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.

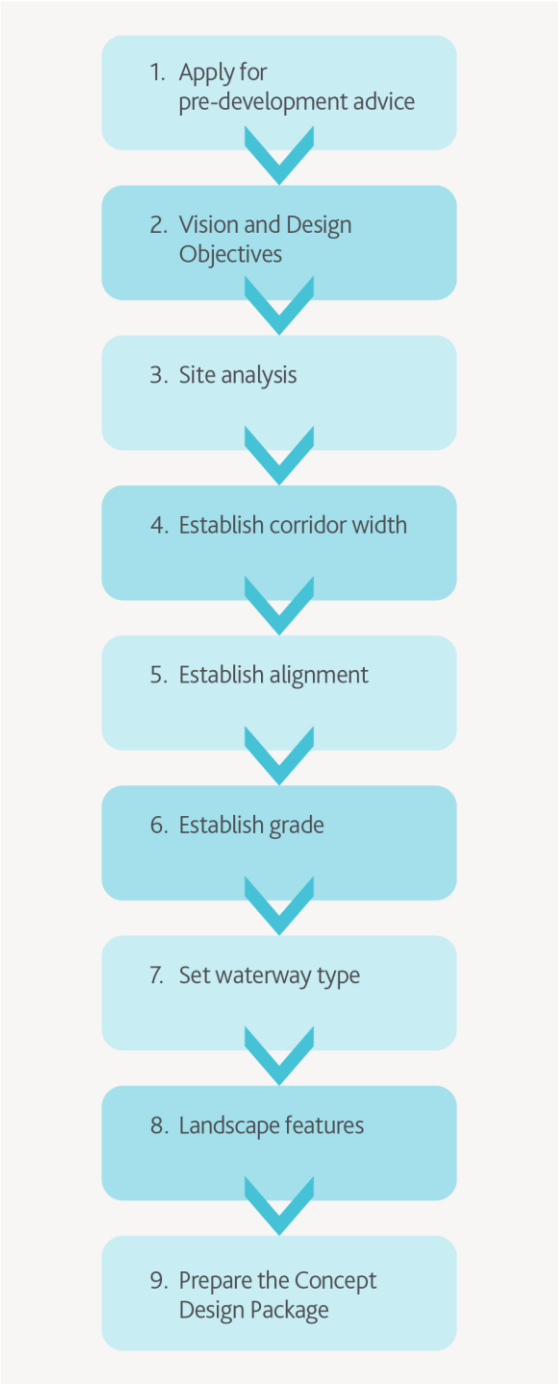


Figure 24 - *Tasks to prepare the concept design package*

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

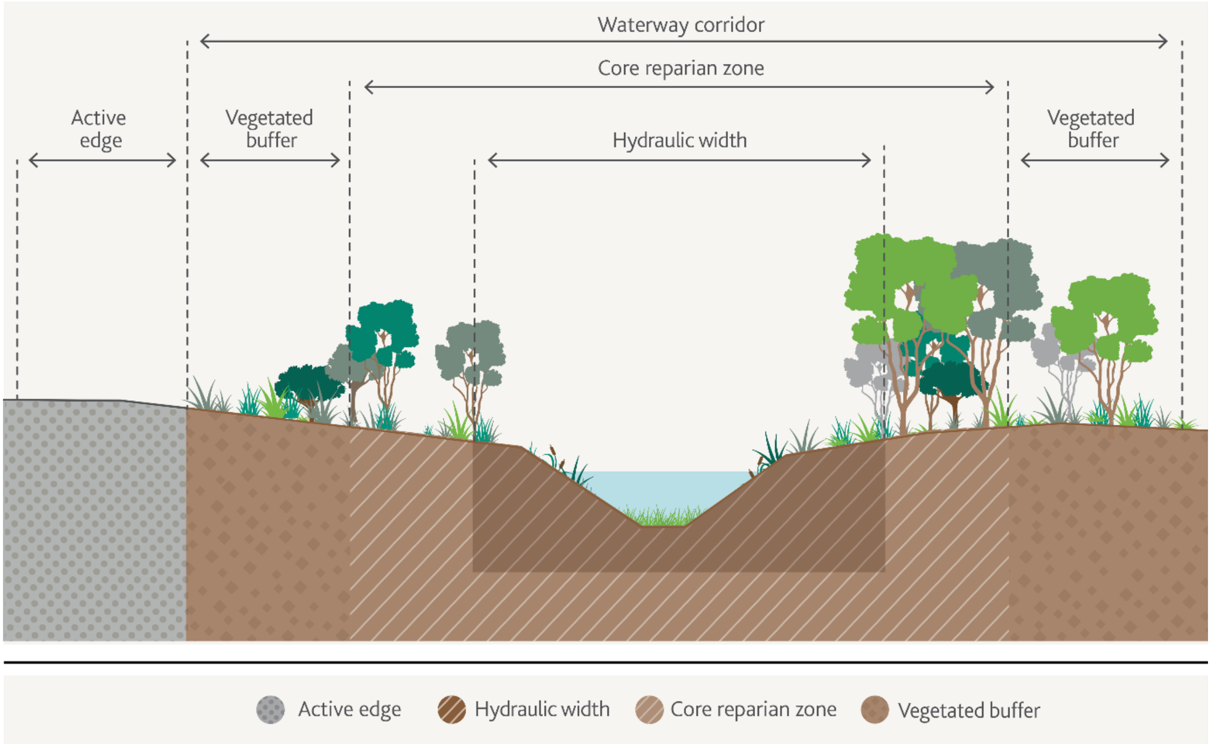


Figure 25 - Example water corridor section for a constructed waterway (*Waterway Corridor Guidelines* (2013).

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.

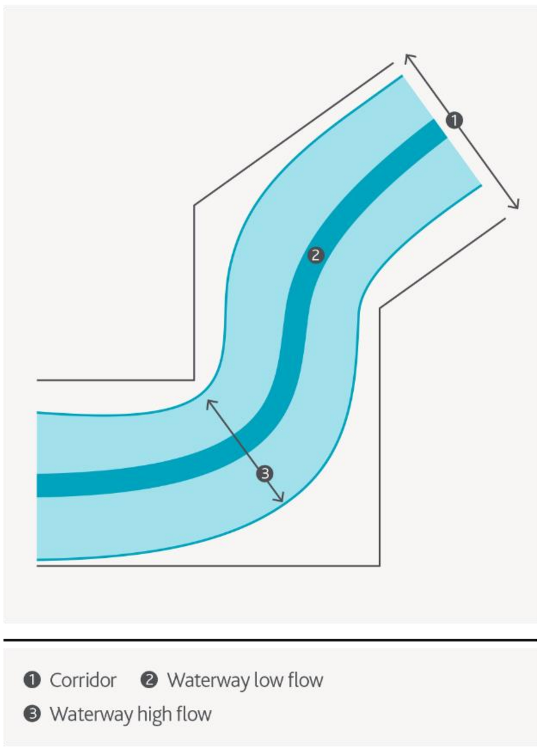


Figure 26 – Example waterway width and alignment

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.

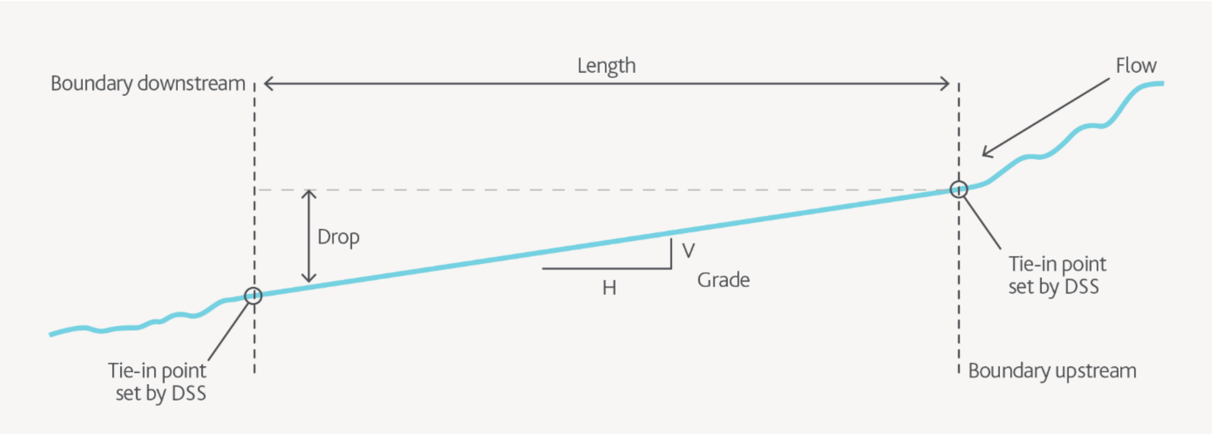
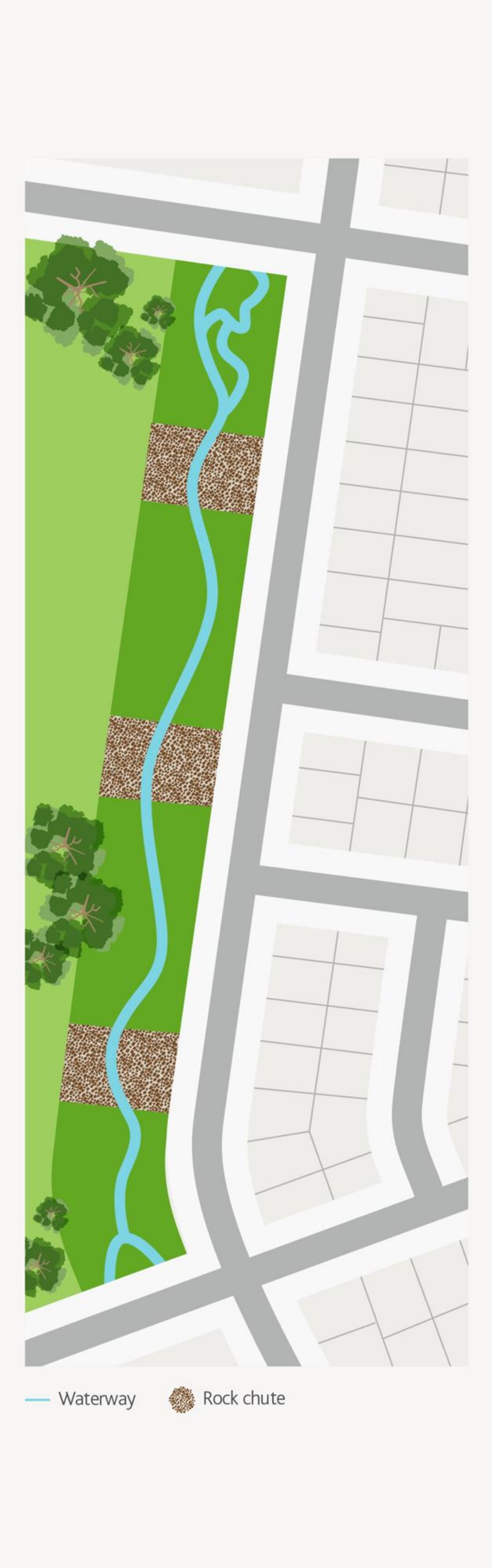


Figure 27 - Parameters used to determine the longitudinal bed grade of a waterway

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.

