

river restoration



Stream Stabilisation



WATER AND RIVERS
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Report No. RR 10

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STREAM STABILISATION

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Jointly funded by



Natural Heritage Trust



**WATER AND RIVERS
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Foreword

Many Western Australian rivers are becoming degraded as a result of human activity within and along waterways and through the off-site effects of catchment land uses. The erosion of foreshores and invasion of weeds and feral animals are some of the more pressing problems. Water quality in our rivers is declining with many carrying excessive loads of nutrients and sediment and in some cases contaminated with synthetic chemicals and other pollutants. Many rivers in the south-west region are also becoming increasingly saline.

The Water and Rivers Commission is responsible for coordinating the management of the State's waterways. Given that Western Australia has some 208 major rivers with a combined length of over 25 000 km, management can only be achieved through the development of partnerships between business, landowners, community groups, local governments and the Western Australian and Commonwealth Governments.

The Water and Rivers Commission is the lead agency for the Waterways WA Program, which is aimed at the protection and enhancement of Western Australia's waterways through support for on-ground action. One of these support functions is the development of river restoration literature that will assist Local Government, community groups and landholders to restore, protect and manage waterways.

This document is part of an ongoing series of river restoration literature aimed at providing a guide to the nature, rehabilitation and long-term management of waterways in Western Australia. It is intended that the series will undergo continuous development and review. As part of this process any feedback on the series is welcomed and may be directed to the Catchment and Waterways Management Branch of the Water and Rivers Commission.



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1. Introduction

Techniques to control the riverbed, stabilise channel alignment, protect stream banks and rebuild habitat are outlined in this manual section. The section provides guidelines on managing erosion and sedimentation problems on waterways. Practical techniques that successfully integrate channel stabilisation and ecological restoration are outlined.

Rivers can be stabilised and habitat restored through techniques such as rebuilding meanders and pool-riffle sequences and managing large woody debris. Engineering techniques are sometimes required to assist river restoration by protecting waterways from erosion so that vegetation can successfully establish.

This manual section aims to provide technical advice that will assist Local Government, community groups and landholders to restore, protect and manage waterways.

1.1 Determining stable stream channel form

Methods to collect and analyse data to assess a stream reach are outlined in *River Restoration Report RR 9: Stream channel analysis*. Channel survey and assessment are essential to determine stable channel form and design stream stabilisation works that conform to this form. These works should be undertaken in relation to broader catchment processes and land use. The causes of channel instability are often due to broader processes in the catchment that require catchment wide management. Restoration techniques should target the causes of instability, rather than focus on attempting to treat the symptoms. The needs of all users of the waterway should also be considered in designing restoration works. For example, some structures may create an obstruction to fish migration or present a hazard to recreational users of the waterway.

1.1.1 Causes of channel instability

In developing a restoration plan, the causes of channel instability need to be understood in order to select appropriate management strategies. Implementation of inappropriate restoration techniques or incorrectly sized works can result in the works being damaged or undermined by subsequent flows or can cause new erosion or sedimentation along the reach.

Erosion and sedimentation are naturally occurring riverine processes, but these processes can be accelerated when a channel becomes unstable. The causes of channel instability relate to changes to the hydraulic and sediment balance of the waterway. These may be caused by human interference such as catchment clearing or urbanisation.

The primary cause of accelerated erosion and sedimentation is clearing of vegetation. Catchment clearing increases surface water run-off into a waterway. The channel then widens or deepens to adjust to the new amount of flow. This process often leads to an oversized channel where there is little vegetation to protect and support the banks. Deposition of sediment from the channel or through broad catchment erosion can cause the filling of river pools, smothering of aquatic habitat, reduction of channel capacity and channel avulsions (a new channel breaking out adjacent to the old channel). When planning to restore channel stability, the current and possible future characteristics of the catchment must be considered. Designs should be developed to restore stability to a waterway, rather than attempt to replicate the original natural system.

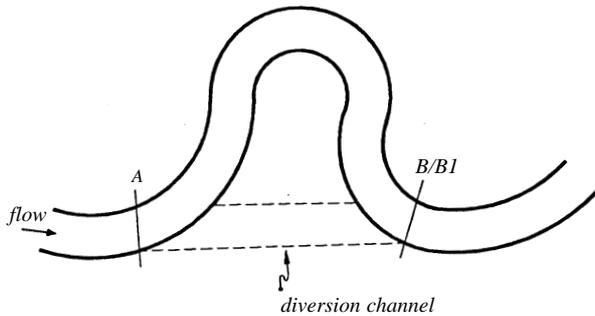
Channel deepening can be initiated by a change in the natural slope of a waterway, a decrease in the sediment being transported from upstream or an increase in streamflow. Channelisation, sand or gravel extraction and the addition or removal of instream bed control points, such as rocky riffles, can alter the channel slope. Many naturally occurring bed control structures such as logs and rock bars have been deliberately removed from rivers in south-west Western Australia. Their removal results in bed erosion and mobilisation of sediment causing major changes to channel form, flow regime and stream ecology.

Channelisation is the shortening of the natural length of the river by straightening the channel and removing the meanders (Figure 1). A new channel is usually excavated across the floodway, cutting off the meander bends. Upstream progressive bed erosion can occur due to the resulting steeper slope of the channel and consequent increase in the velocity and force of flows. This unstable zone progressively incises upstream, a process which can continue over several kilometres, as

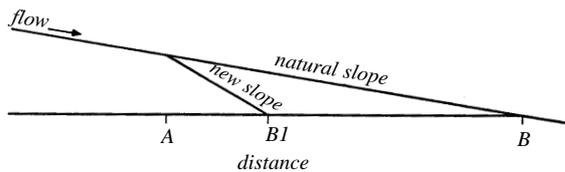


the river re-establishes a stable channel slope. Channel deepening often leads to bank erosion. As the bed lowers, the 'toe' or base support of each bank is removed. Flows can under-cut the banks, which subsequently collapse. In this way the channel widens to adjust to the lower bed level.

PLANFORM



BED SLOPE CHANGE



BED LEVEL ADJUSTMENT

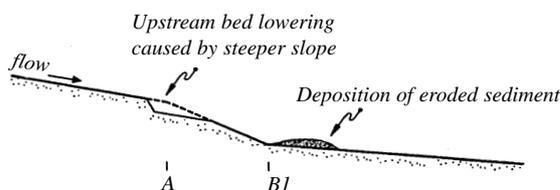


Figure 1: Bed lowering caused by channel straightening. Copied from *Riverwise Guidelines for Stream Management*, Department of Water Resources, NSW (1993).

River training can involve both straightening and clearing of the channel. However, in WA it usually consists of removing woody debris and/or fringing vegetation. While this does not increase the slope of the bed, it does reduce the roughness of the channel (Manning's n), with the effect of increasing flow velocity. This in turn increases stream power and may lead to the same problems as channel straightening, as described above.

Channel instability can also occur at a stream confluence with a tributary or drain. High velocity flows from the tributary can cause bank erosion and scour in the receiving waterway. This often occurs where culverts are producing a jetting effect. Also, if the tributary enters at a higher level than the bed of the receiving waterway, it can head-cut back upstream along its own channel, possibly producing a much oversized channel and delivering large quantities of sediment to the receiving waterway. Protective works such as a concrete outlet structure or rocky riffle are sometimes used to prevent erosion.

Bank erosion processes are described in *Report No. 6: Stream channel processes*. The cause and the extent of the bank erosion should be examined to determine the appropriate stabilisation strategy. Bank erosion often occurs following channel deepening. The stream bed level should be stabilised prior to carrying out bank stabilisation or revegetation works as channel deepening may undermine any protective works.

1.1.2 Natural stream patterns

Analysis of river behaviour in different parts of the world has found that stable channels generally follow a similar meander pattern. Where channels have been straightened, such as in a drainage channel, over time the flow can often be observed to rebuild the meander pattern. Sediment is deposited in the low velocity zone in the inner meander and eroded from the opposite bank as flow accelerates around the outer bend. Many rivers also follow a naturally undulating profile as shown in Figure 2. This is formed by high flows scouring pools and causing the build up of coarse bed material forming a riffle. A riffle is like a small 'rapid' and forms an obstruction during low flow conditions (Plate 1). The stream forms a shallow pool upstream of the riffle and a scour hole or splash pool at the downstream base as flows accelerate over the crest and down the slope of the riffle.

The key to defining a stable stream form is to determine a suitable channel width for the dominant flow called the "bankfull" flow. The bankfull width is the width of the channel at water level during an average 1 to 2 year peak flow event. The bankfull flow is the dominant channel forming discharge. Bankfull width can be calculated by using theoretical relationships between the catchment area and channel geometry derived from field measurements of river systems. Graphs relating channel





Plate 1: Riffle structure on Spencers Brook, Northam (WA).

width to the catchment area are presently being prepared by the Water and Rivers Commission. Bankfull width can also be determined by on the ground measurements. Field indicators of bankfull width are described in *Report RR 9: Stream channel analysis*.

Channel alignment is related to the bankfull width. Several formulas have been developed to characterise the meander shape. The pattern of river behaviour observed by Leopold, Wolman and Miller (1962) is summarised below and shown in Figure 3.

- A full meander wavelength (the distance between two similar points along the channel between which the waveform is complete) is found to occur between 7 and 15 times the bankfull width.
- The average distance between the ends of riffles is half the meander wavelength.
- Generally the river forms a series of regular sinusoidal curves with an average radius range of 2.3 to 2.7 times the bankfull width.

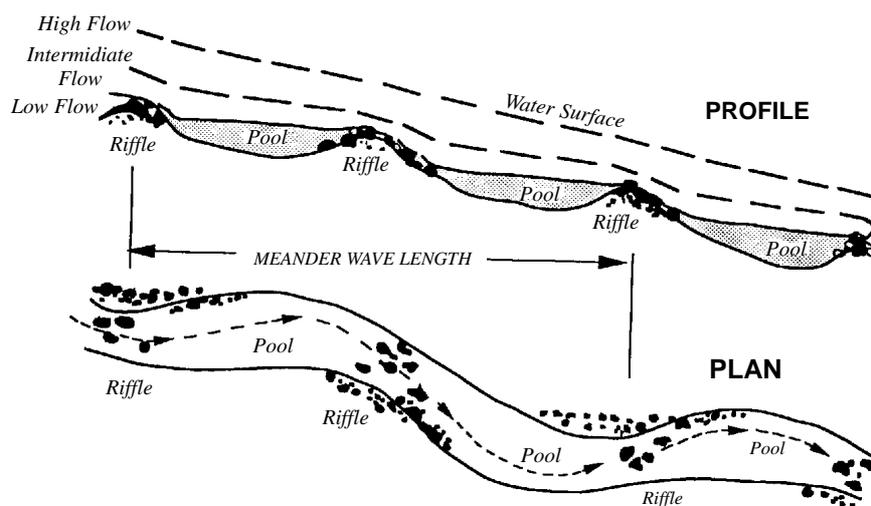


Figure 2: Schematic channel pattern and profile.
Copied from Newbury & Gaboury (1993).



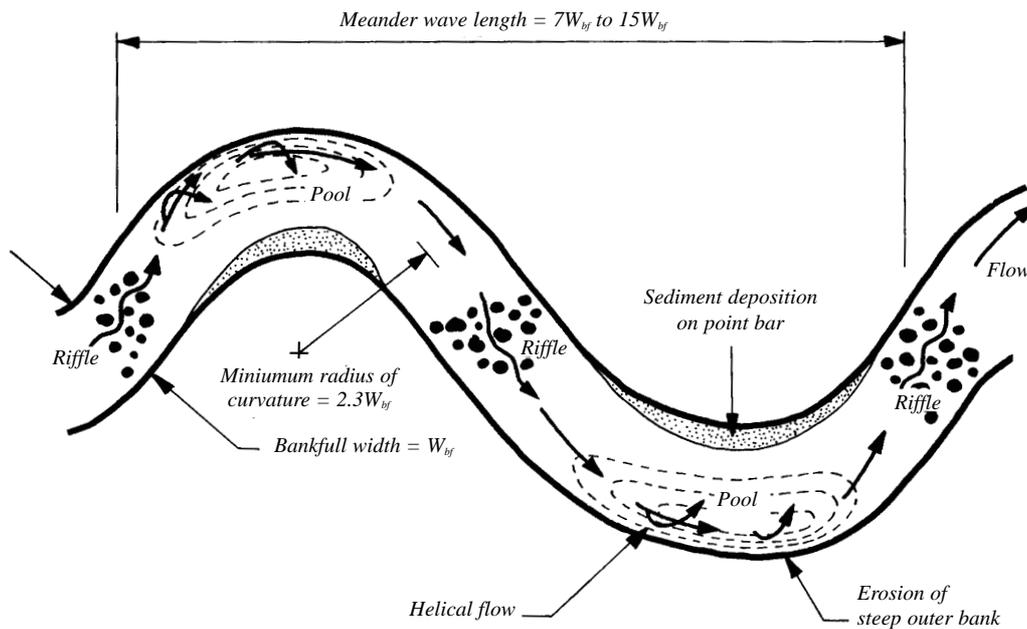


Figure 3: Meandering stream channel form.

Adapted from *Stream Analysis and Fish Habitat Design*, Newbury & Gaboury (1993).

These calculations can be used as a guide to rebuilding meanders and selecting sites to install bed control structures on artificially designed channels or degraded rivers. This analysis can also be used in restoration planning to prioritise works that address problem areas. For example, the analysis may indicate that a bend in the river is unstable as it is too sharply angled, leading to erosion of the outer bank or to an avulsion.

Determining and maintaining a stable bankfull width is important to developing and implementing a restoration design. Where the channel width is found to be too narrow, the velocity of flow is accelerated through the constricted section and erosion can result. Conversely, an over-widened channel may result in sediment deposition and vegetation choking the channel.

1.2 Stream Stabilisation Techniques

Managing livestock access and regeneration or revegetation works are essential components of waterway restoration. Rivers that are out of balance with their hydraulic and sediment transport regimes may require some form of additional channel modification to achieve long term stability. Structural works may be required on degraded streams to:

1. control stream bed level,
2. stabilise stream meanders, and
3. protect stream banks.



