RiverLandscapes

Riparian Land Management Technical Guidelines

Volume Two:

On-ground Management Tools and Techniques

Land & Water Resources
Research & Development Corporation

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Together...
we can restore, protect and enhance our river landscapes for present and future generations.

Riparian Land Management Technical Guidelines. Volume Two:
On-ground Management Tools and Techniques.
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PREFACE

In 1993, shortly after its establishment, the Land and Water Resources Research and Development Corporation commissioned a brief review of riparian management issues in Australia. It quickly became apparent that there was a growing recognition of, and participation in, active riparian management by landholders, community groups and government agencies. However, it was also apparent that there was little quantitative data that could be used to develop management methods likely to deliver the desired results. As a result, the Corporation, in collaboration with the Cooperative Research Centre for Catchment Hydrology and the Centre for Catchment and Instream Research at Griffith University, established a national research and development program into the rehabilitation and management of riparian lands. The program operates Australia-wide, with several experimental and demonstration sites established in collaboration with State agencies, local government and catchment management groups, rural industry bodies and individual landholders. The aims of the program are to achieve a much improved understanding both of the processes operating in riparian lands, and of the interactions between riparian land, vegetation and aquatic ecosystems.

In early 1997, the Corporation and its partners released a series of issues papers on riparian management. These were designed for a non-technical audience, to promote awareness of riparian functions. They discussed a range of riparian management issues and techniques for stabilising banks, trapping sediment, improving the ecological condition of streams, and managing stock access. There was a huge response to the issues papers—further evidence of the widespread demand for better information on riparian management. The papers are available on the Internet at <www.rivers.gov.au>.

These guidelines are a follow-up to the issues papers. They provide additional information of a technical nature and have been designed to provide professional land managers, advisers, State and Territory agency staff and local government staff, with the information they need to assist non-technical people operating at the farm or catchment level to design and implement best-practice riparian management. The guidelines augment and complement other sources of information on riparian management. They provide sufficient technical information so that readers can understand important principles underlying riparian issues and adapt them, as required, to their particular objectives, climate, farming enterprise or other circumstance.

The focus of the document is on agricultural catchments where riparian land has been degraded in the past and where rehabilitation is required. While the guidelines do not refer specifically to forest management (where there are specific codes of practice relating to riparian land) the principles are the same and the guidelines are likely to be of use to foresters. Similarly, particular issues of urban settings are not addressed, but many of the same principles apply.

Because one of the major purposes of riparian management is to maintain healthy in-stream ecosystems, some of the material contained in these guidelines addresses the functioning of aquatic ecosystems.

The guidelines are divided into two volumes.

Volume 1, Part A provides the technical information on which management recommendations are based. The information is provided to remind, update or prompt the professional land manager, adviser or government officer about the technical issues that need to be considered. Part B provides a review of legislation relating to riparian management in each State and Territory.

Volume 2 contains the management strategies themselves. Each guideline can be used on its own by practitioners interested in particular objectives, but readers are encouraged to look at all the guidelines to see if additional objectives can be achieved.

Three qualifications

1. These guidelines are intended to have a national scope, but Australia has a huge diversity of environments. Thus it is not possible to be prescriptive about what to do in every particular region. What is provided, is a review of crucial factors for riparian management that need to be considered in each

situation, with suggestions about how to vary management in line with local conditions. The aim is provide the technical framework which will empower those with local knowledge to make appropriate local decisions.

2. Some issues are beyond the scope of these guidelines. Issues not covered specifically, include the use of riparian land to reduce the level of pesticides and herbicides in streams; riparian management in non-agricultural areas; some causes of problems in streams (such as point sources of pollution and sand and gravel extraction); and 'non-vegetative' forms of management such as structural works.
3. There has been a large amount of research conducted overseas on the functions and management of riparian lands, but scant attention has been given to the subject in Australia. The overseas research cannot be simply transposed because of the distinctive characteristics of Australian environments—for example, native vegetation is largely evergreen and soils are old and poor in nutrients. In the absence of local research, these guidelines combine our knowledge of Australian catchments and the physical laws controlling in-stream ecosystems with overseas riparian research. Results of current research will improve our understanding over the next few years.

The intention is to revise these guidelines as knowledge of key processes improves. Your feedback is vital to this process—we welcome any comments or suggestions for improvement and any relevant examples and case studies of riparian management issues in Australia. If you would like to provide input, please contact

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DISCLAIMER

These Guidelines have been prepared from material (current at November 1999) drawn from research and development studies with specialist input from researchers, practitioners and land managers. However, they do not purport to address every condition that may exist on riparian land in Australia.

LWRRDC and the authors accept no responsibility or liability for any loss or damage caused by reliance on the information, management strategies or recommendations in the Guidelines. Users of the Guidelines must form their own judgement about the appropriateness to local conditions of a management strategy or recommendation in the Guidelines.

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The information (including the management strategies, recommendations and review of legislation) in the Guidelines is provided only as a reference point for professional land management and advisers involved in land management privately and in government.

Users are warned that, by law, the implementation of some management strategies and recommendations in the Guidelines require prior authorisation from government and environmental agencies. Usually, prior authorisation is required to destroy or control trees and other vegetation or to use chemical agents on land. All appropriate government and environmental authorisations from the relevant state/territory agencies must be obtained before implementing a management strategy or recommendation in the Guidelines. If the user is uncertain about what authorisations are required, he/she should consult a legal adviser.

Where technical information has been prepared or contributed to by authors external to LWRRDC, users should contact the authors or undertake appropriate independent enquiries before relying on that information.

To the extent that the Guidelines contain references to publications by other parties, the inclusion of such a reference is not an endorsement of the view or information expressed in such references or publications by LWRRDC or vice versa.

GUIDELINE A

Stuart Bunn, Thorsten Mosisch, Peter Davies

Controlling nuisance aquatic plants

Management objective

To maintain and, where necessary, restore stream ecosystem health and water quality by using shade to control excessive growth of aquatic and semi-aquatic plants.

A CONTROLLING NUISANCE AQUATIC PLANTS

Nature of the problem

Although aquatic plants are a fundamental component of stream ecosystems, when highly abundant they can cause problems. In some cases, algal growth is so prolific that entire water surface areas may be covered; access to the water by wildlife and stock is limited; and the quality of the environment for stream animals is severely diminished. These problems stem from the following

- Decomposition of accumulated aquatic plants in sediments leads to high rates of benthic respiration and high oxygen consumption. Respiration by aquatic plants (at night) also decreases dissolved oxygen levels. In some cases, variation in the levels of dissolved oxygen in nutrient-enriched pools can be extreme; oxygen can be completely depleted overnight. Such low-oxygen (anoxic) conditions typically lead to a significant reduction in those species intolerant to anoxia, and can contribute to
    - insufficient oxygen to sustain benthic invertebrate communities;
    - occasional fish kills as oxygen levels in the water column fall;
    - liberation of nutrients from anoxic sediments, which further stimulates algal or macrophyte growth;

  - the release of other contaminants (for example, manganese and iron) from sediments, which further compounds water quality problems.
- Plant groups unpalatable to aquatic animals may dominate, with many of the potential 'nuisance' groups of plants (macrophytes, filamentous green algae and toxic cyanobacteria) not readily eaten by fish and aquatic invertebrates. Macrophytes (for example, para grass) do not appear to enter aquatic food webs even after the plants have died and entered the detrital pool.
- Dense accumulations of aquatic macrophytes reduce aquatic habitat because
  - there is less open-water habitat for fish (note, however, that in the absence of overhanging and fringing riparian vegetation some species of fish may depend on macrophytes as cover in open streams);
  - as sediment is deposited and trapped, benthic habitat is eliminated and channel morphology is changed. If this process is allowed to continue, stream channels become narrower and filled with sediment and weeds. This results in more frequent flooding (the reduced channel capacity cannot convey even moderate flows) and the loss of instream habitat.
- Extreme sedimentation can be hazardous for stock and humans. Deep deposits associated with aquatic weeds can act as quick-sand, trapping livestock, humans and equipment such as tractors.
- Toxic algal blooms may occur. Blue–green algal blooms can be a major problem in larger, slow-moving rivers and in 'receiving' water bodies such as estuaries, wetlands, farm dams and larger water storages. They are not generally a problem in small, forested streams. Some forms of blue–green algae are toxic to stock, pets and humans on contact and/or if ingested. Evidence is accumulating that several algal toxins cause chronic degenerative disease if unwitting ingestion is continued.

What are 'nuisance' plants?
"A plant whose virtues are yet to be discovered."
Ralph Waldo Emerson (1803–82)

It is worth noting that many aquatic plants are not necessarily a nuisance and should not always be regarded as weeds. For example

~ emergent and submerged macrophytes provide important habitat and spawning sites for some species of fish (such as some native minnows *Galaxias* spp.) and food for some ducks, geese and other waterfowl;
~ emergent and submerged macrophytes can help to stabilise stream banks (see Guideline C);
~ some filamentous green algae are consumed by herbivorous or omnivorous fish (for example, bony bream *Nematolosa erebi* and rainbow fish *Melanotaenia splendida*) or are used to form the tube houses of aquatic invertebrates (for example, some chironomids);
~ some blue–green algae (for example, *Sciizothrix*) are a major source of food for aquatic consumers in the turbid arid-zone rivers such as Cooper Creek;
~ some riparian species of macrophytes provide an efficient trap for sediment and are particularly important in moist run-on areas (see Volume 1, Chapter 5).

It is important to carefully assess the significance of aquatic plant growth (for example, by reference to undisturbed stream reaches) and to then determine whether or not management intervention is warranted. It is also important to recognise the synergistic and cumulative effects of overclearing riparian vegetation (leading to higher light levels and water temperatures) in combination with elevated nutrient levels (resulting from irrigation drainage, sediment and runoff, or uncontrolled stock access).

Summary of the issues

(For details of these issues, see Volume 1, Chapters 3 and 4.)

Excessive aquatic plant growth can result when the light, temperature and nutrient levels of streams are elevated. In most forested stream systems, the shade created by riparian vegetation regulates light and temperature and, thereby, the distribution and growth of aquatic plants.

The Millstream, Queensland with floating *Salvinia* which can cover wetlands and river pools. Photo by Stuart Bunn.

Shade-tolerant groups of aquatic plants, such as bryophytes and unicellular benthic diatoms, are important components of the stream ecosystem. The latter can play an important role in some stream food webs because they provide higher quality food than do other forms of organic carbon.

With no riparian shading, some plant groups proliferate (particularly if stimulated by nutrient inputs from the catchment upstream) and become weeds. The absence of riparian vegetation also reduces the local filtering of catchment-derived nutrients, further encouraging such proliferation. Examples of potential weeds are conspicuous filamentous macroalgae and emergent and submerged macrophytes. In the more open and slow-moving reaches of larger rivers, toxic blue–green algae and floating macrophytes can also become major problems. Many of the nuisance weeds in Australian streams are introduced species.

Lack of shading by riparian trees can also lead to the proliferation of semi-aquatic and terrestrial riparian weeds. For example, para grass (*Brachiaria mutica*) was originally introduced into Queensland as an effective plant for bank stabilisation and has since been actively promoted as a ponded pasture species. In practice, it not only overgrows stream channels but can also vigorously out-compete native plant seedlings. This has resulted in para grass becoming a major riparian weed.

Species such as this may, however, prove very effective in stabilising streambank sediments or trapping sediments and contaminants in overland flow. There is an obvious need to carefully consider whether the benefits of encouraging dense understorey weeds for these purposes can be justified in light of the known impacts on terrestrial and aquatic biodiversity, as well as stream ecosystem function. These weeds may be valuable for specific purposes in difficult situations, but perhaps only in combination with shading by native riparian vegetation to reduce their invasive capacity.

In the absence of riparian shading, many other species of terrestrial plants become understorey weeds. Often it takes only minor disturbance to the riparian canopy cover for the growth of understorey weeds (for example, blackberries, privet) or of 'woody weeds' (such as rubber vine, willows, camphor laurel) to increase.

Research has shown that

~ riparian zone protection and restoration for stream shading will result in only a small loss of land available for cultivation because a narrow strip of trees may suffice;

Azolla (native floating fern) mats, Barkers Creek, Queensland. Photo by Stuart Bunn.

Channel in Clemenson Creek, Queensland choked with macrophytes (active Cyperus and para grass). Photo by Stuart Bunn.

~ riparian shading may decrease the sediment/nutrient trapping efficiency of understorey and groundcover vegetation; a combination of maintained grass strips and native riparian species may be the optimal combination;
~ riparian vegetation may increase flooding risk by increasing floodplain roughness. However, this may be balanced by increased channel capacity when macrophytes and in-stream sediment are diminished as a result of shading following replanting;
~ riparian plantings increase ecological values, both in-stream and off-stream;
~ riparian shading offers a long-term solution to nuisance plant control;
~ in the medium to long term, riparian shading is a more cost-effective strategy than other means of nuisance plant removal.

Critical factors

~ Technique used for control
~ Stream order
~ Stream orientation
~ Geographic location
~ Species
~ Width of riparian vegetation zone
~ Nutrient input
~ Modifications to flow

Guidelines

Consider the long-term costs and benefits of alternative means of controlling aquatic plants

Often the most direct solutions are sought to overcome problems of nuisance plants in stream channels. Unfortunately, they are generally ineffective in the long-term, are costly (because of the need for continuing control), and can lead to further degradation of the stream and river ecosystems. The various control techniques (mechanical excavation, herbicides and shade) are summarised below.

Mechanical excavation

Various mechanical methods have been used to remove aquatic plants in stream channels. These range from aquatic mowers to full-scale excavation of the channel.

Unfortunately, with mechanical means of control

~ if plants are not totally removed by the process, they simply re-grow. Given the enormous rates of production of some weeds, it is not surprising that mechanical removal is ineffective even in the medium term;

~ disruption of the streambed and bank can have a major impact on the aquatic fauna;

~ it is often necessary to remove riparian vegetation and keep banks clear of obstruction for the harvester. This further compounds the total problem of nuisance plant growth in the longer term.

Cleaning drain to remove para grass, Bamboo Creek, Queensland. Photo by Pete Gleeson.

Herbicides

Various herbicides are used to control aquatic and riparian weeds. In the wet tropics, herbicide is used to suppress weeds of riparian areas, such as para grass, and to prevent them from out-competing newly-planted native tree species. This control may be required for 1–2 years—that is, until the canopy cover and shading become re-established.

Unfortunately with herbicides

~ complete control of nuisance plants is often impossible because they can easily re-invade from up-stream or from across the channel (if neighbours do not choose to control them);

~ effects on non-target aquatic plants are not well known. If, as in some stream systems, aquatic microalgae are an important component of the food web, stream ecosystem function could be seriously affected;

~ some chemicals harm aquatic and semi-aquatic animals (for example, the surfactants contained in some herbicides are detrimental to tadpoles).

Shade through vegetation

There is little doubt that shade has an overriding control on the growth and distribution of aquatic and semi-aquatic plants. Research has shown that shading alone can control nuisance aquatic plants even when nutrient levels are enhanced. In some instances, artificial shade (such as shade cloth) can be used to reduce the productivity of weed species, as well as control their distribution and biomass.

Planting trees is, however, a cost-effective measure for long-term control. This is because

~ once established, a dense stand of trees eliminates the need for continual mechanical or chemical intervention;

~ trees eliminate the likelihood of the replacement of one weed species by another;

~ trees can provide a multitude of other important ecological benefits (for example, a reduction of stream temperatures, a source of leaf litter/food for aquatic biota, terrestrial wildlife habitat, and a positive influence on aquatic habitat).

Keep in mind that control activities undertaken upstream will also deliver benefits downstream

Protection and, where necessary, restoration of upstream tributaries may go a long way to reducing the problem of nuisance plants in larger, 'receiving' rivers because

~ lowered water temperatures (a result of shading upstream) will reduce the risk of downstream blue–green algal blooms;
~ lowered water temperatures will increase oxygen solubility and reduce oxygen demand through lower rates of biological respiration;
~ reduction of nutrient inputs upstream can limit aquatic plant production further downstream where light is not limiting.

Based on recent research in coastal forest streams, the degree of riparian cover needed to control nuisance plants (such as filamentous algae and macrophytes) is thought to be about 75%.

This should be achievable in small streams which drain sub-catchments of less than 10 km^2 (1000 ha), or where the active channel is less than 10–15 m wide (Note: in disturbed catchments, streams may have wider or narrower channels than predicted. It is important to estimate an appropriate width for the stream channel, based on known relationships between channel size and catchment area.)

Lower levels of shading may be sufficient to reduce stream temperatures, because vegetation is more effective at filtering light in the infra-red/red end of the solar spectrum than it is at filtering light in the visible/UV end. Most of the solar energy that is converted to heat by absorption in water is in the infra-red/red end of the solar spectrum.

Although riparian vegetation may never reach a high level of stream cover in larger streams and rivers, it may still be effective in reducing build up of nuisance plants in the shallow littoral margins and on riparian land following the retreat of flood waters.

Shading of larger streams and rivers by riparian vegetation can reduce sedimentation of littoral areas and the loss of important habitat in the photic zone. It may also encourage the development of benthic diatoms and other more light-sensitive species of aquatic plants that are important to grazing stream fauna.

Remember that the orientation of a stream partly dictates how much light it receives

Channel orientation can influence the effectiveness of riparian shading in streams. This is most apparent in the tropical north of Australia where the sun can traverse directly over stream reaches flowing in an east-west direction. In these instances, light thresholds for filamentous algae may be exceeded during the summer months and a more closed canopy would be required. It is worth noting, however, that high summer discharge flow events may prevent build-up of nuisance plants.

At more southerly latitudes (greater than 30° S), vegetation on the north bank of streams intercepts most of the solar radiation in channels flowing in an east-west direction, and trees on the south bank have little direct influence. If time and/or budget is limited, planting on the north bank of east-west flowing streams is likely to be the most cost-effective strategy. Additional plantings on the south bank could follow when time or money permits, so that other important ecological goals can be achieved. (See Volume 1, Chapter 3.)

Vary your strategy in line with your geographic location

The effectiveness of riparian shading is influenced by latitude.

~ Due to higher solar radiation in northern latitudes, denser vegetation and/or more canopy cover is required to keep below-canopy light levels low enough to discourage nuisance plant growth.
~ Planting on the north bank of east-west flowing stream reaches may be effective at southern latitudes, but not in the tropical north where the sun can be directly overhead.

Controlling nuisance aquatic plants by riparian shading is appropriate in regions where riparian land is naturally densely forested. This includes

~ temperate regions of south-western and south-eastern Australia;
~ sub-tropical and tropical forests of the eastern coast;
~ streams in the wet–dry topics where the riparian zone is monsoonal rainforest.

Healthy riparian vegetation providing shade in Koolmoon Creek, far north Queensland. Photo by Stuart Bunn.

In arid and semi-arid regions, sparse vegetation may never be sufficient to reduce below-canopy light intensities to below the threshold levels for potential weed species.

- Many inland river systems are naturally turbid, and this can influence in-stream plant production. Although turbidity may effectively control submerged aquatic plants in deeper water, it will not affect emergent macrophytes or surface blooms of planktonic algae (for example, blue–greens).
- Riparian shading may influence the composition of aquatic plants in the littoral margins of rivers.
- Riparian shading may also be sufficient to reduce water temperatures and have other important ecological benefits.

Select species for their shade-producing characteristics

Choose species of native trees with the potential to grow out and over the stream channel. You can close the riparian cover over a stream if the tree canopy has the potential to attain a width equal to (or greater than) the active channel width. Examining less disturbed areas in the locality may give an indication of suitable species.

~ Choose species which are wide in comparison with their height.
~ Choose species with highest shade indices (that is, with dense foliage all year) and avoid deciduous trees.

Adjust width of riparian vegetation stand in line with supplementary objectives and budgets

Effective shading (to levels similar to those of undisturbed forest) can be achieved with a very narrow band of trees (around 5–10 m). However, consideration of other aspects of microclimate (such as humidity and wind speed), which influence the suitability of riparian land as terrestrial habitat, may necessitate larger widths (see Volume 1, Chapter 8 and Guideline F).

