/ signage, and seating nodes	BBQ and picnic facilities, playgrounds, passive open space, sporting facilities	Stormwater quality treatment systems adjacent to the waterway corridor
Flood capacity and conveyance	Yes	Yes				Yes
Drainage outfall	Yes					Yes
Channel stability	Yes	Yes	Yes			Yes
Aesthetics		Yes	Yes	Yes	Yes	Yes
Accessibility		Yes		Yes	Yes	
Habitat	Yes	Yes	Yes			
Connectivity		Yes	Yes	Yes		
Operation and maintenance		Yes		Yes	Yes	Yes
Renewal		Yes	Yes			Yes
Efficient investment	Yes	Yes	Yes	Yes	Yes	Yes

The designer should consider future maintenance of the waterway features to ensure the waterway is a sustainable asset that will continue to deliver the desired outcomes over time. Resolving maintenance requirements early in the design process and ensuring sufficient allowance has been made for maintenance is essential.

The landscape architect should identify the placement of features and recreational infrastructure to create points of interest and access to and movement around the waterway and its corridor. Close collaboration between the design engineer and landscape architect is critical in bringing the constructed waterway to life and in producing a concept plan that can clearly communicate the intent of the waterway design to Melbourne Water and Council (Figure 32).

In addition to the place-making design considerations, the landscape architect will work with the waterway designer to ensure:

- Vegetation plantings are designed to provide shear resistance to the waterway bed and banks, enhance the amenity of the waterway as well as provide important habitat for urban tolerant native animals;
- Utilise vegetation that is dense or spikey to restrict access to areas (e.g. sensitive habitat or to mitigate safety issues).
- Melbourne Water and council have the ability to safely access the waterway and its corridor to undertake the range of activities required to maintain the proposed structures and features that they will become responsible for via access tracks/roads.
- Maintenance activities and responsibilities are documented in a schedule and indicated on a plan that will ultimately form part of the Maintenance Agreement that will be developed in the detail design phase.

An **ecologist** will work with the waterway designer to ensure:

- Habitat features are included to support the Key Values identified within the Healthy Waterways Strategy;
- Where appropriate, the Ecological Vegetation Class (EVC) for the site is used to determine what species may be suitable for planting within the waterway corridor;
- Plant species are selected relevant to different inundation levels within the waterway.

Recreational infrastructure in the waterway
Recreational infrastructure may be installed within the waterway and its corridor, subject to the type of infrastructure and its location not compromising waterway function. Any recreational infrastructure must meet any applicable public safety standards. Addressing such criteria will often determine whether the infrastructure sits within the waterway or within the broader waterway corridor.

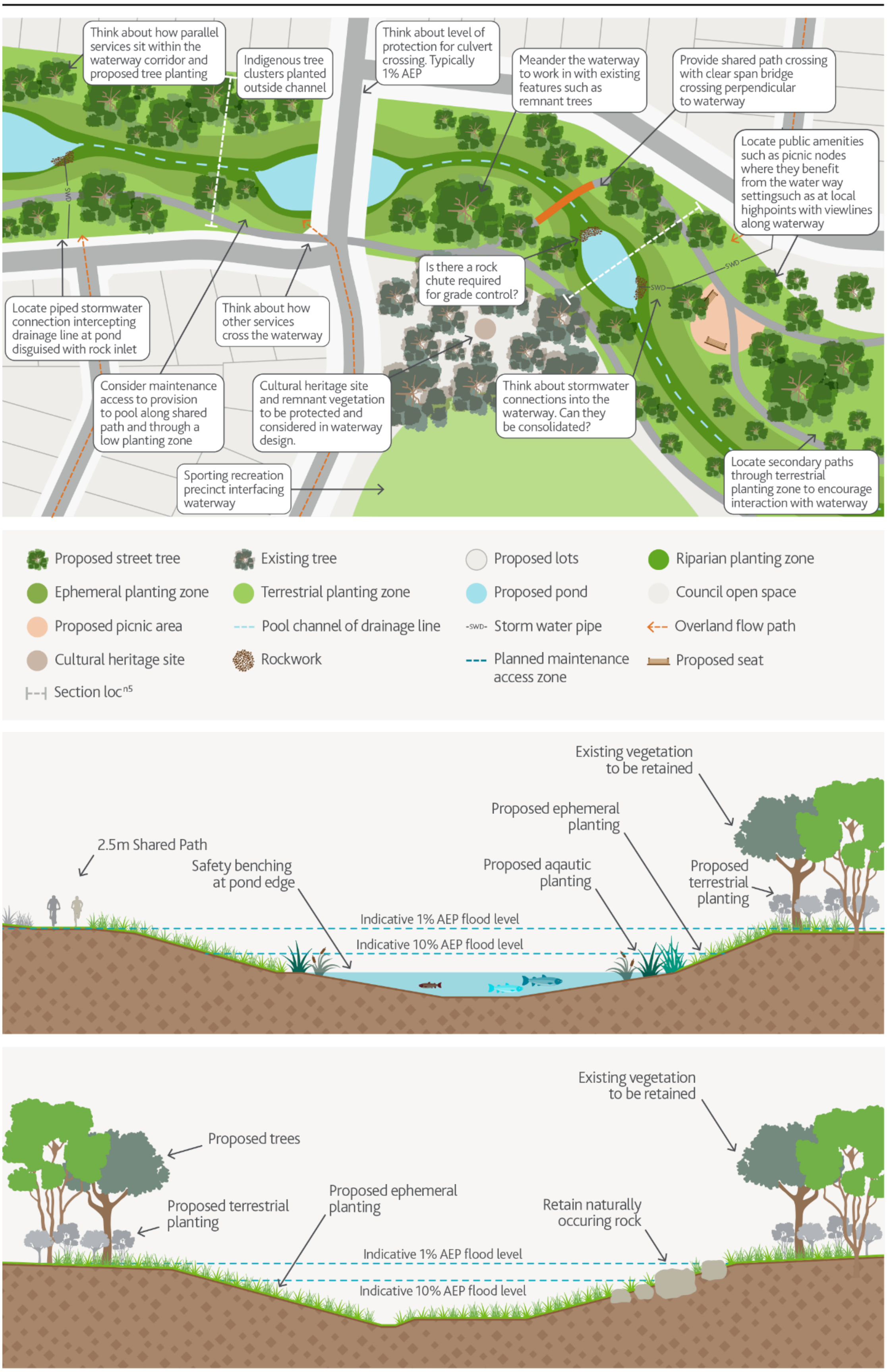


Figure 32 – Example constructed waterways concept design

D2. FUNCTIONAL DESIGN

The purpose of the functional design stage is to develop the waterway design to test and evaluate the options developed in the concept stage. The functional design should demonstrate that the proposed design will:

- Meet drainage outfall, public safety and flood protection requirements
- Be stable within the tolerable shear stress limits at a reach-scale (i.e. the channel bed and banks do not erode in the design flow event/s)
- Fit within the proposed waterway corridor width
- Meet the objectives for the subject reach agreed in the concept stage

The functional design phase is likely to include the tasks shown in Figure 33.

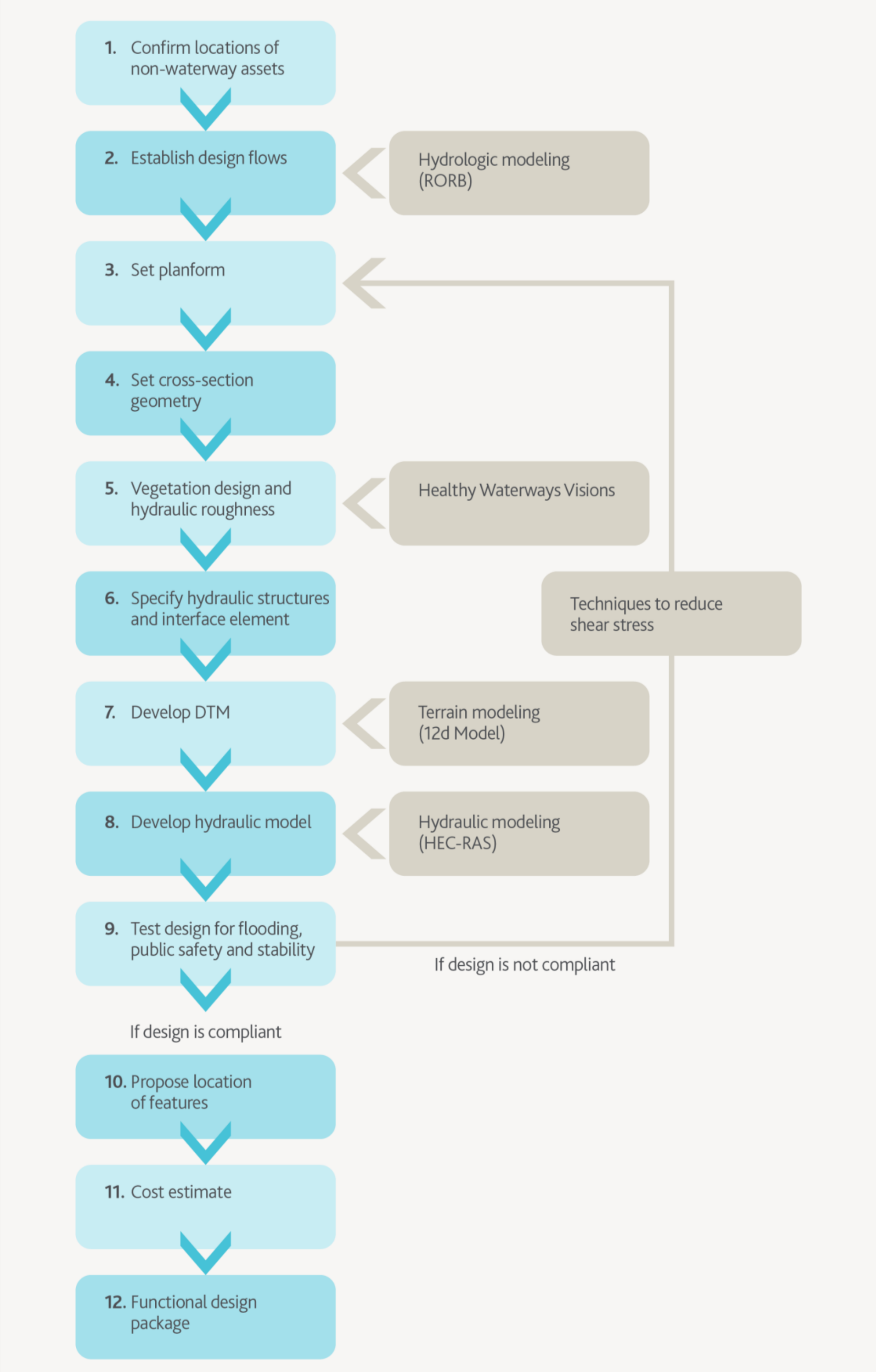


Figure 33 - Tasks to develop the functional design package.

D2.1 Hydrology - design flow rates

Depending on the nature of the catchment and its stream network, design flows tend to increase from upstream to downstream as the waterway collects additional flows from drainage outfalls and tributaries. The designer must account for the increased flow volume and energy associated with greater flows by changing the geometry of the waterway.

Design flow rates of interest

Waterways are required to safely convey the 1% AEP flow event. This can be achieved either by containing the 1% AEP flow event entirely within the high flow channel, or containing it within the overall waterway corridor. Melbourne Water does not support the 1% AEP flow event extending to roads adjacent to the waterway. Assets that are to be sited within the waterway corridor and are intended for public use (e.g. paths) must be located above the level of a 10% AEP flow event.

Compound waterway types are required to have a low flow channel with sufficient capacity to convey the 4EY to 1EY flow event. Flows exceeding the low flow channel capacity will engage the adjacent benches and other surfaces as flows spill across the base of the high flow channel.

It is preferable to maintain this arrangement in constructed waterways because issues arise when containing the energy of the 40% AEP (approximately 2 year ARI) flow event within the low flow channel. If water in excess of the 1EY flow event level is allowed to spill onto the base of the high flow channel then the flow is wider and shallower on the benches than it otherwise would be if fully contained within the low flow channel. This reduces shear stresses and helps maintain low energies within the low flow channel.

At a minimum the peak flow magnitude for the 4EY, 1EY, 40% AEP, 10% AEP and 1% AEP flow events must be determined through the design process. The 4EY and 1EY flow events are important for designing the low flow channel geometry, while the less frequent flow events are important to position benches and other waterway features (Table 9). Additional design flows that may help to size waterway features later in the process include the 5% AEP and 2% AEP flow events. The recommended hydrological modelling procedure to obtain these flows is set out in Table 9.

Table 9 - Design flows, their importance and calculation method

FLOW EVENT	IMPORTANCE	DERIVED
4 EY flow	Minimum capacity of the low flow channel of the compound type waterway	Calibrated RORB model
1 EY flow	Maximum capacity of the low flow channel of the compound type waterway	Calibrated RORB model
39.35% AEP flow, 6 hour duration	Compliance with Environmental Guidelines for Major Construction Sites	Calibrated RORB model
10% AEP flow	Flood inundation level above which some waterways assets are set (wetlands, basins, shared pathways, etc.)	Calibrated RORB model
1% AEP flow	Must be completely contained within waterway or corridor	Calibrated RORB model
Others (20% AEP, 5% AEP, 2% AEP)	As required for waterway features (grade control structures, rock beaching, fish passage through crossings, etc.)	Calibrated RORB model

Hydrologic modelling

In many cases, the Development Services Scheme will provide some of the design flows for the waterway, including large/infrequent and small/frequent events. In addition, Melbourne Water will often be able to provide a RORB model for the catchment.

RORB is a general runoff and stream flow routing program used to calculate flood hydrographs from rainfall and other channel inputs. Using stream network data specified by the user, RORB routs runoff (rainfall less losses) through the stream network to produce a hydrograph. The model is suited to urban catchments and is freely available online via the Monash University Website.

Understanding the existing and future hydrology of the system is critical in the selection of design flows. The designer is responsible for reviewing and checking that any catchment and flow data provided by Melbourne Water in the Scheme Servicing Advice are correct. To do this the preferred hydrological modelling approach is to use RORB.

The designer must consider the ultimate developed conditions when analysing the waterway corridor. That is the entire catchment must be fully developed to the extent of the current Urban Growth Boundary. Guidance on the use of RORB to generate the design flows is outlined in Part E of the manual.

Charged catchments

Ordinarily, urban development stages are sequenced so that new waterways are implemented from downstream to upstream. The advantage with this sequence is that the waterway has time to become established before the next upstream area is developed. In some cases however, development staging may occur in the opposite direction (upstream to downstream). In this case the catchment is said to be ‘charged’ as the contributing area upstream of the waterway has already been built or modified and contributes fully developed flows immediately after commissioning (i.e. throughout the vegetation establishment period). This increases the risk of erosion occurring during the maintenance period.

Melbourne Water can inform the developer/designer of the projected development staging within in the catchment (if known) for the duration of the waterway's maintenance period. The designer must ensure the appropriate development stages are incorporated into the design. In the case of 'charged' catchments it is recommended that:

- Peak flows under existing catchment conditions be calculated
- Two interim catchment condition design flows be assessed:
- Immediately after commissioning of the waterway (i.e. at year 1)
- At the end of the maintenance period
- Ultimate developed conditions be assessed (see above)

D2.2 The waterway planform

The task of setting the waterway planform is different for each waterway type. In this step the designer will build upon the initial width, alignment and grade agreed with Melbourne Water in the concept design stage (supplemented by further details in E2.2 Waterway Types).

Bedrock type

For bedrock waterways the design planform is determined for the most part by the valley planform itself. However, this is not to say that the planform must follow the valley in all cases. For example, there are likely to be cases where some deviation from the valley alignment is preferred to suit landscape design and planning purposes. Any deviation of this nature must be agreed with Melbourne Water.

The key criteria for the physical form is flow conveyance and capacity. The opportunities for significant vegetation are likely to be limited to terrestrial planting when the presence of bed rock diminishes close to the surface where topsoil isn't present.

Construction costs and bedrock waterway type
It is critical the designer and stakeholders are aware of the increased construction effort and cost associated with working into bedrock. The ideal bedrock alignment meets the design objectives and minimises construction effort. A geotechnical investigation should be undertaken to inform the functional design.

System of linear pools type

The use of the linear pool type is governed by the topographic nature of the site. The use of this waterway type should ideally be limited to very flat sites, where typically designers will struggle to achieve outfall and/or conveyance, if trying to design a compound type, which requires a sloping bed.

The system of linear pools creates long sections of flat water level (grade) in the high flow channel invert, with small (less than 200 mm) drops in water level between pools. This is sufficient to create the depth and low flow conveyance required to achieve drainage outfall for adjacent subdivision in such sites.

The linear pools type waterway planform is set by any reasonable means to achieve drainage outfall and meet the design objectives for the site.

Compound waterway type

The compound waterway consists of a high flow channel with a sinuous, inset low flow channel.
The planform for the high flow channel is set separately to the low flow channel.

Compound channel design terminology
The terms used to describe compound channel design are described in detail in Part B – Feature-scale physical form.

The planform of the low flow channel within the high flow channel is set through an iterative approach. The approach can be streamlined by working within certain bounds of sinuosity and meander geometry, as described in the following sections. Some of the planform design terms are shown in Figure 34 below.

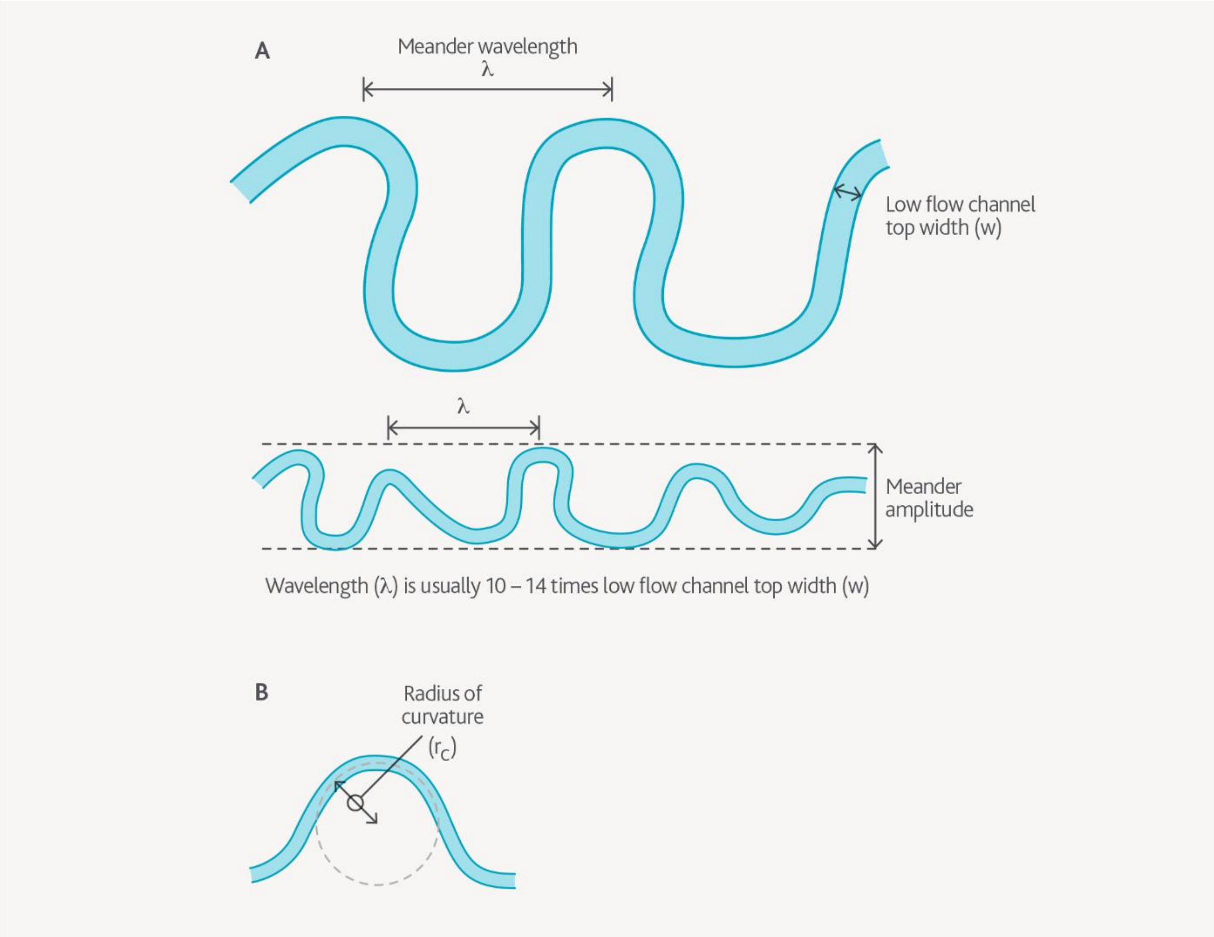


Figure 34 - Aspects of meander geometry (a) Meander wavelength (b) Radius of curvature

Sinuosity

Sinuosity is a term that is used to describe the shape of the waterway in planform using the pattern of bends. Such a pattern is commonly called 'meandering'. Sinuosity is a measure that quantifies the amount of meandering as the ratio of the low flow channel length to corridor length.

$$Sinuosity = \frac{Low\ flow\ channel\ length\ (m)}{Corridor\ length\ (m)}$$

Equation 4

Sinuosity is a very important variable in waterways. In natural waterways, channel sinuosity provides a longitudinal grade control function, helping to maintain hydraulic conditions within an acceptable range to ensure bed and bank stability are maintained at rates the channel can adjust to. Channel sinuosity also creates and sustains in-stream habitat features such as pools and riffles. Sinuosity helps achieve many of the Melbourne Water design objectives for waterways.

Note: For compound waterways in the Melbourne region the sinuosity criteria is:
– at least 1.05 (low sinuosity)
– no greater than 1.25 (moderate sinuosity)

It is suggested that the designer begin their design at the lower end of this scale, but allows sufficient high flow channel base width for greater sinuosity (if required) by ensuring the high flow channel base width is greater than the meander amplitude of the low flow channel at a sinuosity of 1.25. This is both an efficiency measure (it is cheaper and easier to construct less sinuous reaches) and allows for adjustment of the low flow channel alignments, if required later in the design process. Unutilised high flow channel base width for sinuosity can later be utilised to incorporate benches and varying batter slopes. Table 10 provides an indication of the acceptable range of sinuosities resulting from different low flow channel lengths.

Table 10 – Acceptable range of sinuosity (dark blue) in the low flow channel for different channel lengths

LENGTH OF LOW FLOW CHANNEL	LENGTH OF HIGH FLOW CHANNEL/CORRIDOR (m)									
(m)	100	110	120	130	140	150	160	170	180	190
100	1.00	0.91	0.83	0.77	0.71	0.67	0.63	0.59	0.56	0.53
110	1.10	1.00	0.92	0.85	0.79	0.73	0.69	0.65	0.61	0.58
120	1.20	1.09	1.00	0.92	0.86	0.80	0.75	0.71	0.67	0.63
130	1.30	1.18	1.08	1.00	0.93	0.87	0.81	0.76	0.72	0.68
140	1.40	1.27	1.17	1.08	1.00	0.93	0.88	0.82	0.78	0.74
150	1.50	1.36	1.25	1.15	1.07	1.00	0.94	0.88	0.83	0.79
160	1.60	1.45	1.33	1.23	1.14	1.07	1.00	0.94	0.89	0.84
170	1.70	1.55	1.42	1.31	1.21	1.13	1.06	1.00	0.94	0.89
180	1.80	1.64	1.50	1.38	1.29	1.20	1.13	1.06	1.00	0.95
190	1.90	1.73	1.58	1.46	1.36	1.27	1.19	1.12	1.06	1.00

Meander wavelength

The spacing of meander bends, or meander wavelength, can be determined by measuring the straight-line distance from one bend to the next (Figure 34). Since the distance between successive meander bends generally varies, a mean wavelength is calculated for several meander bends along the reach of interest.

Meander design criteria

For compound waterways in the Melbourne region the reach average meander wavelength should be around 10 to 14 times the low flow channel top width.
To avoid the artificial appearance of a sequence of regular bends that will create a uniform planform, the following break-down should be used as a guide for meander wavelength:
– 50% at 10-14 times the low flow channel top width
– 25% at 6-10 times the low flow channel top width
– 25% at 14-20 times the low flow channel top width

Typical meander wavelength and low flow channel length values are shown for a range of acceptable low flow channel base width and sinuosity combinations in Table 11.

Table 11 - Meander wavelength for various low flow channel length widths

LOW FLOW CHANNEL TOP WIDTH	MEANDER WAVELENGTH		
(M)	25% BETWEEN (6-10X)	50% BETWEEN (11-15X)	25% BETWEEN (16-20X)
7	42-70	77-105	112-140
8	48-80	88-120	128-160
9	54-90	99-135	144-180
10	60-100	110-150	160-200
11	66-110	121-165	176-220

Table 11 illustrates that by following the geometric design criteria, a low flow channel with a top width of 7m will create a waterway planform with a median meander wavelength of between 77-105m, 25% of wavelengths between 42-70m, and 25% between 112-140m.

It is Melbourne Water's preference that sinuosity be designed into the low flow channel in an irregular fashion, to avoid the artificial appearance of a sequence of regular bends with the same design criteria. The designer has the freedom to accommodate landscape constraints by implementing an irregular sinuous low flow channel within the broader corridor, but must ensure the design criteria outlined are met at the reach-scale. An example compound type waterway with irregular low flow channel in shown in Figure 35. Irregularity can be introduced by varying the length of straight sections in between bends, and the radius of bends in the low flow channel.

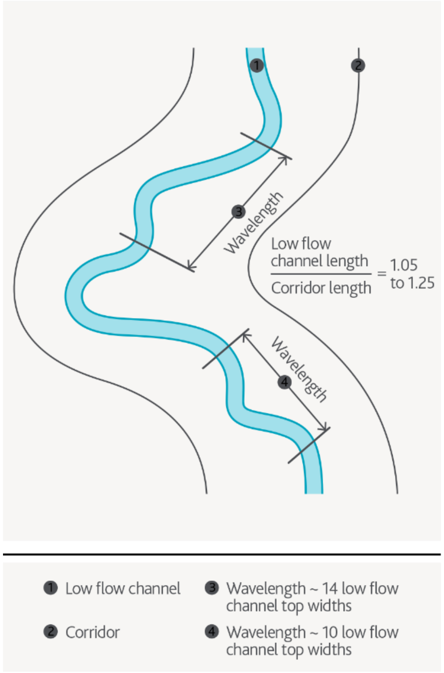


Figure 35 - Low flow channel variability in design of compound type waterways

Bend sharpness

Bend sharpness is the ratio of the bend radius of curvature to low flow channel base width (Figure 36). This ratio is relatively small for tight bends and increases for bends that curve more gradually.

$$Bend\ sharpness = \frac{Bend\ radius\ of\ curvature\ (m)}{Bend\ LF\ channel\ base\ width\ (m)}$$

Equation 5

- Wholly straight waterways are not acceptable because this does not represent what would occur naturally and also creates unfavourable hydraulic conditions within the channel that become problematic for managing bed and bank stability.
- Straight sections are permissible but **must not exceed a length of eight times the low flow channel top width** in question. The straight section of a high flow channel must not be greater than eight times the high flow channel width and the straight sections of the low flow channel not greater than eight times the low flow channel width. This does not apply to the bedrock type where the designer is encouraged to follow the alignment and form of the existing terrain.
- Observations have shown that many bends develop a bend sharpness ratio of between 2 and 3. For bends that are tighter than this (i.e. a sharpness ratio of less than 2), flow separation leads to increased energy losses (Bagnold, 1960), which compromises the objectives for compound waterway design in urban developments. Therefore:
- **Right-angled and sharp bends in the waterway**, regardless of the waterway type and including both the high and low flow channels of the compound waterway type, are **not acceptable**.

Sharp and right-angled bends in the overall waterway corridor are also undesirable, however may be acceptable in rare circumstances if it can be demonstrated that the overall corridor is of sufficient width so that the high and low flow channels (in the compound type) can transition the bend according to the bend sharpness criteria, and that the resulting form of the waterway and corridor in the affected cross sections achieves the design objectives and design criteria; and is acceptable to both Melbourne Water and stakeholders.

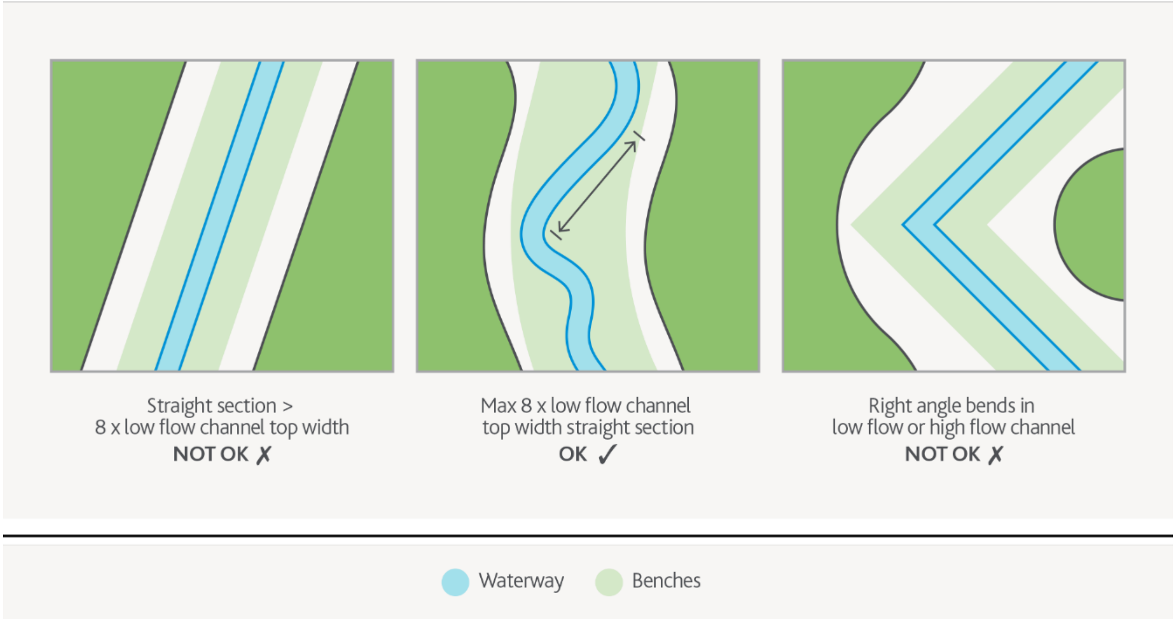


Figure 36 - Bend sharpness acceptable limits for compound waterways

Bend sharpness design criteria

In compound waterways, bends must have a bend sharpness ratio of greater than 2 to 3. Bends in the range 2 to 3 represent the upper limit of the acceptable range. Bends with a sharpness ratio less than 2 to 3, which include right-angled bends, are not acceptable; regardless of the waterway type (this includes both the high and low flow channels of the compound waterway type).

To avoid significant increases in shear stress (and therefore the need for extensive rock work), bend sharpness ratio along a meander reach should desirably be greater than seven. Therefore, the minimum desirable radius of curvature is about 20 metres for a low flow channel with a bottom width of three metres. See Table 12 below for combinations of low flow channel base widths and radius of curvature, and the resultant bend sharpness.

Table 12 - Bend sharpness and acceptable ranges (low flow channel)

BEND RADIUS OF CURVATURE	LOW FLOW CHANNEL BASE WIDTH (m)									
(m)	1	2	3	4	5	6	7	8	9	10
1	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.13	0.11	0.10
2	2.00	1.00	0.67	0.50	0.40	0.33	0.29	0.25	0.22	0.20
3	3.00	1.50	1.00	0.75	0.60	0.50	0.43	0.38	0.33	0.30
4	4.00	2.00	1.33	1.00	0.80	0.67	0.57	0.50	0.44	0.40
5	5.00	2.50	1.67	1.25	1.00	0.83	0.71	0.63	0.56	0.50
6	6.00	3.00	2.00	1.50	1.20	1.00	0.86	0.75	0.67	0.60
7	7.00	3.50	2.33	1.75	1.40	1.17	1.00	0.88	0.78	0.70
8	8.00	4.00	2.67	2.00	1.60	1.33	1.14	1.00	0.89	0.80
9	9.00	4.50	3.00	2.25	1.80	1.50	1.29	1.13	1.00	0.90
10	10.00	5.00	3.33	2.50	2.00	1.67	1.43	1.25	1.11	1.00
11	11.00	5.50	3.67	2.75	2.20	1.83	1.57	1.38	1.22	1.10
12	12.00	6.00	4.00	3.00	2.40	2.00	1.71	1.50	1.33	1.20
13	13.00	6.50	4.33	3.25	2.60	2.17	1.86	1.63	1.44	1.30
14	14.00	7.00	4.67	3.50	2.80	2.33	2.00	1.75	1.56	1.40
15	15.00	7.50	5.00	3.75	3.00	2.50	2.14	1.88	1.67	1.50
16	16.00	8.00	5.33	4.00	3.20	2.67	2.29	2.00	1.78	1.60
17	17.00	8.50	5.67	4.25	3.40	2.83	2.43	2.13	1.89	1.70
18	18.00	9.00	6.00	4.50	3.60	3.00	2.57	2.25	2.00	1.80
19	19.00	9.50	6.33	4.75	3.80	3.17	2.71	2.38	2.11	1.90
20	20.00	10.00	6.67	5.00	4.00	3.33	2.86	2.50	2.22	2.00
21	21.00	10.50	7.00	5.25	4.20	3.50	3.00	2.63	2.33	2.10
22	22.00	11.00	7.33	5.50	4.40	3.67	3.14	2.75	2.44	2.20
23	23.00	11.50	7.67	5.75	4.60	3.83	3.29	2.88	2.56	2.30
24	24.00	12.00	8.00	6.00	4.80	4.00	3.43	3.00	2.67	2.40
25	25.00	12.50	8.33	6.25	5.00	4.17	3.57	3.13	2.78	2.50
26	26.00	13.00	8.67	6.50	5.20	4.33	3.71	3.25	2.89	2.60
27	27.00	13.50	9.00	6.75	5.40	4.50	3.86	3.38	3.00	2.70
28	28.00	14.00	9.33	7.00	5.60	4.67	4.00	3.50	3.11	2.80
29	29.00	14.50	9.67	7.25	5.80	4.83	4.14	3.63	3.22	2.90
30	30.00	15.00	10.00	7.50	6.00	5.00	4.29	3.75	3.33	3.00

Gentler · In range · Too sharp (not acceptable)

D2.3 Waterway cross-section geometry

The cross-section geometry describes the shape of the waterway at a variety of points through the reach. The cross-section geometry will vary through the reach, and in combination with the waterway planform, an initial design surface can be created in a terrain modelling software, as a precursor to developing an initial hydraulic model of the waterway.