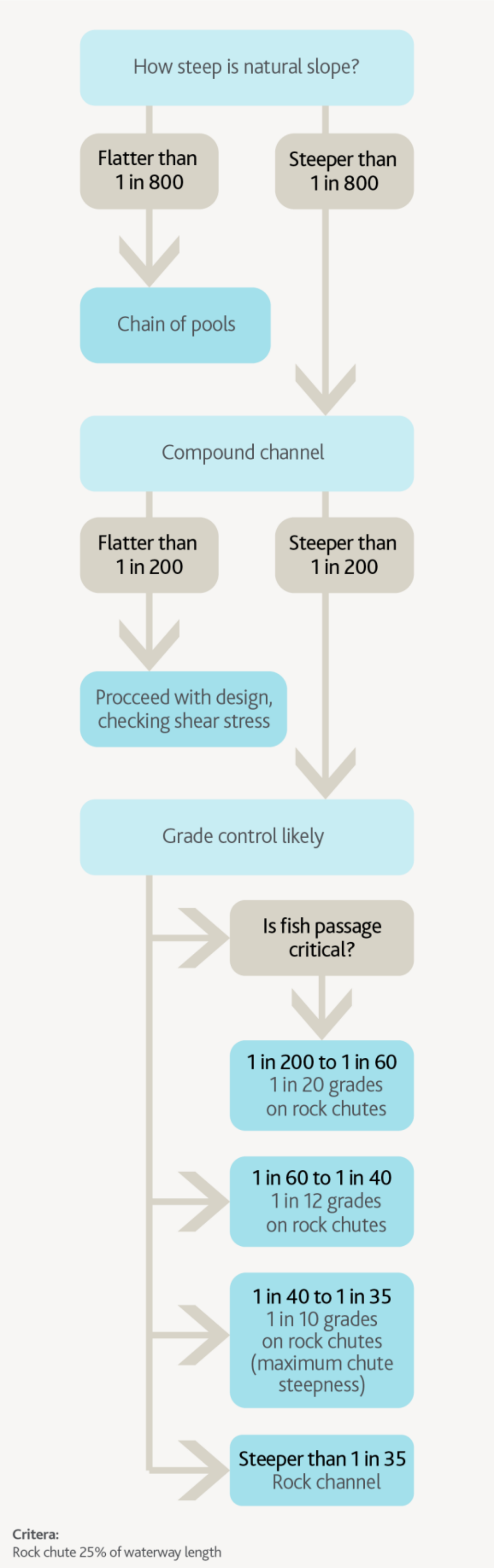


Figure 28 - Decision tree for longitudinal grade (existing grades shown)

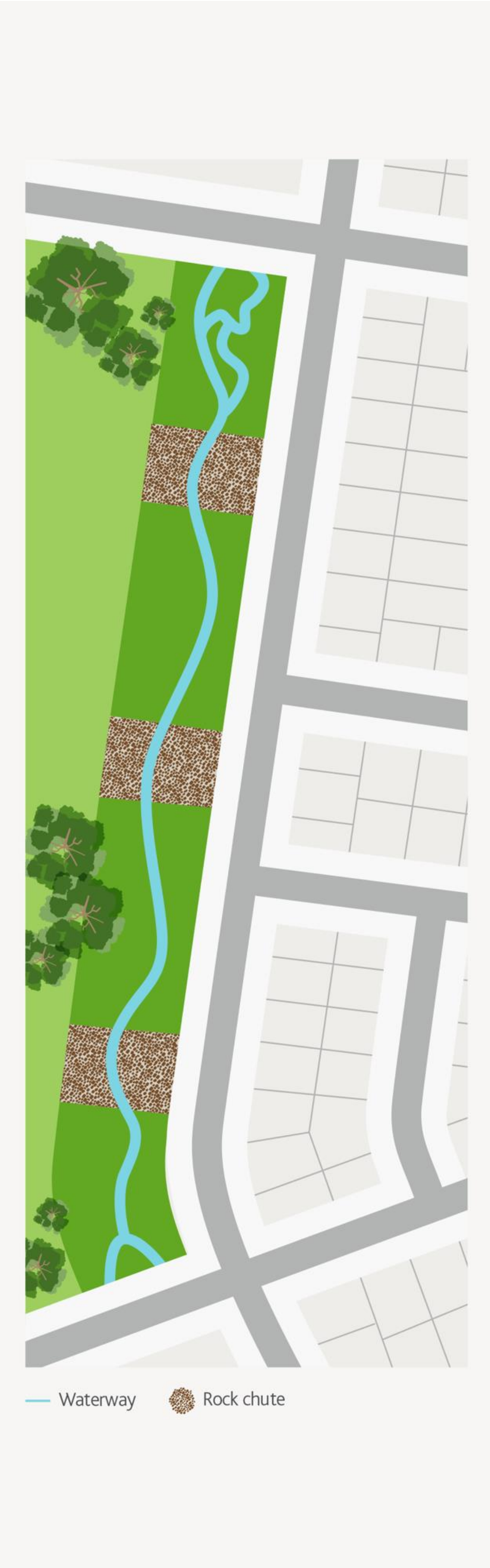


Figure 29 - Plan view schematic of 25% rock chute coverage on a waterway

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.

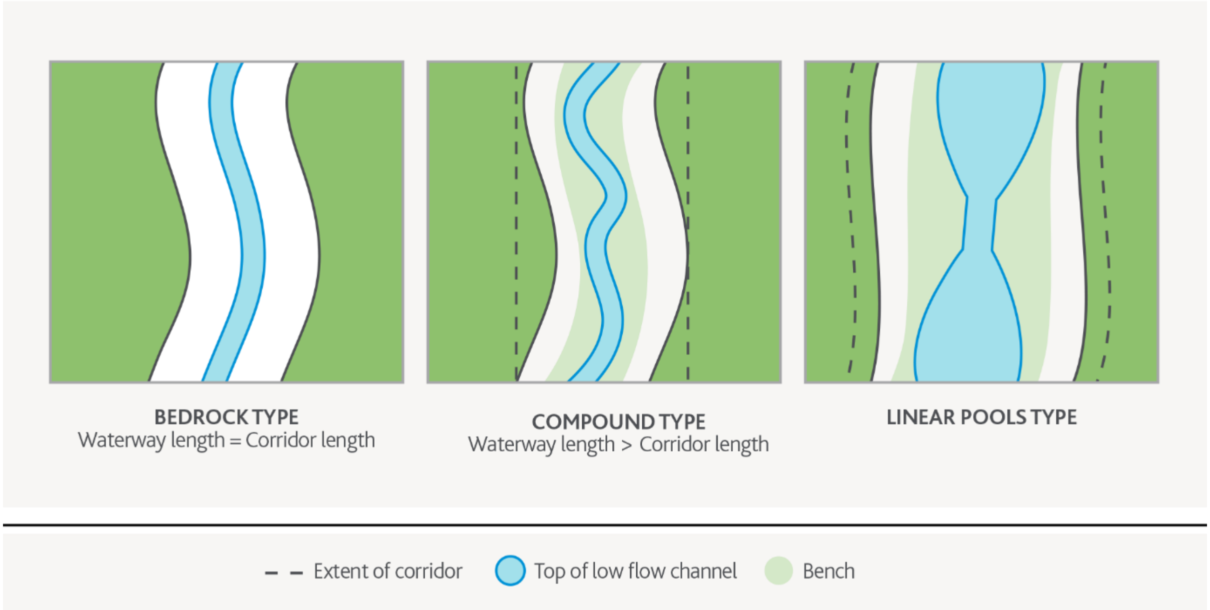


Figure 30 - Examples of the three constructed waterway types

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.

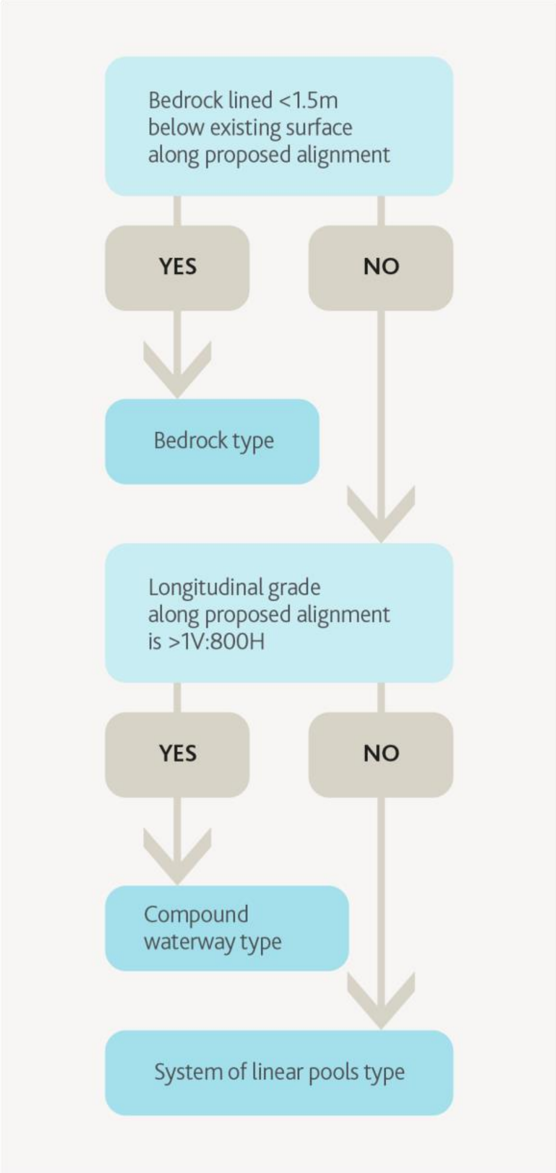


Figure 31 - Constructed waterway type decision tree

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.

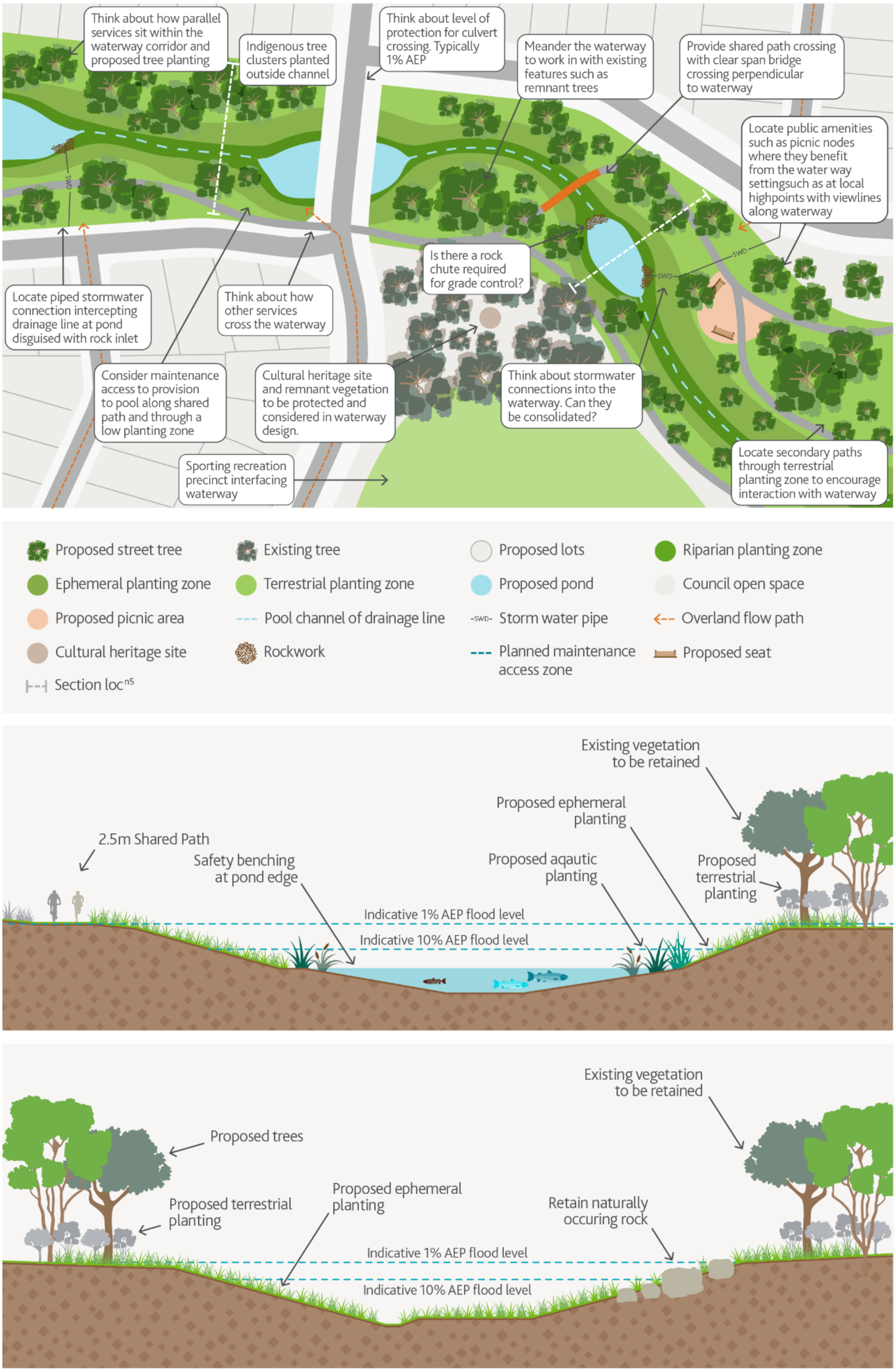


Figure 32 – Example constructed waterways concept design

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.