Where possible, limit the input of nutrients to streams in the catchment

As indicated above, it is possible to limit nuisance aquatic plant production with riparian shading in small streams even if nutrient inputs are high. However, this may simply transfer nutrient problems downstream, to where the vegetation has little shading influence (for example, wider river channels, lakes and farm dams) and perhaps, ultimately, to receiving coastal ecosystems.

For this reason, it is important to consider means of controlling nutrient inputs at the same time as increasing shade. This two-pronged attack is likely to achieve the best result. However, some conflicts arise when trying to optimise effective shading and at the same time enhance nutrient and sediment-trapping efficiency by understorey and groundcover vegetation. This is because of the different types of vegetation required for the two tasks. Resolution of these conflicts can be achieved by trapping nutrients and sediment in a buffered zone (for example, a grassed strip) before they enter a shaded riparian zone of native tree species.

If the objective is to control nuisance plants in larger streams and rivers, it is very important to identify and control upstream sources of nutrients (see Volume 1, Chapter 5 and Guideline D).

Remember that flow regulation compounds many of the problems associated with excessive plant accumulation

Low flows increase the likelihood of poor water quality because dissolved oxygen will be low. Mixing of water and re-aeration are not sufficient to counter the high oxygen demand from plant respiration and from the bacterial decomposition of accumulated organic debris. Blue–green algal blooms are often associated with periods of low flow.

Modifying flow to eliminate moderate floods reduces channel maintenance flows that regularly scour the active channel and remove accumulated plant production and sediment.

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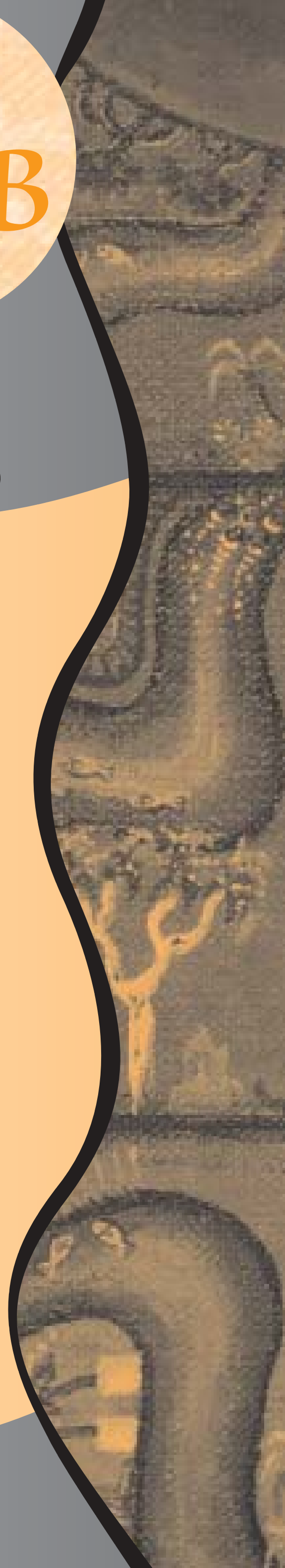
GUIDELINE B

Simon Treadwell (ed.), Proceedings of a workshop *(see page 32)*

Managing snags and large woody debris

Objective

To manage large woody debris in such a way that the ecological health of the river is enhanced at the same time that risks of flooding and streambank erosion are diminished.



B MANAGING SNAGS AND LARGE WOODY DEBRIS

Nature of the problem

The problem in managing large woody debris (LWD) is not so much its negative impact, but the long and widely-held *perceptions* of its impact.

~ LWD is important in streams and rivers from both an ecological and a geomorphic/hydraulic viewpoint. However, the positive ecological contribution of LWD has been overlooked or down-played; while impacts on water flow (especially flooding) and erosion have been misunderstood and exaggerated.

~ LWD provides important in-stream habitat for aquatic animals, as well as stable sites for the processing of carbon and nutrients. Through its impact on channel structure and flow, LWD also assists in the formation of habitat (such as scour pools). This latter process has led to the misguided belief that LWD also causes significant channel erosion. Another false belief was that snags significantly reduced channel capacity, leading to overflowing of banks during flood events. These misunderstandings about the effects of LWD on erosion and flooding, has meant that snag removal programs have continued throughout Australia, even after the initial rationale for snag removal (safer river transport) had ceased to be relevant.

~ It is now apparent that de-snagging has had a significant negative environmental impact on stream ecosystems. Major effects include the loss of habitat for fish and other aquatic and terrestrial organisms, to the point where some native species are threatened or locally extinct. The removal of snags has also had a significant impact on channel morphology. De-snagged rivers typically become uniform drainage channels, with fewer channel features such as scour holes and bars that retain, or act as substrates for the processing of carbon and nutrients by instream organisms. Furthermore, extensive research on the hydraulic effects of snags has indicated that snags, especially in large rivers, have little adverse impact on channel capacity and snag removal does little to reduce the height of major floods.

~ The challenge in achieving 'best practice' LWD management lies in maximising the positive contribution of LWD in both of its major roles; including, where appropriate, the restoration of snags in de-snagged rivers. Fortunately, this challenge has been made easier by recent research which confirms the real (as opposed to the perceived) impact of LWD on streams, rivers and riparian land.

Summary of the issues

LWD is very significant in the ecology of streams and, by reason of the linkages between water and land, in other ecosystems. (For more information on the following issues, see Volume 1, Chapter 7.)

Large woody debris as habitat for fish

Woody debris provides important habitat for direct use by a number of aquatic and terrestrial organisms. Such uses include shelter from high current velocities, shade, feeding sites, spawning sites, nursery areas for larvae and juvenile fish, territory markers and refuge from predation.

Snags are most effective as habitat if they have a complex structure providing a number of different-sized spaces, including hollows within the debris piece and spaces between branches. Branches extending into the water column and above the water

Natural snags provide a range of habitat types suitable for fish and other aquatic and terrestrial organisms, Ovens River, Victoria. Photo by Simon Treadwell.

surface provide habitat at the different water levels required by different fish species. Single large trees that fall into a river can often provide the full range of complex spaces required.

Snags positioned at different locations within the stream channel benefit different species. For instance, Trout cod *Maccullochella macquariensis* utilise snags that are located in high-current zones towards the middle of the channel and downstream of a bend. Murray cod *Maccullochella peelii peelii*, on the other hand, reside around the base of snags in slower-flowing currents closer to river bends.

Snags as habitat for other organisms

In general, the types of snags that provide habitat for fish also provide habitat for other aquatic and terrestrial organisms. Submerged wood, with a complex surface structure of grooves, splits and hollows, provides space for colonisation by a range of invertebrates, microbes and algae. Some invertebrates feed directly on the wood while others graze the biofilm (that is, the combined microbe and algal community).

The species composition within the biofilm community depends on the position of the wood substrate within the water column. The shallower the water in which the substrate occurs, the higher the density of algal species compared with substrate located deeper in the water column where light does not reach.

Species composition of both biofilm and invertebrates also depends on the substrate type. Willows and other introduced tree species appear to have a less diverse invertebrate community compared with native/indigenous tree species. Similarly, community composition varies according to the type of substrate (for example, wood compared with concrete pipes).

Birds, reptiles and mammals also use woody debris for resting, foraging and lookout sites. Birds commonly use the exposed branches of snags as perch sites, while turtles often climb out of the water using snag surfaces. Snags spanning the channel may also be used by mammals and reptiles as stream crossing points. Many aquatic invertebrates have a terrestrial adult stage and require snags extending above the water surface to provide sites for emergence from their larval to adult stages.

Snags as sites for carbon and nutrient processing

Another important but often overlooked function of snags is their role in carbon and nutrient processing. Snags provide important substrate for the development of biofilms. The bacterial and fungal components of biofilm contribute to the decomposition of the woody substrate and, hence, to the supply of dissolved and particulate organic material (carbon) to the water column. Organic matter is a major source of food for invertebrates and fish. The algal component of biofilm may also produce a significant amount of carbon and, hence, food through photosynthesis. Many invertebrate species and some fish eat the algae that are growing on wood surfaces. In sandy, turbid rivers where woody substrate may be the only hard substrate available for colonisation, or in rivers that have been isolated from floodplain carbon inputs by river regulation and clearing, most of the food for aquatic animals is found on snags.

In upland streams, debris dams (large accumulations of woody debris that often span the entire channel) retain large amounts of

Snags help stabilise sandy and silty river beds and promote organic matter deposition which contributes to further bed stabilisation, Murrumbidgee River, New South Wales. Photo by Simon Treadwell.

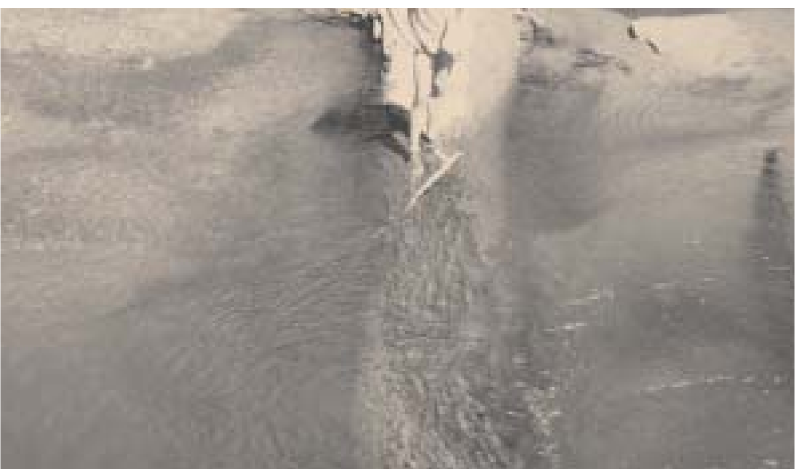
particulate organic material. This material decomposes into smaller pieces and is then transported downstream. (As stream size increases, large debris dams become less common and the ability of woody debris to retain these small particles may decrease.) However, retention of organic material and stabilisation of sandy substrate by snags may still be significant in lowland rivers. Water flowing over snags also helps to re-oxygenate that water and prevent stagnation which can cause fish deaths, odours and other water quality problems.

The role of snags in habitat formation

As well as providing habitat for a range of aquatic and terrestrial species, snags also contribute to the development of other habitat types by their impact on channel structure. The main types of habitat formed by snags depend on snag orientation and stream power (see Table 1). Scour pools formed by snags spanning the channel are particularly important for wildlife, especially in streams with low or no summer flow. When flow ceases, these pools provide the only habitat available for aquatic species, and are a source of recruitment for re-colonisation when normal flow returns.

Table 1: Habitat development as determined by snag orientation

Orientation to flow	Habitat formed	
	Upstream	Downstream
Parallel	Scour pool	Bar/island
Angled	Combination pool/bar	Combination pool/bar
Perpendicular – on bed	Depositional zone	Scour pool
– above bed	Scour pool	Scour pool



Above: Channel habitat formed by snags parallel to flow, Warren River, Western Australia. Photo by Simon Treadwell.

Left: Channel habitat formed by snags perpendicular to flow, Kiewa River, Victoria. Photo by Chris Gippel.

Stream power is an important determinant of whether snags influence habitat development. Stream power is a function of gradient and discharge and often peaks in middle reaches where high flows and high gradients occur. In lowland reaches, stream power typically declines because of the decrease in stream gradient, even though total discharge may increase. Where stream power is high (in middle reaches and in some tropical streams with high cyclonic discharge), snags will tend to be flushed out of the main channel and deposited along the banks or downstream where stream power is lower.

The role of snags in erosion

In particular situations, snags may contribute to some erosion of banks. However, similar patterns of erosion can also be found in de-snagged rivers, so removal of snags will not necessarily prevent bank erosion. Snags help to stabilise the bed, and there are many instances recorded where removal of snags has resulted in severe degradation of the channel bed and, eventually, the banks.

A river channel needs to be substantially blocked by LWD before there is a significant effect on the movement of floodwaters. Only

Minor localised bank and bed scouring caused by snags, Ovens River, Victoria. Photo by Chris Gippel.

Perched channels occur where the stream bed is higher than surrounding land and is separated by a high bank. An avulsion at this point could cause significant flooding of low lying land below the level of the stream bed, Latrobe River, Victoria. Photo by Chris Gippel.

LWD which is large (that is, it covers more than 10% of the channel cross section) and is oriented across (perpendicular to) the direction of water flow causes substantial local water level increases, and increases the chance of water overflowing stream banks during flood flows. Smaller items have little or no impact on local water levels. LWD has the least effect on water flow when it is aligned with the flow (at 140–180° to the direction of water flow), is located on the channel margins or in other areas of low flow velocity, and is streamlined in shape.

Snags are involved in the normal erosion and deposition processes that result in channels changing their shape, but these processes occur whether snags are present or not. The actual amount of erosion caused by snags is usually small.

In most cases, flood height is not controlled by snags but by some other channel constriction such as a perched channel or bridge abutment. It is common for a bridge and its approaches to be smaller than the natural channel cross-section. This leads to flood water being backed-up above the bridge.

Critical factors

I. Critical factors for managing existing snags

The actual contribution of snags to flooding and erosion

~ Are snags the actual cause of observed problems?
~ Determine hydraulic effect of constructions/ impoundments on flooding elsewhere in the river
~ Determine if bank erosion is caused by other factors (for example, channel instability)

II. Critical factors for managing snag restoration

~ Loads
~ Types and structure of material
~ Sources
~ Position in channel
~ Orientation
~ Stability
~ Nature of land adjacent to the river
~ Timing of restoration project
~ Local factors

Guidelines

I. Guidelines for managing existing snags

'Let sleeping logs lie'

~ Remnant snags are best left alone and rarely need to be removed.
~ Snags have little effect on flooding, unless the channel is choked with debris, and are often not the major cause of bank erosion and channel widening. Look for other contributing factors to flooding, such as channel constrictions at bridges or bank erosion, such as channel instability.
~ Snag re-orientation or lopping will compromise their important ecological functions and is not recommended in other than exceptional circumstances.

Remember: removing snags may trigger other problems of channel instability and erosion, particularly downstream. A seemingly simple solution to a local problem may lead to an ever-increasing dependence on expensive stream engineering works.

~ Re-aligning snags alongside and parallel to banks *may* deflect flow on to the bank and trigger unwanted bank erosion, although, with large logs, the degree of any such erosion is likely to decrease with the angle to the bank.

II. Guidelines for managing snag restoration

Loads

~ Aim to restore sufficient snag material to return the river to its natural load.

Snags are not a natural feature of all stream systems. Streams in the northern tropics, where high gradients and flows tend to flush debris from the stream, and where high temperatures result in rapid decomposition of organic material, may have low natural levels of wood. Other streams naturally lacking woody debris include intermittent desert streams in which vegetation is sparse and stunted. Organisms in these streams are generally adapted to alternative habitats such as those provided by boulders, macrophytes, leaf packs, etc.

Natural loads can be determined by measuring the amounts of wood present in undegraded reaches of similar stream types. In some cases, historical documents available from local river management authorities and state agencies may provide information on natural loads. These documents may include records of the number of snags removed from particular rivers. If no information is available, the general rule is that the volume of wood should be around 0.01 m^3 for every m^2 of channel bed area.

~ Balance the amount of wood restored with the condition of the riparian land.

Degraded riparian land with reduced woody debris input to the stream may require a larger amount of wood to be restored compared with a stream that has a more intact riparian land, which has the potential for local re-supply. In instances of relatively intact riparian land, restoration of only a few key snags to the stream may be adequate, provided that the riparian zone is managed in such a way that future sustained supply is achieved.

A degraded river channel and riparian zone which requires significant in-stream snag restoration, fencing of stream banks and riparian zone revegetation. Photo by Alena Glaister.

A degraded river channel with relatively intact riparian vegetation, requires the restoration of some key snags and careful management of the riparian zone to ensure a sustained wood supply to the river in the future, Murray River tributary, New South Wales. Photo by Chris Gippel.

~ Leave overhanging branches.
Branches overhanging rivers should not be lopped and removed to reduce the chance of them falling in. These branches form the bulk of woody material entering rivers and should be allowed to do so.

Types and structure of material

~ Use the range of indigenous tree species found on local riparian land.
For many lowland rivers in southern Australia, river red gum *Eucalyptus camaldulensis* is a common large riparian tree species that contributes significantly to instream woody debris. River red gum decays slowly and large snags may persist for many years. It is important that other riparian species (for example, black box *E. largiflorens*, manna gum *E. viminalis*, wattles *Acacia* spp.) also contribute to a diversity of snag types, especially as these species decay more rapidly, thereby providing a diversity of habitat types.

~ Avoid the uses of introduced tree species such as willows *Salix* spp. and poplars *Populus* spp.
When used as snags, these species do not provide an appropriate substrate for invertebrate and biofilm colonisation. They also tend to rapidly regenerate from small pieces and can infest and restrict channels and shade out native riparian species.

~ Avoid the use of artificial material
The use of artificial materials such as car bodies and concrete/clay pipes needs to be avoided because they perform few of the functions of a natural snag and are alien to the stream environment. They are also aesthetically unpleasing and may introduce contaminants into the stream.

Willow growth restricts channel capacity much more than natural vegetation and snags, Plenty River, Victoria. Photo by Simon Treadwell.

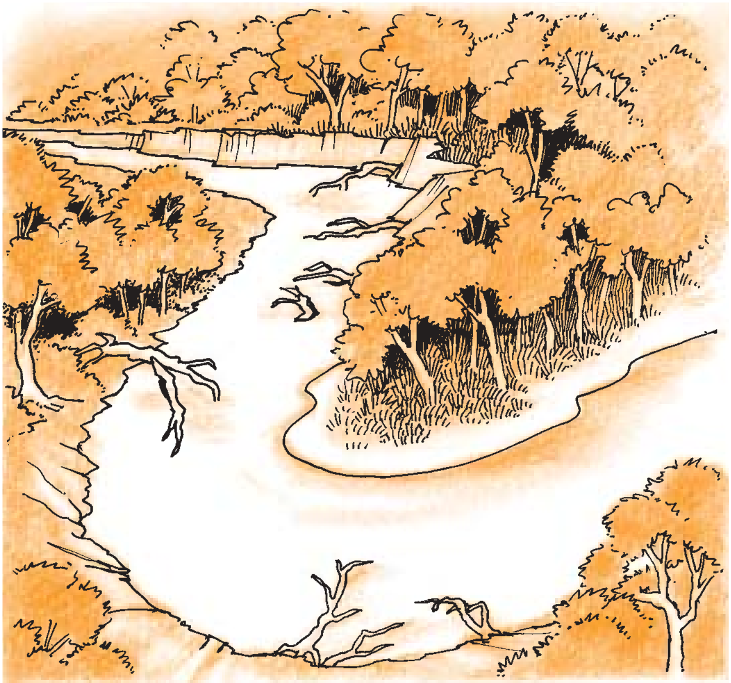
- Introduce LWD in a range of sizes
  Single large trees that fall into a river can provide the full range of complex spaces required. However, when restoring snags to a degraded stream, complexity may need to be developed by the addition of a number of smaller debris pieces to form a single, multi-piece snag.
- If necessary, consult an experienced biologist to ascertain the needs of various species.

Sources of material

- Avoid using LWD from the riparian zone.
  Sources of material for restoration purposes requires careful consideration. Fallen material already present on the floodplain or in the riparian zone should not be used because this debris is just as important in the terrestrial environment as in-stream debris is to rivers and streams.
- Explore the use of logging waste as a source of snags.
  It may be possible to use logging waste, which usually includes parts of trunks and main branches that may be of little commercial value, but would make excellent snags especially if several pieces where used to form a single, complex snag.