2. Bed control techniques

Determining an appropriate flow capacity for the channel is essential in designing stabilisation works. Channel erosion resulting from increased flow conveyance may require the capacity of the channel to be increased or the implementation of catchment wide management strategies to reduce runoff rates.

The flow and channel characteristics should be examined and attended to prior to carrying out revegetation. River restoration works should be designed so that they reinforce the natural stream geometry and alignment as determined by the bankfull discharge. Works that interfere with the natural stream processes are often damaged by the stream flows or can cause further problems along the stream reach.

There are a number of 'hard' and 'soft' engineering techniques that can be applied to protect and restore rivers. Hard engineering techniques involve using concrete, rock or other building materials to construct often fixed, permanent structures. Soft engineering solutions are based on re-establishing the natural geometry, materials and habitats found in the environment rather than applying fixed unnatural geometries and materials. Softer techniques are often more aesthetic and can be designed to provide environmental benefits.



Plate 2: Head-cut on Spencers Brook, Northam (WA).

Bed control and slope reduction structures can be used to halt the advance of an unstable zone that can progressively cause further upstream erosion. These structures include rock or grass chutes, riffles and drop structures. Rocks, vegetation and woody debris placed in the channel also increase the stability of bed material by dissipating flow energy and increasing the bed resistance to erosion.

2.1 Pool and riffle design and installation

A technique used to enhance and restore degraded rivers consists of re-building the pool-riffle sequence. The technique is used where channel deepening, or incision, is the main cause of instability. Channel deepening can be controlled by using riffles to increase the bed level and adjust the slope of the reach so that it is stable within the overall slope of the stream system across the catchment.

Stream flow is controlled over an unstable reach by creating a series of step pools. A demonstration site of the technique is being established on the lower reaches of Spencers Brook, near its confluence with the Avon River, near Muresk Agricultural College. Plate 2 shows the brook prior to restoration works. The channel bed had incised by over 1.5 metres and the head-cut was advancing upstream. The banks of the channel were also collapsing and causing considerable bank widening.

Plate 3: Riffle built on Spencers Brook.



A series of riffles were installed along the brook. Plate 3 shows the lower riffle on Spencers Brook following two winter flows since construction. The riffle was constructed at the location of the head-cut shown in Plate 2. The site plan of the restoration works is shown in Figure 4. The brook is considerably straighter than the theoretical meander pattern described in Section 1.1.2. The riffle sequence was constructed to cater to the existing meanders of the brook, rather than conforming

to the ‘text book’ riffle spacing determined by bankfull width. The series of riffles have been successful in controlling the severe bed erosion that was occurring. Sediment has been deposited along the river channel, raising the bed level and filling the head-cut. Note that the rocks of the riffle were rearranged during flooding and there was some scouring about one corner, requiring some maintenance work until the riffle became fully stable.

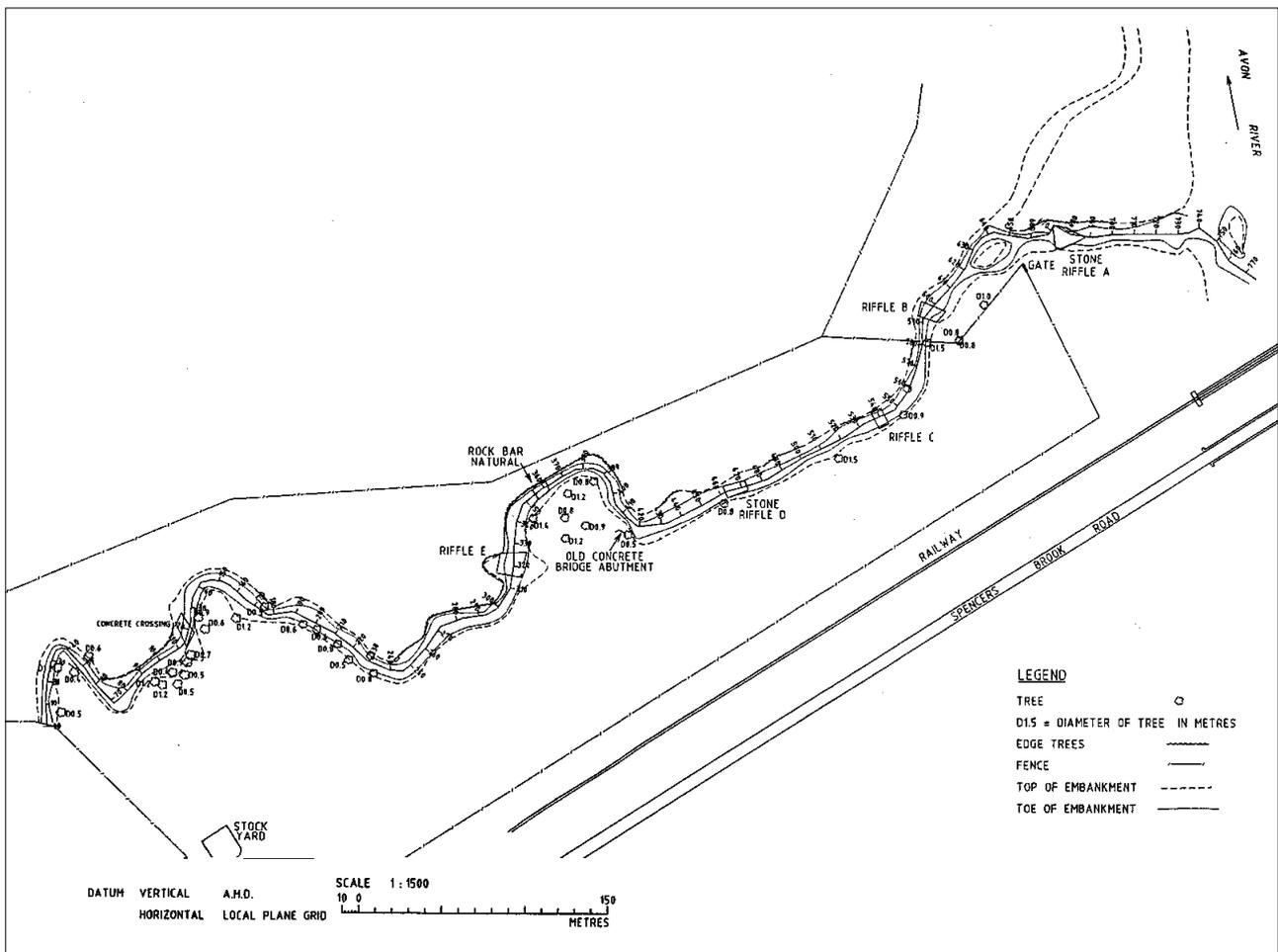


Figure 4: Spencers plan view of riffle sequence.



2.1.1 Benefits of pools and riffles

Riffles, snags and other channel controls are important to the stability and ecology of stream systems. The pool-riffle sequence provides a variety of riverine habitats that are able to support a greater diversity of species than sections that have uniform characteristics. Riffles and meanders create variable water speeds and depths and maintain river pools that are important in providing summer refuges and breeding areas. The pools also provide resting zones for migrating aquatic fauna after tackling higher velocity flows.

Pool-riffle sequences contribute to channel stability by controlling the velocity of flow and reducing the downstream movement of sediments into the river. Stabilised bed material is important for the establishment of instream vegetation and habitat for aquatic fauna. Sediment accumulates behind the riffle and vegetation can be established on the flanks, stabilising the banks. By locking the sediment and reducing flow velocities, nutrients in the water column can be removed through biological processes or remain bound in the bed material. Water quality is also improved as the riffle creates turbulence that aerates the water, which in turn supports microbial activity that breaks down organic matter and assimilates nutrients.

A riffle structure can be designed to provide a livestock watering or crossing point. The pool created by the riffle can be used for livestock watering or to supply, via a pump, an off-stream tank or trough. Formalised crossings protect both livestock and stream habitat from the problems associated of unrestricted access. These include a reduction in the spread of bowel and urinary water borne diseases that afflict stock and overgrazing and trampling of fringing vegetation. A demonstration



Plate 4: Riffle/stock crossing on the South Dandalup River, Pinjarra (WA).

rock crossing has been constructed on the South Dandalup River by Alcoa at Fairbridge, Pinjarra (Plate 4). Livestock do not remain in the river channel for prolonged periods, as the cobbled surface of the crossing is very rough and uncomfortable on the feet of livestock.

Additionally, riffles are simple to design and construct and can be relatively inexpensive to build where stone is readily available.

Riffles generally do not adversely affect the flood capacity of the river channel, which is often oversized due to erosion anyway. An assessment of the channel capacity should be undertaken when designing instream works. The structures will have negligible impact on flood levels if designed to obstruct less than 10 % of the cross-sectional area of the channel. The riffles are fully submerged during medium to high flows.

2.1.2 Designing pool and riffle sequences

Site survey

The riffle structures are designed by using channel measurements from a local river survey. The site should be surveyed to establish the profile, slope, geometry and alignment of the channel. The flow history (if available), land uses, catchment size and location of the reach within the catchment should be examined. The method of assessment is outlined in Report RR 9: *Stream channel analysis*.

Sizing of materials

The tractive force calculation presented in Section 6.1 of Report RR 9 can be used to select adequately sized rocks to construct the riffles. The tractive force is used to determine the size of the bed paving material the river is capable of moving. In performing the calculation, a suitable depth of water should be selected to prevent movement of the rocks under high flow conditions, such as the depth of a ten year flow event or a flow event that would fill the channel up to floodplain level. Figure 6.1 in Report RR 9 shows the relationship between the tractive force and the size of bed paving material that will be transported. This calculation can be used to determine the stability of the existing distribution of bed materials and to select adequately sized rocks to construct the riffles.

The theoretical equations provide a reference estimate when designing restoration works, but the discharge, bed material, bank vegetation and catchment slope in each situation will differ and some judgement and practical experience is required in the application of these equations. It is recommended that technical advice be obtained from the Water and Rivers Commission or other river engineering experts when designing instream structures. The types and sizes of materials occurring naturally in the waterway can be used as a guide to selecting appropriate materials to construct instream structures.

Riffle location and height

The riffle sequence should be constructed to cater to the natural meanders of the river rather than strictly conforming to the riffle spacing determined by the dominant channel width suggested by Newbury and Gaboury, (1993). Where a river has been straightened, the equations provided by Newbury and Gaboury, (1993) can be used to space the riffles in order to recreate the pools and riffle forms found in naturally meandering rivers.

Riffles should always be constructed along a straight section of the river or at the crossover point in the middle of a meander (Figure 5). By constructing a riffle following a bend, the energy of flows that can erode the outer banks of the channel is dissipated. The riffle reduces the flow velocity by creating a pool that back-floods the upstream section and reduces the power of the downstream flow. The height of the riffles should be selected to stabilise the slope and back-flood the base of the previous riffle or channel control point (Figure 12).

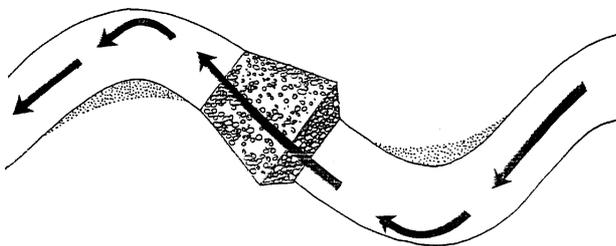


Figure 5: Riffle located at meander crossover.

The selection of a location to construct a riffle should also consider the existing bed profile. Siting should take advantage of natural high points along the profile (Figure 6). This means a lower riffle can create a deeper, longer pool. Riffles should not be constructed to significantly obstruct the channel or retard flood flows. Typical riffle heights are only about 0.2 – 1.0 metres above the general bed level. A series of numerous low riffle structures should be installed rather than only one or two large structures.

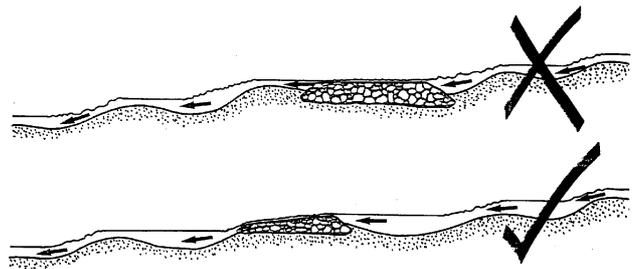


Figure 6: Riffle located on high point of channel profile.

2.1.3 Riffle construction

The crest of the riffle should be built with a shallow "V" shaped cross-section. The lowest point of the riffle should be in the centre of the channel to direct flows away from the banks. A schematic diagram of a riffle is shown in Figure 7. Flows accelerate over the riffle along a straight section of the river. The force of the flow is dissipated along the downstream face of the riffle and by forming a scour pool at the base or 'toe' of the structure. By suitably selecting the sites of the riffles and pools, the stability of the channel is assisted by guiding the flow from meander to meander. The sides of the riffle should typically extend to the top of the channel. This is to avoid the acceleration of high flows around the riffle that can cause bank scouring.