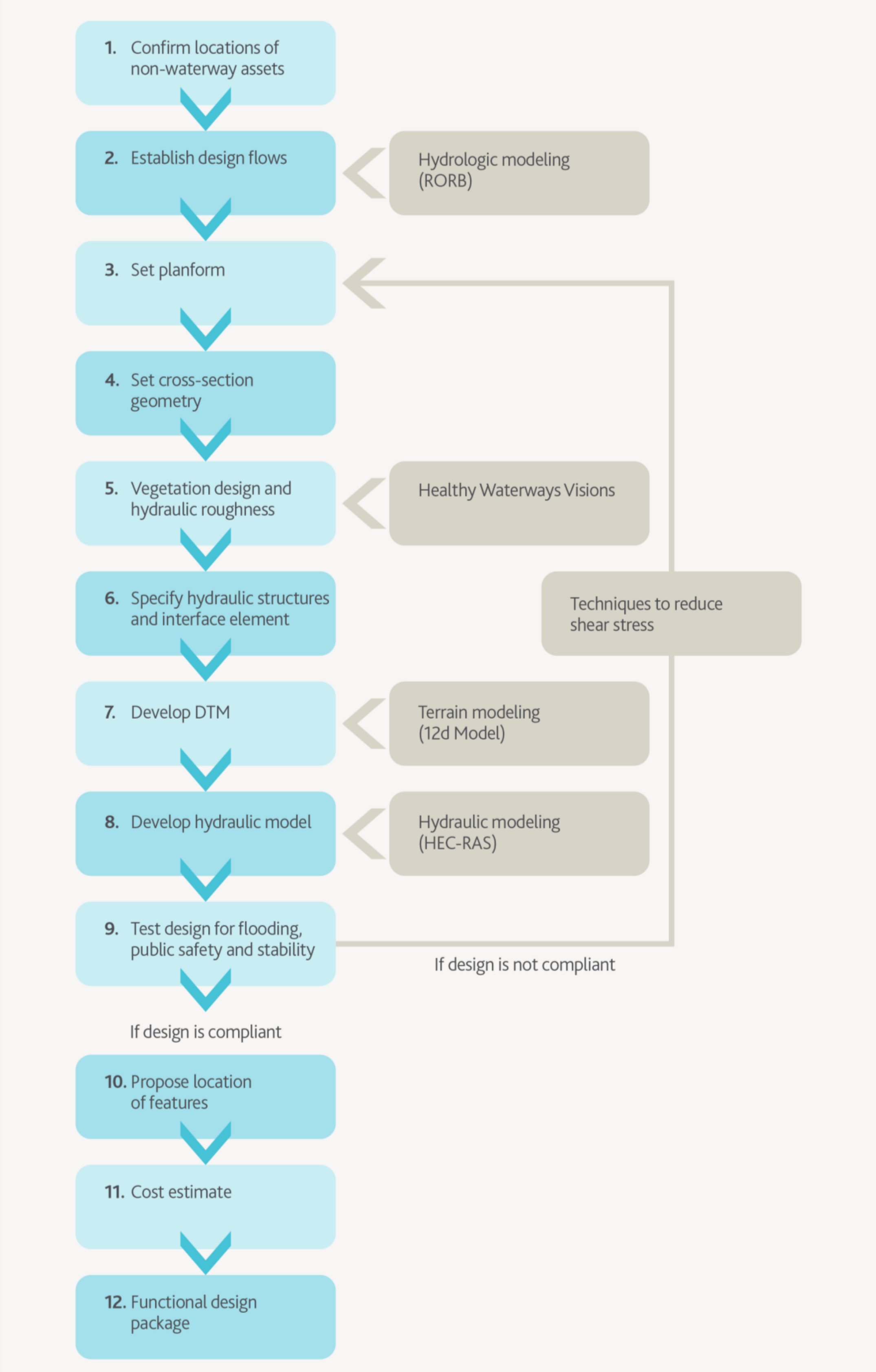


Figure 33 - Tasks to develop the functional design package.

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.

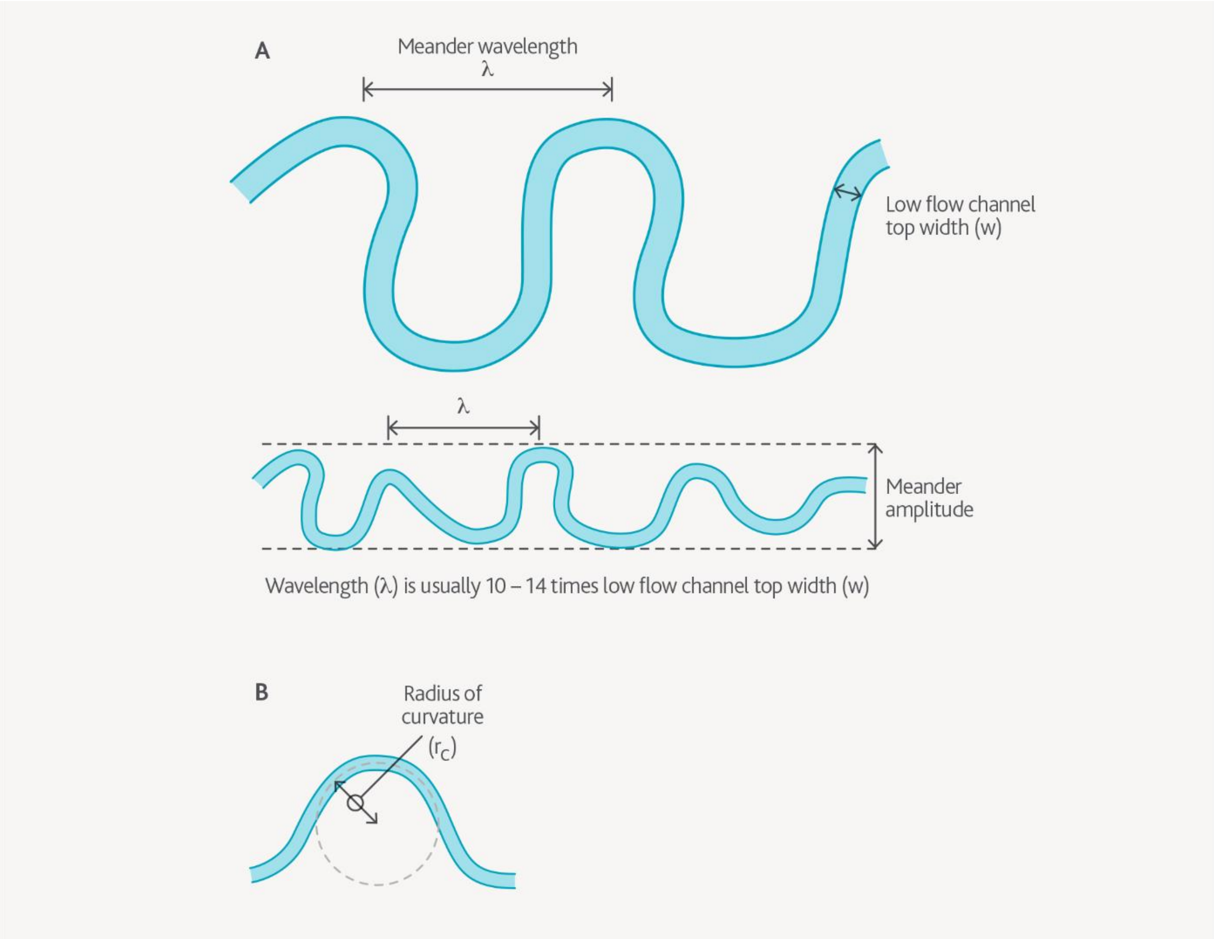


Figure 34 - Aspects of meander geometry (a) Meander wavelength (b) Radius of curvature

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.

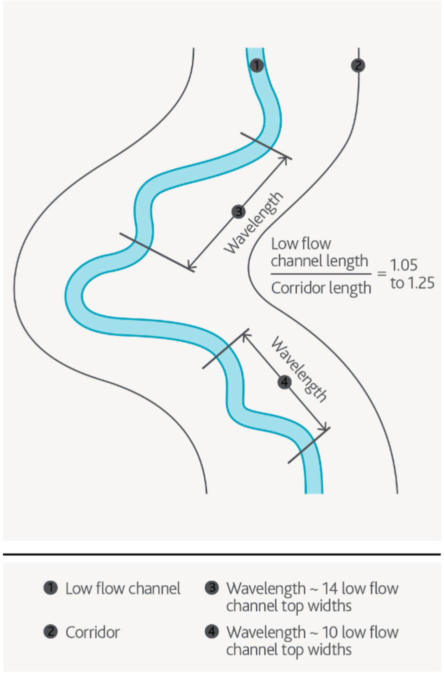


Figure 35 - Low flow channel variability in design of compound type waterways

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.