There are several design criteria that should be followed when developing acceptable cross-section geometries. These are:

- Shear stress
- Flood capacity
- Batter slopes
- Channel shape

In the compound channel type, the above criteria are specified for both the high flow and low flow channels.

The above criteria combine to create waterway cross sections that are not overly deep for their width, have gentle batter slopes and a naturalistic, more asymmetrical shape that reflects their location along the waterway planform. Achieving these criteria will be especially important where there are geomorphic and other values requiring protection. Additional measures will need to be proposed to achieve ongoing protection of these values.

There are two methods used to develop an initial cross-section shape: move directly to a terrain modelling software (such as 12d) and develop a hydraulic model to test the stability (shear stress) and flood capacity of the channel; or develop an initial cross-section using simple hydraulic calculations that can then be incorporated into the terrain model. The hydraulic calculation approach is described in following sections.

There are several guidelines that should be followed when developing acceptable cross-section geometries. These criteria are largely applicable to the compound waterway type. Melbourne Water has developed minimum criteria for batter slopes, widths, depths and flow capacity in constructed waterways (Table 13). These criteria must be met when designing the cross-section shape as shown below (Figure 37).

Table 13 - Melbourne Water cross-section geometry design criteria

ELEMENT	CRITERIA
High flow channel batter slope	• Typically 1V:5H to 1V:8H • If the system is to be maintained by Council the acceptable batters for turf requiring maintenance is 1V:6H • 1V:3H only allowed in exceptional circumstances and if a valid restriction exists. Such a slope requires further protection and safety considerations.
Low flow channel batter slope	• Typically 1V:8H for waterways holding water at all times (e.g. linear pools type) • Typically 1V:5H for ephemeral waterways (only holding water in storm events)
Low flow channel shape	• Low flow channel base can be 'U' or dish shaped

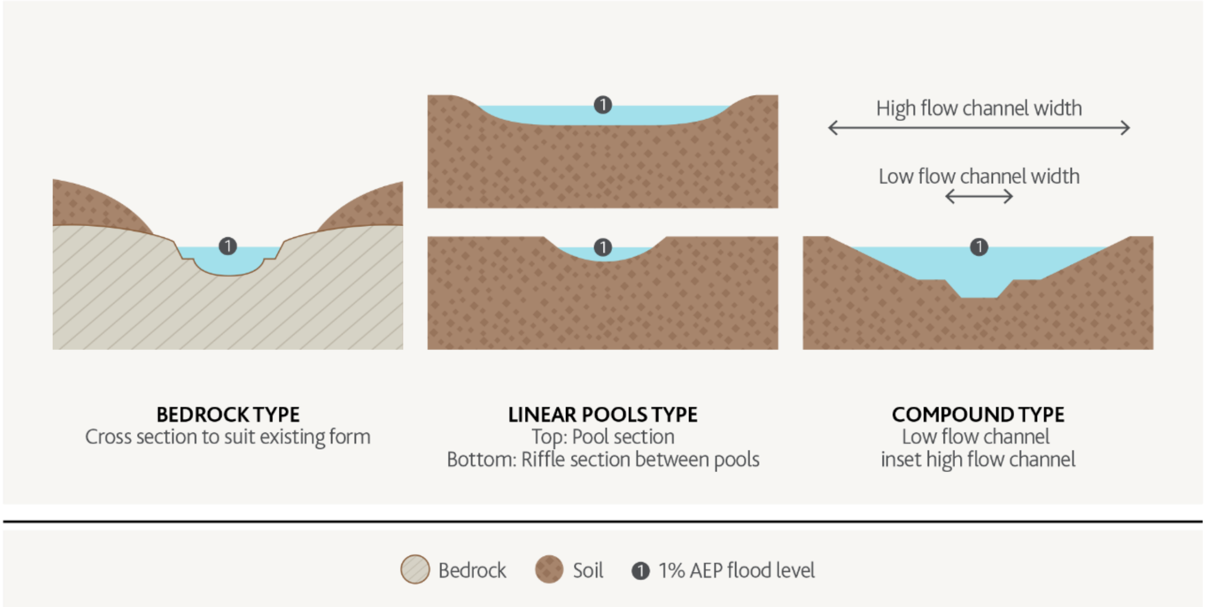


Figure 37 - Typical waterway type sections

The low flow channel and maximum width criteria

The low flow channel is intended to be well defined within the main channel and corridor. The situation often arises where, to meet flood conveyance and hydraulic performance (stability) objectives, as well as to meet Melbourne Water batter slope criteria, the low flow channel extends to the entire base width of the main waterway. This is not a desirable outcome and should be avoided.
In this case it is suggested that the designer trial a range of low flow channel capacities and configurations to investigate the effect on hydraulic force and flood levels. The order of preference for redesigning the low flow channel includes:

– Increase the low flow batter slope (no steeper than 1:3)
– Decrease the low flow channel width
– Decrease the capacity rating of the low flow channel. The minimum capacity is the 4EY flow event

If these measures are insufficient to achieve a suitable width of the low flow channel the designer may seek further advice from Melbourne Water regarding the waterway corridor width. It may be necessary to revise the corridor width to enable a suitable design solution to be found.

Simple hydraulic calculation to develop initial cross-section geometry

Developing and testing an initial design in the terrain and hydraulic modelling tasks can be time consuming, as several iterations may be required before an appropriate design is reached. To save time and reduce the number of iterations it is helpful to estimate the approximate waterway size and shape prior to developing terrain and hydraulic models. To do this, the designer must have a basic understanding of the principles of open channel flow and be familiar with the Manning's equation and the equation for estimating shear stress (see Equation 3, Part B).

The intent of this task is to quickly develop a number of cross-section shapes that meet the design criteria (e.g. batter slopes), the flow capacity and channel stability objectives. The cross-sections can then be used to create the terrain and hydraulic models in later steps.

Estimate the high flow channel and low flow channel slope

The DSS sets the inflow (upstream) and outflow (downstream) points that the constructed waterway must tie into (Figure 38). Knowing these the designer can simply calculate the elevation difference (inflow elevation minus outfall elevation), the high flow channel or waterway corridor (assuming they are the same alignment), and low flow channel lengths. The low flow channel length is equal to its sinuosity multiplied by the high flow channel length.

$$High\ flow\ channel\ slope = \frac{elevation\ in - elevation\ out}{length}$$

$$Low\ flow\ channel\ slope = sinuosity\ \times high\ flow\ channel\ slope$$

Equation 6

Example *– a 500 metre length of waterway with an upstream tie in level of RL 105.0 and a downstream tie in level of RL 103.0. The sinuosity is 1.10*

$$High\ flow\ channel\ slope = \frac{105.0-103.0}{500} \quad = 1 \text{ in } 250$$

$$Low\ flow\ channel\ slope = 1.10\ \times 250 = 1\ in\ 275$$

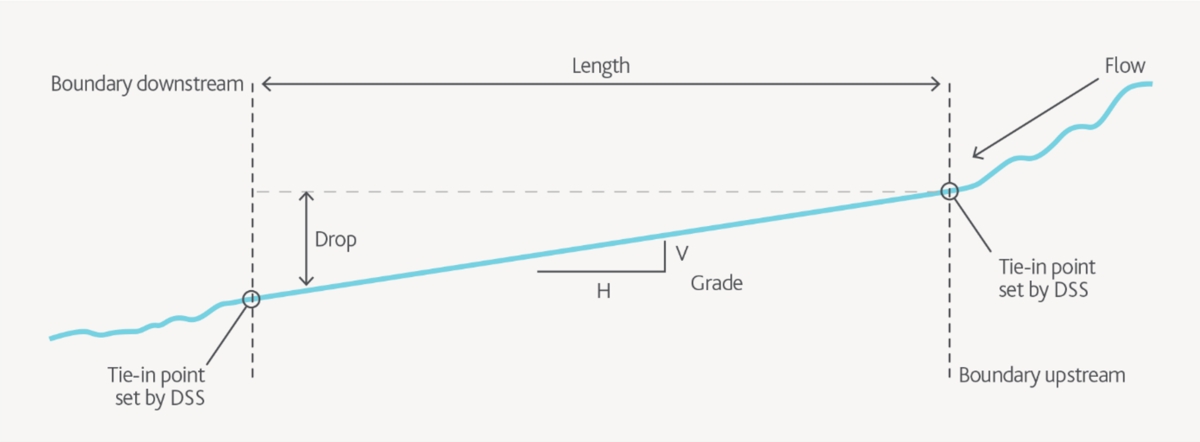


Figure 38 - Example calculation of chanel slope

Note that the sinuosity and bend sharpness criteria must be met. Variability in bed slope and channel depth within a waterway is an important factor in providing habitat for in stream animals and plants. The average low flow channel slope, calculated at this reach-scale design stage, will therefore be refined during detailed design.

Using Manning's equation to check cross-section geometry capacity

The designer can use the Manning's equation, which requires the design longitudinal slope, the flow rate and cross-sectional area. The Manning's equation (Equation 3) for open channel flow is presented as:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where Q = discharge (m^3/s), n = Manning's roughness coefficient (dimensionless), A = cross-sectional area (m^2), R = hydraulic radius (m), and S = friction gradient (equal to channel bed gradient for uniform flow, m/m).

At the functional design stage a cross-sectional average hydraulic roughness is sufficient, i.e. the designer can use one value of 'n' across the whole cross-section (conservative). Detailed information on appropriate roughness parameters/coefficients is provided in Table 14.

The waterway capacity must be the 1% AEP flow event for high flow channel, and 4EY to 1EY flow for low flow channel (Figure 39).

Check that the shear stress is within tolerable limits

The shear stress (a measure of the force exerted by water on the waterway boundary as it flows) can then be determined using the Du Boys equation (Equation 1):

$$\tau = \gamma RS$$

Where τ = shear stress (N/m^2), γ = the specific weight of water (N/m^3), R = hydraulic radius (m), and S = friction gradient (equal to channel bed gradient for uniform flow, m/m)

Using the Threshold Waterway Design approach (USDA, NRCS 2007) the resultant shear stress can then be compared with allowable shear stress values (erosion threshold) for the boundary material. The approach to threshold waterway design, along with threshold shear stress values for various materials, is detailed in the "hydraulic assessment section".

To meet the hydraulic performance objectives (flood conveyance and shear stress) of the waterway, the designer can manipulate:

- The width and/or depth of the low flow channel to ensure it meets the capacity objective and the shear stress objective (for example that the maximum shear stress in the 1EY flow event is below the threshold for long native vegetation)
- The width and/or depth of the high flow channel (for the same reasons as above)

Typical cross sections

Example cross-sections suitable for further analysis are shown below (Figure 39 to Figure 42). A number of cross-section shapes should be produced for different parts of the waterway, rather than just one (for example, cross sections taken at straights and bends in the high flow channel and cross sections showing the effect of the sinuous low flow channel on the variation in batter slopes of the high flow channel). This supports Melbourne Water's preference for natural looking, irregular waterway designs as opposed to uniform cross sections for the entire waterway.

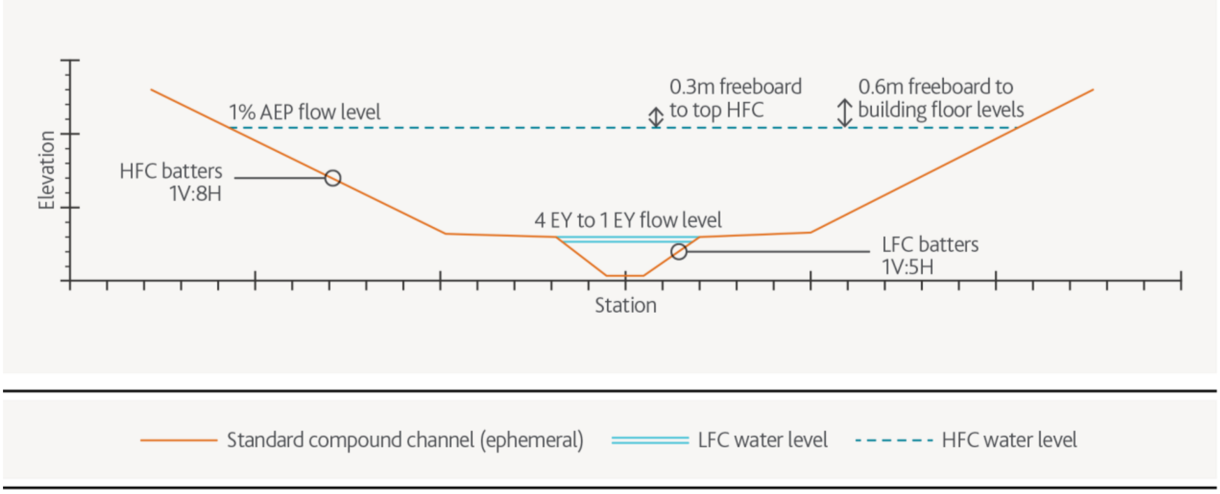


Figure 39 - Typical compound type waterway meeting cross-section geometry, capacity and shear stress criteria

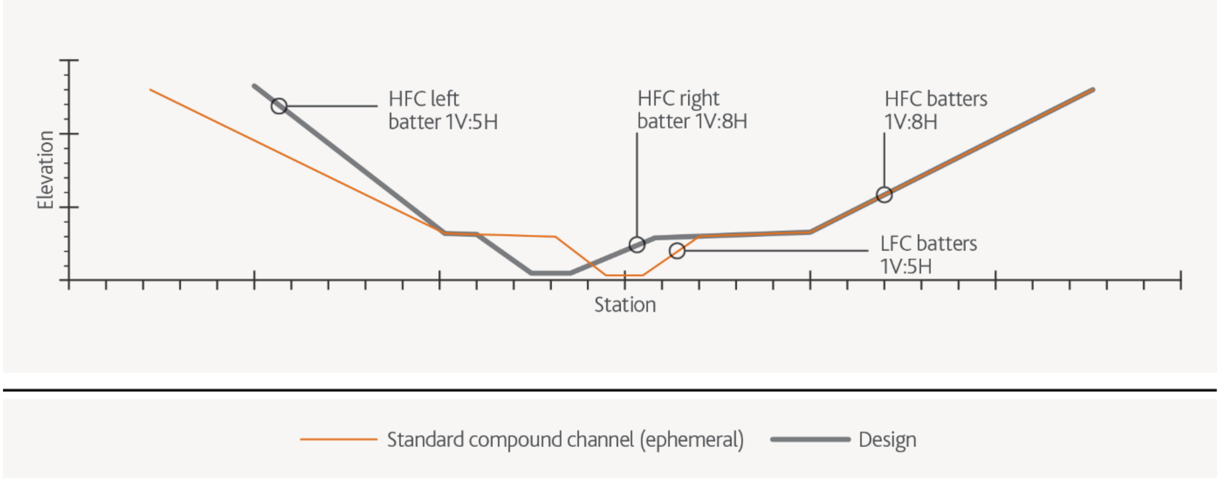


Figure 40 - Compound type waterway with steeper left batters (HFC and LFC) at outside of meander bend

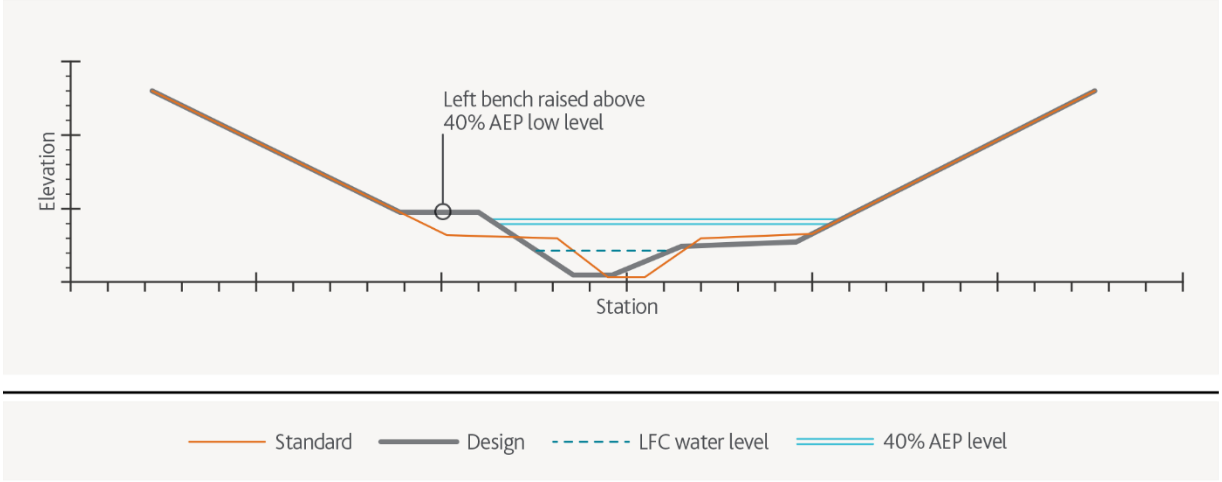


Figure 41 - Compound type waterway with bench variation

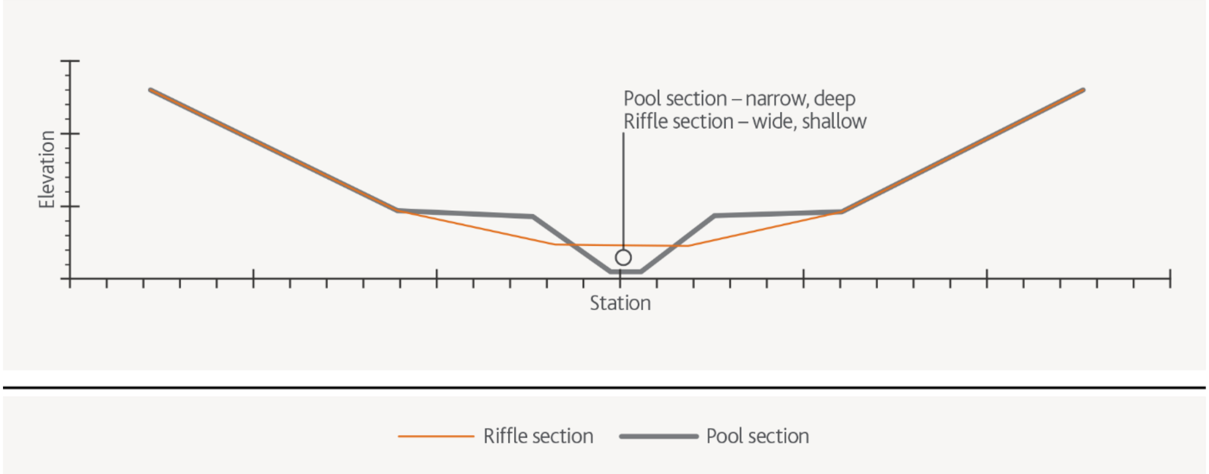


Figure 42 - Typical riffle and pool section for compound type waterway

Once the average waterway cross-sections (usually referred to as 'typical sections') are specified, the designer is well prepared to commence the terrain modelling and begin creating the waterway design.

Worked example

A compound type waterway is set in predominantly alluvial silts and silty loams (non-colloidal) and has a corridor length of 1000m, with a total drop of 4m from the corridor inlet to outlet. The ephemeral waterway will be planted out with long native sedges and grasses in the low flow channel, and a mixture of short and long native grasses and shrubs in the high flow channel. The corridor width is set at 45m by the DSS. The low flow channel is to pass the 4EY flood event (1.3m^3/s) while the high flow channel is to carry the 1% AEP event (15.3m^3/s) with freeboard.

- High flow channel length = 1,000m, and slope = 0.0040m/m (or 1V:250H)
- Sinuosity = 1.1
- Low flow channel length = 1,100m and slope = 0.0036m/m (or 1V:275H)
- Manning's n is 0.05 for the low flow channel and 0.05 for the high flow channel
- Batter slopes are 1V:3H for the low flow channel (ephemeral) and 1V:6H for the high flow channel

Using Manning's equation we can find a number of possible solutions to meet the conveyance requirements for the low flow channel and the high flow channel:

- Low flow channel:
  Base width 3m, depth 0.50m
- High flow channel[3]:
  Base width 19 m, depth 1.24 m (plus 0.6 m freeboard)

[3] Note the high flow channel 'base width' extends from the left to right bench extent. The adjustment factor for maximum shear stress should be undertaken separately for the 'left of bank' and 'right of bank', which excludes the low flow channel width. For the 'left of bank' calculations the base width used is the left bench width (which is likely to vary from section to section). For the 'right of bank' calculations the base width used is the right bench width (which is likely to vary from section to section).

Using the equation for shear stress (Equation 1) we can check which of the above arrangements meet the threshold shear stress criteria for post-construction (bare earth) and fully vegetated (short native grasses, long native grasses, shrubs and trees).

Low flow channel width/depth of 3m/0.50m gives wetted perimeter 6m and cross section area 2.1m^2. The resultant hydraulic radius ($R = A/P$) is therefore 0.35m.

The low flow channel average shear stress is 40.5 N/m^2 for the 1% AEP design event. Using a scale factor of 1.47 to account for maximum boundary shear stress (refer to

Figure 49) on the bed, the adjusted applied shear stress is 59.5 N/m^2. This is below the threshold for long native grass (80 N/m^2), but not below the alluvial silts threshold (3 N/m^2).

The high flow channel average shear stress is 17.8 N/m^2 for the 1% AEP design event. Using a scale factor of 1.45 to account for maximum boundary shear stress (refer to Figure 49) on the bed, the adjusted applied shear stress is 25.8 N/m^2. This is below the threshold for short native grass (45 N/m^2) once established.

Immediately post construction (i.e. bare soil) the shear resistance is very low (refer to Fischenich, 2001) as plants have not established or matured. Therefore, the waterway designer will need to consider the use of another material (e.g. jute mat) to protect it against erosion in the post-construction period. For further information refer to Section D2.9 (Post Construction Risk Assessment.

It is important to check that the initial sizing fits within the waterway corridor. A high flow channel depth of 1.24m at a batter slope of 1V:6H provides a hydraulic width of 25m. Melbourne Water Corridor Guidelines suggest that a corridor width of 45m apply to a hydraulic with of between 25m and 35m.

The designer can also employ the above ‘check’ when evaluating the proposed corridor width during the concept design phase to inform the waterway corridor that is to be shown on the development plan at the time of preparing an application for a Planning Permit for example.

D2.4 Vegetation design

The waterway designer, in close consultation with an ecologist and landscape architect, will develop a vegetation design for the waterway corridor at the site. This section provides information on various aspects and resources for vegetation design, and the implications for amenity, maintenance, erosion protection, and flooding. Detailed information on the hydraulic roughness of different types of vegetation is also provided.

The creation of a diverse and healthy native vegetation community in the waterway is an integral design objective. A critical factor in developing the vegetation design is accurately estimating the hydraulic roughness of the selected plant communities, as this will affect flood levels in the waterway.

The waterway designer should have acquired the Healthy Waterways Visions for Vegetation (Species and Quality) for the site during Concept Design. The designer will use the species lists and other information in the visions to develop a vegetation design that specifies the location of different types of plants throughout the waterway and its corridor.

Vegetation design requirements

The vegetation design for a waterway requires the designer to be cognisant of the following principal considerations:

- Existing native vegetation should always be retained and protected, especially mature remnant trees that provide substantial habitat and shading. Standing dead trees and large fallen trees must be retained as important habitat.

- Sufficient physical areas within the waterway design at different water levels should be created to provide the hydraulic conditions that favour certain assemblages of plant species and allows sufficient space for them to establish and regenerate (Figure 43).
- Structural complexity in riparian and wetland vegetation should be incorporated to support ecological diversity and provide an acceptable level of landscape amenity. A range of plant life forms should be included, as set out in the Healthy Waterway Visions for Vegetation (Species and Quality) applicable for the site.
- The vegetation design must does not increase flood levels to a point where the 1% AEP flow event cannot be conveyed in the waterway corridor because the hydraulic roughness of the (particularly mature vegetation community) is too great. Understorey plants should be considered.
- The amount of vegetation introduced within the waterway corridor reflects the Healthy Waterway Visions for Vegetation and allows for easy long-term maintenance by Melbourne Water.

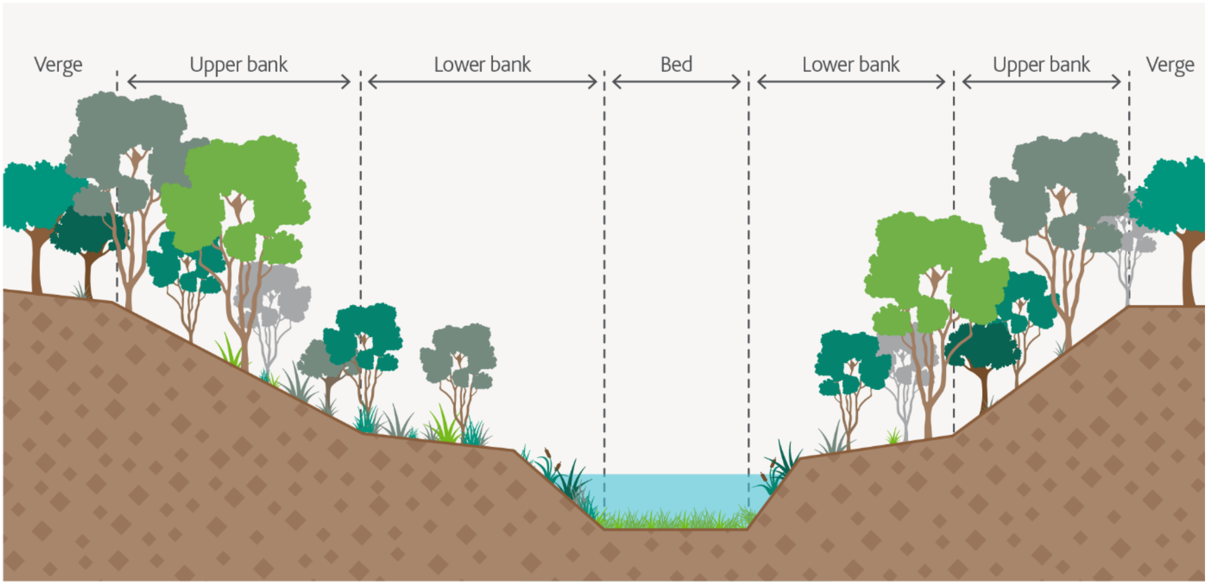


Figure 43 - Hydraulic and vegetation zonation across the waterway

The Healthy Waterways Visions for Vegetation Species provide information on the preferred planting zones for the different species in relation to expected inundation.

The design of vegetation into the waterway is therefore somewhat of an iterative process from a hydraulic perspective. The different vegetation assemblages being proposed are given different roughness coefficients (values of Manning's n) so that the roughness of each bank and the bed at each cross-section can be assigned in the hydraulic model to be representative of what roughness those plants will generate within the waterway.

Further consideration in the hydraulic modelling must be given to the hydraulic effect that vegetation has when it is establishing (post-planting) and once it has matured. The final consideration is the impact of the hydraulics of the waterway on the vegetation itself during the establishment phase. Once matured, the vegetation community will be robust and able to resist a range of flood events however, some localised damage to vegetation could be expected in flood events greater than 2% AEP flow event.

Vegetation as amenity

Vegetation design also needs to consider public amenity outcomes for the site. Considerations for visual connectivity will come into play when planning for sightlines to open water and the waterway. Key vantage points and pedestrian routes along the waterway may influence species selection.

Considerations for vegetation as barrier planting to limit pedestrian access in key areas may also need to be considered. This function will largely be implemented outside the core riparian zone through the terrestrial planting that forms part of the vegetated buffer and waterway corridor.

These influences on waterway vegetation design will need to be addressed holistically as part of the broader landscape and open space design by the landscape architect.

Vegetation and maintenance access

Vegetation design must consider and support maintenance requirements. For example, informal access tracks to assets must be planted out with grass and sedge species and not shrubs or trees.

Vegetation for erosion protection

Erosion is the process by which alluvial sediment is removed from the waterway bed or banks. Abernethy and Rutherfurd (1999) define three erosion categories that can occur independently or in unison in any given waterway:

- Mass failure – erosion caused when large volumes of bank material slide or topple from the bank into the channel.
- Fluvial scour – erosion resulting from the entrainment of bed and bank sediments due to hydraulic forces exceeding the resistance force (e.g. cohesion, gravity etc.).
- Sub aerial erosion – erosion by processes external to the stream (i.e. cattle pugging, desiccation, and groundwater seepage).

Different vegetation types limit each of the three erosion categories in different ways:

- Riparian trees strengthen bank substrate and tend to resist mass failure. The extent of reinforcement is dependent on root strength and the density of the root structure. The effect of the roots is to increase the effective cohesion of the sediments. The longer and more extensive the root network the greater the degree of reinforcement. As a result, smaller shrubs and grasses are less effective at limiting mass failure. (Abernethy and Rutherford 2000).
- Saturated banks are less stable than unsaturated banks as water increases the weight of the bank, encouraging mass failure. All vegetation types decrease the level of bank saturation by intercepting precipitation and by transpiration. (Abernethy and Rutherford 2000).
- Dense vegetation on the bank increases cohesion and bank strength through the root networks. Smaller shrubs and grasses, which have limited impact on mass failure processes, are more effective at limiting fluvial scour due to their more extensive coverage of the bank surface area (Blackham 2006).
- Dense vegetation increases hydraulic roughness, which reduces near bank velocities. The shear force exerted against the bank is thus reduced. The impact of vegetation on hydraulic roughness is complex and varies with type of vegetation and discharge. At low flow, grasses and shrubs that stand rigid have a high wetted surface area and provide hydraulic resistance (Blackham 2006). As discharge increases, the herbaceous vegetation often cannot withstand the force and is flattened against the bank. Hydraulic resistance is reduced but the vegetation protects the bank substrate from erosion (Abernethy and Rutherfurd 1999).

- Large trees provide minimal resistance during low flow but as discharge increases their large trunks and branches provide the majority of the hydraulic resistance once the herbaceous vegetation has been flattened.

In summary, instream and riparian vegetation plays an important role in minimising the rates of erosion through providing additional hydraulic resistance and structural reinforcement to the bank material.

These roles in limiting erosion are rarely provided by a single species. A suite of vegetation types is required to fulfil these various roles in limiting erosion. This suite of vegetation includes instream vegetation, stream bank ground covers, terrestrial shrub species and trees. This relevant species for each suite is set out in the Healthy Waterways Visions for Vegetation (Species and Quality). Consideration could be given to the use of long-stemming where shear stresses are high or there are likely to be challenges establishing vegetation. Long-stemming guidance can be found in the Long-Stem Planting Guide.

Table 18 in the Section D2.8 (shear stress thresholds) provides details of the shear resistance of different vegetation types equivalent to the life form size and vegetation structure at planting and during the vegetation establishment phase. Once matured, life forms such as shrubs and trees will have different shear resistance to those values shown in the table, however their role in shear resistance is modelled indirectly via the hydraulic roughness they create.

Vegetation establishment

Successful establishment of the proposed vegetation community is critical in the first two years of the life of the waterway once civil works have been completed.

Establishment of desired species and management of weed species, will not only protect the waterway and deliver the required objectives but will also reduce the source of weed species and likelihood of seed dispersal to connected downstream systems.

Mitigation of weeds through either installation of a bio-degradable jute-matting within the 1% AEP flow level, and organic mulch above this level will help suppress establishment of weeds, protect newly placed topsoil (to topsoil specifications) and retain moisture, enhancing plant establishment. Where jute matting is difficult to install due to the presence of natural or placed rock, plant densities should be increased to provide stronger cover and resilience to outcompete weed species in the spaces between rocks.

Planting of native species at an appropriate installation size of forestry tube stock and hiko-cells will also be influential in the successful establishment. This level of detail should be established in the detailed design stage. Melbourne Water's planting standards and auditing requirements should be referred to for further guidance.

Further guidance on appropriate vegetation design and planting and establishment techniques can be found in Sections 3.3 and 5.3 of *Technical Guidelines for Waterway Management* (DSE 2007).

Successful vegetation establishment is influenced by the impact of flood events on the planting. Some guidance for the designer on how to assess the risk of damage to the channel boundary, including vegetation plantings is provided later in this Post Constructed Risk Assessment chapter.

