Restoring Waterway Form

Page

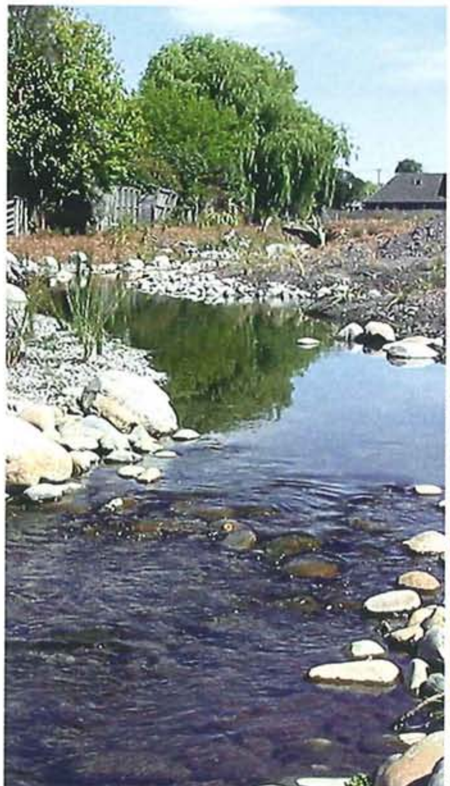
Papanui Stream Restoration Above Grants Road

Modification of channel form: Autumn 2002.

Alterations included removing the original wooden drain and creating a meandering channel with riffle-run-pool sections and several natural springs. Large stumps were used to create overhangs at pool areas.

Riparian Planting: Spring 2002.

Plants included native sedges, rushes, shrubs, and tree species. Plants should be established in 1–2 years time.



Above and right: During construction.

Below: One week after planting.

9.1 Introduction

This chapter outlines the changes that can be made to waterway form in order to enhance or restore the ecology of a stream.

Changing the form of a stream includes making alterations to the cross-sectional and longitudinal shape of waterways, and the materials used within the channel and on the banks (including marginal and aquatic vegetation).

The form of a waterway will strongly influence how many values it can support: an extreme example is a channelised reinforced waterway that caters almost exclusively for drainage (Figure 9-1A). More naturalised waterway forms can provide for a greater range of values (ecology, landscape, recreation, heritage, culture), in addition to ensuring effective drainage (Figure 9-1B).

It is recommended that *Part A, Chapter 3.6: Developing Visions,* is also read prior to undertaking any waterway restoration planning.

For additional information regarding the alteration of waterway form, as well as other components of waterway restoration, refer to the following publications:

- Brookes (1988): Channelised Rivers. Perspectives for Environmental Management.
- Gore (1985): The Restoration of Rivers and Streams. Theories and Experience.
- Riley (1998): Restoring Streams in Cities. A Guide for Planners, Policy Makers, and Citizens.

While these are not New Zealand publications, the information is still relevant to the New Zealand scene, and all provide useful information regarding the restoration process.

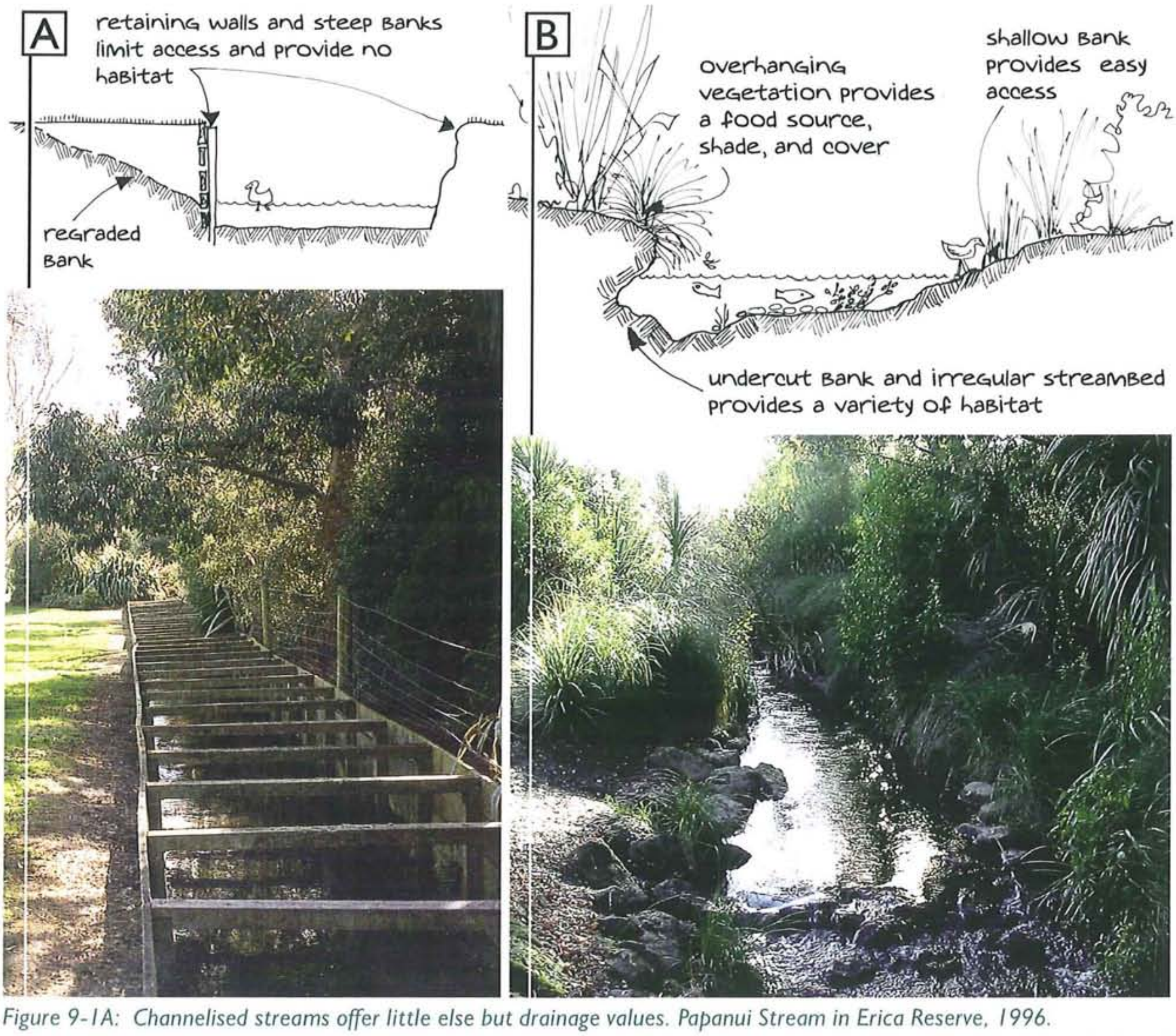


Figure 9-1A: Channelised streams offer little else but drainage values. Papanui Stream in Erica Reserve, 1996.

Figure 9-1B: Proper restoration can create a waterway system with ecological, landscape, recreation, heritage, and cultural values, and is a greater asset to the community. Papanui Stream in Erica Reserve, 2002 (5 years after restoration).

9.1.1 Determining the Extent of Restoration

The Christchurch City Council expects that when an artificial waterway is altered, the design will achieve as natural a waterway form as possible. However, it is important to initially determine what extent of restoration will, or can be achieved. There are several steps to consider before progressing to the design and construction of waterway form. The goals and features identified in the following 5 steps will help determine which design features can be incorporated into the waterway restoration.

Remember to consider the restoration in a wider context, including the placement of the restored section in relation to other natural areas in the surrounding landscape. It is always advisable to consult with a freshwater ecologist, hydrologist, and engineer during the design process to ensure that all factors relating to waterway form and possible complications have been considered.

Part A, Chapter 3: Making Visions Real, details the development of visions for restoring waterway resources, and so should be referred to during the planning stage.

Step 1:

Identify the goals and objectives of the enhancement, as they will affect the level of restoration that is undertaken. Possible goals can include a combination of the following:

- protection of existing drainage values
- recreational enhancement
- ecological enhancement
- landscaping improvements.

Step 2:

Identify various current and potential hydrological features, as this will ultimately determine the form of the restored stream. Some of this information may require investigating historical records and local knowledge.

