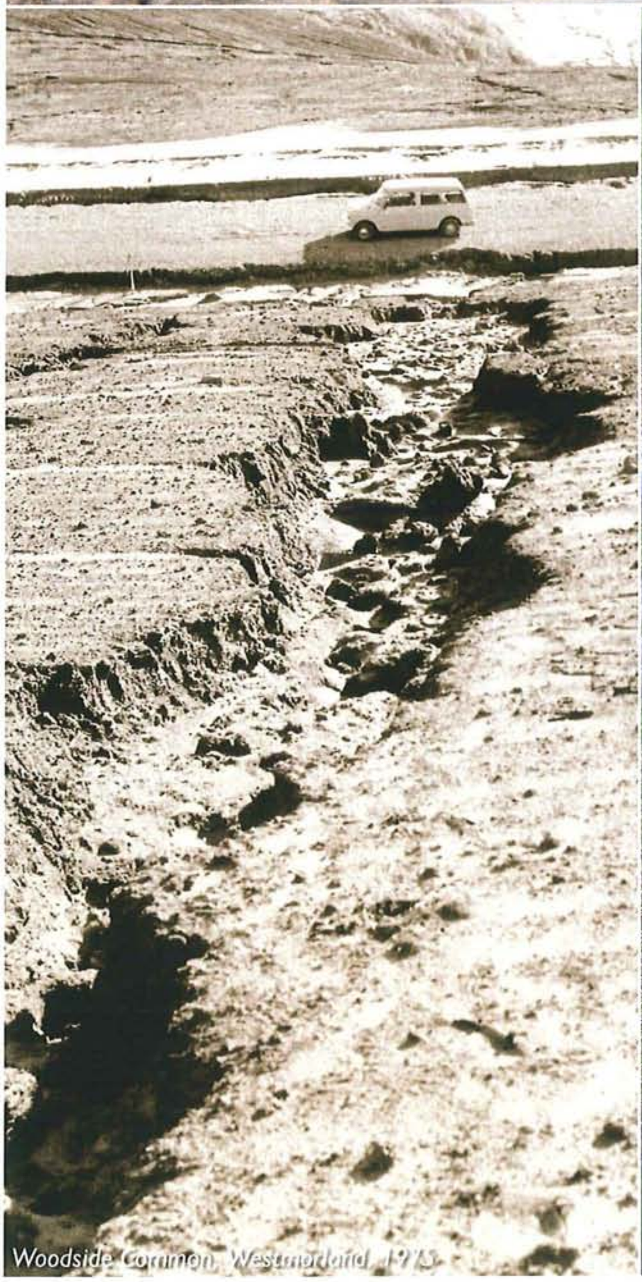
John Walter

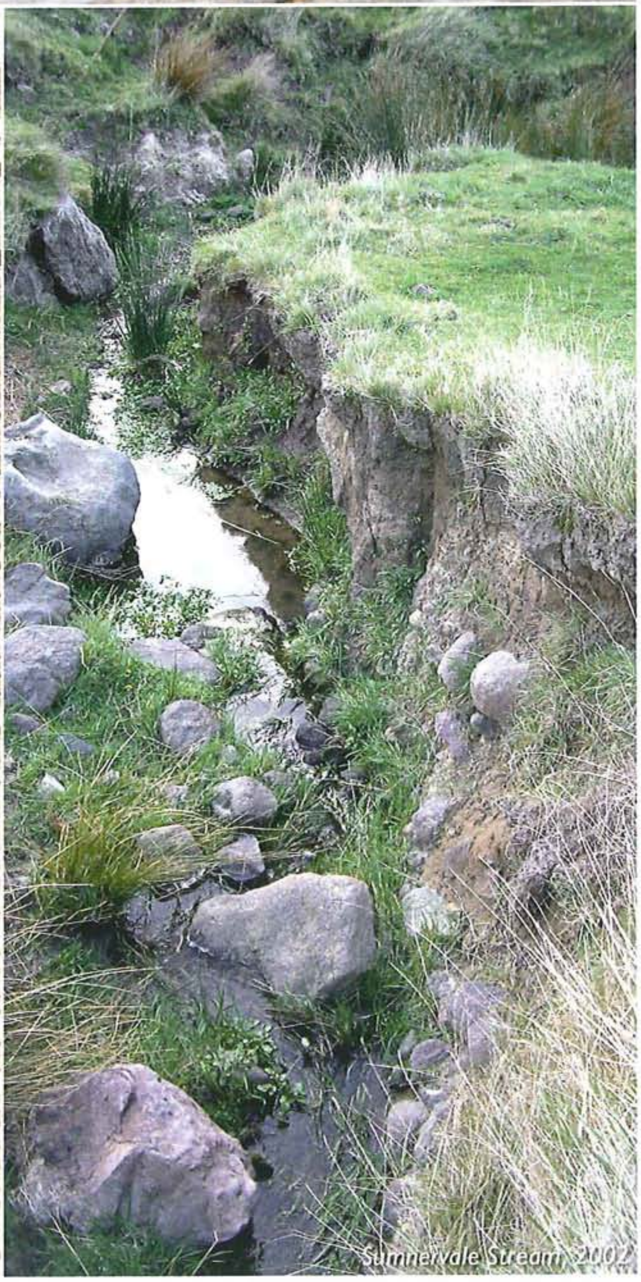
Waterway Erosion Protection

Page

Westmorland East Valley, 1974



Woodside Common, Westmorland, 1975



Sumnervale Stream, 2002

12.1 Natural Erosive Processes

Channel form derives from a constant interaction between the various states of water flow and the range of channel substrates. Change in form results from sediment transfer via various erosion and deposition mechanisms including bank slumping, mobilisation of bed load, suspension of sediment, and settlement.

In nature the development of form is usually gradual, but waterways do tend to mature towards a semi-stable erosion resistant state. This state comprises of pool, run, and riffle sequences, where the riffles consist of larger sized material, or even rock bars, with additional channel stabilisation provided by marginal vegetation.

The eventual channel form type relates to available flow energy and erodibility of the channel bed and banks. Various sources suggest that the channel form relates predominantly to the "bank full" flow state, which in turn corresponds to a flood return period ranging from 6 months to 2 years. Basic form types and erosion potential are as follows:

- Hillside waterways: rapid flow/highly erosive flow; beds dominated by bedrock and colluvium; some lengths on erosion prone loess; relatively straight.
- Upper tributaries (upper to middle reaches): moderate flow on coarse gravels; well developed pool/riffle systems; small scale meanders.
- Lower rivers/marshlands: sluggish flow on silty sand or peat soils; weak banks with easily eroded soils; deep pool and shoal systems; extensive tidal reaches with salinity impacts; large scale meanders.

12.1.1 Erosion and Bank Slumping Mechanisms

Pool/riffle and pool/shoal sequences tend to be reasonably stable but the channel form is frequently destabilised by bank slumping and erosion during larger storm flows. Bank slumping and erosion can arise in a number of different ways:

- from high water velocity that undermines the toe of the bank, particularly at the outside of bends
- from groundwater seepage due to a high water table or tidal cycling
- from wave action
- from bank overloading.

Erosion mechanisms by which these occur include:

- water velocity related erosion
- groundwater erosion
- wave erosion.

Water Velocity Related Erosion

Erosion takes place when the fluid drag and lifting forces exceed the restraining forces holding the bank constituent particles in place. Restraining forces include gravity and inter-particle cohesion and friction. Fluid forces increase particularly with increasing near bed velocity. Restraining forces decrease with decreasing particle size, which is why finer materials are more erodible.

Velocity generally increases with increasing flow, increasing slope, around any feature that causes flow to change direction, and through channel narrowing.