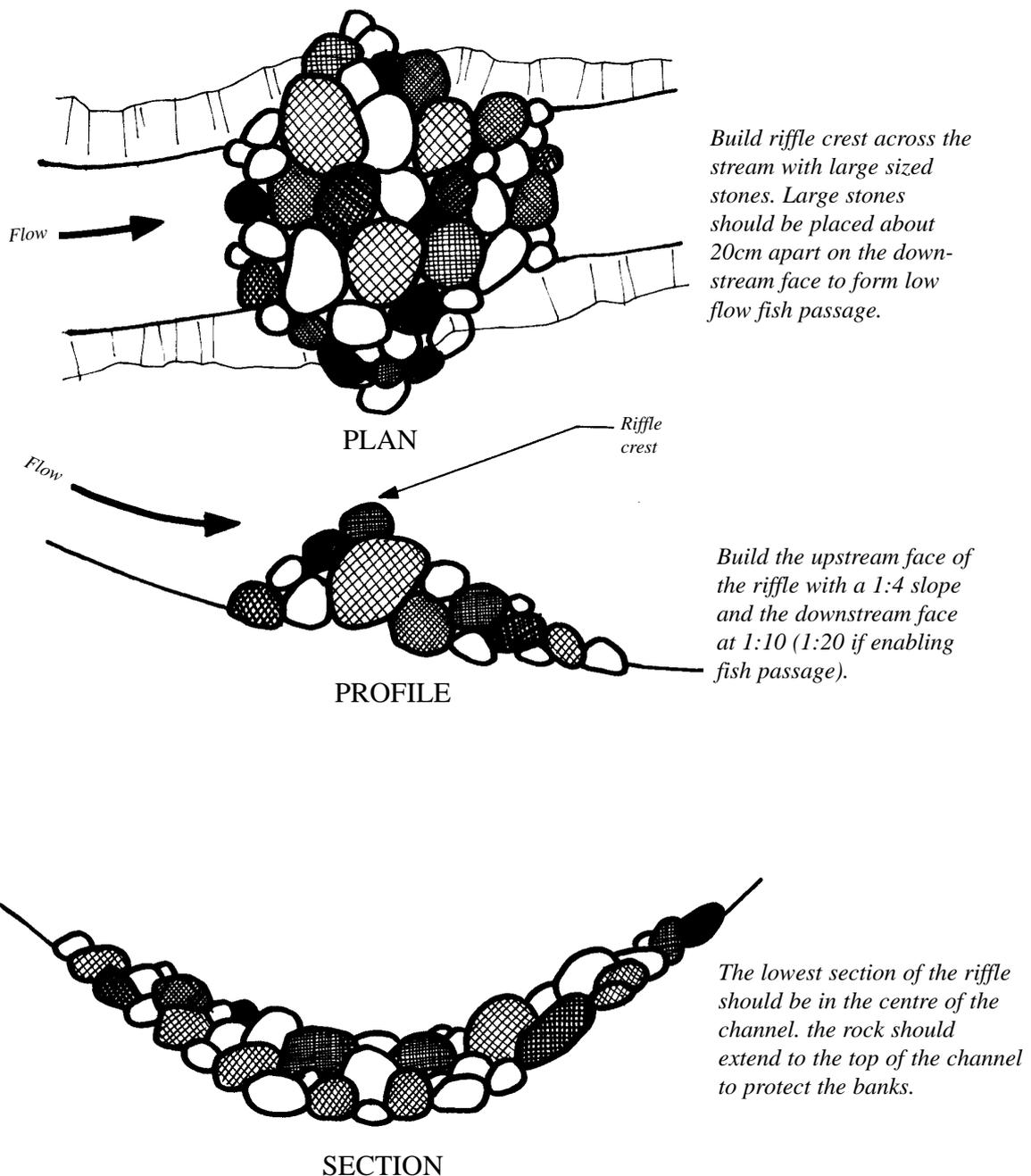


Figure 7: Schematic diagram for riffle construction.

The upstream face of the riffle should be constructed with a maximum slope of 1:4 (vertical:horizontal) and the downstream face with a slope of 1:10 (1:20 if enabling fish passage). The crest of the riffle may need to be dug in to below bed level in highly erosive or dispersive soils to prevent undermining of the structure. A trench should be dug out along the cross-section at the

crest location, and the rock laid into the banks and below bed level.

Filter cloth may be required between the rock and the bed material to prevent undermining. Allowance should be made for a scour pool at the downstream base of the riffle. The sides of the riffle should have a maximum slope of 1:4.



A range of materials may be suitable for constructing the riffles. The site conditions and the resources available should be considered in selecting the materials. Rock is typically used, but old tyres, broken concrete, sandbags and even secured logs have been used in some constructions. The types of materials occurring naturally in the waterway in undisturbed reaches should be used as a guide to the materials and sizing of works.

Rock riffles are the most commonly constructed type. A mix of rock sizes is required for the riffle to become interlocking and thus achieve greater strength. Hard, clean, angular-shaped rock is required. Flat rock is inappropriate. Larger stones or boulders should be placed on the surface of the riffle and spaced about 20-30 centimetres apart on the downstream face to break up the flow of water and assist in fish passage. Large diameter boulders should be used to construct the V-shaped crest of the riffle (Figure 7). The rocks should not be concreted into position.

The installation of riffles must be carefully supervised during construction to ensure correct placement of materials. Some rock movement may occur during initial high flows until the structure settles and stabilises. Maintenance and possibly the addition of more rock will be required following the first few big floods.

2.1.4 Using large woody debris to build riffles

Using large woody debris to construct riffles may be more applicable to sandy stream systems such as those found on the coastal plain. Here rock structures are not normally found and would in any case be prone to undermining and movement. Large woody debris consist of tree trunks and large branches. A demonstration site of the restoration technique has been established on the South Dandalup River at Fairbridge, Pinjarra. Plate 5 shows a woody debris riffle constructed at the site. The logs were installed manually as heavy machinery would have caused substantial damage to the well-vegetated banks. Logs were placed against the banks to direct the flow towards the riffle.

Two logs can be used to form a V shaped riffle across the channel (Figure 8). The riffle should be constructed with the butt of the logs buried into the bank and the tapered end pointing slightly upstream. The lowest point of the riffle should be at the join of the two logs in the centre of the channel. Alternatively a large log, at least two metres longer than the channel width, is required to form a whole of channel structure. Bundles of branches can also be used for construction.



Plate 5: Large woody debris riffle built on the South Dandalup River, Pinjarra (WA).

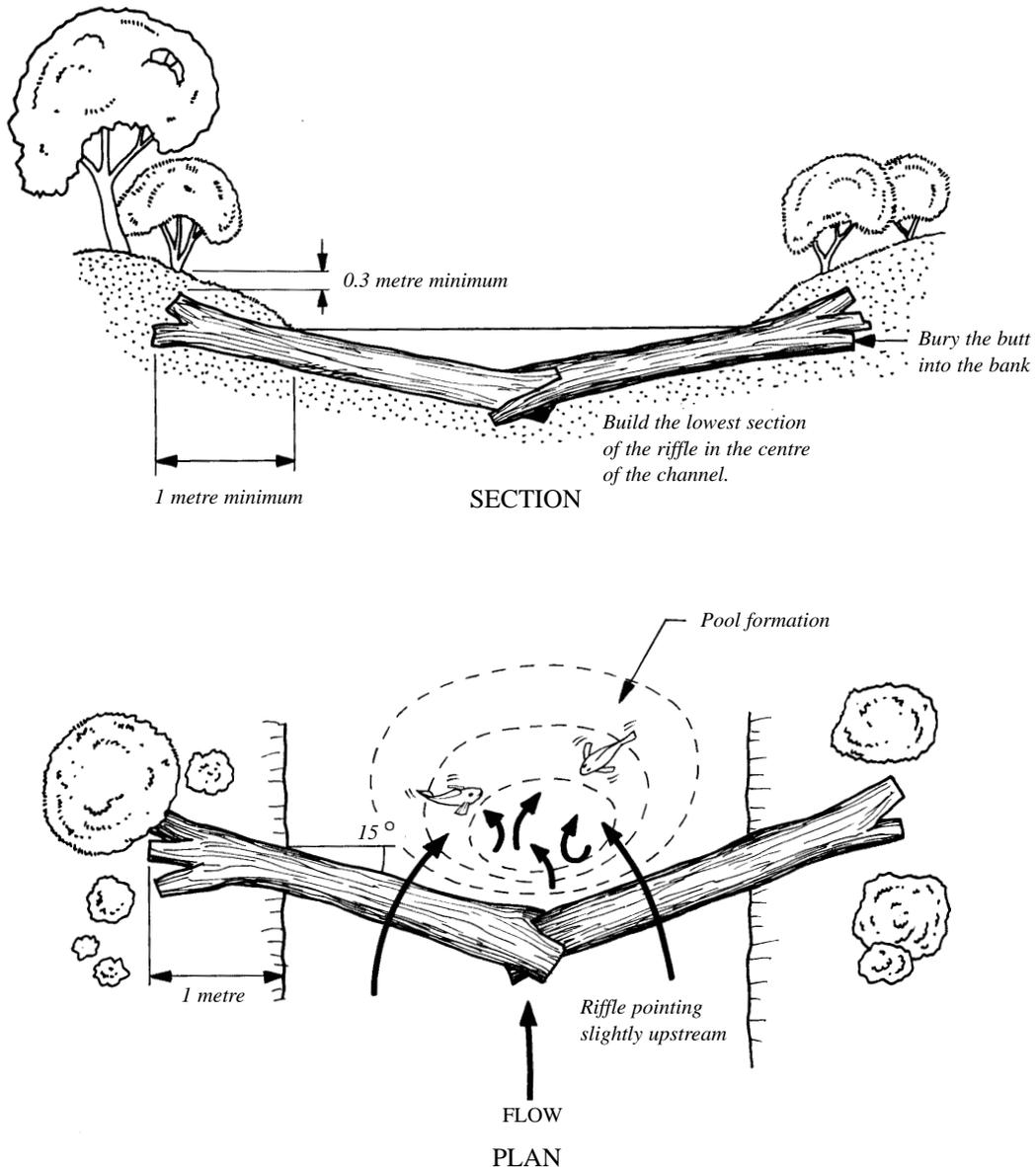


Figure 8: Log riffle cross-section and plan view.

The ends of the log riffle need to be buried at least 1.0 metre into the bank and below a minimum of 0.3 metres of bank material. The butts of the logs can be sharpened so that disturbance to the bank is minimised when the end is pushed into the bank. The bank can be stabilised by pinning brushing or matting and revegetating. The riffles should not be constructed more than about 0.3 metres high to allow fish passage.

Additional stabilisation may be required such as pegging or weighing down the logs into position. This will depend on the bed material and flow regime of the reach. Large woody debris may be redistributed under high flows, particularly where it occurs on mobile, sandy streambeds. The logs can be anchored by wiring

to posts or metal stakes driven into the bed. The posts should be driven approximately 1.5 metres into the riverbed. This will not be possible in rocky sections of the channel. Alternatively, the logs can be chained to weights such as logs ('dead men') or concrete blocks buried beneath bed level.

Where using log riffles to control bed erosion, methods to control the flow and hold sediment in place will be required. In unstable sandy bed systems, filter cloth should be installed on the upstream side of the riffle (Figure 9). The filter cloth should be wrapped over the log and pinned. The edge of the cloth should be buried to approximately 1.5 metres into the bed to prevent undermining of the structure.

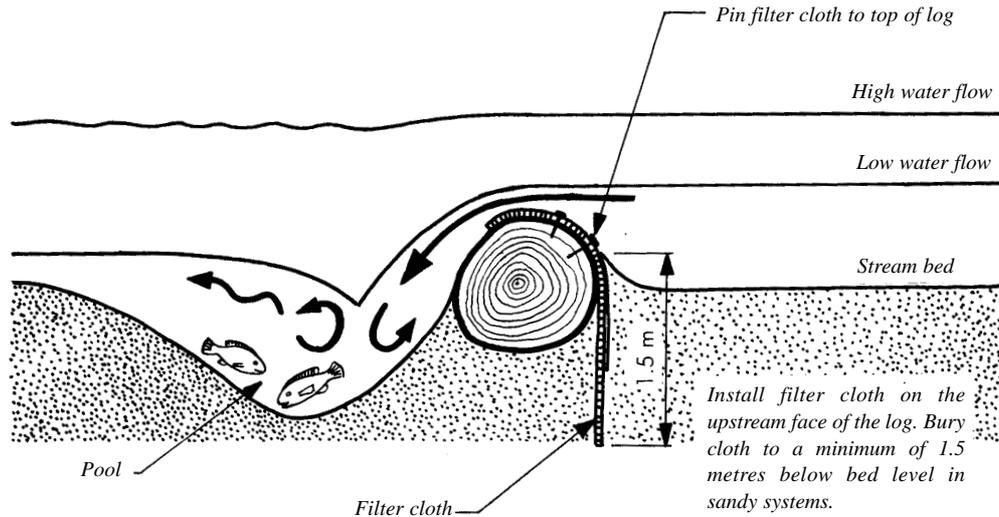


Figure 9: Installation of filter cloth on log riffle.

Wood from tree species that are native to the area should be used in preference to non-local tree species. Wood that has been treated with chemicals that may be harmful to stream fauna and should not be used.

2.1.5 Project Costs

Costs to construct riffles will vary depending on the site conditions and availability of suitable material and equipment. Survey information will be required and the site inspected before an accurate estimate of the quantity of rock or logs, the number of riffles needed and the costs involved can be made.

The costs of two demonstration projects undertaken by the Water and Rivers Commission to promote river restoration are outlined below. The project costs do not include Commission staff time to design the restoration works and manage the projects. Cost savings can be gained by undertaking the channel surveys using the methodology outlined in *Report No.9: Stream channel analysis*, rather than contracting a licensed surveyor. The use of volunteer resources and donations of materials can also reduce the project costs.

The rock riffle and large woody debris demonstration sites cost approximately \$44,000 and \$48,000 per kilometre respectively, including site assessment and monitoring. Riffle construction is more cost effective to stabilise and rehabilitate waterways in some situations than concrete drop structures. Drop structures can cost in the order of ten times more to construct than riffles and do not provide habitat enhancement benefits.

The total cost for the construction and enhancement of four riffle structures along a 500 metre reach of Spencers Brook is summarised in Table 1. The average bankfull width of the brook is 8.0 metres.

Table 1: Project Costs - Spencers Brook Rock Riffle Demonstration Site

Item	% of Total Project Cost
1996 Data collection	
Establishment of gauging station *	14 %
Catchment photographic mosaics *	2 %
Channel survey and cartographics +	10 %
Construction of the riffle structures	
Materials - rock	16 %
Excavator hire	6 %
1997 Data collection	
Channel survey and cartographics +	31 %
Maintenance of the riffle structures	
Materials - rock	7 %
Excavator hire	6 %
2000 Maintenance of the riffle structures	
Materials - rock	3 %
Excavator hire	5 %
TOTAL 1996-2000	\$23 500
* costs which are optional	
+ activities that can be done by the volunteer group at a reduced or no cost	



The construction cost for the installation and enhancement of the rock riffles was approximately \$10,000 (\$2,500 per riffle). The riffle structures were constructed by the landowner using local stone. This reduced the construction costs.