Position in channel and orientation

- When restoring snags to a river, place them at a variety of locations, generally on the outside and downstream of a bend. (Snags placed on the outside of bends may help reduce bank erosion.)
- Place snags in different orientations to channel flow in order to obtain a variety of habitat, recognising that those angled perpendicular to the flow are most effective at creating scour pools and reducing current velocity.
- Place snags so that branches extend into the water column and above the water surfaces to provide habitat to meet the various requirements of different organisms, and to allow for changes in water height and stream power.
- Place some snags touching the bank to provide access points for reptiles and mammals. It is also important to have a few snags spanning the channel to provide stream-crossing points.



The best location to position snags is on the outside and downstream end of bends.

Stability

- Consider the need for anchoring introduced snags.
  When a large tree falls into a river, the base of the trunk usually remains on the bank, sometimes partially buried. This prevents the snag from being swept downstream. In restoration projects, it is unlikely that material used will be heavy enough to remain in place without anchoring. Complex snags formed by combining a number of smaller pieces can be tied together and then anchored.
- Anchoring can be achieved by burying part of the trunk in the stream bank or stream bed, securing the trunk to a fixed point some distance back from the bank with steel cables, or by tying the snag to piles driven into the stream bed. These anchoring techniques have often been used by engineers when constructing groynes and other channel structures, so practical expertise is available.

Management of adjacent land

~ Manage LWD on riparian land as well as that instream.
  Restoration of snags to a degraded stream or river requires careful planning and must consider riparian land and the wider floodplain as well. It is vital that in-stream restoration involves riparian restoration, because riparian vegetation is critical for providing a sustained supply of woody debris to the river. It will take many years, however, before riparian vegetation will have grown large enough to provide sufficient wood to the stream.

~ Protect infrastructure.
  In some cases, the addition of wood to a river may cause minor localised erosion and scouring of the bank and bed around the snag. This should be viewed as an essential part of the restoration process as it contributes to the development of the unique habitat features associated with snags. Ensure that fences and other capital structures (for example, off-stream watering pumps) are not at risk, by providing a conservative set-back distance from the stream.

Timing of restoration project

~ Work from the stream out.
  Complete any in-stream restoration before riparian and floodplain restoration is conducted. It is counter-productive to revegetate riparian zones only to disturb this work when restoring snags to the channel.

~ Be prepared to wait.
  Snag restoration may not produce instantaneous results. Many ecological processes (for example, the decay of river red gum) operate over long time-scales. Nevertheless, these processes are important in contributing to the development of features such as surface complexity, hollows and increased palatability as a food source. Colonisation of new substrate by biofilm, invertebrates and fish also takes time.

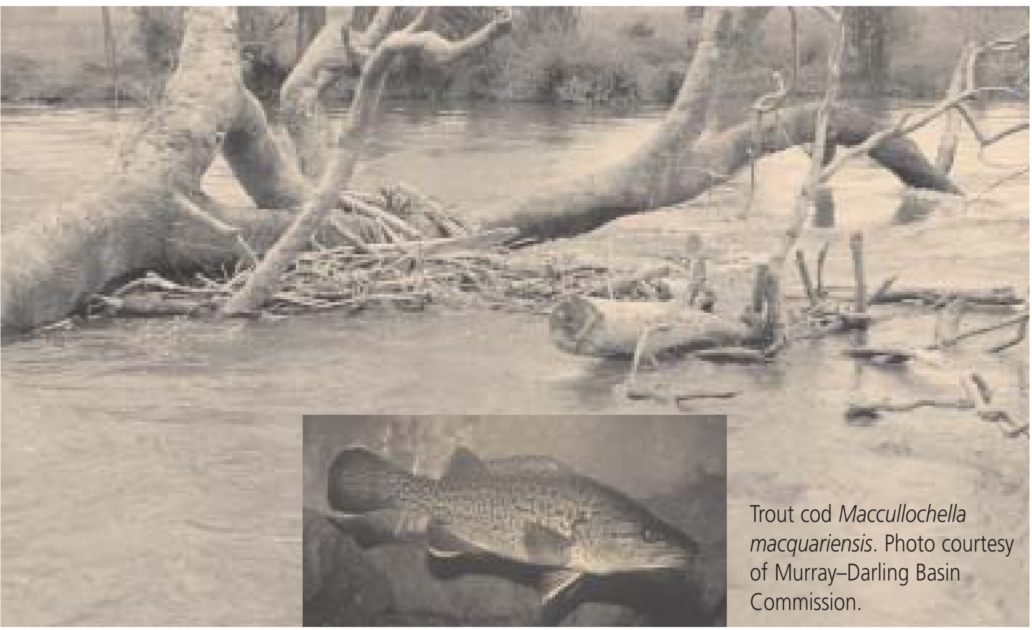
~ Monitor effectiveness.
  The effectiveness of any snag restoration project should be monitored. Monitoring programs should be designed by experts and be conducted prior to and after restoration. Monitoring will

help to refine future restoration projects and provide important information on how river communities respond to habitat improvement.

Accommodate local factors

~ Consider re-stocking streams with fish.

In some instances, restoring snags to a degraded river will not be enough to encourage fish to recolonise the new snags. In some rivers, fish populations have been severely reduced or have become locally extinct through loss of habitat. In these situations it may be necessary to implement a fish stocking program alongside habitat restoration. Such programs are being implemented for endangered species like the Trout cod and Mary River cod *Maccullochella peelii mariensis*. Fish translocation is illegal in some States, so an experienced fish biologist familiar with the requirements of the target species and the relevant legislation should be consulted prior to a snag restoration program.



Trout cod *Maccullochella macquariensis*. Photo courtesy of Murray–Darling Basin Commission.

One piece of LWD providing a range of different habitats. Photo by Chris Gippel.

Further reading

Gippel, C.J. 1995, 'Environmental hydraulics of large woody debris in streams and rivers', *Journal of Environmental Engineering*, vol. 121, pp. 388–95.

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Snag restoration guideline

This guideline was developed at a workshop held on 25 March 1997. The guideline was prepared by Simon Treadwell with comments from Ian Campbell, Ralph MacNally, John Koehn, Bill O'Connor, Jane Growns, Chris Gippel and Ian Rutherfurd. A list of the workshop attendees follows.

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GUIDELINE C

Ian Rutherfurd, Bruce Abernethy

Controlling stream erosion

Management objective

To manage riparian vegetation in such a way that its contribution to erosion control is maximised.

CONTROLLING STREAM EROSION

The physical processes involved in erosion, on which this guideline is based, are discussed in detail in Volume 1, Chapter 6 of this publication. Readers are also directed to Guideline B for a discussion of how large woody debris (LWD) can be managed to minimise its contribution to erosion and to provide aquatic habitat.

Nature of the problem

While erosion is a natural process, the wholescale removal of natural vegetation, the planting of exotic flora and the introduction of grazing stock since European settlement, has contributed significantly to increased levels of soil erosion.

Problems created by erosion involve

~ the 'loss' of land;
~ damage to infrastructure;
~ sedimentation, leading to degraded aquatic habitat;
~ changes to flow regimes, with the potential for increased flooding.

Since European settlement, many of the land management and agricultural practices used in the northern hemisphere have been, often inappropriately, introduced. One such practice has been the use of willows in southern Australia to limit erosion and for aesthetic reasons. Unfortunately, in Australia, willows can contribute to the problem of stream erosion as well as create other problems for native ecosystems. For example, native ecosystems are not attuned to the annual leaf-fall of willows.

Because of the extent of the 'willow problem' and the debate which has surrounded them for many years, this guideline discusses, at some length, how to manage willows in order to minimise stream erosion in the long-term.

Summary of the issues

Streambank erosion is strongly influenced by the density and type of riparian vegetation; in most cases riparian vegetation helps banks to resist erosive forces. Other factors which play a role in bank erosion are bank material, geometry, hydrology and stratigraphy. Bank erosion processes can be categorised as sub-aerial erosion, scour and mass failure.

~ Subaerial processes include windthrow of trees on the stream bank, damming by LWD, frost heave, desiccation, rainsplash and micro-rills, slaking and trampling by stock.
~ Scour occurs when the force applied to a bank by flowing water exceeds the resistance of the bank surface to withstand those forces. Types of vegetation vary in their capacity to limit the impact of flow.
~ Mass failure of various types occurs when blocks of the bank collapse. Scour and mass failure can be interlinked by the process of basal scour. Vegetation can influence mass failure through surcharge, buttressing and soil arching, transpiration and improved drainage, and root reinforcement.

The rate at which channels erode is related to their size. In general, small streams experience relatively little scour or mass failure. The dominant process in mid-basin streams is attrition of the bank as individual particles are removed by the flow and transported away. In larger streams and rivers, mass failure is the dominant process.

Gully erosion originates in steep valleys and towards the foot of long slopes where flows naturally accumulate. In some cases, gully erosion can be impeded by vegetation, particularly groundcover, which slows the flow and limits the capacity of the flow to entrain sediment.

Critical factors

~ Location of planting
~ Complementary engineering solutions
~ Point bars
~ Surcharge
~ Species

Guidelines/strategies

Target areas where vegetation has most chance of becoming successfully established

If resources are limited and erosion control is the primary aim, it can be a mistake to target a revegetation program at the *most unstable* section of a stream. Often money is better spent targeting a reach where erosion may not be so severe, but where vegetation will be more successful. To know where vegetation will be most successful it is important to know what the dominant erosion process is. This may take some detective work and astute observation. There are often several erosion processes operating on one river bank at the same time, and it may not be clear which one is dominant. The key is to match the vegetation to the erosion process, and this is largely a question of location in the catchment.

Be aware that, in addition to the dominant erosion process in the part of the river that you are treating, other processes are also operating. A diverse planting strategy is preferable to one that targets only one erosion mechanism. A general rule of thumb is that the major root ball of a tree extends for about five times the diameter of the trunk. This is the length of stream bank that a single tree can generally protect from erosion. This distance may be longer on a river bank where the trees tend to grow along the bankface.

If the bank is scouring from the toe (which is usually the case), determine how far down the bank vegetation can be established. In the lower reaches of a stream, where the seasonal range of flow

A bank with an actively eroding toe. Photo by Ian Rutherfurd.

stages is high, it may be easier and most effective to establish vegetation on the bankface.

Sometimes tensile forces reduce bank strength behind the bankface. Extending plantings over and beyond the banktop will provide additional protection from mass failure by reducing the growth of tension cracks on the bank-top.

The key to most bank erosion problems is an actively eroding toe. This is also the most difficult part of the bank to revegetate with woody species. Macrophytes, like *Phragmites*, are useful in these locations. Match the rooting depth of the vegetation to be established with the size of slumps. If the roots of the species planted do not cross the potential failure plane, they will have limited ability to reduce erosion.

Consider complementary engineering solutions

Where erosion is threatening a high value asset (such as a bridge or a building) or in high energy situations (such as gullies) with high, steep stream banks, vegetation may not provide sufficient resistance to protect the asset or control erosion. Whilst vegetation will often provide the long-term resistance to erosion, an engineering structure is often needed to provide a strong base for establishment of that

Protecting major assets, rock used to stabilise bank below dam wall, ACT. Photo by John Baker, courtesy of ACT Waterwatch.

vegetation. On eroding banks this base can be a stone-toe (a line of rock around the toe of the bank). Alternatively, the bank above the toe can be battered to provide better revegetation opportunities. In other cases, vegetation can be established within a retard field. The main challenge in these situations is to sustain the young plants for long enough for them to become sufficiently strong to resist the erosive forces. This is a particular problem with slow-growing native tree species.

When deciding whether vegetation will be sufficient to protect a particular part of a stream, always ask—'Why is there no vegetation there now?' It is common to see native vegetation, or even willows, extend along a bank face as far as the entrance to a bend, and then stop. This demonstrates that the erosion rate at the bend is too high for vegetation to survive. If this is the case, your revegetation efforts may be similarly unsuccessful unless complementary engineering solutions are implemented.

Carefully consider the effectiveness of removing vegetation from point bars

The effectiveness of removing vegetation from point-bars in order to reduce bank erosion is unclear. Overall, this practice is not recommended because

~ Where the vegetation is in a 'backwater', removing it will have no effect;

~ The further back on the point-bar the vegetation is removed, the less hydraulic impact the removal will have. In other words, there is probably not much more hydraulic benefit from removing all of the vegetation from a point-bar, than from removing only the vegetation right at the water's edge. Thus, if native vegetation is to be removed from a point-bar, only the vegetation a few metres back from the water's edge needs to be removed.

Take account of the mechanical effects of trees

The effect of a tree depends upon the size of the tree and the size of the bank. Roots from a tree extend to about the dripline of the canopy. If the roots cross a potential failure plane, the tree will probably reduce the chances of failure, even with surcharge.

~ Trees planted low on a stream bank will probably increase bank resistance to slumping. This means that in many situations, the weight of a tree on a river bank will increase its stability.

~ By buttressing the upslope substrate, trees planted low on a bankface may provide additional support for the bank.

~ The effects of surcharge can be exacerbated by wind. A staggered planting strategy is preferable to a single line of trees which may weaken the bank along a single axis in strong winds.

Carefully select the type of vegetation to use

Native species

There are some native vegetation species that are particularly useful in controlling erosion because they

~ grow right at the waters edge, and into the water, thus protecting the bank face;

~ produce a dense mat of adventitious roots;
~ are flexible and rapidly recover following floods.

Some of the most useful species are

~ *Eucalyptus camaldulensis* (river red gums)
  The river red gum can grow close to the water line and is the most common riparian Eucalypt in lowland Australian streams. Although it has the highest root to shoot ratio of all the eucalypts, its root matrix is not nearly as dense as that of willows. (This is not the case in the rare situation where its roots are exposed on the bank and these are then inundated for long periods. In this situation the roots can develop a dense mat of fine roots that are erosion resistant.)
~ *Phragmites spp.*
  These emergent macrophytes develop a dense mat of roots on the bank face and close to the water line, although the roots are not as strong as those of willows. *Phragmites spp.* can be inundated for a few weeks.

(Note: Raine and Gardiner provide detailed information on the characteristics of eight plant species with great potential for stabilising banks, and replacing willows in parts of New South Wales, see reference list at end of guideline for details.)

River red gums, *Eucalyptus camaldulensis*, during a period of inundation. Photo by Murray Fagg, courtesy of the Australian National Botanic Gardens.

Willows

In the northern hemisphere, willows are extensively used to stabilise banks against the forces of erosion. Since European settlement, willows have also been planted in Australia for both aesthetic reasons and in order to combat erosion. However, in Australia, many species of willows can invade streams and rivers and exacerbate the problems they were intended to overcome.

In recent years, following introduction of both sexes of some willow species, there have been massive seeding events with millions of new seedlings now choking entire channels and their sand bars.

Where headcuts have progressed up the bed of the river and are held by dense willow roots, the bed of the river will actually be scoured between the willows. Removing willows in these cases will almost certainly lead to bed erosion as these headcuts progress up the bed. Total deepening can be estimated from the cumulative height of the falls over several willows. If the depth of likely bed scour cannot be tolerated, as measured by the fall over the willows, consider replacing them with appropriate bed-control structures.

Remember, however, that willows can also act as a weir across a stream, building up the bed by trapping sediment. The willow then creates a drop in bed-level below the build-up that resembles a headcut. Removing willows in this case is less likely to lead to bed erosion than in the former case, but it will lead to a pulse of sediment moving down the steam when the willows are removed. Artificial removal of the sediment trapped above the willows could be considered in extreme cases. The degree of scour and deposition can be determined by probing the bed above the willows and checking whether the changes in bed-level are controlled by deposition or scour. If in doubt, it is reasonable to assume that it is caused by scour, and you can expect erosion to occur.

Assess the way in which particular stands of willows affect the local environment

Willows can be protecting stream banks from erosion, and their removal should be considered in relation to the cost of your revegetation program. Table 1 prioritises which willows to remove according to the way in which they are affecting the local environment.

Priorities for removing willows

Priority	Description	Comment
Very high	All willows identified as species and hybrids that are supplying seed or large amounts of branches/twigs to the river	Most willow species in New South Wales can produce seed and branches but *Salix nigra* is the worst offender for seeding and *Salix fragilis* is the worst offender for production of branches and twigs. Note: special training is needed to identify willow species and hybrids. Remember that 'offending' willows may be located up to 30 km away as willow seeds are transported by wind as well as streamflow (see Cremer).
High	Willows in river beds and on bars that are obstructing and diverting flow	Immediate physical benefits
Medium	Willows on alluvial banks on straight reaches of rivers in equilibrium	No physical benefit but has a long-term ecological benefit
Low	Willows on alluvial banks on all outside bends and on straight reaches of degrading rivers	Costly and time-consuming with no physical benefit, risk of starting accelerated erosion but a long-term ecological benefit

- ~ In smaller streams, willows can often be holding several metres of head-cuts in their roots. These need to be identified and managed.
- ~ The general rule with willows in larger streams appears to be that they should be removed wherever possible, so long as removal does not trigger major erosion, and so long as they will be replaced quickly with native vegetation. Ecologically, native riparian species are better than willows, which are better than nothing. It will only take about 3–4 years for dead willows to rot away in streams.
- ~ Not all willows are a problem. For example, shrub willows (unlike tree willows) can be shaded-out by native tree species and possibly don't need to be removed.
- ~ In a retard field, willows grown between the retards are very successful at trapping the fine sediment that is essential for growing native plants. With no willows it may be difficult to trap this fine sediment. In gravel bed streams without willows or some other vegetation type, the dominant sediment deposited behind the retards is gravel or coarse sand. Willows tend to be better than native tree species as primary colonisers of this sediment. When the fine sediment is established, the willows can be progressively replaced by natives.
- ~ Willows can be useful on aggressively eroding outside bends where further erosion would result in the loss of native riparian vegetation and other assets on the stream bank.
- ~ In many cases willows have been planted to control stream erosion in the belief that their ability to sprout and grow quickly from planted canes was unique. However, it has now been shown that a range of native plant species can be grown as long stems suitable for water-jetting into the bank, and are capable of rapid establishment and root growth. These species are preferred over willows for many situations due to their ecological benefits.

If the decision is made to remove willows

On channel beds and bars, and on bedrock banks, all the willows can be completely removed (roots included) in one operation, provided that

Willows as a dominant species in the riparian zone, ACT. Photo by John Baker, courtesy of ACT Waterwatch

~ individuals in the bed are not controlling bed degradation (if they are preventing degradation, consider installing bed control structures before willow removal);

~ there are other trees along the stream to provide shade and other ecological benefits (if not, consider establishing native plant communities on adjacent land and waiting at least 10 years for them to mature before removing the willows).

On long lengths of channel that have aggraded due to the build up of sediment around the willows, their removal would need to be considered in segments of no more than 1 km per year. If too much sediment is released at once, the resulting sediment slug may choke the river channel downstream. Alternatively, the sand and gravel can be removed from the river at the same time as the willows and sold to help pay for the cost of the operation. An example of this type of operation is located on the Fish River at Bathurst, New South Wales. Here, the full cost of the willow removal was covered by the sale of the sand and gravel that had deposited in the river over many years. However, care must be taken to ensure that extraction does not lower the river bed below its pre-aggradation equilibrium level.

On alluvial banks, on equilibrium or aggrading inside bends, and on straight reaches, all of the willows can be replaced in one operation provided that

~ replacement native species are planted immediately and maintained until well established;
~ the willow roots are retained to hold the banks until the replacement trees mature;
~ there are other trees along the stream to provide shade and other ecological benefits (if not, consider establishing native plant communities on adjacent land and waiting at least 10 years for them to mature before removing the willows); or
~ the willows are immediately replaced with permanent structural erosion controls in locations where flow energies are too high for native plants to survive.

On alluvial banks, on all outside bends, and on straight degrading reaches, the willows can be phased out provided that

~ they are killed in strips of three phases along the bank with an interval of at least five years between phases to allow the replacement trees/shrubs to become well established—this reduces the length of bank exposed to erosion;
~ the roots are retained to hold the banks until the replacement trees mature; or
~ in locations where flow energies are too high for native plants to survive, the willows are only replaced after the installation of permanent structural erosion controls (this can be done to the whole site at once).