Erosive velocities also increase around the outside of bends, due to the near surface flow momentum endeavouring to carry on in a straight line. This results in the generation of a cross-channel rotating flow that erodes the bed on the outside of bends and builds up of beaches on the inside of bends (Figure 12-1). While this may become a problem in urban streams, it is a natural feature of a natural meandering stream and helps create a heterogeneous stream habitat.

On hillside waterways, steeper gradients can lead to high energy, high velocity seemingly out of control, cascading storm flows. This is not a problem on areas of bedrock where space allows free flow, but is frequently a problem where development has over-confined a waterway, or where the substrate is of erodible loess or colluvium. See *Chapter 7: Hill Waterways,* for further discussion on hillside erosion and *Chapter 4: Soils and Geomorphology of Christchurch,* for more on the nature of loess.

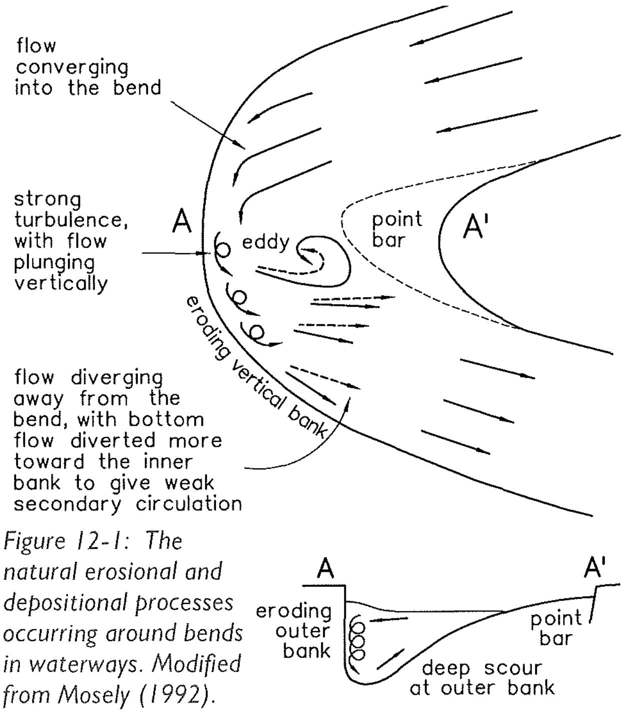


Figure 12-1: The natural erosional and depositional processes occurring around bends in waterways. Modified from Mosely (1992).

Groundwater Erosion

The emergence of water from the ground at the boundary between a coarse and fine soil may cause scour of the finer material, provided the velocity of the discharging water is sufficient.

Scour usually begins with the formation of small springs at different points along the boundary, from which channels are eroded in a backward direction to that of the groundwater flow. Hence the process is known as backward erosion.

This phenomenon is very common along many of Christchurch's rivers and shores, due to the deep layering of the sediments, and the rise of water tables towards the Port Hills and the coast. It is also common through the tidal zone where there is tidal movement of water into and out of the banks and reduced vegetative protection.

Wave Erosion

Wave erosion generally occurs in larger waterbodies where the wind has the opportunity to develop larger waves. This is especially so in coastal and estuarine environments.

Wave erosive power relates to wave height, which in turn is dependent on the sustained wind velocity, wave fetch, and water depth. Some attenuation of wave energy may take place if there is a long shallow beach backed by a vegetated margin immediately in front of any zones of erodible material.

Wave erosion occurs not only from direct wave impact on a hard edge but also as toe scour from backwash as the wave collapses back from the edge.

Table 12-1: Modifying factors present in rural and urban areas that can cause erosion and other effects.

Area	Modifying Factors and Effects
Rural	Stock ➟ bank collapse ➟ sedimentation ➟ ecological decline.
	Drain construction ➟ ongoing maintenance ➟ ecological decline.
	Overgrazing ➟ high sediment yield ➟ sedimentation ➟ ecological decline.
Urban	Hard surfaces ➟ flow increase ➟ accelerated erosion ➟ sedimentation.
	Sedimentation ➟ shoaling ➟ flooding ➟ dredging ➟ channel migration ➟ structures threatened ➟ bank stabilisation works ➟ ecological decline.