The large woody debris restoration project involved installation of about 50 logs along a 600 metre reach of the North Dandalup River in Pinjarra. The average bankfull width of the river reach is 12.5 metres. Three large woody debris riffles were installed along the reach. The riffles cross the low flow channel, forming small weirs. Between the riffles, woody debris was strategically placed as toe protection to direct flow around the channel meanders.

Table 2: Project Costs – Dandalup River Log Riffle Demonstration Site

Item	% Total Cost
Nov 1997 Monitoring – fish and macroinvertebrate diversity *	8 %
April 1998 Survey and cartographics +	12 %
May 1998 Log riffle construction	
Supervisor +	6 %
Plant (chainsaw, A64 loader, low loader/transporter, excavator and bull-dozer) and operators	19 %
Materials (40 logs ^{at} 48 m ³)	2 %
"Jutemats" – erosion control mats (\$600 worth of products provided by the distributor at no cost as a promotion exercise)	
Jan - Feb 1999 Log Riffle Stabilisation and Enhancement	
Materials – 70 Pine poles and galvanised tie wire	4 %
Plant hire (Ford loader rake, Volvo & float, 25 tonne Excavator) and operators	11 %
Supervisor +	8 %
Feb 1999 Monitoring – fish and macroinvertebrate diversity *	15 %
Nov 1999 Monitoring – fish and macroinvertebrate diversity *	15 %
TOTAL 1996-2000	\$28,500
* costs which are optional + activities that can be done by the volunteer group at a reduced or no cost	

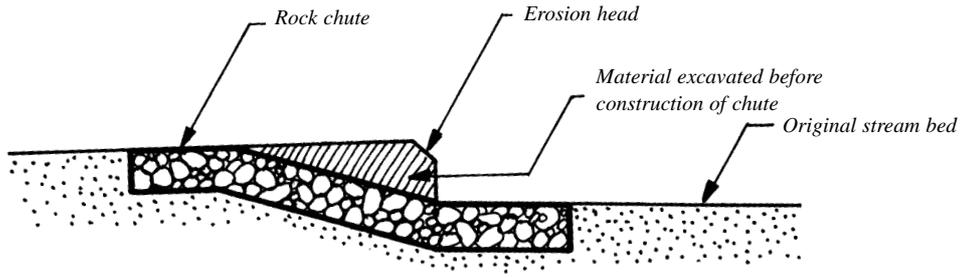
The construction cost for the installation and enhancement of the log riffle structures and toe protection was approximately \$10,500 (ie, about \$260 per log placed).

2.2 Rock and grass chutes

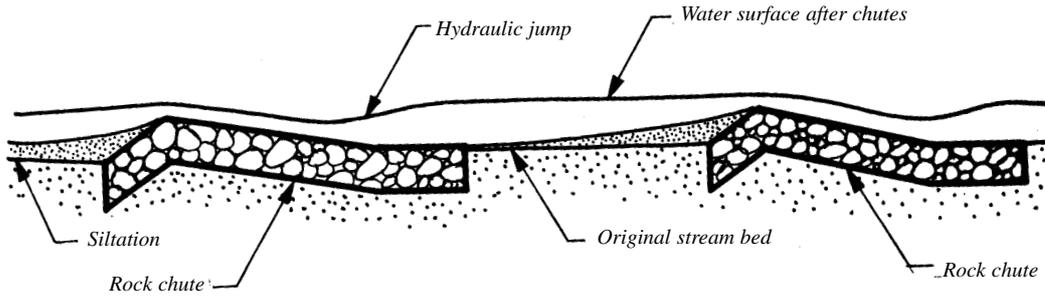
A rock chute is similar to a riffle structure and can be used to control the advance of a head-cut. Chutes can be used to stabilise sudden streambed drops, typically 1 to 5 metre falls (Figure 10.a). A series of chutes can be installed to reduce the slope of the river reach (Figure 10.b). Sediment is deposited upstream of the chute. A chute can be built downstream of a head-cut (Figure 10.c) to drown out the fall and halt the upstream progression of bed erosion. The chute can be structured as a drop structure with a fixed crest, forming a weir above the riverbed, or can be more flexible in shape. A fixed crest is a solid wall built along the crest, extending through the chute and into the channel bed (Figure 10.d). Weir type structures are not preferred as they may impede the passage of aquatic fauna.

Detailed design techniques and programs have been developed to construct rock chutes. A section of the riverbed is hardened with graded rock to increase the bed resistance. Rock armouring is extended to above bankfull stage height to avoid outflanking. The streambed may need to be prepared by excavating a smooth surface and filter cloth may be required between the rock and the bed material on highly erosive or dispersive soils to prevent undermining. The rocks do not require concreting into position. Some rock movement may occur during initial high flows until the structure settles and stabilises. The downstream and upstream ends of the chute can be constructed with 'cut-offs' as shown in Figure 10.d. Cut-offs are vertical barriers such as a wall or geotextile used to prevent sediment movement through the chute. The cut-offs act to reduce the risk of failure of the chute caused by undermining. Cut-offs are required for steep chutes or in streambeds with high permeability or low cohesiveness.

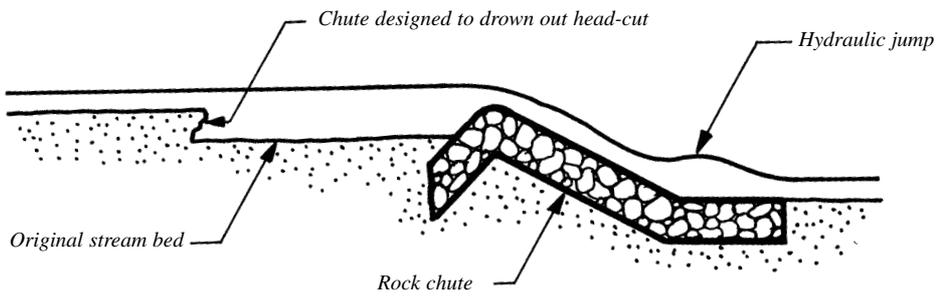




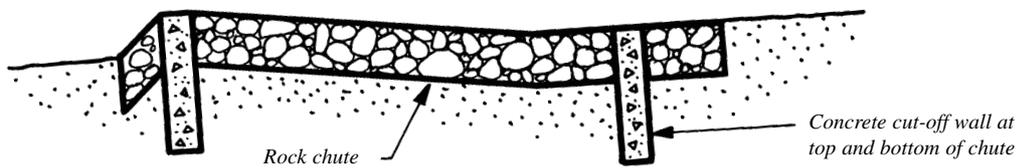
A. Rock chute applied to stabilise head-cut



B. Series of chutes built to reduce reach slope



C. Chute designed to back-flood head-cut



D. Chute cut-offs

Figure 10: Applications of rock chutes.



Grass chutes can be constructed in waterways to stabilise head-cuts or steep slopes (Figure 11). The technique is most applicable on seasonal waterways or where base flows are low. Grass chutes can be used in channels that accommodate occasional bypass or high flows usually located on broad floodplains. A section of the channel is vegetated with dense grass. The grass reduces the velocity of flows, trapping sediment and inhibiting erosion. The species of suitable grass is site specific and will be determined by the climate, soil type and water quality. Grass chutes are not appropriate in channels exposed to heavy livestock grazing or prolonged periods of inundation. Grass chutes are low cost, but require ongoing maintenance. There may also be difficulties in establishing the grass, and it may be necessary to protect the channel during this period.

Grassed area can be lightly grazed, however dense cover should be maintained during the flow season

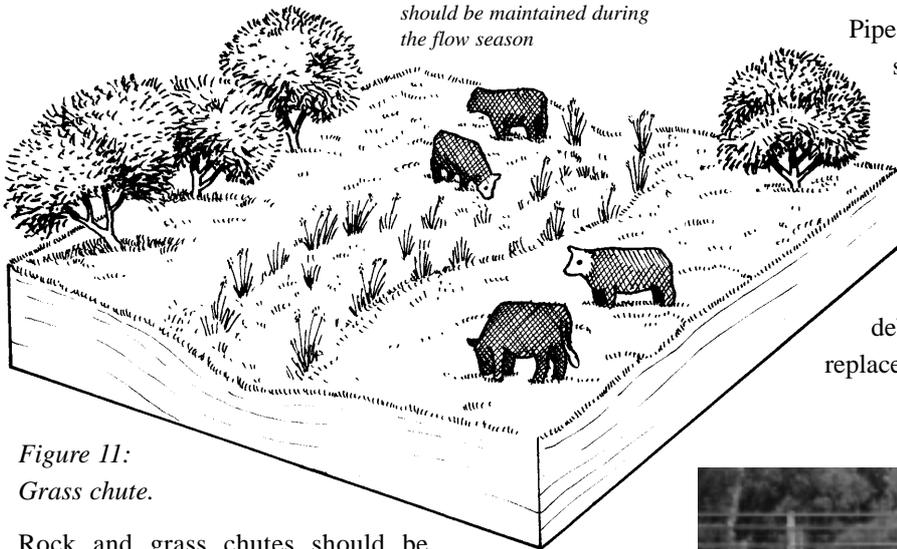


Figure 11: Grass chute.

Rock and grass chutes should be combined with revegetation to provide long term sediment stabilisation. The chutes may be fully submerged during medium to high flows that may have sufficient power to shift sediment.

2.3 Drop structures

Drop structures consist of a weir and stilling basin or apron as shown in Plate 6. Drop structures control the transfer of flow over a large change in height or fall of the streambed. The structures can be used to stabilise steep slopes or control a head-cut. The energy of the streamflow over the vertical drop in bed level is reduced

by the formation of a hydraulic jump. Flow energy is dissipated along a sloping rock apron or a stilling basin at the downstream end of the structure to prevent scour in the channel. Headwalls or wingwalls are constructed at the downstream end of the structure to prevent erosion around the outlet caused by back eddying. Reinforced concrete and steel piles are use in construction. Drop structures may be required for large flows, at significant drops or at an outlet of a spillway or pipe structure.

Drop structures should be built along a straight section of the channel and aligned perpendicular to the main flow. A stable base is required as bed movement or uneven settlement may cause undermining or cracking of the fixed structure. A series of smaller drop structures can be used rather than one large structure to gradually step the flow down the steep slope and reduce the potential for erosion.

Pipes can be used as part of the drop structure to transfer flows over a change in bed level. The technique requires limited earthworks and can be applied to high drops, but is only applicable for low flows. Maintenance works will be required to clear sediment and debris from the pipe entry and periodic replacement of the pipes will be required.



Plate 6: Drop structure.



Expert design and construction are required for drop structures and they are relatively high cost to construct and repair. Concrete drop structures are not very suitable to the stream environment, being unaesthetic and an obstruction to the passage of aquatic fauna. The feasibility of alternative techniques should be examined.

2.4 Outlet structures

Outlet structures are often used where channel instability could occur at a stream confluence with a tributary or drain. The condition of the receiving waterway and the approach angle, level and velocity of the entering flow will determine the potential for erosion and requirement for protection. Protective works or an outlet structure to modify the flow prior to entering the stream may be required to prevent erosion. The bed slope can be reduced or the cross-sectional area of the tributary increased to reduce the velocity of the entry

flow. The level of the flow should be the same or slightly less than the water level of the receiving stream. A stilling pond can be constructed at the outlet of a drain or tributary to reduce the flow velocity. Bank protection and bed armouring may be required at the confluence where the depth and width of the receiving stream is insufficient to absorb the energy of the entering flow. Energy dissipaters such as rock scour aprons and gabions or geotextiles and matting can be used to stabilise and protect the stream.

2.5 Instream retards

Silt traps can be built in the channel to control the bed level. Low wire, log or brushing fences can be installed across the channel to reduce flow velocity and cause sediment deposition. Fences will require maintenance due to damage caused by the flow or accumulation of debris.



3. Alignment stabilisation techniques

The construction of pool-riffle sequences may need to be combined with other stabilisation and channel realignment techniques. There are a number of engineering options available to stabilise banks that are too steep for revegetation. However, the alignment and slope of the channel should firstly be stabilised.

Channel realignment, or "river training", techniques involve installing structures to realign the river by selectively creating sediment depositional zones. Structures are installed that increase the resistance to flow, reducing the flow velocity and trapping sediment. The sediment is usually stabilised through vegetation establishment to provide long-term bank protection. Groynes, vane dykes and retards can be used to realign waterways. The structures can be applied to control channel width and form, protect eroding banks and control shifting meanders. Expert design and

construction is required as river-training structures can have a major impact on the river reach.

Earthworks can be carried out to change the alignment and form of a river channel. Techniques to improve stability include the selective removal or redistribution of sediment in a river channel or introducing meander patterns.