- Is the stream slow flowing, and with little slope through the section to be restored? This type of stream may not be suitable for the creation of riffle areas or the addition of coarse substrate.
- Does the stream have a reasonable flow and some change in slope through the section to be restored? This waterway would benefit from the creation of riffle sections and the addition of clean, coarse substrate.
- Is the stream ephemeral (i.e. temporarily dries out)? While streams that are ephemeral are still important natural systems, the aquatic organisms they can support will be less diverse than those waterways with permanent flow.

•Step 3:

Identify possible limitations or features that will affect the type or level of restoration that can be achieved:

- encroachment of existing buildings, trees, roads, structures, and utilities that will limit the amount of area available for restoration (i.e. for a floodplain or meandering of the channel)
- very low base flow conditions, including the potential to dry up during summer months.

Step 4:

Identify features that may contribute to the stream restoration or naturalisation:

- presence of natural springs, wetlands, reserves, and other natural areas nearby
- reasonable amount of clear land around the stream that can be fully utilised in the restoration
- a good base flow, which is unlikely to dry up over summer
- some slope through the section to allow the creation of small riffle sections.
- presence of mature trees that may help to shade the restored stream section
- location of the restored area under known flight paths for birds (see *Chapter 3.3.2: Providing Habitat for Wetland Birds*).

Step 5:

Identify other factors to consider:

- information regarding flood flows (including flood capacity) and base flows
- hydraulics: clear waterway area, bank and bed resistance
- erosion control
- presence of culverts and bridges
- safety issues
- construction and maintenance access, and other maintenance requirements
- natural landforms and existing riparian vegetation
- habitat requirements of organisms in the area or of organisms that may be introduced or attracted to the area (see *Chapter 3: Fish, Invertebrates, Birds, and Their Habitat*)
- access to the water (for the public and waterbirds)
- requirements of nearby property owners.

9.2 Hydraulic Capacity

In terms of providing efficient water drainage, a heterogeneous, natural waterway form is less hydraulically efficient than an homogenous artificial channel of similar waterway area. This is because many factors of a more natural waterway can impact on the drainage capacity of the stream, including:

- a narrow central channel
- a meandering waterway form
- the presence of marginal vegetation
- the presence of large, stable substrates in the channel or on the banks.

However it is possible for an urban stream to cater for a wider range of values (ecology, landscape, recreation, heritage, and culture), while still retaining drainage values. Potential conflicts between ecology, landscape values, and drainage can be resolved by consulting a hydrologist and ecologist to ensure that all values are catered for. The following factors should be considered:

- It is important to protect as much of the floodplain area as possible and identify opportunities to increase floodplain capacity. Secondary flow paths also need to be clearly identified and provided for, so that large flood events cause minimum damage to property.
- Natural secondary paths normally do not exist, or have frequently been filled or obstructed in urban areas, so it is often necessary to provide one artificially and protect it from inappropriate development by a drainage easement.
- Educate any owners and occupiers of adjoining properties that stream flooding is natural, and part of the risk of having a property adjacent to any waterway. When undergoing, initiating, or assisting with any property development in these locations, designers should be made aware of the options for reducing flood damage to buildings, such as not building in the waterway's own floodplain, and minimum floor level requirements.
- Hydraulic modelling may need to be part of the investigation for waterway restoration. Modelling will identify the hydraulic controls, as well as opportunities for planting in the floodplain without adversely affecting flood levels.
- Use of constructed wetlands, detention ponds, and swales can also contribute to reducing flood flow conditions, as they store stormwater and slowly release it into the downstream environment over time. Refer to *Chapter 6: Stormwater Treatment Systems,* for more information.

9.3 Longitudinal Channel Profile

Urban waterways are typically devoid of any variation in their longitudinal channel profile; they have historically been designed as straight, often reinforced conduits with little channel variation. Conversely, a restored waterway channel profile should vary longitudinally in order to increase heterogeneity and therefore provide a greater range of habitats.

The following factors should be considered as part of the restoration process:

- Meandering the waterway channel.
- Creating riffle (not always possible in Christchurch due to low gradients), run, and pool habitats.
- Considering the creation of islands within pond or pool areas where adequate space is available (Figure 9-2). Islands promote useful habitat, a place of refuge, and riparian landscape diversity.

Design Procedure

- draw the waterway corridor centre line
- draw a meandering channel within the corridor (*Section 9.3.1: Meandering the Channel*)
- draw the thalweg (line of maximum depth)
- place riffles at the inflection points (*Section 9.3.2: Riffle, Run, Pool Sequences*)
- determine gradients needed to create the riffle and run habitats.

Figure 9-2: Vegetated islands in pool areas in waterways provide refuge and nesting sites for birds, and riparian landscape diversity. Dicksons Pond by Anzac Drive.

9.3.1 Meandering the Channel

All streams have a natural tendency to meander. A natural meandering channel is far superior to a straight channel in its physical diversity and so can sustain more complex instream communities (Petersen et al. 1992):

- A meandering channel creates variable flow patterns, which alternately scour and deposit sediment, thereby helping to dissipate energy and create a range of microhabitats (Figure 9-3). The deeper water on the outside of curves are used by fish, which hide beneath the undercut banks. Shallows that form on inside curves are useful refuges for small fish, which hide under cobbles or among rushes.
- A meandering stream increases the effective length of the stream and so increases the time for nutrient spiralling before the water is discharged to the sea. Retention and spiralling of nutrients within the system is a vital component of stream health.

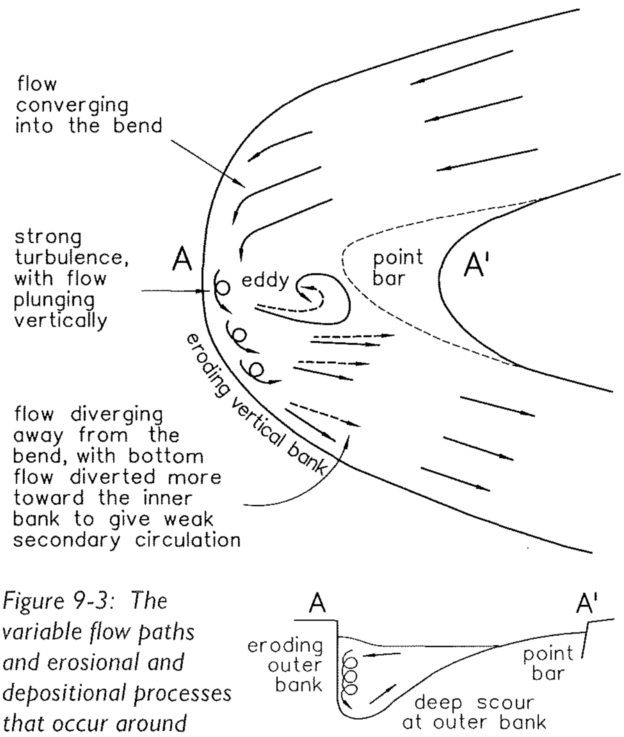


Figure 9-3: The variable flow paths and erosional and depositional processes that occur around bends in waterways. The bend creates a cross-channel rotating flow, that erodes the substrate from the outside of the bend, and deposits it on the inside of the bend. This process creates a heterogeneous instream habitat, which greatly benefits the ecology of the waterway. Source: Mosley (1992).

Meander Layout Design

A meander is generally classified as a channel flow path length that is at least 1.5 times the down-valley distance (a straight channel has a channel length of 1.0, Petersen et al. 1992).

A stream meander can also be classified in terms of a wave. Wavelength (L) and loop radius (r_c) are related to the "bank full" surface width (B) by Equation (9-1) and Equation (9-2) below (Henderson 1966). These values are graphically represented in Figure 9-4.

$L/B = 7$ to 11 (mean value) Eqn (9-1)

$r_c/B = 2$ to 3 (mean value, ranges from 1.5-10) Eqn (9-2)

Various authors have suggested that the "bank full" surface width be defined as the mean water surface width equating to the 6-9 month flood level. It is not clear why this is so but it is likely to correlate with the flow condition generating maximum bed shear stress (*Chapter 22.7: Bed Shear Stress and the Stable Bed*).

For Christchurch, with its low gradients and generally high infiltration rates, it is thought that the 2 year flood level will produce acceptable results. Further investigation on this is required.