Figure 44 - Example of a recently planted constructed waterway, showing in stream, bank and riparian plantings

Hydraulic roughness

The hydraulic roughness of a waterway influences the amount of energy lost by water as it flows through the waterway. As vegetation grows, its size and shape changes, leading to changes in hydraulic roughness. It is therefore important to correctly estimate the hydraulic roughness of vegetation in a constructed waterway at the various stages of its lifetime to ensure the stability of the design.

A representative hydraulic roughness value should be selected that best estimate the hydraulic conditions in the waterway corridor. Once vegetation is established the hydraulic roughness must change accordingly. The following table presents a summary of the standard Manning's *n* values for the flow channel and high flow channel for the different waterway types under established conditions. Note a minimum vegetation quality of 3 is assumed as per the Healthy Waterways Visions.

Table 14 - Typical hydraulic roughness values for the different waterway types

MATERIAL	LFC	HFC
Compound	0.05 (min. 0.045 max. 0.06)	0.05 (min. 0.045 max. 0.06)
Bedrock	0.040 (min 0.035, max 0.050)	As above unless bedrock extends to 1% AEP flood level.
Linear pools	0.035 (predominately open water) (min 0.03, max 0.040) 0.05 (predominantly marsh)	0.05 (min. 0.045 max. 0.06)

Some parts of the waterway may be lined with rock or other bank strengthening materials if it is not possible to modify the design or vegetation alone will be sufficient. A list of potential bank linings and their associated hydraulic roughness are included in Table 15.

Table 15 - Typical hydraulic roughness values for rock and other bank protection material (from Fishenich 2001)

MATERIAL	MANNING'S *n*
Rock 250 mm	0.030
Rock 450 mm	0.035
Other bank strengthening fabrics (jute matting, ecomat, etc.)	0.025

For the post-construction period the recommended Manning's *n* values for the low flow channel and the high flow channel include:

1. Earth, straight and uniform (low sinuosity reaches) 0.018 (min 0.016, max 0.020)
2. Earth, winding and sluggish (sinuous reaches) 0.025 (min 0.023, max 0.030)
3. Bedrock cuts, jagged and irregular 0.040 (min 0.035, max 0.050)

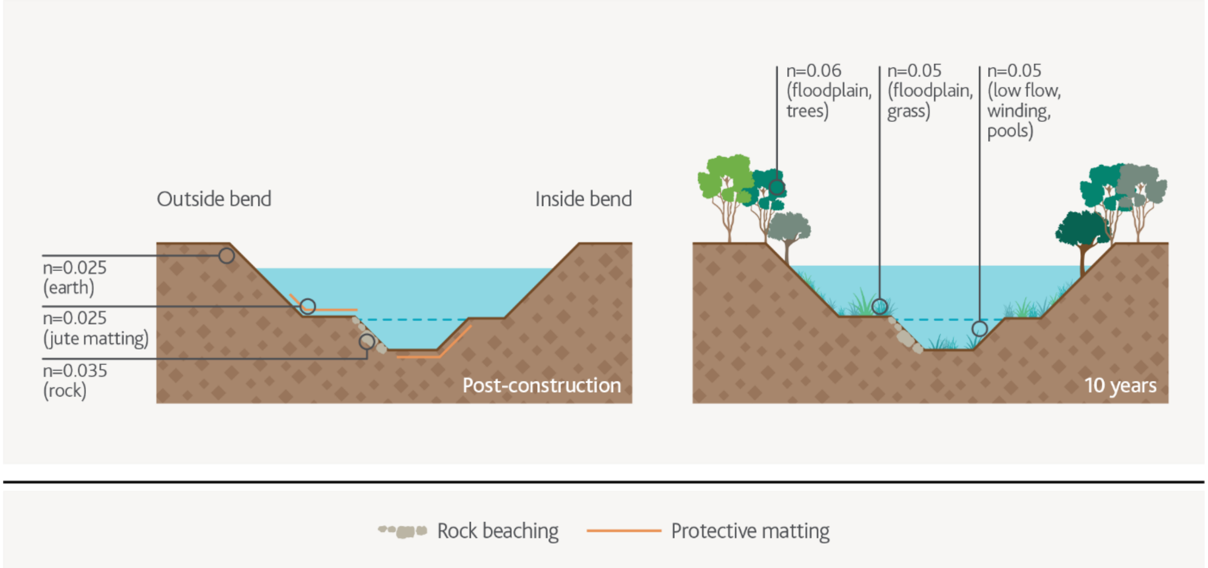


Figure 45 - Waterway corridor showing regions of similar vegetation species/hydraulic roughness in the immediate post-construction period when mature condition are reached (10 years plus)[4]

Additional hydraulic roughness resources are provided in Part E1.3 – Hydraulic modelling.

D2.5 Hydraulic structures and interface elements

Constructed waterways are situated within corridors that provide a buffer between the waterway and the adjacent development. There may be the requirement to locate many different biodiversity and amenity features, as well as services within the corridor and roads adjacent to the corridor. The designer must ensure these interface elements are managed to Melbourne Water's satisfaction. At the functional design stage the designer must specify the hydraulic structures having a reach-scale impact on the hydraulic performance of the waterway. The functional design package must include enough detail in the hydraulic model to provide confidence in the reach-scale hydraulic functioning. The structures and considerations that must be included in the hydraulic model at this stage are:

- Waterway crossings (such as bridges and culverts)
- Stormwater connections (drainage outfalls)
- Grade control structures (e.g. rock chutes)
- Fish passage considerations
- Other interface elements (i.e. paths located above 10% AEP flood level)

These are described and discussed in detail below.

Waterway crossings

Waterway crossing detail must be added to the hydraulic model to demonstrate the hydraulic impacts of the proposed crossing design arrangement. Approximate culvert sizing may have been carried out by Melbourne Water as part of preparing the

[4] Typical interim conditions (i.e. between post-construction and mature phase) are hard to represent because every waterway and it's vegetation community will respond differently post-construction, meaning that the trajectory of vegetation growth over time and the roughness that it creates within the waterway cannot reliably be estimated. The focus instead is on the mature (ultimate) condition of the waterway and the highest risk time in the life of the waterway, being for the first two to three years post-construction, during the vegetation establishment and juvenile phases.

Development Services Scheme for any existing road crossings that need upgraded hydraulic capacity. However, the designer must perform their own calculations to design the final bridge or culvert configuration to be included in the hydraulic model. The designer will need to perform their own design and analysis for all waterway crossings associated with proposed subdivisional roads and other crossings. For more information refer to the Constructing waterway crossing guidelines.

The main waterway crossing design considerations are:

- Design objectives for the crossing (pedestrian only, road access with provision for fish passage, other faunal passage etc.)
- Crossing type – single span bridge, box culvert or other
- For single span crossings - pier width and spacing (if any), deck width and extent (including railing that may retard flow)
- For culvert crossings - culvert type (box, pipe or arch), size and configuration, including details of wing wall configuration (note: box culverts should always be used unless otherwise permitted by Melbourne Water).

Specific design methods, requirements and procedures for waterway crossings are provided during D3 - detail design.

Stormwater connections

Drainage outfalls and tributary connections must be incorporated within the design waterway in accordance with the requirements of Melbourne Water's Planning and Building website. The functional design must demonstrate that the following:

- all outfalls and tributary connections fit with the proposed alignment
- invert levels are appropriate
- tributary connections must meet the design waterway at the appropriate elevation to avoid, the requirement for stabilisation measures at the junction
- drainage outfall should meet the design waterway without the need for energy dissipation measures at the junction.
- the additional flows do not adversely impact waterway health

The stormwater connection should be to a pool or direct to the low flow channel. There should be no bench at this point (i.e. the low flow channel is an extension of the high flow channel batter). Refer to Standard Drawings on Melbourne Water's website.

Grade control structures

Grade control structures influence the hydraulic performance of the waterway at the reach-scale and as such must be modelled as part of the functional design stage.

The designer must first size the structure. Rock chutes can be sized using CHUTE (http://www.toolkit.net.au/tools/CHUTE). The specific configuration and extent of the structure including: the crest level and length of the grade control structure/s is then sized using the terrain model.

Fish passage should be considered at grade control structures. The recommended approach to designing fish friendly grade control structures is provided in section D3-Detailed Design. Whether fish passage is critical as well as feasible given the natural bed grade should have been established in the concept stage and confirmed with Melbourne Water.

Other interface elements

There are many other interface elements worth considering at the functional design stage, such as inclusion of or connection to nearby public open space, recreational infrastructure, siting of biodiversity protection assets such as frog ponds, and siting of services and opportunities to link and connect into pedestrian and bicycle networks. Whilst these interface elements do not necessarily need to be incorporated into the hydraulic model for the functional design they are worthy considerations when developing the model. The designer must understand these interface elements, where they are located, and how they interact with the waterway to ensure that the waterway design and corridor design are appropriately integrated.

D2.6 Developing a digital terrain model for functional design

The designer should use terrain modelling software to represent the existing terrain in 3D computer space and build the waterway surface within it.

There are many terrain modelling software packages available with the capability of establishing a design waterway surface for the purpose of hydraulic investigation. The 12d application is used widely in stream management and planning throughout Victoria. It is not the only product suitable for the task of waterway design; however, it has been used in this manual to demonstrate the use of terrain modelling software in stream design.

The terrain model is used to grade the proposed configuration of the waterway. The tools and methods required in this process are set out in Part E of this manual but in summary:

- Import the existing digital elevation model (DEM) to the terrain model
- Generate a triangulated irregular network (TIN) of the existing terrain
- Place 'alignment strings' along the alignment of the proposed waterway for both the high flow and low flow channels. Separate strings are recommended, especially for the compound waterway type to aid with creating diverse, non-uniform sections.
- Use 'grading templates' of the proposed cross section to grade the waterway shape. The use of templates should be carefully considered such that the same cross section is not created for the entire length of the waterway (i.e. cross sections – grades, bench width etc. need to vary).
- Generate a combined TIN of the design waterway and existing terrain

The designer can now use the terrain model to begin building the hydraulic model.

D2.7 Developing the hydraulic model

The Hydrologic Engineering Centre of the US Army Corps of Engineers developed the River Analysis System (HEC-RAS) software. The software allows the user to perform one-dimensional steady and unsteady river calculations.

Within HEC-RAS the designer can specify the system hydrology, boundary conditions, any hydraulic structures such as bridges or culverts, and the hydraulic roughness of the waterway boundary to reflect the vegetation design and layout. The model can then be used for analysis of the design waterway hydraulic performance: flood capacity; and bed and bank stability.

Creating the geometry file in the terrain model

Once the proposed waterway configuration is established in the terrain model the designer can generate a hydraulic model of the waterway. The tools and methods required in this process are all detailed in Part E of this manual. In summary, using the terrain model:

- Place 'river strings' to sample the waterway centreline and left and right banks along the length of the waterway (plus some extension to tie into whatever is up and downstream)
- Place 'source strings' at the location of desired cross-sections. Cross-sections are placed to represent in the best way possible, the water as it flows through the waterway.
- Use the 'river module' to generate the HEC-RAS ready geometry file
- HEC-RAS river stations must correspond with chainages shown on drawings. Chainage must start with chainage zero (CH0) at the downstream end of the model.

Hydraulic modelling in HEC-RAS

Once the geometry file has been exported from the terrain model the designer can set-up and run the hydraulic model to check the hydraulic performance of the proposed waterway configuration. The tools and methods required in this process are detailed in Part E of this manual. In summary:

- Start a new HEC-RAS project
- Start a new geometry file and import the geometry information (from the terrain model)
- Start a new flow file and input the flow information and boundary conditions. Flow information is based on the hydrologic modelling steps previously completed (see Section D2.1 and Part E1.1), or from the DSS supplied by Melbourne Water. Flow boundary conditions are specified by the user and may be calculated in several different ways.
- Input all flow constriction (such as culverts and bridges) information to the geometry file
- Input the hydraulic roughness values (Manning's n) consistent with the vegetation design for the waterway
- Run the model in steady flow analysis mode, using the mixed flow regime.
- Interrogate the model and once the waterway is optimised export the hydraulic performance (various flood event extents, flood levels, shear stresses etc.) for further analysis or presentation to Melbourne Water

Modelling crossings

The HEC-RAS User Manual (USGS 2009) provides guidance on modelling bridges and culverts in HEC-RAS. The designer must pay particular attention to:

- Cross-section locations upstream and downstream of bridges and culverts
- Contraction and expansion loss coefficients (HEC-RAS default values for various culvert and bridge types are recommended)
- Entering bridge data to reflect the proposed design (bridge deck, sloping abutments, or pier/s)
- Entering culvert data to reflect the proposed design (dimensions and configuration).

Modelling grade control structures

Grade control structures must be incorporated into the terrain and hydraulic modelling step of the functional design. The longitudinal profile must reflect the location and extent of any grade control structures proposed. The size of rock utilised within the structure (as established in CHUTE) should be reflected in the model by updating the manning's 'n' for the section of channel occupied by the structure.

Modelling drainage outfall connections and contributing flows

Contributing flows from tributaries and drainage outfalls must be incorporated into the HEC-RAS flow file. This involves specifying the flow change at the appropriate cross-section (where the contributing flow enters) along the subject reach.

Modelling other interface elements

Ancillary interface elements such as public open space and recreation reserves need only be considered in terms of spatial location in relation to flood levels within the waterway. As part of the hydraulic performance check the designer must ensure that any design criteria specifically relating to interface elements are met. For example, this may include but is not limited to:

- Minimum flood protection for public open space
- Maximum flood protection (i.e. the 10% AEP flood level), depth of inundation, or flow velocity for a rain garden

D2.8 Hydraulic assessment

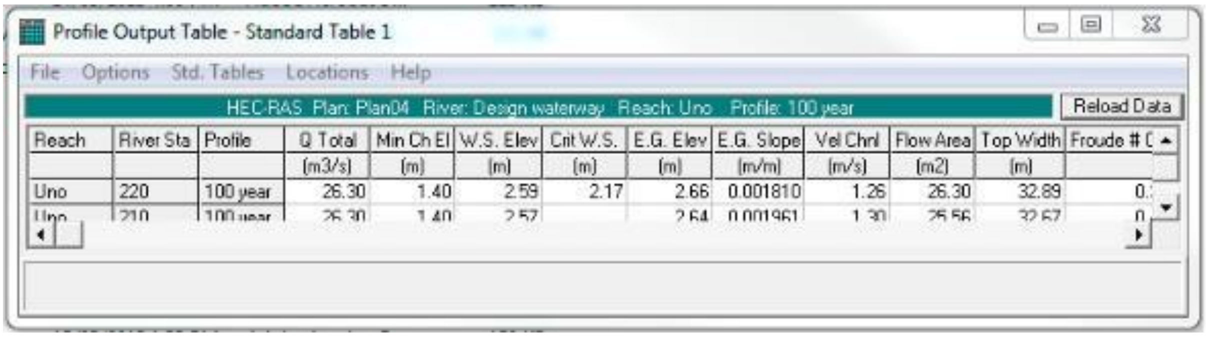
The designer must ensure that the waterway meets the asset protection and connectivity design objectives set out in Part B of this manual. This task is therefore concerned with testing the initial design for flood capacity and conveyance, public safety, channel stability, and overall hydraulic performance including fish passage.

Flood capacity and conveyance

As stated in Part B, waterways should safely convey a range of flood events within the specified Waterway Corridor:

- The maximum flood event to be conveyed is the 1% AEP flood event.
- 600 mm of freeboard from the 1% AEP flood level must be provided to the to the floor of the neighbouring development floor. A minimum of 300 mm of this freeboard must be contained within the Waterway Corridor.
- The low flow channel (in compound waterways) must convey the design flood event (between 4EY to 1EY).

The designer must check each cross-section in the model to determine the flood levels for the design events of interest and the available freeboard. The flow data, including water surface elevation, can be exported from the HEC-RAS model as a table (Figure 46).



Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # C
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Uno	220	100 year	26.30	1.40	2.59	2.17	2.66	0.001810	1.26	26.30	32.89	0.
Uno	210	100 year	26.30	1.40	2.57		2.64	0.001961	1.30	25.56	32.67	0.

Figure 46 - Example HEC-RAS output table showing parameters used to check flood levels and freeboard

The designer should also undertake a sensitivity assessment around blockages at culvert structures. A hydraulic analysis based upon a 50% blockage scenario for the 1% AEP event should be considered to check that potential flood levels induced by such a blockage is contained within the freeboard provisions adjacent to private allotments.

Public safety

Floodway Safety Criteria for grassed floodways' in drainage reserves must be applied to the proposed waterway corridor. The safety criteria are appropriate for the safety of children. Full child safety is to be maintained to a depth of 0.4m on both banks wherever free access is available:

$$\text{For } d \leq 0.4\,m,\; V \times d \leq 0.35\,m^2/s$$

Equation 7

Where V is the average cross-sectional velocity in the area of the bank zone that contributes to flow (m/s), and d is the actual depth of the floodway at any reference point (m).

Waterway stability

The threshold channel design method (described in Section B1.2) considers the forces exerted on the waterway boundary material (e.g. sediment type, protective matting, vegetation and rock).

The waterway boundary is stable if the exerted shear stress is lower than the threshold shear stress for the boundary material or substrate. Otherwise, it is eroded. In this method the designer balances the:

- Applied shear stress – the force of flow on the waterway boundary
- Shear stress threshold– the flow force that can be withstood by the design boundary material or channel substrate

For a simple channel the applied shear stress is equal to the weight of water acting in the direction of flow. In reality however, most channels are not simple and the distribution of shear stresses between the stream bed and its banks is different (Lane 1955). In terms of waterway design, the difference can be managed by assuming an adjustment factor (details below).

Flow forces also concentrate around the outside of bends. The applied shear stress increases according to the nature of the geometry of the bend, and a scaling factor must be applied when calculating the applied shear stress. The following paragraphs set out the necessary information to check the channel stability.

Average applied shear stress

The cross-section average shear stress can be exported from HEC-RAS. The designer must consider the full range of shear stress values in the subject reach, not just at a single cross-section.

HEC-RAS allows the user to specify top of bank markers to delineate the main channel from the left and right over bank (or low flow channel to high flow channel). With respect to the compound waterway type it is recommended that the top of bank markers be placed at the top of the low flow channel (Figure 47).

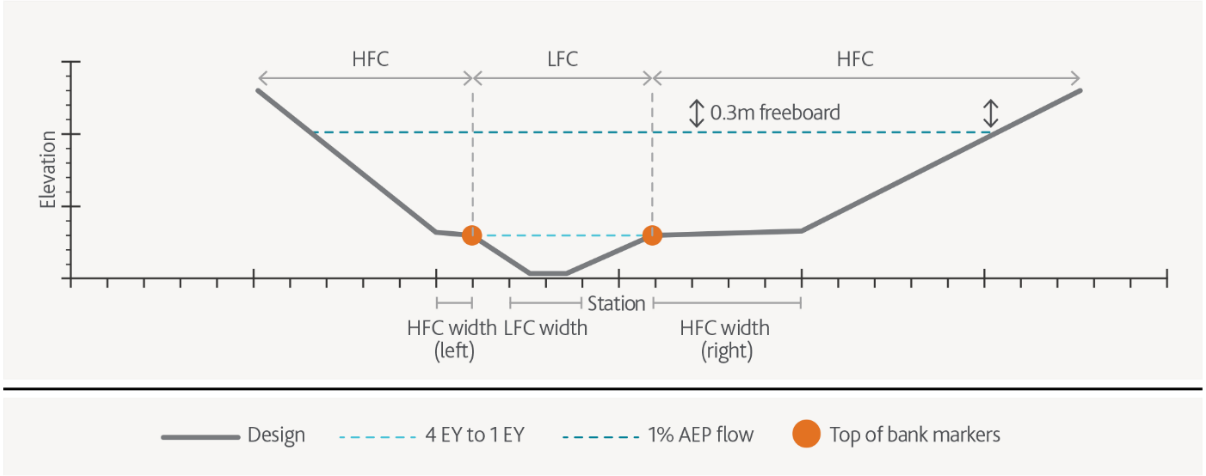


Figure 47 - Markers placed at top of bank to differentiate between low flow channel and high flow channel

The HEC-RAS hydraulic performance output table can then be specified to delineate according to the bank markers as shown in Figure 48. This enables easy comparison of the applied in-channel shear stress (Shear Chan), and left overbank (LOB) shear stress (Shear LOB), and right overbank (ROB) shear stress (Shear ROB) with the appropriate erosion threshold.

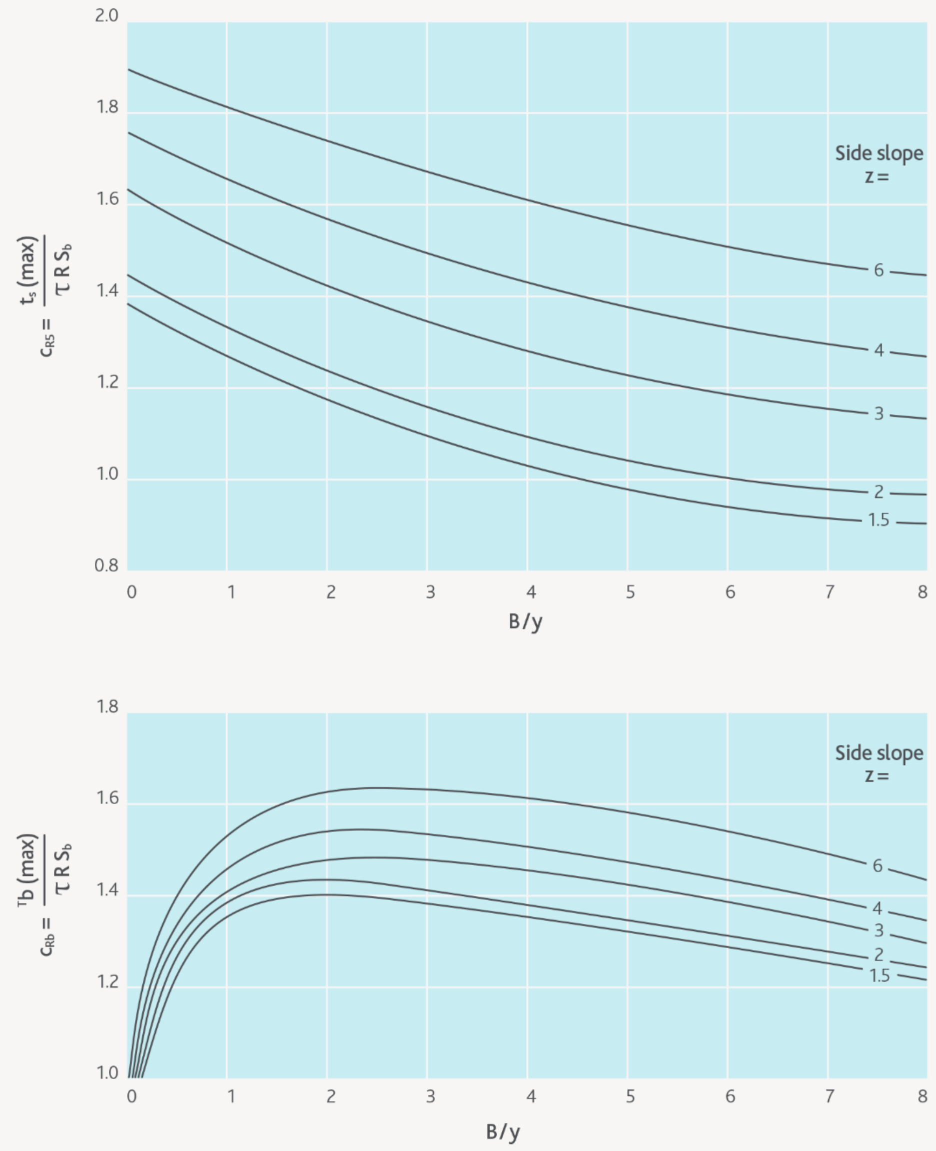
HEC-RAS Plan: Plan 01 River: Kettle Creek Reach: Supply

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Slope	Top Width	Vel Left	Vel Chnl	Vel Right	Shear LOB	Shear Chan	Shear ROB
			(m3/s)	(m)	(m)	(m/m)	(m)	(m/s)	(m/s)	(m/s)	(N/m2)	(N/m2)	(N/m2)
Supply	2000	Q2	107.30	1.60	6.86	0.000300	40.77	0.13	1.03	0.17	0.59	8.88	0.59
Supply	2000	Q10	323.60	1.60	9.32	0.000300	89.79	0.49	1.51	0.63	4.18	15.76	4.18
Supply	2000	Q20	408.80	1.60	9.94	0.000300	102.33	0.56	1.63	0.71	5.10	17.51	5.10
Supply	2000	Q50	523.90	1.60	10.66	0.000300	116.61	0.63	1.75	0.81	6.14	19.51	6.14
Supply	2000	Q100	612.80	1.60	11.13	0.000300	126.17	0.68	1.83	0.87	6.85	20.86	6.85

Figure 48 - Example HEC-RAS output table showing hydraulic parameters split between in channel, left and right over bank

Adjust for bed and bank shear stress

The applied (average) shear stress calculated by HEC-RAS needs to be factored up to estimate the maximum shear stresses occurring on the bed and sides of the cross section. The relationships developed to estimate the maximum shear stress on the bed and sides of a trapezoidal channel are shown in Figure 49.



Where:
CRB = scale factor for the bed
CRS = scale factor for the sides
B = base width
Y = flood depth

Figure 49 - Maximum boundary shear stress on the bed (bottom image) or sides (top image) of a trapezoidal cross-section (U.S. Highway Research Board 1970)

Note: the flood depth 'Y' for the HFC is the flood level minus the low flow channel depth.

An adjustment factor can be established by looking at the relationship of base width (either for the low flow channel or high flow channel/bench) divided by the depth of the 1% AEP flow, and the side slope. The adjustment factor can then be applied to the average shear stresses obtained in HEC-RAS.

To simplify the analysis, a conservative approach can be adopted by selecting the highest scale factor from either graph shown in Figure 50 and applying that adjustment factor to the entire channel under consideration (e.g. low flow channel or high flow channel bench).

It is worth noting that the flatter the side slope, the greater the shear stress adjustment factor.

For example, for a low flow channel with a base width of 3m and a depth of water (1% AEP) of 0.8m, B/y = 3.75. Low flow channels will typically have a side slope of 1:3, which together give an adjustment factor of approximately 1.45.

Note that for the high flow channel the overall 'base width' extends from the left to right bench extent.

Scale for concentration of flow at waterway bends

Curved waterways have higher maximum shear stresses than straight channels. Maximum shear stress occurs on the inside bank in the upstream portion of the curve and on the outer bank in the downstream portion of the curve. The smaller the radius of curvature, the more shear stress increases along the curved reaches.

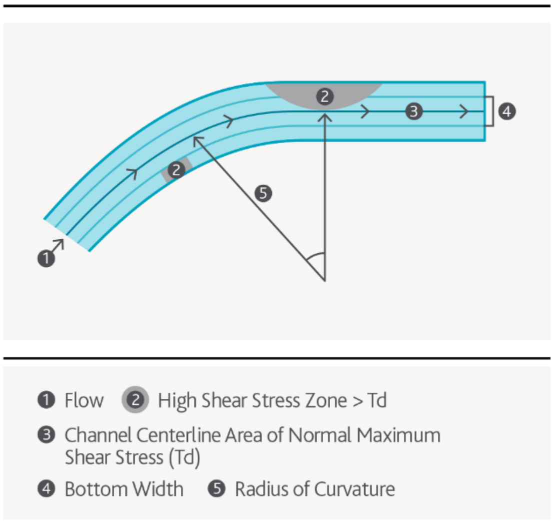


Figure 50 - Location of increased shear stress due to channel bend (adapted, Nouh and Townsend, 1979)

The designer can estimate the increased shear stress applied to the outer bank relative to the cross-section average shear stress outputted from HEC-RAS using Figure 51.

For example, a low flow channel, with a base with (b) of 3m and radius of curvature (of the low flow channel) (R_c) of 20m, the radius of curvature to base width ratio (R_c/b) ratio is 6.7. Therefore, the ratios are:

- Shear stress on the channel bed on a curved reach to that of a straight reach (τ_{bc} / τ_b) is 1.35
- Shear stress on the channel side slopes in the curved reach to that of a straight reach (τ_{sc} / τ_s) = 1.35

So the average shear stress output from HEC-RAS (and disaggregated into the bed and bank components, as outlined above) can be scaled by 1.35 for the curved section.

The shear stress values referred to Figure 51are based on experimental data collected in laboratory experiments under controlled conditions. In addition, there is a large body of scientific research into changes in waterway form and process that clearly indicates that the erosion of bends in waterway channels predominantly occurs on the outside of the bend (Charlton 2008 and Knighton 1998). As a result in the majority of situations the maximum shear stress value to focus on is the outside of a bend.

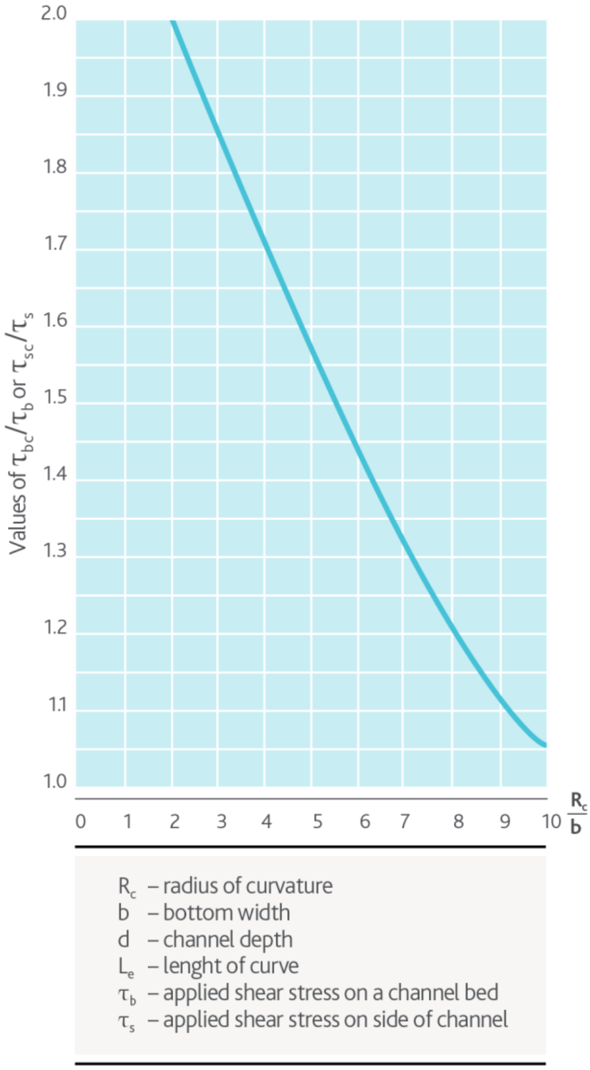


Figure 51 - Applied maximum shear stress on bed and banks of trapezoidal channels in a curved reach (from NRCS 2007)

Using this approach, the designer will be able to estimate the shear stress on the channel boundary at any location in the proposed waterway for the design flow(s) of interest (noting that the 1% AEP will be the most conservative as the depth of water will be the greatest).

As part of the design package the designer must present tabulated shear stress values along the waterway length. The table should include the cross section chainage, the cross section average shear stress, and where applicable the multiplications factors (e.g. around a meander bend) as shown in Table 16 and Table 17. This should be done for the low flow channel and the high flow channel (left bank and right bank).

Table 16. Example shear stress output table showing multiplication factors for scaling shear stress at meander bends for low flow channel

CHAINAGE	STRAIGHT OR CURVED	B BASE WIDTH (M)	Y FLOOD DEPTH (M)	AVERAGE SHEAR STRESS (N/M2)	CRB / CRS MAX SHEAR FACTOR	MAX SHEAR STRESS (N/M2)	RC RADIUS OF CURVATURE (M)	SCALE FACTOR FOR CURVES	APPLIED MAX SHEAR STRESS (N/M2)
NORTH-SOUTH REACH									
0	S	3	1.56	2.54	1.45	4	n/a	1	4
50	C	3	0.99	25.86	1.5	39	28	1.1	43
100	C	3	0.95	26.73	1.5	40	45	1.05	42
150	C	3	0.95	25.67	1.5	39	82	1.05	40
200	C	3	0.94	26.49	1.5	40	115	1.05	42
250	C	3	0.93	26.27	1.5	39	88	1.05	41
300	C	3	0.89	29.17	1.5	44	47	1.05	46
400	C	3	0.91	30.3	1.5	45	27	1.1	50
450	C	3	0.92	29.81	1.5	45	27	1.1	49
500	C	3	0.93	28.76	1.5	43	37	1.05	45

Table 17. Example shear stress output table showing multiplication factors for scaling shear stress at meander bends for high flow channel

CHAINAGE	STRAIGHT OR CURVED	B BASE WIDTH (M)	Y FLOOD DEPTH (M)	AVERAGE SHEAR STRESS (N/M2)	CRB / CRS MAX SHEAR FACTOR	MAX SHEAR STRESS (N/M2)	RC RADIUS OF CURVATURE (M)	SCALE FACTOR FOR CURVES	APPLIED MAX SHEAR STRESS (N/M2)
NORTH-SOUTH REACH									
0	S	5	1.06	0.27	1.55	0.4	n/a	1	0.4
50	S	5	0.49	7.86	1.45	11	n/a	1	11
100	C	1	0.45	6.15	1.45	9	135	1.05	9
150	C	4	0.45	7.81	1.45	11	135	1.05	12
200	S	6	0.44	8.94	1.45	13	n/a	1	13
250	S	3	0.43	8.12	1.5	12	n/a	1	12
300	C	5.5	0.39	9.83	1.45	14	253	1.05	15
400	C	5	0.41	9.29	1.45	13	253	1	13
450	S	2	0.42	8.1	1.6	13	n/a	1	13
500	S	7	0.43	8.71	1.45	13	n/a	1	13

Shear stress thresholds

There is a large body of literature on erosion thresholds of many different types of boundary material. The designer should use the erosion thresholds set out in the table below (Table 18), which are reproduced from Fischenich (2001), and have been selected as they are the most comprehensive data set for the types of boundary materials used in constructed waterways.