12.2 Erosion Caused by Catchment Development

Human arrival in a waterway catchment inevitably leads to intervention and modification to a waterway's natural processes; ranging from vegetation clearance and overgrazing, to channel straightening and general drainage of the land. Collectively these impacts can lead to greatly increased flood flows and increased sediment yield, either directly from surface sources or from accelerated waterway bank erosion. Some of the modifying factors and their consequential effects in rural and urban areas are shown in Table 12-1.

The rate at which erosion takes place can be further accelerated by local areas of turbulence arising from:

- over-confining the waterway width
- inappropriate construction within the waterway
- stormwater outfalls with excessively high discharge velocities
- destruction of the bank root mass through the use of herbicides or from salt-water intrusion relating to channel straightening
- loss of soil particle cohesion due to salt-water intrusion (due to calcium ion depletion through sodium/calcium ion exchange)
- burrowing by the marine mud crab (in saline tidal reaches).

Sudden Collapse

Sudden collapse can take place as a result of sudden application of weight, the slow weakening of soil strength, or the build up of pore water pressure, causing shear plane failure and sudden rupturing. The overloading force or loss of strength can be due to:

- vehicle loading
- channel bed over excavation (by dredging)
- stopbank construction
- significant groundwater flow increase (excessive pore water pressure)
- adaptation to salt water intrusion.

Most bank failures in Christchurch result from a cycle of progressive erosive undercutting of the bank followed by either slow or sudden slumping. Channel and bank erosion and deposition are natural processes in natural waterways. However, development within a catchment and the encroachment of structures and earthworks into the floodplain typically result in accelerated erosion and deposition. When the stability of structures and private land is at risk, a demand for bank protection works inevitably arises.

12.3 Erosion Protection Methods

12.3.1 Site Assessment

Always consider whether any structural bank work is in fact needed. This should always be determined in consultation with an experienced Waterways Engineer.

In situations where waterway capacity is more than adequate, planting on a slumped surface may provide sufficient stability. Ensuring that sufficient space or buffer exists between waterways and structures to allow natural processes to occur without threatening structures or property is often a good preventative measure that may reduce the need for extensive structural erosion protection.

It is important that with every new subdivisions development, water quality and quantity controls such as constructed wetlands, basins, and ponds (*Chapter 6: Stormwater Treatment Systems*) are located immediately downstream from the source of increased runoff so that the occurrence of accelerated erosion further downstream is minimised.

Most of Christchurch's tributary waterways flow through private properties, where concern about bank erosion often arises from filling and building too close to the water's edge. Owners are responsible for structural support of their buildings and other development. Enquire with the Parks and Waterways Unit for more information.

Whether an existing problem or a site of proposed works, there is a need to assess the following:

- the cause of existing erosion or local factors likely to influence future erosion
- subsurface strata or soil types
- areas of fill, and what it consists of
- flow characteristics, especially velocity and flow changes of direction, including storm flows
- rate of erosion, or likely rate of erosion
- implications of erosion on any adjacent land use
- the potential threat to nearby structures.

Failure Cause (if failure has occurred)

Reasons for bank instability need to be determined, as these will indicate the forces to which that section of bank is imposed and may reflect the underlying soil type or types.

Foundations

Foundation soils vary from peats to soft silts and sands through to gravels. Silty sands are the most common soil types in Christchurch, especially in the lower reaches of waterways and estuaries. However, there are significant stretches of gravels lining waterways where there are sections of higher velocity.

Bank design is usually greatly simplified where sound foundation conditions occur and, although many of the proposed types can be made to stand up in poor conditions, solutions that utilise deep posts or low ground bearing pressures are preferable. Foundation soils of fine materials are likely to be more susceptible to erosion problems, as restraining forces decrease with decreasing particle size.