At particular sites and in other circumstances (for example, on outside bends, areas of high flow energy, or where there is no money for structural erosion control)

~ consider maintaining the willows so that their potential to control erosion and protect native vegetation is retained.

Phragmites growing over the bank of the Murrumbidgee River helping stabilise it against scour. Note also the protection from tree roots and the contrast with the vertical bank on the outside of the bend. Photo by Ian Rutherfurd.

Macrophytes

There are many emergent macrophyte species in Australia. Three important ones are described below.

Phragmites australis, the Common Reed, is native to temperate eastern Australia, north as far as Mackay, and west to South Australia. A different species, *Phragmites karka*, with similar characteristics, occurs in northern Australia. While *Phragmites australis* has been dramatically reduced by grazing. It is probably the best reed for bank protection because it

~ is rhizomatous (that is, it grows from roots as well as from seed);
~ develops a long-lived network of underground stems, which can travel for several metres;
~ produces a mat of surface roots;
~ can grow to a depth of 2 m into the water, depending on the flow, and protect the bank at the soil/water interface;
~ will grow up the bank, some distance from the water edge, providing protection from flood flows;
~ provides valuable aquatic and riparian habitat; and
~ makes an important contribution to the sediment and nutrient trapping function of riparian vegetation.

Location of planting and management of Phragmites

~ Phragmites is able to control erosion on any bend where it can be established (that is, where the banks are not too steep), and is especially effective where the erosion is caused by wave action.

~ It is particularly appropriate on medium to large streams where it will be unable to choke the channel. It is not recommended for small or aggrading streams where flooding due to loss of channel capacity is likely to be a problem.

~ Phragmites can survive moderate rates of scour, but is unsuitable as the only form of protection in a severely eroding site.

~ Phragmites can be very effective in stabilising the floors of gullies, and accelerating the natural recovery of a stable channel within a gully. The reed will trap sediment and raise the floor level significantly, provided some access to moisture is available year round.

~ The planting position depends on the flow regime of the stream. Phragmites should be planted at a level which is least likely to dry out, or be deeply flooded, for a few months after planting. For example, on a stream with a maximum winter-spring flow, planting should be high on the bank in autumn, in anticipation of a water level rise, and lower on the bank in spring or summer, when the water level is likely to fall. The leafy stems will die if submerged for more than 10–15 days, and rhizomes must be sufficiently developed to support new growth. Control of grazing is essential for establishment and persistence, because Phragmites is very palatable.

~ Banks should be fenced sufficiently far back to allow spread of the Phragmites back from the edge, to obtain maximum stabilising effect. Shading by associated tree and shrub planting will prevent Phragmites from completely dominating the riparian zone.

~ The time needed to establish dense reed beds will depend on the site. On high nutrient soils, mature stands will develop within a few years. On lower fertility sites, growth will be slower and reeds will not be so tall and dense. On these sites, maximum development may take up to 10 years. Density of planting will also have some influence. On high nutrient sites, or where reeds are fertilised at planting, large plants spaced 1 m apart will close up within two years. On poorer sites, planting at 30–50 cm spacings is suggested.

~ Phragmites can slow flow and increase flooding, although it tends to lie down in high flows which may actually reduce resistance. Dense stands, however, do trap a large amount of sediment, and this can affect flood levels.

Typha (Cumbungi) will only grow in deep silty sediments below the water margin. It is good for bed stabilisation, but does not protect the bank from flow. Because it tends to grow in low velocity streams, and only down the middle of the channel, it deflects the water against the bank. (Phragmites will also do this if the banks are heavily grazed.) Cumbungi is good for protecting against wave action in lakes, although it is not as resistant to scour as Phragmites. Cumbungi is also less drought resistant, and needs longer flooding (although *Typha domingensis* is more drought resistant than *T. orientalis*).

Lomandra longifolia is a common species along the margins of coastal streams in north-eastern Australia. It is resistant to scour but does not grow below the water line, so protects only the upper bank from floods.

Lomandra longifolia. Photo courtesy of the Australian National Botanic Gardens.

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GUIDELINE D

Ian Prosser, Linda Karssies, Ralph Ogden, Peter Hairsine

Using buffers to reduce sediment and nutrient delivery to streams

Management objective

To reduce the amount of sediment and nutrient delivered to streams in order to sustain water quality, protect native instream biota, and help to maintain flow capacity.

D USING BUFFERS TO REDUCE SEDIMENT AND NUTRIENT DELIVERY TO STREAMS

Nature of the problem

Under natural conditions, sediment and nutrients are transported from land to water in runoff and in groundwater. Vegetated riparian land, by acting as a 'buffer', plays an important role in moderating this transfer. When riparian vegetation is cleared for agriculture, for some other human purpose, or by natural catastrophe, the ability of riparian land to act as a 'buffer' is diminished, and the rate of transfer of sediment and nutrients from land to water is accelerated.

The increased rate of delivery of sediment and nutrients to water can cause stream sedimentation problems (with associated changes in the capacity of channels to carry flow and the consequent potential for flooding) as well as the loss or degradation of aquatic habitat. Accelerated delivery of nutrients to streams can also lead to eutrophication of waterways and the excessive growth of nuisance aquatic plants (see also Volume 1, Chaper 5).

Summary of the issues

Several features of healthy riparian land (such as dense vegetation cover, deep, organic, permeable soils and typically low gradients) combine to form a buffer which moderates the delivery of sediment and nutrients to streams by absorbing runoff, trapping sediment and nutrients, and absorbing nutrients from groundwater. Nitrogen and phosphorus are the two main nutrients of concern for managers. These nutrients are generally attached to, and carried by, sediment. Rather than dealing with nutrients or sediment in isolation, managers must recognise the inseparable nature of the two factors and develop management strategies accordingly.

~ Agriculture can accelerate erosion and nutrient loss and provide both a diffuse source and a point source of pollutants for streams, however, it is not the only source of pollutants to streams. Erosion of stream banks, channel beds and connected gullies is a source of pollutants (how to control erosion is dealt with in Guideline C). Understanding the source of pollutants—that is whether they are from stream channels and gullies, from hillslopes or from groundwater—is important in determining the appropriate management strategy. A questionnaire designed to help determine the source of sediment and nutrients in particular situations, is provided at the end of this guideline. (Note: These guidelines do not address point sources of sediment and nutrients.)

~ Riparian buffers can reduce sediment and nutrient loads arising from hill slope sources or from groundwater; they do not influence (at least directly) those arising from bank and bed erosion.

~ When determining the source of sediment and nutrients it is important to remember that comparisons are useful in ranking the issues and prioritising actions, but the rankings will not be highly accurate. Remember also that inter-regional comparisons require care because, for example, the rate of surface erosion may naturally be higher in tropical, semi-arid environments than it is in humid temperate environments, and, in both cases, the rates may be outweighed by channel erosion processes.

~ In all cases, it is far easier to manage a low intensity source than a high intensity source. Riparian buffers can trap and store sediment and nutrients from overland flow only if the incoming overland flow is diffuse and less than approximately 1 cm in depth. This is the case where the flow spreads out into many different pathways over the slope and threads its way between the grass and litter, rather than swamping the grass or pushing litter out of the way.

- Anything that confines the flow, or deflects it around vegetation, will increase flow velocity and reduce the extent of trapping. Clumpy vegetation (such as tussock grass), tree trunks, roots, and topographic hollows can act in this way. Thus, grass buffer strips are more effective in trapping sediment and nutrient than are forested strips. (Of course, despite this, riparian forests have many other ecological benefits—including the fact that they promote the infiltration of runoff through the soil into groundwater.)
- There will be little deposition on poorly vegetated riparian land with a gradient greater than 5%; and such land is often an additional *source* of sediment. Because of this, smaller source streams, which generally drain approximately 70% of a catchment, are a major source of sediment.
- The main nutrients of concern which are carried by groundwater are dissolved nitrogen (in the form of nitrate) and, in sandy soils, dissolved phosphorus (in the form of orthophosphate). There is probably little prospect of trapping orthophosphate in riparian soils unless a large proportion of the groundwater is transpired by riparian vegetation and prevented from reaching the stream. (It is possible to absorb orthophosphate if the riparian soils are more clayey than the sandy soils upslope, but this is an unusual circumstance.)

Deposition in a grass riparian buffer downslope of a ploughed paddock.
Photo by Ian Prosser.

- There are greater prospects for absorbing nitrate transported by groundwater. Riparian soils can transform nitrate to gaseous nitrogen, thus removing it from groundwater. This process is called denitrification. It can occur if the gradient of riparian land is low enough, and the distance through the riparian land is long enough, to allow sufficient time for the slow chemical reactions to take place. This probably requires land with a gradient of less than 5% for a distance of at least 50 m before the stream.
- Denitrification also requires anaerobic conditions (so gradients and stream incision need to be low enough to allow for at least seasonal soil saturation) and soil with moderate amounts of organic matter (to provide food energy for the microbes that convert nitrate to gaseous nitrogen). Soil rich in organic matter is a common feature of riparian forests. Nitrate may also be absorbed directly as a nutrient during vigorous growth of riparian vegetation.

Critical factors

- Source of sediment and nutrients
- Location of vegetation
- Width of buffer strip
- Species
- Stock management
- Complementary engineering works
- Overall farm management

Guidelines/strategies

Buffering hillslope sources

Source of sediment and nutrient

Identify all areas of diffuse overland flow that are also problem areas for sediment and nutrient generation—such as agricultural land with straight slopes, or areas where spurs and ridges approach a stream.

Location of vegetation

Addressing this critical factor requires consideration of terrain, soil type, land use and stream order. It also requires consideration of where to use grassed waterways as buffers for concentrated overland flow.

~ Preserve existing riparian vegetation and plant native trees from the stream bank top for 10 m or more back from the top of the bank.
~ Try to keep existing ground vegetation cover. Grasses that may compete with the tree seedlings should only be removed from the immediate base of the seedling.
~ If diffuse overland flow passes over riparian land with a gradient of more than 5%, a dense continuous groundcover of vegetation will be required to trap sediment and nutrient. This will involve maintaining or planting a purpose-built grass buffer strip at the outer edge of riparian land. Trees should still be planted—or maintained—along the stream bank in order to obtain ecological benefits (for example, from shading). The grass filter strip may have to be set back from the trees to avoid shading and competition from the trees.
~ Grassed waterways should extend upslope in any situation where one hectare or more of land drains through a single streamline. Streamlines with catchment areas greater than one hectare need permanent dense grass cover to protect the surface from rill and gully erosion.

Width of buffer strip

The width of a buffer strip is measured perpendicular to the stream. The chosen width will reflect the intensity of source, the topography, and whether the buffer is to protect streams from groundwater or surface water sources.

~ For the purposes of filtering out sediment and nutrients, aim for a buffer width of at least 10 m for a forest buffer on low gradient land, and 5 m for a dense grass buffer on steeper riparian land. Wider buffers are only necessary if there is an extremely intense source of sediment, such as might occur in the wet tropics where surface erosion rates are greatest. Where possible, however, it is more efficient to reduce the intensity of the source.

~ Where overland flow is funnelled into narrow (less than 3 m) streamlines several centimetres deep, it is not possible to trap large quantities of sediment, particularly fine sediment, using grass filter strips. In these situations, a grass waterway needs to continue up the hillslope hollow for a width of at least 10 m (see diagram) so that overland flow hits the grass before it is confined, and deposits sediment at the edge of the waterway.

Species

In general, dense grass will provide a more effective buffer on steeper riparian land, and in association with the most intense sources. Trees provide ecological benefit in all situations. A combination of both should be considered.

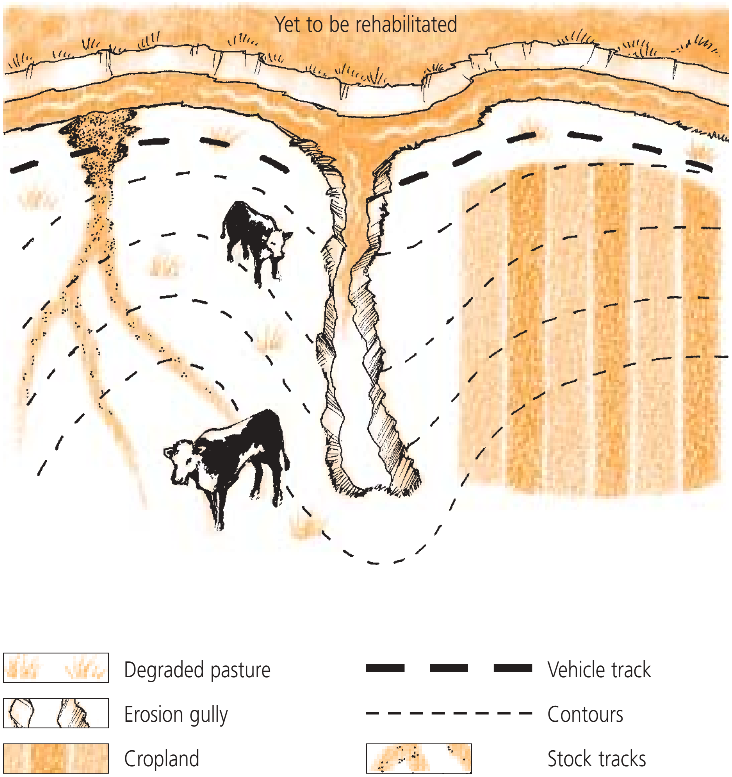
~ Establish grass with a spreading rather than a tussock or bunch habit. Existing tussock or bunch grasses should be removed and replaced with seed of perennial spreading grasses such as *bracciarri*a, couch, or buffalo grass. Occasional slashing may be required to maintain both dominance of the desired species and a dense groundcover. There are probably few benefits in allowing grass to exceed 20 cm in height.

~ For areas of most intense runoff, hedges of upright grasses or other dense species can be used in the waterway to trap additional sediment.

Stock management

In general, control stock in such a way as to avoid damage to the soil, nutrient-loading in streams and degradation of vegetation.

~ Stock access to buffer strips needs to be carefully controlled because: stock tracks confine runoff; grazing reduces vegetation cover; and, stock are a source of concentrated nutrients. Strategies for stock management in riparian lands are provided in Guideline G. A grass buffer strip can be used, if necessary, as a periodic fodder source. To prevent damage to the soil surface, stock should only be allowed on the buffer strip when the soil is relatively dry. Stock should also be excluded in seasons with a high probability of intense runoff. Grazing needs to be managed carefully in order to maintain dense groundcover.



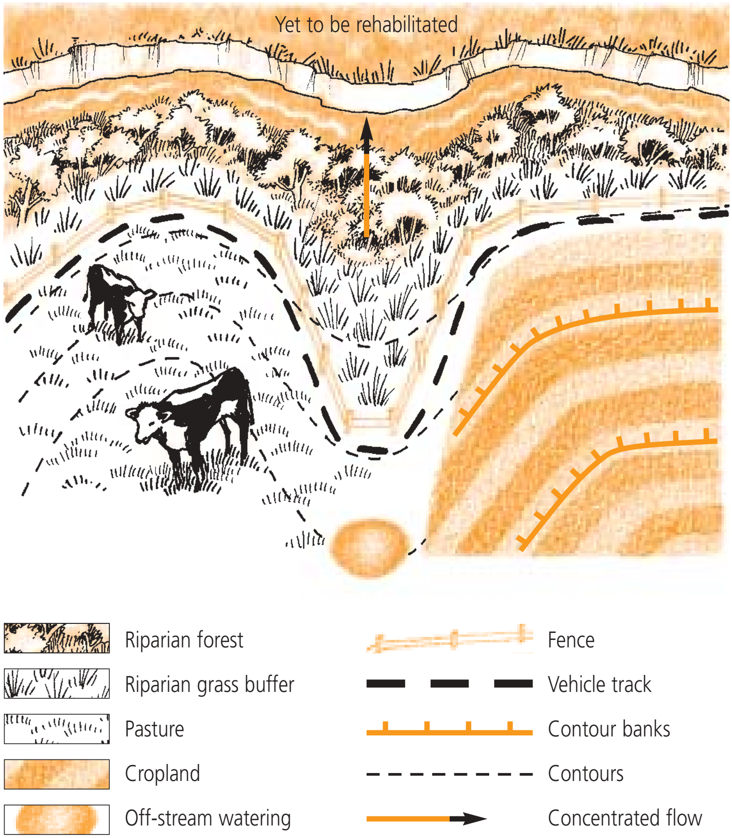
A degraded catchment and riparian land. Significant sediment and nutrient is derived from degraded pasture, poor crop management, unlimited stock access and gully erosion.

Complementary engineering works

Contour banks, farm dams, and hedges of upright grasses or other dense species may be needed in areas of concentrated flow.

~ Where engineering work is appropriate (for example, where confined runoff results from road and laneway drainage, stockyards and stock tracks), drainage should be set back at least 30 m from the stream. Runoff should be allowed to disperse immediately downslope of the source and then pass through a grass filter strip (see diagram).

~ Forest buffers are probably not capable of trapping significant amounts of sediment from confined sources. Additional structural works can help cope with intense confined sources.



A combination of good on-farm management and good riparian land. Riparian forest provides ecological benefits and absorbs nutrients, variable width grass buffers trap sediment and stock access is limited.

Such measures might include farm dams, settling ponds, wetlands, contour banks, straw bale barriers, and sediment control fences.

Buffering groundwater sources

Groundwater is usually the predominant source of nitrate in streams. The main function of a riparian buffer to improve water quality from groundwater sources is to remove nitrates from the flow.

Two zone tree and grass riparian buffer near Mt Barker, South Australia. The belt of trees also functions as commercial timber. Photo by Ian Prosser.

Source of sediment and nutrient

Use the questionnaire at the end of this guideline to identify sites of probable groundwater and nitrate input. Riparian land at these sites should be planted with trees or deep-rooting perennial grasses. This vegetation serves two purposes.

~ First, vigorous growth of the vegetation will absorb nitrate and orthophosphate.

~ Second, the development of organic soils associated with these vegetation types promotes the denitrification process that removes nitrate from the flow.

Location of vegetation

Focus on planting riparian vegetation in areas of low relief and low gradients in riparian land. (These will tend to be sites where groundwater flow is slow enough for significant denitrification to take place before the water reaches the stream.) This will tend to focus management on the larger streams with associated extensive valley flats. Choose sites that experience seasonal saturation of the soil, which promotes denitrification.

Remember that riparian management is less likely to remove nitrates from groundwater in semi-arid environments where soils are almost permanently dry, or in areas where there is rapid sub-surface stormflow. This would include steep slopes with shallow, open-structured soils.

Revegetation of a buffer strip in the wet tropics, Johnstone River, Queensland. Photo by Michael Askey-Doran.

Note that deeply-incised streams may receive groundwaters from below the root zone of trees and, while this water will not be exposed to denitrification from riparian land, it may undergo denitrification in sediments underneath the stream bed, regardless of riparian vegetation.

Width of buffer strip

Establish buffer strips at least 10 m wide, measured back form the top of the bank. This is the distance over which most improvements have been measured in groundwaters that flow less than 1 m per day. In faster flowing groundwaters, greater benefits will be experienced with buffer strips of 50–100 m width. The practicalities of reserving this much land need to be weighed up against the importance of nitrate removal.

Stock management

Concentrated point sources of nitrate in groundwater, such as stock yards or dairy feedlots, merit special treatment. The loading of nitrate from these sources is likely to exceed the denitrification in natural riparian soils. It has been demonstrated that the natural processes of denitrification can be enhanced by digging a trench that intercepts the groundwater flow. This trench can then be backfilled with a source of organic matter (such as straw). Clearly this is impractical for large areas of diffuse sources.

Overall farm management

Improved on-farm management may reduce the intensity of overland flow, groundwater flow, and sediment and nutrient loads.

Low impact harvesting of grasses and trees in riparian vegetation that has been planted for nutrient retention needs to be avoided. This is because such activity causes the nitrogen and phosphorus that is being absorbed by plants to be recycled back into the soil.