Table 18 - Erosion thresholds for different waterway boundary materials (Fischenich 2001)

BOUNDARY CATEGORY	BOUNDARY TYPE	SHEAR STRESS EROSION THRESHOLD (N/M2)
Soils	Fine colloidal sand	1.5
	Alluvial silt and silty loam (non-colloidal)	3
	Firm loam and fine gravels	4
	Stiff clay and alluvial silts (colloidal)	12
Gravel/Cobble	25 mm, 51 mm, 152 mm, and 305 mm	16, 32, 96, and 192 respectively
Vegetation	Turf	45 to 177
	Long native grasses	80
	Short native and bunch grass	45

The designer will need to demonstrate the proposed design meets the following **criteria**:

- Shear stress for the 1% AEP event in the high flow channel is lower than the erosion threshold for the selected boundary material, especially in the vicinity of any built assets in the waterway corridor. Waterway related assets such as drainage outfalls, bridges and culverts should be designed to withstand the 1% AEP flow in their own right.
- Shear stress for the 20% AEP year event is lower than the erosion threshold for the selected boundary material throughout the design reach in both the low flow and high flow channels (Table 19).
- Applied shear stress for some events is allowed to exceed the threshold for the boundary material (Table 19).
- Juvenile vegetation is less resistant to erosion than mature vegetation. Melbourne Water requires that the designer consider the risk of erosion during the establishment phase is. The designer should calculate the overall likelihood that an event causing damage to juvenile plantings will occur in the post-construction window (refer Post-construction risk assessment).

Table 19 - Shear stress thresholds for different parts of the channel

DESIGN EVENT (AEP)	LOW FLOW CHANNEL	HIGH FLOW WATERWAY
4 EY	Below threshold for boundary material	Below threshold for boundary material
1 EY	Below threshold for boundary material	Below threshold for boundary material
40%	Below threshold for boundary material	Below threshold for boundary material
20%	Below threshold for boundary material	Below threshold for boundary material
10%	Thresholds exceeded by no more than **2%**	Below threshold for boundary material
5%	Thresholds exceeded by no more than **5%**	Below threshold for boundary material
2%	Thresholds exceeded by no more than **10%**	Below threshold for boundary material
1%	Thresholds exceeded by no more than **10%**	Below threshold for boundary material

For a waterway with a compound channel it is typical to expect the vegetated low flow channel to have an erosion threshold of $80N/m^2$ (i.e. long native grasses) and the high flow channel to have an erosion threshold of $45N/m^2$ (i.e. short native/bunch grass).

Hydraulic performance - Tributary and stormwater connections

The flow conditions at tributary connections must also meet the maximum shear stress threshold criteria. There may be cases where these conditions cannot be met. For example, where the existing form of the tributary exhibits velocity and shear stress values that exceed the recommended thresholds. In this case, the designer must demonstrate that the hydraulic parameters (velocity and shear stress) are not increased by the proposed design. There must not be a drastic change in the form (slope or cross-section shape) of the tributary as it meets the design waterway. Where a sharp transition is unavoidable, protective measures (bioengineered material or rock material) should be recommended by the designer, and designed accordingly.

The proposed design must also integrate any drainage outfalls without causing unfavourable hydraulic conditions such as:

- In appropriate freefall from drainage outfalls
- Velocities greater than 1.5m/s (maximum) from drainage outfalls
- Drowning of outfalls causing flows to be backed up and potentially flood the local drainage network upstream of the outfall

Where unfavourable hydraulic conditions arise at the drainage outfall interface (i.e. there is an unavoidable elevation difference between the outfall point and the design waterway) the designer must run possible alternative approaches past Melbourne Water for approval as this would not be following the Deemed to Comply.

Hydraulic performance - Grade control structures

Grade control structures are designed using the CHUTE spreadsheet: for a specific flood event, to meet the target rock size and distribution (according to what is available for construction), and include a nominal factor of safety. The hydraulic model must also meet these design criteria. For example:

- Velocity must be equal to or less than that calculated by the CHUTE spread sheet (accounting for factor of safety applied in CHUTE)
- Depth of inundation must be equal to or less than that calculated by the CHUTE spread sheet

These criteria must be met for the component of the hydraulic model that represents the structure.

Note that the designer can export the stage-discharge relationship from the tail-water cross-section in HEC-RAS to increase the accuracy of the calculation in CHUTE. Guidance on using rating tables as the downstream tail-water conditions is outlined in the CHUTE User Manual.

Hydraulic performance - Other interface elements

The hydraulic conditions at other interface elements such as public open space, recreational assets, and shared pathways (etc.) must be met. Most interface elements will require some degree of flood protection, for example:

- Shared paths, boardwalks, viewing platforms, and seating nodes generally sit above the 10% AEP flood level (e.g. see Melbourne Water Shared pathways guideline);
- BBQ and picnic facilities, playgrounds, council owned and maintained passive open space, and sporting facilities must sit outside the 1% AEP flood level.

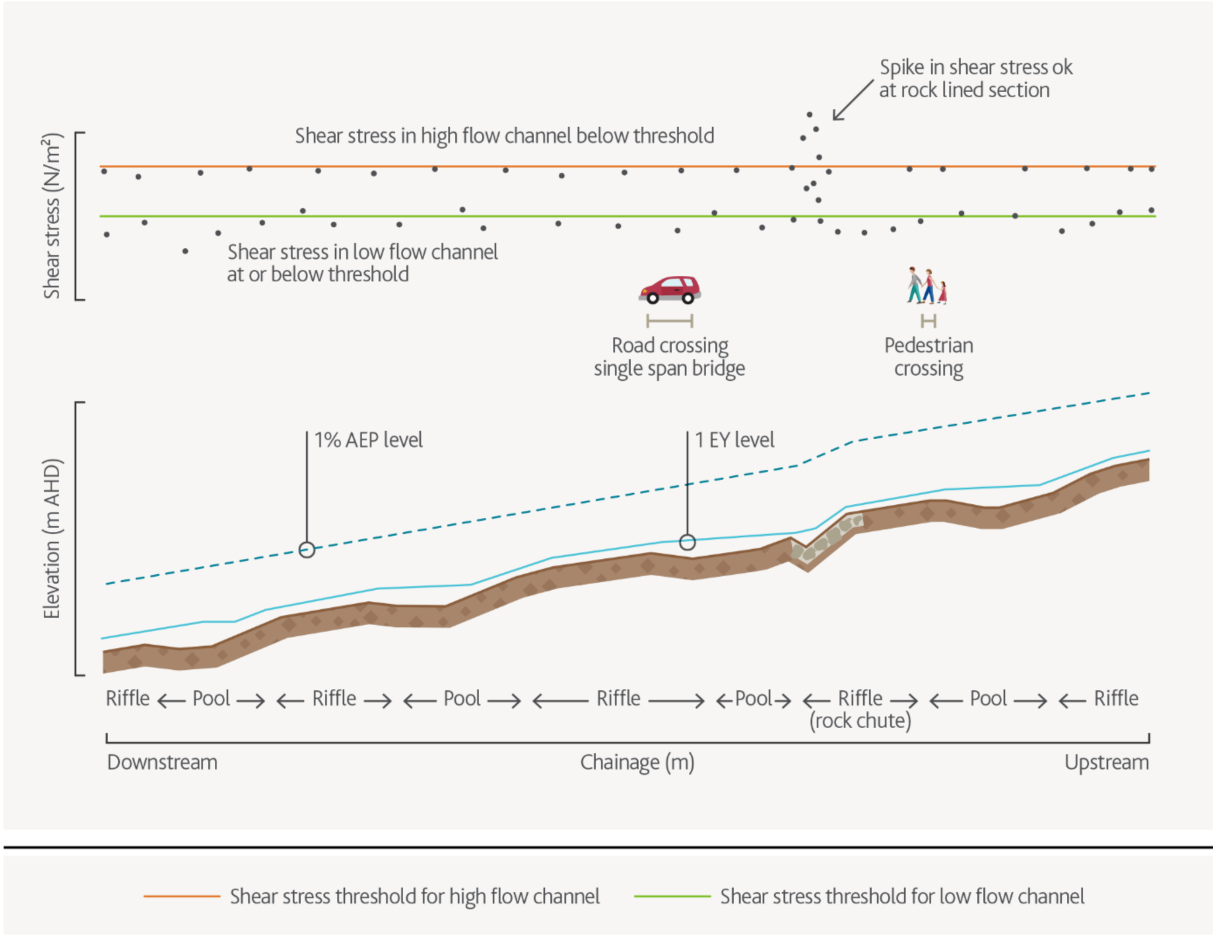


Figure 52 - Example longitudinal profile of constructed waterway shear stress, thresholds, relevant features and infrastructure

D2.9 Post-construction risk assessment

In the post-construction window, prior to vegetation becoming mature, there is a possibility that the waterway bed and banks may erode, causing damage to plantings and degrading the overall integrity of the waterway. The designer should therefore make an assessment of damage probability in the post-construction window. This probability can be quantified by summing the likelihood of a threshold event occurring in each individual year following construction. Assuming that damage to the waterway is expected at flows greater than the threshold, it follows that the probability of damage is given by the AEP.

- Take the AEP of the event that would cause damage in each year of the post-construction period, from year = 0 through to maturity.
- Sum the AEP from each year to give an overall likelihood of damage
- If the cumulative likelihood of damage is unacceptably high the design may need to be revised.

Post-construction risk assessment – worked example

The following information and example provided is for guidance only. Prior to handover to Melbourne Water, for all flow events the liability with respect to waterway damage lies with the developer/ designer/contractor. The Developer/design/contractor needs to make their own judgment regarding risk.

A newly established waterway is planted out with native grasses and shrubs as forestry tubestock. Seeds are also spread to establish temporary groundcover quickly. Once mature, the stand of grasses, shrubs and trees allows shear stress of up to 80 N/m^2 to pass through without any failure of the waterway. Understorey communities are expected to establish quite quickly (within 12 to 24 months), which will give a baseline level of protection throughout the waterway. The mid and upper storey will take longer to establish.

Immediately post construction (i.e. bare soil) the shear resistance is very low, with values typically less than 5 N/m^2 (refer to Fischenich, 2001) as plants have not established or matured. Therefore, the design will need to consider the use of another material (e.g. jute mat) to protect it against erosion in the post-construction period. When analysing the resistance of bank protection materials such as jute mat, velocity should be used rather than shear stress as the product specifications refer to a velocity threshold. Melbourne Water has a jute mat specification which should be adopted. The velocity threshold for jute mat is 1.8 m/s.

In order to inform the risk assessment, a hydraulic analysis is undertaken using the previous HEC-RAS model of the waterway that was prepared during the functional design. Curved waterways have higher maximum velocities than straight channels. Maximum velocity occurs on the inside bank in the upstream portion of the curve and on the outer bank in the downstream portion of the curve. The smaller the radius of curvature, the more velocity increases along the curved reaches.

An estimate of the increased velocity applied to the outer bank relative to the cross-section average velocity outputted from HEC-RAS can be determined using Figure 53. This is done for both the low flow channel and the high flow channel. Figure 54 shows the maximum velocities along the reach of a waterway for a 10%AEP rainfall event.

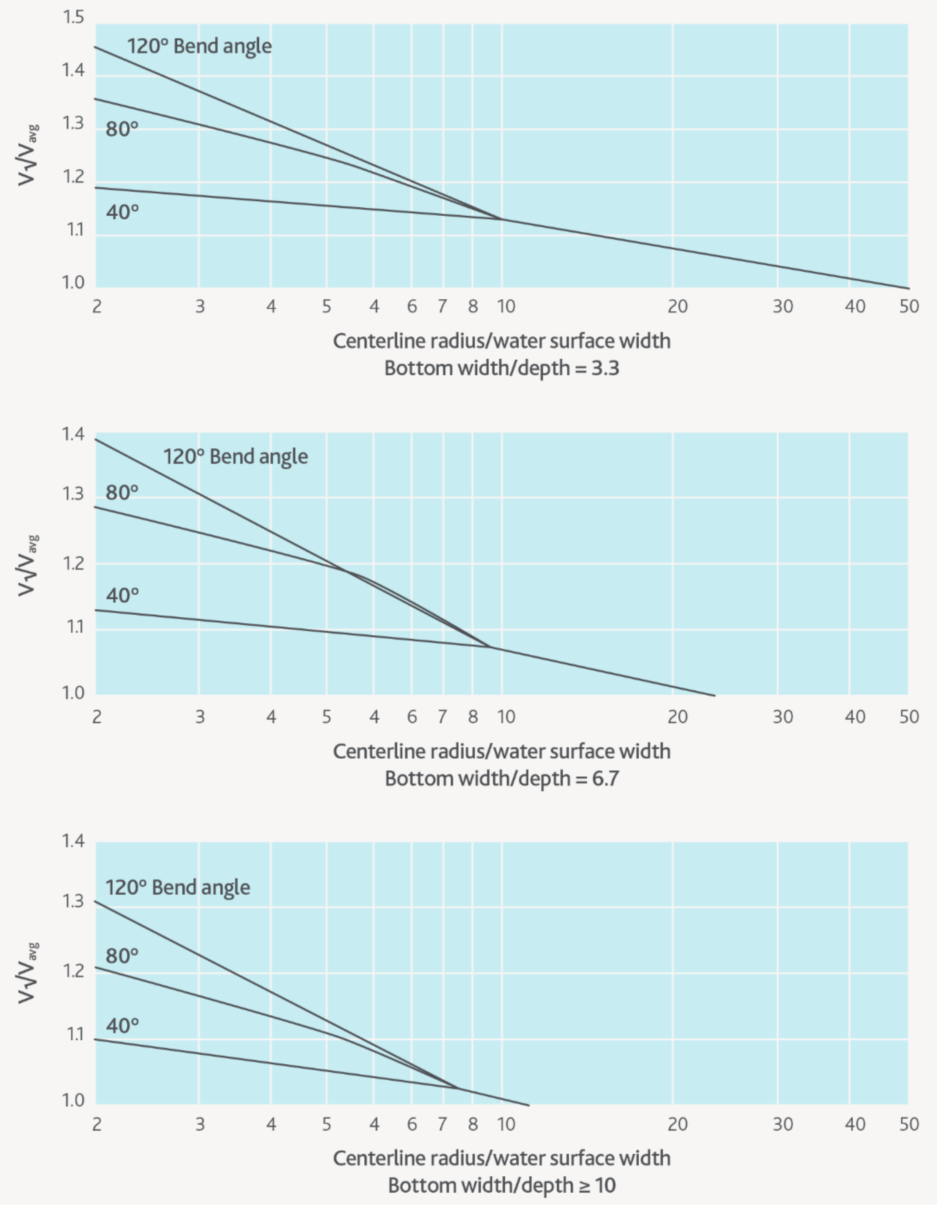


Figure 53 - Applied maximum velocity on bed and banks of trapezoidal channels in a curved reach (from NRCS 2007), where Vss is depth-average velocity at 20% of slope length up from toes, maximum value in bend. Curves based on STREMR model (Bernard 1993), Vavg = 6ft/s, 1:3H side slopes. N = 0.038, 15ft depth

Figure 54 – Post-construction maximum velocity along the waterway for a 10%AEP event

As shown in Figure 54 the maximum velocity along the waterway for a 10% AEP event is generally below the velocity threshold of jute mat (i.e. 1.8m/s). The locations that are above 1.8m/s are at culvert crossings or grade control structures, where rock will be used as the threshold treatment.

Based upon this analysis, jute mat protection should be provided up to the 10% AEP event. That is for all events up to the 10%AEP event, the post construction waterway should have sufficient protection to avoid any significant erosion. The cumulative probability of erosion was then calculated for a two year period (which corresponds to the defects liability period for this example) as shown in Table 20.

Table 20 - Cumulative probability of post-construction risk assessment

YEAR	VELOCITY THRESHOLD (M/S)	AEP OF FAILURE FLOW = PROBABILITY OF FAILURE IN YEAR X	PROBABILITY OF SURVIVAL IN YEAR X	PROBABILITY OF SURVIVAL AFTER X YEARS	PROBABILITY OF EVENT	NO. OF YEARS
1	1.8	10%	90%	90%	10%	1
2	1.8	10%	90%	81%	19%	2

Table 20 highlights that there is an 19% chance of the waterway receiving a rainfall event greater than the 10%AEP over a 2 year period. That is there is an 19% chance of failure or significant damage to the waterway bed and/or banks. This information should be used by the designer/developer/contractor in understanding their liability exposure during the defects liability period and in informing decisions regarding waterway design to ensure that the waterway is intact and functional prior to handover to Melbourne Water.

D2.10 Locating engineering and habitat features

Aquatic habitat features such as pools and riffles, benches, vegetation, and large wood are designed to meet the ecological, stability, and aesthetic objectives for the waterway. Engineering features such as culverts, stormwater outfalls, rock chutes, and rock beaching are designed to support channel stability. Landscape features such as vegetation, and infrastructure such as shared pathways are designed to support the amenity values of the waterway and its corridor. At the functional design stage it is important to locate the range of waterway features (Table 21) within the waterway and its corridor. Features are not sized in this stage of the design. This is carried out in the detailed design stage.

Table 21 - List of waterway features in constructed waterways

ENGINEERING STRUCTURES	LOCATION DESCRIPTION
Vegetation design*	• Distributed throughout corridor as set out by Healthy Waterway Visions
Rock chutes	• For grade control or designed pool-riffle sequence
Rock beaching and other bank strengthening treatments (matting, coir logs, etc.)	• Where shear stress thresholds are exceeded for the boundary material, and to provide additional protection in the vegetation establishment phase. • Used only when preferred shear stress reduction techniques have been exhausted • Where shear stress thresholds are exceeded, such as on the outside of bends • In the vicinity of high value assets
Culverts and bridges	• As required by DSS and landscape plan
Stormwater outfalls	• As required by DSS and landscape plan
HABITAT FEATURES	
Pools and riffles, benches, large wood, vegetation*	• As required to meet objectives for waterway. Pools near the apex of meander bends. Riffles generally at the meander bend inflection point. Benches anywhere along the reach for the compound type (generally not at meander bend apex, where pools are sited).
LANDSCAPE FEATURES	
Integrated Features	
Vegetation*, shared paths, viewing platforms, maintenance tracks, pedestrian bridges, cultural interpretation and signage, and seating nodes	• As required by landscape plan. Must suit waterway functional design layout (i.e. viewing platforms at location of retention basin, maintenance tracks sites with assets to be maintained, etc.).
Peripheral Features	
BBQ and picnic facilities, playgrounds, passive open space, sporting facilities	

D3. DETAILED DESIGN

The objective of the detailed design stage is to further develop the design to include the full range of physical features and vegetation so the design meets the required objectives.

Design guidance is provided in this section for the features listed below (Table 22). Not all features will be present in every waterway—the range of features in a particular constructed waterway will have been identified at the concept design stage and will have been informed by the waterway type and the surrounding landscape and urban design context. The detail design phase is likely to include the tasks shown in Figure 55.

Table 22 - List of waterway features covered in this section

ENGINEERING STRUCTURES	HABITAT FEATURES	LANDSCAPE FEATURES	
		Integrated Features	Peripheral Features
• Vegetation design* • Rock chutes • Rock beaching • Bank strengthening treatments • Culverts and bridges • Stormwater outfalls	• Vegetation* • Pools and riffles • Benches • Large wood	• Vegetation* • Pedestrian bridges and crossings • Shared paths and walking tracks • Boardwalks and viewing platforms • Jetties • Signage • Seating nodes • Maintenance tracks	• BBQ and Picnic Facilities • Playgrounds • Passive and Active Open Space

* Melbourne Water considers vegetation as a structural component of the waterway, offering erosion protection and channel stability in the same way as does the more traditional engineered structures (such as rock beaching). Vegetation design is presented as part of the engineered structures however the designer must remain aware of the multiple objectives of vegetation design (e.g. providing habitat and landscape amenity)

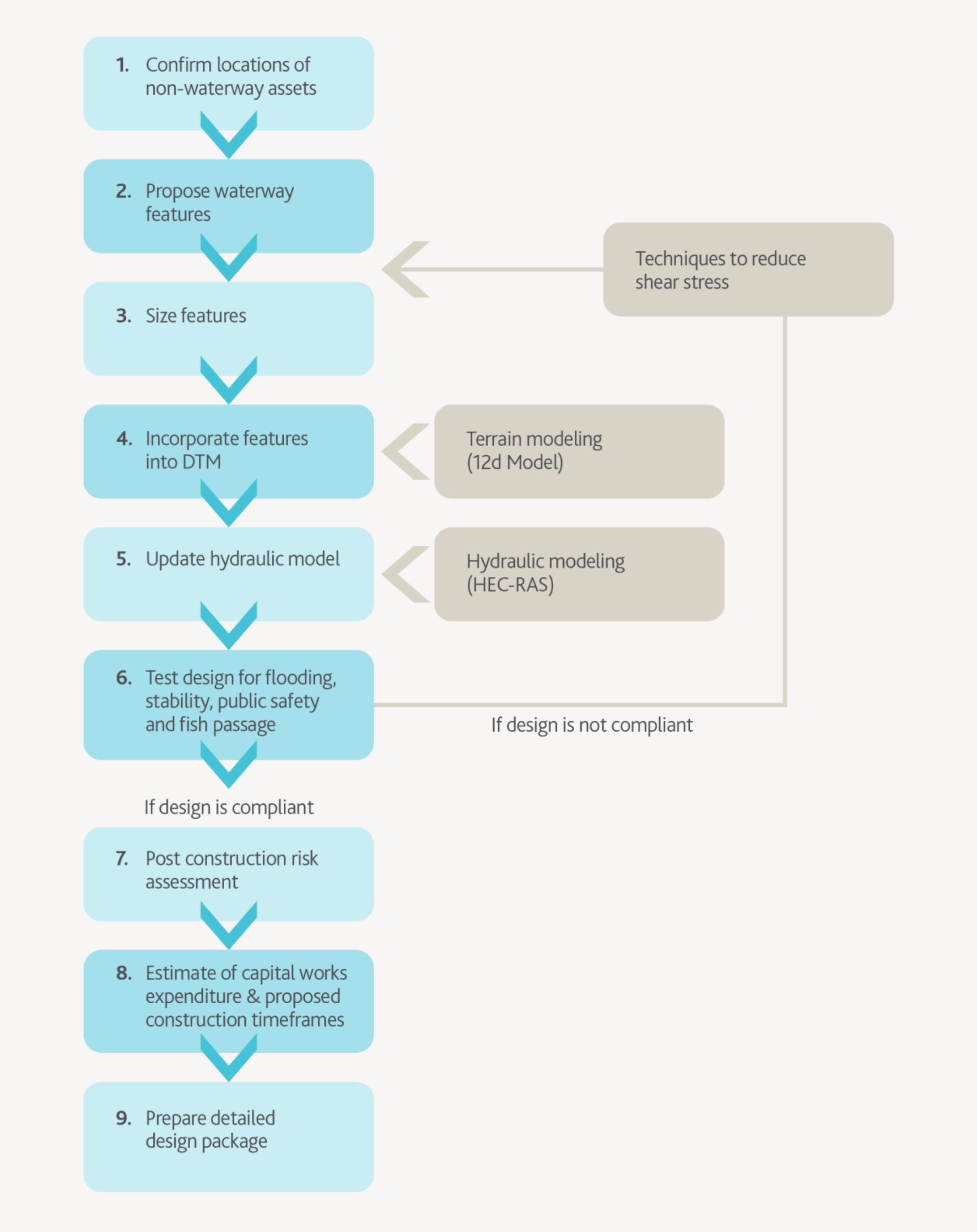


Figure 55 - Tasks to develop the detailed design package.

D3.1 Design of waterway features

Once all features and their locations have been identified, the designer can develop the detailed design by using the specific design processes set out for each feature in the following section including:

- Vegetation design
- Engineered structures
- Habitat features
- Landscape features
- A useful resource designers can draw on is the Cooperative Research Centre (CRC) for Water Sensitive Cities fact sheets about improving the ecological function of urban waterways.

Vegetation design

The designer must develop a fully detailed vegetation design at this stage. The *Healthy Waterways Vision – Vegetation Template* applicable to the site should be used as the primary resource. The minimum vegetation quality standard is level 3. The templates provide important information on the preferred planting zones for the different species. Vegetation visions are available for most communities, but not all. Where they are not available a landscape architect could differ to the DELWP EVC templates.

During the functional design phase the key vegetation design steps are worked through at the reach-scale. In this stage, the vegetation design should take into account the effect of varying batter slopes and introducing physical features such as benches to the high flow channel, on the inundation frequency of and the water depths and shear stresses over the nominated vegetation communities.

The landscape designer must provide:

- A plan view clearly showing the location of zones of different vegetation communities within the waterway corridor
- Typical cross-sections showing the vegetation zones in relation to areas of different inundation frequency in the waterway (i.e. areas inundated by base flows, the 4EY month flow, other low flows, and the 15% AEP year flow) (Figure 56)
- A list of species, numbers and planting densities for each vegetation zone
- Details of the presumed shear resistance of the proposed vegetation zones at establishment, and during the juvenile and mature phases
- Details of any additional treatments required to increase the erosion resistance of the bed and/or banks of the waterway during the vegetation establishment phase

The designer must then incorporate the vegetation design in the hydraulic model by inputting the different hydraulic roughness of the different vegetation communities within the waterway.

Under a changing climate, the window for terrestrial vegetation planting has reduced to only 4-5 months of the year (May to August/September). This may continue to change and the designer will review the current version of Melbourne Water's planting standards, which will be updated as more is understood about provenance and species selection in light of climate change.

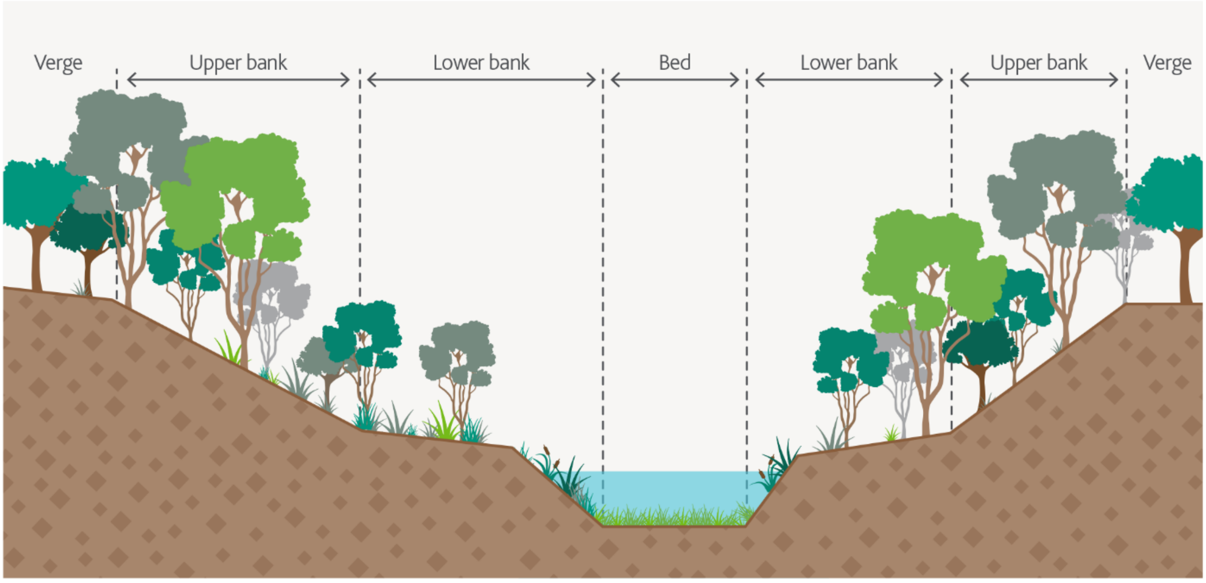


Figure 56 - Hydraulic zonation and native vegetation

Engineered structures

Incorporating engineered structures into the waterway ensures the asset protection design objectives will be met.

In this section the design of the following features is covered:

- Waterway crossings
- Stormwater connections/drainage outfalls
- Grade control structure (rock chutes)
- Bank stabilisation treatments (rock beaching)
- Bank strengthening materials.

Waterway crossings

Waterway crossing design details are set out in Melbourne Water's Constructing Waterway Crossings Guidelines. The guideline provides design criteria for single span and culvert crossings as well as pedestrian crossings. **Design criteria** include:

- Minimum freeboard
- Abutment offsets from bank (for single span structures)
- Shared pathways (see also Melbourne Water's *Shared Pathway Guidelines and Waterway Crossings Guidelines)*
- Rock work configuration
- Minimum safety criteria for culvert crossings

Final details of all waterway crossings must be added to the hydraulic model to determine the hydraulic impact of the design arrangement. Proposed waterway crossings must also incorporate accommodations for fish passage which should be developed in consultation with an experience aquatic ecologist.

Stormwater connections

Design of stormwater outfalls must consider:

- Appropriate sizing of the outlet for the design contributing flow. This is set by Melbourne Water in the DSS for Scheme pipelines only (i.e. not subdivisional pipelines). The designer will have to check Melbourne Water's design to ensure the assumptions are still valid, or alter the design as required before finalising. The designer will have to perform their own design for all non-Scheme pipeline connections to the waterway.
- Configuration to facilitate access and maintenance requirements.
- Protection, such as additional rock or vegetation, where flows are likely to cause scour due to increased turbulence or shear stress.
- Stormwater drainage outfall standard drawing.

Except where there is a significant change in the channel cross-section around the stormwater outlet, the outfall is generally not required to be represented in the terrain model (or the hydraulic model) in a physical sense. Stormwater outfalls are always incorporated into the hydraulic model in terms of their contributing flow.

Grade control structures

Rock chutes are typically large engineered rock structures used to stabilise the channel bed and promote a stable longitudinal grade. The placement and configuration of rock chutes within a stream corridor can vary according to the objectives and the constraints of the waterway. Typical applications of rock chutes include:

- Stabilising the stream bed (i.e. engineering a fast moving, high energy, rock lined section of waterway to ensure the stream bed upstream remains stable)
- Creating an artificial pool-riffle sequence for the provision of habitat. Further guidance on pool-riffle design is provided later.
- Other applications such as provision of fish passage, diversion weirs, or sediment stabilisation.

Two references provide all the rock chute design guidance required:

- The Technical Guidelines for Waterway Management (DSE 2007):

  Sections 3.3.27 outlines rock chute construction, uses, benefits and failure mechanisms;

  Section 5.4.6 describes the use of rock chutes as part of a reach-scale grade control strategy. This is of particular importance to constructed waterways in steep settings where a number of rock chute structures are required to establish a stable bed grade through the corridor.

  CRC for Catchment Hydrology (2003) Guidelines for the Design of Rock Chutes using CHUTE

Although the concept of a rock chute is simple, proper hydraulic design is critical to ensure that the chute geometry and rock size are matched with the expected flow conditions, such that the rock remains stable under all expected flow conditions. Rock chutes are designed using the CHUTE spread sheet (available via the eWater Toolkit http://www.toolkit.net.au/tools/CHUTE).

Inputs to the spread sheet and depicted in Figure 57 include:

- Chute drop - the elevation difference between the crest and apron start. The apron rise height should also be specified. This has the effect of pulling the hydraulic jump back onto the apron (usually required in steeper settings)
- Chute length. Length of crest, chute and apron are entered separately. The total constructed length is the sum of crest, chute and apron lengths;

- Width – the width of the chute
- Flow rate. The lower flow can be set to any nominal value of interest. The upper flow rate is generally set at the design flow rate (refer to functional design stage)
- Tail water condition. There are four options for setting the tailwater condition. It is recommended that a rating curve be extracted from HEC-RAS for this purpose. The conservative design approach is to assume the lowest tailwater level of the four options available
- Factor of safety. Generally, set at 1.3 for the purpose of constructed waterway design however may be altered on a case by case basis to balance cost with risk of failure (CRC for Catchment Hydrology 2003).