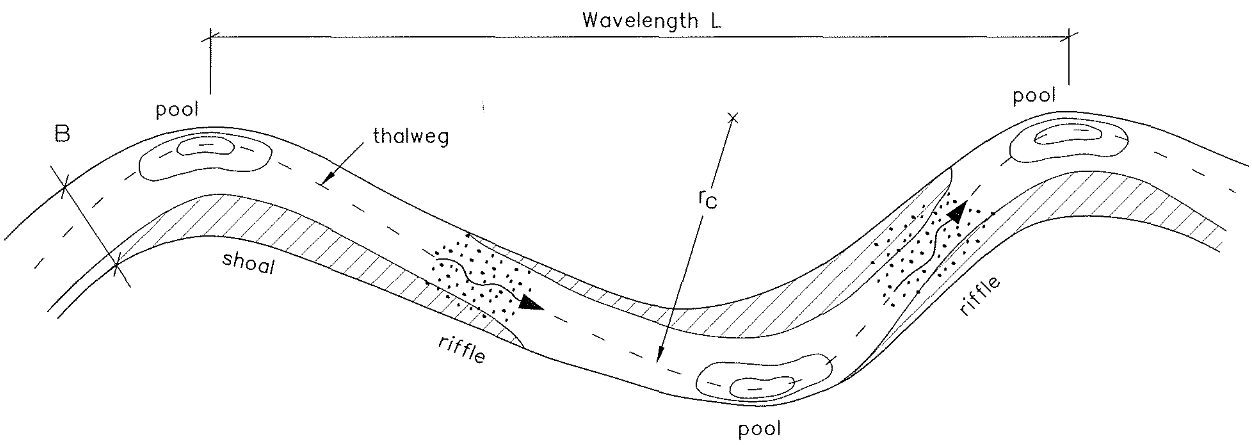


Figure 9-4: Waterway meander showing meander wavelength (L), loop radius (r_c), bank full surface width (B), and the relative positioning of riffle and pool habitats.

The ability to create an effective meandering section will depend upon the amount of land available on either side of the stream. Channel meandering should therefore effectively utilise the available area.

Meanders may also require some form of erosion protection, although it is always better to provide sufficient buffer width at these areas to allow the natural process of erosion to occur (providing there are no safety issues).

Further information regarding the nature of channel sinuosity can be obtained from Mosley (1992) and Henderson (1966).

9.3.2 Riffle, Run, Pool Sequences

Natural waterways are often characterised by a longitudinal sequence of riffles (turbulent areas), runs (smooth water surface), and pools (deeper and slow-moving areas, Table 9-1). The Christchurch region has many lowland waterways that are naturally dominated by run habitats.

A restored stream should be designed to have riffles at the points of inflection between bends, as stream gradient permits, and pools should typically be located at the outside of the bends (see Figure 9-4). Riffle, run, pool spacing should therefore follow the determination of meander pattern (refer to *Section 9.3.1: Meandering the Channel*).

Table 9-1: Riffle, run, and pool definitions.

Habitat Type	Definition
Riffle 	• Shallow, swift flowing areas with broken water surface and large substrate (gravel, cobbles). • Usually found at the point of inflection between meander bends. At this point the thalweg (Figure 9-4) is typically central and the channel cross-section profile is approximately symmetrical. • Increased water turbulence with increased bed roughness reduces the thickness of the boundary layer (the low velocity region that exists at the substrate surface), and increases the exchange of dissolved gases, nutrients, and organic matter between the bulk of the flow and the stone surface and interstitial layers (Quinn & Hickey 1990). Thus riffle sections with coarse substrates provide more suitable habitat for invertebrates with high oxygen demand (i.e. many 'clean water' species). • Many of the drift feeding fish, such as trout, prefer to feed just below these riffle areas to catch any invertebrates drifting in the water column.
Run 	• Intermediate between pools and riffles. • Characterised by an undulating but relatively unbroken water surface. • Substrate generally varies from a mixture of small particles (gravel, sand) to cobble substrates, but generally consists of smaller particles than in riffle sections. • This is the main instream habitat for the majority of Christchurch's lowland waterways.
Pool 	• Deeper slow flowing areas with an almost level, smooth water surface and often containing deposits of finer substrate (sand or gravel). • Small pools often form on the outside of curves. • Provide an area of deeper water, which may be utilised by larger fish and by wading and other wetland birds. Pools may be especially important during low flow conditions as refuge areas. • Act as important storage areas for organic material that is gradually released into the stream. • Often areas of sediment deposition, although this sediment may become resuspended and transported downstream during times of flood.

Consider creating all three hydrological habitats when restoring a waterway, as it will help create a diverse habitat that can support diverse invertebrate and fish communities. However, the development of these habitats needs to be considered in the context of the environment prior to restoration. For example, many of Christchurch's lowland streams naturally do not have riffle habitats due to a shallow or flat gradient and naturally fine substrate. The creation of such areas may therefore not be possible.

If the potential for a riffle section exists (i.e. sufficient gradient and reasonable flow) the creation of such should be prioritised in the restoration process.

9.3.2.1 Design Considerations for Riffles

Hydraulic Definition of Riffles

Measurements by Allen (1951) and Mosley (1992) suggest a hydraulic definition of pool, run, and riffle habitats based on Froude number (Fr), that relates inertial forces to gravity forces (Eqn 9-3). The Froude number is important hydraulically wherever gravity dominates (e.g. waves and open channel flow), and

$$Fr = \frac{v}{\sqrt{g y_m}} \qquad \text{Eqn (9-3)}$$

where: v = velocity (m/s)

g = gravitational acceleration

= 9.81 m/s^2

y_m = mean depth (m)

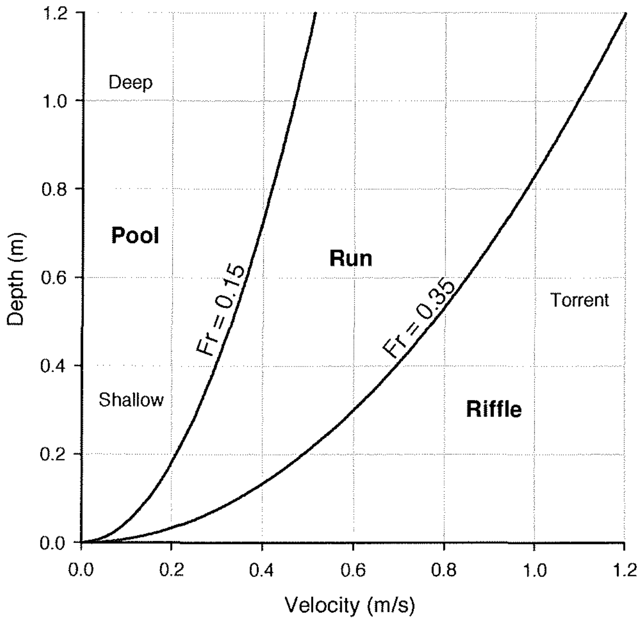


Figure 9-5: Froude number (Fr) classification for riffle, run, and pool waterway habitats, as given by Equation 9-3.

is the criteria that distinguishes tranquil and rapid flow. For tranquil flow $Fr < 1$, for rapid flow $Fr > 1$.

The Riffle/Run threshold is set to $Fr = 0.35$

The Run/Pool threshold is set to $Fr = 0.15$

Equation 9-3 is reproduced below in Figure 9-5. Correlation of this definition with habitat type at 1152 sites showed a 56% match (Jowett 1992). A further study on the Ashburton River (Jowett in preparation, cited in Jowett 1992) has shown a slightly improved predictive match when watersurface slope was included, but it is thought that this could be specific to larger rivers.

For Christchurch, with its generally low volume, flat gradient streams, Eqn (9-3)/Figure 9-5 is considered the most appropriate definition at this time.

General Considerations for Riffles

In order to create a riffle section there needs to be some gradient. The following points outline factors that should be considered when changing the gradient in order to produce a riffle section.

- When designing riffles it is appropriate to use a coarse substrate of variable size to create a heterogeneous environment and to contribute to water turbulence. This will provide many microhabitats thereby enabling the establishment of a more diverse instream community.
- The use of coarse substrates such as cobbles and boulders will also help prevent erosion of the streambed in the riffle areas. Refer to *Chapter 22.7: Bed Shear Stress and the Stable Bed,* for determining suitable substrate size to combat bed shear stress.
- Riffle sections should be kept as flat as practical while still complying with the riffle definition that is given in Figure 9-5.
- There are certain logistical and hydrological considerations involved with altering a stream's slope in order to create a riffle area. In some instances, creating greater slope in one section could cause the waterway to pool or stagnate upstream if there is insufficient flow. It is advisable to always consult a qualified engineer during the design process.

