PART B:
DESIGN APPROACH AND FUNDAMENTALS

B1. DESIGN APPROACH

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

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

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

B1.1 Design stages

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

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

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

B1.2 The threshold waterway design method

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

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

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

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

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

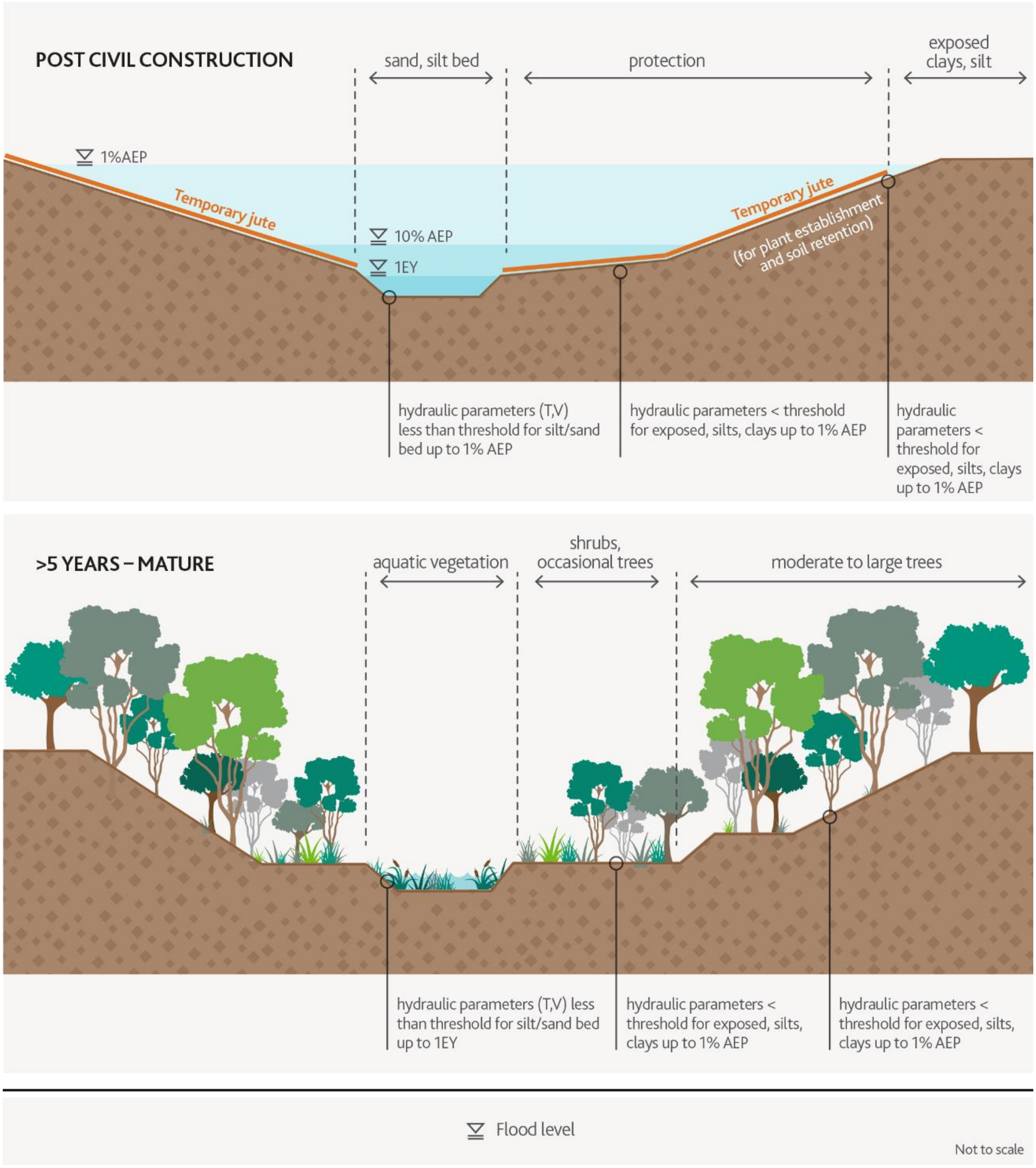

Figure 1 - Spatial and temporal variability of waterways – implications for the threshold design approach (T=shear stress, V=velocity)