3.1 Rebuilding meanders

Channel stability on straight drains or streams can be restored by rebuilding the meanders as shown in Figure 12. The proportions of channel dimensions outlined in Section 1.1.2 can be used as a guide to excavation of a stable channel alignment. A survey will be required to assess the reach and determine a stable slope and channel geometry. The bankfull width will need to be determined. The channel alignment should be

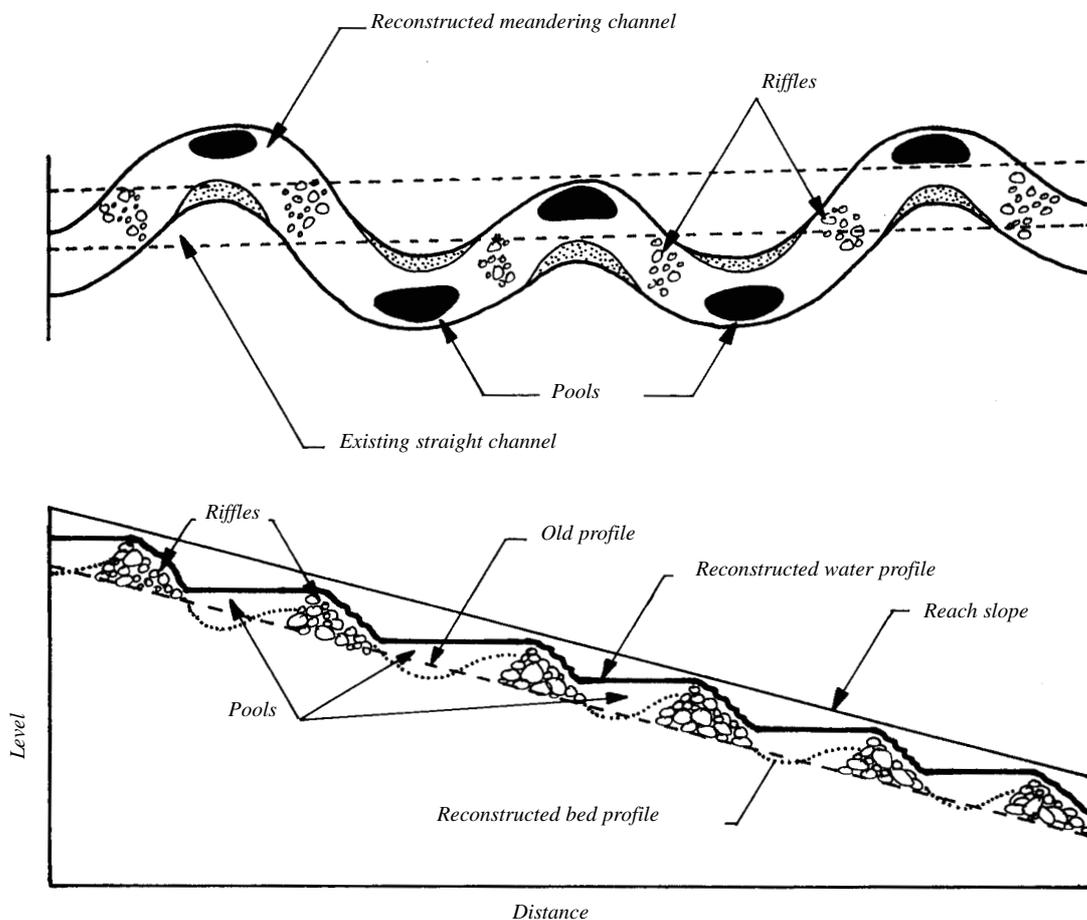


Figure 12: Rebuilding meanders.



determined on the basis of bankfull width and then pegged out at the site.

The channel will be exposed to erosion following the earthworks, especially in steep or rapidly flowing waterways. Additional stabilisation works will be required to control the bed and banks. The banks of the channel should be battered to a maximum slope of 1:4. Brushing or matting can be installed to stabilise the banks until vegetation establishes. Riffle structures could be installed at the site to stabilise the bed level and enhance the stream habitat. Riffles should be constructed at the crossover point in the middle of a meander. Recreating pools and riffles is outlined in Section 2.1.

Rebuilding channel meanders can be used to create a more aesthetic landscape, with higher environmental value. The technique may not be feasible where space for the stream and floodway are limited, particularly in urban areas.

3.2 Sediment management

Channel realignment works may include excavating sediment deposited on the inside of bends. Point bars can build up on the inner meander and restrict the channel width as shown in Figure 13. The flow is forced against the outer bank and can cause erosion. Vegetation that becomes established on point bars may need to be cleared so that the river can erode the bar. If the flow does not have enough power to move the sediment, then it may need to be excavated to convey the flow in a smooth alignment. The bankfull width should be determined and sediment removed to re-establish the required channel width.

Determining an appropriate flow capacity for the channel is essential in designing stabilisation works. Channel erosion resulting from increased flow conveyance may require the capacity (usually cross-sectional area) of the channel to be increased or techniques implemented to improve water retention in the upper catchment. Strategies to increase channel capacity can be used to reduce channel and floodway erosion, control meander alignment and manage sedimentation, waterlogging and flooding.

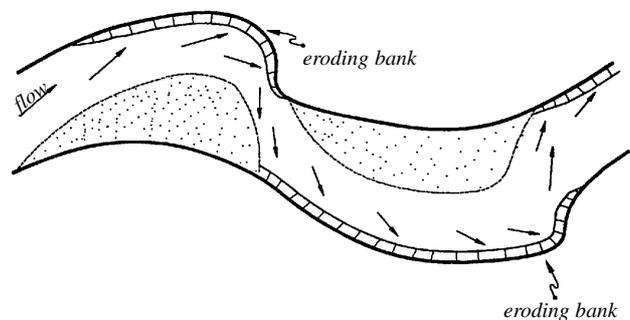
However these techniques can have major impacts on a waterway due to possible changes to the slope of the channel, increase in the power of flows and mobilisation of sediment. The increased amount of flow being

conveyed by the channel may cause further erosion of the banks or bed. Increasing the capacity of the channel can also increase the risk of flooding or sedimentation downstream.

The preferred management strategy is to relocate sediment within the channel. The point bar sediment can be pushed against the outer bank to provide additional protection and create areas for planting. The sediment will need to be stabilised using a geotextile.

Earthworks may be required where the channel capacity needs to be increased to accommodate increased flows. Techniques employed in drain management to increase channel capacity include excavating to deepen and/or widen the channel, raising embankments to reduce overtopping of the channel and straightening the channel alignment to increase flow velocity. Section 1.1.1 and Figure 1 show the process of channel straightening. An alternative technique to cutting a new channel is to create a floodway channel to relieve pressure on the main channel only during high flows. The entry level of

ROUGH & UNEVEN ALIGNMENT



SMOOTH & EVEN ALIGNMENT

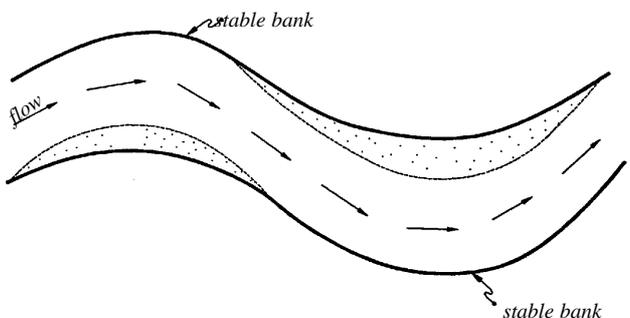


Figure 13: Channel point bars causing erosion.
Copied from *Riverwise, Guidelines for Stream Management*,
Department of Water Resources, NSW (1993).



the floodway channel will be higher than the level of the main channel bed. The floodway channel will need to be stabilised and entry and exit points will need to be protected, for example by rock paving (riprapping) the banks. The floodway should be maintained with almost complete groundcover to prevent erosion.

3.3 Installing large woody debris

Channel realignment may require the installation or repositioning of instream logs and debris. Large woody debris can be installed or reorientated to improve channel alignment and protect the riverbanks. Large woody debris is important to the stability and ecology of waterways. Woody debris should not be removed from waterways unless it represents a significant risk to flooding or is contributing to erosion. The preferred management approach is to modify or relocate and reorientate, rather than remove large woody debris from river channels. This approach is also often cheaper than full-scale removal of woody debris.

Trees falling across the channel can cause debris and leaf litter to accumulate and can dam the waterway. This can exacerbate flooding or cause channel avulsions. Woody debris angled across the flow path can direct flow towards the banks and cause erosion. Obstructions also act to restrict the channel, causing accelerated flow that can have sufficient power to erode the bank. Selective removal or relocation of logs and other woody debris obstructing the channel may be required to increase flow capacity. Heavy material may need to be removed by winch or excavator. Rather than removing material from the channel, the debris can be relocated against the bank to provide habitat and erosion protection.

Large woody debris can be installed to stabilise channel alignment by directing flows away from the toe of the riverbank. Stream flow should be smoothly directed around the meander and to the centre of the channel. The logs should typically be installed against the outer bank, pointing downstream at an angle of approximately 30°, as shown in Figure 14. The butt of the log should be buried approximately one metre into the bank and the logs pegged or anchored into position. The end of the log can be sharpened to reduce disturbance to the bank when being installed.

When installing or reorientating woody debris, it should not block more than 10% of the cross-sectional area of the channel in order to minimise the impact on water levels. Alternatively, more than 10% of the cross-sectional area can be blocked to increase wetland habitat

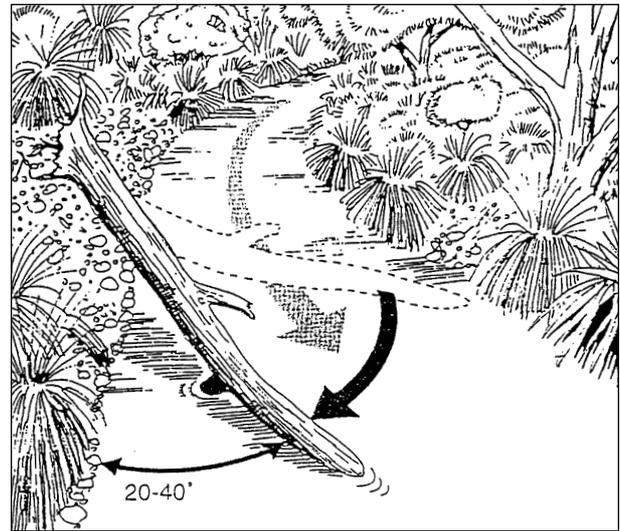


Figure 14: Large woody debris bank protection.

across the floodplain, where this is a desirable outcome. Woody debris spaced further apart will affect water levels more than pieces that are closely aligned (about 2 to 4 m apart). Branches that protrude above the water level and trap large amounts of debris moving downstream, should be trimmed. However, remember that protruding timber can help to oxygenate the water column. Also, timber projecting into the flow will increase habitat for microbial life and invertebrate fauna.

Nearby undisturbed river reaches of similar size can be used as a reference to determine the amount and type of large woody debris that should naturally be present in the waterway. The original quantity of woody debris does not need to be reinstated to restore habitat. Using the results of channel surveys, woody debris can be strategically placed to create pools and enhance stream habitat.

Wood from tree species that are native to the area should be used. Logs of different sizes and shape and with rough surfaces and hollows should be used in order to increase habitat diversity. Wood that has been treated with chemicals that may be harmful to the environment should not be installed, for example, timber treated for white ants.

3.4 Flow Retards and Groynes

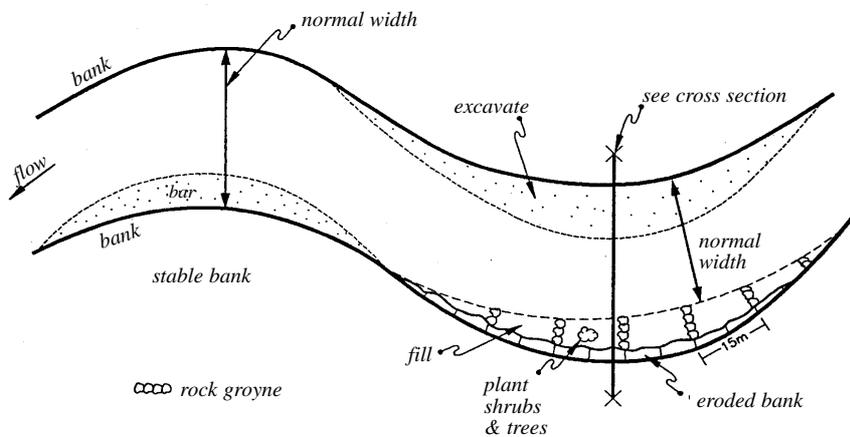
Flow retards and groynes can be installed in waterways to stabilise channel alignment and meanders, protect the toe of an eroding bank and control channel width and form. Retards and groynes are flow obstructions protruding from the bank, angled downstream into the channel of the waterway. Groynes are usually timber fences or concrete blocks or rock structures. Retards are generally lower and longer than groyne structures, however they work in a similar way. Retards only extend up to one metre above bed level, whereas groynes are usually as high as the top of the bank.

A series of groynes or retards are constructed along an eroding bank to direct flow away from the bank and to the centre of the channel (Figure 15). The alignment of the waterway can be controlled by the placement of the structures to reduce flow velocity near the bank. Sediment is deposited at the base of the eroding bank and can be revegetated.

A variety of materials including timber, rock, brushing or wire mesh fencing can be used to construct retards. The structures are secured to piles driven into the riverbed and anchored to the bank to prevent erosion of the abutments. Scour at the downstream end of the structure may occur due to back eddying. A rock apron or 'tail' structure at the end of the retard or groyne can limit this effect. The tail is built by extending the end of the groyne at an angle parallel to the direction of flow. Generally groynes and retards allow through-flow to reduce the pressure on the structure. Impermeable structures are more prone to scour and undermining. Maintenance will be required to clear debris accumulation that may cause unwanted effects.

It is important to maintain the bankfull channel width. Groynes and retards can be installed if the channel is over-widened, but should not extend more than to the stable channel width. The point bar may need to be removed to create a stable width and alignment. In some carefully planned circumstances, groynes and retards

PLAN VIEW



CROSS SECTION VIEW

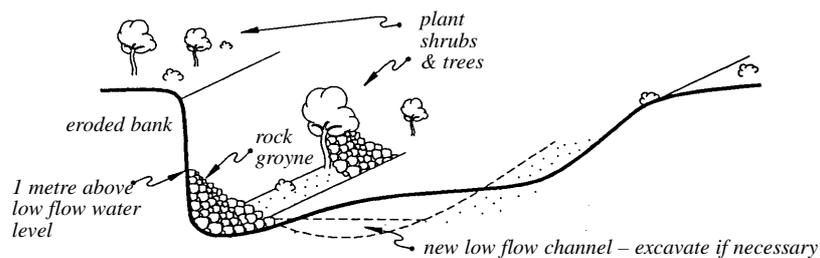


Figure 15: Series of rock groynes reinforcing channel alignment.

Copied from *Riverwise, Guidelines for Stream Management*, Department of Water Resources, NSW (1993).



can be projected into the bankfull channel to deflect the main flow into the point bar and thus excavate a portion of the bar.

Groynes and retards will not work in systems with a very limited sediment source. Sediment deposition is required and the site made suitable for vegetation establishment to successfully restore and protect the bank in the long term. The technique can be used in deep channels, however the structures may fail in fast flowing waterways. Groynes and retards also enhance habitat diversity by introducing a range of flow conditions in the waterway.

3.5 Vane Dykes

Vane dykes are used on meandering waterways to reduce bank erosion on outer bends and control channel alignment. A series of short vane structures are positioned mid-stream along an eroding bank to encourage sediment deposition (Figure 16). The shape and alignment of the vanes interrupt secondary currents that can cause bank erosion. An advantage of the technique is that the bank and bed of the river remain relatively undisturbed during installation as the structures do not require anchoring. Vanes can be used in deep water. The technique will not be as effective in straight or irregularly aligned rivers.