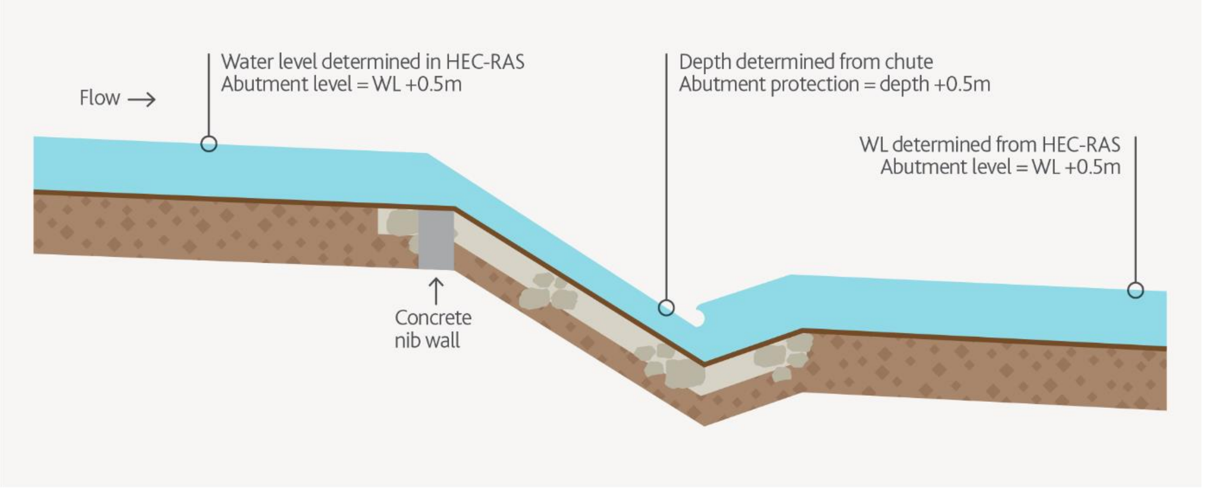


Figure 57 - Schematic of a typical Chute

The design rock chute geometry must be practical to construct. The following guidelines are recommended to achieve a practical design:

- The recommended rock size should be rounded to the nearest 50 mm. For example a design rock size of 328 mm is not acceptable. The designer should round to 350 mm and alter the geometry accordingly.
- D50 600mm is recommended as the upper limiting median rock size in any rock chute design. This size is the recommended upper limit from a sourcing/production, transport, and construction perspective. D50 is a nominal rock diameter of which 50% of the rocks are smaller and represents the median rock size.

The abutment height along the rock chute is determined from the CHUTE output. The abutment protection must be 0.5m above the maximum depth predicted by CHUTE at the hydraulic jump and must be rounded to the nearest half meter. For example, in the CHUTE output shown in Figure 58 below, the jump depth for the design flow ($6m^3/s$) is 0.3m. Therefore, the abutment protection must extend at least 0.8m up each batter, however rounding to the nearest half-meter means that rock protection must be constructed 1m up the batter all the way along the chute. The abutment protection height upstream (leading into the chute crest) and downstream (extending downstream of the chute apron) is determined using the HEC-RAS model. Again, a 0.5m buffer must be applied to this level.

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	29	4	21	0.046	0.02	0.0315	0.047	0.053	0	2	jump in chute; OK	29.440	0.031	0.032	0.000	2.894
0.69	106	106	21	0.146	0.138	0.1143	0.171	0.181	0	2	jump in chute; OK	29.440	0.065	0.184	0.035	2.855
1.28	160	160	21	0.213	0.256	0.1726	0.259	0.27	0	2	jump in chute; OK	29.368	0.098	0.278	0.053	2.836
1.87	206	206	21	0.268	0.374	0.2222	0.333	0.345	0	2	jump in chute; OK	29.477	0.127	0.358	0.068	2.820
2.46	247	247	21	0.316	0.492	0.2668	0.4	0.411	0	2	jump in chute; OK	29.608	0.152	0.430	0.082	2.807
3.05	285	285	21	0.360	0.605	0.3079	0.462	0.473	0	2	jump in chute; OK	29.725	0.175	0.496	0.095	2.794
3.64	321	321	21	0.402	0.664	0.3464	0.52	0.531	0	2	jump in chute; OK	29.832	0.197	0.558	0.107	2.782
4.23	355	355	21	0.441	0.7345	0.3829	0.574	0.585	0	2	jump in chute; OK	29.935	0.218	0.617	0.118	2.771
4.82	387	387	21	0.477	0.823	0.4177	0.627	0.637	0	2	jump in chute; OK	30.032	0.238	0.673	0.129	2.761
5.41	418	418	21	0.512	0.8705	0.4512	0.677	0.687	0	2	jump in chute; OK	30.131	0.257	0.727	0.139	2.751
6.00	448	448	21	0.545	0.9	0.4834	0.725	0.735	0	2	jump in chute; OK	30.228	0.275	0.779	0.149	2.741

Figure 58 – example output from CHUTE spread sheet

Angular quarried rock (basalt/granite) is recommended for the construction of rock chutes. There are particular quality and gradation objectives for the quarried rock. See Melbourne Water's Rockwork Construction guidance. Sedimentary rock is not acceptable.

Appropriate rock chute design requires that a number of other issues are adequately addressed. In particular:

- Chutes should be located where they can serve their function most efficiently and effectively
- The abutments must be treated to prevent failure by outflanking of the crest
- The grading of rock sizes within the rock mixture must minimise the presence of voids and minimise the area of individual rocks exposed to forces from the flow
- Where the underlying material is largely non-cohesive or where high ground-water levels or seepage occur, consideration should be given to the use of filter layers.

Rock chutes, or rock riffles, must be designed to facilitate fish passage where required. The industry standard recommends that chutes must not be steeper than 1V:20H longitudinal grade to enable fish passage, noting that a requirement for steeper chutes may have been established and agreed upon with Melbourne Water in the concept stage design.

The designer must first design the chute according to its proposed location within the waterway and then once the chute meets the applicable performance criteria, the relevant chute characteristics can then be incorporated into the hydraulic model.

Some iteration in chute location within the hydraulic model may be required depending on the modelling results. For example, the location of the hydraulic jump, and the shear stresses upstream and downstream of the chute need to be assessed, and the chute design and/or location be modified accordingly. This also applies if a series of chutes is being used. It is necessary to confirm in the hydraulic model that over the reach, dissipation of stream energy is being managed within the acceptable erosion thresholds for the waterway.

Bed and bank strengthening materials

Bed and bank lining materials can be used to protect the waterway against erosive flows and are especially important in the immediate post-construction period, as vegetation is yet to establish. Materials such as organic meshes (e.g. coconut fibre) protect against lower energy flows for a shorter time span. The choice of material is specific to the application and must consider:

- The design life. Through exposure to ultraviolet light, soil, and water the material will deteriorate over time. The design life of the material must meet the objectives of the site and must be study enough to allow vegetation to establish and supersede the protective material (generally 18 months maximum).
- Technical specifications. Material strength, maximum slope of application, and maximum flow velocity or shear stress criteria

- Aesthetics. Some materials allow vegetation to establish throughout and will quickly be hidden beneath. Others suppress all or most vegetation and will be visible for the design life.
- Biodegradable. Organic based materials degrade and become mulch as they break down. Synthetic based products (such as HDPE or PP) will not be accepted by Melbourne Water.
- Permeability. Water infiltration and retention of soil moisture are important consideration for soil health and the establishment of vegetation. Soil temperature is also an important consideration.
- Weed suppression. Some materials will suppress weeds however this must be balanced with the objective of establishing grasses at the site.
- Seed germination. Seed infused fabrics offer significant advantage in establishing consistent grass coverage over the site
- Construction. Some materials may require pins or adhesives to install the material. Manufacturers specifications for application and installation should be followed.
- Cost. Cost of treatment versus level of protection provided

The Melbourne Water jute mat specification has details on the specifications for various materials and the velocities they can withstand.

Rock beaching

Rock beaching involves the placement of angular, quarried rock, typically basalt/granite, on stream banks. The rock is founded on the bed of the stream and generally extends up the portion of the bank threatened by erosion. This technique provides localised protection only and does not address system-wide geomorphological processes. If inappropriately designed, rock beaching can cause erosion issues further downstream. Typical applications of rock beaching in urban waterways include (see **Error! Reference source not found.**):

- Stabilising the outer bank of meanders, where local shear stresses exceed acceptable thresholds
- Waterway protection at drainage outfall points
- Upstream and downstream of culverts, and around bridge piers

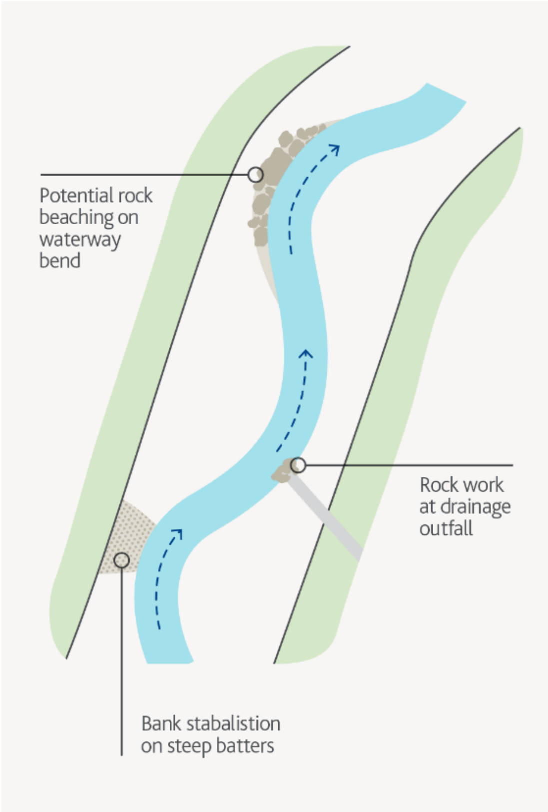


Figure 59 - Typical applications of rock beaching

A significant amount of rock beaching design guidance is already available in existing literature as follows:

- The Technical Guidelines for Waterway Management (DSE 2007):

  Sections 3.3.26 outlines rock beaching construction, uses, benefits and failure mechanisms;

  Section 5.4.4 describes the design procedure and application of rock beaching;

  Section 4.1.3 (materials specification), 4.2, 4.3 and 6.4.

- Guidelines for the Design of River Bank Stability and Protection using RIP-RAP (CRC for Catchment Hydrology 2005), available via: www.toolkit.net.au/riprap

Rock beaching is typically designed using the RIP-RAP spread sheet (available via the eWater Toolkit). Inputs to the spread sheet include the rock material parameters, bank angle, and depth of flow and energy grade slope. Flow parameters can be used from the HEC-RAS model.

As with chutes, once localised rock beaching features have been designed using RIP RAP and meet the required performance criteria, the designer must incorporate the relevant characteristics into the hydraulic model and test the features by running the model. Similarly, to chutes, the location and design of rock beaching may need to be amended depending on the results of the modelling.

Habitat features

Habitat features are a core component of ensuring a waterway design will meet the required habitat and connectivity objectives, as well as contribute towards the amenity objectives.

In this section the design of the following features is covered:

- Pools and riffles
- Benches
- Large wood
- Fish passage
- Frog ponds

Pools and riffles

Pools and riffles are critical waterway features, as discussed in Part A, providing habitat, refuge, hydraulic variability and visual interest. Riffles do not perform a formal grade control function like a rock chute does.

Riffles typically occur in a series and are not necessarily designed to survive in-situ during all flow events in natural waterways. In constructed waterways, a nominated design event must be chosen that equates to the objectives of the riffles.

Riffles are typically located at meander inflection points (Figure 60). While the location of meander inflection points and bend apexes are geometrically defined, the location of pools, defined by the position of maximum bend scour, is variable (NRCS 2007). Pool location is controlled by: the meander configuration, complex velocity distribution, and large-scale coherent flow structures which pulse sediment along the channel to form alternate zones of scour and fill. In natural meanders, the deepest pool is usually located downstream from the bend apex.

Pools are also required upstream and downstream of all culverts and this transition is important (see standard drawing).

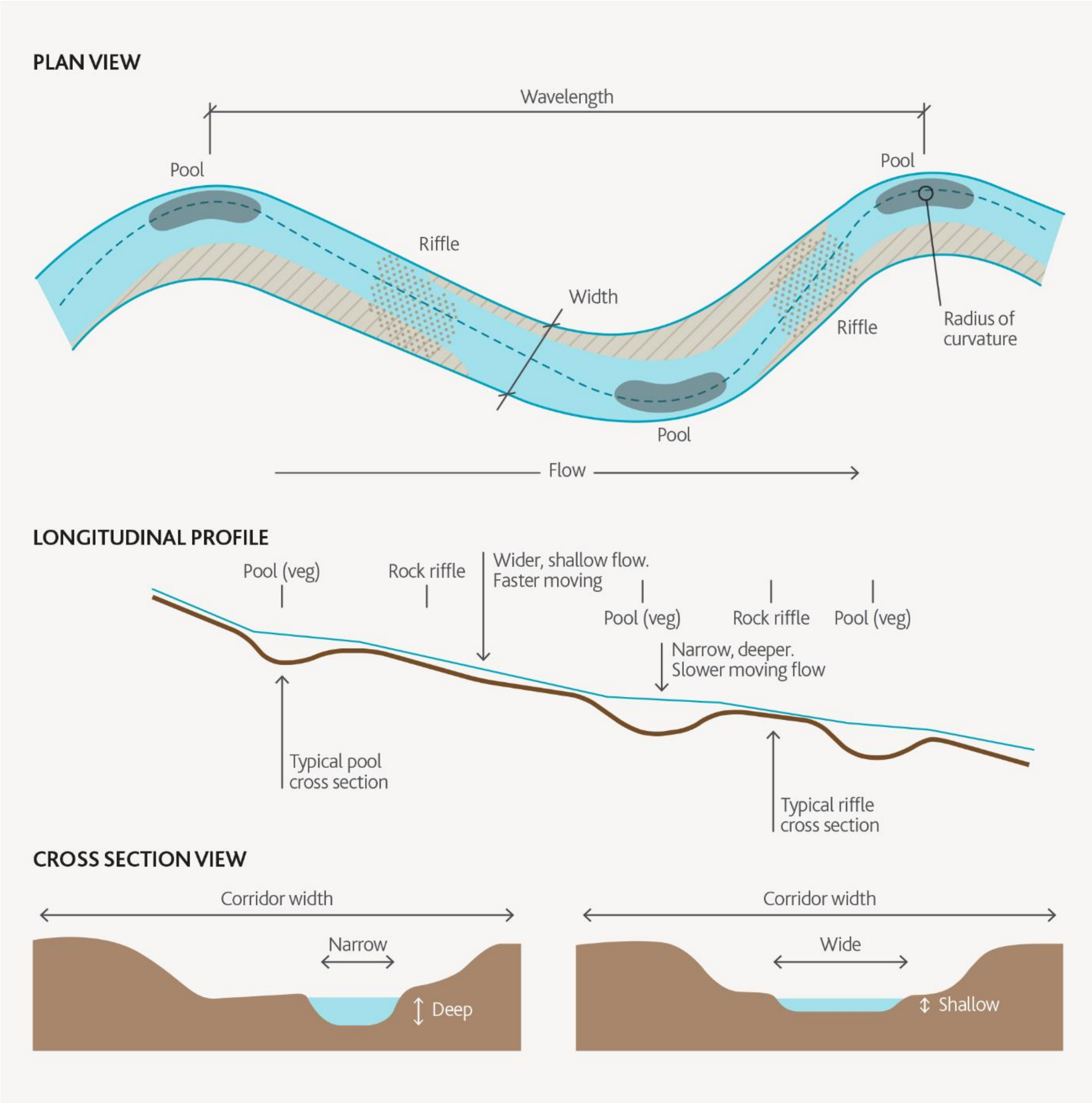


Figure 60 - Idealised pool-riffle sequence

To assist the designer to locate pools and riffles, the appropriate pool and riffle geometry and configuration can be determined according to the design criteria in Table 23.

Table 23 - Pool-riffle geometry design criteria

ELEMENT	CRITERIA
Spacing	Typically between 20-30 times low flow channel top width
Location	The deepest point in the pool is generally located a short distance downstream of the meander apex – one fifth the distance from the meander apex to the downstream inflection point. The location can range between: • Just upstream of the meander apex – no more than one fifth of the distance from the apex to the upstream inflection point • Distance downstream of the bend apex – no more than half the distance to the downstream inflection point
Length	Typically between 3-4 times the maximum pool width
Width	Maximum width extends to the outer extent of the beaches. Pools are generally of a 'tear drop' shape
Depth	Intermediate pools typically 600mm deep. Culvert pools typically 700mm deep below the 'dry cell' culverts

Urban streams are typically more ephemeral than their natural equivalent. The hydrology of developed urban areas often exhibits no base flow whatsoever. Pools therefore represent important habitat refugia for fish and other aquatic communities during a dry period. Where pools are required as critical drought refuge (flagged at the concept design stage) the pool geometry and configuration must demonstrate that critical habitat objectives are met.

The designer may use any rainfall-runoff model (MUSIC is recommended) to demonstrate that the pool will not run dry at critical times over a typical rainfall period. MUSIC may be used to represent the urban catchment draining to a series of pools, using the 'pond' node or the 'sedimentation basin' node. The model should be run over a representative rainfall series. The exfiltration rate, the rate at which pooled water is lost to soil storage, may be based on knowledge of the local soil conditions within the guidance provided by Melbourne Water's MUSIC Guidelines. The rainfall and evaporation data must also be for local conditions as set out in the MUSIC Guidelines.

The approach to pool-riffle design and construction can vary between catchment settings. Waterways constructed in stable catchment settings, where the existing grade is largely stable and does not require bed stabilisation measures such as rock chutes, may have pools excavated in-situ as shown in Figure 61 (left).

In unstable catchments where grade control is required to establish a stable bed grade the rock chutes may be employed to also provide a pool-chute sequence (refer Grade Control Structures in this section). Once the stable bed grade has been achieved between successive chutes, pools are excavated and shaped.

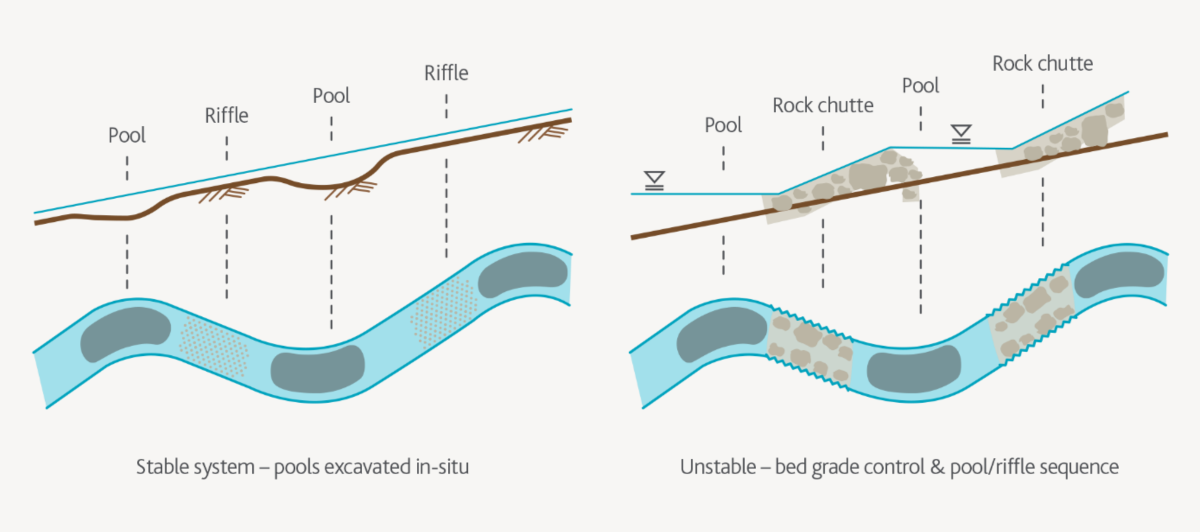


Figure 61 - Conceptual diagram of two approaches to pool-riffle construction

It is important to incorporate the proposed pool-riffle sequence into the terrain and hydraulic modelling.

Benches

Benches in natural waterways are horizontal geomorphic features formed by the deposition of sediment during flow events. As described in Part B, benches are important habitat features for native biota in waterways. Benches must be incorporated into the terrain and hydraulic models.

Benches are constructed by creating areas within the channel cross-section at different water levels and inundation frequencies. The designer can adjust the levels to provide the right hydrologic conditions (frequency and depth of inundation, and shear stress) for the proposed vegetation communities for these features (Figure 62). Information on the preferred hydrologic conditions for different plant species is provided by the Healthy Waterways Visions for Vegetation Species.

- Benches must not sit above the 10% AEP flood inundation level otherwise they will be too dry to perform the required habitat and ecological function.
- Benches should have a 1:20 to 1:40 cross fall toward the waterway to facilitate drainage.

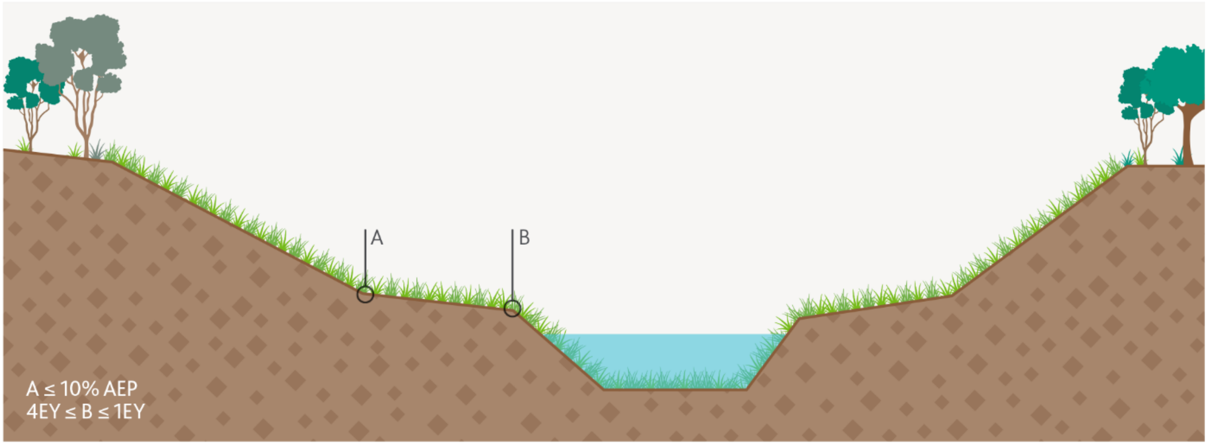


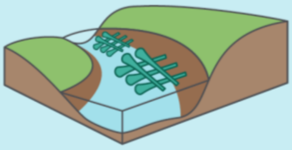
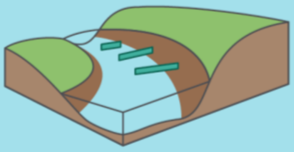
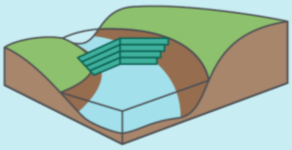
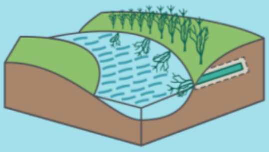
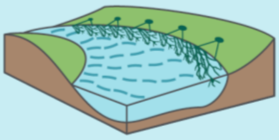
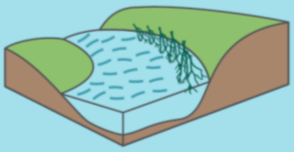
Figure 62 – Example cross-section illustrating the bench design criteria

Figure 63 - Example of benching contributing to a varied planform and diverse vegetation (Mernda Village)

Instream Woody Habitat

Instream woody habitat (IWH)is installed to provide instream habitat by creating flow diversity and providing shelter, habitat, and resting places for a variety of native animals. IWH structures include engineered log jams, vanes, weirs, toe logs, etc. (Table 24, NRCS 2007).

Table 24 Limitations on applicability of instream woody habitat structures (from NRCS 2007)

CONFIGURATION	SKETCH	DESCRIPTION	STRENGTHS	REFERENCES
Engineered logjams		Intermittent structures built by stacking whole trees and logs in crisscross arrangements	Emulates natural formations. Creates diverse physical conditions, traps additional debris	Abbe, Montgomery, and Petroff (1997); Shields, Morin, and Cooper (2004)
Log vanes		Single logs secured to bed protruding from bank and angled upstream. Also called log bendway weir	Low-cost, minimally intrusive	Derrick (1997); D'Aoust and Millar (2000)
Log weirs		Weirs spanning small streams comprised of one or more large logs	Creates pool habitat	Hilderbrand et al. 1998; Flosi et al. (1998)
Rootwads		Logs buried in bank with rootwads protruding into channel	Protects low banks, provides scour pools with woody cover	
Tree revetments or roughness logs		Whole trees placed along parallel to current. Trees are overlapped (shingled) and securely anchored	Deflects high flows and shear from outer banks; may induce sediment deposition and halt erosion	Cramer et al. (2002)
Toe logs		One or two rows of logs running parallel to current and secured to bank toe. Gravel fill may be placed immediately behind logs	Temporary toe protection	Cramer et al. (2002)

Selecting the appropriate type of structure and its configuration must consider the site specific hydraulic parameters (velocity, shear stress), address the habitat objectives, and must not cause unacceptable levels of channel instability at the site. The choice of structure must also consider cost and constructability, safety, access, and maintenance requirements.

Table 25 - Classification of instream woody habitat (IWH) structures (from NRCS 2007)

VARIABLE	CONSIDERATIONS
Habitat requirements	Provides physical diversity, cover, velocity shelter, substrate sorting, pool development, undercut banks, and sites for terrestrial plant colonisation using natural materials
Existing IWH density	Absent or depressed relative to similar nearby reaches that are lightly degraded
Sediment load	Generally not suitable for high-energy streams actively transporting material larger than gravel. IWH structures may be rapidly buried in high sediment load reaches, diminishing their aquatic habitat value, but accelerating recovery of terrestrial riparian habitats
Bed material	Anchoring will be difficult in hard beds such as cobble, boulder or bedrock
Bed stability	Not suitable for avulsing, degrading, or incising channels. The best situations include areas of general or local sediment deposition along reaching that are stable or gradually aggrading. Deposition induced by LWM structures may be stabilised by planted or volunteer woody vegetation, fully rehabilitating a naturally stable bank by the time the placed woody materials decay (Shields, Morin, and Cooper 2004). Unlike some of the other structures, rootwads often create scour zones, not deposition
Bank material	IWH structures places in banks with >85% sand are subject to flanking
Bank erosion processes	Not recommended where the mechanism of failure is mass failure, subsurface entrainment, or channel avulsion. Best when toe erosion is the primary process
Flow velocity	Well-anchored structures have been successfully applied to situations with estimated velocities – 2.5m/s (D'Aoust and Millar 2000). Rootwad installations have withstood velocities of 2.7 to 3.7 m/s (Allen and Leech 1997) Engineered logjam (ELJ)-type structures withstood 1.2 m/s in a sand-bed stream (Shield, Morin, and Cooper 2004)
Site access	Heavy equipment access usually is needed to bring in and place large trees with rootwads
Conveyance	IWH structures can increase flow resistance if they occupy significant parts of the channel prism (Shields and Gippel 1995; Fischenich 1996)
Navigation and recreation	IWH should not be located where they will pose a hazard or potential hazard to commercial or recreational navigation. Potential hazards are greatest for structures that span the channel
Raw materials	Suitable sources of trees needed nearby
Risk	Not suited for situations where failure would endanger human life or critical infrastructure

Technical details regarding the design and implementation of large wood structures is available in the existing literature. Large wood is to be included in the hydraulic model. The designer is directed to these resources for further guidance:

- Technical Guidelines for Waterway Management (DSE 2007):
  Sections 3.3.16 described engineered log jams and their application
  Section 3.3.22 describes large wood installation
  Section 5.4.7 guides the designer through instream scour hole and habitat design
  Section 6.3 guides the designer through the stability analysis process for large wood and engineered log jams
  Section 4.1.2 describes the required timber/large wood material specification

- Design guideline for the reintroduction of wood into Australian streams (Brooks et al. 2006.) describes the design considerations for reach-scale large wood reintroduction strategy. Although this resource is tailored for re-introduction strategies to existing streams, many of the design objectives are applicable to constructed waterways. In particular:

  Data requirements to perform force-balance stability analysis and design of a wood reintroduction strategy

  Selecting a design flood, hydraulic modelling and scour prediction

  Anchoring strategies and stabilisation using piles

  Structure stability analysis

  Alternative log structures (pre-fabricated deep water fish habitat structures)

- Managing Woody Debris in Rivers (Rutherfurd et al 2002) includes limited design criteria such as placement angle, minimum lengths and diameters.
- The National Engineering Handbook technical supplement 14J Use of large woody material for habitat and bank protection(NRCS 2007 TS 14J ref) summarises the available design variables (Table 26) and provides extensive design guidance relating to placement, sizing, materials considerations, force and moment analsys and anchoring techniques.

Table 26 - Published values for design of instream woody habitat structures (from NRCS 2007 TS 14J)

QUANTITY	USED FOR	TYPICAL VALUES	SOURCE
Density of wood in g/cm^3 (lowest, or worst-case condition[1/])	Buoyant force computation	0.4 to 0.5 0.5 0.4 to 0.5	Shields, Morin and Cooper (2004) D'Aoust and Millar (2000) D'Aoust and Millar (1999)
Drag coefficient	Drag force computation	0.7 to 0.9 Up to 1.5 0.4 to 1.2 1.0 1.2 to 0.3 (tree) 1.2 (rootwad)	Shields and Gippel (1995) Alonso (2004) Gippel et al. (1996) Fischenich and Morrow (2000) D'Aoust and Millar (2000) D'Aoust and Millar (1999) D'Aoust and Millar (1999)
Design life for wood, yr	Planning	5 to 15	Fischenich and Morrow (2000)
Soil strength	Analysis of loads/ anchoring provided by buried members	Soil forces on buried members neglected in order to be conservative. Range of values based on soil types	Shields, Morin and Cooper (2004)

Fish and frog passage

Waterway design should be carried out to ensure there are no barriers to fish and frog passage in the proposed waterway. Barriers may include available light as some fish species will not enter dark places, and flow conditions such as depth and velocity. If the waterway velocity exceeds the fish species burst speed the fish cannot move through the high velocity area.

Fish passage is required where specified by the objectives of the proposed waterway. Fairfull and Witheridge (2003) recommend types of waterway crossings over waterways with fish habitat (Table 27)

Table 27 - Recommended waterway crossings in fish habitats (adapted from Fairfull and Witheridge 2003)

CHARACTERISTICS OF WATERWAY	RECOMMENDED CROSSING TYPE
Major fish habitat	
Permanently flowing river or named permanent or intermittent flowing stream, creek or watercourse containing threatened fish species.	Bridge, arch structure or tunnel
Moderate fish habitat	
Named permanent or intermittent stream, creek or watercourse with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and/or fish observed inhabiting the area.	Bridge, arch structure, culvert
Minimal fish habitat	
Named or unnamed watercourse with intermittent flow, but has potential refuge, breeding or feeding areas for some aquatic fauna (eg. fish, yabbies). Semi-permanent pools form within the watercourse or adjacent wetlands after a rain event. Otherwise, any minor watercourse that interconnects with wetlands or recognised aquatic habitats.	Culvert
Unlikely fish habitat	
Named or unnamed watercourse with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools after rain events (eg. dry gullies or shallow floodplain depressions with no permanent wetland aquatic flora present). No aquatic vegetation present within the channel.	Culvert

The default position is that **all** waterways provide fish and fauna passage movement to preserve future opportunity.

To achieve this outcome at crossings a free-span bridge or 'dropped cell' box culvert (Figure 64) must be adopted. If an alternative approach is proposed, then the designer must demonstrate the following:

- Seek expert advice from a fish ecologist regarding the light requirements, and maximum burst speed and sustained swim speed for the particular species being designed for.
- Other design parameters may include minimum or seasonal flow requirements (maintaining a certain flow over the structure at all times or during particular seasons when fish are known to be moving through the waterway).
- Ensure that the design flow velocities across the crossing do not exceed the sustained swimming speed of the fish species. Ideally the maximum burst speed should also not be exceeded.
- Where more than one species is being designed for, the slowest sustained swim or burst speed must be used as the maximum velocity criteria through the crossing or grade control structure. The fish passage design flood event is a function of the objectives for fish passage (and other considerations) in the reach. For example, if fish passage is required for everything up to the 10% AEP flood event, then the crossing must be designed to have velocities at or below the sustained and burst speed and length for all events up to the 10 % AEP flood event.
- Where velocities exceed the sustained swimming speed, ensure that appropriate fishway design methods are applied to facilitate fish passage through the crossing. Culvert crossings may need to have a more gradual grade or be larger in area. Small flow obstructions (rocks, concrete baffles) can be strategically placed along the length of the crossing to provide refuge/resting places for fish as they navigate the crossing.

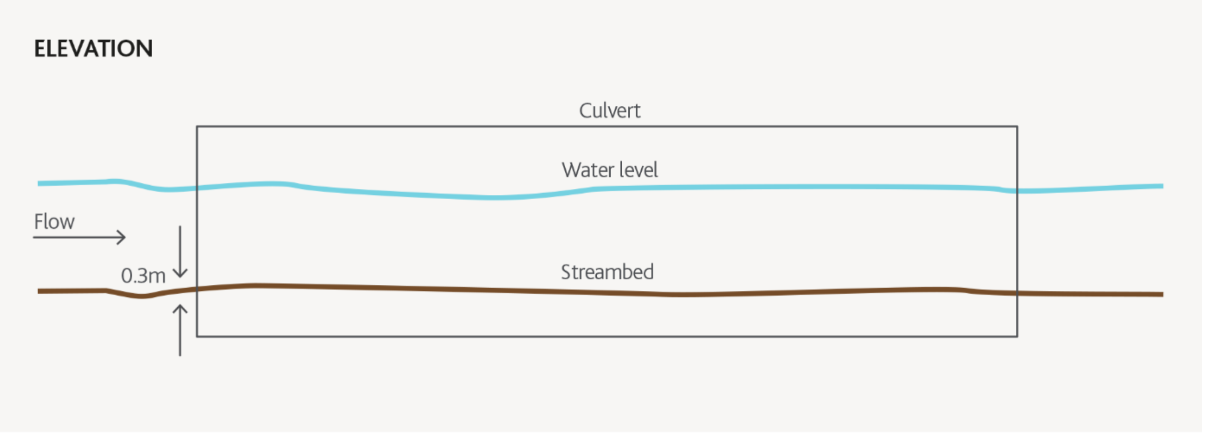


Figure 64 - A box culvert sunk by 0.3m to enable stream bed material to accumulate and encourage fish passage (Arthur Rylah Institute, Guidelines for fish passage at small structures, 2017)

Fish passage design can only be addressed on a case by case basis. Presenting the various options explored as part of the functional design package will help Melbourne Water, the designer, and stakeholders to agree on the appropriate solution.