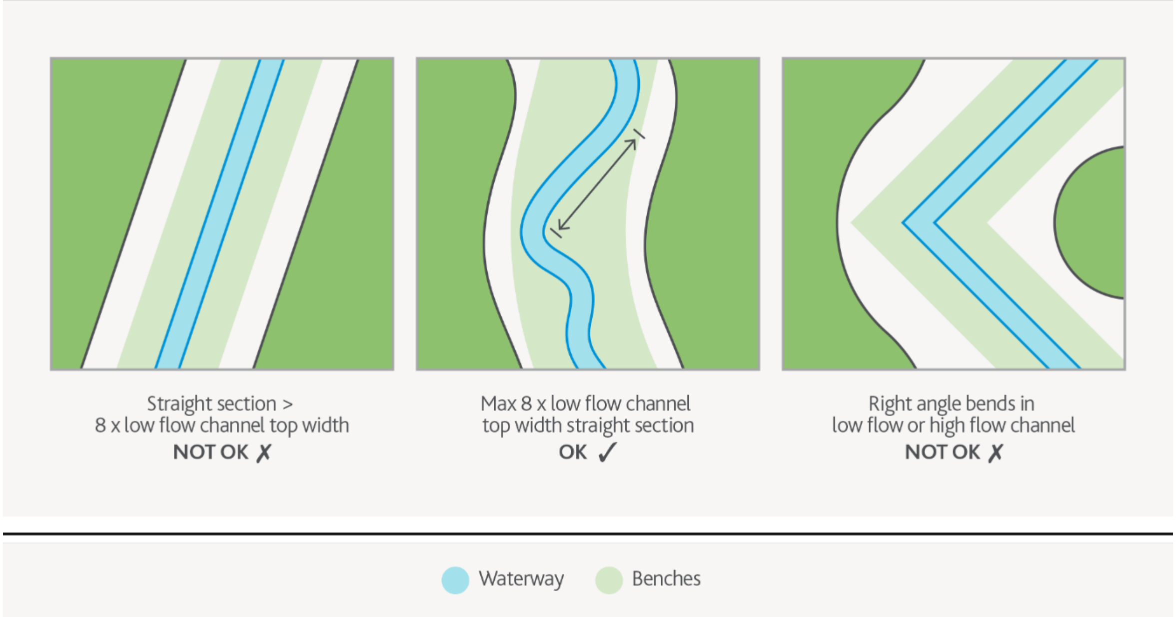


Figure 36 - Bend sharpness acceptable limits for compound waterways

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

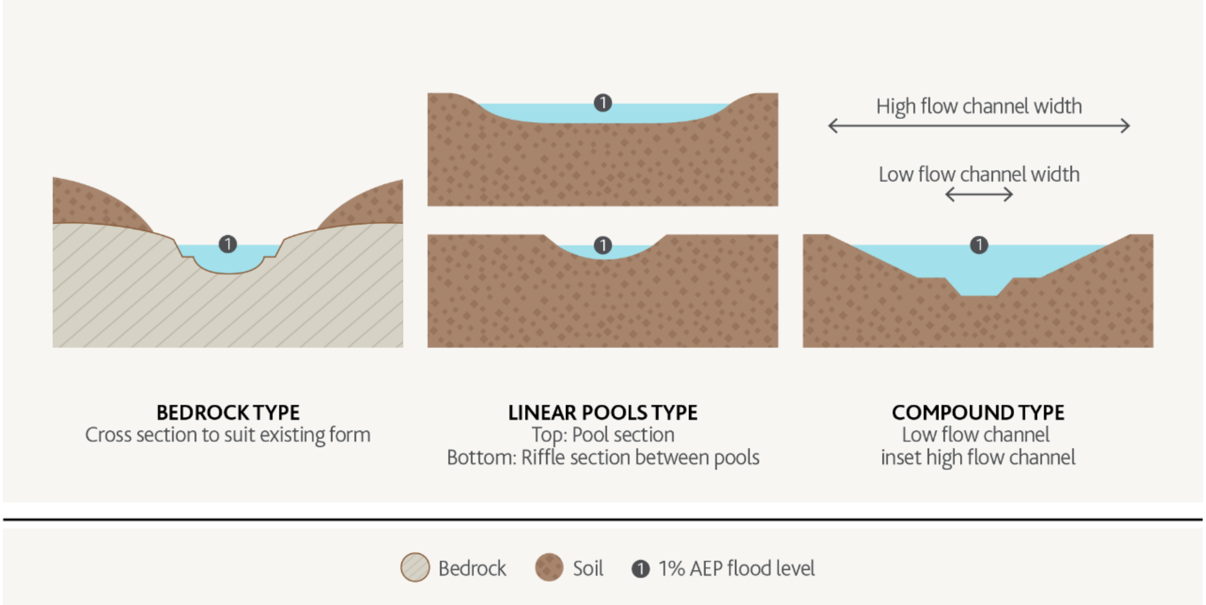


Figure 37 - Typical waterway type sections

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*

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

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

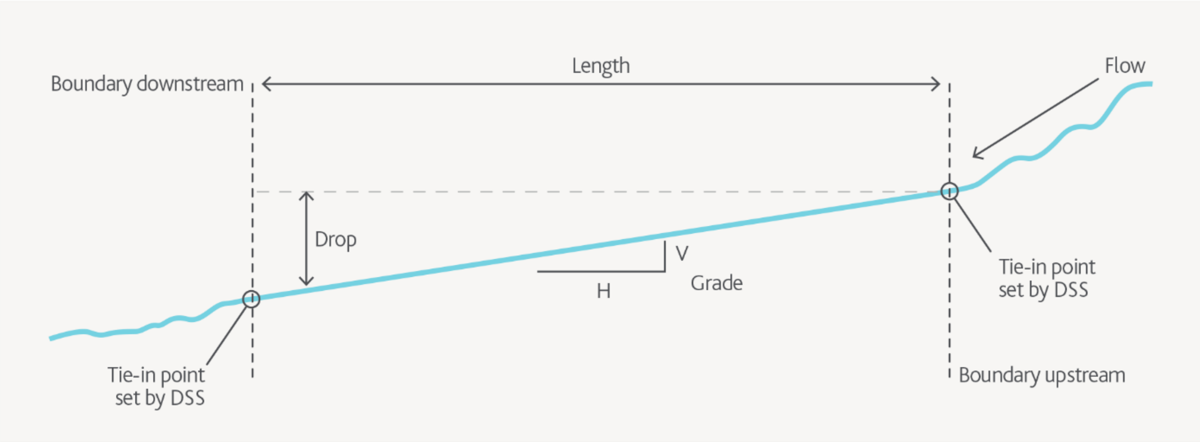


Figure 38 - Example calculation of chanel slope

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):

$$\tau = \gamma R S$$

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.

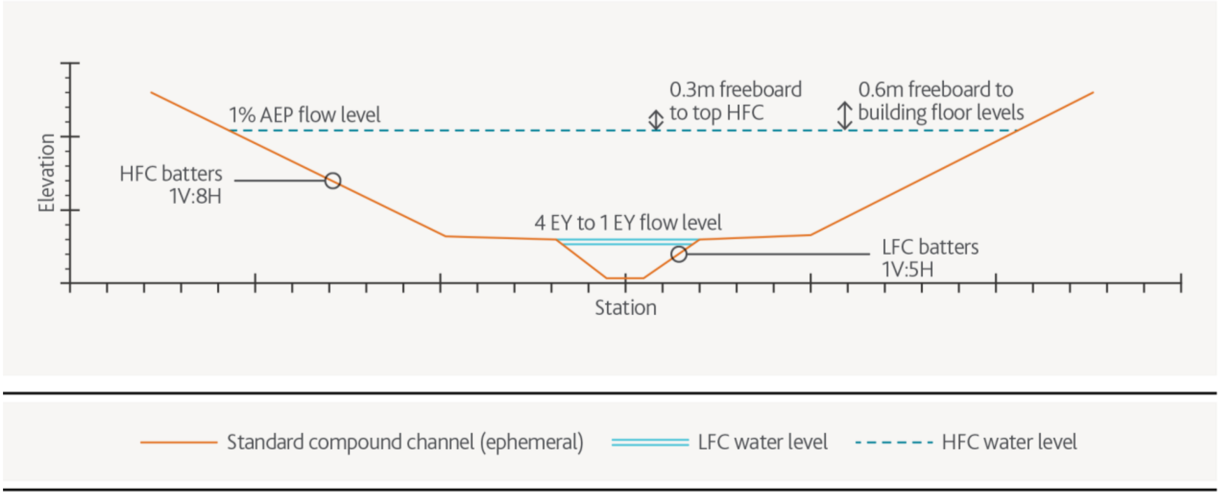


Figure 39 - Typical compound type waterway meeting cross-section geometry, capacity and shear stress criteria

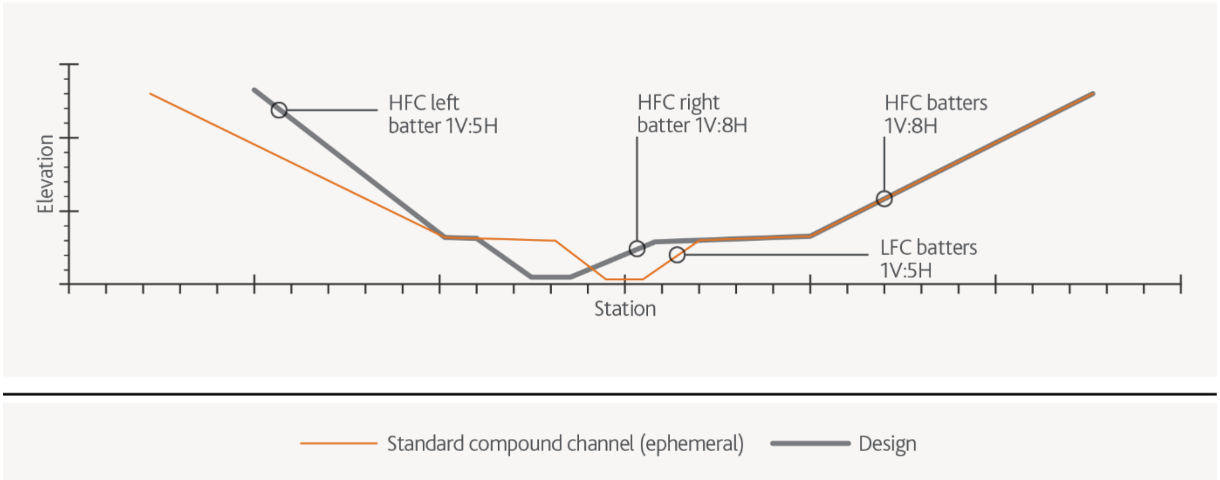


Figure 40 - Compound type waterway with steeper left batters (HFC and LFC) at outside of meander bend

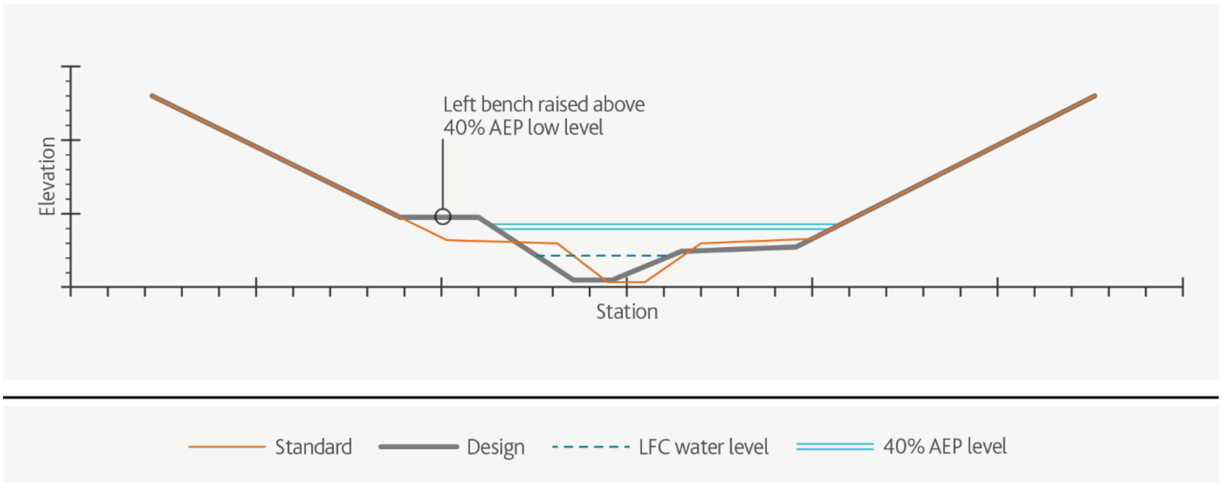


Figure 41 - Compound type waterway with bench variation

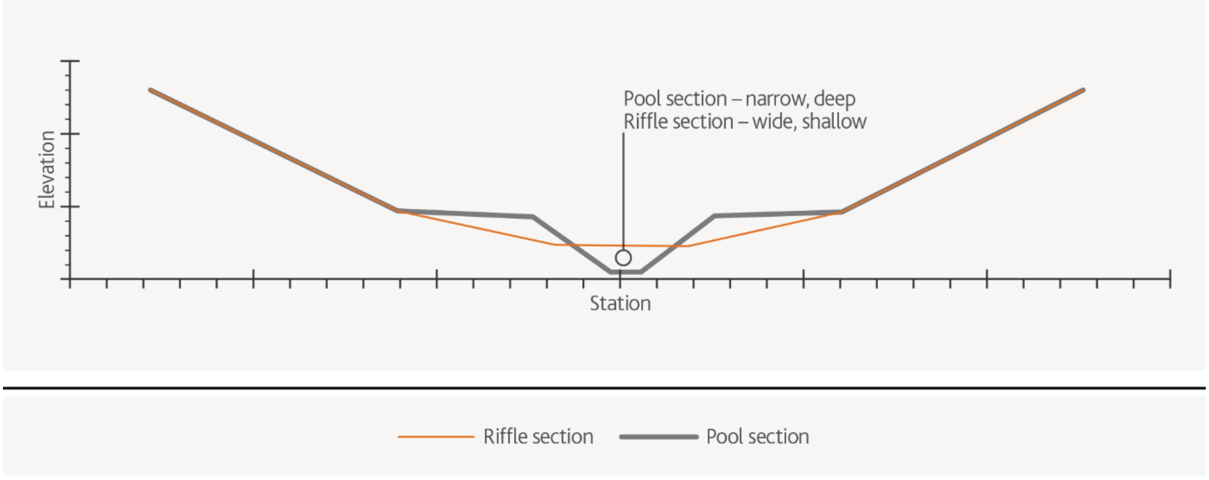


Figure 42 - Typical riffle and pool section for compound type waterway

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.