To minimise surface compaction and sediment generation, harvesting (for example, grazing of grass or felling of timber) should take place when the soil is dry. To minimise the time when there is little tree cover and little nutrient absorption, it is preferable to use selective logging of trees rather than clear felling. Selective logging also reduces ecological impacts.

Intact riparian zone as part of an overall farm management strategy. Gudgenby River above Glendale Crossing, ACT. Photo by John Baker, courtesy of ACT Waterwatch.

Sediment source questionnaire

Part A. Stream channel and gully sources

This part of the questionnaire asks you to consider the history and other characteristics of gullies and eroded streams in your catchment in order to assess the potential risk (rated on a sliding scale from low to high) of stream channels and gullies being sources of sediment and attached pollutants.

1. Have gullies incised into valleys and hillslopes in living memory?

No	Frequent or small changes to channels	Massive channel incision and gully erosion
Low	Medium	High

2. Are gullies and channels eroded into

Well aggregated soils	Poorly structured or sandy soils	Dispersive, clayey, sub-soils
Low	Medium	High

3. What is the vegetation cover on the gully and incised channel walls?

Complete groundcover	Some bare patches	Completely bare
Low	Medium	High

4. When did the gully erosion and channel enlargement first start?

No enlargement	Last century	Last 20 years
Low	Medium	High

Scoring: If you record a rating at the high end of the scale for two or more factors, gully and channel erosion are likely to contribute to poor water quality in your catchment. Of course, the other two sources dealt with in the questionnaire may also be important.

Part B. Hillslope surface sources

This part of the questionnaire asks you to consider the landuse and erosion characteristics of hillslopes in the catchment in order to assess the potential risk (on a sliding scale from low to high) of them being a source of sediment and attached pollutants.

1. Does landuse involve

No tillage and no over-grazing	Minimum tillage/ some overgrazing	Annual traditional tillage/extensive over-grazing (bare ground)
Low	**Medium**	**High**

2. Is your catchment located in

Mediterranean climate areas of southern Australia	Sub-tropical and semi-arid areas	Wet tropics and wet-dry tropics areas
Low	**Medium**	**High**

3. Is agriculture in the catchment practised mainly on

Slopes of less than 5% or extensive alluvial flats	Gentle hillslopes with no alluvial flats	Moderate to steep slopes with no alluvial flats
Low	**Medium**	**High**

4. Are the soils used for cropping

Well aggregated	Sandy or weakly aggregated	Dispersive, slaking or silty
Low	**Medium**	**High**

Scoring: If you record a rating at the high end of the scale for two or more factors, hillslope surface sediment sources are likely to contribute to sediment and nutrient delivery and, thus, to poor water quality.

Part C. Sub-surface flow sources

This part of the questionnaire asks you to consider the landuse and soil factors that often lead to significant phosphorus and nitrogen reaching streams from groundwaters.

1. Are the soils

10% sand	30% sand	90% sand
Low	Medium	High

2. Are the subsoils

Sealed and clayey	Moderately clayey, with small cracks	Sandy or extensively cracked clays
Low	Medium	High

3. Does the catchment landuse involve

No irrigation, drains or gullies	Infrequent irrigation, some gullies or constructed drains	Intensive irrigation with dense drainage networks (natural or constructed)
Low	Medium	High

4. Does the land management involve

No fertiliser application, low stocking	Low fertiliser application, intensive stocking	High fertiliser application, intensive feedlots
Low	Medium	High

Scoring: If you record a rating at the high end of the scale for two or more factors, groundwater nutrient sources are likely to contribute to poor water quality.

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GUIDELINE E

Michael Askey-Doran

Managing and rehabilitating riparian vegetation

Management objective

To manage intact and degraded riparian vegetation in such a way as to obtain the multiple benefits offered by that vegetation.

E MANAGING AND REHABILITATING RIPARIAN VEGETATION

Nature of the problem

The condition and extent of native riparian vegetation along Australia’s rivers and streams varies greatly. There are extensive areas dominated by native riparian vegetation, but there are also extensive areas that have been cleared, where the vegetation is fragmented, or where the vegetation has been largely replaced by introduced species. Where remnant native riparian vegetation occurs in agricultural regions, it is often confined to narrow strips or is part of ‘bush run’ country used for grazing. Whilst much attention has been given to rehabilitating the badly degraded areas, remnant riparian vegetation has generally been left to look after itself. In many cases, it is gradually being degraded through overgrazing, high fire frequencies and weed invasion. This is occurring despite the fact that healthy riparian vegetation can help to

~ limit streambank and instream erosion;
~ trap sediment, nutrients and other contaminants before they reach the waterway;
~ contribute to healthy terrestrial and aquatic ecosystems;
~ provide essential habitat for terrestrial, riparian and aquatic species;
~ help control the growth of nuisance plants and algae;
~ enhance recreational and aesthetic values;
~ increase capital values.

In contrast, degradation of riparian vegetation can lead to
~ increased erosion of the stream bank and channel;
~ diminished water quality for stock and domestic use;
~ sedimentation;
~ loss of habitat for essential species;
~ algal blooms;
~ loss of amenity value.

Summary of the issues

Riparian plant communities are often more productive and more diverse than plant communities of adjacent uplands. This is a result of two factors: there is more water available; and riparian soils are richer in nutrients than are soils located further away from a waterway. Riparian vegetation contributes to microclimatic variation by influencing temperature, humidity and wind speed. The diversity of vegetation is generally most evident on broad river floodplains.

Flooding is the most common form of natural disturbance to riparian areas, although human activity—such as stock grazing, clearing and recreation—can impinge severely on riparian vegetation. Floodplain ecosystems tend to depend on disturbance; they exhibit instability at the sub-system level, but stability at the meta-system level.

The extent of disturbance dictates the successional processes that occur as plant communities recover. Regeneration of riparian vegetation depends largely on adaptive traits—such as water and wind-driven seed dispersal—and on the existence of microsites particularly suited to the species. Changes to, for example, flow regimes at micro-sites can limit riparian vegetation's capacity to recruit, establish and survive.

Riparian land is often the only significant remnant vegetation present in the landscape. Consequently it is important as habitat for both flora and fauna. This is especially significant for many rare and threatened species that rely on riparian land for refuge.

Large areas of riparian land in Australia are infested with exotic species. The nature of this land encourages invasion by weeds, although not all the weeds are detrimental to all native species.

Guideline E is divided into two sections. The first section covers management of riparian vegetation that is largely intact, but is potentially threatened by land-management practices. The second section deals with the rehabilitation of riparian vegetation.

Critical factors

~ Stock management
~ Weeds
~ Fire
~ Feral animals
~ Nutrients
~ Land use
~ Monitoring

I. Guidelines for managing largely intact riparian vegetation

The highest priority for managing riparian vegetation should be to protect areas in good condition. It is much more cost-effective to protect these areas than to rehabilitate them later because of poor management. Protecting areas in good condition provides benefits for water quality, the physical condition of the stream, and aquatic and terrestrial ecology.

Stock management

(See Volume 1, Chapter 10, and Volume 2, Guideline G, for advice about managing stock in such a way as to avoid damage to vegetation in the riparian zone.)

Weeds

Limit the opportunity for weeds to invade.

Riparian environments experience frequent natural disturbances, such as flooding. When these are combined with disturbances from adjacent land use, weeds can have a great opportunity to invade. Weeds in intact riparian vegetation can be controlled by

~ retaining a complete canopy cover for each of the different vegetation layers;
~ maintaining a riparian zone that is wide enough to retain some structural integrity (a minimum of 30 to 50 m);
~ avoiding disturbance to the riparian zone resulting from, for example, fire, vehicular access and clearing;
~ excluding stock from the riparian zone.

Weeds can also be controlled by regular spot-spraying or removal by hand. This can be done every two or three years until the problem is resolved. Only herbicides registered for use along waterways should be used. Care should be taken not to disturb the natural vegetation unnecessarily as this will encourage further weed invasion.

In general, if intact riparian vegetation is kept in a healthy condition weeds should not be a problem.

Fire

Fire is an important component of the Australian landscape and is often used as a tool in vegetation management. Much of the Australian flora is adapted to fire; some plant communities are fire-dependent. There is little information available about riparian vegetation's response to fire, although we do know that the response varies according to vegetation type, climate and management practices.

While fire can be a useful tool, it is also a serious threat to the integrity of riparian vegetation. In most instances, fire exclusion rather than use, will be the management aim.

Fire should only be used in riparian land under special circumstances. Its use should be carefully managed and its reason for use carefully considered, as there may be more appropriate options available.

Due to the moist environment, fire is uncommon in riparian land. Many riparian species do, however, possess mechanisms that allow them to regenerate following fire: dycotyledenous genera from the Myrtaceae, Proteaceae and Fabaceae and the monocotyledenous genera *Lomandra*, *Poa*, *Themeda*, *Lepidosperma*, *Carex*, *Phragmites*, *Typha* and *Dianella* all contain species that are able to recover vegetatively following fire.

Many species may be able to recover following fire, but they may not necessarily benefit from it. Fire can initially reduce vigour and flowering potential, and alter patterns of dominance within vegetation types. Few species can tolerate frequent burns, which inhibit successful regeneration as new growth or seedlings are killed by the next fire. Over time, frequent fire can exhaust the soil seed store, resulting in the removal of particular species from a site. There are also species that are sensitive to fire; river red gum (*Eucalyptus camaldulensis*) is an example.

In managing riparian vegetation, fire may be used

~ to reduce fuel loads and so protect economic and natural assets;
~ in combination with herbicides and/or grazing, to control weeds;
~ to encourage the growth of 'green pick' for stock;
~ to stimulate the germination of particular species (for example, members of the Fabaceae);
~ to reduce the inhibiting and competitive effects of particular species, allowing regeneration of other species;
~ to maintain a particular level of diversity within a vegetation community.

The following points should also be considered before using fire as a management tool.

Riparian vegetation being burnt (mainly *Pandanus spiralis*), Kapalga, Kakadu National Park, Northern Territory. Photo by Michael Douglas.

Understand the fire response of a particular vegetation community or species.

This is especially important where fire-sensitive communities or species exist and in areas where rare or threatened species are present. Understand the fire history of the site. It is important to know how frequently the area has been burnt in the past as there may be a need to actively exclude fire.

~ Consider the timing of the burn, weather conditions, the soil moisture level, the condition of the vegetation, and the probable intensity of the burn. For example, summer burning in temperate regions has been found to be deleterious to *Phragmites australis* and *Typha* spp.

~ Allow sufficient time between burns so that plants can regenerate and the soil seed bank is replenished.

~ Relate fire intensity to the management goal and the environmental conditions. For example, a fuel-reduction burn may be less intense than an ecological burn; their outcomes also differ.

~ Design burns to increase the diversity of current vegetation patterns. Vegetation that has experienced a history of burning often contains a mosaic of patches of different ages. These patches are important for a variety of reasons, among them community and species diversity, the capacity to respond to disturbance, and as wildlife habitat.

~ Minimise the risk of wild fires. Prescribed burns should be organised with particular conditions, such as fuel load and frequency, in mind. They should not be carried out on an ad hoc basis. It is important to be sure that any natural or economic assets are not damaged or destroyed.

Remember that

~ fires that are too hot will kill plants outright;

~ fires that are too frequent will prevent regenerating plants from becoming established and setting seed and may ultimately exhaust the seed bank;

~ some plant species and communities are sensitive to fire and, if burned, will disappear from a site or have their composition or structure changed;

~ fuel-reduction burns designed to improve habitat for macro flora and fauna may be detrimental to micro flora and fauna such as litter and soil fauna and lower plants;
~ weed species can be encouraged by the disturbance and initial input of nutrients that result from fire;
~ fire can reduce the filtering capacity of riparian vegetation;
~ fire can partially or totally remove vegetation cover and affect the shading characteristics of that part of the waterway, with consequences for the aquatic habitat.

Site monitoring

Monitor the riparian zone regularly to reduce the risk of problems developing or becoming more serious.

Monitoring can be based simply on familiarity with a particular area and taking action when necessary. Many government agencies provide kits that landowners can use to assess the condition of their property, including the riparian zone. Such an assessment will provide the basis for continued monitoring of riparian areas. Regular monitoring of riparian vegetation should aim to detect
~ changes in species composition and the structure of plant communities;
~ the extent of recruitment and regeneration of native species;
~ changes in the composition and extent of weed species;
~ the health of native species.

II. Guidelines for rehabilitating degraded riparian vegetation

In developing a plan for rehabilitating riparian land it is important to have a clear set of objectives, which may involve restoring habitat values, reducing erosion, managing weeds, improving water quality, increasing farm productivity, or a combination of these things. It is important that rehabilitation ultimately results in enhanced, rather than reduced, natural values. Depending on the particular objective, a number of different aspects of these guidelines may need to be considered.

Revegetation should not be seen as a 'cure-all'; rather, it should form part of a wider stream-rehabilitation approach that takes account of hydrological, geomorphological, social and economic factors. Failure to consider these other factors could undermine the long-term success of revegetation efforts.

Assess the condition of the area to be rehabilitated.

This will involve documenting the vegetation's condition (the extent and health of both native vegetation and introduced species), the streambanks' condition, and the impact of adjacent land uses. The local community and experts in river management should take part in this process, which will include examination of detailed maps (showing native and introduced vegetation, areas of riparian pasture, the types of and extent of erosion, fenced areas and adjacent land uses and tenures), flora and fauna surveys, reviews of aerial photos and orthophoto maps, reviews of literature relevant to the site, and examination of hydrological information.

The level of detail for any assessment will be determined by the resources available to the group, the skills possessed by the group, and the scale of the project. The purpose should be to obtain sufficient information to meet management and rehabilitation objectives.

Conduct a local catchment survey.

This survey will be less detailed than the survey of the rehabilitation site and will provide information relating to land uses (such as gravel extraction, forestry and stream regulation) that might affect rehabilitation efforts. It will also provide information about the best species to use in revegetation, as well as the ecological requirements and relationships between different species.

A local catchment survey provides a good opportunity for gathering information about what the site was like before disturbance. The survey should concentrate on areas known to contain healthy, native vegetation that was probably present at the rehabilitation site. This may require a search of several different streams or tributaries to create a picture of what the rehabilitation site used to look like.

Make up a herbarium of plants occurring along the waterway, this will help landowners to become familiar with the different plant

Local community group using aerial photographs to assess where their catchment's management efforts should be directed. Photo by Michael Askey-Doran.

species. These streams and tributaries can become reference sites for the rehabilitation project. If the local catchment has been greatly altered it may be necessary to extend the survey to a broader area.

Collect other environmental information relevant to the rehabilitation of riparian vegetation.

This information can be collected from the reference site and might include data on climate, vegetation—channel morphology relationships, soil type and stream flow data, as well as information gained from reviewing aerial photos and orthophoto maps and any relevant literature.

Consult government agencies with an interest in land management.

Permits are usually required before any works on rivers can proceed. State and local government agencies can grant these permits and provide useful information, such as some indication of the typical species and communities that might have previously existed at the rehabilitation site and other relevant environmental information.

Ascertain the appropriate approach. In doing this, ask

1. are there any native species at the rehabilitation site?
2. are there intact stands of riparian vegetation nearby?
3. is uncontrolled grazing a problem?
4. what problems other than vegetation-related ones need resolution?

If the answer is 'yes' to the first three questions, the initial step will be to remove or reduce the grazing pressure in order to protect the remnant native vegetation. This can be done in a number of ways (see Guideline G), the most effective being fencing, with either a permanent fence or an electric one. It is worth fencing and then waiting to see if there is any regeneration of native species from the soil-stored seed bank. In some restoration projects natural regeneration has outstripped plantings and, in the long run, saved time and money.

If the answers to questions 1 and 2 are 'no' but the answer to question 3 is 'yes', stock will need to be excluded and the site will probably have to be planted with suitable native species.

Aim to mirror natural systems appropriate to the region.

This will involve identifying zones in which particular species occur. This can be done by using the information collected in the local catchment survey or may be available from local agencies or community groups.

Select species that suit the particular situation.

The priority should always be to replicate nature, but there will be many situations where this is not possible. Decisions will need to be made about what species are most suitable: using Australian natives not found in the area or using introduced species will affect the outcome of the rehabilitation project. These are important decisions, since quite a deal of effort is needed to revegetate sites and the species used will influence processes elsewhere on the waterway.

Work from the stream out.

It is important to resolve any problems relating to stream channel stability before embarking on revegetating the stream banks. Otherwise, much of the revegetation work might be wasted, for example, if channel widening continues.

If the decision is made to revegetate, consider the most appropriate technique for the site and resources.

Try to gather as much information about the species—flowering periods, time of seed set, germination requirements, typical habitat, and so on—that are present on or near the site to be rehabilitated and incorporate it in the revegetation strategy. Additionally, soil cores can be collected and placed in trays to see what germinates. This will provide some indication of the capacity for natural regeneration, as well as information about which species are likely to germinate. Some form of treatment, such as heat or smoke, may be required for the regeneration of some species.

Timing is important.

It is important to get the timing of the different stages of rehabilitation right. For example, don’t plant or direct seed if you need to take machinery onto the site for instream works at a later date.

Minimise disturbance during revegetation work.

Riparian land is sensitive to the use of heavy equipment and other forms of physical intervention, so it is important that careful planning precede actual site preparation and revegetation.

Monitor systematically, using a methodology that is consistent over time.

The level and nature of monitoring will depend on the expertise available. It may involve the use of photos of vegetation cover or the use of records of change at the individual species level, from seedling through to adult.

Most sites will need continuing maintenance for some years. This will include fence maintenance, weed control, replacing failed plantings, and the removal of any non-biodegradable materials used as part of the rehabilitation process.

Implement a weed-management strategy.

Weed management on riparian land requires careful consideration because of the potential to affect water quality and streambank and channel stability. Pesticide use has implications for aquatic environments: studies demonstrate adverse impacts on aquatic fauna such as tadpoles. Long-term management of weeds in both the riparian zone and aquatic habitats is often best done by maintaining healthy native bush with intact canopy, by limiting disturbance to the minimum, and by limiting the flow of nutrients to both habitats.

Before any weed eradication along rivers takes place, seek advice from the relevant agencies. They will provide information about the best methods for a particular situation and about health and safety considerations.

Natural regeneration

This method of re-establishing vegetation is especially worthwhile for individuals and groups with limited resources. The area can be fenced off, allowing natural regeneration to occur. This means further action can be delayed for a year or two; if the regeneration fails or is poor, direct seeding or planting seedlings can be considered.

Natural regeneration results from soil or canopy-stored seed or seed transported to the site by water, wind or animals. The areas to be revegetated are usually fenced to exclude stock and allowed to regenerate naturally. Some form of pre-treatment, such as a burn or herbicide treatment, may be applied to the site. As with other methods, the implementation of a long-term weed-management strategy is important.

Advantages

~ Natural regeneration is relatively cheap to establish, requiring only the cost of fencing and then continuing weed maintenance.
~ The labour requirement is minimal.
~ Natural regeneration can outstrip plantings.
~ Seedlings have well-developed root systems and tap roots and so are better able to cope with climatic extremes.
~ Natural regeneration mirrors the local flora and successional processes.

Natural regeneration should always be the first choice. It is cost-effective and utilises species which are adapted to the site.

~ Natural regeneration can result in vegetation communities that are diverse in composition and structure.
~ The method can be used in conjunction with other revegetation techniques.

Disadvantages

~ Successful natural regeneration usually requires a nearby source of propagules. These propagules will come from local plants, from vegetated areas upstream or from seed stored in the soil.
~ Regeneration can be patchy, either confined to one side of the stream or in patches along both sides. This is not necessarily a bad thing and may be part of the successional process, but if areas of bare ground persist, direct seeding or planting may be necessary.
~ Once grazing is excluded, weeds may become a problem if not treated.