The designer is directed to these resources for further guidance:

- Arthur Rylah Institute Fishways and fish movement
- The Technical Guidelines for Waterway Management (DSE 2007). Of importance to constructed waterways in urban developments, Sections 3.3.19 provides planning and design guidance on fish passage through culverts.
- Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings (Fairfull and Witheridge 2003) describes various fish barriers and presents a brief overview of the design considerations for fish friendly waterway crossings within Australia
- Fish Passage in Streams – Fisheries Guidelines for Design of Steam Crossings (Cotterell, E. 1998)
- The Culvert Fishway Planning and Design Guidelines (Kapitzke 2010) are intended to introduce designers to fish migration barrier problems at waterway structures; assist in the identification of mitigation options; present a framework for planning, design and implementation of fish passage facilities; and provide a basis for achieving multipurpose outcomes in relation to fish passage, drainage, utility and environmental values (James Cook University 2012).
- Information on freshwater fish fauna within Australia and for particular regions can be obtained from several primary references, including: Australian freshwater fish – Biology and management (Merrick and Schmida 1984); Freshwater fishes of Australia (Allen 1989); and Field guide to the freshwater fishes of Australia (Allen et al. 2003)

Culverts can be designed to be frog friendly by raising a section of the base above the normal water level to provide a dry passageway through the culvert. The Growling Grass frog Crossing Design Standards should be followed if the site falls in a GGF conservation area to meet the design criteria required.

Fish and frog passage is provided by well-designed grade control structures and waterway crossings. Fish and frog passage is not always able to be directly represented in the terrain or hydraulic models, however these aspects must be clearly shown in the corresponding structures detailed design plans.

Growling grass frog ponds

The Growling Grass Frog Masterplan and Growling Grass Frog Habitat Design Standards (DELWP 2017) should underpin any design to provide habitat for the Growling Grass Frog within the constructed waterway corridor. The Standards describe critical habitat features, vegetation species and layout, and hydrologic regime.

The Sub-Regional Species Strategy for the Growling Grass Frog (DSE 2011) recognises important populations that are currently known to occur in the following areas:

- Merri, Darebin, Edgars and Kalkallo Creeks, and their tributaries
- Kororoit Creek, lower Skeleton Creek, sections of Werribee River, and their tributaries
- Jackson and Emu Creeks, and their tributaries
- Within the Casey-Cardinia growth area principally along the southern parts of Cardinia Creek and Clyde Creek.

Landscape features

Recreational infrastructure may be installed within the waterway and its corridor, subject to the type of infrastructure being located so that it does not compromise waterway function and must meet applicable public safety standards. Addressing such criteria will often determine whether the infrastructure sits within the waterway or outside of it.

In this section the design of the following features is covered:

- Pedestrian bridges and crossings
- Walking tracks and shared user paths
- Boardwalks, viewing platforms
- Jetties
- Playgrounds and picnic areas

Maintenance agreements will be required for any infrastructure that sits within the waterway and its corridor to ensure clarity of future asset management and maintenance considerations between Melbourne Water and council.

Pedestrian bridges and crossings

Where pedestrian crossings are proposed, the safety of users and the impact on the hydraulic regime need to be considered. The ownership and responsibility for public amenity and landscape design assets rests with council, therefore their safety and maintenance requirements must be adhered to.

The preferred type of pedestrian crossings considered by Melbourne Water is a single span structure with abutments. Design criteria for pedestrian crossings are outlined in Melbourne Water's *Shared Pathway Guidelines* and *Waterway Crossings Guidelines*, and include:

- Pedestrian crossings should not adversely impact the functioning of nearby assets (e.g. road crossings) by increasing the flood height or flow velocity
- The underside of a pedestrian bridge should be set at or above the 1 in 10 year ARI flood level and should not result in an increase up to and including the 1 in 100 year ARI level.
- There should be no crossings in the upstream or downstream general vicinity of critical culverts or bridges, except where the proposed crossing is above the 1% AEP flood level (this minimises potential impacts to critical culvert functions during flood events)
- Rock armouring for scour protection is required under bridges and decks where vegetation cannot grow due to lack of sunlight
- Crossings must be designed to facilitate fish or frog passage (where required).

Details of all waterway crossings must be added to the hydraulic model to estimate the hydraulic impact of the design arrangement.

Walking tracks and shared user paths

Siting of shared paths located within the waterway corridor must be set above the 10% AEP flow level. The designer must refer to Melbourne Water's Shared Pathway Guidelines and also seek Melbourne Water's guidance on the requirements of this type of infrastructure on a case-by-case basis. The encroachment of paths into the core riparian zone is limited and must be in accordance with the criteria specified in Melbourne Water's Waterway Corridor Guidelines.

Boardwalks and viewing platforms

Boardwalks and viewing platforms may be desired as a means to provide integration between the waterway and the Public Open Space. These platforms must:

- Sit above the 10% AEP flood level.
- Not obstruct the capacity and hydraulic functioning of the waterway up to and including the 1% AEP flood level.

The designer must refer to Melbourne Water's Shared Pathway Guidelines and also seek Melbourne Water's guidance on the requirements of this type of infrastructure on a case-by-case basis.

Jetties

Jetties should be designed to not cause additional maintenance issues, in particular trapping sediment and rubbish which may impact upon the way the waterway functions. The designer must refer to Melbourne Water's Guidelines for the Approval of Jetties and also seek Melbourne Water's guidance on the requirements of this type of infrastructure on a case-by-case basis.

Playgrounds and picnic areas

Where playgrounds are nominated within proximity of a waterway, design requirements for safe play will come into consideration. If the playground is close to permanent open water, the safety of the playground must be increased by providing a physical barrier between the two. Where possible this barrier may take a more natural form working with topography, rockwork, and planting as an alternative to a formal fence subject to council approval. Ideally however, playgrounds should be set back away from permanent open water and any immediate waterway related hazards (see Public Safety note below).

Picnic areas are recreational assets that benefit from a positioning with a vantage point from which to view the waterway. An elevated location with visual connections is desirable. As physical interaction with a waterway is not the principal objective, it is best to position the picnic area with a level of physical separation from the waterway itself. Where a formal barrier may be desirable this can be incorporated into a positive feature of the picnic area, contributing to its overall amenity rather than detracting from it.

Design of playgrounds must not adversely impact the hydraulic functioning of the waterway (i.e. cause an appreciable increase in the flood level for all events up to and including the 1% AEP event). For these reasons it is preferable to both Melbourne Water and Council that these assets are located outside of the waterway corridor and above the 1% AEP flood level. However it may be acceptable to locate small pieces of equipment or furniture above the 10% AEP event.

Note that all playgrounds and picnic areas are subject to Council approval as the responsible authority.

D3.2 Incorporate waterway features into the terrain model

Now that the designer has sized and placed all the applicable features of the waterway, it is important to test the hydraulic performance of the proposed arrangement. To do this it is necessary to return to the terrain model to implement some, but not all, of these features in the constructed waterway TIN. Specifically, the terrain model must be refined to include:

- Engineered structures such as grade control structures, stormwater outfalls, and stormwater quality treatments (only when 'online');
- Habitat features such as pools and riffles; benches and bars

These features are graded into the functional design terrain model (Figure 65). The tools and methods required in this process include:

- Introduce cross-section variability to represent pools and riffles either by manipulating existing alignment strings and/or grading templates, or by creating new ones.
- The designer may introduce longitudinal variability by changing the alignment string's 'vertical geometry'
- The designer may introduce cross-section variability using the modifier function when applying the grading template/s
- Generate a combined TIN of the waterway design and existing terrain (to represent areas outside of the waterway itself). An example terrain model is shown in Figure 65.

Terrain modelling methods and procedures are detailed further in Part E**.**

Once the combined terrain model (or TIN) is established, the designer can generate the revised hydraulic model. As outlined in Section D2.7, the method to achieve this includes placement of river strings and source strings and using the river module to generate the HEC-RAS ready geometry file.

River strings and source strings may be moved accordingly with the outcomes of the detailed design. For example, should the feature-scale design entail a wide, extensive riffle at a meander inflection point, it would be pertinent that the left and right bank markers align with the top of bank as it expands and then contracts around the riffle section. Likewise, for the placement of source strings (cross-sections) it is generally a good idea to place more source strings through sections of waterway variability. For example, coming into and out of pools and riffle, or where benches appear/disappear in the waterway cross-section. More discussion on the placement of source strings at the feature-scale level of hydraulic investigation is provided in the next section.

The remaining waterway features are best specified within HEC-RAS itself, such as:

- Vegetation species distribution and extent (manning's n values);
- Engineered structures such as waterway crossings (bridges and culverts), bed and bank strengthening treatments, and rock beaching;
- Habitat features such as large wood structures;
- Landscape features such shared pathways, jetties, boardwalks and viewing platforms;
- Maintenance access tracks.

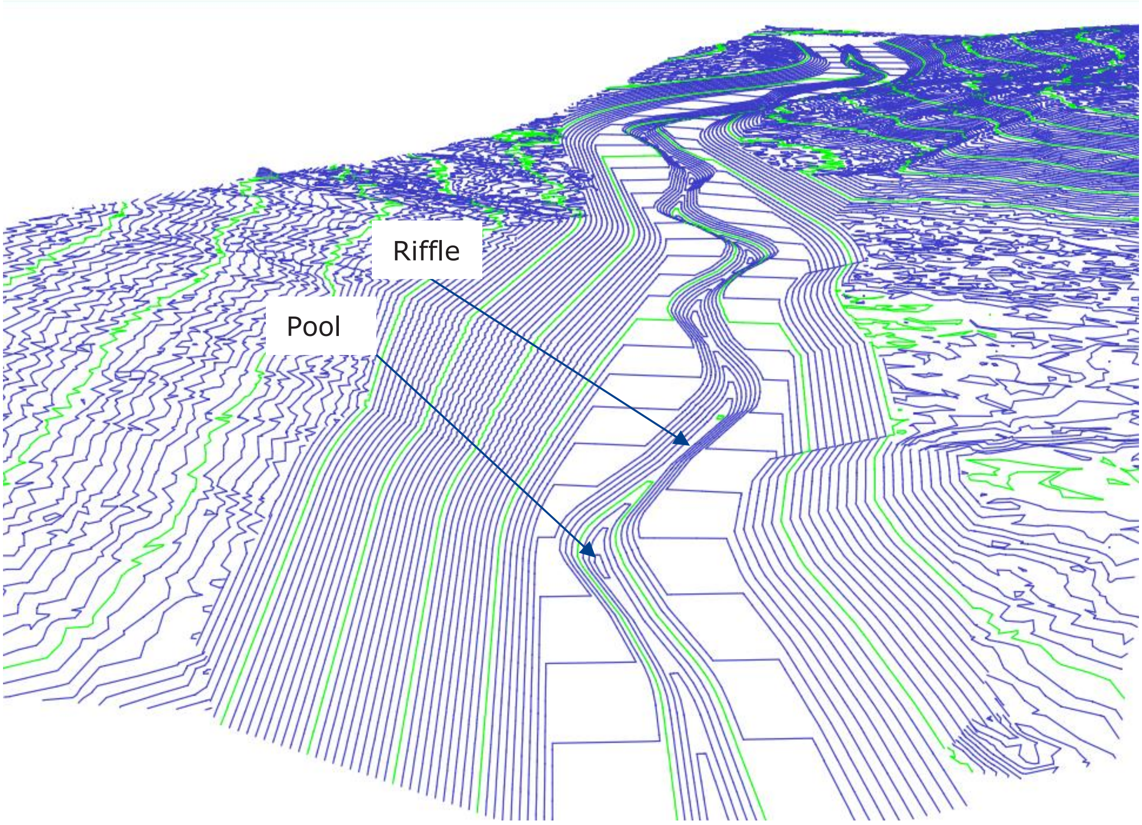


Figure 65 - Example terrain model of compound type waterway showing platform variation. Pools and riffles have been introduced at meander bends in the low flow channel

D3.3 Hydraulic modelling - placement of cross-sections

For the functional hydraulic investigation it was important to strike a balance between getting the minimum level of hydraulic detail to inform the design process, but not make the hydraulic model set-up, run and analysis steps too onerous or time consuming. The same principles are applied to detailed design hydraulic modelling, however given that this stage of design is concerned with feature level detail, there is the need to place source strings (cross-sections) at a finer resolution at each feature.

To meet the basic principles and objectives of sound one-dimensional hydraulic modelling there are a few rules of thumb that can be used to guide the designer in placement of cross-sections around features. They include:

- Place, at the very least, two cross-sections at the inflow and outflow extents of pools (more cross sections could be used if desired);
- Place one cross-section at the deepest point in the pool;
- Place one cross-section at the inflection point in the riffle;
- Place cross-sections at the widest point along benches and bars;
- Place, at the very least, two cross-sections at the inflow and outflow extents of bridges and culverts (as per HECRAS recommendations);
- Where fish passage is required a minimum of three cross-section must be placed both upstream and downstream of flow constriction (such as bridges and culverts), within 20m of the constriction, to enable the fish passage criteria to be explored;
- Place cross-sections where changes of roughness is proposed;
- Place cross-section where change of flow occurs.

PART E: DESIGN TOOLS AND RESOURCES

E1. DESIGN TOOLS

This section equips the user with the necessary tools required for waterway design. The information is provided in support of Part D and should be consulted in tandem with design procedures therein.

Part E includes detailed guidance regarding the application of the following design tools:

- Hydrologic modelling - RORB
- Terrain modelling – 12d Model
- Hydraulic modelling – HEC-RAS
- Methods for reducing shear stress in the design waterway

There are other tools available to design waterways, but these tools are considered the baseline package of tools.

Part E also includes key resources required as part of the design process:

- Geology and soil resources
- Constructed Waterway Types
- Healthy Waterways Visions (vegetation, stream form)
- Waterway Protection and Rehabilitation
- Waterway Maintenance Requirements
- Useful Guidelines

Where the waterway designer is using hydrologic and hydraulic modelling software, Melbourne Water requires the waterway designer to use RORB and HEC-RAS.

Various terrain modelling packages are available and widely used across the industry and are therefore acceptable to Melbourne Water. It is Melbourne Water's preference that a software package such as 12d is used.

E1.1 Hydrologic Modelling

The catchment hydrology can be estimated using RORB runoff routing software. ARR2019 should be followed. The ARR2019 website includes guidelines (ARR2019 – A guide to flood estimation), software and a data hub for all hydrologic inputs for the modelling (including links to the latest 2016 BoM IFD data).

The Melbourne Water recommended RORB modelling procedure includes:

- Set-up the undiverted RORB model
- Calibrate the undiverted RORB model
- Use the calibrated undiverted RORB model as basis for modelling future scenario/s

Terminology

Two approaches are used when describing the probabilities of flood events. The definitions of these as per ARR2019 are shown below:

- Annual Exceedance Probability (AEP) - the probability of an event being equalled or exceeded within a year. Typically the AEP is estimated by extracting the annual maximum in each year to produce an Annual Maxima Series (AMS);
- Average Recurrence Interval (ARI) - the average time period between occurrences equalling or exceeding a given value. Usually the ARI is derived from a Peak over Threshold series (PoTS) where every value over a chosen threshold is extracted from the period of record.

The terminology adopted in this manual is shown in Figure 66 below. In general, the 20% AEP design flood is used in place of the 5-year ARI design flood even though these are not exactly equivalent (20% AEP corresponds to 4.5 years ARI and 5-years ARI corresponds to 18.13% AEP). Similarly, the 10% AEP is used to describe the 10 year ARI.

FREQUENCY DESCRIPTOR	EY	AEP (%)	AEP (1 IN X)	ARI
Very frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			↓ PMP / PMPDF	

Figure 66 - Australian Rainfall and Runoff Preferred Terminology (ARR2019: A Guide to Flood Estimation). Dark blue outline shows acceptable terminology.

Modelling scenarios

Hydrological modelling of existing and proposed conditions is required. Modelling of the existing condition is to be based on the current planning zones (or historical if current zone is Urban Growth) and should only consider existing topography and infrastructure. Modelling of future conditions is to be based on the proposed planning zone and include all infrastructure (drainage, storage, etc.) and any changes to topography.

The full suite of design events required for the design of waterways must be modelled. Generally, this includes (but is not limited to): the 3 month flow, the 1EY, 40% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP and 1% AEP flows. For all events the full range of storm durations from 10 minutes to 72 hours will need to be run in order to adequately capture and hydraulically model the rainfall event that leads to the maximum flood level.

A climate change scenario should also be modelled to reflect a 19.5% increase in rainfall intensity (predicted under a 2100 climate scenario). The 2016 IFD values are to be increased by a factor that scales rainfall intensity. The increased peak flow for the 1% AEP will be used as an input to the hydraulic modelling to test the sensitivity of the model to this flow (i.e. does the climate scenario 1% AEP flood level still fall within the 600mm freeboard to building floor levels).

See ARR2019 Book 1 Chapter 6 for more details.

Delineation of RORB catchment and sub-catchment boundaries, nodes and reach alignments

The Developer must take note of the following requirements in relation to the delineation (or review) of RORB sub-catchment areas, nodes and reach alignments:

- Catchment boundary must match adjoining catchment boundaries that have been provided by Melbourne Water.
- Sub-catchments to be delineated as most appropriate for the 1% AEP event.
- Sub-catchments, nodes and reaches to be named/numbered as recommended by Melbourne Water
- Nodes to be located where required and also at the downstream end of each sub-catchment.
- Where relevant, the local Council drainage systems should be considered when delineating sub-catchments.
- In order to ensure adequate routing for upstream locations where design flows are required for hydraulic modelling, a sufficient number of sub catchments are required, e.g. minimum of 5.

The final sub-catchment boundaries must be provided to Melbourne Water in the structure of the final MapInfo table deliverables.

Fraction impervious methodology

The fraction impervious must be determined using the existing planning zones (as per the Planning Schemes Zones MapInfo table provided by Melbourne Water) as a starting point. The Developer must then assess the fraction impervious for each zone in a sub-catchment.

The fraction impervious must be reported in table format detailing the fraction impervious for each zone within a sub-catchment as well as the overall fraction impervious for the sub-catchment. This must be reported as part of submissions made to Melbourne Water.

RORB model calibration

The undiverted RORB model must be reconciled to an estimated flow. Past practice has included the reconciliation of RORB models to peak flow estimates based on the urban rational method. This approach is no longer supported. Instead, alternative approaches can be used as discussed below.

In cases where simple RORB models are used to generate rainfall excess hydrographs for input to hydraulic models, and no routing is used, the choice of kc value is not important. However, where RORB is used to model design flows, routing parameters must be selected.

The value of kc should be based on local data, knowledge or experience if possible. Regional methods can be used to guide selection of initial values of kc (Table 28). If there are reliable kc values from nearby catchments, these can be scaled to the catchment of interest. kc is approximately proportional to dav or the square root of the catchment area (Pearse et al., 2002; Laurenson et al., 2010). Selected values then need to be refined by calibration, or sanity checking, of model outputs.

Table 28 - Regional equations for RORB routing parameter kc (sourced from Melbourne Water's Flood Mapping Projects Guidelines and Technical Specifications)

NO.	REGIONAL EQUATION	APPLICATION	SOURCE
1	$k_c = 0.49 \times A^{0.65}$	Areas with annual rainfall < 800mm	ARR2016 Book 7, Chapter 6.2.1.3
2	$k_c = 2.57 \times A^{0.45}$	Areas with annual rainfall < 800mm	ARR2016 Book 7, Chapter 6.2.1.3
3	$k_c = 2.2 \times A^{0.5}$	General	RORB V6 User Manual Equation 2-5
4	$k_c = 1.25 \times d_{av}$	Victoria	Pearse et al. (2002)
5	$k_c = 1.19 \times A^{0.56}$	Yarra and Maribyrnong areas	Melbourne Water
6	$k_c = 1.53 \times A^{0.555}$	South East areas. The area that was formerly managed by the Dandenong Valley Authority	Melbourne Water

An undiverted RORB model can be defined as a model:

- Without special storages;
- Without diversions to separately route multiple flow paths (i.e. overland flows and underground asset flows); and
- With a structure and reach types consistent with the regional equations.

Calibration at multiple locations within the catchment will be required when:

- the topography varies significantly across the catchment; and/or
- the land use varies (i.e. urban vs rural) across different parts of the catchment; and/or
- the size of the catchment is larger than 20km2 and/or
- the Developer considers it necessary

As a minimum the calibration checks must occur at the upstream end of the Melbourne Water drainage system but some projects may require calibration at the upstream end of the modelled council drainage system, the catchment outlet and/or at confluences of drainage systems.

Calibration/validation should focus on large events such as the 1% AEP flood. which is the design event for planning purposes.

Sanity checks can also be undertaken by comparing results to approximate methods that include:

- Nikoloau/vont Steen equations
- For definitions of the Nikoloau/vont Steen equations see Grayson, R. B. et al. (2006) Hydrological Recipes, page 108. For catchment area in square kilometers. Approximate 1% AEP floods are as follows.
- For rural catchments Q 1% = 4.67A 0.763
- For urban catchments Q 1% = 10.29A 0.71
- RFFE (Regional Flood Frequency Estimation tool see http://rffe.arr-software.org/

Undiverted RORB model

The following parameters should be adopted for the calibration and analysis process:

- IFD data is to cover storm durations from 10 minutes to 72 hours and be calculated at appropriate intervals.

Specifically relating to RORB:

- A value of 0.8 must be assigned to the exponent *m* unless the Developer believes this is inappropriate, in which case the recommended value is to be discussed with Melbourne Water prior to proceeding with this part of the work;
- k_c must be adjusted so the flow from the undiverted RORB model matches the regional equation estimated flow and is validated from checks detailed above;
- AR&R method must be used for the Areal Reduction Factor. These are obtained from the ARR2019 Data Hub;
- Initial loss values. These are obtained from the ARR Data Hub.
- Temporal patterns must be fully filtered.
- Runoff coefficients for RORB model – the runoff coefficients for an urban catchment of 0.6 for the 1% AEP event is to be used as a guide. If the Developer proposes to use other values (e.g. for interim development conditions), the rationale for adopting other values must be discussed and agreed with Melbourne Water prior to undertaking this part of the work. For rural catchments, the Developer is to propose an approach to be used regarding the use of a Runoff Coefficient versus Initial loss/Continuous loss.

RORB *model* data

The *.catg files of all scenarios modelling, along with parameter files and IFD parameters and data must be provided to Melbourne Water as part of carrying out the project.

Please note, all RORB reach alignments, node locations, sub-catchment and catchment boundaries are to be populated with appropriate descriptions, slopes, lengths to correspond with the RORB model code.

E1.2 Terrain Modelling

Terrain modelling software allows the designer to represent, in three-dimensional computer space, the existing terrain surface (such as the whole catchment) and to build the constructed waterway surface within it. The 'terrain' model is made up of a digital elevation model (DEM).

The digital elevation model (DEM)

A DEM is a representation of a topographic surface by a regular array of elevation values. In raw form it is a text or ASCII file containing a grid of elevation values (for example easting, northing and elevation, or X, Y, and Z values).

For the purpose of constructed waterway design a DEM is used to represent the design waterway surface to enable the designer to build a hydraulic model. The DEM is manipulated through various means to build different waterway configurations and then test these in a hydraulic model.

The information used to build a DEM comes in multiple formats. Melbourne Water usually provides information in text, grid or image format (Table 29)

Table 29 - Common DEM formats issued by Melbourne Water

FORMAT NAME	FILE EXTENSION	POINT DISTRIBUTION
ASCII XYZ	.xyz or.thn	Randomly distributed points Gridded DEM
ESRI GRID – ASCII format	.asc	Gridded DEM
ESRI GRID – binary format	.adf, .log and info folder	Gridded DEM
TIFF	.tiff	Gridded DEM

Terrain modelling

There are numerous terrain modelling software packages with the capability of establishing a design waterway surface for the purpose of hydraulic investigation. 12d Model is used widely in stream management and planning throughout Victoria. It is not the only product suitable for the task of constructed waterway design; however it has been used in this manual by way of example to demonstrate the use of terrain modelling software in waterway design.

Largely a civil engineering-based application, 12d Model enables users to construct a design surface such as a waterway. 12d Model interfaces with various hydraulic analysis software packages. Specifically, 12d Model's 'River Module' interfaces with HEC-RAS and works on a single stretch of river, or a complex system of branched rivers. The River Module is used to generate the waterway geometry, such as longitudinal and cross section detail, based on the underlying DEM. Additional hydraulic information such as hydraulic roughness and flow rate can be input from within the 12d Model river module.

Further information on 12d Model can be found at https://www.12d.com/ and, specific the river module, at https://www.12d.com/product/Rivers-Dams-Hydrology.html.

The process for establishing the waterway surface using 12d Model is outlined in this section. This information is considered essential for designing constructed waterways however it is not comprehensive or a substitute to referencing the 12d Model's user manual or seeking professional training.

Reading in raw spatial data

12d Model is capable of reading a wide range of input spatial information formats. For the most part spatial data will be provided in Ascii (XYZ) or Grid (DEM) format by Melbourne Water. These formats are easily imported to 12d Model using: (i) File I/O | Data input | xyz, and (ii) File I/O | Data input | DEM. As part of the import process the spatial information is assigned to a 'model' (this is sometimes known as a 'layer' in other spatial packages) specified by the user. This model (and the spatial information it contains) is then used to generate a Triangular Irregular Network (TIN). The TIN can be thought of as the terrain surface upon which the waterway information is layered.

Generating a TIN

A TIN is basically a three dimensional representation of a surface. TINs form the basis for designing the constructed waterway and generating the hydraulic model within 12d Model. A TIN is created by selecting Tins | Create | Triangulate Data. The input spatial data, TIN name and model are all assigned by the user.

Multiple TINs can be superimposed to make a new TIN, known as a supertin, in 12d Model. Supertins are particularly useful once the user has designed the waterway surface (detailed below) and wishes to amalgamate the two surfaces (Figure 67). A supertin is created from two or more separate TINs by selecting Tins | Create | Supertin.

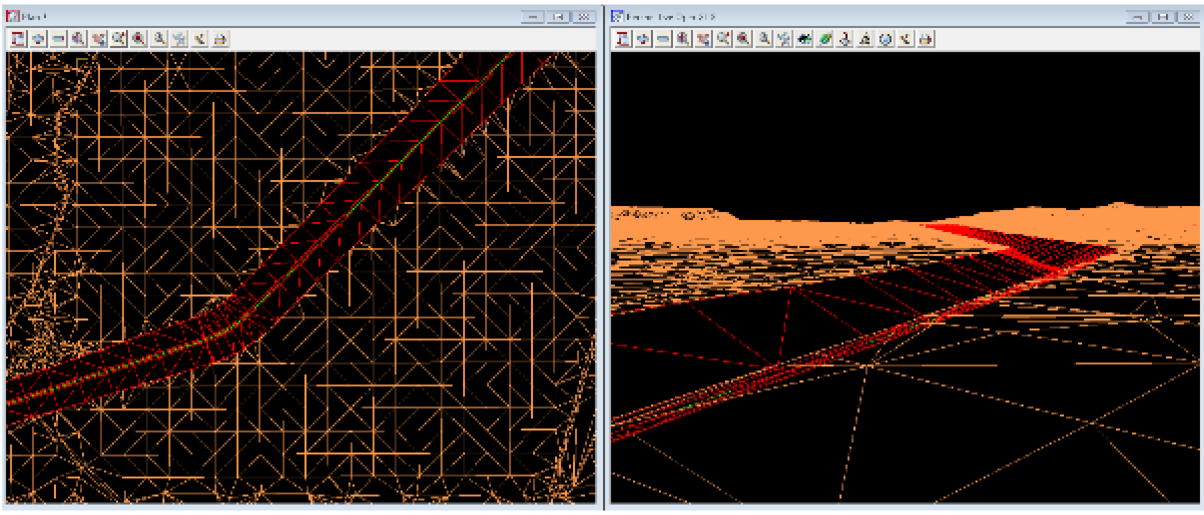


Figure 67 - Example supertin plan view (left) and isometric view (right)

Building the constructed waterway

12d Model enables the user to grade the designed waterway geometry into the existing terrain. There are numerous steps to this process and professional training is advised. The key steps involved include:

- Create a super alignment string (Strings | Create | Super Alignments) along the alignment of the design waterway. The super alignment string must be assigned both horizontal and vertical position information (for example the alignment may represent the centreline of the design waterway at its base).
- Create a grading template (Design | Templates | Create/edit). Templates are basically the cutting tool used to carve out the waterway shape along an alignment string. Templates are used to set desired widths, depths and batter slopes from the super alignment.
- Apply the grading template (Design | Apply | Apply many). In applying the template the user specifies the relationship between the underlying terrain (TIN), design waterway alignment (alignment string/s) and design template/s. The function is used to shape the constructed waterway any which way. For example the user can specify that the base width of the constructed waterway increases over a transition distance around the location of a contributing tributary so as to accommodate increased flows. Likewise, the outside bank angle may be steepened at the outside of a bend, or a mid-level bench appear at the inside of a bend, in accordance with the design intent. Importantly, the waterway surface TIN is generated by this function.
- Amalgamate the constructed waterway surface TIN and the existing surface TIN (as outlined earlier).
- The designer is required to represent the various waterway features in the hydraulic model. In the case of pools and riffles, benches and bars, it is best to achieve this by building the designed pools and riffles in to the terrain model. Pools and riffles are carved into the previously established terrain modelling using the same tools and methods as previously discussed.
- Use concept stage TIN of waterway
- Introduce cross-section variability to represent pools and riffles either by manipulating existing alignment strings and/or grading templates, or by creating new ones. That is:

  The designer may introduce longitudinal variability by changing the alignment string's 'vertical geometry'

  The designer may introduce cross-section variability using the modifier function when applying the grading template/s
- Again, generate a combined TIN of the waterway and existing terrain (to represent areas outside of the waterway itself)

Other features such as vegetation design and distribution, instream woody habitat structures, pile fields, and bed and bank stabilisation measures are more efficiently represented within the HEC-RAS model. More information is provided in the hydraulic modelling section below.

Building the hydraulic model

The 12d Model river module requires the 'river strings' and 'source strings' to be specified before the hydraulic model can be generated.

Three individual strings (left bank, centre line, and right bank) must be created for each reach to make up the river strings model. If the constructed waterway consists of a network of three reaches then the river strings model must contain nine individual strings with the appropriate labelling. Strings must be sketched in the upstream direction.

The source strings model must be populated with strings at the location of cross sections. Source strings must be sketched from left to right overbank when facing downstream, must be placed perpendicular to the direction of flow, and must intersect each river string (left bank, centre line, and right bank) only once (Figure 68).

Source string may be generated automatically using the river module, however this method is not recommended as the automatically generated source strings often break the rules of source string placement for one-dimensional hydraulic modelling.

The functional design stage is focussed on reach scale design. As such, a lower resolution of source strings is appropriate for this step. In the detailed design stage the resolution of cross sections must be increased to a suitable level for feature scale analysis and design. For example, 50m cross section spacing may be appropriate for the reach scale design of a one kilometre waterway. For the detailed design the spacing may be reduced around individual features of interest. For example the designer may place additional cross sections at the inlet, deepest point (bend apex), and outlet of a pool, or a bench, or any other feature of interest. This way the designer can be confident that the hydraulic model is estimating, to the best level of accuracy as can be expected in 1D modellings, the particular the hydraulic conditions around waterway features

Exporting the geometry

The river module is then used to generate a hydraulic model of the constructed waterway for use in HEC-RAS. After selecting *Design* | *Rivers* | *HEC-RAS interface* | *Create HEC-RAS project* the user must specify: (i) the river strings model, (ii) the source strings model, (iii) the cross section model (in the first instance this is a new model to be filled with cross section information generated by the river module), (iv) the surface tin, (v) the start-up data (Manning's *n*, discharge, zero chainage location and units), and (vi) the project file path and name.

Once the river module has processed the written geometry file can be read directly into HEC-RAS.