Shear stress and resistance

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

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

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

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

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

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

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

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

Vegetation and waterway stability

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

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

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

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

B1.3 Waterway design tools

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

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

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

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

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

B1.4 Waterway design inputs

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

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

B1.5 Waterway design outputs

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

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

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

B2. WATERWAY DESIGN FUNDAMENTALS

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

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

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

B2.1 Hydrology and hydraulics

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

Constructed waterway hydrology

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

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

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

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

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Rainfall and runoff

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

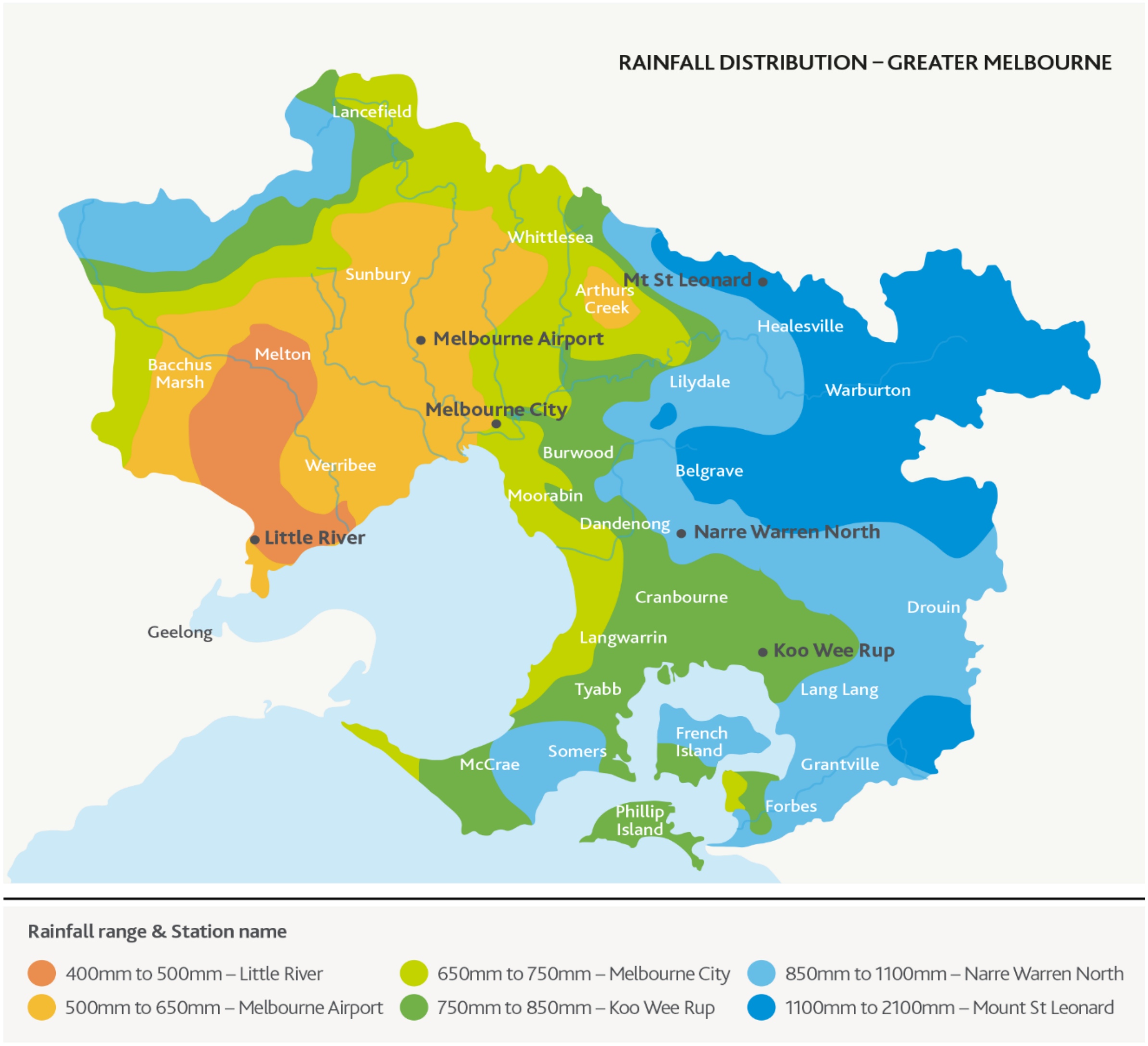

Figure 2 – Regional rainfall distribution (source: Melbourne Water's MUSIC guidelines)