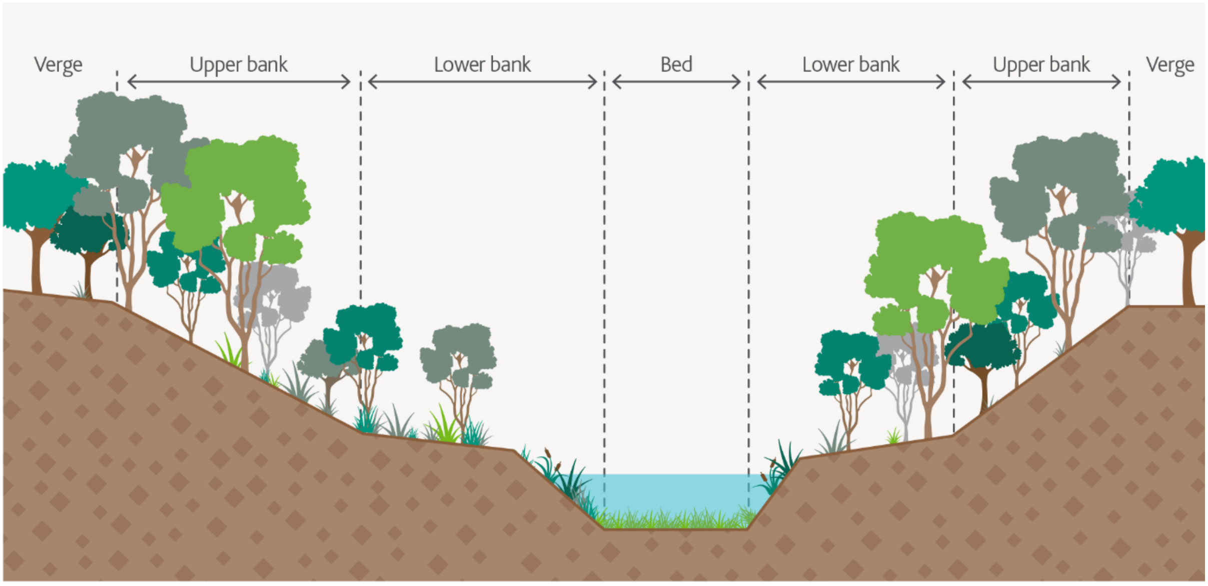


Figure 43 - Hydraulic and vegetation zonation across the waterway

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)

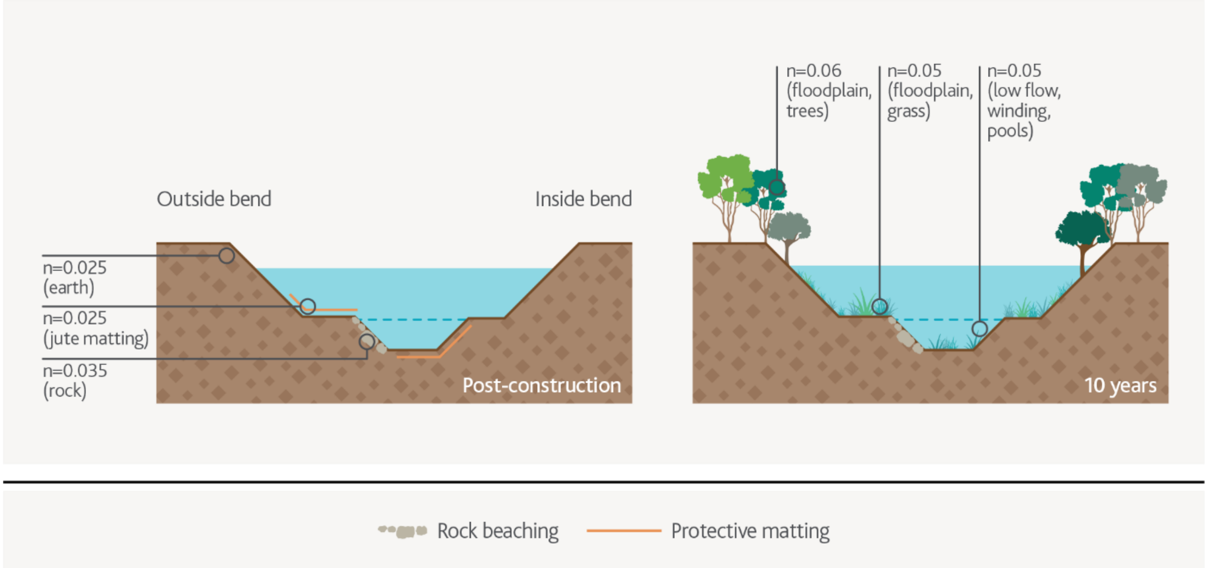


Figure 45 - Waterway corridor showing regions of similar vegetation species/hydraulic roughness in the immediate post-construction period when mature condition are reached (10 years plus)[4]

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).

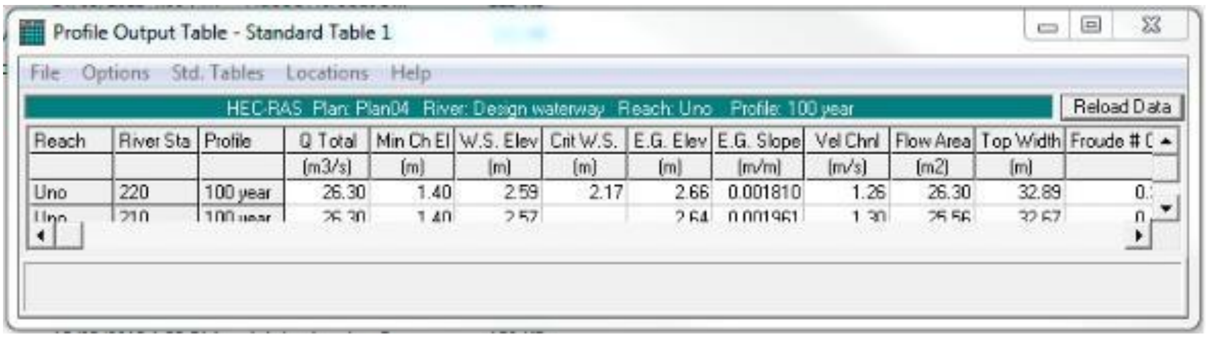


Figure 46 - Example HEC-RAS output table showing parameters used to check flood levels and freeboard

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).

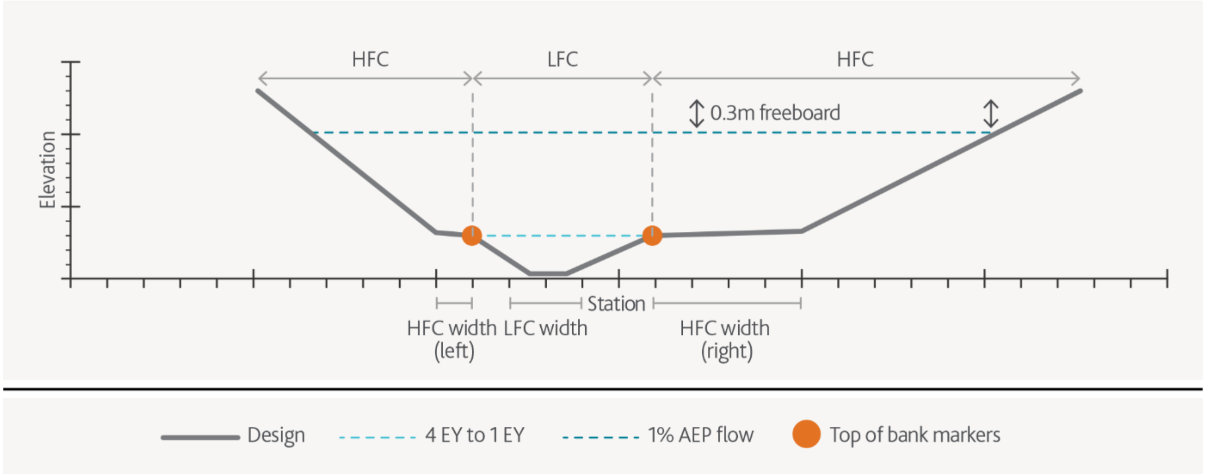


Figure 47 - Markers placed at top of bank to differentiate between low flow channel and high flow channel

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.

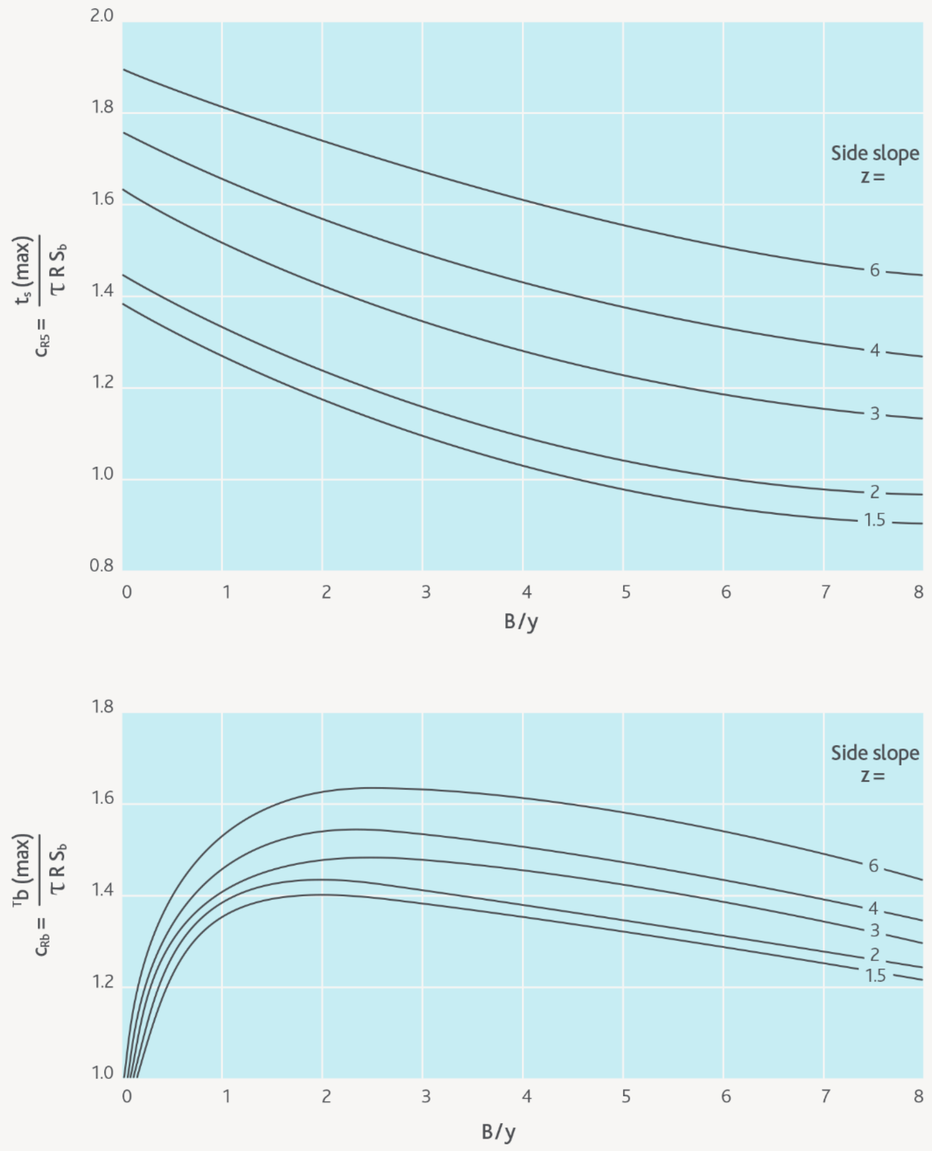
HEC-RAS Plan: Plan 01 River: Kettle Creek Reach: Supply

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.