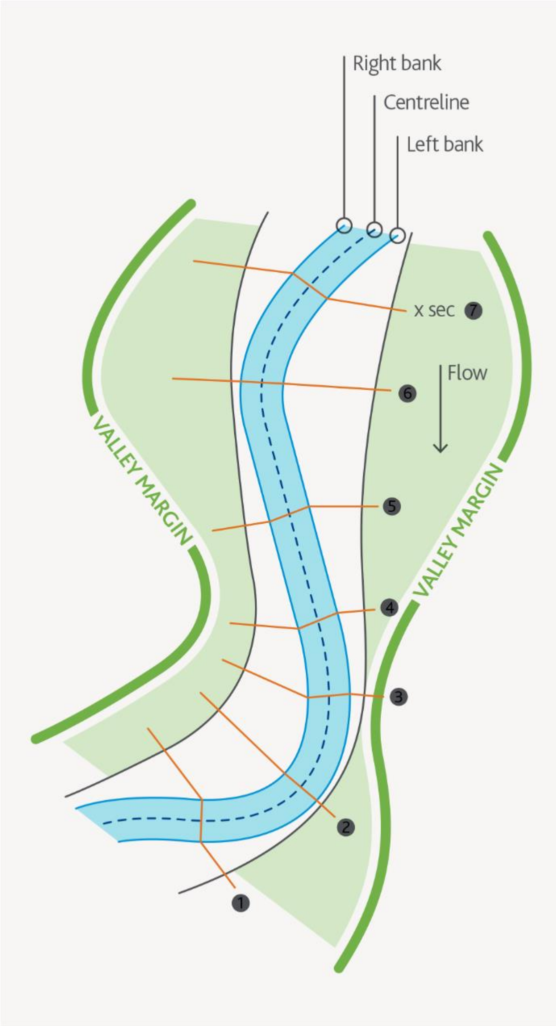


Figure 68 - Placement of source strings (cross sections) perpendicular to direction of flow

E1.3 Hydraulic Modelling

The Hydrologic Engineering Centre of the US Army Corps of Engineers developed the River Analysis System (HEC-RAS) software. The software allows the user to perform one-dimensional steady and unsteady river calculations (US Army Corps HEC RAS manual) through interaction with the graphical user interface.

HEC-RAS comprises four river analysis components: (i) steady flow water surface profiles, (ii) unsteady flow simulation, (iii) sediment transport/movable boundary computations, and (iv) water quality analysis. For the purpose of waterway design it is important to be familiar with the steady flow water surface profile component only.

Getting started

The HEC-RAS software and supporting resources (user's manual, applications guide and the hydraulic reference manual) is freely available at https://www.hec.usace.army.mil/software/hec-ras/.

The user's manual is a guide to using HEC-RAS and provides an overview of installation, getting started, entering and editing geometric and flow input data, modelling components and processes, and using the output results. The user's manual also contains simple example applications.

The hydraulic reference manual provides the background theory (equations, assumptions, and modelling approaches) to HEC-RAS.

The applications guide contains a series of examples to demonstrate the various modelling aspects (data requirements and modelling approach) with supporting illustrations.

This manual assumes that the user is familiar with the steps required to set-up a basic steady flow simulation project in HEC-RAS. The user must be familiar with:

- The install/uninstall procedure
- Starting a new HEC-RAS project
- Data management and storage (project file, plan/s, geometry file, and flow file)
- Entering geometric data (river reach and cross section information)
- Entering flow data and boundary conditions (steady flow only)
- Performing hydraulic computations (steady flow only, and mixed flow regime)
- Viewing and printing results (cross section, longitudinal section, and X-Y-Z perspective plotters)

The information below is specifically related to HEC-RAS modelling for constructed waterways in the Melbourne region. There is particular focus toward assimilation with terrain modelling software (12d Model) for the design and analysis of the waterway.

The geometry file

Starting with a new HEC-RAS project and empty geometry file, the user can then (i) import the geometry file, (ii) add detail to the waterway geometry file to property represent the proposed design surface. Importantly, this step is used to:

- Import geometric data (geometry exported from terrain modelling package)
- Specify the waterway's hydraulic roughness (Manning's *n*)
- Where applicable, specify bridge/culvert, inline and lateral structure information

Importing geometric data

HEC-RAS can import geometric data in several different formats (GIS, HEC-RAS, and others). The HEC-RAS format may be used when importing geometric data from 12d Model.

- From 12d Model (HEC-RAS format). Geometric data created in 12d Model is imported to HEC-RAS in HEC-RAS format by selecting *File | Import geometry Data | HEC-RAS Format* from within the geometric data editor window. The HEC-RAS user's manual (pp. 6-131 to 6-137) provides supporting information for the process.
- Alternatively, cross sections can be created directly in the RAS mapper function of HEC-RAS, where terrain can be imported and cross sections draped across this data.

Top of bank markers

Top of bank markers are used to differentiate between the low flow channel and the main channel (or floodplain). They are placed at the top of the low flow waterway bank (Figure 69). There are multiple ways to shift the top of bank markers in HEC-RAS. The recommended method is to use the graphical cross section editor (*Tools | Graphical Cross Section Edit* from the geometry data window) and the various bank station tools therein.

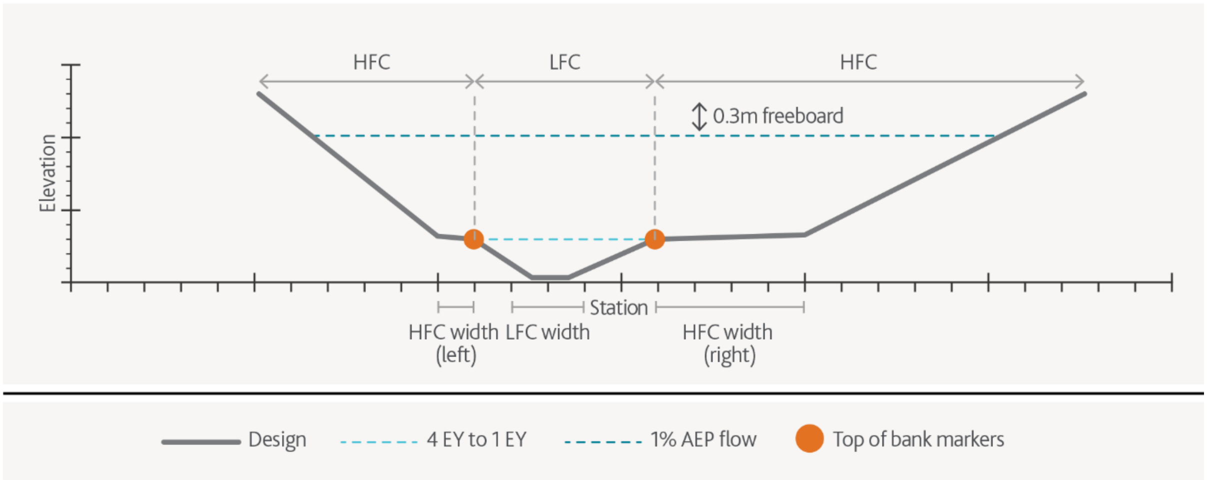


Figure 69 - Markers placed at top of bank to differentiate between low flow channel and main channel (floodplain)

Hydraulic roughness

A waterways hydraulic roughness determines the amount of energy lost by water as it flows through the waterway. Densely vegetated waterways flow more slowly than concrete lined channels. This is because the hydraulic roughness of the relatively smooth concrete is much lower than the vegetated channel. Greater energy loss gives rise to slower flow. It is important to correctly estimate the hydraulic roughness of the waterway at the various stages of its lifetime. For example, the waterway in the immediate post-construction phase is likely to be largely a bare earth surface. At 3 months, it is likely to be planted down with some vegetation that is not well established. At 10 years, the waterway is likely to be populated by an array of both mature and establishing vegetation species with variation between the floodplain, banks and bed of the waterway.

The user must select the appropriate hydraulic roughness to best represent the waterway at various time scales. There are numerous references for hydraulic roughness values for typical waterways.

- For the post-construction period the recommended Manning's n values for the low flow waterway and the main waterway include:
- Earth, straight and uniform (low sinuosity reaches) 0.018 (min 0.016, max 0.020)
- Earth, winding and sluggish (sinuous reaches) 0.025 (min 0.023, max 0.030)
- Bedrock cuts, jagged and irregular 0.040 (min 0.035, max 0.050)

Once vegetation is established the hydraulic roughness must change accordingly. All vegetation in the corridor will influence hydraulic conditions to some extent depending where it is located, and how much flow resistance it offers. The nature of this effect varies with plant species and flow depth. The following table presents a summary of the nominal Manning's *n* values for different waterway types.

Table 30 - Typical hydraulic roughness values for the different waterway types

MATERIAL	LFC	HFC
Compound	0.05 (min. 0.045 max. 0.06)	0.05 (min. 0.045 max. 0.06)
Bedrock	0.040 (min 0.035, max 0.050)	As above unless bedrock extends to 1% AEP flood level.
Linear pools	0.035 (predominately open water) (min 0.03, max 0.040) 0.05 (predominantly marsh)	0.05 (min. 0.045 max. 0.06)

Some parts of the corridor may be lined with rock or other bank strengthening materials. A list of potential bank linings and their associated hydraulic roughness are included in Table 15 and Table 31.

Table 31 - Typical hydraulic roughness values for rock and other bank protection material

MATERIAL	MANNING'S *n*
Rock 250 mm	0.030
Rock 450 mm	0.035
Other bank strengthening fabrics (jute matting, ecomat, etc.)	0.025

Additional resources

The following references provide information on the selection of Manning's roughness (Queensland Urban Drainage Manual 2007):

- The HEC-RAS user's manual provides a concise summary of some of the more common waterway types (Table 3-1 from pp 3-14 to 3-16, refer table from HEC-RAS manual).
- Tables relating channel type and surface conditions, to recommended roughness coefficients, e.g. Argue (1986) Table 6.1, Books 7 & 8 of ARR (1998), Henderson (1966) Table 4.2, Chow (1959) Table 5.6.
- Photographs and descriptions of channels with known roughness coefficients, e.g. Brisbane City Council (2000), Chow (1959), Barnes (1967), French (1985), Hicks & Mason (1991) and Arcement & Schneider (1989). Caution: Hicks & Mason (1991) provide roughness values usually relating to low-flow conditions, not to bankfull or overbank conditions presented in the photos. Arcement & Schneider (1989) provide roughness values for vegetated floodplains in the USA; however, the supplied photos show the vegetation in winter conditions (i.e. low leaf matter) even though the roughness values refer to summer conditions (i.e. dense leaf and vine matter).
- Equations to derive estimates of channel roughness and which incorporate modifying factors representing the individual components of the effective Manning's roughness coefficient, e.g. Brisbane City Council (2000), Book 7 of ARR (1998), Chow (1959) Table 5.5 and French (1985).

The designer should use an appropriate reference to estimate hydraulic roughness, such as those suggested above and include justification of the selection of roughness in the functional design report.

Representing the true waterway geometry

It is important to understand the interaction between the waterway and any intersecting bridges or culverts. Bridges and culverts must be modelled in accordance with the guidance notes in the HEC-RAS user manual (pp. 6-25 to 6-58). Other structures that may be required to be modelled include:

- Inline structures such as weirs or gates.
- Lateral structures to model connection to offline structure (wetland, retention basin, etc.)
- Levees, ineffective areas and blocked obstructions

The flow file

Once peak flows have been estimated at the appropriate location/s along the waterway we can input these directly to HEC-RAS for steady flow simulation.

The steady flow file allows the user to specify the flow rate at any location in the model (including changes to flows along the reach length). In order for the simulation to run, the flow rate must be specified at the top of every reach in the model. The user then has the option of specifying any amount of variation to the flow rate along the reach length. Note that HEC-RAS will automatically combine two flows at the junction of two or more contributing streams. This does not have to be entered manually by the user.

Boundary conditions

The steady flow file requires that hydraulic boundary conditions be specified at the top and bottom of every reach (when running missed flow regime). Boundary conditions are necessary to determine the starting water surface at each end of the waterway to begin the simulation. The downstream boundary condition is required when modelling all flow regimes while the upstream boundary condition is only required for super-critical (or mixed) flow regime.

There are several options for specifying boundary conditions: a known stage-discharge relationship, critical flow depth, or normal flow depth. Specifying the normal flow depth is the simplest and most common approach for constructed waterway design. The normal water depth is the longitudinal slope of the water surface at the boundary in question and can be estimated by the longitudinal slope of the waterway base.

The longitudinal slope is established by sampling the waterway base (at its lowest point) for a nominal distance at the boundary. For example, the user may employ terrain modelling software, Excel, or even HEC-RAS to determine the bed level fall over an appropriate distance. The slope (fall divided by distance) is then input as the boundary condition in the steady flow file (Figure 70).

When a network of waterways is modelled HEC-RAS will automatically specify the boundary conditions at junctions.

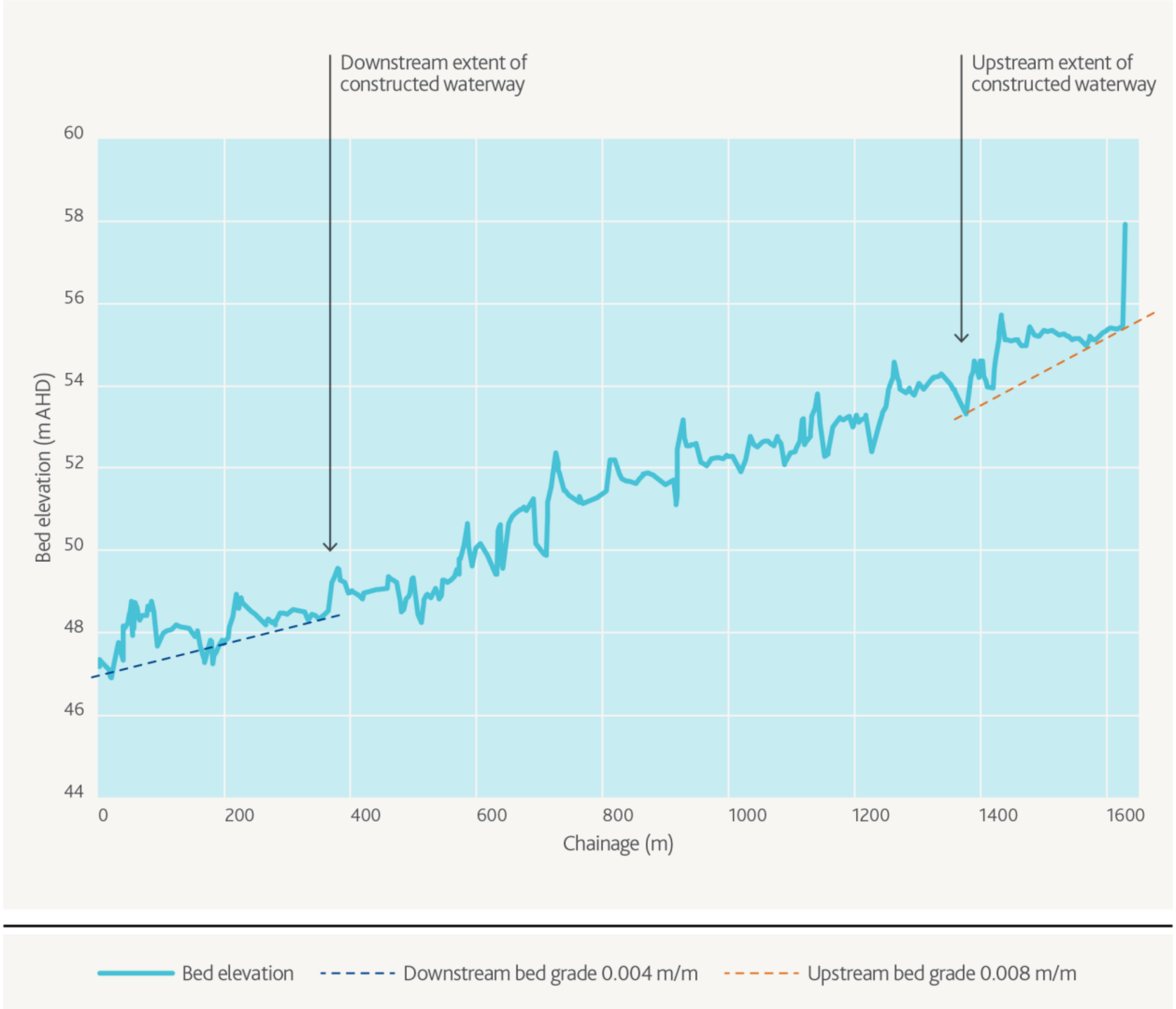


Figure 70 - Example longitudinal section profile showing boundary conditions

Steady flow analysis

Water surface profiles for steady flow are calculated for a single reach or a full network of reaches. Where flow is gradually varied, calculation is based on the solution to the one-dimensional energy equation with frictional and expansion/contraction losses estimated. For rapidly varied flow (hydraulic jumps, at bridges, or at confluences) the momentum equation is used to calculate the water surface profile. Refer Chapter 7 of the HEC-RAS user's manual for guidance through the steady flow analysis procedure.

- Once the geometry file has been exported from 12d Model the designer is ready to set-up and run the revised hydraulic model to check its hydraulic performance and the proposed feature configuration. The tools and methods required in this process are all detailed in Part D of this manual, but in summary, include:
- Open the concept stage HEC-RAS project
- Use either the existing geometry file, or start a new one, and import the geometry information from 12d Model export
- Revise the flow file if required
- Revise any flow constriction if required (reminder that these include culverts and bridges) in the geometry file
- Revise the hydraulic roughness values (Manning's n) consistent with the vegetation design, and feature-scale design of the waterway.
- Run the model in steady flow analysis mode, using the mixed flow regime.

Interrogate the model and export the hydraulic performance for further analysis or presentation to Melbourne Water (once the waterway is optimised).

Methods for reducing shear stress

Managing shear stress within the waterway can be achieved in a variety of ways. The below techniques can be used in isolation or in combination and apply to both the low flow and high flow channels equally. For the compound type the main advantage of the low flow channel is that sinuosity can be used as a tool to manage shear stress. For example, increasing the sinuosity increases the length of the low flow channel, reducing its bed slope/grade and therefore shear stress.

Melbourne Water requires flow energy management design options to be fully explored rather than resort directly to artificial armouring of the waterway to cope with increased flow energy. High shear stress should be managed in the following sequence:

- Alter the waterway geometry to the fullest extent possible within the bounds of the available waterway corridor (see methods below)
- Explore the use of alternative vegetation species and distributions to provide additional protection where required (subject to the ecological requirements of the waterway). Also consider the use of long-stemming or tubestock with larger root system so that they can be planted deeper
- Explore the use of soft engineering protective materials such as jute matting and coir logs. Note that these products generally have a limited design life, however can often be used successfully to protect the waterway boundary for the vegetation establishment period
- Explore options for relocating assets further from the waterway to reduce the consequences of erosion
- Where the above options are exhausted explore the use of rock protection. Melbourne Water requires that shear stress be managed as the first priority before extensive armouring of the bed and banks is introduced. Armouring should only be used as a last resort where no other technique or combination of techniques has been able to produce the desired effect.

Methods to reduce shear stress in the design waterway may be reduced either by lengthening the waterway, or by increasing the resistance to flow. Specifically, bed shear stress can be reduced by:

- Altering the width of the channel to increase its capacity and reduce flow depth. Some iteration will be required here to ensure that flow depths at higher flows now contained within the wider channel do not generate shear stresses of concern for channel stability. If this is the case, channel depth will need to be reduced to create a wider shallow channel. If this is the required design response, then consideration should be given to incorporating benches within the channel cross section (see below);
- Creating a series of benches within the channel at different flow levels to increase flow extents and reduced flow depths. This can be done on both sides of the low flow channel or on one or other side, to create either symmetrical or asymmetrical cross sections using benches;
- Altering the roughness (Manning's 'n') of the channel by modifying any vegetation, in-channel structures, rock work etc., which is generating roughness to either increase or decrease roughness to achieve a reduction in shear stress;
- Altering the longitudinal grade of the channel to reduce its steepness.

Bank shear stress can be reduced by:

- Creating a series of benches within the channel at different flow levels to increase flow extents and reduced flow depths. This can be done adjacent to one or other or both banks, depending on which bank is subject to high shear stresses.

Bend shear stress can be reduced by:

- Reducing the sharpness (Rc/W) of the bend, by modifying the bend radius and/or channel width;
- Creating a series of benches within the channel at different flow levels to increase flow extents and reduced flow depths. This can be done adjacent to one or other or both banks, depending on which bank is subject to high shear stresses.

E2. DESIGN RESOURCES

The following design resources are provided to assist the waterways designer through the concept and functional design phases:

- Geology and soil – used in site analysis and concept design phases
- Constructed waterway types – used in concept design phase
- Healthy Waterways Visions – used in concept/functional design phases
- Waterway protection and rehabilitation
- Waterway and associated asset maintenance requirements
- Useful Guidelines

Image 3 – Dandenong Creek at Jells Park

E2.1 Geology and Soil

The design of waterways must consider the local soil type and rock type because of the potential impact they may have on the civil and landscape design of the waterway. This is particularly important for properties with dispersive soils as it can jeopardise the stability of the waterway.

This manual references the following information on the geology and soils of the Melbourne region:

- Geological information (ref http://dpistore.efirst.com.au/categories.asp?cID=4)

  1:250,000 Geological Map Series: Melbourne SJ 55-5 (Edition 2, May 1997)

  1:250,000 Geological Map Series: Queenscliff SJ 55-9 (Edition 2, May 1997)

- Soil information

  Australian Soil Classification (ref http://www.clw.csiro.au/aclep/asc_re_on_line/soilhome.htm)

  Australian Soil Resource Information System (ASRIS) (ref http://www.asris.csiro.au/themes/Atlas.html)

  Victorian Data Online (ref

  https://www.data.vic.gov.au/)

  Landcare Note – Melbourne Soils (ref http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/soils/melbourne-soils)

From the available mapping across the Melbourne region, there appear to be the following broad groupings of rock types and soils within the developing areas around Melbourne:

- Quaternary Extrusive basalts "Newer Volcanics" (Qvn) from the extensive lava flows of the Victorian Volcanic Plains, with overlying heavy clay soils of varying character (e.g. Vertosols, Ferrosols). Occurrence is extensive, covering most of the major growth corridors (developing areas) to the west, north west and north of Melbourne;
- Ordovician Marine Sedimentary deposits (Our/Ou) with overlying dispersive clay soils (e.g. Sodosols). Occurrence is mostly in pockets to the north west and north of Melbourne, particularly the developing areas around Sunbury and Diggers Rest;
- Silurian Marine Sedimentary deposits "Dargile formation" with overlying dispersive clay soils (e.g. Sodosols). Occurrence is mostly to the north east of Melbourne in the developing areas around Whittlesea;
- Quaternary Fluvial Sedimentary deposits (Qra) with overlying alluvial soils (e.g. Stratic to Fluvic Clastic Rudosols). Occurrence is extensive in the developing areas to the south east of Melbourne, particularly in the area to the north of Westernport Bay;
- Quaternary Aeolian Sedimentary deposits (Qpd) with overlying lightly acidic sandy top soils and alkaline sub soils (e.g. Lutic Rudosols). Occurrence is mostly restricted to the developing areas around Cranbourne; to the south-east of Melbourne;
- Quaternary Paludal Sedimentary deposits (Qrm) with overlying silty-clay organic rich soils (e.g. semi-aquic and aquic Podosols). Occurrence is extensive in the developing areas to the south east of Melbourne, particularly in the area to the north of Westernport Bay;
- Tertiary Fluvial Sedimentary deposits "Brighton Group" (Tpb/Tpx) with overlying alluvial soils (e.g. Stratic to Fluvic Clastic Rudosols). Occurrence is extensive in the developing areas to the south east of Melbourne, particularly in the area to the north west of Westernport Bay;

Some of the broad soil types typical of the Melbourne region are presented below. Of particular note are the characteristics of those soil types that can be problematic for waterway design.

Table 32 - Design considerations of the main Melbourne area soil types
http://www.clw.csiro.au/aclep/asc_re_on_line/

SOIL	DESCRIPTION	DESIGN CONSIDERATION
Ferrosol	Soils with B2 horizons which are high in free iron oxide, and which lack strong texture contrast between A and B horizons. These soils are almost entirely formed on either basic or ultrabasic igneous rocks, their metamorphic equivalents, or alluvium derived therefrom.	These soils are friable, which means they are very crumbly when dry and most, and can become soft when wet. They are therefore prone to erosion by water if left exposed.
Vertosol	Clay soils with shrink-swell properties that exhibit strong cracking when dry and at depth have slickensides and/or lenticular structural aggregates. Many such soils exhibit gilgai micro relief. Clay context is >35%.	These soils are reactive and prone to expansion/swelling when wet and shrinkage/cracking when dry. This presents issues for: • vegetation establishment and survival, due to the highly variable moisture contents and physical disturbance to the roots of establishing plants; and • can contribute to erosion of the soil surface by water on slopes, due to the increased effectiveness of sub-aerial weathering during dry periods causing crusts to be easily removed, and water to penetrate the deep cracks, dislodging material.
Sodosol	Sodosols have an abrupt clay increase down the profile (strong texture contrast between A horizons and B horizons) and high sodium content (ESP > 6) in the sodic B horizon, which are not strongly acid.	These soils are usually very hard when dry and are prone to crust formation. The dispersive subsoil makes them prone to clay dispersion and instability when wet, which frequently results in tunnel and gully erosion. Seasonally perched water tables are common because of the subsoil structure.
Podosol	Usually infertile sandy soils with B horizons dominated by the accumulation of compounds of organic matter, aluminium and/or iron. Typically slightly acidic.	Due to the coastal and floodplain landscapes to the south-east of Melbourne where the large majority of these soils occur, high groundwater tables are common and they are prone to seasonal inundation. Poor drainage.
Rudosol	These soils are typically free draining and poorly structured. The Lutic Rudosols are prone to wind erosion. Due to the floodplain landscape to the south-east of Melbourne where the large majority of the Fluvic Rudosols occur, they are prone to seasonal inundation. (Note – some Rudosols may be Tenosols).	These soils are typically free draining and poorly structured. The Lutic Rudosols are prone to wind erosion. Due to the floodplain landscape to the south-east of Melbourne where the large majority of the Fluvic Rudosols occur, they are prone to seasonal inundation. (Note – some Rudosols may be Tenosols).

Designers should establish soil characteristics through the engagement of soil assessment studies.

- Soil needs to be tested for dispersivity (pinhole or Emerson Class). This should be informed by geotechnical advice.
- Soils might need treatment to manage dispersivity (e.g. gypsum) which should be informed by geotechnical recommendations.
- Soil amelioration should be considered to ensure ideal plant growth conditions (e.g. if topsoil not being imported or cultivation of subsoils is required). This should be informed by soil science/ agronomist advice.
- Clay to be considered also.
- Refer to Melbourne Water's topsoil specification.

E2.2 Waterway Types

The manual has introduced the concept of waterway types to assist the designer tailor their design to the predominant landscape characteristics. This is to ensure the design responds to site opportunities and constraints, and to assist in achieving the design objectives.

Urban waterways can be grouped by landscape setting and boundary material.

There are three broad waterway types prescribed for constructed waterways in the Port Phillip and Westernport catchments, as described below.

- Bedrock waterway type
- Linear pools type
- Compound waterway type

These waterway types are broad and flexible – the waterway designer can select and modify a wide range of design parameters with each of these types to develop a design that provides the required outcomes for the waterway and the site.

Waterway type decision criteria

The criteria that distinguish between the three waterway types: presence of bedrock close to the surface of the site and longitudinal bed slope (i.e. slope in a downstream direction). The criteria are used to select an appropriate waterway type using a decision tree (

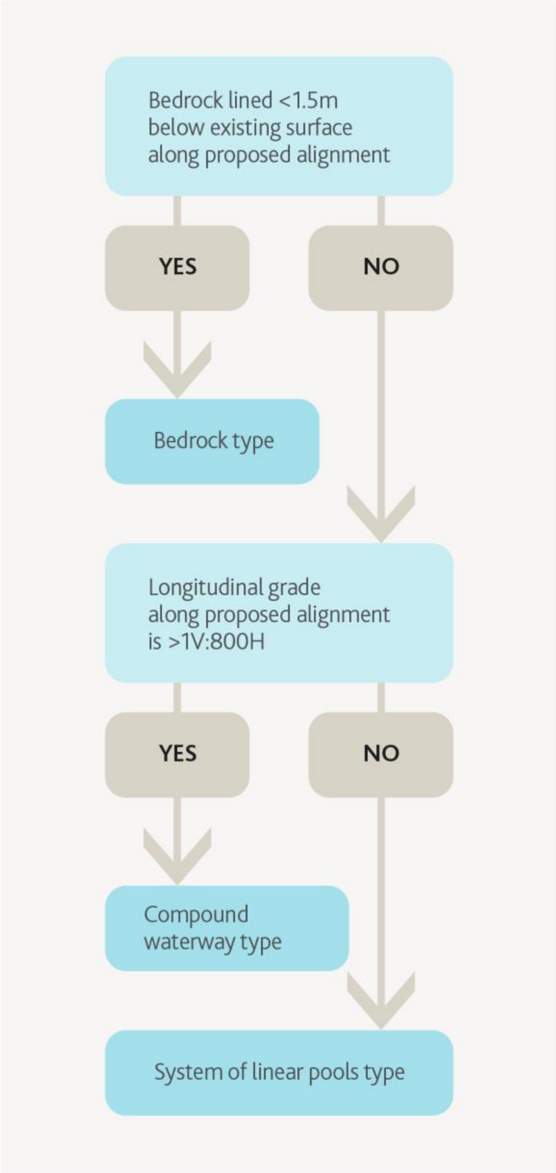


Figure 71) by answering these questions:

- Is the bedrock lined with bedrock at a depth not greater than 1.5m?
- Is the longitudinal grade of the proposed alignment greater or less than 1V:800H?

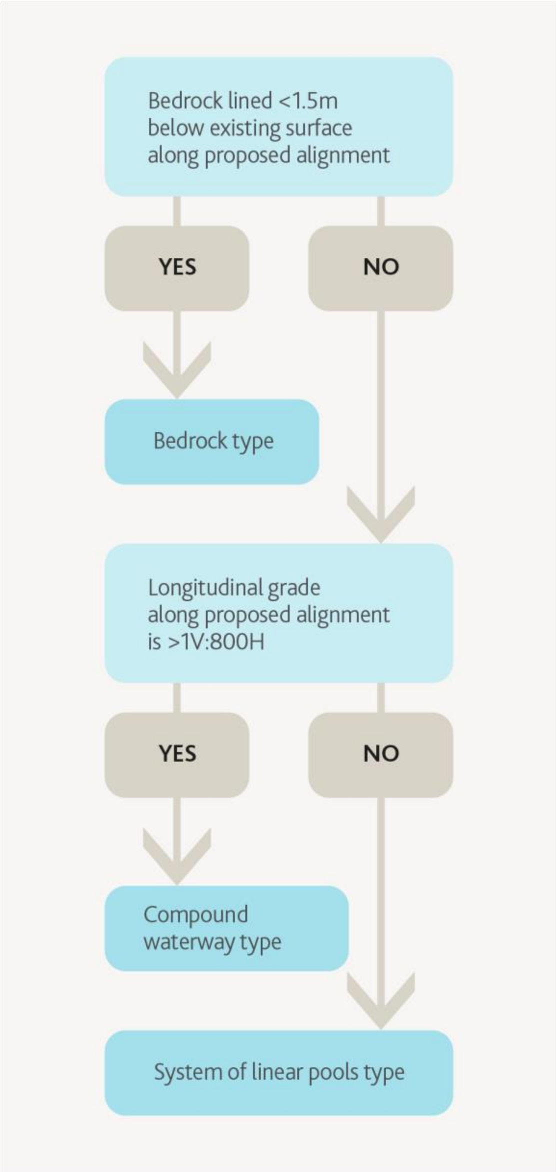


Figure 71 - Constructed waterway type decision tree

Bedrock type

Waterways constructed into corridors lined with bedrock have different design considerations to the more typical waterway set within erodible sediments such as clay, silt and sand. The geotechnical survey carried out as part of the concept design stage will determine the presence or otherwise of bedrock material. The geotechnical survey must indicate the presence of bedrock between existing surface and 1.5m (min) below existing surface or design invert level.

Compared with the more common alluvial lined types (detailed below) bedrock is inherently more stable, and therefore allows for the construction of a waterway with greater resilience to velocity and shear stress.

An indicative form for the bedrock type is shown below (Figure 72). There is no prescribed cross-section geometry, longitudinal profile, or planform for this type. Instead, the designer must demonstrate than the proposed form meets the required design outcomes for waterway as set out in Part A. At the same time, the designer must utilise, where possible, the natural features and form of the bedrock boundary. For example, using natural riffles and freefall sections where they appear in the existing bedrock boundary.

For the bedrock type the design must minimise construction effort and ensure the design objectives are met.

