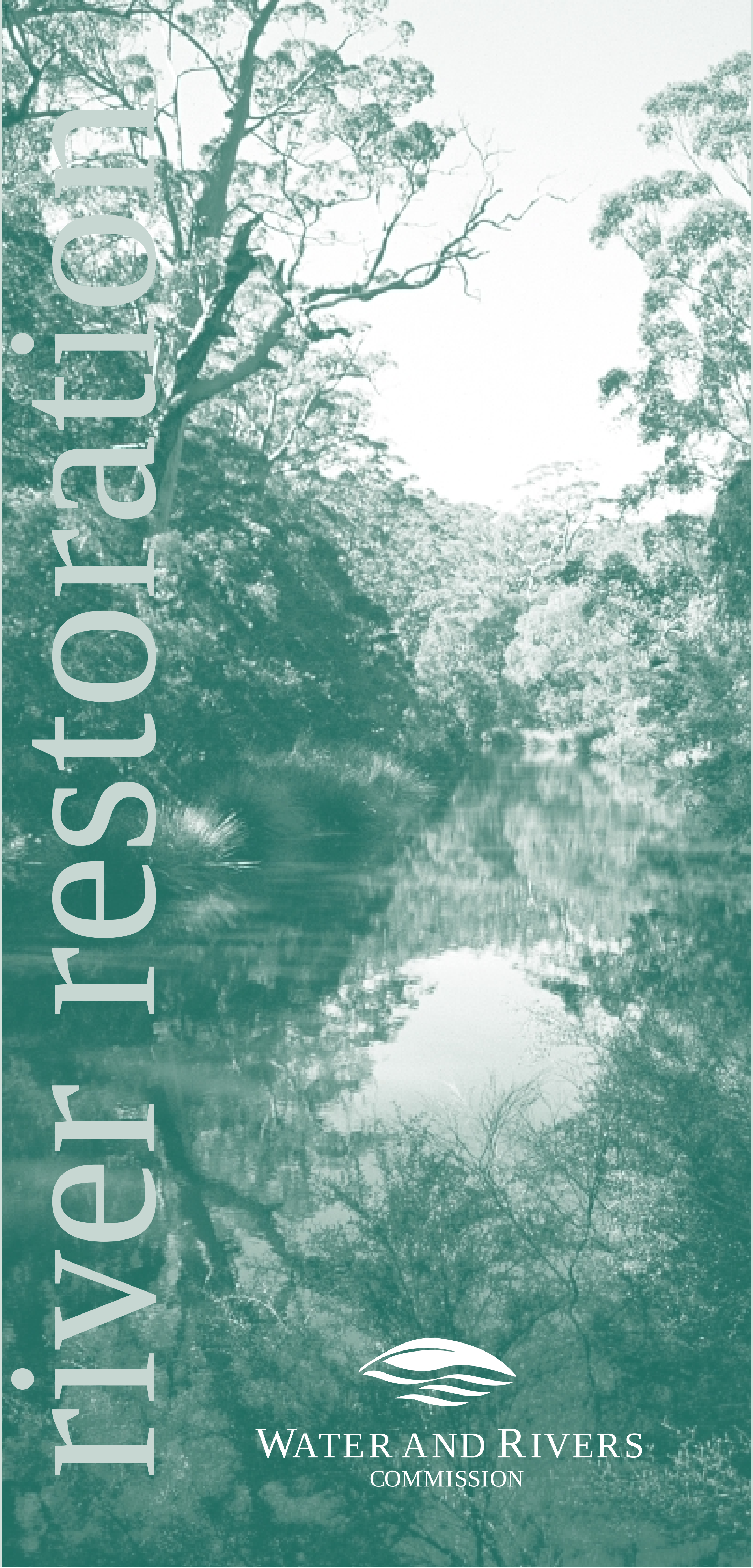

THE GOVERNMENT OF WESTERN AUSTRALIA

Stream channel and floodplain erosion

September 2002
Report No. RR18

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STREAM CHANNEL
AND FLOODPLAIN EROSION

Prepared by
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COMMISSION

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Foreword

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

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

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

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

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Introduction

This chapter is about stream erosion. It touches on the connection between the power of flowing water, its natural tendency to follow a winding path, and some of the specific erosion features we see along our rivers. The chapter is divided into four sections: bed erosion, bank erosion, floodplain erosion and, finally, a section explaining the characteristics of bends in streams and how erosion plays a natural part in their development.