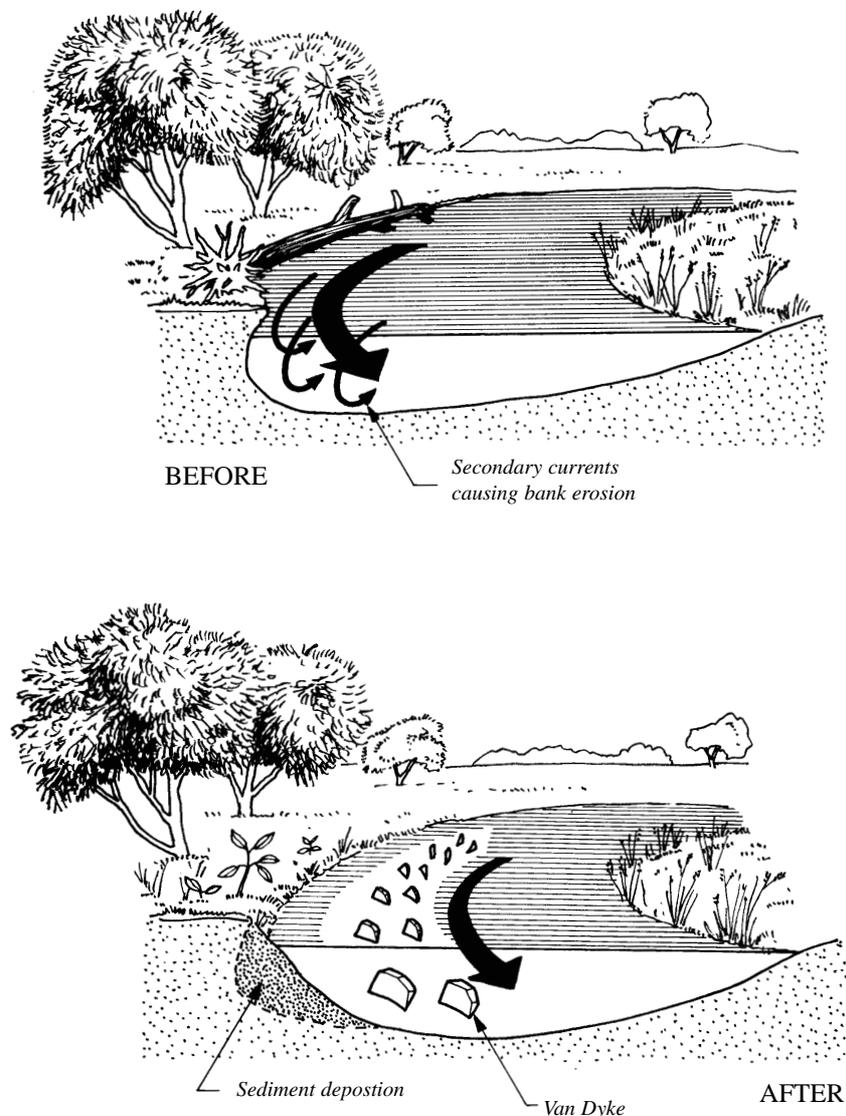


Figure 16: Vane dykes applied to reduce bank erosion.



4. Bank protection techniques

There are a number of engineering options available to secure and protect banks that are too unstable to support vegetation. The process of bank failure should be examined to determine the appropriate treatment technique. Erosion often occurs on the outer banks of a bend in the channel. Bank erosion is also caused by instream vegetation and sediment deposits concentrating flows towards the banks. Techniques to direct flows around meanders and stabilise alignment are outline in Section 3.

Bank erosion caused by undercutting will require some form of toe protection. Logs, rock riprap (Section 4.4.3)

or gabions (Section 4.4.2) may be used to stabilise the toe of the bank. Earthworks, matting or brushing can be used to stabilise the surface of steep banks. Surface or subsurface drainage may be required to reduce bank slumping caused by high soil moisture content. Additional weight on the top of the bank such as very large trees, buildings or roads may need to be removed to reduce the risk of bank failure. Engineering techniques should be combined with revegetation, which is required to bind the bank material and provide long-term bank support.

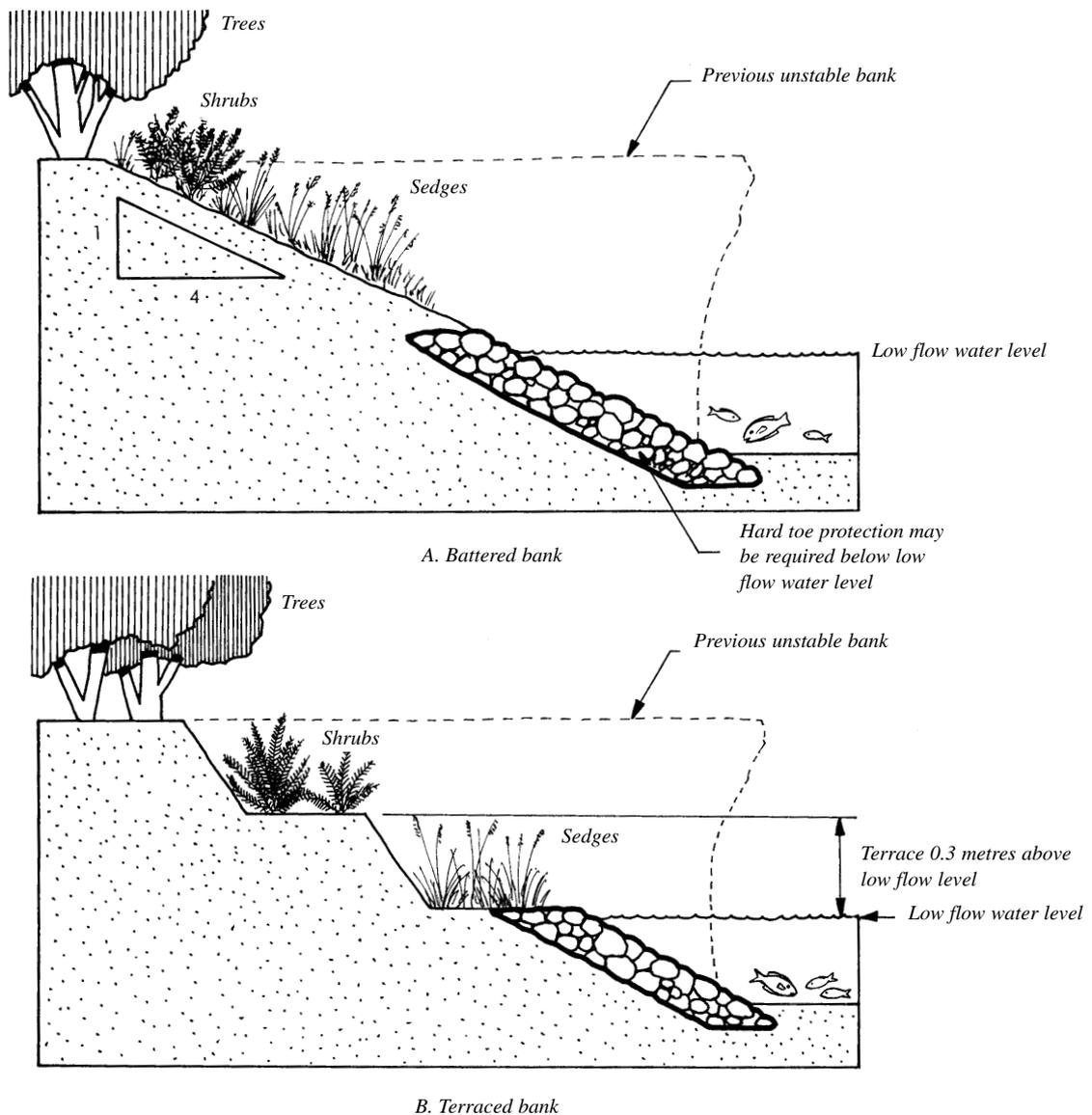


Figure 17: Reshaping banks to a stable slope.



4.1 Battering and terracing

Earthworks may be required to reduce steep banks to a stable slope and provide areas for vegetation to establish. This can be achieved by battering or terracing the banks. Earthmoving equipment can be used to reshape the bank to an even slope as shown in Figure 17.a. Banks will need to have a maximum slope of approximately 1:4 (vertical:horizontal) for vegetation to be able to take hold. Terracing involves levelling steps up the bank to create benches for planting, as shown in Figure 17.b. Terraces should be created at a maximum of 300 mm above the low flow level so that plantings have access to soil water moisture.

Using earthworks to stabilise stream banks will involve the loss of vegetation already established on the bank and can result in widening the eroding channel. Additional material brought to the site or obtained from within the channel can be used to reshape the banks. Sediment deposited on point bars can be excavated and placed against eroding banks to create a stable slope.

The stream bank will be exposed to erosion until vegetation is established to protect the bank. The technique is more applicable to seasonal waterways where there is opportunity to undertake the earthworks and stabilise the area prior to seasonal flows. Continuous flow can cause ongoing erosion. Brushing or matting can be used to stabilise the banks until vegetation establishes.

Battering or terracing the banks can be used to prevent bank failure caused by material being washed from the face of the bank or due to overland flow. The technique may not be successful in controlling undercutting or erosion occurring below water level. Additional protection may be required at the base of the bank using hard engineering techniques (Section 4.4).

4.2 Brushing

Brushing consists of cut trees or branches that can be used to provide superficial bank protection. The technique is most applicable to controlling bank erosion caused by the washing action against the face of the bank.

The brush is layered horizontally against the bank, with the butt of the branch facing upstream. Alternatively the branches can be placed with the butts at the top of the bank and the heads facing down the bank, angled downstream. The brushing should be secured into place. It can be tied to anchors on the top of the bank, such as buried logs or posts, and weighted down or pegged into position. Wiring or steel cables can be used to secure the brushing as shown in Figure 18. Smaller pieces of brushing can be used to provide bank protection by bundling the material to form mattresses against the bank. The bank may need to be battered prior to placing the material.

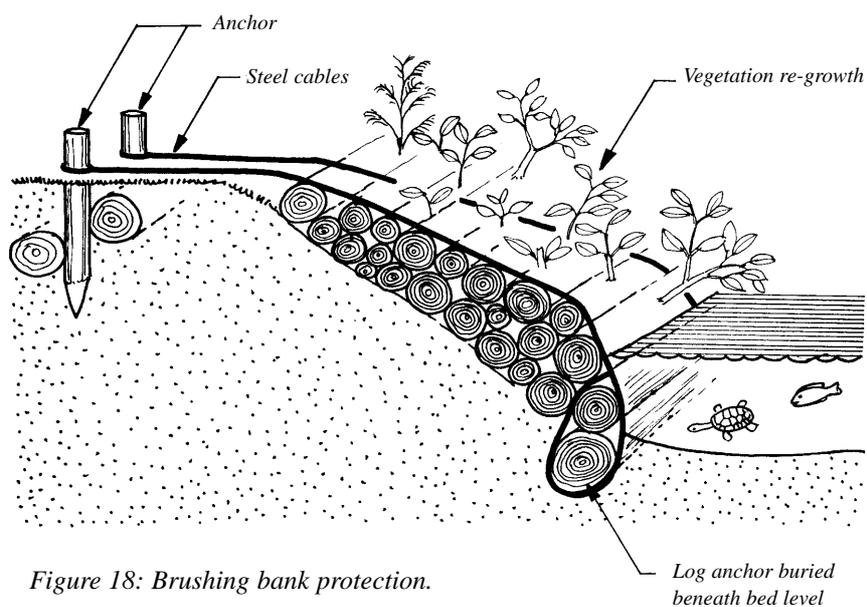


Figure 18: Brushing bank protection.





Plate 7: Brushwood on the South Dandalup River, Pinjarra (WA).

Plate 7 shows brushwood that has been used along a section of the South Dandalup River to prevent bank erosion. Woody debris has also been installed along the bank. The brushwood has been threaded through ring-

lock fencing wire and pegged to the bank by securing to posts driven into the riverbed.

Branches of local native plants (mostly *Melaleuca* species) bearing seed should be used for brushing. The seed is released to the soil and the brushing provides protection during germination and early growth of seedlings. Obtaining suitable material may be difficult and riparian vegetation should not be permanently damaged or killed by harvesting branches and foliage. Brushing only provides temporary bank protection. The stabilisation technique relies on bank revegetation to stabilise the sediment once the brushing has rotted away. The technique is not as stable as harder methods and may not be effective where deep and powerful flows are experienced. Brushing is a low cost bank stabilisation technique that provides a variety of additional environmental benefits, such as encouraging regeneration and creating instream habitat and food sources.