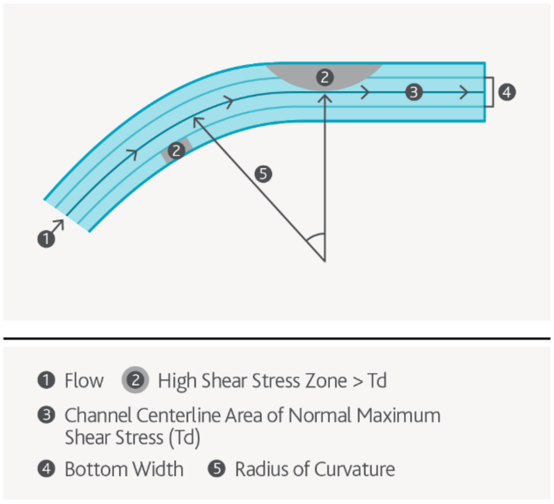


Figure 50 - Location of increased shear stress due to channel bend (adapted, Nouh and Townsend, 1979)

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 (τbc / τb) is 1.35
- Shear stress on the channel side slopes in the curved reach to that of a straight reach (τsc / τs) = 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.

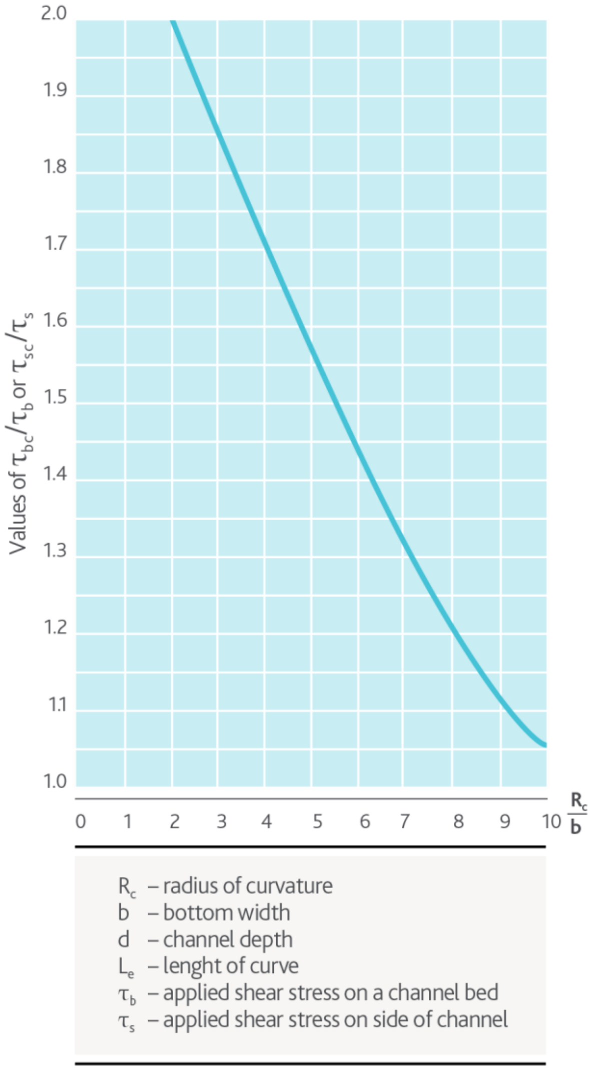


Figure 51 - Applied maximum shear stress on bed and banks of trapezoidal channels in a curved reach (from NRCS 2007)

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.

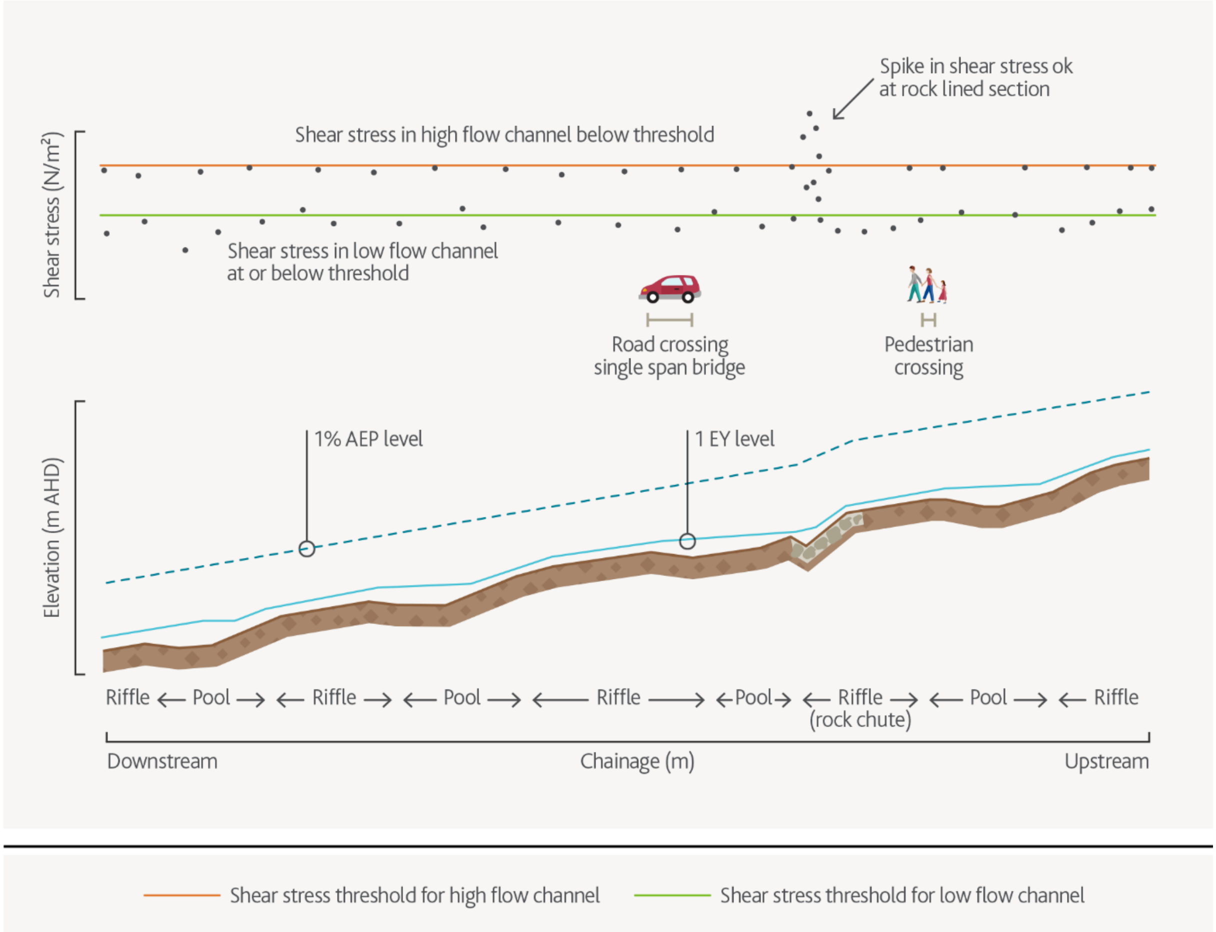


Figure 52 - Example longitudinal profile of constructed waterway shear stress, thresholds, relevant features and infrastructure

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.

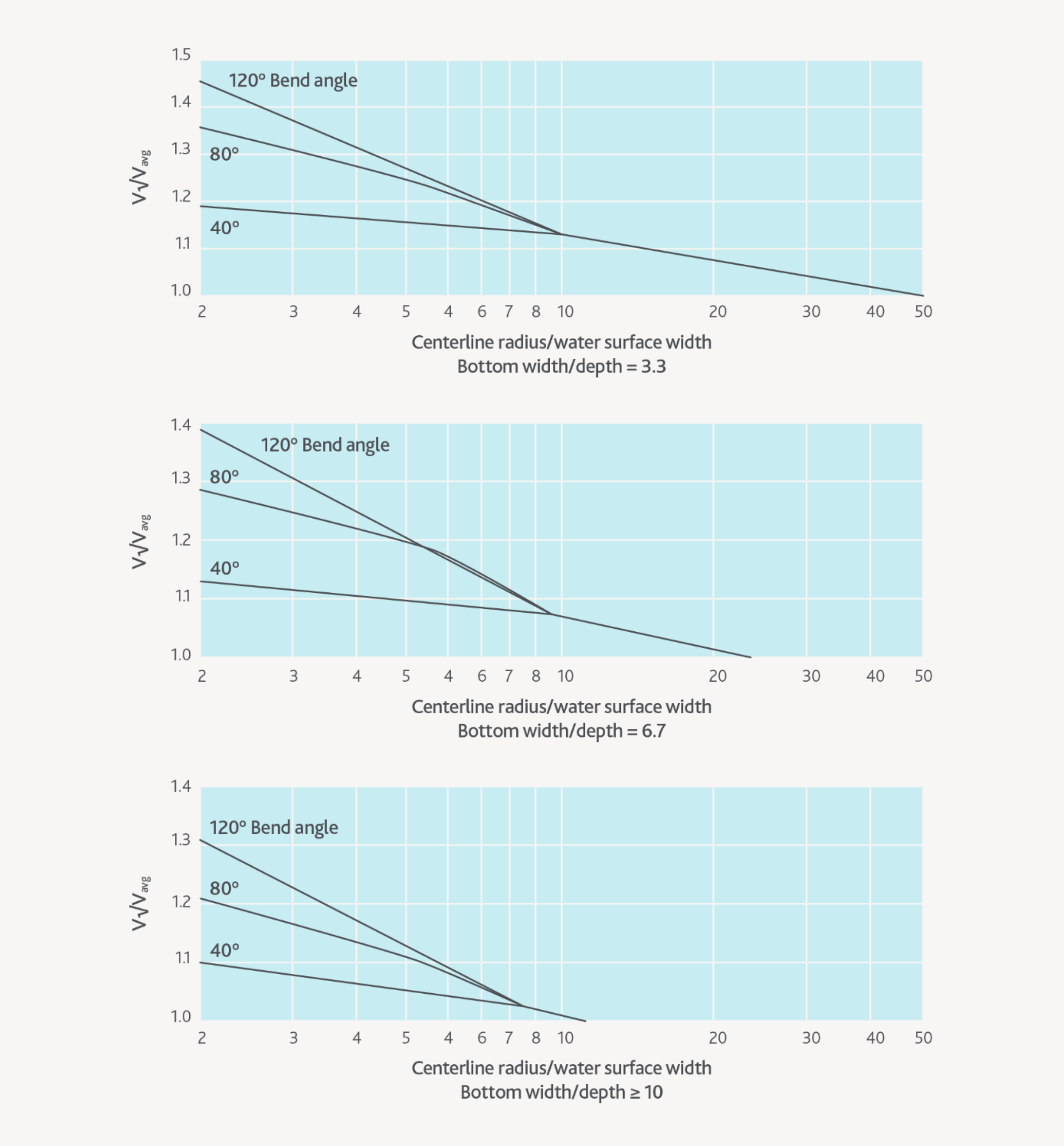


Figure 53 - Applied maximum velocity on bed and banks of trapezoidal channels in a curved reach (from NRCS 2007), where Vss is depth-average velocity at 20% of slope length up from toes, maximum value in bend. Curves based on STREMR model (Bernard 1993), Vavg = 6ft/s, 1:3H side slopes. N = 0.038, 15ft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