High/Low Energy Environments

Wherever erosive forces are greatest (for example at the outside of bends or at headlands), more substantial bank works may be appropriate. In these high-energy situations a more vertical treatment is likely to be required, with less substantial and flatter slopes on the inside of bends.

Erosion and deposition on the curve of a stream helps to create a healthy and heterogeneous stream habitat. Thus prevention of these mechanisms should only occur if the resulting bank erosion is becoming a problem. If possible, allow for plenty of space at these bends and prevent encroachment of buildings, etc, into this area. If significant structural protection is required in the high energy areas, it is important to make them appear as natural as possible (i.e. use rock work, stumps, and vegetation).

Construction Access

Ease of construction will be influenced by riverbank access, working space, the need to avoid damaging existing trees, underground services, etc. In a sensitive environment it is inappropriate to clear the site of landscape features prior to construction. Therefore, the ability to construct bank works without creating serious adverse impacts is a consideration.

12.3.2 Channel Bed Stabilisation

As a general principle the designer should work with substrates natural to the local area and should look to local existing natural streams for guidance on appropriate form. Where erosion is present then means should be sort to bring this under control. This is likely to include introduction of more coarse substrates than occur naturally, preferably to create pool riffle sequences. On exceptionally soft substrates the use of geotextiles should be considered. Many of the principles applying to bank design (providing space, general appearance, etc) also apply to bed stabilisation design.

More detailed guidelines on channel bed stabilisation can be found in the following sections:

- streambed materials in *Chapter 9.6: Streambed Substrate*
- bed anti-scour design in *Chapter 22.7: Bed Shear Stress and the Stable Bed*
- riffle form in *Chapter 9.3.2: Riffle, Run, Pool Sequences*
- riffle design in *Chapter 22.8: Riffle, Run, Pool Design*
- hillside channel stabilisation in *Chapter 7.4: Design Considerations for Hill Waterways.*

12.3.3 Waterway Bank Protection

Traditionally, structural integrity has been the single most important design criteria for bank protection works. That emphasis has now changed; bank works design must now reflect the full range of values (ecology, landscape, recreation, heritage, culture, drainage). A minimalist approach is preferred and thus one must always consider whether work is required in the first place.

If bank work is needed, an hierarchical approach to acceptable bank works has been adopted, which is outlined below in descending order of preference:

1) bank regrading
2) waterway structural lining.

Only where the first preferred design cannot be implemented due to site constraints, or because it will be technically or aesthetically incompatible with adjacent bank works, will the next best preference be acceptable.

Bank work treatments should involve the minimum amount of engineering intervention necessary. This approach is likely to be more sustainable from an environmental and economic perspective.

12.3.3.1 Bank Regrading

A minimalist approach should be taken to increasing bank stability (i.e. the method that involves the least engineering). Reshaping the bank profile to a more gradual slope is often sufficient to stabilise a bank.

It is important to allow sufficient waterway corridor width for relatively gentle but varied bank slopes on which the use of natural materials such as gravel, vegetation, and toe protection, where appropriate, can provide adequate stability, without the need for more structural materials such as gabions, cemented rock, timber, or concrete retaining walls.

Removal of old fill to create a stable slope should be considered in areas where the fill would otherwise require additional support.

The designer should assess the need for support of the wetted toe. Factors include the ability of the soil type to withstand wetting from normal stream flows and emergent groundwater flow.

For bank stability, firm silts can stand as steep as 1 in $^1/_4$ (Vert:Hz) but soft or loose material may need to be flatter than 1 in 3. A common range is 1 in $^1/_2$ to 1 in $1^1/_2$. Banks steeper than 1 in 4 are difficult to machine mow although it is preferable to vegetate the banks with low maintenance planting.

12.3.3.2 Waterway Structural Lining

Artificial waterways have been lined wherever the bank or bed of the waterway is inherently unstable due to the nature of the *in situ* soils, or to achieve vertical or very steep bank slopes where space is limited. Examples include the timber-lined Dudley Creek Diversion through peat soils in Marshlands, and the concrete-lined City Outfall Drain through sand with high groundwater levels in Linwood.