A procedure for the hydraulic design of riffles is outlined in *Chapter 22.8: Riffle, Run, Pool Design.*

9.3.2.2 Design Considerations for Ponds

Question the Need for Any Pond

If a proposed pond cannot provide for drainage, ecology, and recreational values, then do not proceed with it; there are many examples of small ponds that become stagnant and unpleasant during summer.

Water Supply for Ponds

Where water supply for the pond is surface derived, (e.g. inline with a stream, diverted from a waterway, pipe supply, or rainfall), consider the following:

- Assess the pond's average water residence time (have regard to low summer flows).
- Ponds constructed in free-draining soils over a low watertable may require bed sealing to prevent excessive loss of water from seepage.
- With liners, check groundwater level rise and fall. Under-drainage may be necessary if groundwater is likely to rise above pond water levels.
- Make provision for peak flows by providing freeboard for pond storage, and providing an adequate flow capacity outlet or overflow.
- The effect of flow fluctuations or loss of flow on the pond's general ecological health. Where available, historical records or local knowledge should be checked.

Where water supply for the pond is derived from groundwater, consider the following:

- Check available borelog information and regional council well logs for seasonal water levels, and groundwater flow rate and direction. Set the pond surface outlet level relative to the lowest groundwater level. Note that a low outlet level will induce groundwater flow into the pond.
- Assess water volume turnover in pond (have regard to the lowest groundwater level and time of year).
- Consider a pump test to help assess potential groundwater inflow.
- For a groundwater through flow with no surface outfall, check groundwater flow rate and maximise perimeter length to pond volume.
- Provide for groundwater level rise and fall.

Discharge of Stormwater

Discharging stormwater runoff into ponds with potential amenity or ecological values shall initially be discussed with Council staff. There may be a requirement for sufficient pretreatment by vegetated swales, constructed wetlands, or soakage facility (see *Chapter 6: Stormwater Treatment Systems*).

Soils and Substrates

The designer can determine the substrate of the site and groundwater level by auger test bores or by digging pits. Department of Scientific and Industrial Research (DSIR) soil maps (Webb et al. 1991) may also assist in understanding soil type.

Soil and substrate types affect pond and basin design:

- Gravels offer reliable bearing and bank slope stability, but can be highly permeable. This property can be useful, however, when the pond must rely on groundwater inflow.
- Sands lack cohesion and the arch support of gravels and are susceptible to slumping with groundwater inflow.
- Silt and clays offer cohesion for bank support, are less permeable, but can be easily eroded.
- Permeability (a measure of the rate at which fluid passes through a porous medium) can be between 103 and 106 times greater in gravels than silts.

Careful design is required where any Port Hills loess is present, or where ponds are constructed on slopes. Loess is highly dispersive and can be very erodible. Even minor leaks from a pond can result in serious voids opening up under or downstream of a pond in a relatively short time. In general ponds on the Port Hills are not recommended.

Volume, Depth, Perimeter Length

Water volume and depth help smooth out daily temperature fluctuations that can negatively effect aquatic life. A water depth exceeding 1200 mm over some of the pond can help reduce algae growth and provide refuge for fish.

A pond with a high water volume, however, requires a high through-flow of water to ensure acceptable water turnover. As a rule of thumb the designer should aim for full pond turnover at least every 24–48 hours. Where groundwater is the primary water supply source, then ensure a large perimeter length to volume ratio to maximise groundwater interception and minimise pond water turnover rates.

Ponds fed from streams or stormwater pipe inflows which are prone to periodic high sediment flows should be designed to allow for sediment build-up. Provide for future sedimentation by over-sizing the pond and increasing depth to allow for natural siltation processes to occur, or by providing machine access for periodic dredging of the pond. Also ensure sediment removal prior to stormwater discharge to the pond by using a stormwater treatment system (see *Chapter 6: Stormwater Treatment Systems*).

Bed and Bank Treatment

The following need consideration when treating the beds and banks of constructed ponds:

- soils and stability
- plantings intended/wildlife expected
- rise and fall of the pond water level
- prevailing wind and sun when deciding on bank slope and treatment.
- available land and relative level for pond margins
- economics
- gravel wave bands in large ponds or ponds which have a long reach exposed to winds
- open soils may require liners in the bed and banks
- choice of liner (e.g. synthetic, silt/clay, or bentonite blanket) must be selected to suit underlying strata and plantings
- gravel overlays on beds may be beneficial for fish, as well as a toe stabiliser
- hard edges or gravel/pebble beaches can improve access areas by providing firmer, drier conditions underfoot
- gravel beaches should be provided where public access is intended
- vertical banks or overhangs are beneficial for fish refuge (see *Section 9.5: Stream Bank Materials*)
- plan for planting of canopy cover to provide shading, roosting areas for birds, reduce water temperatures, and assist with soil consolidation
- provide for machinery access where siltation may be an issue
- imitate natural landforms
- provide variation in bank slopes, ranging from supported, but undercut areas, to gently sloping 'beach' areas
- control of surface water flow to ponds to minimise bank erosion
- anticipate/design for bank erosion in the first three months of service, when soils are not fully consolidated or plants not established. Use of ready lawn, erosion mat, or weed mats on pond banks can reduce erosion and sediment inputs while bank vegetation is becoming established.

Bank slope design should consider the following:

- bank slope less than 1:6 is desirable for safety where access is proposed
- access should be discouraged by plantings, or other means, where steep banks are proposed
- bank slope less than 1:3 is desirable for ease of maintenance
- to avoid slumping 'running sands' may require either flat bank slope (flatter than 1:4) or gravel toe loading for steeper banks
- for wave action in large ponds, slopes of 1:2 and 1:3 will dissipate waves, whereas vertical slopes will create spray and increase potential for scour.

Safety

Design should always have regard to safety:

- restrict access with fencing or plantings where bank/bed slope is steeper than 1 in 2
- highlight safe access points (bed slope flatter than 1 in 6), such as gravel beach areas, jetties, or steps
- encourage informal surveillance by landowners.

Refer to *Chapter 15: Safety,* for further information.

Maintenance

Consider prevailing wind direction when considering litter and debris accumulation areas. Deliberate use can be made of the wind to collect debris.

Design to minimise or control algae and weed growth by the following factors:

- shading (over 70% shade)
- identifying and reducing any nutrient sources, such as overland flow from excessive use of fertilisers in the riparian zone
- removing shallow littoral zones and increasing water depth (this may not preclude all macrophytes as some can grow in water up to 3 m deep)
- provide easy access to remove nuisance species.

Consider methods of minimising insect pests such as biting midges and mosquitoes. Refer to *Chapter 18: Mosquitoes and Other Insect Pests.*

Ponds can increase the sediment in downstream environments due to re-suspension of trapped sediment during heavy rainfall. As a consequence, pond maintenance should always involve regular checking of pond sediment levels, with removal when required. Consider long-term machine access if siltation is thought to become an issue, and ensure the area is monitored to determine the appropriate time for sediment removal.

Consents

Surface water diversions, abstractions, damming, and works within streambeds all require consents from Environment Canterbury (ECan). Exposure of groundwater also requires a consent from ECan.

Earthworks beyond a certain magnitude, works within waterway setbacks, and structures will require City Council consents.

9.4 Channel Cross-Section

Urban streams have historically been designed and managed to quickly carry water to the sea, and as such are usually straight, uniform and sometimes reinforced channels. Creating a more natural stream channel cross section can be achieved by:

- creating variable widths and depths within the channel as well as creating an overall narrower channel to reduce low flow problems
- varying the bank profile by providing both steeper areas, more gentle slopes (usually a maximum of 2:1 gradient) and 'beach' areas that allow access to the water's edge
- excavating to increase floodplain area and storage.

Refer to *Chapter 12: Waterway Erosion Protection*, to ensure that the bank profile design considers the acceptable approaches to stream bank erosion protection.

Bank erosion is usually only an issue when it affects buildings, private property or general safety. Thus, ensuring there is sufficient space between the waterway and any structures is sometimes the most effective protection against erosion. This should reduce the need for intervention and instead provide room to allow the channel to naturally adjust to its own hydrological regime.