Direct seeding

Direct seeding is regarded as an efficient means of re-establishing native vegetation. It is cost-effective compared with other methods—8 to 15 cents per stem compared with $1 to $10 per stem for seedlings (Harvey 1997)—and is relatively easy to do. A diverse mixture of plants can be established through direct seeding, the main limit being the availability of seeds. Seeds are broadcast, by either hand or machine, directly onto prepared ground.

Melaleuca bracteata. Photo courtesy of the Australian National Botanic Gardens.

Advantages

~ Direct seeding is relatively cheap—1 kilogram of seed can contain up to 2 million seeds for small-seeded species such as *Melaleuca bracteata*.

Direct seeding at Crocodile Farm in the Johnstone Catchment, Queensland. Top photo: March 1998, below April 1999. Photos by Pete Gleeson.

- Direct seeding requires less labour and time than planting seedlings.
- Large areas can be sown rapidly.
- Seedlings develop good root systems and tap roots, which means the plants will cope better with climatic extremes and will require little maintenance.
- A diverse seed mix can be sown, using trees, shrubs and groundcovers to mimic the natural situation.
- The mix of species can be varied for different soil types and different topographic conditions.

Disadvantages

- Direct seeding can be less reliable than planting seedlings, especially for small-seeded species.
- Results can range from prolific germination of a diverse range of species through prolific germination of one or a few species, to very little or no germination.
- Seed predation by ants can be a problem.
- Poor seasonal conditions, such as low rainfall, will affect germination.
- Poor soil conditions, such as heavy clay soils or highly erodible soils, will affect germination.
- Particular species require particular germination conditions.
- Requires careful pre-planning and site treatment for effective weed control.

Planting seedlings

Planting seedlings is the traditional method of revegetating areas and is widely used. As with direct seeding, site preparation is essential and will involve weed control and fencing. Plants can be propagated by a nursery and brought to the site when conditions are suitable. Propagation can be by seed or by cuttings. Another method, often used with tussock-forming species, is division, whereby plants are separated at their bases into parts and planted.

Planting seedlings by stepped technique, Bamboo Creek, Johnstone Catchment, Queensland. Photo by Pete Gleeson.

Advantages

- Techniques for seedling planting are well developed and generally produce reliable results.
- Plants have a 'head start' compared with direct seeding, and this provides instant satisfaction for the effort.
- The method is good for sites requiring fixed spacing of plants or where a particular species is needed in a particular space.
- Seedling planting can be done in combination with direct seeding and to provide back-up in areas or patches where the response has been poor.
- The method is useful for species that do not germinate readily and need to be propagated by cuttings or to have special treatment.
- It is a useful method in areas where access for machinery is limited.

Disadvantages

- Generally, the costs of seedling planting are higher than those of direct seeding and planting is more labour intensive. This assumes importance when large areas are to be planted.
- 'Transplant shock' may occur—seedlings may take a while to begin to grow following planting.
- The roots of seedlings are not as well developed as those of seedlings from direct seeding or natural regeneration.

Revegetated riparian zone following seedling planting, Bamboo Creek, Johnstone Catchment, Queensland, April 1999. Photo by Pete Gleeson.

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GUIDELINE F

Romeny J. Lynch and Carla P. Catterall

Managing riparian land for terrestrial wildlife

Management objective

To retain and/or restore riparian land in order to protect wildlife habitat.

F MANAGING RIPARIAN LAND FOR TERRESTRIAL WILDLIFE

Nature of the problem

Riparian areas are critically important to wildlife, but have experienced widespread clearing and degradation in Australia and elsewhere (see Volume 1, Chapter 1).

Loss and degradation of riparian wildlife habitat are occurring as a result of a wide range of threatening processes. These include clearing, grazing, draining and infilling of wetlands, weed invasion, water extraction for irrigation, instream contaminants (pollutants etc), changes in fire regimes, road construction, mining, and recreation. Of these, the first two have had the most severe and widespread impact upon wildlife.

Large areas of riparian vegetation have been cleared for intensive agriculture and other forms of development. Riparian lands are often preferred for production because they are moist and fertile. However, they are also key wildlife habitats. Widespread clearing has resulted in substantial losses of wildlife habitat and, in many cases, the areas of native vegetation which remain in cleared landscapes have reduced value for wildlife because of their fragmented nature. Loss of riparian habitat as a result of draining or infilling of wetlands has also been a cause of decline of many species.

About 60% of the Australian continent, mostly land around the centre, north and north-west, are rangelands used primarily for grazing.

The impact of grazing practices is often greatest on riparian lands because they are focal points where stock congregate to water, shelter and forage. Livestock can remove and damage ground vegetation by grazing and trampling, compact the soil and inhibit new plant growth, break down stream banks and reduce stream water quality (see Figure 1). Both the plant species and habitat structure of riparian vegetation may change dramatically after prolonged heavy grazing. Increased grazing pressure in the dry season or during droughts may exacerbate these effects. Riparian grasslands in northern and eastern Australia have suffered widespread degradation as a result of grazing and trampling by stock, feral pigs and horses.

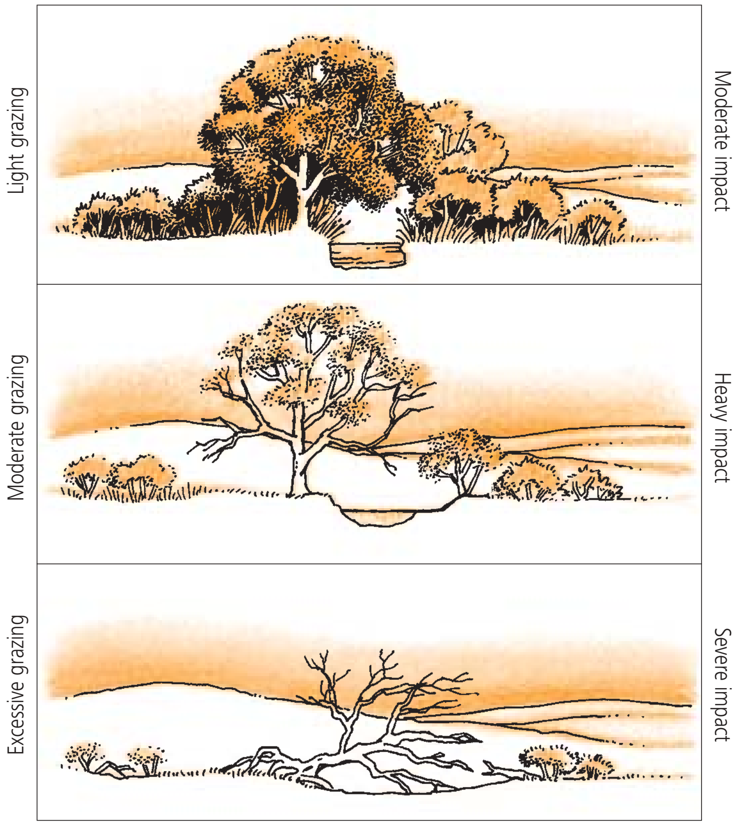

Figure 1 Heavy livestock grazing in riparian areas can eventually result in near-total collapse of the native riparian vegetation cover (after Thomas et al. 1979).

This degraded creekline in subcoastal Queensland shows the combined impacts of past clearing, drought and continued grazing. The surrounding tree cover has been reduced, the shrubby understorey and aquatic plants eliminated. The grass cover is moderate because of recent rainfall. Photo by C. Catterall.

In addition to direct effects on established plants, grazing may result in long-term degradation of vegetation by limiting tree recruitment. As mature trees die off, they are not replaced. Consequently, both the cover provided by saplings and young trees, as well as the tree hollows they provide that are important as nest and retreat sites, are lost.

A variety of other factors may reduce the value of riparian habitats for wildlife. Riparian lands are particularly susceptible to invasion by introduced weed species. Wildlife is little affected by many of these, but some may damage the vegetation structure and inhibit regrowth of native plants, thereby diminishing the area's habitat value. Extraction of water for irrigation of agricultural lands reduces the amount of surface and groundwater available to riparian vegetation and leaves less surface water available to animals. The effects of water abstraction may severely stress riparian plant communities during periods of drought. Use of chemicals such as fertilisers, herbicides and pesticides close to riparian areas can result in contamination or pollution of water sources, whilst overspraying and wind-blown contamination of the adjacent riparian habitats can have negative impacts upon riparian fauna.

A relatively intact watercourse in subcoastal Queensland. Standing water, snags within the waterway, aquatic plants, shrubs and an intact tree canopy provide diverse habitats for wildlife. Photo by C. Catterall.

Summary of the issues

Riparian lands provide particularly important habitat for wildlife because they have

~ a greater availability of moisture;
~ vegetation which is typically taller than the immediately surrounding vegetation, more dense and usually contains a greater number of plant species;
~ a greater availability and diversity of food resources;
~ a favourable microclimate without extremes of temperature and humidity;
~ a greater availability and/or higher quality of shelter and nest sites.

Native riparian vegetation is habitat for a wide variety of wildlife. Some semi-aquatic and terrestrial species occur only in riparian areas. Many species are not restricted to riparian habitats, but may depend on access to them on a daily or seasonal basis, at particular stages in their life cycles, or at times of environmental stress.

Animals move within their environment for many different reasons and over a range of distances and time scales. Some of these movements are important for the long-term maintenance of populations. Bands of riparian vegetation may function as corridors for wildlife movement. This role may be particularly important in drier regions where riparian vegetation is different from that of surrounding areas, and in landscapes where much of the original native vegetation cover has been removed for agriculture or development.

The nature of riparian zones, the kinds of wildlife which inhabit them, and the ecological processes involved in the relationships between wildlife and their habitat all vary immensely from one place to another. Some of this variation is biogeographical. For example, riparian zones in the channel country of central Australia function in a different manner, support different types of species, and are threatened by different processes from those in the wet tropical rainforests of the north. Other sources of variation include catchment position and stream order, and surrounding local vegetation type. For instance, in the upper catchment, streams may be seasonal or ephemeral and have narrow bands of homogeneous riparian vegetation, whilst in the lower catchment, complex and variable riparian vegetation may cover an extensive floodplain. In some regions, vegetation adjoining riparian areas is a complex mosaic of different vegetation types (for example, tracts of rainforest interspersed with eucalypt forest and heathland) and the way the riparian zone functions will vary among these habitats.

Critical factors

Before commencing any program that aims to manage riparian land for terrestrial wildlife, it is essential to clearly identify and state the specific management goals. These will vary considerably depending on both the history of human use and ecological disturbance within a target area and the region surrounding it, and the types and patterns of human use planned for the future.

Potential history-related goals vary widely. Examples include: managing recreation and possible weed invasion in riparian zones of large habitat reserves; improving the habitat value of naturally-vegetated stream banks within pastoral lands; or replacing native vegetation cover within areas that have been fully cleared for a century or more.

More specific ecological aims may include: creating a vegetated movement corridor for a wide range of common, but forest-dependent wildlife between two isolated, non-riparian forest remnants; creating a linear, vegetated riparian strip to provide habitat for wildlife that are riparian specialists; improving existing riparian habitat within the range of a threatened riparian-dependent species; or making some improvement to an area's wildlife habitat value while undertaking a project to stabilise stream banks and improve water quality.

Riparian zones are so varied that generalised animal-to-habitat relationships are often difficult to develop for these areas. Formulating a sound management plan requires a knowledge of the species which occur in the area (or which could reasonably be expected to occur if habitat were restored), how they use riparian areas, their specific habitat requirements and threatening processes. For many species, this information may not be known, but management plans can often be based on knowledge of key species that are present.

The specific guidelines that are applied for management, restoration or rehabilitation will depend on the particular goals of the project, which is why it is essential to clearly define these at the start of the project. Consultation with wildlife biologists familiar with local fauna and habitats is recommended.

Spatial scale and regional context are also essential elements of a riparian management plan, and should be considered when the project's goals are being formulated. These issues are particularly important in cases where clearing of vegetation has been the major threatening process. For example, a project might be underway to restore a 200 m wide buffer of natural vegetation along a 1 km length of stream. If there are no other areas of natural habitat nearby, then the restored riparian buffer is likely to have much less wildlife habitat value (because many species are unlikely to reach it, and even if they did it would be too small to meet their needs) than if there were forest remnants nearby. Its value could be even greater if it was located in such a way that at least one if its ends was linked with an existing vegetation remnant, or if it ran adjacent to the remnant.

Rehabilitation and revegetation efforts by individual property owners may be limited by the size of their property, the length of stream frontage on it and financial resources. In many cases, enhancement of riparian habitat for wildlife at the property scale is likely to be a secondary consequence of actions taken for other primary goals (such as stream improvement). However, with careful planning, riparian management undertaken to achieve other goals can be of substantial benefit to wildlife at little or no extra cost.

Useful questions to consider as a background to setting goals for riparian habitat restoration in cleared sites include

~ what proportion of the region around the site is vegetated and where do the areas of vegetation occur?
~ what nearby areas of native riparian vegetation exist, and what condition are they in?
~ what nearby areas of other native vegetation exist, and how large are they?
~ what is the tenure and management of riparian and other areas in, adjacent to, and near to the site under consideration?

Useful questions to consider as a background to setting goals for riparian habitat management in rangeland sites include

~ what is the condition of riparian vegetation in the area under consideration?
~ what is leading to degradation—for example, overgrazing, trampling at specific points, etc?
~ what potential is there for altering stock access and movement by activities such as fencing or offering alternative watering points?
~ what are the conditions of riparian and rangelands adjacent to the site under consideration?

Critical factors

~ Managing disturbances
~ Restoration

Guidelines

The following set of guidelines are based in part on Recher (1993) and Thomas et al. (1979).

Managing disturbances

Retain existing native vegetation cover

Riparian areas have been extensively cleared in the past, and the most cost-effective means of managing riparian lands for wildlife is to retain existing indigenous riparian vegetation.

Additionally, an adequate native vegetation cover in non-riparian areas of the catchment makes an important contribution to wildlife values in the riparian zone. This vegetation protects waterways and riparian areas from the impacts of excessive catchment clearing (such as increased runoff and erosion) and helps support wildlife populations.

Manage stock impacts

Excluding stock by fencing riparian areas is a fundamental step towards improving habitat values for wildlife on pastoral lands. Studies have shown that the effectiveness of narrow riparian buffers may be increased simply by the exclusion of stock and, in many cases where degradation is not extreme, restoration will occur naturally if grazing impacts are moderated. This, and a variety of other measures which minimise the impacts of stock on riparian areas, are discussed in Chapter 10 and Guideline G.

Riparian vegetation being burnt, Kapalga, Kakadu National Park, NT. Photo by Michael Douglas.

Manage fire

Frequent burning to reduce fuel loads may also destroy old and dead trees with nest hollows and reduce woody debris which provides shelter and foraging sites for many animals. In other situations, burning too infrequently may cause species of concern to decline. The most suitable fire regime varies greatly both among and between biogeographic regions. It is important to have a fire regime which is suited to the local flora and wildlife (consult local wildlife biologists).

Manage recreational use

Where there is a potential conflict between recreational and wildlife use of riparian lands, develop strategies to minimise impacts. For instance, recreational use may be restricted to a few areas, so that disturbance to wildlife is localised; or access to important breeding areas may be limited during breeding seasons.

Place roads and fences wisely

Site roads away from riparian zones. When this is not possible site all roads and other utilities at a reasonable distance from the waterway and along one side of the corridor so that vegetation along the other side remains undisturbed. Fencing along the riparian zone's margin may be needed to minimise the impacts of people and domestic animals. Avoid fencing across riparian zones, as this will inhibit the movement of wildlife.

Minimise chemical contamination

Minimise transport of pesticides, herbicides and fertilisers onto riparian lands and into watercourses. Transport may occur indirectly by wind or water runoff, so topography and the seasonal patterns of prevailing winds must be considered, together with information concerning off-site pollutant sources.

Limit water abstraction

Water is vital for riparian vegetation, riparian fauna, and wildlife from surrounding areas. This is particularly so during dry seasons and periods of drought; maintenance of environmental flows within waterways is essential.

Restoration

Maintain continuity and maximise the total area of vegetation

Riparian rehabilitation is likely to be most effective for wildlife where both the total habitat area and its links with other areas are maximised. The width and length of the rehabilitated area are both important (see later discussions of target width) as are connections with upslope and along-channel areas. Recolonisation or recruitment of native plants and animals may be limited if sites are isolated from healthy native communities or have been cleared for a long period of time. This is one reason for choosing sites which adjoin intact riparian communities or connect bushland remnants.

Remove dominant and damaging weeds

Weed infestations which seriously compromise restoration or rehabilitation attempts (that is, those that substantially modify or dominate the vegetation, such as willows and rubber vine) should be removed if the project is to succeed. However, a major problem created by removal of weed-dominated vegetation and revegetation is the initial loss of habitat and food resources for the existing fauna. This problem can be minimised in some cases by removing weeds and restoring in stages (that is, not the entire area at one time), and by promoting growth of understorey plants such as tall grasses and fast-growing shrubs which will provide shelter and foraging sites until other vegetation becomes established.

In many cases, it will not be practical or feasible to remove weeds from riparian areas, and the presence of some exotic species will have to be accepted as part of the rehabilitated community. Sometimes, the growth and spread of weed species is suppressed as rehabilitation of native vegetation progresses.

Plant a variety of species

The choice of plant species will depend on the ecological goals. Strategies will differ depending on whether restoration efforts are aimed at a particular wildlife species or the entire natural community. In either case, it will be necessary to seek out information on the specific habitat requirements of the range of wildlife concerned. Where the aim of the project is to restore a partly degraded area to an approximation of its former natural state, plant species selection is largely determined by the original community composition. If the aim is to revegetate a badly degraded or cleared area, a suitable community may be one that differs from the presumed 'original'. If historical events have altered the nature of the site (for example, changes to drainage resulting from works upstream or downstream), the target community may be one that is native to the region but which did not formerly occur on the site.

Actively eroding reach of Paddy's River in the ACT, stock tracks, no native vegetation and uncontrolled stock access year round. The banks are further damaged by regular wombat holes. Riparian wildlife habitat is virtually non-existant. Photo by Alison Elvin.

To create habitat likely to support as many of the animal species native to that area as possible, it may be best to choose as wide as possible a range of the species which occur (or used to occur) naturally in that habitat. Where little information is known about the original vegetation of an area, it may be best to plant a range of local native species with a variety of life-forms which are suited to the riparian soil and moisture conditions. These should be planted at a variety of densities and mixes. In general, areas which are structurally and floristically diverse will favour more species of wildlife.

Information on the native species which are likely to occur in a given area may be obtained from relevant local authorities, local nature study societies or books, and will be useful when formulating ecological goals, but it is best to consult with wildlife biologists at the planning stage.

Establish an appropriate vegetation structure

Vegetation structural diversity is an important habitat component which allows a range of different species to use the area. It is important to plant or protect the full range of plant life-forms typical to an area. Understorey plants, such as low shrubs and grasses, are often overlooked in favour of higher strata species, such as trees. Self-sustaining native forest has a high level of vertical structural

Paddy's River, ACT, with undisturbed riparian vegetation, naturally occurring pool and riffle sequences and high water quality, providing a range of wildlife habitat. This reach of river still has stock access, but in controlled numbers and intermittently. Photo by Alison Elvin.

complexity, with layers of foliage in the tree canopy at mid-height and close to the ground. Foliage beneath the canopy is provided by tall grasses, shrubs and young trees. Different wildlife species are typically found at different vertical levels, and many species depend on the middle and lower levels. Horizontal diversity and patchiness are also important: even spacing is rare in nature, and densely-clumped groups of plants provide protective cover for some wildlife, while scattered openings provide habitat for other species. Reference sites that contain relatively undisturbed native vegetation should be visited, and the typical distances that separate all plants at the sites (including trees, saplings and shrubs) used as a guide.

Manage for different successional stages of vegetation

Areas of natural vegetation consist of a mosaic of plant communities at different stages of development. Different fauna are associated with vegetation communities and individual plants of different ages. Consider this when planning revegetation projects and use both long and short-lived plants. Some vegetation types also experience (and may depend on) cycles of disturbance (for example, a fire every 10–20 years). Some wildlife only use areas of a particular age, so different times since disturbance should be maintained if the total area is sufficiently large.