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

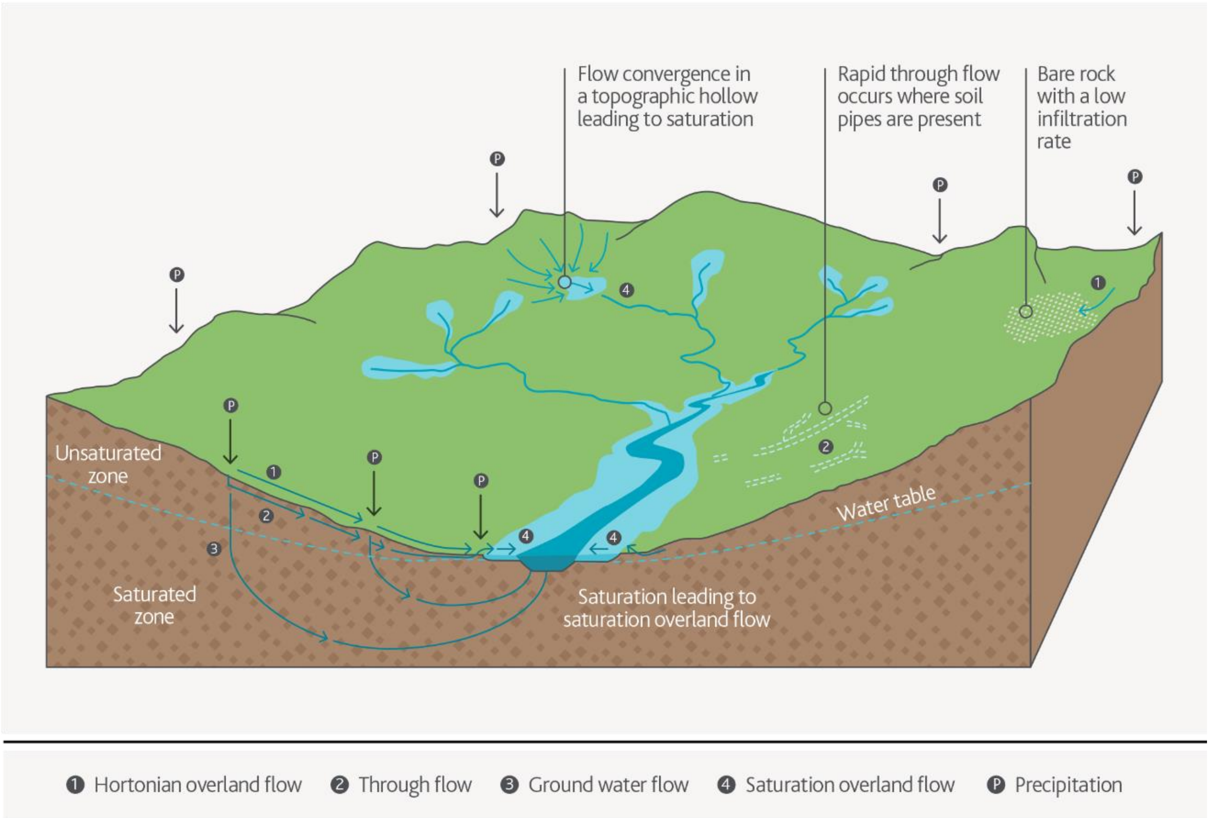

Figure 3 - Hydrologic pathways generating flow in an undeveloped catchment

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

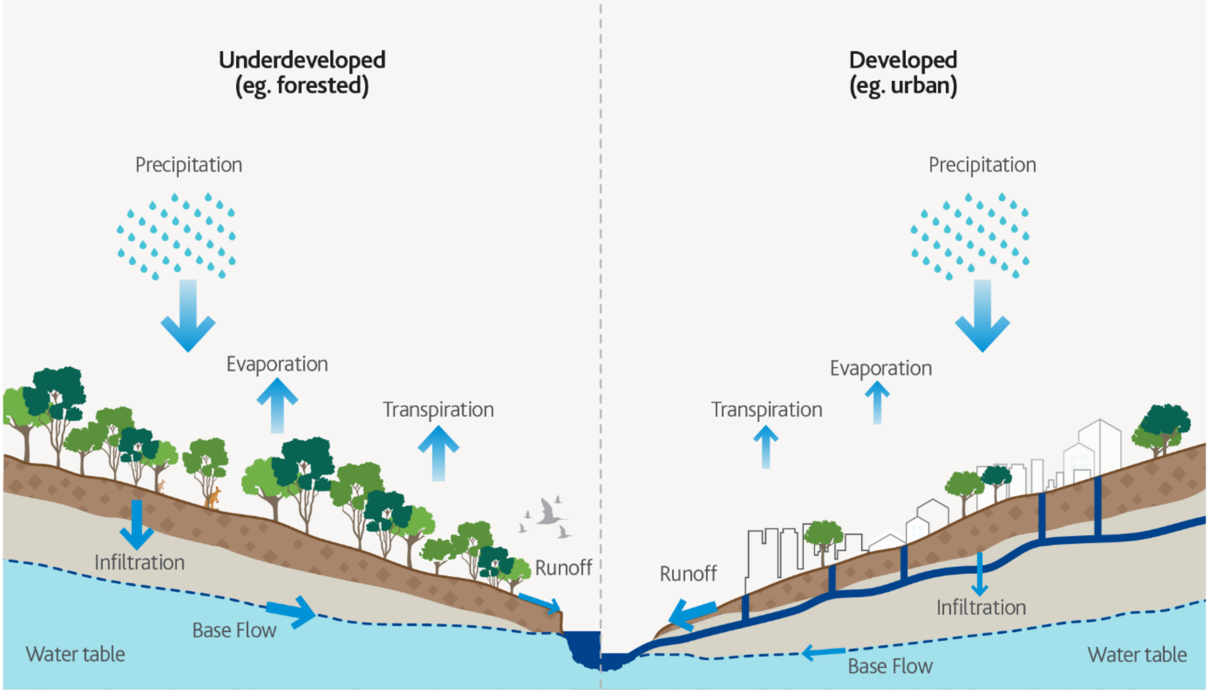

Figure 4 - Comparison of hydrologic pathways generating waterway flow between a developed and an undeveloped catchment.