9.4.1 Channel Width and Depth

Provided there is not significant reinforcing to prevent any natural erosion and deposition, a stream will gradually form its own channel morphology, including varying widths and depths. However, when undergoing restoration it is often useful to assist this natural process by creating variable channel widths and depths. This is an important component of creating a stream with improved landscape features and conditions better suited to support aquatic organisms from the outset.

When restoring a waterway it is often advisable to:

- decrease the overall wetted channel width if the existing channel has been unnaturally widened
- provide a low flow channel within the main channel (Figure 9-6)
- create a range of channel widths and water depths both longitudinally down the stream section and laterally across the stream channel.

Narrowing the channel in some areas can:

- Contribute to locally increasing velocity. There is a direct relationship between water cross sectional area and water velocity: the smaller the area, the faster the velocity for a given discharge. This method of increasing velocity may be useful in areas where there is only a shallow gradient.
- Create a heterogeneous habitat with variable depths, widths, and velocities, which can cater to a wider range of species.

Creating a low flow channel will:

- provide an area of deeper water in the main channel to help to ensure some water is retained during low flow periods (Figure 9-6)
- help maintain velocities and therefore assist in minimising sedimentation.

An area of deeper water during low flow conditions will contribute to the survival of many aquatic animals as it will:

- provide habitat for instream animals
- help to keep the water temperature lower
- reduce the lowering of dissolved oxygen levels.

Positioning of the low flow channel is described in *Section 9.3: Longitudinal Channel Profile.*

Mean depth preferences for some invertebrates inhabiting small streams range from 0.06 m to 0.12 m (Jowett 2000). Because such invertebrates also inhabit deeper waters in larger water bodies, depth can be increased where there is sufficient water. A good design guide is to ensure a minimum average low flow depth of at least 0.1 m, which will support both invertebrates and small native fish. Deeper water may

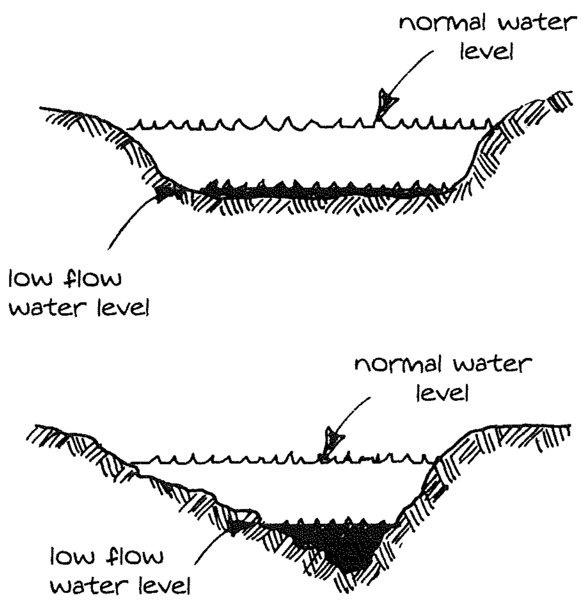


Figure 9-6: A channel with uniform depth (top) may have insufficient water to sustain instream life during periods of low flow. Creating variation in depths, and narrowing the wetted channel (bottom) ensures sufficient water depth will remain in the channel, even during low flow periods.

be needed to support large fish such as adult trout, which require a minimum depth of 0.4 m. Note that invertebrate abundance will generally start to drop off at depths greater than 0.4 m (Jowett & Richardson 1990).

When narrowing the main channel it is important to not reduce the flood carrying capacity. Providing a good floodplain and even identifying a secondary flow path could compensate. The details of any channel alterations should be discussed with a hydrologist. Refer to *Section 9.4.3: Floodplain Area,* for more information.

Creating variation in stream widths can be achieved by methods other than bank work: large boulders, rocks, logs, or vegetation growth can also contribute to altering the stream width.

9.4.2 Bank Profile

The bank profile refers to the immediate bank along a waterway, not including the wider floodplain area. Bank profile should be varied longitudinally down the stream channel, and can include the following features.

Beach areas and gently sloping banks:

- Beach areas can allow access to the water's edge for some waterbirds (e.g. mallards, paradise shelducks, herons) and people.
- Gently sloping banks can be used to plant semi-aquatic and marginal vegetation. These areas may sometimes become inundated, and vegetation growth will eventually help to further alter the channel form.

Figure 9-7: If creating a vertical bank, ensure that the opposite bank is shallow to prevent channel incising and to allow accommodation of flood flows. Newly restored Papanui Stream above Grants Road, still to be planted.

Areas of near vertical banks:

- In natural streams there are usually areas of near vertical banks on the outside of curves.
- These areas should also be well vegetated to prevent major erosion, and if erosion is a problem, should not extend for long sections. Embedding large stumps into vertical banks is a natural option for potentially improving bank stability (see *Section 9.5.2: Logs and Stumps*).
- It is generally best to have a gently sloping bank profile opposite a vertical bank, to ensure drainage capacity is maintained and to avoid the creation of an incised channel (Figure 9-7).

Areas of undercut banks:

- Undercut areas are usually associated with vertical banks, and are the natural result of water erosion, particularly on the outside of curves.
- Creating undercuts may conflict with drainage and management issues if bank structural integrity is not ensured. The following section offers some options for creating a stable undercut.

Undercut Banks

Undercut banks can be used as cover by fish and are therefore a good restoration design option, if properly designed. In a natural stream environment, undercut areas are created by the erosion of the bank, and are typically found on the outside of curves. However, in an urban environment continual erosion is not always desirable, so the following options should be considered to create stable, undercut banks.

Always consult an engineer and hydrologist to ensure that the creation of artificial undercut banks conforms with bank structural integrity in order to prevent future extensive bank erosion problems.

Let the vegetation do the work:

- Sedges and other similar vegetation planted at the edge of a stream bank will eventually create an overhang of vegetation. It may be best to plant these on a small vertical bank to create a good overhang and to prevent eventual trapping of sediment around the plant.
- The use of vegetation to create overhangs will provide little benefit during the first year while the plants are becoming established. This could be remedied by combining planting with one of the structural options outlined below.
- Larger trees and vegetation planted close to the waters edge may eventually create overhangs if their roots extend to the water's edge, and if the soil between the roots gradually erodes away.

However, bank structural integrity could become an issue.

Create undercut banks using natural stable materials:

- Artificial banks can be created to look natural while still ensuring structural integrity of the bank. For example, the strategic use of tree stumps placed and secured into the bank upside down, so that the roots extend to create the overhang (see *Section 9.5.2: Logs and Stumps*). Consider the life of such material, and use more durable, harder wood types.
- Undercuts of 0.3 m should be adequate for fish, particularly if riparian vegetation droops over to partially enclose the overhang.

9.4.3 Floodplain Area

The floodplain area is an integral and important part of a stream's environment and also creates a more natural surrounding. A floodplain area should therefore be an important part of any waterway restoration design, and can be established by creating gently sloping banks extending out from the main channel, as opposed to a sharp and steep profile.

A floodplain will enable the water to rise above the smaller low flow channel and expand into the larger floodplain area (Figure 9-8). Expansion into the floodplain will slow the water velocity; sediment will be deposited on the floodplains instead of flowing downstream, and energy that would otherwise have eroded the lower banks will be dissipated.

While it is natural for streams to flood, in urban environments floods can be exaggerated (flashy, peaking earlier, higher flows, and shorter duration). A restored urban stream may further exacerbate the potential for floods due to a narrowed stream channel and the presence of bank and instream vegetation that could slow the flow of water. However, the likelihood of flooding can be reduced by following the recommended guidelines below:

- Maintain equivalent pre-existing flood waterway cross sectional area, as well as an additional area allowance for the increased drag created by the greater surface area and riparian planting.
- Determining additional area would require a proper analysis, allowing for increased drag and obstructions. Alternatively, it may be sufficient to provide the equivalent area above the profile of the vegetation (allowing for plant growth).
- Consider the use of soakage systems and wetlands within the larger catchment to decrease the amount of stormwater that is directly discharged into the waterway, and to allow a more controlled and gradual discharge of stormwater (refer to *Chapter 6: Stormwater Treatment Systems*).