In the past structural lining of waterways has also occurred in response to bank erosion, which has threatened the stability of adjoining structures and land. Such need for lining has generally resulted from building and filling too close to the waterway in the first place.

The total length of lined waterways in Christchurch is approximately 60 km. This length is gradually reducing, as lining near the end of its life is replaced by naturalisation methods. The predominant lining materials used in the past have been timber and concrete. However, examples of masonry, stonework, stone filled gabion baskets, and Reno mattresses also exist in some areas.

Natural or naturalised waterways are the appropriate design and management option except in special circumstances. Waterway lining (concrete, timber, etc) is discouraged as it commits future generations to expensive replacement, encourages inappropriate development and filling located too close to the edge of the waterway, and cannot support an ecologically diverse environment.

Alternative softer treatments like reinforced earth and geotextiles (Figure 12-2), although used sparingly in the past, should be used more in future as they are more compatible with other values such as ecology and landscape.

Large stumps could potentially be used at the outside of curves for bank erosion protection in streams where the erosive force is not great. Such materials have additional landscape and considerable ecological values. However, their design and use should be discussed with the Parks and Waterways Unit. Refer to *Chapter 9.5.2: Logs and Stumps.*

Retaining Walls

Structural support may be necessary to reinstate steep banks. Special care will be necessary to ensure that the use of such materials meets landscape criteria.

Keep vertical walls to a minimum height. Where vertical retaining walls cannot be avoided, they should be located as far away from the water's edge as possible (i.e. against any nearby building rather than at the toe of the bank).

The choice of material used for bank protection will influence waterway form and landscaping. Aspects to be considered include:

- site context: materials used in adjacent structures or bank works, e.g. stone construction near the Law Courts beside the Avon River/Ōtākaroro
- local context: use materials sourced from the local area wherever possible, e.g. volcanic rock on the Port Hills.

Retaining wall types include the following:

- bank terracing
- stonework
- gabions
- reinforced earth
- timber
- sprayed concrete
- structural concrete.

Bank Terracing:

- Bank terracing is a useful means of improving appearance where there is a limited opportunity for softening the waterway edge. This is achieved by breaking up the overall height with a low height toe supporting structure, an intermediate terrace, then vegetating the terrace to screen the upper wall (Figure 12-3).
- This approach is structurally beneficial because of the reduced overall soil loading to each wall and the ability to sometimes incorporate cross tying between the two walls.
- Partial inundation of the vegetated terrace during high tides will also assist in the establishment of marginal vegetation.

Figure 12-2: Sand-filled hessian bags offer an alternative option to more traditional materials for retaining walls. Heathcote River/Ōpāwaho at West Spreydon School.