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

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

Flow components

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

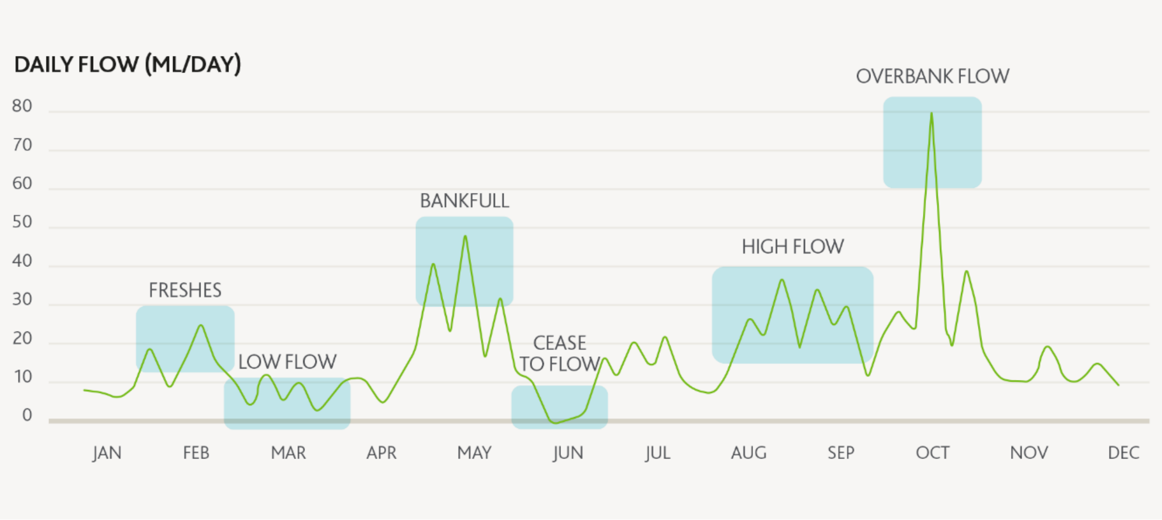

Figure 5 - Illustrative guide to flow components in a natural waterway

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

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

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

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

Waterway hydraulics

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

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

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

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

Equation 2

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

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

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

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

The uniform depth equation

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

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

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

Equation 3

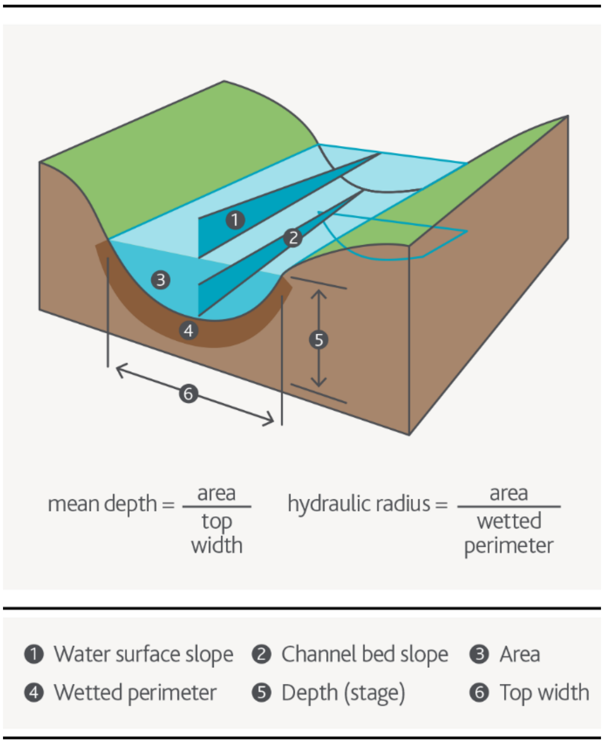

Figure 6 - Illustration of parameters in the Manning equation

Measuring flow resistance

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

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

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

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

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

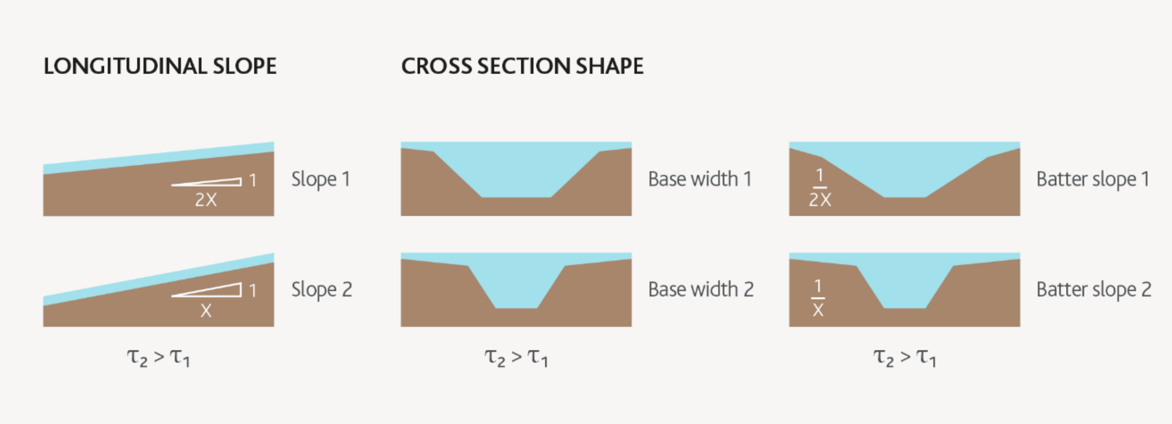

Figure 7 – Concept of average shear stress as a function of various channel parameters