The following factors will affect the space available for a floodplain:

- The amount of land available for restoration. With increasing development on the outskirts of Christchurch there is much potential to establish a reasonable setback distance along existing streams before commencement of property development.
- The presence of existing structures in the potential floodplain area will diminish the ability to create a floodplain. Waterway restoration could be limited, and any design will need to cope with a reduced floodplain capacity.

Failing to create and protect a natural floodplain area that is appropriate to the waterway and catchment size will result in future flooding problems. Always consult a hydrologist to ensure that suitable drainage capacity for flood flows is provided for.

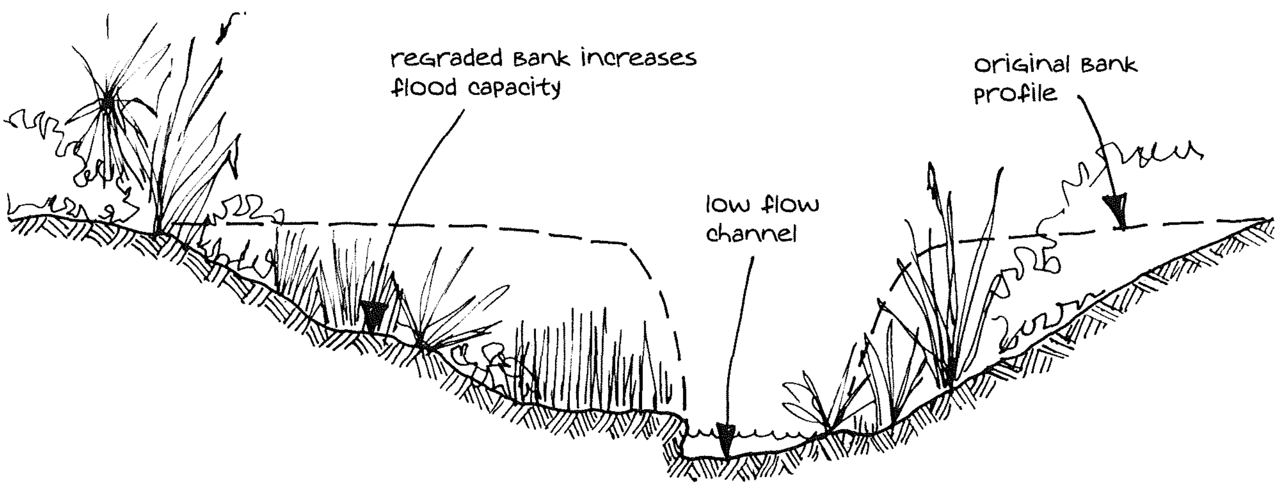


Figure 9-8: Gently sloping banks will become inundated during flood flows, enabling the dissipation of flow energy that would otherwise contribute to channel damage. Ensure flood waterway capacity is maintained where there is heavy vegetation.

9.5 Stream Bank Materials

Stream bank materials such as rocks (boulders; > 256 mm, cobbles; 64 - 256 mm) or logs, in combination with vegetation, can be used to line the lower bank.

9.5.1 Boulders and Cobbles

Correct placement of rocks along a waterway's lower bank will provide the following ecological benefits:

- Large stable boulders or cobbles that break the water's surface will serve as safe entry points for ovipositing (egg laying) adult insects. They will seek out large rocks or logs where they can crawl under the water's surface and deposit their eggs on the undersides of such structures. Some newly emerging insects may also use them to crawl out of the water.
- Bully species may use the underside of large stable rocks for egg laying, if there is sufficient space.
- Can be used to vary channel width, helping to alter local velocities (in areas with discernable flow) and improve marginal habitat variation (Figure 9-10).
- Interstices will provide cover and refuge areas for small fish. If sufficiently stable they will also provide refuge areas during periods of high flow.

Figure 9-9: The overuse and incorrect placement of rocks along waterway banks creates an unnatural appearance that lacks any significant ecological value. Small tributary of Papanui Stream above Grants Road.

Consider the following when placing boulders or cobbles along a waterway bank:

- Avoid the use of mortar to secure boulders that are in the water; this infills the interstices which are utilised by fish and invertebrates.
- Make placement haphazard; a solid line of rocks does not enhance instream values (Figure 9-9). Random placement of rocks that in areas extend into the main channel is recommended (Figure 9-10).
- Do not overuse along waterway banks. There are some instances where rocks have been used to excess, which look out of context or unnatural.
- Source materials from the local area to ensure a more natural appearance in context with the surrounding landscape.
- Consider impacts on drainage functions such as the potential for blocking the main flow during flood flows.
- Consider using boulders for erosion protection instead of other, less natural materials.

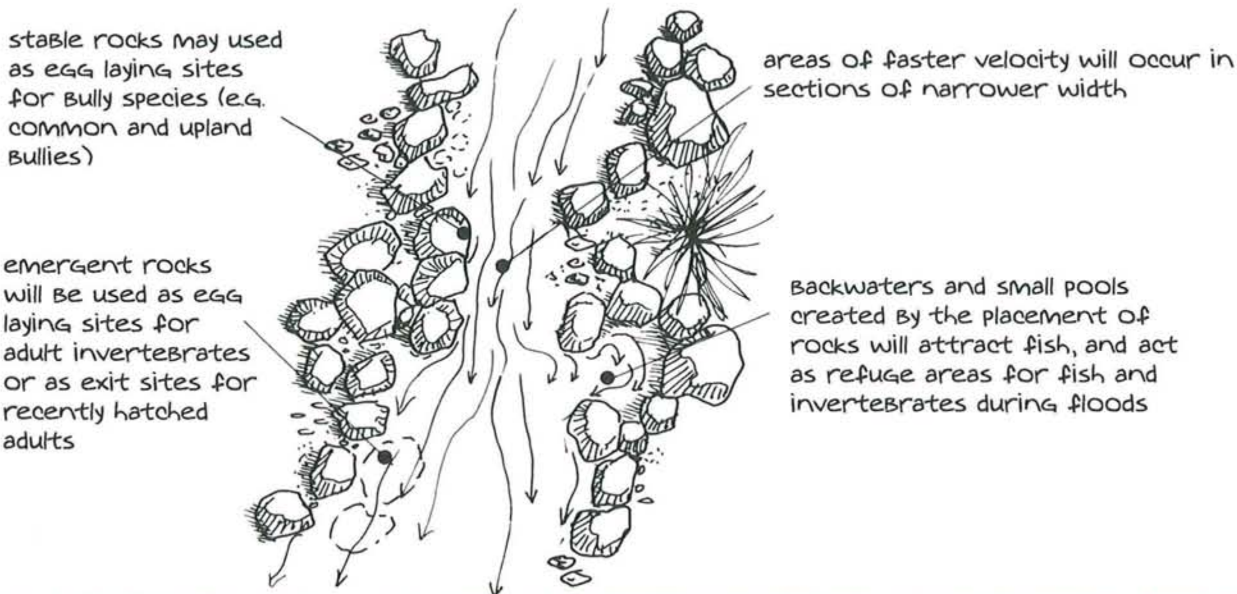


Figure 9-10: The haphazard placement of cobbles and small boulders along the banks and extending into the channel, in conjunction with coarse streambed substrates, will create a variety of velocities and habitat throughout the stream.

9.5.2 Logs and Stumps

Woody debris is an excellent structure for use in waterways, and will improve the landscape of most waterways, pond, and wetland areas. In areas where large rocks may not be a suitable addition due to the surrounding landscape and context, the use of logs could be a very useful alternative. They provide natural and stable structures that could be placed in various ways to improve instream habitat; partially submerged within the main channel, or tree stumps set upside down in the bank to create overhangs. The correct placement of tree logs or stumps can:

- locally alter water velocity and improve habitat heterogeneity
- provide excellent cover for fish and invertebrates, and refuge areas during periods of high flow
- provide an additional habitat and food source for invertebrates, and a stable habitat in streams with fine substrates
- provide emergence and egg laying sites for invertebrates (if partially submerged), and egg laying sites for some fish (Figure 9-11)
- if constructed correctly, will provide some bank support, create a natural and stable overhang, and be an interesting landscape feature (Figure 9-12).