Incorporate plants which provide a range of food resources

The fruit of figs (*Ficus* spp.) is important in sustaining frugivores such as the fig parrot. Photo by Stuart Bunn.

By providing a greater variety of food resources, a greater diversity of wildlife may be encouraged. For example, the choice of plant species native to the region's indigenous plant communities may include some that have foliage palatable to herbivores, some that bear nectar-rich flowers and fruit, and others that support high insect densities. Care must be taken, however, to balance these resources appropriately. For example, some nectar-feeding birds require a supply of flowers year-round. On the other hand, in eastern Australia an open tree canopy combined with many nectar-rich flowers in some areas results in high densities of aggressive honeyeaters, such as the noisy miner, which exclude other bird species.

Choose plants which provide nest hollows

Many riparian tree species (such as river red gums *Eucalyptus camaldulensis*) are an important source of nest hollows for many native wildlife species. These trees take decades or centuries to grow to maturity and form suitable nest sites. In the interim, it may be beneficial to provide artificial nest boxes if a shortage of nest hollows is known to be a factor limiting target species. Nest boxes have a limited life and cannot replace themselves and, hence, must not be seen as a long-term substitute for ageing trees.

Retain or add dead trees and woody debris

Dead wood, whether standing or fallen, provides habitat, foraging sites and shelter for invertebrates, reptiles, amphibians, birds and small mammals and should be left in situ.

Inoculate the soil and litter

Areas that have been cleared or severely degraded may have lost soil microorganisms and invertebrates which break down dead wood and leaf litter. These play a role in improving soil quality for plants and provide food for larger animals. One option for assisting recolonisation and rehabilitation is to transport leaf litter, dead wood and soil containing microorganisms and invertebrates from nearby, less disturbed riparian areas to the rehabilitation site—this process is known as 'inoculation'.

Consider target width

Corridor widths suggested as suitable for wildlife habitat and movements range from a minimum of 50 m to several hundred metres. While some broad guidelines are possible, it is likely that appropriate widths for riparian buffers and corridors will depend on the specific ecosystem and bioregion, the target taxa (which types of wildlife) and the desired functions (the width required for a movement corridor may differ from that required for local habitat). In some cases, the suggested widths may exceed the natural extent of riparian vegetation and incorporate adjacent vegetation types into the buffer. This is because narrow riparian zones are more easily affected by disturbances in the surrounding landscape, and rehabilitation of adjacent vegetation may be particularly important as a buffer zone to protect the riparian community. Within cleared areas, target widths for riparian rehabilitation may need to be wider than within landscapes still retaining some vegetation cover, since edge effects may be a problem in the former situation.

Aim to revegetate land at least 30 m either side of a watercourse. Even the narrowest vegetation strips are preferable to none. Restoring wider strips of riparian habitat (100 m or more) is much more desirable if the available area and resources are sufficient. Fencing or otherwise protecting a wider area may allow natural regeneration processes to revegetate these areas.

Monitor progress

Incorporate a monitoring program into the rehabilitation project. The information collected will help to measure success and be valuable for planning future efforts. Ideally, monitoring should: encompass both the plants (species and vegetation structure) and the animals using them; start before the rehabilitation commences; occur at regular intervals (for example, annually, every 3 years, etc);

allow for seasonal variation; and, if possible, include monitoring of 'reference areas' of established vegetation.

Be patient

Restoration and rehabilitation are slow processes. In completely cleared sites, it may take decades for even a tree canopy to develop. Restoration of the complex vegetation structure and characteristics of the former riparian community will require over a century. However, even the early stages of growth in a densely-planted site will provide habitat for some of the wildlife absent from cleared areas, and some changes should be apparent within a few years.

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GUIDELINE G

Michael Askey-Doran

Managing stock in the riparian zone

Management objective

To manage stock in such a way as to avoid degradation of riparian land and to sustain ecosystems.

G MANAGING STOCK IN THE RIPARIAN ZONE

Nature of the problem

A variety of grazing systems—ranging from total exclusion of stock, through temporal and/or spatial spelling of the pastures, to continuous grazing—are used on Australian farms. The different systems have differing impacts on riparian land. Some systems (such as continuous grazing) lead to degradation of native vegetation, stream banks and channels and adversely affect the ecology and function of the stream and riparian environments (see Volume 1, Chapter 9).

Among the problems arising from the grazing of stock on riparian land are

- suppression of regeneration and recruitment, and the reduction of floristic and structural diversity of the native vegetation;
- streambank erosion—including pugging of the soils around the waterway, bank collapse as a result of stock movement towards or along the stream edge, stock trails in the riparian zone, and trampling;
- decreases in water quality—increased turbidity, foul smells, poor-tasting water, increased algal growth (filamentous and/or blue–green algae) and increased growth of aquatic weeds;
- damage to riparian vegetation—heavily browsed groundcovers, palatable shrub and tree species, and broken stems and branches;
- high levels of weed infestation;

~ a change in the number or types of fish usually present in the waterway;
~ a change in the number or composition of other fauna groups such as birds, platypus or insects.

Summary of the issues

Stock are attracted to riparian areas for a number of reasons, such as shade, protection from wind, and quality of forage—the reasons are likely to vary with location.

The animals' most obvious impact on riparian land is associated with grazing, which can have deleterious affects on biodiversity and the structural diversity of flora. This is especially important in riparian land because of the close links between the waterway and the land. In general pasture, intensive grazing by sheep and goats can do more damage to vegetation than can cattle, because grazing sheep and goats crop closer to the base of the plant. Not only does this put greater stress on the plant; it also means that sheep and goats can survive longer when feed is in short supply, thus prolonging and exacerbating the stress (Partridge 1992). In riparian zones, however, intensive grazing by cattle is more threatening for stream banks and channels. This is because sheep and goats generally cause less physical damage and are less likely to enter the stream channel (Otago Regional Council 1996).

Maintenance of structural and floristic diversity is important in ensuring that the habitat remains healthy and able to provide refuge for both aquatic and terrestrial wildlife. Trampling by stock can damage vegetation and cause soil compaction. The deep roots of trees and shrubs bind the soil and groundcovers, especially perennial grasses, reduce surface runoff—if the vegetation is damaged these functions will be limited. Compaction limits root penetration (and thus plant production) and facilitates erosion (see Volume 1, Chapter 6).

Grazing and trampling of groundcovers is of particular concern because groundcovers are important for trapping sediment and nutrients that would otherwise enter the stream and affect water quality. Stock contribute significantly to poor water quality through faecal contamination. Controlling stock access to riparian land may significantly improve water quality for this reason.

Degradation of riparian vegetation by stock may increase the amount of light reaching, and the temperature of, streams. This effect, especially in combination with increased nutrient levels, then has consequences for the growth of instream algae and macrophytes and can encourage the growth and dominance of exotic species.

Critical factors

~ Timing, intensity and frequency of grazing
~ Grazing systems
~ Fencing
~ Stock watering
~ Stock behaviour

Guidelines

Timing, intensity and frequency of grazing

If riparian land is to be grazed, it should be grazed only when the bulk of the vegetation is dormant and when soil moisture levels are low. Generally, native plant species are dormant during winter, although it must be remembered that species go into, and come out of dormancy at different times. In addition, some native species such as wallaby grass (*Danthonia* sp.) and plume grass (*Dichelacne crinata*), can be active in winter (Groves 1965). The length of the dormancy period also varies from year to year and from region to region, according to weather patterns.

Danthonia nivicola. Photo courtesy of the Australian National Botanic Gardens.

Stock should be excluded from riparian areas if soil moisture levels are high and there is a risk of pugging and compaction.

Avoid grazing riparian land in the growing and flowering season, which generally means spring and summer, and when germination is occurring.

Continuous grazing when plants are putting on new growth will reduce the plants' vigour and lead to poorly developed root systems. Healthy root systems are important not only for binding the soil, but also for ensuring access to moisture in dry periods and for nutrient cycling. Continuous grazing during flowering will also limit the ability of palatable species to set seed.

Germination can occur seasonally—in spring, for example—or in response to a particular triggering event such as flooding or fire. Grazing in the riparian zone after flooding or a fire can greatly reduce the chance of seedlings surviving and result in even-aged stands of vegetation. Seedlings can be destroyed by both grazing and trampling.

When planning a grazing regime, it is important to understand the life-cycle characteristics of riparian plant species, especially those of important functional groups and endangered species.

If it is necessary to graze riparian land adjust both the stocking rates and the frequency of use to suit the sensitive nature of the land.

This will mean low stocking rates for short periods and long rest periods. The riparian zone should be seen as an emergency store of feed that is available for controlled use during times of shortage elsewhere on the property.

Grazing systems

Riparian land as part of whole farm management.

Riparian land should be treated as a component of the property's entire pasture system. In this way it should be seen as an integral component of the whole farm, and managed as a sensitive area with special management requirements, rather than a piece of land at the bottom of a paddock.

Exclude stock when and where damage is likely to occur.

Depending on the type of riparian land being managed, it will be necessary either to exclude stock totally, or to use spatial and temporal controls when the land is grazed. Stock should be totally excluded if the stream banks or channel are likely to be damaged or if the quality of the vegetation or water is of paramount concern.

Three grazing strategies used in Australia, that are similar to those detailed in the table, are summarised in the following paragraphs (Martyn 1995; Earl & Jones 1996).

1. Continuous grazing (set stocking)

Continuous grazing means there are no controls on stock access to land. Paddocks are stocked at a fixed rate for all or part of the year. This management strategy is not suitable for riparian land because it has a high level of impact on stream banks and vegetation.

2. Rotational grazing

In a rotational grazing system, stock are rotated through a number of paddocks in an organised manner. This may be done over a full year or for part of a year. Stock are held in each paddock for a fixed period (perhaps as little as a week) before being moved on to the next paddock. Rotational grazing paddocks can include ‘bush runs’, which are used for supplementary feed. The number of paddocks being used in the rotation will determine how long each paddock is rested.

There are a number of disadvantages associated with rotational grazing

~ rotational grazing can fail to take into account variability between paddocks and changes in pasture growth rates;
~ pasture is rested for shorter periods than with cell grazing;
~ paddocks may be under- or over-grazed at different times of the year;
~ the system is fairly inflexible.

Research shows that rotational grazing offers little benefit over continuous grazing.

3. Cell grazing (time-controlled grazing)

Cell grazing involves a combination of grazing periods and rest periods and provides a means of controlling stock access to riparian land. Decisions about the grazing and rest periods for

Table 1 Grazing methods for riparian land in the western United States

	Corridor fencing	Rest rotation with seasonal preferences	Rest
Definition	Entire riparian corridor (or required portion of) fenced for complete rest or for the application of desired grazing strategy.	One pasture completely rested for at least 1 year during the grazing cycle. Rest period rotated among several pastures. Grazing occurs when impact likely to be the least.	Selected areas rested until aquatic and terrestrial habitats recovered.
Problems	Extensive fencing required. Reduces the availability of riparian land for occasional forage use.	Moving stock between cells to meet seasonal requirements is labour intensive.	Exclusion of stock or limitations on use by stock to allow for recovery. Weed infestations can be a problem.
Benefits	Allows riparian land to be rehabilitated whilst providing a simpler grazing system for upland paddocks. Total exclusion avoids the risk of animals drowning.	Gives plants and stream banks time to recover from past damage. Riparian land can be grazed with optimal timing and intensity.	Riparian land begins to recover quickly with benefits to instream environments. Degraded pastures and riparian land can be returned to productive states, ready for a more suitable grazing strategy.
Compatibility	More likely to provide quality aquatic and terrestrial wildlife habitat. Can provide shelter and forage during dry periods.	High. Grazing can be programmed to meet the needs of both riparian and upland habitats.	Allows both aquatic and terrestrial habitat recovery. Following recovery, stock can be excluded or allowed to graze on a rotational basis.

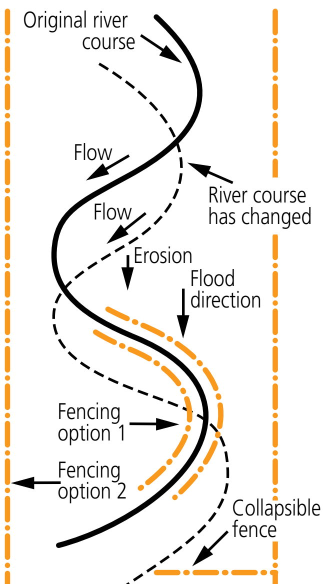
each paddock are based on pasture growth rates. The preferred method is to use a cell design that treats riparian land as a separate paddock, running parallel to the stream. The paddock's low level of use within the cell system can then be determined on the basis of individual condition and the amount of feed available in other paddocks in the cell.

Table 1 outlines grazing methods that have been used on riparian land in the western United States (Platts 1991) and that are regarded as suitable for maintaining instream habitat values. Each of the methods needs to be considered in the light of the riparian land's condition and the overall farm-management strategy.

Fencing

Install fences suited to the flood regime.

Fencing in riparian areas needs to be able to cope with flooding but still be strong enough to keep stock out. The most suitable fence design will depend on the stock being excluded, the nature of the land, and which portion of the stream is to be fenced. Generally, the fence should be above the annual peak flood level, in a position that avoids not only high flows but also debris. Fencing design and early warning of floods can reduce the risk of flood damage to the fences. No fencing is totally immune to flood damage, and all fencing requires a continuous program of maintenance. Some fence types are, however, better than others and require less attention.



Install fencing suited to the land use.

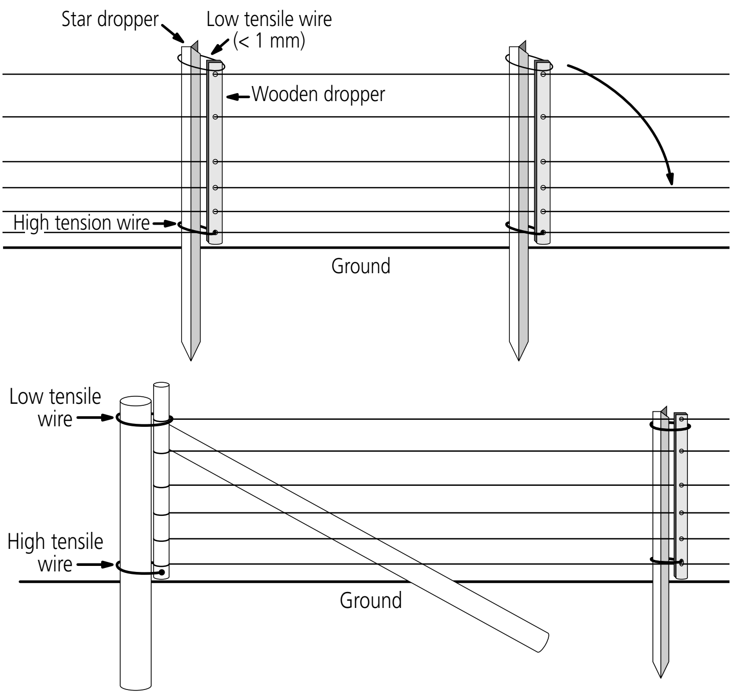
Placement of fences will be influenced by a range of factors—the purpose of the fencing, the topography of the area, the flow regime of the river, and so on. If the fencing is being done to improve the natural values of riparian land, and to provide habitat for wildlife, a minimum of 30 m (preferably 50 m) from the stream banks is recommended. For many farmers, though, this will represent a sizeable portion of land removed from productive use.

Fencing parallel to the stream and floodplain areas.

Drop fences

These fences drop automatically as pressure from water and debris builds up behind them. Once the flood has receded they can simply be pulled back up: tension is automatically retained and the fence is re-tied ready for the next flood. These fences are suitable for both stream banks and floodplains. Two designs are in use.

(a) Grooved wooden droppers (not driven into the ground) are permanently attached at their base to the bottom of each star picket by a loop of high-tensile wire that acts as a hinge. The top of the dropper is attached to the star picket with a loop of low-tensile wire (less than 1 mm diameter). When flood pressure is exerted on the fence the top wire breaks, the fence lies flat, and any debris is released. Four or five wires are recommended for cattle and sheep.



Drop/laydown fence

Top showing drop-down wooden posts at star droppers and bottom showing drop-down end strainer post.

(b) A design recently patented in Tasmania is currently being trialled. This fence pivots at ground level during a flood and lies flat on the ground. It consists of intermediate spring-loaded steel posts (which replace the star pickets) and triangular end assemblies, which also pivot at ground level. A special release wire runs the length of the fence and triggers when a flood passes through. Tension in the wires is maintained at all times and the whole fence can be easily re-erected after the flood. The fence can also serve as an emergency 'long gate' for access to paddocks or riparian land.

Lay-down fences

Lay-down fences are similar in design to drop fences but are laid down manually before a flood. This means that their effective use depends on good flood forecasting. The fences are hinged at the assembly end, allowing easy release and re-attachment. Once the flood has passed through, the fences are pulled upright again and the tension is retained. These fences are effective on broad floodplains where access to the fences poses no difficulties.

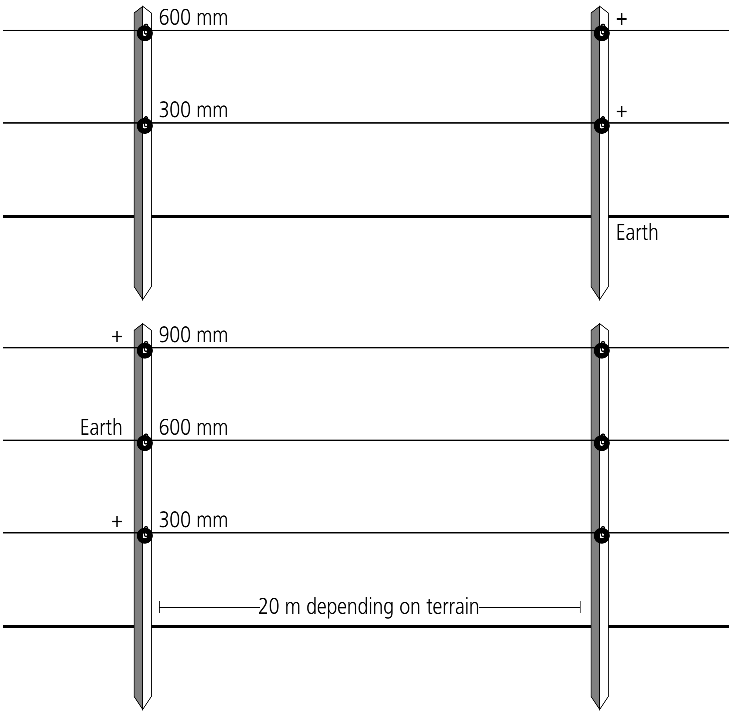
Photo by Ian Bell.

Electric fences

Electric fences allow more flexibility and are cheaper than traditional fences: they require fewer posts and droppers and less wire, and the gates are cheaper. They also offer greater flexibility in terms of location because they can more easily follow the meandering pattern of streams. Electric fences can be either temporary structures using tape, or permanent structures using plain wires.

Two- or three-wire electric fences work well for cattle, sheep and fat lambs. It is important that there is a good earth between the animal and the ground; this limits the effectiveness of electric fences in dry conditions.

In particular areas or at particular times, portable electric fences which can be put up are an inexpensive option for managing stock along streams.



Low-level electric fences can be be semi permanent as here or temporary.
Above: Energised 2 wire fence with 3 wire fence below.

Fences crossing streams.