B2.2 Physical form, processes and stability

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

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

Perspectives for visualising and describing waterways

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

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

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

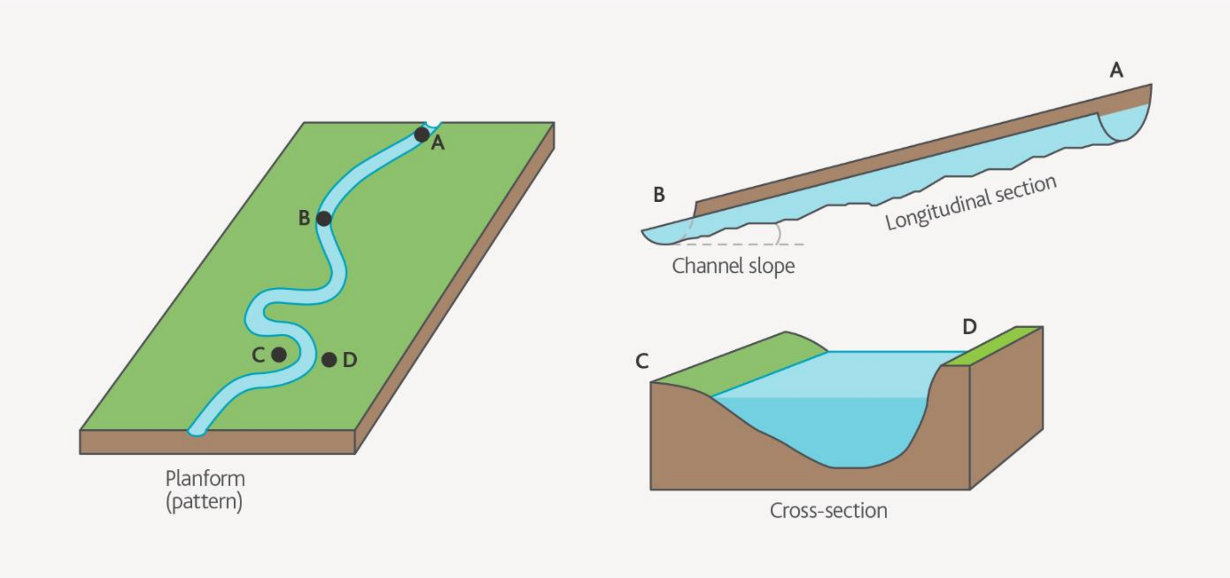

Figure 8 - The three waterway perspectives used: planform, longitudinal and cross section

Waterway types

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

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

Physical processes

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

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

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

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

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

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

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

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

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

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

Reach-scale physical form

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

Sinuosity expressed through planform

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

Why is sinuosity important for waterways?

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

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

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

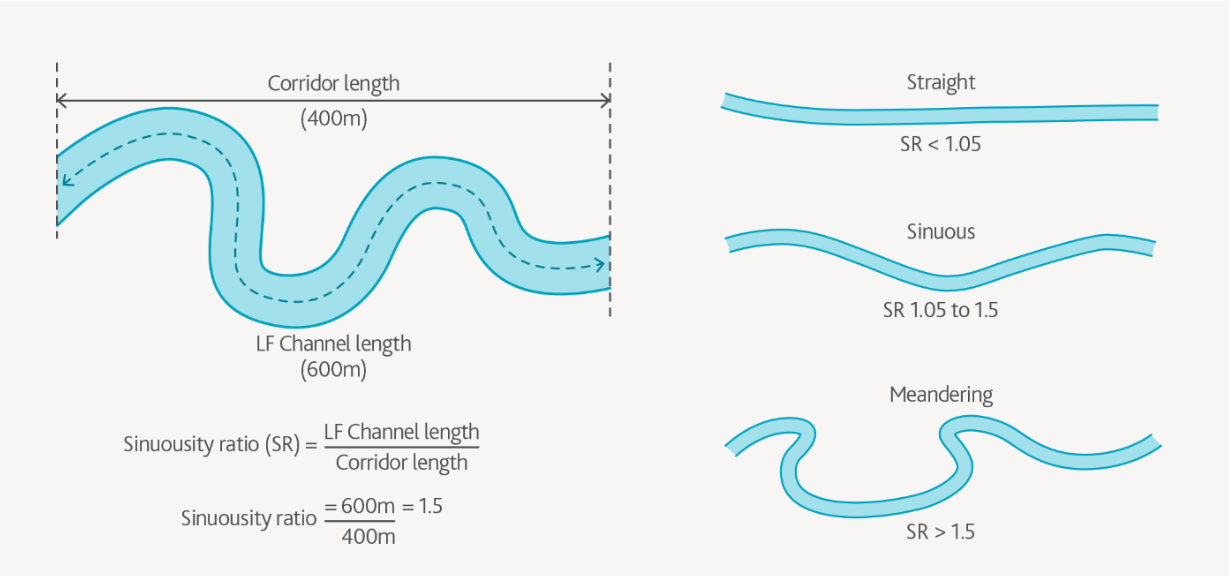

Figure 9 - Sinuosity ratio definition (from Charlton 2008)