Follow these guidelines when securing tree stumps into waterway banks:

- Durable hardwood stumps are preferable with a root plate still attached, but trimmed of any long roots. For structural support they need a minimum trunk diameter of 0.7 m.
- Stumps are to be placed upside down in the bank with the root plates interlocking. Support under the stump may be required depending on the existing substrate. The top of the stumps should be slightly lower than the finished ground level.
- Each stump needs to be secured back into the bank to a deadman or similar system.
- Geotextile mat of an appropriate ply is placed over the stumps and filled with a mixture of TNZ M/4:AP40 and topsoil. The mat is pegged into place, folded back and covered with topsoil. The mat should not be laid in a uniform, straight line, but should follow the irregular line of the stumps edges. This can be achieved by pleating the mat and securing it before topsoiling.

For the first time in Christchurch, old native timbers are being re-used for stream restoration work. A stock-pile of stumps and logs is now being kept for such projects. See the Parks and Waterways Unit for more advice on the use of logs and stumps in waterways.

9.6 Streambed Substrate

The use of coarse substrates in sections with some velocity will have many beneficial effects, including:

- Provision of stable habitat that will trap and retain more detrital matter (food for invertebrates).
- The creation of more complex, three dimensional habitats and greater small-scale variability in stone-surface velocities. This generates a greater range of microhabitats, enabling fish and invertebrates to find their preferred velocity and habitat type.
- Provide refuges from predation and from scouring during flood flows, for both fish and invertebrates.
- Provide a stable substrate for the growth of fine epilithon layers that grazing invertebrates feed on.
- Cobbles that are free of sediment may be sought out by spawning bullies for egg laying sites.

Shelley McMurtrie

Figure 9-11: Submerged logs and large debris can provide spawning sites for fish like this female common bully (Gobiomorphus cotidianus)*, which is laying eggs (see arrow) on the underside of a piece of woody debris.*

Figure 9-12: Large stumps placed upside down on the outside of a bend will create a stable overhang, and create an interesting landscape feature. An area of deeper water under the stump will provide excellent cover for fish. Papanui Stream above Grants Road, 2002.

- Pebble and gravel (2–16 mm) substrates that are free of fine sediment may be sought out by spawning trout for the construction of redds.
- Large rocks emerging from the water will be sought out for egg laying by aquatic invertebrates in their terrestrial adult stage. Rocks will also be used by aquatic insects emerging from the water.

Follow these guidelines when using coarse substrate:

- Coarse substrate should be added to most stream sections, but especially in areas where velocity is sufficient to maintain a relatively clean substrate in most flow conditions.
- The bed should be covered with a range of coarse substrates, including pebbles (16–64 mm), cobbles (small; 64–128 mm, large; 128–256 mm), and boulders (> 256 mm; sizing based on the Wentworth classification, Cummins 1962). For surface layers use grades without a high percentage of fines, and that are rounded or uncrushed.
- Select substrate to prevent scour. See *Chapter 22.7: Bed Shear Stress and the Stable Bed*.
- Coarse substrate depth should be at least 300 mm, and in most cases, placed over a geotextile.
- Large substrates, especially those lining a bank, should be sourced from the local area to ensure context with the surrounding landscape.

Figure 9-13: Prevention of marginal and instream maintenance in Okeover Stream (Canterbury University) has enabled the natural establishment of riparian and instream vegetation. The vegetation has helped create riffle-run habitats and assisted in flushing sediment from some areas.

9.7 Bank Vegetation

Riparian zones are closely linked to the instream environment, and riparian vegetation (including marginal vegetation and canopy cover) is particularly beneficial to the instream environment:

- Overhanging vegetation provides immediate cover for fish and invertebrates.
- Marginal vegetation provides additional food sources, not only from plant material, but also from terrestrial invertebrates that fall off the plants into the water.
- Bank vegetation stabilises banks, helping to prevent bank erosion.
- Marginal vegetation in tidal reaches that is partially submerged during high tides provides spawning sites for inanga.
- Marginal vegetation can cause a natural alteration to stream flow patterns and so increase instream heterogeneity by eventually encroaching on the stream. This has been the case for several restored stream sections in Christchurch, such as Okeover Stream, where instream heterogeneity has been increased by the natural establishment of riparian and marginal vegetation (Figure 9-13).
- Canopy trees provide shading and help to prevent large temperature fluctuations in smaller streams, which stress invertebrates and fish. This becomes a particular issue in small, shallow streams where water temperature can greatly fluctuate without the provision of shade.

Riparian zones need a minimum width to protect the functioning of aquatic environments. Refer to Parkyn et al. (2000) for information. The Department of Conservation have published information on riparian zones: Collier et al. (1995a) provides comprehensive information on the importance and functions of the riparian zone, while Collier et al. (1995b) provides guidelines for managing riparian zones.

9.7.1 Planting Recommendations

There are many factors to consider when deciding on the type and structure of riparian planting for stream margins that will have significant impacts on the stream and its inhabitants. Be cognizant of these considerations and plant accordingly. The choice of suitable marginal plants should always be discussed with a botanist.

See *Chapter 3.3: Birds and Their Habitat,* for details on vegetation preferred by avian fauna. See *Chapter 11.2.1: Site Planning (Special Considerations for Marginal Planting),* for marginal planting recommendations.

9.8 Aquatic Vegetation

Macrophytes (aquatic vegetation) pose considerable management problems in water-bodies throughout New Zealand. However not all macrophytes create a nuisance. Many of the native macrophytes are not intrusive, and these plants play an important role in stream ecosystems as they:

- provide habitat for invertebrates and provide some cover for fish in streams that are otherwise dominated by fine sediments
- contribute to the uptake of nutrients such as nitrogen and phosphorus
- alter local water velocities
- can, over time, develop a diverse macrophyte community that can increase instream habitat heterogeneity (Figure 9-14).

Purposeful macrophyte colonisation following stream restoration can reduce the chance of nuisance species becoming established. Many nuisance macrophytes are fast and efficient colonisers that can outcompete the less invasive native species. Thus, to reduce the chance of nuisance macrophytes becoming established consider the following:

- actively planting preferred species into areas where nuisance species are likely to become established
- minor weeding of any nuisance species in the early stages to enable the continued dominance of the preferred species until a point when they can naturally out-compete the introduced species.

In some situations ongoing maintenance of weed species may be required and any restoration project needs to take this into account.

Relatively non-invasive native macrophytes that can be used in waterway restorations include:

- *Callitriche petriei* (Figure 9-15), not to be confused with *C. stagnalis,* which is introduced
- *Glossostigma elatinoides*
- *Myriophyllum propinquum*
- *Potamogeton cheesmanii* (in larger streams).

Placement and choice of macrophytes needs to be considered carefully. Non-guided planting of species in inappropriate stream habitats can potentially create future problems. Active planting of macrophytes in restored stream sections should therefore only be undertaken with the advice of a freshwater ecologist that specialises in aquatic plants.

The practice of planting macrophytes in waterways is in its infancy in Christchurch, and is currently being researched by NIWA Christchurch, in collaboration with the Christchurch City Council and environmental consultants. In addition, the City Council is considering the development of sustainable maintenance practices for aquatic vegetation in small Christchurch waterways.

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Figure 9-14: In the slow flowing waters at the source of the Ōtūkaikino a diverse lentic macrophyte community has become established, creating useful instream habitat.

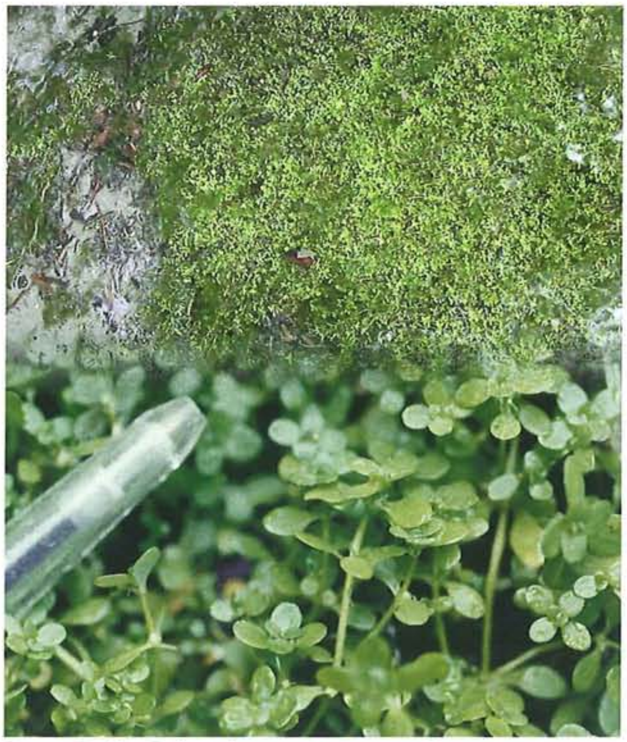

Figure 9-15: Callitriche petriei *is a small, compact, non-invasive macrophyte. It is particularly useful in stream sections with soft sediment as it creates stable habitat.*