Channel erosion features and their offspring, sediment deposits, are a natural part of all rivers. They conform to recurring processes and patterns throughout both small and large systems. Once we understand erosion and sedimentation we can sensibly apply techniques for managing them. When erosion and sedimentation processes are forced out of their normal balance, usually by human influences, river functions are affected, often for the worse. Human history contains a long chapter on people's attempts to make water and sediment behave in a manner that suits their aspirations. Despite these attempts rivers typically have their own way in the end. They are relentless, and respond to their own agenda!

There are many environmental, social, spiritual and economic reasons why our streams should be allowed to function in a balanced and healthy manner. Rivers are irreplaceable assets. Among other functions, they drain water from the landscape and provide water, food and shelter for us and many plants and animals, large and small. Rivers are also places that we value for recreational activities.

It is therefore important to learn how rivers behave when planning and undertaking restoration works and management activities. It is all too easy to forget that the local stream features we encounter are subject to influences that arise from the behaviour of the whole catchment, and water, a fluid which is subject to specific forces.

Stream channel erosion – an overview

Most of the time stream erosion is confined inside a channel, where water flows nibble away at the material of the bank to a greater or lesser extent, according to the water depth, speed of flow and bank cohesiveness. Channel erosion does not necessarily stop if the stream dries out. The sun, rain and wind beat upon the exposed soil surfaces causing chemical and physical changes, known as weathering, that crumble both rock and soil. These effects are particularly active in the outer few centimetres of the surface layer. In our Western Australian conditions, salt in the soil can also contribute to weathering. Soil structure and hence erosion potential is also affected by vegetation growth and by animals walking across or burrowing through the soil. People can affect stream channel erosion both directly and indirectly, for example by building structures that change the natural flow regime, and via land use practices occurring elsewhere in the catchment.

During high flows and floods, channel erosion continues, with the bed and banks under considerably greater stress. Erosion is accelerated and the confined power of the currents may rapidly reshape the bed and banks. When water spills onto the adjacent floodplain it interacts with features of the landscape that may not have experienced the influence of flowing water for a year, decades, or even centuries. During extreme floods, major new stream features can be formed, even to the extent that new channels can be created where previously there were none (Figure 1). It is not uncommon to find old, partially filled stream channels on a floodplain, but it requires a bit of detective work to determine their age and their role in the development of the river. Each flood leaves its own 'graffiti' on the river landscape. Local stories of past floods are often worth considering for clues about the changes that have taken place.

Figure 1. Shows a complex pattern of recent flood erosion at the junction of the Dalyup and West Dalyup Rivers, near Esperance, in January 2000.

Over a long period of time, one in which a range of typical flood levels tends to be repeated, the river channel adopts more predictable dimensions. The channel also adopts a style or form according to the nature of the processes at work and the time span over which they are active. River style may change as the water and sediment discharge conditions change. Stream channels are hardly ever changeless, or to be more technical, 'in a stable equilibrium'. If the overall characteristics remain reasonably similar we can define the appearance of the system as a particular *planform*. A more detailed explanation of river planform can be found in River Restoration Report No RR 17, *Recognising channel and floodplain forms*.

In order to explore the processes behind specific erosion features, the next three sections deal separately with bed, bank and floodplain erosion. Although the boundary between bed and banks may seem a bit vague, we can generally agree on which part is largely the bed and which is the bank.

Bed erosion processes

When sediment is removed from the bed of a channel faster than it arrives from upstream, we can expect the bed to lower. Conversely, if sediment arrives faster than it leaves, the bed will fill in. Indicators of deepening or incision may be the exposure of fresh bare rock, clay or other soil surfaces, as in Figure 2, or perhaps a trench-like appearance to the low flow channel. Exposed tree roots can be seen in Figure 3. This photograph was taken a short distance upstream of Figure 2, and indicates that channel deepening has only recently commenced. In fact, if a channel has robust, self-supporting banks, the carving action of the water is often expressed as an aggressive downward excavation. Figure 4 shows such trench-like incision. In this case a road culvert has also focused the water flow, aiding the formation of the slot-like incision.

Figure 2. Recently exposed basement rock in an incised section of a creek.

Figure 3. Recently exposed tree roots are evidence of active incision.

Figure 4. Trench-like incision.