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

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

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

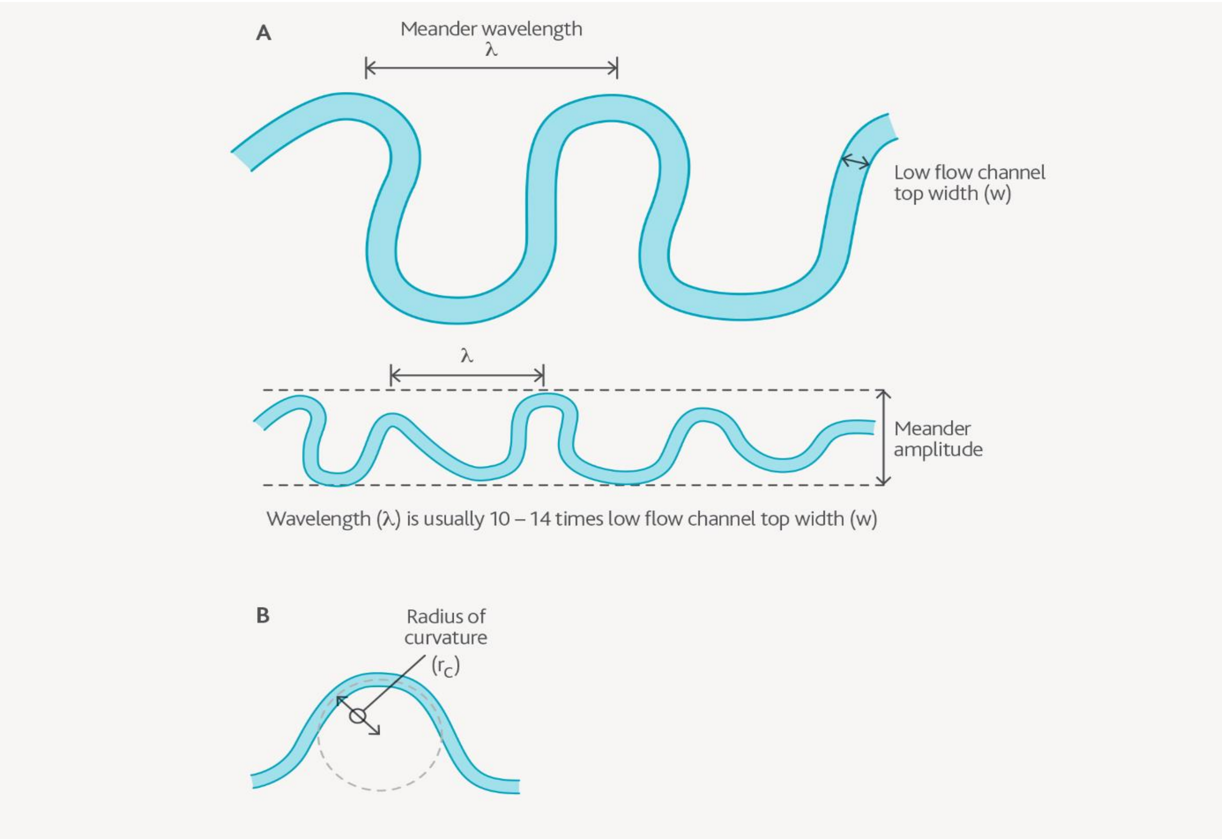

Figure 10 - Aspects of meander geometry (a) Meander wavelength. (b) Radius of curvature

Depth variability expressed through the long-section

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

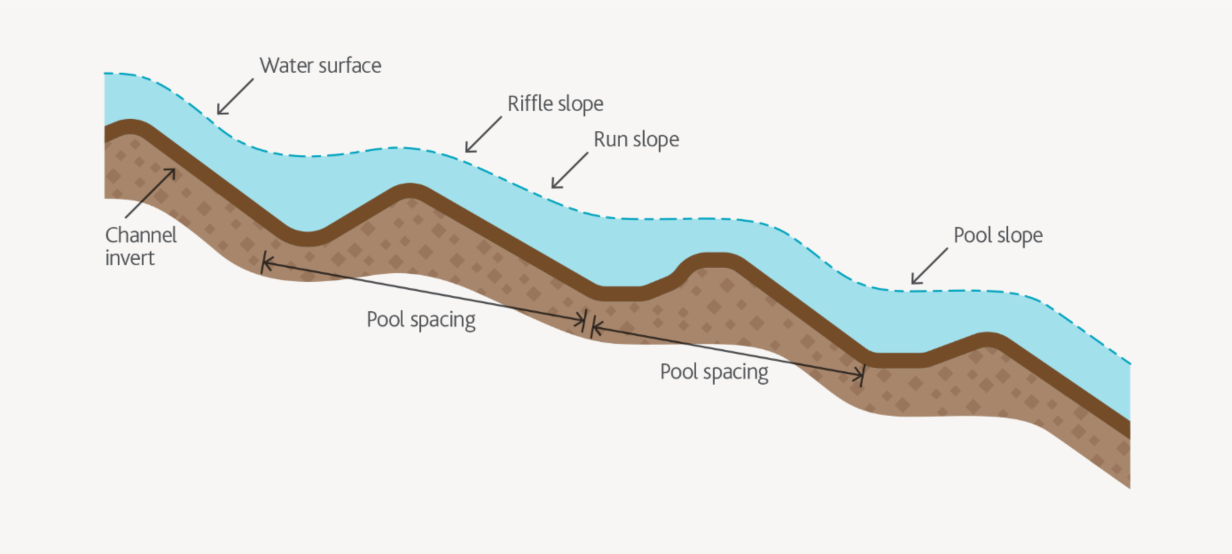

Figure 11 – Example waterway long-section (longitudinal profile)