A set of water quality guidelines for the control of undesirable biological growths in water can be obtained from the Ministry for the Environment (MfE). A synopsis is provided at http://www.mfe.govt.nz/management/rma/rma2.htm

A set of guidelines for monitoring and managing algal proliferation (Biggs 2000) is available from the MfE web site: http://www.mfe.govt.nz/new/Periphyton.PDF

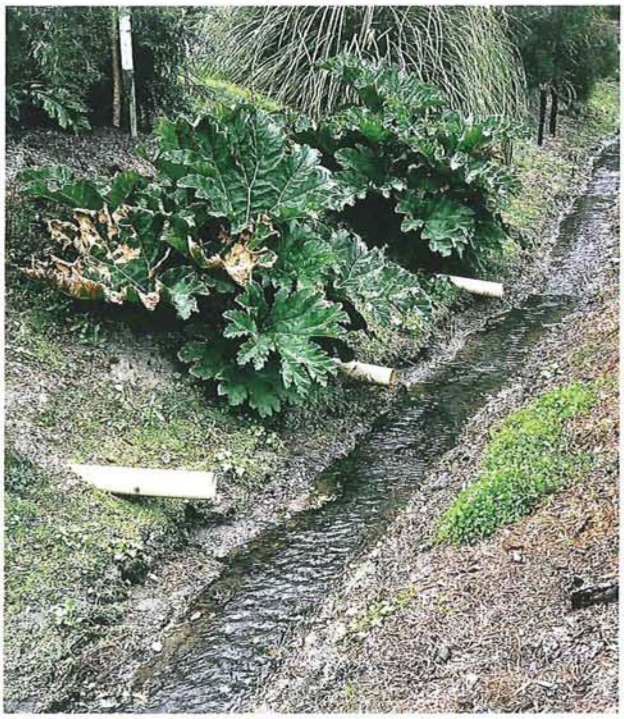

Figure 9-16: Outfalls extending past the stream bank (as above) in new waterways illustrates a lack of consideration for waterway values, and is unacceptable.

9.9 Stormwater Outfall Pipes

No stormwater outfall should protrude beyond the bank of a waterway (Figure 9-16). Stormwater outfall pipes should be set well back from the stream itself, where space allows, and connected to the stream via a gravel-lined drain planted with wetland vegetation (Figure 9-17).

In time vegetation planted around the outfall will hide the point of discharge and allow for a more natural look of the waterway. There are some other possible benefits from such an outfall design, however the latter two points may be negligible due to the small distance from the outfall to the stream:

- Reduce erosion at the bank and streambed around the outfall due to the dissipation of energy.
- Thick vegetation may partially slow the flow of the discharged water, and so help to remove a small proportion of sediments and any litter from the stormwater before it enters the stream.
- Any soakage of water into the soil will be related to the permeability of the soil type, and may be negligible in some areas. Pollutant removal efficiency is related to the distance of the pipe setback, therefore the greater the setback distance, the better.

Where sufficient space is not available for the accommodation of a setback outlet, install a low level outfall. Such an outfall will minimise visual impact, but potential water treatment is lost.

Refer to *Chapter 14.7: Pipe Outfall Structures,* for design criteria on low and elevated pipe outfalls.

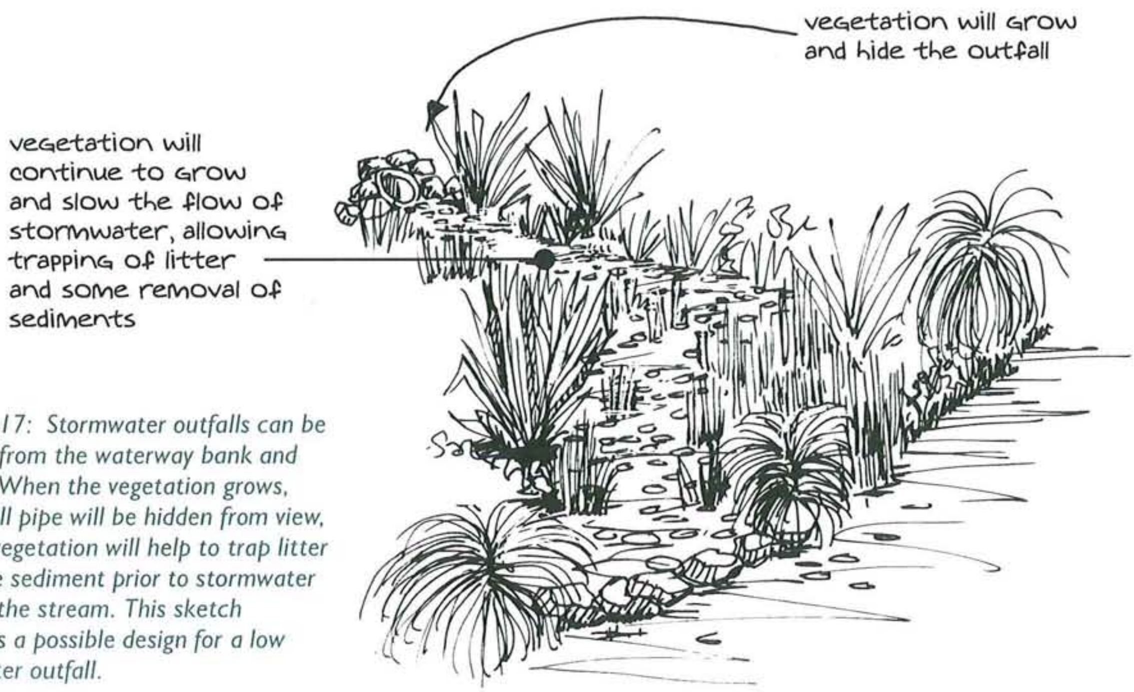

Figure 9-17: Stormwater outfalls can be set back from the waterway bank and planted. When the vegetation grows, the outfall pipe will be hidden from view, and the vegetation will help to trap litter and some sediment prior to stormwater entering the stream. This sketch illustrates a possible design for a low stormwater outfall.

9.10 Cables, Ducts, and Service Pipes

Exposed cables, ducts, and service pipes across waterways are unacceptable because of their negative visual impact, and potential to impede flood flow and collect litter and other debris. All such services should be placed a safe distance below the streambed (with at least 600 mm cover) or incorporated unobtrusively into culvert or bridge structures. It is not acceptable to simply clip such services onto the exposed outside, or underneath of an existing bridge.

9.11 Holistic Restoration

If the goal of any waterway restoration is to improve ecological values, then there is a need to plan with some level of prescience, and on a larger scale than the waterway reach that is being restored. Individual restorations can be planned to eventually link with other naturalised areas, creating a continuous linkage of restored areas; this approach will engender greater ecosystem viability than would the equivalent length of restored waterway scattered across the urban landscape in isolated pockets.

Consideration should also be given to the protection of restored waterway sections during the restoration process. In particular, take suitable measures to reduce the amount of sediment input to the newly restored section and to downstream reaches:

- Ensure that as much of the bank and channel construction as practicable is completed before adding the coarse substrate and diverting the flow into the restored section.
- Plant banks as soon as practicable to reduce the input of sediment from surface runoff. Consider using some form of ground cover with riparian planting to further reduce overland runoff (see *Chapter 11.2.7: Planting, Fertiliser, and Mulch*).
- Undertake measures to contain the sediment generated from channel construction within the constructed reach, so that it does not impact on downstream sections. For guidlines refer to Auckland Regional Council (1999).

With the considerable effort (both physical and financial) that is invested in waterway restorations it would be pertinent to protect this investment from the deleterious impacts of urbanisation. The discharge of stormwater into soakage areas, or indirectly into streams via detention ponds or constructed wetlands may help mitigate some of the negative impacts of development. Refer to *Chapter 5: Surface Water and Groundwater Interception*, and *Chapter 6: Stormwater Treatment Systems*.

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