Suspended fences and floodgates

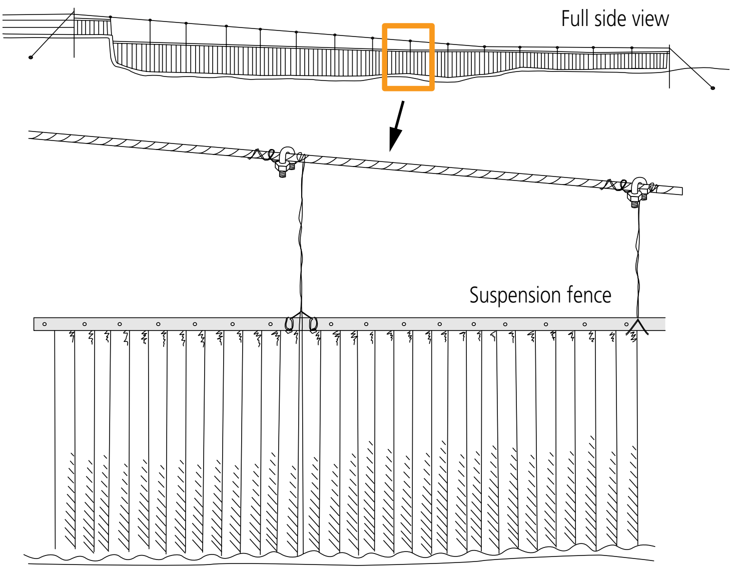
Suspended fences hang across the stream to prevent stock from entering riparian land during times of low flow.

The fence relies on good strainer posts on either side of the stream. These posts can be made of railway iron, treated timber or even a tree or large stump: whatever is used must have a firm footing in the ground and be able to take the strain of the suspended fence. This may mean placing a pair of straining wires at 45° to the strainer post. A cable is hung between the two strainer posts to support the hanging fence.

Non-electric suspended fence

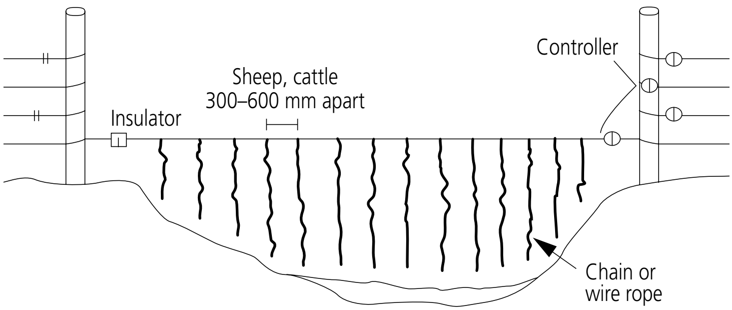
The hanging panels can be made from a range of materials, such as galvanised iron ring-lock attached to a frame or vertically hanging narrow lengths of timber. The panels are attached to the suspended cable and move independently of each other. When the river level rises or there are floods, the fence rides up with the water.

Photo by Ian Bell.



Used galvanised sheets or chain wire mesh suspended from strained cable.

Electrified flood gate



Electric floodgates

Electric floodgates overcome the maintenance problems associated with panels or cables, which can be damaged by large floods.

All electric floodgates should incorporate a controller unit that limits voltage loss to the entire fencing system when flooding occurs. A cut-out switch can be used in the event of prolonged flooding.

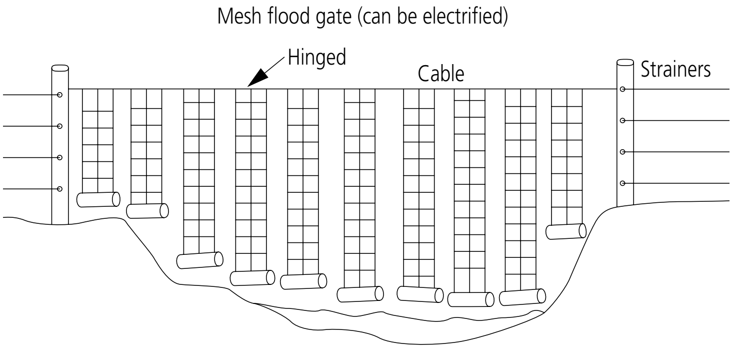
Flotation devices at the base of the panels help the floodgates ride over debris. The gates can be permanent or semi-permanent, and the panels can be made of hinged lightweight mesh or chain (2.5 mm) or single-strand wire. If the floodgate is a continuation of an existing electric fence system, additional electrified wires should be run above the floodgate so that power is not lost if the floodgate is damaged.

Permanent electric fences across streams

Fences of this kind are suitable for deep, narrow crossings. Lightweight chain or hinged mesh is suspended from steel cable (for example, 8 mm) that has been strained and firmly secured at both ends. The spreader wire between each chain can also be the wire that is electrified.

Semi-permanent electric fences across streams

Fences of this kind are suited to wide, flat crossings, including fords. Hinged and separated galvanised mesh panels are hung across the river from steel cable. A positive, electrified connection is made to the top of the panels; the moist bank and green grass act as the earth.



Semi-permanent fences with disposable sections

Fences of this kind are suited to uneven crossings. Using single-strand wire, individual sections or groups of sections are constructed separately. Star pickets are used for each section, and the joins between each section act as the breakaway point. A positive, electrified connection is made to the top wire of the sections, and one of the lower wires acts as the return.

Mesh floodgates

Mesh floodgates can be electric or non-electric. As with other hanging fences, steel cable is strained across the waterway and reinforced matting or strips of large open mesh are hung to just above normal water level.

Electronic fencing

Electronic fencing uses audio stimulation to control the movement of cattle. Developed in the United States, the system consists of special ear tags worn by stock and one or more transmitters strategically located to form an electronic boundary. Fencing of this kind can be used to separate riparian land from adjacent paddocks. Each transmitter emits a signal that defines the area from which stock are to be excluded. The ear tags consist of a receiver, an audio warning emitter, and a device that provides a small electrical stimulus to the animal's ear. An 'unlock' transmitter is placed at feeding or watering points the animal is likely to visit often and, after unlocking, the activation sequence can be repeated. This technique is also being developed in Australia and is known as 'Virtual Fencing'.

Stock watering

If fences exclude stock from the stream, provide alternative watering sources.

If streams are to be fenced off it is important to provide alternative watering sources for stock. Bouchier (1996) provides an excellent review of the various watering systems. Some of the more innovative designs are

~ Nose pumps. These small pumps, operated by cattle, can water between 30 and 50 beasts. The pump is a single unit consisting of a trough and a lever and diaphragm unit. The cattle push the lever aside to get at the water and, in so doing, pump more water into the trough.

~ Solar-powered pumps. Solar power is a cost-effective means of operating pumps in remote locations. The outfit consists of a solar panel, a controller and the pump. The panels can be either fixed or designed to track the sun. Pumping performance varies with both latitude and season, and the volume pumped in summer exceeds the winter volume—demand for water is greatest in summer, so the system is quite efficient.

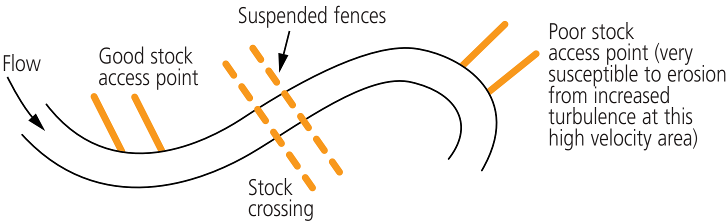
Other watering systems can also be incorporated in cell grazing designs. For example, it is common to have a wagon-wheel layout of cells with a trough as the central hub. Water for the trough is gravity fed from a dam upslope. If there is sufficient pressure, the dam may also feed other troughs on the property. Stock can be rotated through the cells and always have access to water.

There will probably be times when it is not practical to install an alternative watering system and use of the stream is the only option. In these situations it is important to restrict stock to designated watering points along the stream to minimise disturbance.

When choosing an access point, keep the following in mind.

~ The site should be relatively flat, with a maximum slope of 1:6, to reduce erosion and to make it easier for stock to get to the stream edge.

~ The site should be located on the inside of a bend, where water movement is slower and the banks are less prone to erosion. The outer bend of streams is the eroding point and is thus more sensitive to trampling.



- To prevent erosion, harden the surface of the access point with gravel. A hardened surface will also provide a better footing for stock.
- To minimise problems associated with stock camping or loafing around the watering point, make sure the site is not well sheltered.
- Angle the access point in a downstream direction, so that stock enter the stream in the direction of water flow. This allows the stream to flow past the access point during peak flows, rather than into it, which can cause further erosion.
- Fencing for the access point will be part of the corridor fencing. The corridor can be broken at selected places and two parallel fences run either from one side of the stream to the other or to the low-water mark in the stream. The important thing is to ensure that stock cannot get into the riparian corridor from the stream channel. Depending on the grazing system in operation, the fence may be permanent or temporary.
- The width of the access point will depend on the number of available access points and the number of stock to be watered. The suggested range is 2 to 20 m.

Stock trampling the banks of Latrobe River, Victoria. Photo by Ian Rutherfurd.

Stock behaviour

Stock tend to use paddocks unevenly, and this affects the condition of both the paddocks and the riparian land. Problems associated with uneven use can be overcome by improving the paddock environment, so that it is used more uniformly. When designing paddocks, keep the following in mind.

~ Locate watering points and salt, protein and mineral blocks away from the riparian margin. This will deter stock from camping around watering points and using paddocks unevenly.

~ Ensure that there is adequate shade in the paddock: this will reduce the likelihood of stock camping on riparian land.

~ Ensure that gates are located away from riparian land and that the paddock design does not channel stock towards riparian land.

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GLOSSARY

A

Absorbed	Nutrient that is bound to mineral or organic sediment and therefore only dissolves into water under particular chemical conditions.
Adsorbed	The linking of a particle or ions to another particle by adhesion or penetration.
Aerobic decomposition	The breakdown of complex organic molecules in the presence of free (gaseous or dissolved) oxygen.
Aggregate	Cluster of soil particles which adhere to each other and consequently behave as a single mass.
Anabranch	A secondary channel of a river which splits from, and then later joins the main channel.
Anaerobic decomposition	The breakdown of complex organic molecules in the absence of free (gaseous or dissolved) oxygen.
Anastomosing channel	A channel that irregularly splits and rejoins.
Anoxic	Deficient or absence of free (gaseous or dissolved) oxygen.
Aquiclude	A rock or soil layer of low permeability. Opposite of an aquifer.
Autochthonous production	Organic matter produced within a stream or river (in contrast with *allochthonous* matter that is produced outside of it).
Autogenic	Processes operating within the system.

B

Basal (area)	Part of the bed or lower bank that surrounds the toe of the bank.

Basal scour	Erosion of the base of a stream bank by the shear stress of flow.
Benthic	Pertaining to the bottom or bed of aquatic environments.
Biofilm	An organic matrix comprised of microscopic algae, bacteria and other microorganisms that grow on stable surfaces in water bodies (for example, on submerged logs, rocks or large vascular plants).
Buffer strip	A vegetated strip of land that functions to absorb sediment and nutrients.

C

Cantilever failure	Undercutting leaves a block of unsupported material on the bank top which then falls or slides into the stream. A type of mass failure.
Carbon flux	Input and movement of organic carbon.
Channelisation	Topography forcing the runoff flow to converge in the hollows or by large objects such as fallen trees.
Cyanobacteria	Uni-cellar organisms such as blue–green algae. Probably the first oxygen producing mechanisms to evolve.

D

Desiccation	Drying and cracking of bank materials causing the bank to erode more easily.
De-snagging	Removal of snags.
Detritus	Organic debris from decomposing organisms and their products. A major source of nutrients and energy for some aquatic food webs.
Diatoms	The common name for the algae of the division *Bacillariophyta*.
Distributaries	Branch of river that does not return to the main river.

Drip line	The limit of a tree canopy, defined by the pattern of drips from the canopy.

E

Ecotone	The transition between two or more diverse communities, for example forest and grassland.
Entrained sediment	Sediment that has been incorporated into a flow by rain drop and flow processes.
Eutrophication	An increase in the nutrient status of a body of water. Occurs naturally with increasing age of a waterbody, but much more rapidly as a by-product of human activity.

F

Fluid shear	The force per unit area exerted by water as it shears over a surface.
Fluvial	Pertaining to water flow and rivers.
Filter strip	See buffer strip.
Frost heave	In cold climates bank moisture temperatures fluctuate around freezing, promoting the growth of ice crystals that dislodge bank material.

H

Headcut	Sharp step or small waterfall at the head of a stream.
Heterotrophic	Organism or ecosystem dependent on external sources of organic compounds as a means of obtaining energy and/or materials.

I

Isotopic signatures	Naturally occurring ratios of stable isotopes in plant or animal tissue. (Isotopes are atoms of the same element with the same chemical properties, but differ in mass.)

J

Julian day	Day based on a calendar year (365 days per year and every fourth year 366 days) introduced by Julius Caesar.

L

Lentic	Standing waterbodies where there is no continuous flow of water, as in ponds and lakes (of freshwaters).
Littoral	The shallow margin at the edge of a lake or wetland. Usually characterised by rooted aquatic plants that are periodically exposed to the air due to fluctuating water levels.

M

Macrophytes	Large vascular plants.
Mass failure	A form of bank erosion caused by blocks of material sliding or toppling into the water.
Microtopography	Variations in topography of the ground surface at the scale of centimetres to metres.

O

Organic colloids	Small, low-density particles that can be transported easily by overland flow.
Overburden	Burial by deposited sediment.

P

Ped	See aggregate.
Periphyton	Algal communities that grow on hard surfaces (such as rocks and logs) or on the surfaces of macrophytes.
Photic zone	Upper portion of a lake, river or sea, sufficiently illuminated for photosynthesis to occur.
Planform	Shape of a river as seen from the air.

Primary production	1. The total organic material synthesised in a given time by autotrophs of an ecosystem. 2. Rate at which light energy is converted to organic compounds via photosynthesis.
Propagules	A dispersive structure, such as a seed, fruit, gemma or spore, released from the parent organism.

R

Rain splash	The dislodgment of sediment by rain which travels down the bank and into the flow.
Refractile riparian particles	Particles of organic matter with low nutrient concentrations and often high levels of lignin (associated with cellulose).
Rhizome	More or less horizontal underground stem bearing buds in axils of reduced scale like leaves. Serves in vegetative propagation.
Riparian zone	Any land which adjoins, directly influences, or is influenced by a body of water.
Rill erosion	Small, often short-lived channels that form in cropland and unsealed roads after intense rains.
Rotational failure	A form of bank erosion caused by a slip along a curved surface that usually passes above the toe of the bank.

S

Scour	A form of bank erosion caused by sediment being removed from stream banks particle by particle. Scour occurs when the force applied to a bank by flowing water exceeds the resistance of the bank surface to withstand those forces.
Serotinous plants	Plants (usually trees) that retain seeds in hard enclosing structures (for example, cones) that are not dispersed until after some event, especially forest fire.
Shear stress	See fluvial shear.

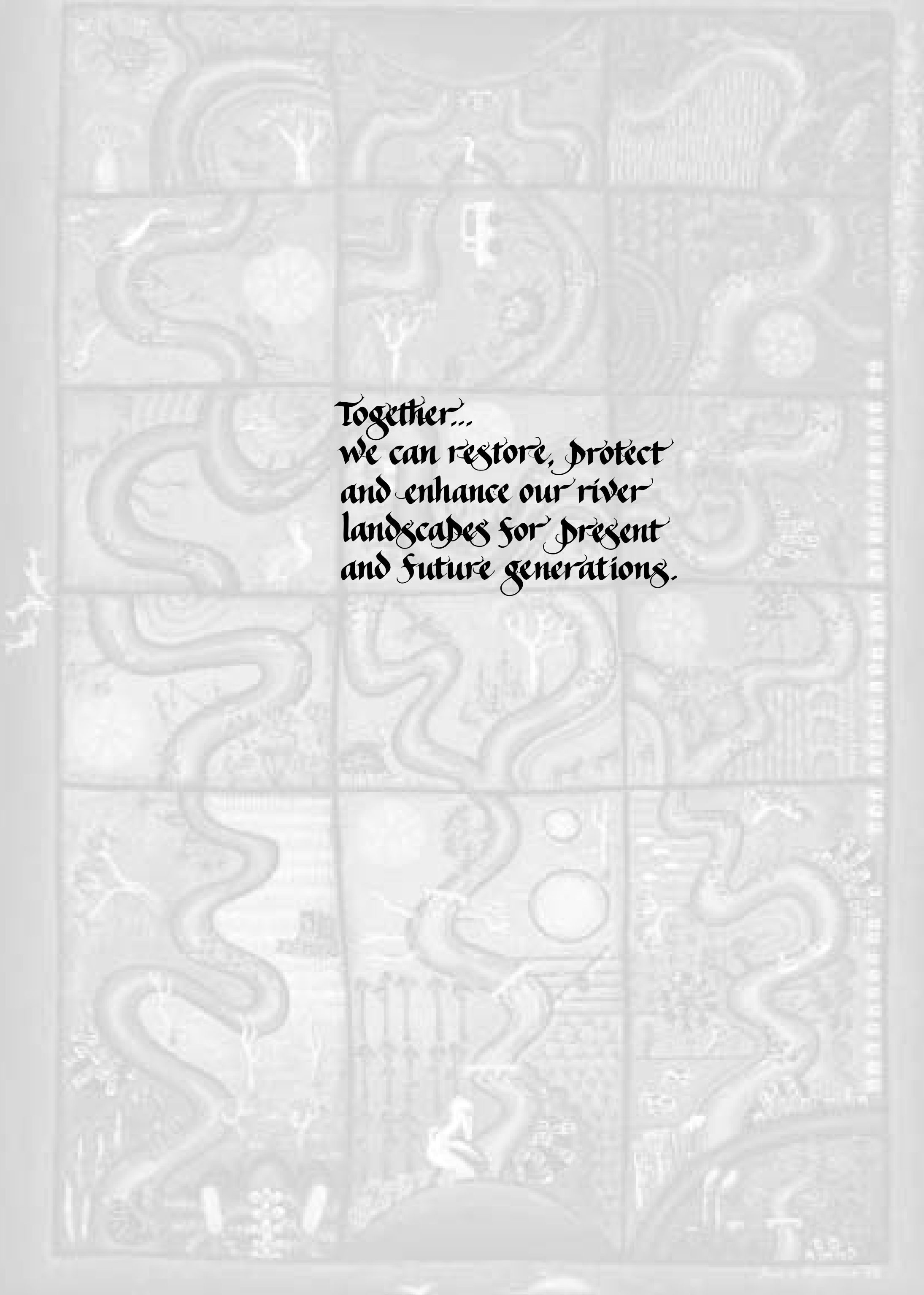
Sheet erosion	Erosion on hillslopes by dispersed overland flow.
Slab failure	A type of mass failure caused by a block of soil toppling forward into the channel.
Slaking	Occurs as a result of the rapid immersion of banks. The soil aggregate disintegrates when air trapped in aggregates escapes.
Slumping	The mass failure of part of a stream bank.
Snags	Large woody debris such as logs and branches that fall into rivers.
Stable isotope analysis	A technique to measure naturally occurring stable isotopes (typically of carbon and nitrogen), increasingly used in food web studies.
Stratigraphy	The sequence of deposited layers of sediment.
Stream order	Classification of streams according to their position in the channel network, for example, a first order stream has no tributaries. Streams become larger as their order rises and an increasing number of segments contribute to the flow.
Sub-aerial erosion	Erosion caused by exposure of the stream bank to air.
Substrate	1. Substance upon which an enzyme acts. 2. Ground and other solid object on which animals walk, or to which they are attached. 3. Material on which a microorganism is growing, or a solid surface to which cells in tissue culture attach.
Succession	Directional and continuous pattern of colonisation and extinction of a site by populations or plants and/or animals. (Not to be confused with seasonal shifts in species composition.)
Surcharge	The weight imposed on a bank by vegetation.

T

Tensile stress	The force per unit area acting to pull a mass of soil or tree root apart.
Toe	Bottom of the bank.

W

Windthrow	Shallow-rooted, stream-side trees are blown over, delivering bank sediment into the stream.



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we can restore, protect
and enhance our river
landscapes for present
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