Waterway shape expressed through the cross-section

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

Feature-scale physical form

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

Floodplains, benches and low flow channel

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

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

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

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

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

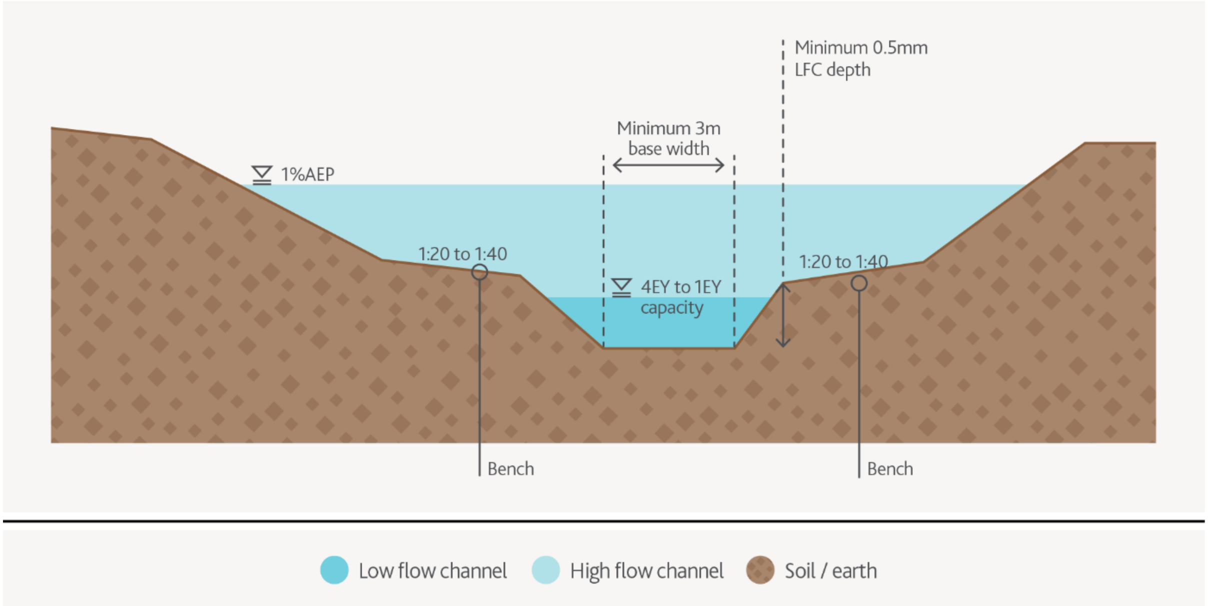

Figure 12 - Typical compound waterway section example

Pool-riffle and pool-run sequences

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

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

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

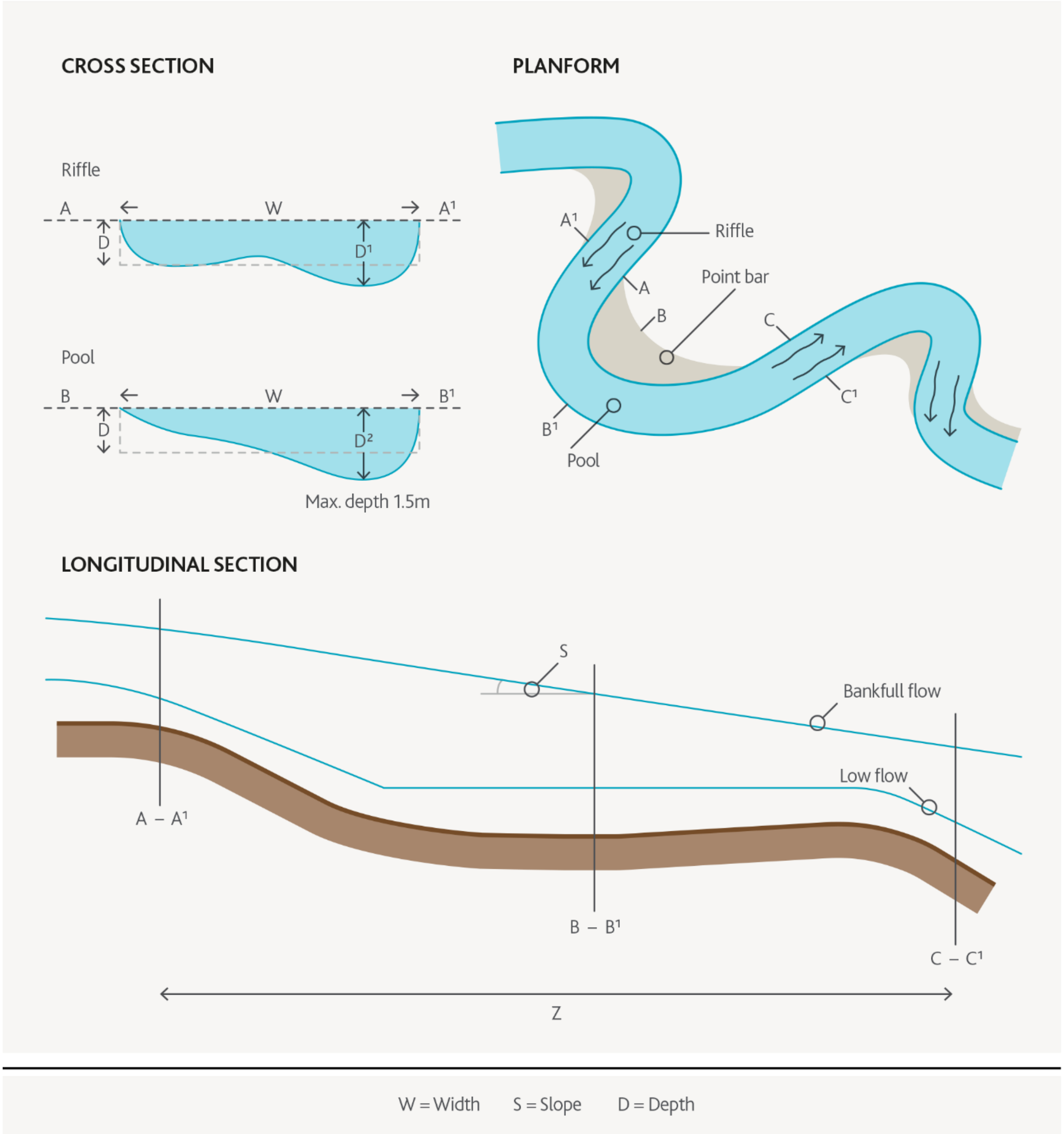

Figure 13 – A typical pool-riffle sequence[1]

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

Figure 14 - Example of a constructed pool-riffle sequence

Large wood

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

The purpose of the large wood installation is to initiate local scour and establish flow diversity to improve habitat. Alternatively, it may be used in a reach to increase hydraulic roughness, reduce overall velocity and to encourage sedimentation.