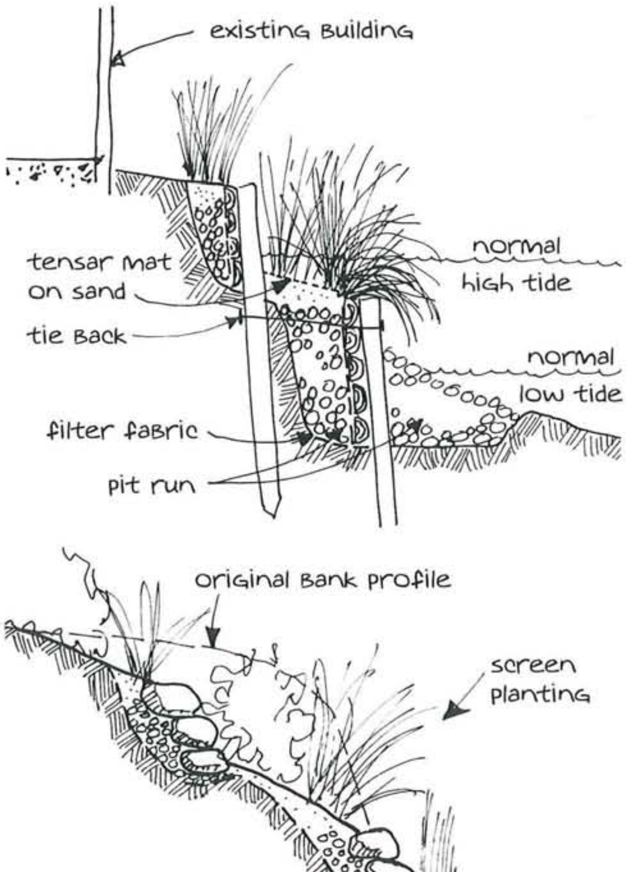


Figure 12-3: Bank terracing using either timber (top) or rock (above) can help soften a steep bank profile where there is little riparian width. Partial inundation of a planted terrace will assist the establishment of marginal plants.

Stonework:

- Dry stone walls are often proposed for economic or aesthetic reasons. Construction is normally of one, two, or three levels of rock utilizing hard, dark, angular basalt (Figure 12-4).
- This wall type should be checked for foundation scouring, settlement, or overturning. Some means of preventing loss of backfill material through the voids between stones is required, but the wall must remain free draining.
- Dry stone walls must be well interlocked and laid back to no steeper than $^1/_2$:1. Larger rock is to be placed at the base, set at least 200 mm below stream bed level, with smaller rock at the higher levels, as required. The use of small, similar sized rock is to be avoided.
- Special attention must be paid to the top edge in order to minimise the opportunity for children to roll rocks into the water. This will require use of rocks of significant size, or burial of the upper edge below a grassed surface, etc. In some cases the designer might wish to mortar stonework in place. However, this is a more expensive option that should only be considered if the mortar can be hidden from view.

Gabions:

- In the past gabions have been used to excess in the lower rivers, with resulting overexposure of an extensive sterile surface. This form of construction is no longer acceptable.

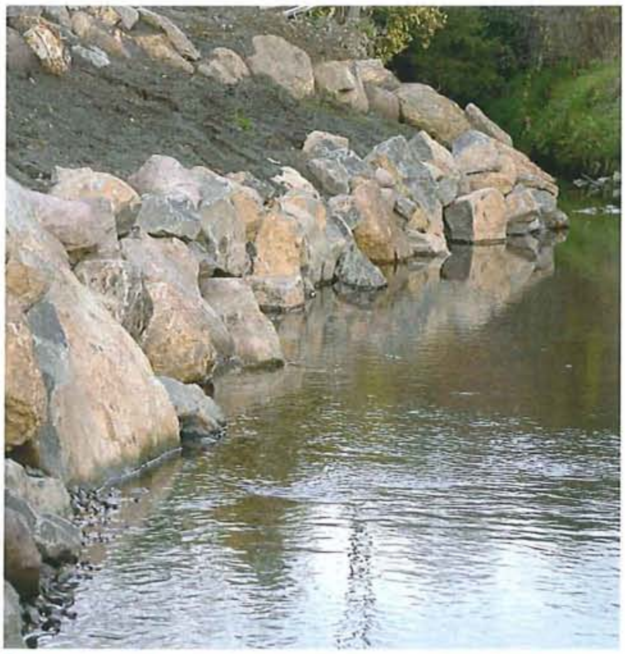


Figure 12-4: Rocks of two to three levels backfilled with gravel can be used for a stone wall. Try to ensure the rocks do not create a uniform edge, but have some 'nooks and crannies' at the water's edge to provide instream habitat.

- Gabions however are still considered useful for restoring a simulated natural vertical edge to say 500 mm above waterline and, in conjunction with bank edge planting, can produce an ecologically beneficial overhang effect while hiding most of the artificial construction from view.
- Consideration must be given to the ability of the gabion fill material to support vegetation growth through drier summer months.
- For durability gabions must be made from PVC coated galvanised wire.

Reinforced Earth:

- Reinforced earth might be considered as an alternative option to gabions for a similar outcome, provided sufficient space is available to construct.