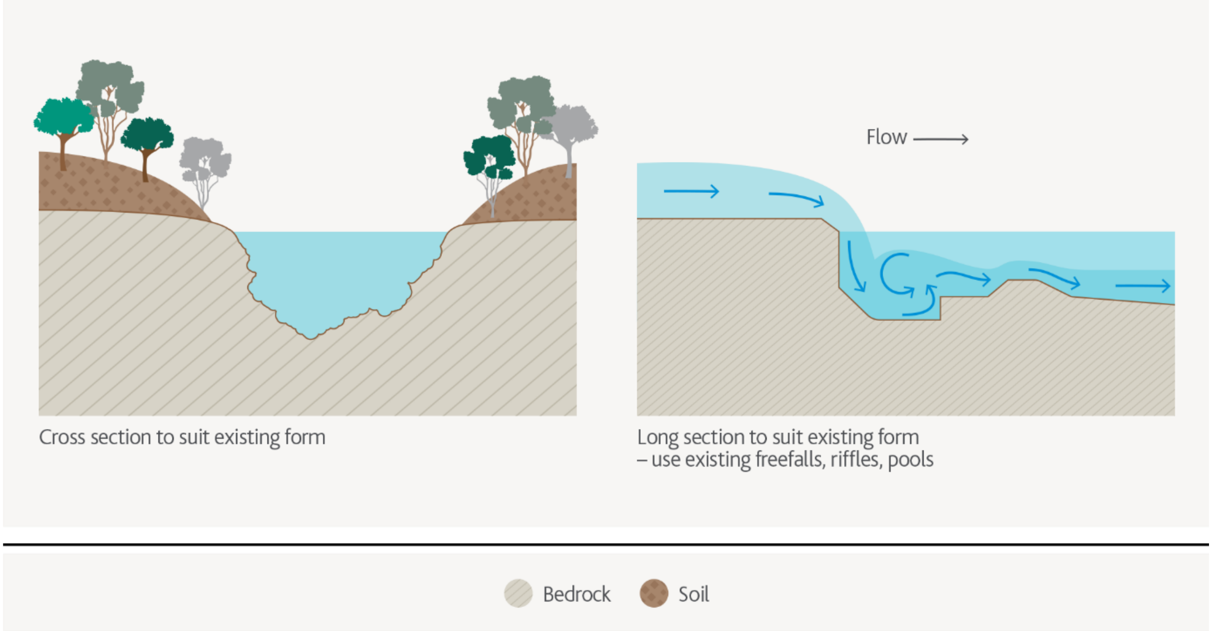


Figure 72 - Bedrock type indicative cross section and longitudinal section profile and planform

Although bedrock is generally much more resistant to erosion by flowing water, there are some instances where fractured or heavily weathered basalt may be encountered. When this type of rock is encountered during the geotechnical investigation or excavation, additional consultation with Melbourne Water in the design process may be required to ensure the required outcomes are achieved.

System of linear pools type

In very flat sites it may be necessary to construct a system of connected pools in order for surrounding development to drain efficiently. An inherent problem associated with waterway with very low longitudinal bed slopes is the base of the waterway does not drain effectively, leading to areas of the channel system that consistently hold shallow water. Depending on the required landscape / amenity outcomes this can lead to problems.

By designing the waterway as a series of pools, the designer can:

- Reduce the overall reach grade by providing flat water sections linked with waterway at a reasonable grade (Type 1, Figure 73) and / or
- Reduce the overall grade by providing flat water sections linked with a crest graded waterway, this is where sections of the floodway grade to pools, whilst a net grade is achieved (Type 2, Figure 73).

It is important to recognise that these pools in a waterway are not designed to serve a water quality objective. Designers need to ensure that scour velocities can be achieved across the pools to ensure that sediment transfer occurs and long-term maintenance requirements are not overly onerous.

The use of online wetland systems (which are generally deemed inappropriate) within a waterway may achieve a similar objective, however the designer needs to meet additional criteria set out in the wetlands design manual and consult with Melbourne Water for acceptance of this proposed design response, before proceeding.

Design of the linear pool waterway type needs to consider:

- Constructed shallow lake systems design guidelines
- Constructed wetlands manual (with reference to safety criteria for edge treatments).

These waterway types are particularly vulnerable to sediment loading during the construction phase of the associated subdivision / housing; as such, when designing these systems it is important to identify ways of preventing high sediment loads from entering the waterway and / or identify additional maintenance requirements during the defects liability period. Designers should consider offline sediment traps, gross pollutant traps and / or sediment pits.

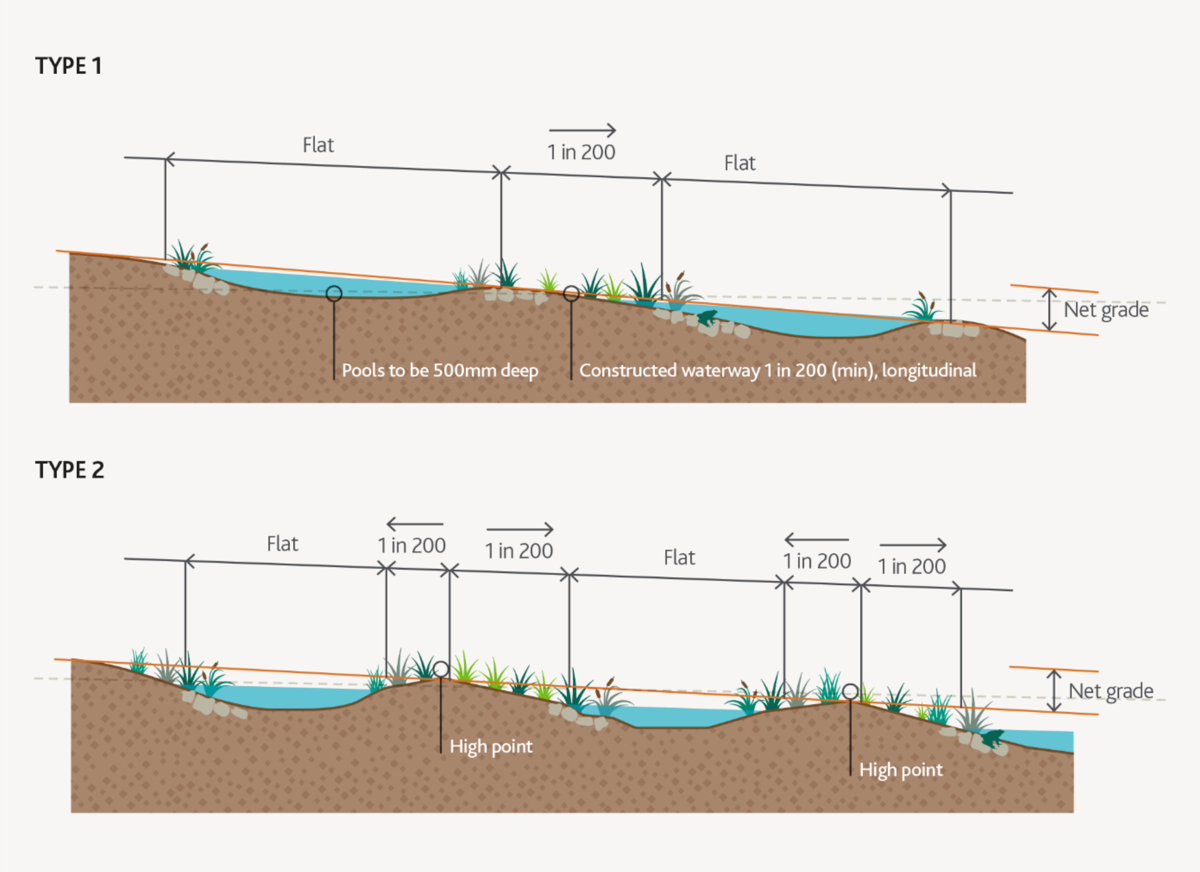


Figure 73 - Types of linear pools types in constructed waterways

Compound waterway type

Waterways constructed in erodible sediments are the most common form of constructed waterway in the Melbourne Water region. This is due to the broad range of landscape settings that this basic type can be applied to. For example, the boundary material can range from stable clays through to silts, sands and gravels. Even though the basic form of the waterway is the same for all of these boundaries, the relative size and alignment will be different due to the inherent strength of the boundary material itself as well as the vegetation community able to be supported by the material.

The ***compound*** waterway type is one with a high flow channel that conveys the 1% AEP flow (with freeboard), and a sinuous low flow channel that conveys flows between the 4EY and 1EY flows. The compound waterway type can contain a variety of features, such as pools and riffles and typically includes a variety of batter slopes and bench levels. An example of a typical cross-section is shown below (Figure 74).

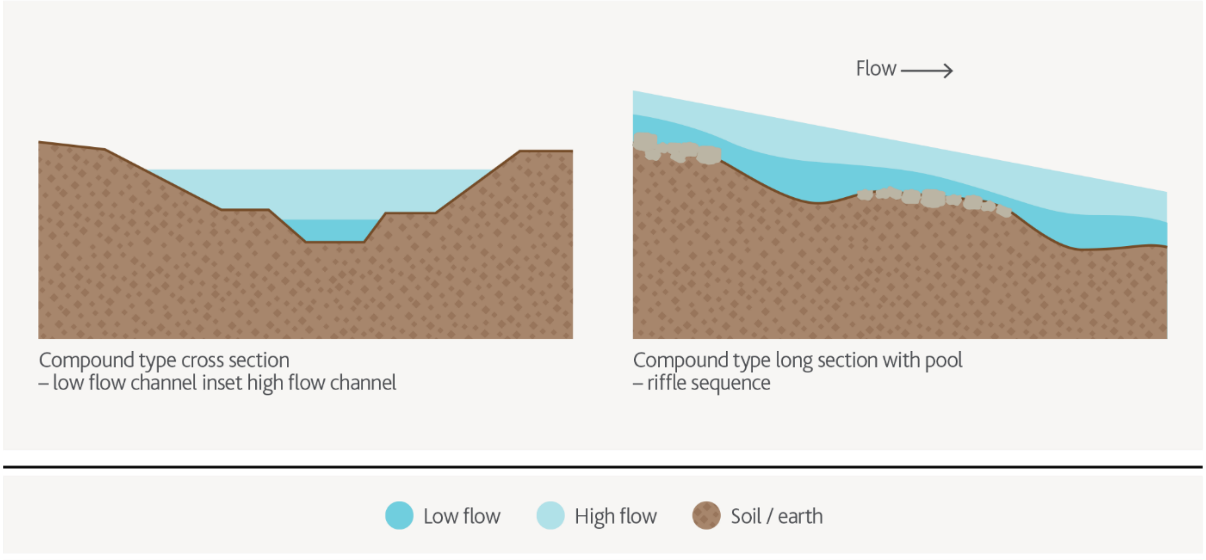


Figure 74 - Compound waterway type indicative cross section and longitudinal section profile and planform

There are obvious differences in the approach to implementing the compound waterway type in areas of highly erosive boundary material, compared with its stable equivalent. For example, in very erosive soils the designer may implement a design which is much more reliant on grade control structures to establish a suitable bed grade for the boundary material. Conversely, for the same waterway in a stable setting there is no need for a grade control-based strategy to be implemented.

Grassed floodway

Grassed floodways have historically been used within urban developments, however they are no longer acceptable within developments where catchment areas exceed 60 Ha. Grassed floodways will now be associated with conveyance of overland flow to an adjoining waterway and these systems will typically be owned and maintained by the respective local council.

E2.3 Healthy Waterways Visions

Melbourne Water has produced a range of 'Healthy Waterways Visions' which communicate aspirations Melbourne Water has for the waterways in Port Phillip and Westernport. Visions have been developed for the following waterway attributes:

- Stream form
- Vegetation quality and species
- Water quality
- Flow

The Healthy Waterway Visions for **vegetation quality and species,** and **stream form** are an integral component of constructed waterway design method. An overview of these visions is provided below.

Vegetation quality and species

The vegetation community is a critical component of the vegetation design for the site, and also has implications for the hydraulic roughness of juvenile and mature vegetation, which will influence flood conveyance and erosion resistance.

The Healthy Waterways vegetation visions communicate Melbourne Water's longer-term vision for riparian and aquatic vegetation across the Port Phillip and Westernport catchments, including constructed waterways. Two vegetation visions were developed: vegetation quality (which indicates the riparian vegetation quality to be achieved and maintained along Melbourne Water's waterways) and vegetation species (which identifies an appropriate range of species at any location in the Port Phillip and Westernport region.

Vegetation quality is rated from 1 (very low) to 5 (very high). Each vegetation quality level describes a number of waterway characteristics such as vegetation structure, species composition, instream vegetation, continuity and connectivity, and suitable vegetation management techniques (Figure 75). The minimum vegetation quality in constructed waterways is 3, so the vegetation quality and species vision templates can be used to identify the appropriate list of species for a constructed waterway at any site in Port Phillip and Westernport.

The vegetation species visions are based on Ecological Vegetation Classes (EVCs), which are spatially explicit representations of a vision for riparian and aquatic vegetation species across the Port Phillip and Westernport catchments. The vegetation species visions provide species lists for each of the five vegetation quality levels set out in the vegetation quality visions (Figure 76).

The vegetation visions for the waterway will be provided by Melbourne Water as part of the Scheme Servicing Advice in the Concept Design stage of the project.

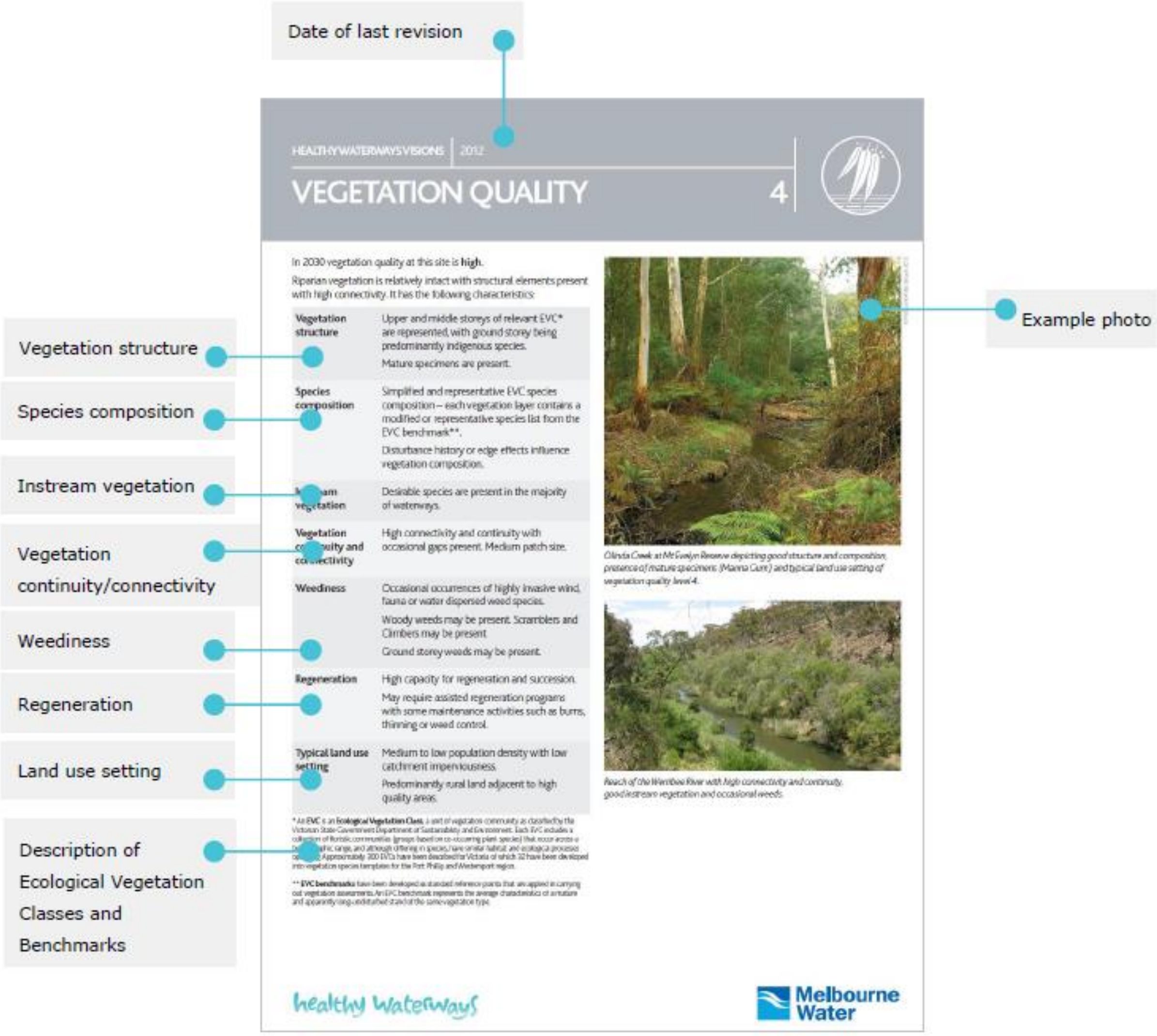


Figure 75 - Example vegetation quality templates for use in constructed waterway design

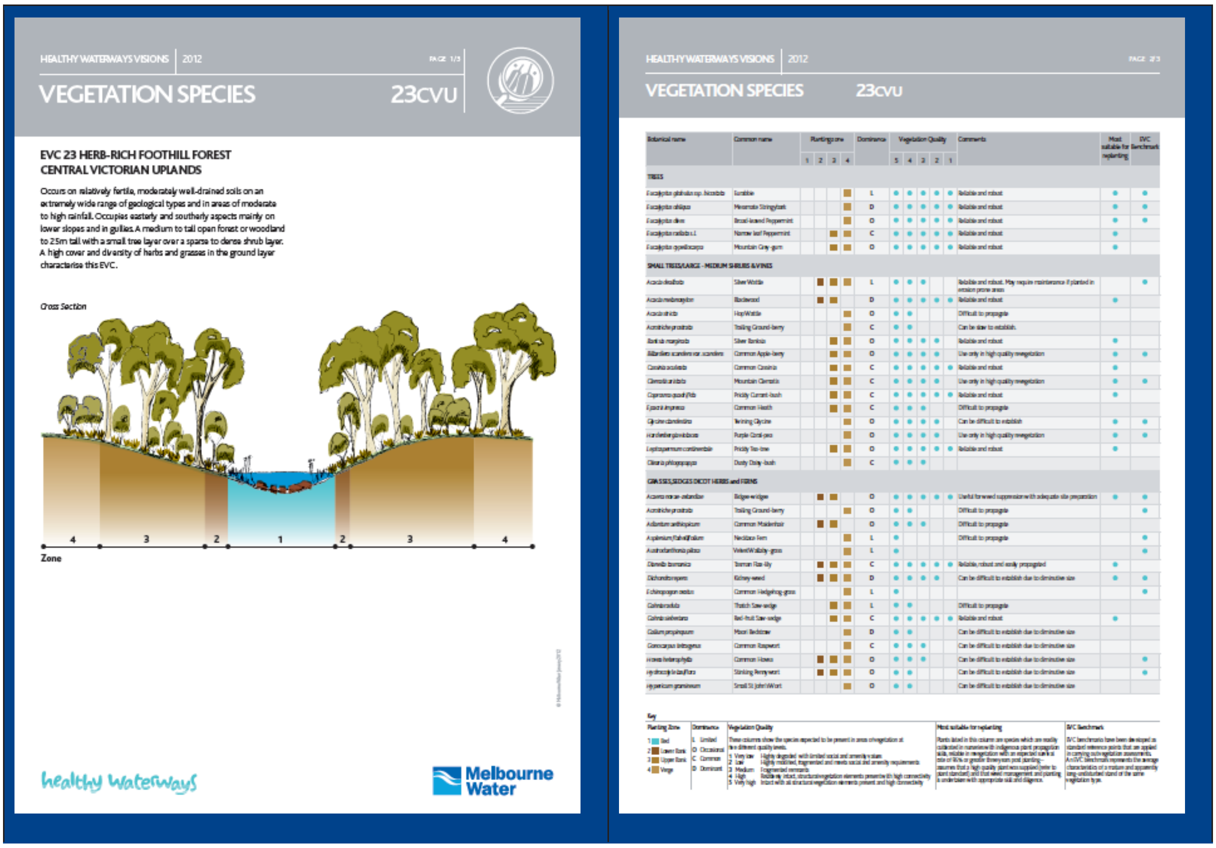


Figure 76 - *Example vegetation species templates for use in constructed waterway design*

Stream form

The Healthy Waterways vegetation stream form visions describe the important aspects of stream form and function, including providing the physical basis for biotic processes in streams (faunal and floral), describing and quantifying channel stability, and describing the relationship between the channel and its floodplain.

The stream form visions outline the physical form and expected ongoing physical processes occurring within the waterway. The visions include a description of channel character (valley abutment, sinuosity, and hydrology), behaviour (stability and timescales of adjustment) and geomorphic features (e.g. pools, riffles, benches).

The stream form visions are an integral component of describing the waterway type that must be selected for each site (as discussed in the previous section). An example stream form vision is presented below (Figure 77 and **Error! Reference source not found.**).

HEALTHY WATERWAYS VISIONS | 2012

STREAM FORM 15

Man-made channel – urban vegetated

The waterway in this reach in 2030 has a single channel with a relatively straight course interspersed by gentle bends. The waterway is likely to have been previously modified to improve drainage of the surrounding floodplain. The channel does not come into contact with the hillslopes at the side of the valley and flow will fill the channel and flow onto the floodplain during relatively large flow events.

The course of the channel is likely to be becoming more winding over time through bank erosion and sediment deposition on the inside of bends. There is likely to be some erosion and deposition during low to medium size events, but the large-scale channel change will occur slowly due to active bank management that will be undertaken to protect urban development and infrastructure that may be in the vicinity of the waterway.

A range of geomorphic features may be present in the channel, although not necessarily all are present in every location. In-channel features could include pools, runs and benches; these features are likely to be actively forming over periods of years.

In some locations the channel may have previously incised, leading to deepening of the bed and widening of the channel. The channel is larger and flooding occurs less frequently. A smaller channel forms in the base of the large channel with a similar range of geomorphic features as described above.

Where incision has occurred bed stabilisation works and revegetation works may be carried out. The banks of the incised channel are often steep. The natural recovery of the waterway to a stable, diverse system should be encouraged to reduce the frequency and magnitude of bank erosion and enhance in-channel habitat.

An example of this type of stream form. Note the surrounding land use may differ from that shown.

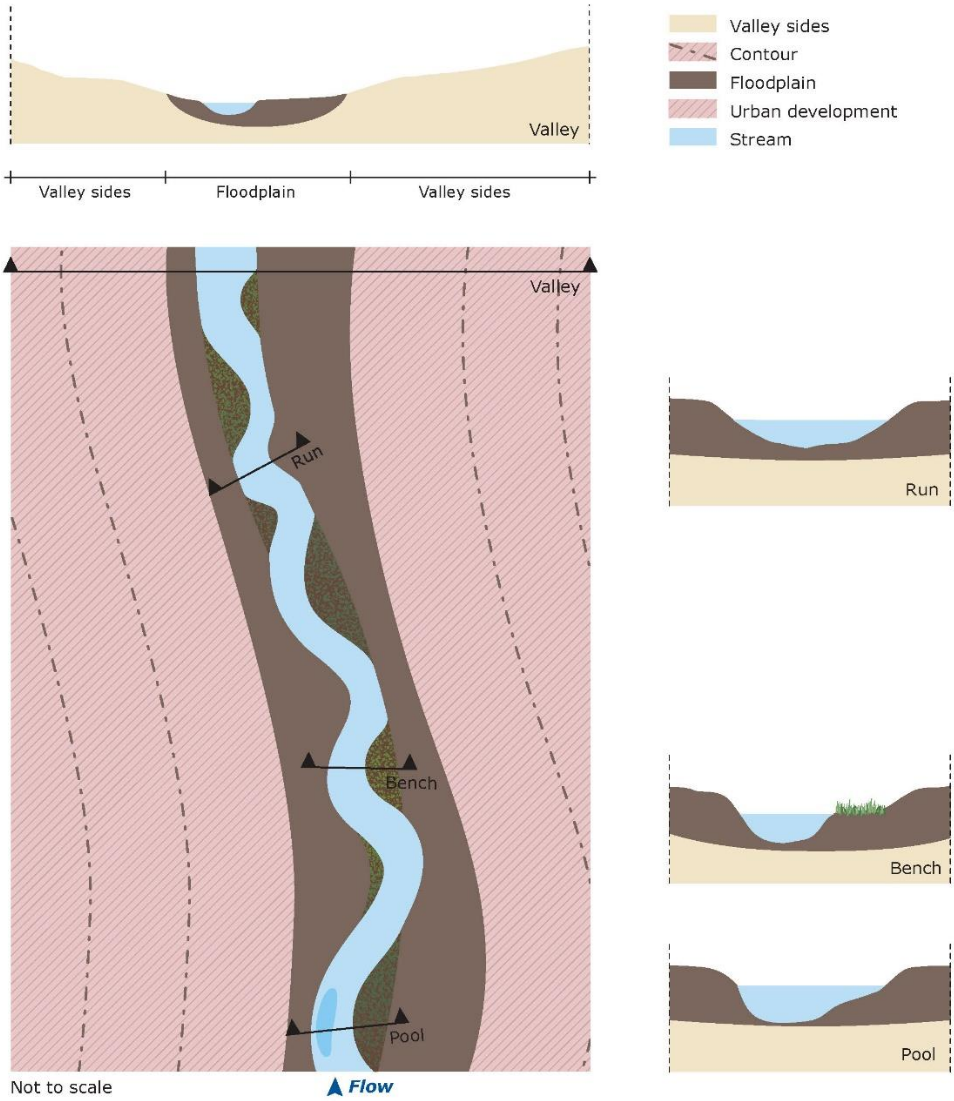
healthy waterways

Melbourne Water

Figure 77 - Example stream form vision for use in constructed waterway design

HEALTHY WATERWAYS VISIONS | 2012

STREAM FORM 15



Cross-sections and plan of this stream form.

Figure 78 – Example Stream Form vision plan view for use in waterway design

E2.4 Waterway Protection & Rehabilitation

Protecting existing valued waterway form

If an existing waterway or drainage line on the site has cultural heritage, flora and fauna, or geomorphic values that must be retained, innovative solutions may be required to enable the existing waterway to perform the function of drainage outfall and conveyance.

Although not covered specifically in this manual some typical types are:

- **Type 1**. The existing waterway **is deep enoug**h to provide outfall and the waterway characteristics (width / grade) allow 1% AEP flow to be conveyed without detrimental impact to the existing values (Base case). No works are required within the waterway however the impact of urban hydrology on waterway values (physical form and ecology) should be assessed to inform the design of stormwater treatment systems across the catchment as part of adjacent developments. Flow and shear stress mitigation for higher volume and more frequent flows may be required.
- **Type 2.** The existing waterway **is deep enough** to provide outfall and the waterway characteristics (width / grade) **do not allow** 1% AEP **flow to be conveyed** without detrimental impact to the existing values. Works to create additional conveyance by enhancing high flow channel capacity in areas where the existing values are not at risk should be considered.
- **Type 3** The existing waterway **is not deep enough** to provide outfall however the waterway characteristics (width / grade) **allow 1% AEP flow to be conveyed** without detrimental impact to the existing values. A low flow pipe and / or surcharge system should be considered in order to avoid deepening the system and protect existing values. Note that Melbourne Water and Council do not accept submerged pipes.
- **Type 4** The existing waterway **is not deep enough** to provide outfall and the waterway characteristics (width / grade) **do not allow 1% AEP flow to be conveyed** without detrimental impact to the existing values. A low flow pipe and / or surcharge system along with additional conveyance (high flow channel capacity) could be considered.

The location of the existing values to be protected will influence the need for low flow pipe and / or additional conveyance and their subsequent location within the cross section and plan form. The designer may also need to consider the use of localised filling to adjacent land holdings to achieve a similar or complementary outcome. Melbourne Water will only consider allowing low flow pipes when the imperative is to protect the existing waterway values from physical and hydraulic disturbance.

Rehabilitating existing waterways

Melbourne Water is sometimes faced with the task of designing major works along a degraded reach of existing waterway within rural and existing urban land uses. Whilst the design principles and approach underpinning this manual are in many ways still applicable, the works delivery, design and acceptance processes are different to a constructed urban waterway.

Where the waterway designer encounters a site for a proposed waterway (or existing waterway that requires major rehabilitation works) with longitudinal grades steeper than 1-in-200 then the designer is encouraged to base their initial design response on a grade control program, then determine what additional design components can be added to this design response that will contribute to meeting the design objectives. Melbourne Water should be consulted at an early stage in the design process for these situations.

For further guidance regarding design philosophy and techniques for major waterway rehabilitation works, including grade control programs, the waterway designer is advised to refer to the *Technical Guidelines for Waterway Management* (DSE, 2007).

E2.5 Waterway maintenance requirements

Maintenance access

Direct maintenance access is required along both sides of the waterway (min 4m wide). The maintenance tracks should be offset from the top of any adjacent batter, to provide safe run off areas for maintenance vehicles. This access can often be incorporated with public amenity objectives via shared paths.

Careful planning of maintenance access and paths can limit vehicular disturbance that leads to damaged riparian vegetation and weed invasion.

The design for access should also consider:

- suitable materials for vehicle loadings, especially at cross-over points along the path network (i.e. where the Melbourne Water maintenance track for heavy machinery access to the waterway crosses over the public pathway)
- the prevention of non-authorised vehicle access (e.g. double-lock bollards/gates for Melbourne Water and Council).

Particular features in or near waterways such as large culverts, sediment basins, and pools that are designed to trap sediment or have access for de-silting purposes rather than only provide habitat, and wetlands will require specific design considerations in relation to maintenance needs, including:

- de-silting
- machinery sizes
- turning circles
- lifting distances.

Batter slopes

Batters on approaches to waterways, particularly areas with permanent water such as pools, must have suitable grades and must reflect these landscape constraints and current safety standards:

- the edge of any deep, open water should not be hidden or obscured by embankments or terrestrial planting, unless measures preventing access are provided
- approaches to batter slopes should be no steeper than 1:5 Vertical to Horizontal (V:H) unless there is special landscape edge treatment that will provide appropriate safety measures/fencing
- the safety bench must be densely planted with emergent macrophytes so that casual entry will be difficult.

Safety measures such as permanent fencing or combined fencing and densely vegetated buffer zones should be used in the following circumstances:

- adjacent to zones of deep water (greater than 350 mm at normal water level)
- adjacent to potentially unsafe structures
- where high velocities may be encountered (refer Melbourne Water’s Land Development Manual floodway safety criteria)
- where batters are 1V:3H or steeper.

Maintenance access areas should be fenced and gated to discourage access where the basic safety measures described above are not met. Non-maintenance access to the top of weirs, orifice pits and outlet structures must be restricted by appropriate safety fences and other barriers.

If any part of the water body is deeper than 350 mm, interim fencing may be required between the periods of construction and the establishment of vegetation. For further safety design details for pools, refer to Melbourne Water's Wetlands Design Manual.

When preparing the concept design package the designer must demonstrate that maintenance access requirements for the proposed features within each of the options has been considered.

Maintenance responsibilities

The responsibility for maintenance falls to both Melbourne Water and council for features within the waterway corridor. To ensure clarity of future asset management and maintenance considerations the designer must highlight waterway features falling under the responsibility of each.

E2.6 Useful Guidelines

Melbourne Water guidelines

Melbourne Water has produced the following range of guidelines which may be of use or further interest to the waterway designer.

Healthy Waterways Strategy
https://www.melbournewater.com.au/media/6976/download

Stormwater Strategy
https://www.melbournewater.com.au/sites/default/files/2017-10/Stormwater-strategy_0.pdf

Waterway Corridor Guidelines
https://www.melbournewater.com.au/sites/default/files/Waterway-corridors-Greenfield-development-guidelines.pdf

Waterway Crossings Guidelines
https://www.melbournewater.com.au/sites/default/files/Constructing-waterway-crossings-guidelines.pdf

Stormwater connections
https://www.melbournewater.com.au/planning-and-building/work-or-build-near-our-assets-or-easements/stormwater-connection-guidelines

Shared Path Guidelines
http://www.melbournewater.com.au/Planning-and-building/Forms-guidelines-and-standard-drawings/Documents/Shared-pathways-guidelines.pdf

Jetties Guidelines
http://www.melbournewater.com.au/Planning-and-building/Forms-guidelines-and-standard-drawings/Documents/Jetties-approval-guidelines.pdf

Guidelines for development in flood prone areas
https://www.melbournewater.com.au/media/580

Constructed Wetlands Design Manual
https://www.melbournewater.com.au/planning-and-building/developer-guides-and-resources/standards-and-specifications/constructed-0

MUSIC Guidelines
https://www.melbournewater.com.au/planning-and-building/developer-guides-and-resources/guidelines-drawings-and-checklists/guidelines

Constructed Shallow Lake Systems – Design Guidelines for Developers
https://www.melbournewater.com.au/planning-and-building/developer-guides-and-resources/guidelines-drawings-and-checklists/guidelines

Topsoil specifications
https://www.melbournewater.com.au/media/624/download

Jute mat specifications
https://www.melbournewater.com.au/planning-and-building/developer-guides-and-resources/guidelines-drawings-and-checklists/guidelines#vegetation

Vegetation supply and installation standards
https://www.melbournewater.com.au/planning-and-building/developer-guides-and-resources/guidelines-drawings-and-checklists/guidelines#vegetation

Security and retention for developer instigated works
https://www.melbournewater.com.au/media/6746/download

Stormwater harvesting guidelines
https://www.melbournewater.com.au/media/619/download

Melbourne Water standard drawings
https://www.melbournewater.com.au/planning-and-building/developer-guides-and-resources/guidelines-drawings-and-checklists/drawings

Other guidelines

WSUD Engineering Procedures – Stormwater (CSIRO, 2005)
http://www.publish.csiro.au/pid/4974.htm

Technical Guidelines for Waterway Management (DSE, 2007)
(Soft copy available from Melbourne Water upon request).

Australian Rainfall and Runoff (AR&R; 2019)
http://arr.ga.gov.au/arr-guideline

Urban Stormwater: Best Practice Environmental Management Guidelines
http://www.publish.csiro.au/book/2190

Arthur Rylah Institute – Fishways and fish movement
https://www.ari.vic.gov.au/research/rivers-and-estuaries/fishways-and-fish-movement

Growling Grass Frog Crossing Design Standards (DELWP 2017)
https://www.msa.vic.gov.au/__data/assets/pdf_file/0020/73415/Growling-Grass-Frog-Crossing-Design-Standards_March2017.pdf

Factsheets about improving the ecological function of urban waterways

https://watersensitivecities.org.au/content/improving-the-ecological-function-of-urban-waterways-a-compendium-of-factsheets/

melbournewater.com.au