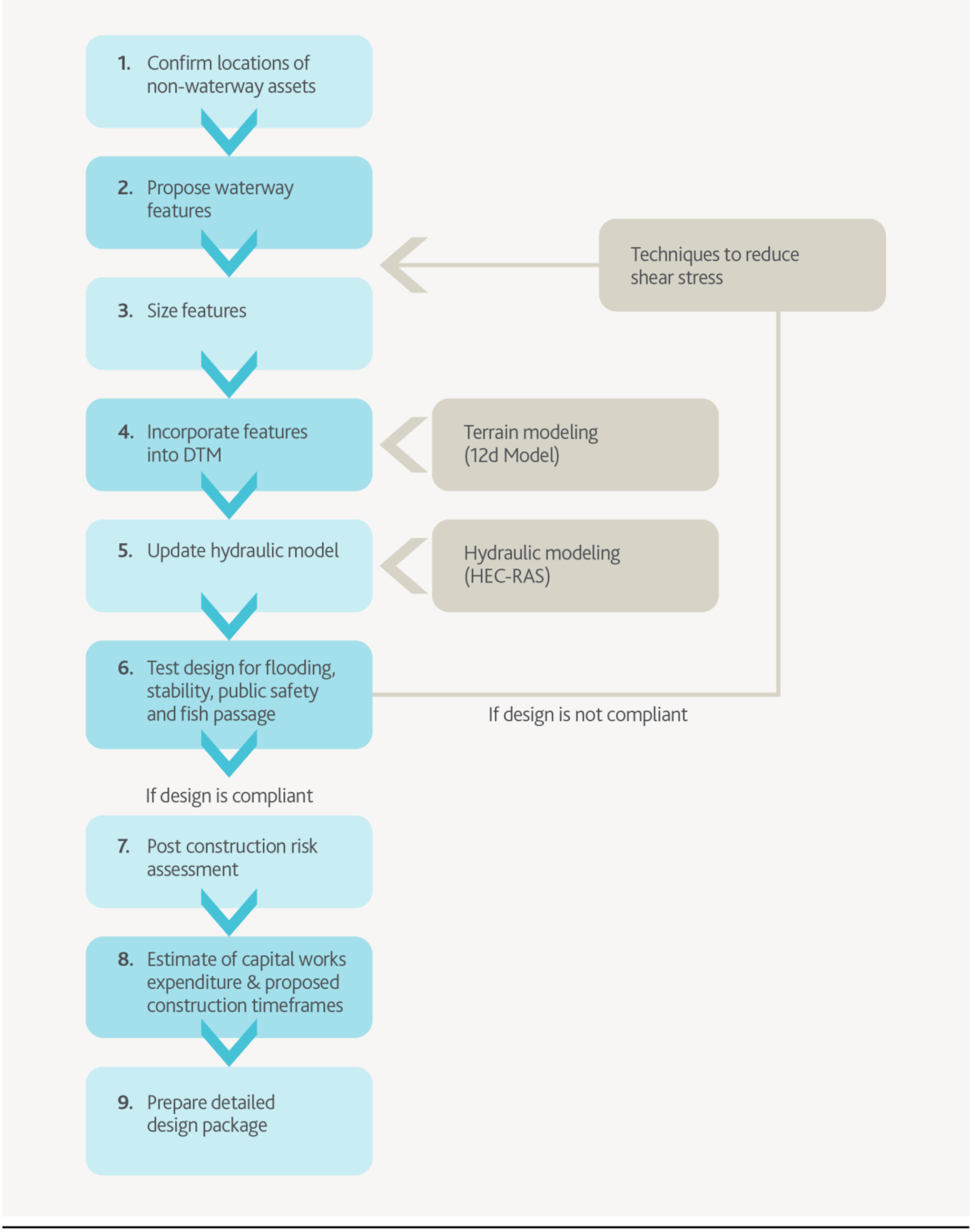


Figure 55 - Tasks to develop the detailed design package.

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.

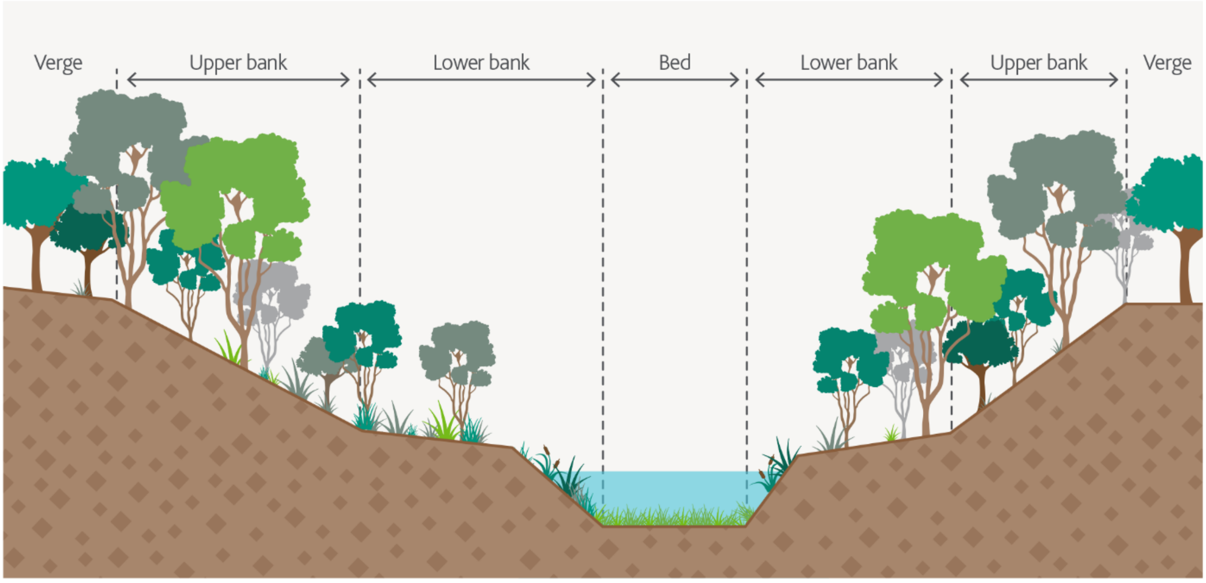


Figure 56 - Hydraulic zonation and native vegetation

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).

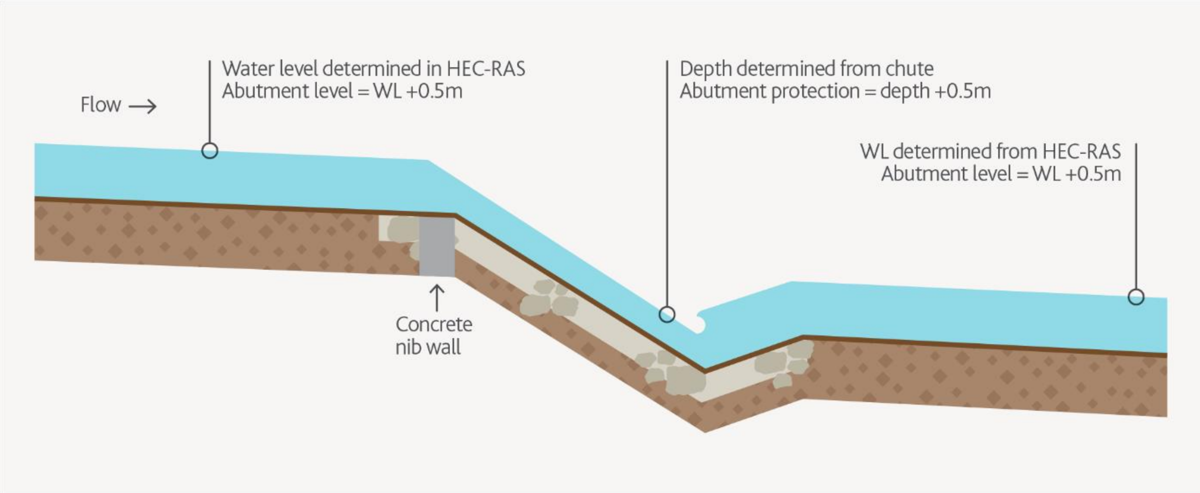


Figure 57 - Schematic of a typical Chute

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

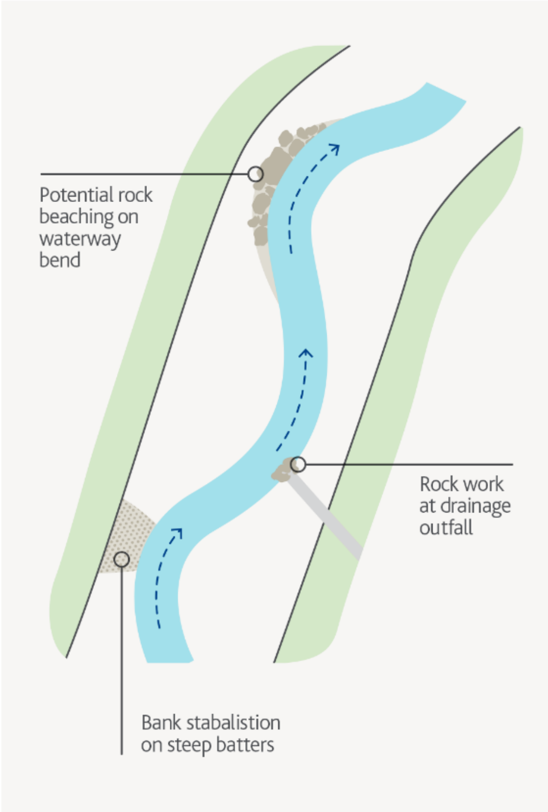


Figure 59 - Typical applications of rock beaching

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).