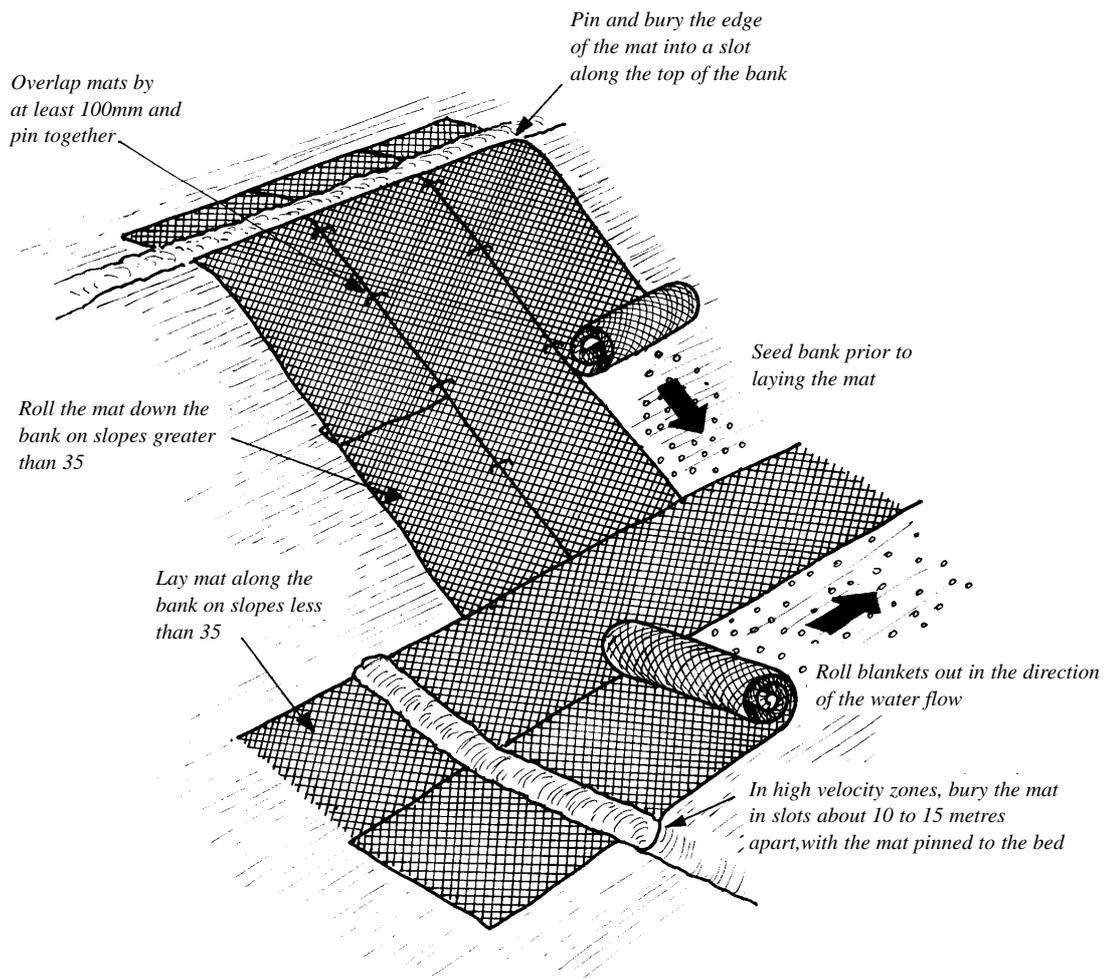


Figure 19: Installation of matting to prevent soil loss.



4.3 Organic geotextiles

Organic geotextiles are vegetative mats which can be used to stabilise banks and prevent soil loss caused by overland flow and a lack of vegetative cover. Mats or blankets are manufactured from natural fibres such as wheat straw, jute (hessian) or coconut fibre. Reinforced mats with a natural fibre or plastic woven mesh can be used to provide longer term protection. Mats and blanket rolls come in a variety of sizes and thicknesses. Rolls are available up to 3.66 metres wide by 30 metres long. The densities of the mats vary to allow or block light diffusion. This enables germination and suppresses weed growth. Mats with slits cut for plantings can also be used to control weeds and enable native vegetation growth. Vegetative mats are biodegradable and add organic matter to the soil as they break down. The mats reduce changes in soil temperature, decrease evaporation and improve infiltration and soil water moisture content, resulting in improved plant survival rates.

Earthworks may be required to prepare the site. The stream bank may need to be battered to an even slope prior to laying the mat. The surface should be even and free from large rocks or stumps. Topsoil and fertiliser may need to be placed to prepare the bank for seeding. The bank can be hydro-mulched or seeded prior to laying the mat. Hydro-mulching involves spraying the bank surface with a mixture of seed, fertiliser and mulch to bind the soil particles together.

Mats should be laid to cover the zone of instability and should extend from below low water level to the top of the bank or above high water mark. The mats should be rolled out onto the bank, down the slope if greater than 35 degrees or perpendicular across the slope if the slope is less than 35 degrees (Figure 19). A trench should be dug along the top and bottom of the bank and the edge of the mat buried. Where numerous mats are used along a bank, the edge of the lower mat should be tucked under the edge of the mat above, and the end of the upstream mat should cover the end of the downstream mat. Mats should overlap by at least 100 mm and be pinned together. The mat will need to be secured into position by burying the side edges and inserting steel "U" shaped pins about every 200-250 mm along the edges of the

mat, with 2-4 pins placed centrally per square metre. Steel pins are available from 150 to 600 mm in length. The pin length required to secure the mat will depend on the bank soil structure and site conditions. Mats should be wetted so as to conform to the contour of the bank.

Mats protect seed and soil from erosion. The mats have a limited life (about six months to two years) and require the establishment of vegetation to stabilise the bank in the long term. Access by livestock will have to be controlled during this period.

The cost of the technique will depend on the location and condition of the site, the type of mat required and the area of application. Typical costs for the mats range from \$2.60 to \$8 per square metre, including pins (2001 prices). Site preparation, delivery and installation costs will be additional, but can be minimised through volunteer contribution to labour.

4.4 Hard Engineering Options

Hard engineering techniques are required for cases where steep banks can not be stabilised by softer techniques. Hard engineering works involve using concrete, rock or other hard material to form walling or reinforcement. These techniques are usually more expensive and require expert design and construction, but provide long term protection. Hard engineering techniques are often used where protection of assets such as buildings, roads or bridges is required or where powerful (super critical) flows are necessary to achieve the required conveyance of flows. There may be constraints such as limited space to undertake restoration works or additional pressures such as in urban areas. Availability of materials, cost and access to the site for heavy machinery will need to be considered in planning implementation of these techniques.

Hard engineering works are often unaesthetic and provide limited environmental benefits. Protective measures involving these techniques can isolate the river environment from the surrounding landscape. The embankment habitat can be destroyed and access to the river obstructed. Engineering techniques that integrate structural stabilisation with revegetation provide longer-term protection, beyond the life of the materials.



4.4.1 Log Walling

A log wall can be constructed along the base of an eroding bank to hold the bank material in place. Piles are driven into the streambed with more than half their length buried beneath bed level. Logs are placed horizontally on top of each other behind the support piles and bolted or wired to the posts. Filter cloth is placed behind the logs and the wall backfilled with soil. Local native sedges and rushes, shrubs and trees are planted behind the wall. The technique can be applied to provide toe protection from undercutting or treat bank slumping. Log walls can not be built on hard riverbeds.

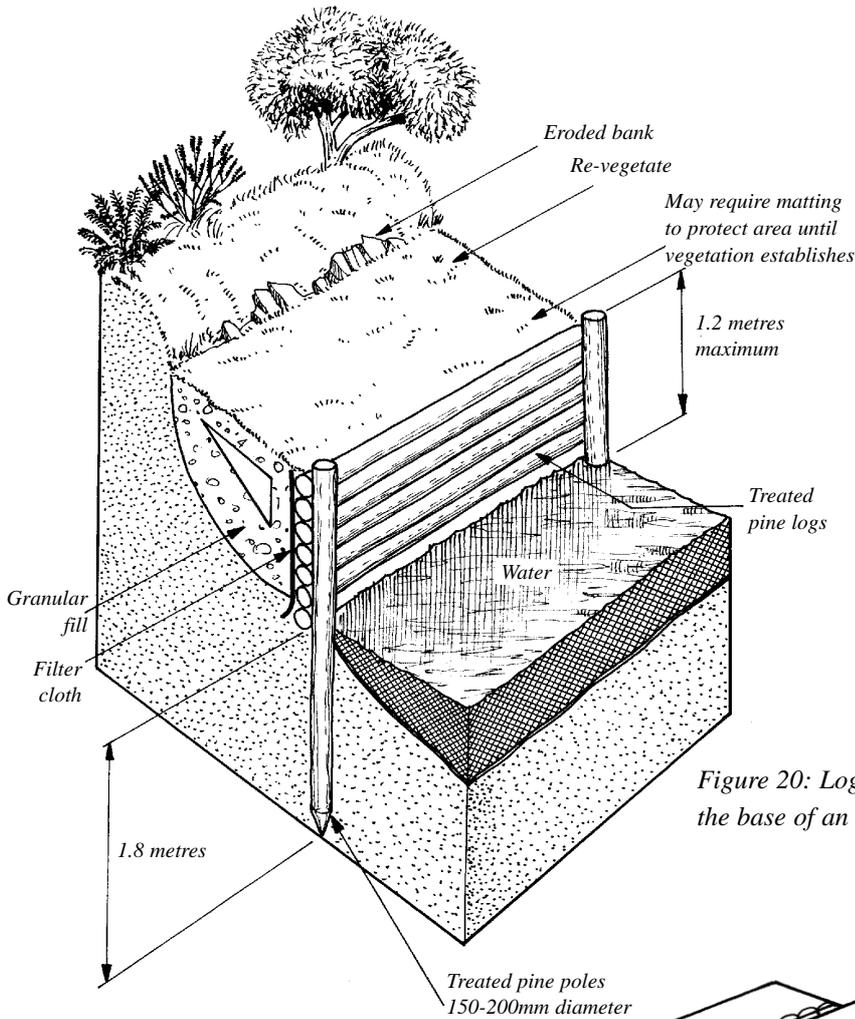


Figure 20: Log walling built to stabilise the base of an eroding bank.

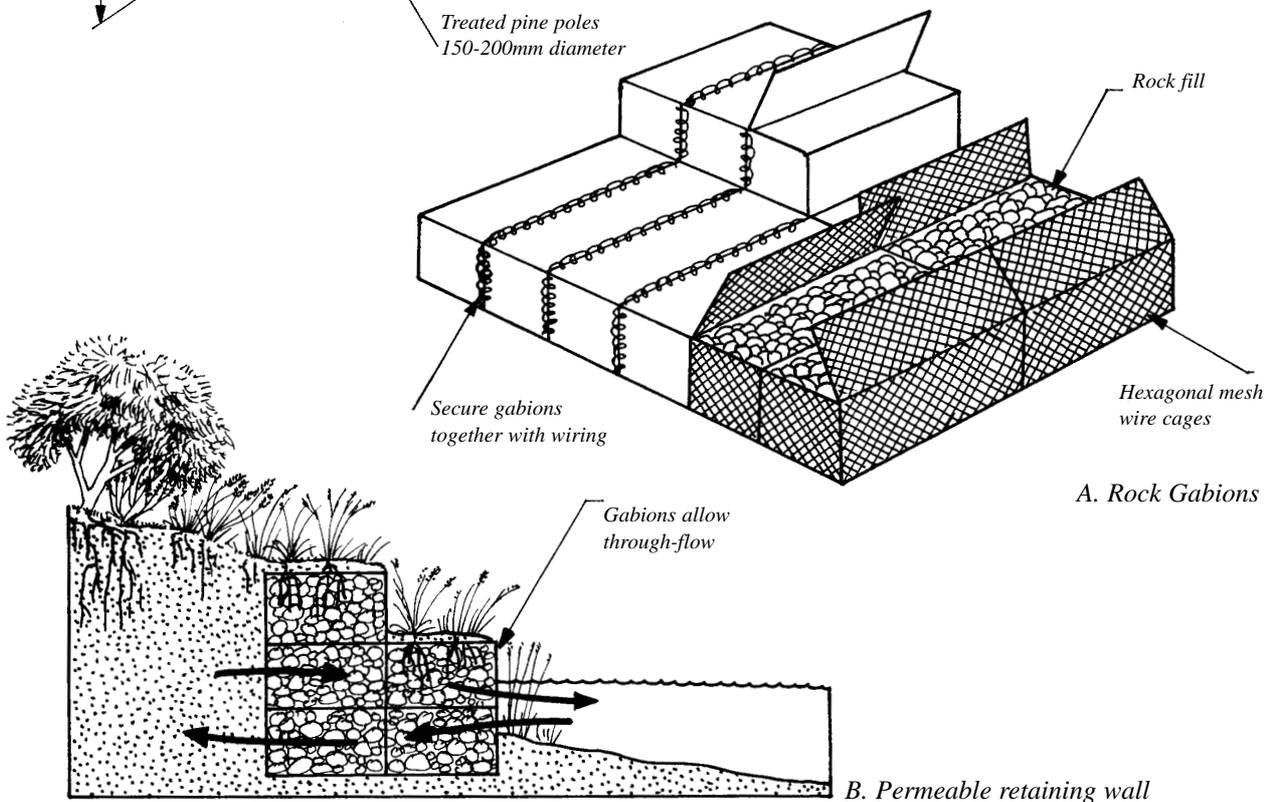


Figure 21: Stabilisation of steep banks using rock gabions.



4.4.2 Rock Gabions

Rock gabions are large, rectangular, hexagonal mesh wire cages filled with stone (Figure 21.a). They can be used to build a retaining wall along the base of an eroding bank and can be used for river training. The wall holds the bank material in place and prevents slumping. Empty gabion cages are placed in position at the toe of the bank, filled with stone and wired closed. Filter cloth is placed behind the wall and the bank backfilled with sediment. The bank should be revegetated. Overtime the voids in the gabion trap sediment on which vegetation is able to establish.

Minor earthworks may be required to prepare the site. The surface should be level and free from large rocks or stumps prior to installing the gabions. Gabions are flexible and can tolerate movement and settlement in the bed material. Fixed structures, for example, concrete walls are more prone to fracture and failure in a riverine environment due to the movement of sediment caused by water flow or wave action. Gabions are also permeable, allowing bank slopes to drain (Figure 21.b). The technique does not require expert construction and requires little maintenance.

Gabions are available in a range of sizes, usually from 1 to 4 metres long, by 0.5 to 1 metre wide and high. The cages can be further reinforced by installing additional mesh panels to divide the boxes into smaller units. The cages are anchored into position and stretched while filling. Empty cages can be wired together to construct a range of structures. The wire is heavily zinc coated to reduce corrosion. PVC coated wire gabions are also available to provide further protection from corrosion in marine or polluted environments.

Hard, durable quarry rock is used to fill the gabions, which is usually carried out by an earthmoving machine. The rock should be tightly packed and the cages slightly overfilled to allow for settlement. Wire bracing is used in the cages to prevent bulging. The rock should be sized slightly larger than the size of the mesh voids (rock sizes 125 mm to 250 mm with less than 7% of smaller material). Gabions can be installed on hard riverbeds, as driving of supporting piles is not required.