Bed grade control structures (rock chutes)

Rock chutes are also known as rock riffles and rock ramps. They generally involve the excavation of the bed and banks of a stream and the placement of graded (quarried) rock often forming a small weir in the stream.

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

Bank stabilisation structures (rock beaching)

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

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

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

B2.3 Ecological values in waterways

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

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

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

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

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

The ecology of constructed waterways

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

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

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

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

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

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

  pools (of different sizes and capacity)

  shallow riffle or run sections

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

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

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

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

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

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

Vegetation in constructed waterways

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

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

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

Birds in constructed waterways

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

Habitat features important for birds are:

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

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

Fish in constructed waterways

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

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

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

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

Frogs in constructed waterways

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

Features important for frogs are:

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

Macroinvertebrates in constructed waterways

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

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

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

B2.4 Social Values

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

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

These are described in the follow sections.

Amenity in constructed waterways

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

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

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

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

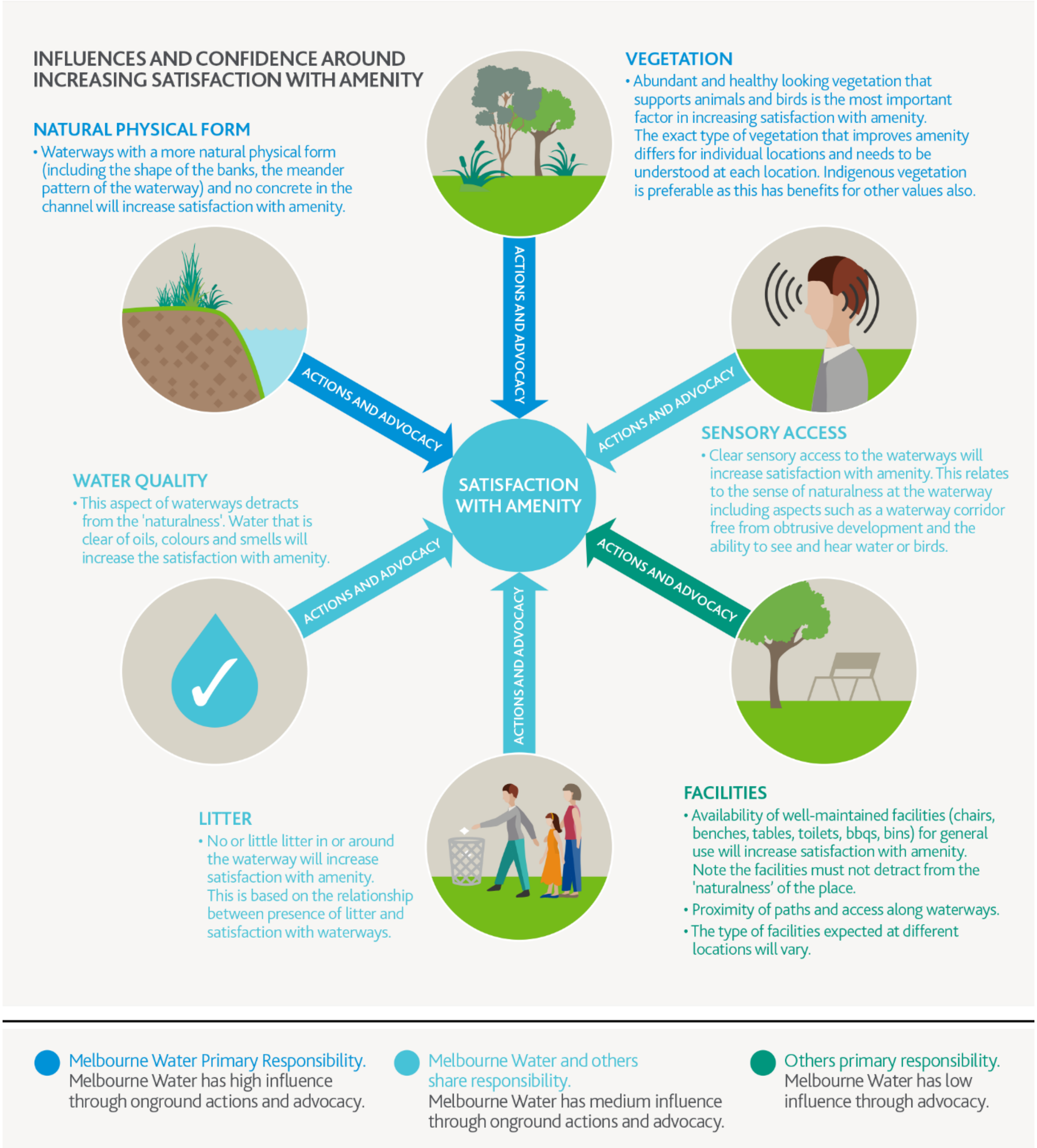

Figure 15 - Amenity conceptual model: actions and influences to protect and improve amenity

Community connection

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

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

Flood protection and drainage services in constructed waterways

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

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

Constructed waterways play two key flood protection and drainage roles:

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

Erosion management for asset protection in constructed waterways

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

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