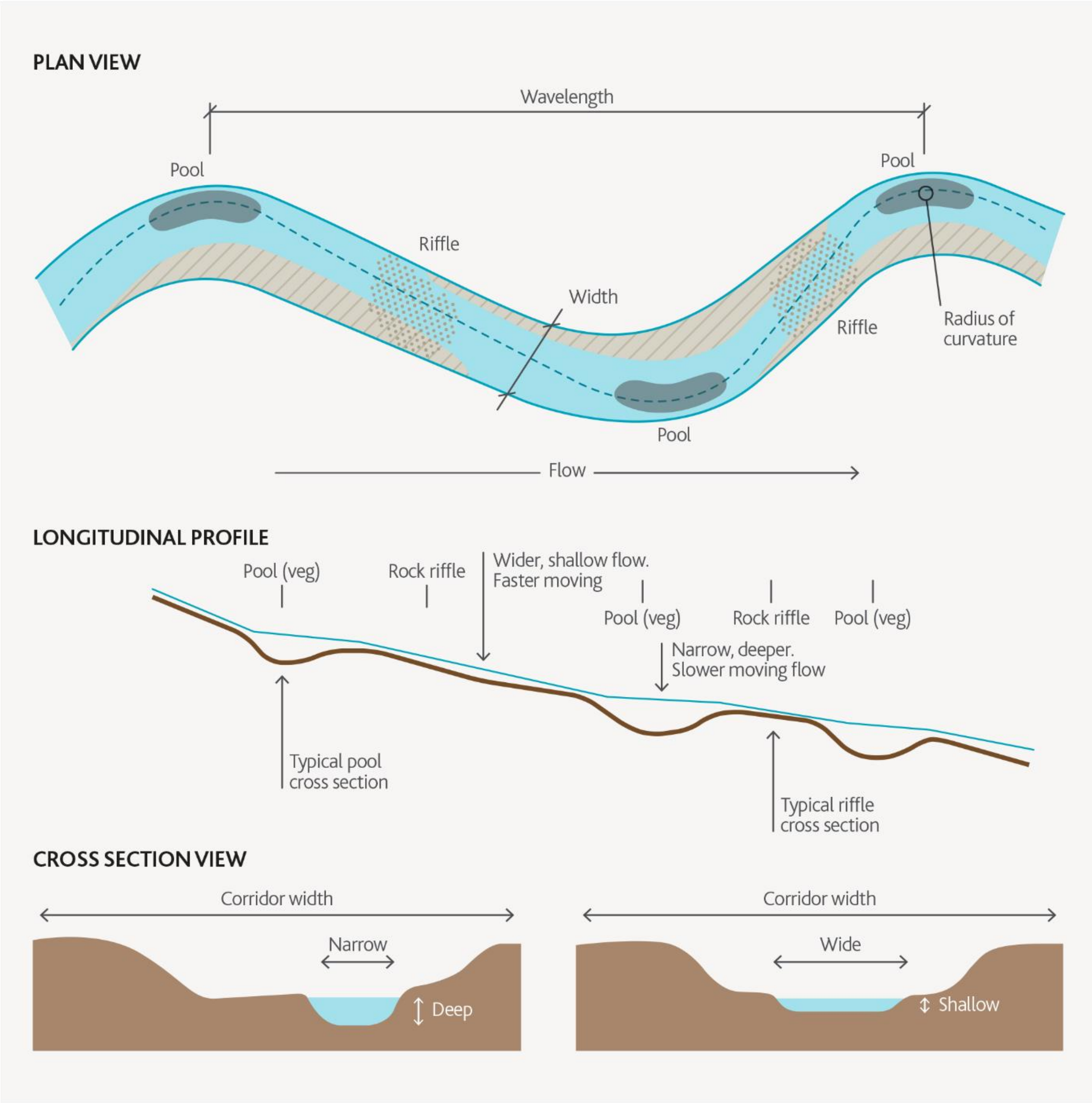


Figure 60 - Idealised pool-riffle sequence

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.

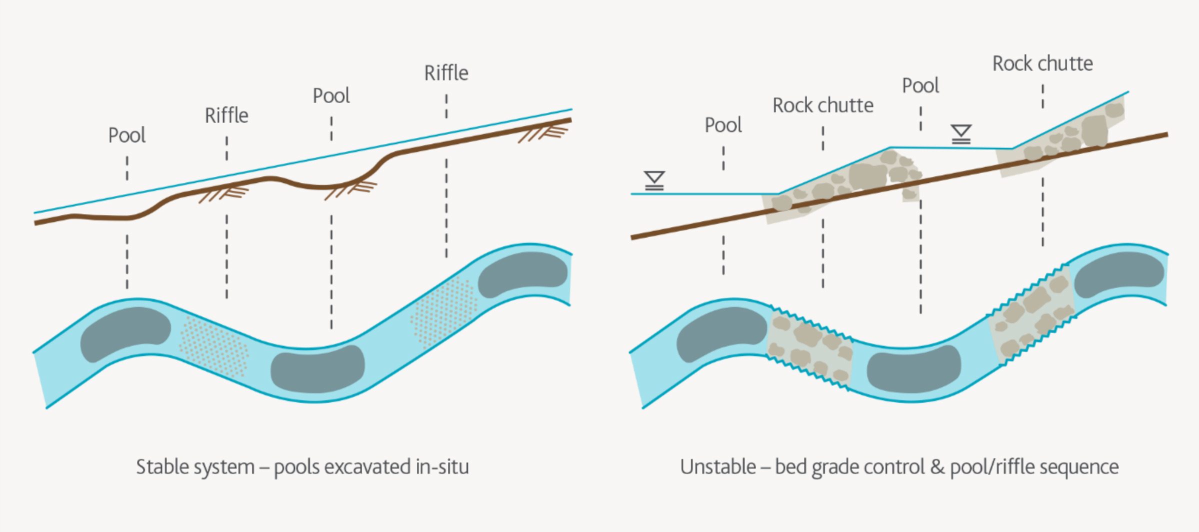


Figure 61 - Conceptual diagram of two approaches to pool-riffle construction

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.

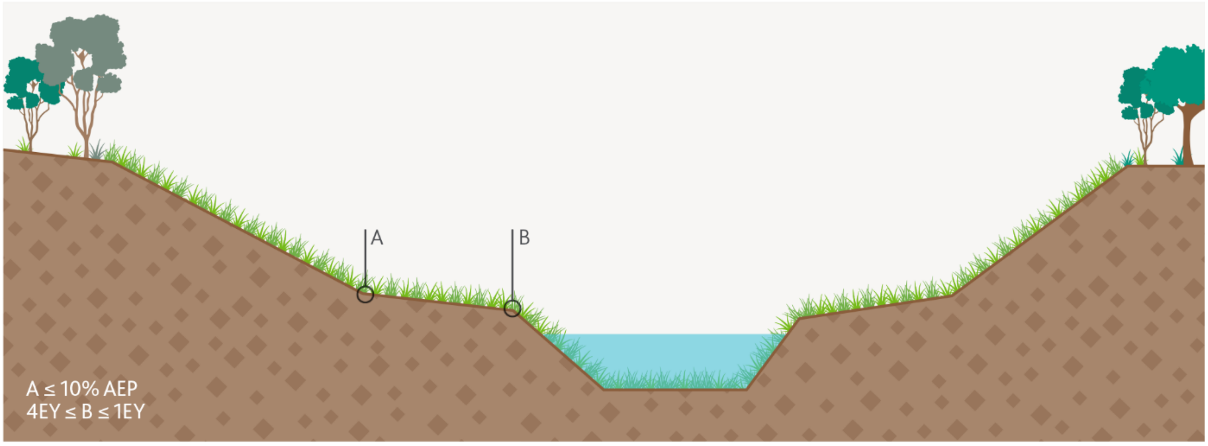


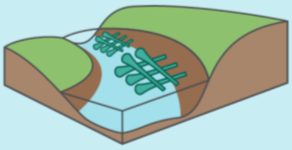
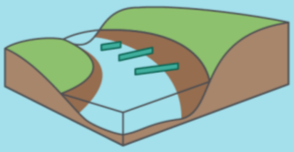
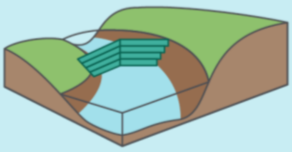
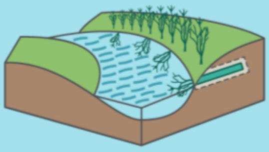
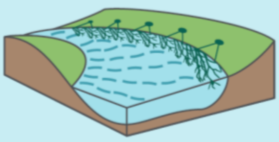
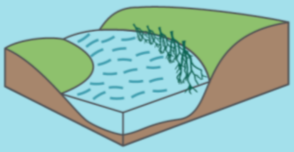
Figure 62 – Example cross-section illustrating the bench design criteria

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.

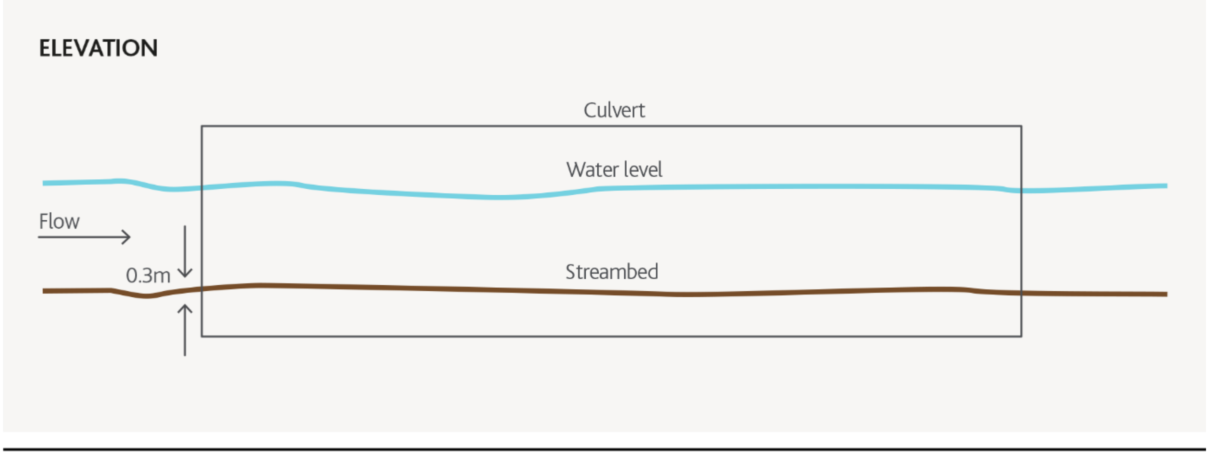


Figure 64 - A box culvert sunk by 0.3m to enable stream bed material to accumulate and encourage fish passage (Arthur Rylah Institute, Guidelines for fish passage at small structures, 2017)

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.

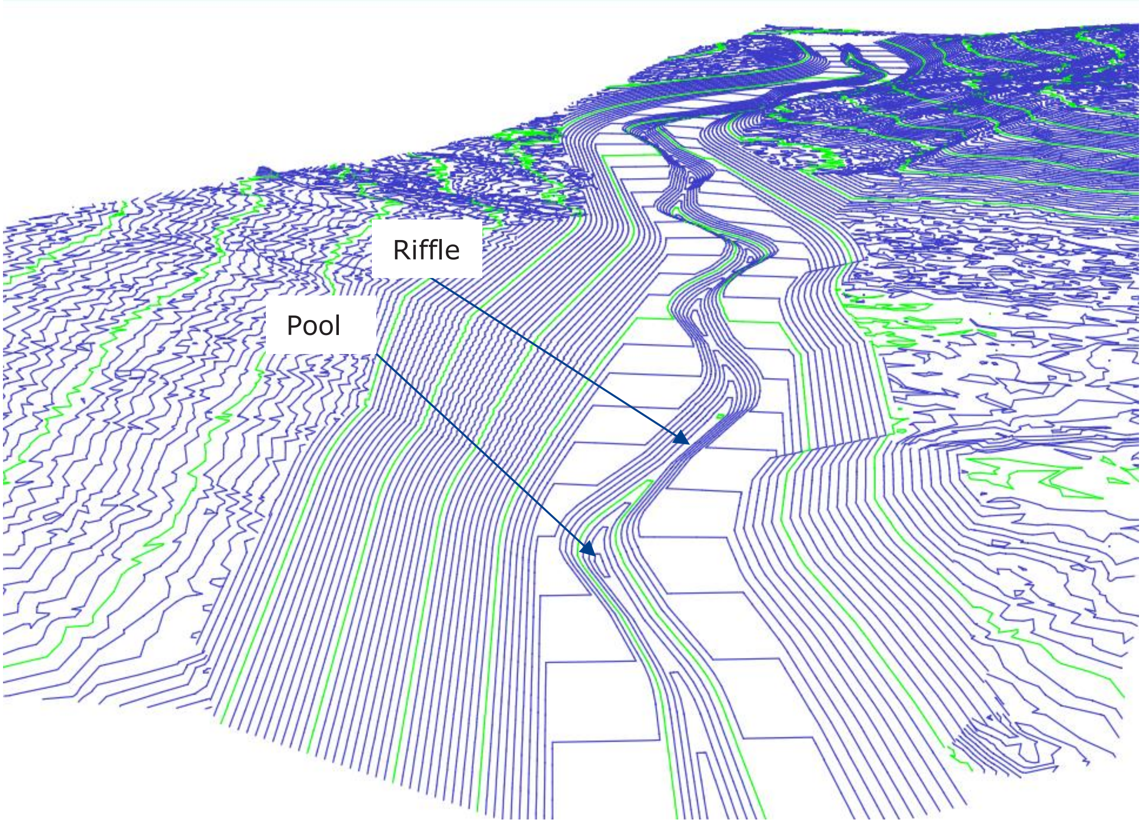


Figure 65 - Example terrain model of compound type waterway showing platform variation. Pools and riffles have been introduced at meander bends in the low flow channel

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.