Timber:

- Timber retaining walls should be used sparingly; lengths of uniform channel cross-sections should be avoided. Timber is not a sustainable option due to the need for future replacement. The average life for most timber used in Christchurch's waterways is 35-45 years. It should be used only if all sustainable solutions have been explored first.
- Timber walls are generally constructed with horizontal boards or half rounds held by well-anchored vertical posts. Channels that are very deep, or in unstable soil could require some special support, such as long cantilevered piles, the use of deadmen, or some form of below-bed strutting.
- Top struts should never be used because they impede maintenance access and are aesthetically unacceptable.
- Deadmen in the form of steel ties should be heavy enough to allow for corrosion and/or have a highly durable coating.
- Bottom boards or half rounds should be taken at least 200 mm below the proposed bed level, generally with the inclusion of a geotextile, in order to prevent piping.

Sprayed Concrete:

- While *in situ* sprayed concrete is not recommended in waterways with instream ecological potential, it is sometimes used as a last resort to line steeper hillside waterways that are on highly erodible soils. Sprayed concrete is expensive, but it can provide good scour resistance and bank support.
- Features such as cascading steps and extensive use of embedded rocks and margin planting should be included in order to keep otherwise high and unmanageable velocities within a manageable range—say less than 2.5 m/s. Weepholes should

normally be provided.

- For stepped cascade design, see Chanson (1994).

Structural Concrete:

- Exposed structural concrete is generally not a suitable option for use in waterways, because of aesthetic and ecological reasons. Concrete should therefore be used only if all other, more appropriate solutions, have been explored first.
- If concrete is used, some judicious planting or screening with rock work may overcome some aesthetic issues. Additionally, consider curved faces or colour additives.
- Weepholes should normally be provided.

General Design Considerations

Whenever waterway lining treatment is contemplated the following aspects need to be considered:

- Channel dimensions must satisfy the requirements of *Chapter 22: Hydraulics.*
- Open channels must also be designed to meet landscape and ecological criteria and other values in addition to the drainage and stability criteria.
- Naturalise the waterway where space allows rather than replace linings at the end of their life.
- Provide space between the waterway and any development, including private paths and gardens to allow natural erosion and deposition to occur.
- Always keep any retaining walls several metres back from water's edge to provide a buffer and to take advantage of better foundation conditions.
- Keep building or filling back from the water edge.
- The type of lining, if required, will depend upon scour, erosion, bank stability, and aesthetic considerations.
- Always consider the full range of lining treatments available, including geotextiles.
- Under NO circumstances should waterway lining provide structural support for adjacent buildings; these must be structurally self-supporting.

Design Life

Materials and structures should generally be designed for a minimum life of 40 years, although a greater life should be considered for the more expensive structures. Accordingly, under this 40 year criteria a structure built in the 1960's could be ready for replacement in the 2000's. If the life expectancy can be enhanced by a relatively small additional expense, then this should be implemented (e.g. corrosion protection of ferrous components).

Wall structure components should all have similar life expectancies to maximise the benefit of the money invested. Where treated softwoods are used, chemical reaction with metal components must be considered: zinc protected components must not be used in contact with wood preservatives unless overcoated with an isolating layer like epoxy or PVC. Polyethylene coatings are generally too soft.

12.4 Building and Filling Next to Waterways

Design all bank protection works to cater for the stability of the waterway perimeter only; buildings close to the waterway should be structurally self-supporting. Council is not normally responsible for the structural integrity of buildings and other development nearby.

Filling close to the banks must be avoided because this increases the need for 'hard' engineering bank protection works. A general rule is that if a building or fill requires structural support along the bank of a waterway to preserve its structural integrity, then the building or filling is too close. Filling also results in loss of floodplain storage, which has the cumulative effect of raising flood levels.

The City Plan (Christchurch City Council 1999) includes filling, building, and excavating adjacent to waterways as a discretionary resource consent. Refer to Section 5.2.4 of the City Plan for further details.

12.5 References

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