4.4.3 Rock Riprap

Rock riprap consists of a layer of rock which is placed on a stream bank to protect it from erosion (Figure 22). The stream bank is rock paved usually to above high water mark. Reinforcement with riprap of only the toe may be required in some cases to support the bank. The bank may require battering prior to placement of materials. Filter cloth can be placed on the bank beneath the rock to provide protection from undermining caused by flows getting above and behind the riprap, washing out sediment and destabilising the works. A trench should be excavated at the toe of the bank and the riprap layed to beneath bed level. Alternatively, on hard riverbeds, a rock ledge can be built along the toe of the bank.

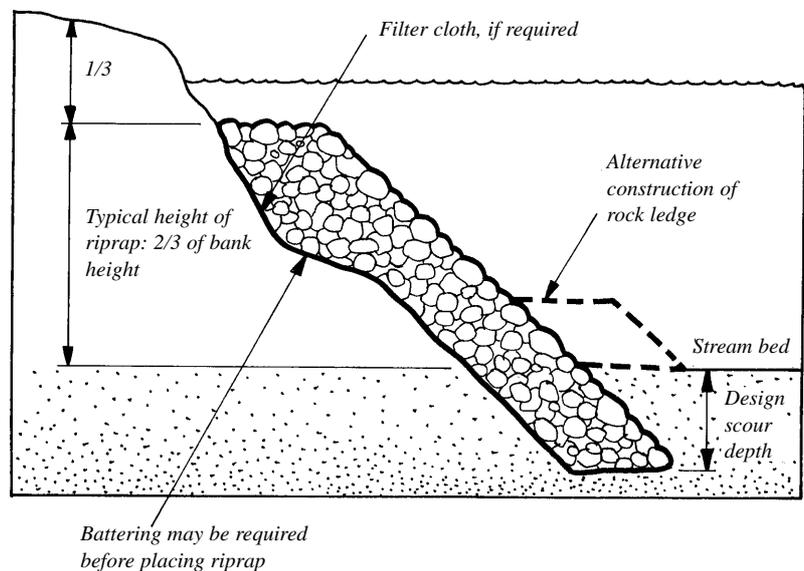


Figure 22: Riprap bank protection.

The technique is applicable to most types of bank erosion and provides long term protection. Sediment accumulation along the riprap can lead to eventual establishment of vegetation. Riprap should not be constructed along banks that are being undermined by bed deepening. The bed level will need to be stabilised prior to undertaking bank stabilisation works.

Riprap should be constructed of well-graded rock. The tractive forces of high flows will need to be considered in selecting the appropriate size range of materials. The size of the riprap required is determined by the slope of the bank, flow depth, rock density and shape, bed slope and width and radius of curvature of the channel at the

site. Detailed design guidelines and programs exist to calculate a design for riprap construction. The area to be protected should extend upstream and downstream of the unstable zone for at least a length approximately equal to the channel width. The thickness of the layer of riprap should be a minimum of double the median diameter rock size or at least the maximum rock diameter.

4.4.4 Geotextiles, mattresses and flexmats

There is a wide range of geotextiles, mattresses and flexmats on the market with applications including slope and bank stabilisation and channel lining. **Geotextiles** are synthetic woven blankets that can be applied to hold sediment in place while allowing water drainage. The fabric acts to support the soil structure and improves the ability of the bed or banks to support and secure a load such as rock or soil placed on top of the material. In highly erosive or dispersive soils, a geotextile is often required beneath structures such as gabions and rock riprap for support and protection against undermining.

Earthworks may be required to prepare an even surface, free from large rocks or stumps. The filter cloth should be rolled on to cover the zone of instability and should extend from below low water level to the top of the bank or above high water mark. Soil, rock or structural works are placed over the cloth. The fabric contours to the bank and is flexible to accommodate further movement. The synthetic fabric has a long life and does not break down under a variety of conditions. Synthetic blankets are available in 100 metre rolls and are about 0.3 to 0.6 mm thick and 1.83 to 5 metres wide.

Synthetic grids can be used to improve the strength of the soil structure. Grids can be installed in horizontal layers through the soil to reinforce the bank against failure along vertical slip planes (Figure 23.a). Synthetic grids can also be used to line channels and prevent erosion in vegetated channels. Grids can be used in combination with revegetation rather than rock paving or concreting the channel. The grid holds the channel material in place while vegetation takes hold. The root systems lock into the grid, improving the channel resistance to high flows. Reinforced vegetated channels can withstand up to double the flow rates of vegetated channels that are not reinforced.

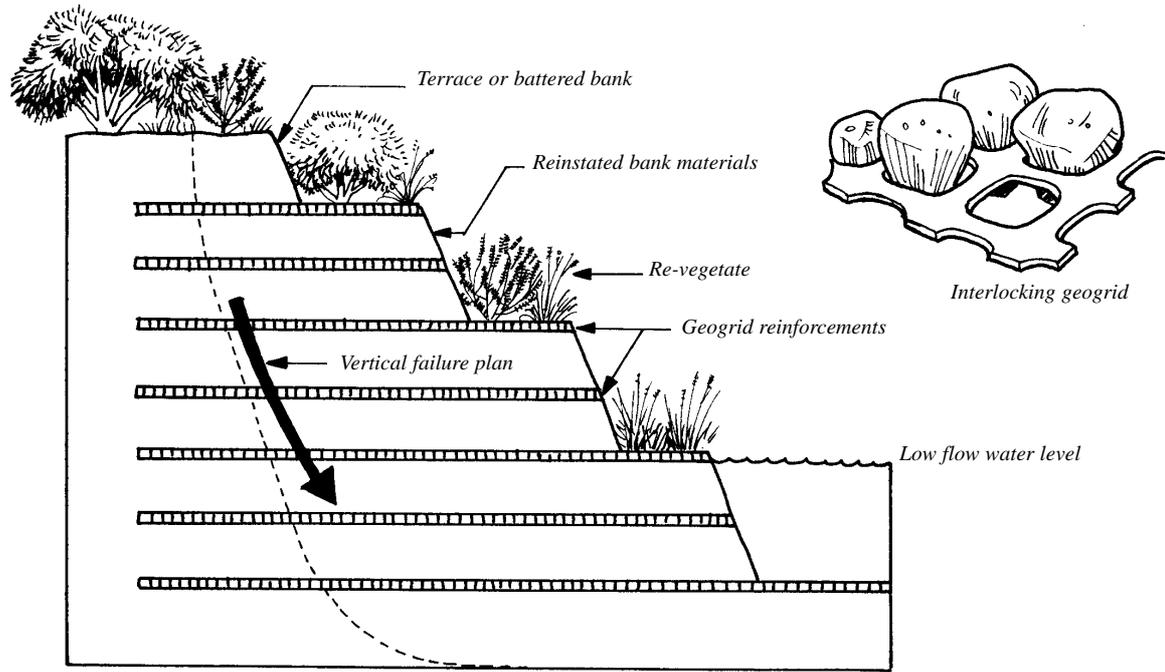
Synthetic or wire mesh can be secured to the bank using "U" shaped pins. The mesh is permeable and allows plantings to provide a more aesthetic finish. The bank can be treated with hydroseeding (spraying a mixture including seeds, fertilisers and binding agents onto the bank). Fine mesh can be used to retain sandy banks and wider mesh sizes for stony or rocky banks.

Concrete flexmats can be used to stabilise steep banks and provide harder bank protection (Figure 23.b). Empty mats that contour to the bank are laid and pumped full of concrete. Concrete bank protection does not allow through-flow of groundwater or the easy establishment of vegetation. The concrete mats may be prone to undermining and failure due to water and sediment movement.

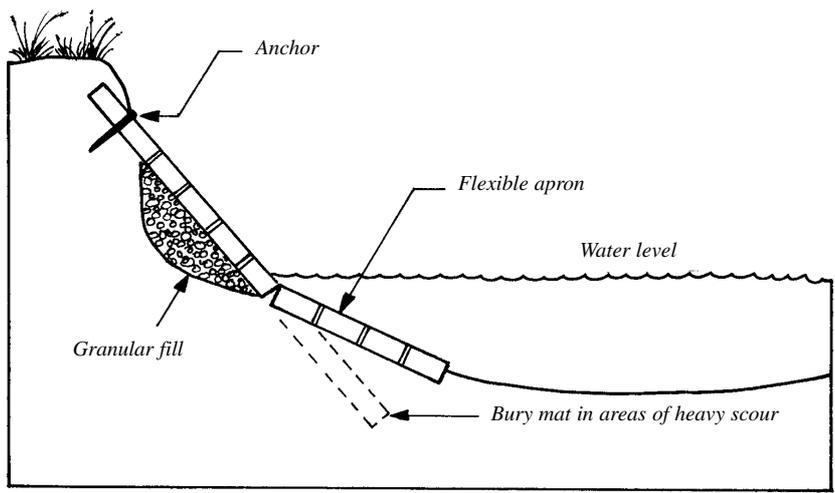
Bank stabilisation can be achieved by placing **rock mattresses** along the bank slopes (Figure 23.c). The empty wire mesh mattresses are laid into position, wired together and filled with rock. Mattresses filled with small stone are more environmentally beneficial than flexmats. The rock mattresses create a rough surface with voids and has similar properties to natural channel conditions, allowing free drainage and greater opportunity for biological activity. Over a period of time, the stabilised banks will become covered with silt and sand and will be able to support vegetation. Alternatively, topsoil may be brought to the site and laid on top of the works, followed by revegetation. The vegetation binds the structural works to the adjacent embankment.

The wire cages that form the mattresses are similar in structure and installation procedure to the gabions, but are thinner and larger in area. They are usually a maximum of 6 metres by 2 metres in area and 0.17 to 0.5 metres thick. Rock sizes should be slightly larger than the mesh void size, but should not exceed two-thirds the mattress thickness. The cages should be slightly over-filled to allow for settling. The bottom compartments should be filled first. The rock material may require compaction to a minimum density specification, depending on the site conditions. A continuous mesh panel can be rolled onto the mattresses and wired to seal the structure. The bank may require battering, to an even slope prior to placing the mattresses. Mattresses may need to be temporarily pegged into position during installation on steep banks (slopes greater than 1:1.5). Suitable local sources of fill material should be investigated when assessing the feasibility of the technique.

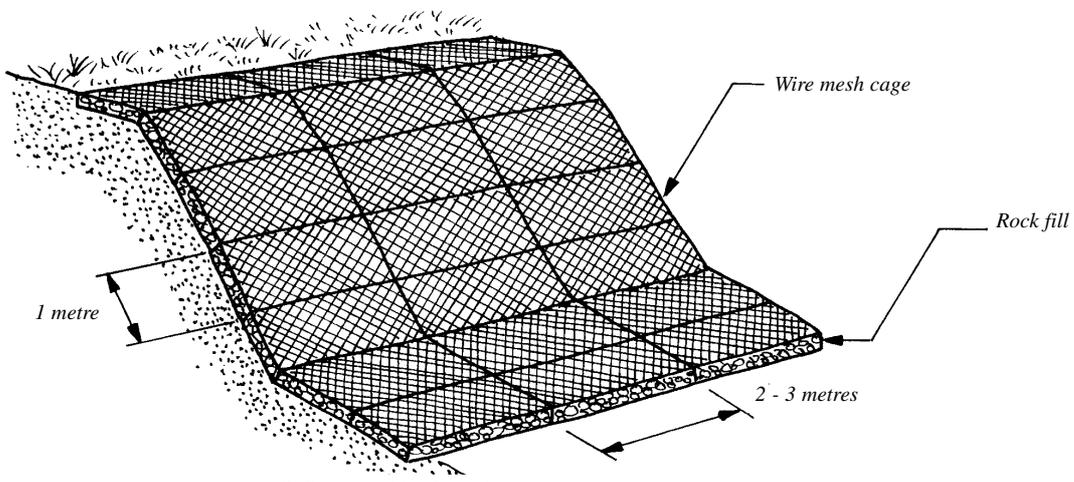




A. Bank reinforced with synthetic geogrids



B. Concrete flexmat used for bank stabilisation



C. Bank stabilisation using rock mattresses

Figure 23: Bank stabilisers.



5. Long term site management

Catchment wide solutions to channel instability and waterway degradation can be achieved through the development and implementation of whole of catchment management strategies. These strategies need to be developed to encompass local government planning processes that impact on land use, flood mitigation and drainage. Catchment management may include the use of retention basins to store floodwaters and control flows downstream. Community education and promotion of sustainable land use is also required to support restoration and ensure the long-term protection of waterways.

Channel modification works such as constructing pool-riffle sequences are used to help manage and control the effects of vegetation clearing until longer-term reforms in the catchment take effect. The establishment of sites demonstrating erosion control techniques will be beneficial to raise community awareness and promote the adoption of stream management and restoration techniques.

Restoration sites should be monitored as the river adjusts to the new profile and channel geometry created by the works. Monitoring the site is important so that the design can be reviewed and to plan further development of the site. The channel may continue to erode due to the instability that continues to exist upstream. Funds

should be set aside to reform and enhance the works if significant damage occurs, particularly during the first major flows. As soft engineering works do not involve fixed structures, some settling and movement should be anticipated. For example, riffles may need to be reshaped or additional rock placed as required to repair rock movement and protect the banks.

Continued maintenance of the site will include selective clearing of channel obstructions prior to winter each year. Some vegetation and logs in the channel may need to be relocated to maintain hydraulic conductivity and minimise local erosion. It is important that the channel width and alignment are maintained for at least the first few years while the channel becomes stabilised.

Livestock exclusion and vegetation enhancement will improve the habitat value of the site and provide long-term channel stability. Instream revegetation works are not recommended where the channel has not achieved a stable channel alignment and adequate width to convey the catchment run-off. While the channel is still unstable, revegetation needs to be concentrated on strengthening and stabilising the upper bank slopes and the verge. Channel stabilisation will gradually be achieved through vegetation binding the banks and control of the bed level by the engineering works.



6. Summary

Revegetation and managing livestock access are essential to river rehabilitation. However, a stable channel alignment needs to be determined and created to determine fence placement and where to plant. This may involve adjusting meander curvature by installing groynes, retards or vane dykes or by realigning woody

debris and removing sediment bars. The stream bed may need to be stabilised by using a series of riffles or chutes to control the reach slope. There are a number of bank protection techniques, including brushing, riprap and matting that can be used to stabilise and protect rivers.



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