In an incising channel, *knick points* often form. A knick point is a place at which the longitudinal (lengthways) slope of the bed suddenly steepens. In severe cases a *headcut* or waterfall can form (Figure 5). A headcut is characterised by an overhanging vertical face with water falling (from the *brink-point*) into a deep hole called a *plunge-pool*. Powerful rotating currents called wall-jets or reverse rollers nibble away at the earth or rock face at the base of the waterfall. The top of the unsupported overhang eventually fractures and falls in and the waterfall moves further upstream. Banks bordering the plunge pool are prone to collapse due to horizontal circulating currents or eddies that move upstream at the edges, and to deepening of the pool. Material that falls into the plunge pool is swept downstream. For these reasons, the channel below a headcut is often wider as well as deeper than the channel upstream.

Figure 5. A typical headcut.

Both knick points and headcuts gradually move upstream and release sediment into the river system. This movement may be imperceptible, but has been known to proceed at the rate of tens of metres per year, depending on the cohesiveness of the channel material and the seasonal flow pattern. Headcuts progress until the entire bed of the channel reaches some stable uniformity in its overall slope. River Restoration Report No RR 9, *Stream channel analysis*, discusses bed slope profile in more detail.

Causeways

Causeways, with or without culvert pipes, are a type of crossing commonly placed across streams. When water spills over the top of a causeway, erosion processes similar to head-cutting can occur on the downstream side. Figure 6 shows an attempt to stabilise a causeway eroded by these processes.

On their upstream side causeways behave like weirs, slowing the water and encouraging the deposition of sediment. The culverts may become buried or partially filled with sediment. This in turn tends to increase the frequency with which water flows over the top of the causeway. The form and height of a crossing are therefore important factors in finding an effective design.

Culvert pipes under causeways or other crossings concentrate stream flow, forming a water-jet at the outlet that can contribute significantly to erosion downstream.

Figure 6. A causeway showing ongoing attempts to stabilise the erosion caused by floods overtopping the road and water jetting through culverts.

Managing bed erosion

The decision to alter the bed of a stream channel should not be done in an *ad hoc* manner. Apart from legal considerations, doing an accurate survey of the bed profile and channel cross-sections is an essential task before deciding on a course of action. Details of how to conduct a stream channel survey are outlined in River Restoration Report No RR9, *Stream channel analysis.*

The survey enables the problem to be seen in the right context, and helps to determine its cause and possibly to predict its outcome. Sometimes calculations can be made to predict the amount of change that is likely to occur. During a survey, some measure of the rate of erosion is also useful. For example, metal erosion pin(s) can be hammered into the face of a headcut (Figure 7). The amount of pin exposed reveals the amount of soil lost at the site over a period of time. By keeping a record of the rate of exposure of the pin, the erosion rate can be calculated. Pegs on a bank, or a rope stretched across a headcut face above the flood peak, can also be used. In some situations paint may be used to determine where erosion hot spots are located.

With this type of information, the proposed solution to a bed erosion issue can then be based on a design that takes into account the behaviour of the flow, rather than guesswork. As mentioned, the proposed solution may also need to meet certain statutory requirements. The 'do nothing' option should always be considered. For example, trying to stabilise a headcut may not be necessary, if just upstream there is a rock bar which will naturally limit its progress.

Figure 7. Shows an erosion pin in a creek bank. More of the pin is exposed as the bank surface erodes away.

There are essentially three options for stabilising a headcut:

1. Back flooding, perhaps through the construction of a 'riffle' downstream. This may work if the height of the overfall is not too great and a riffle, rather than a dam, is sufficient to achieve the result.
2. The headcut itself may be converted to a rocky riffle or rock chute with a more stable bed slope. The design should ensure that flood flows do not erode a bypass channel around the structure. Simply dumping rocks or rubbish into the pool below the headcut is of negligible value in the long term as the erosion face moves upstream. It may even aggravate bank erosion downstream.
3. In some special cases, for example hill slope gullies, it may be possible to divert the water flow around the site of the headcut, spreading the flow or creating a new channel with a reduced slope. Care must be taken with this course of action since the problem may simply be shifted to another location. The design of various bed control structures is outlined in River Restoration Report No RR 10, *Stream stabilisation*.

A fourth course of 'action' is no-action; the incision process is allowed to continue its progress unhindered. A sound knowledge of the channel form and processes is required to understand what may be the eventual outcome of a 'do-nothing' approach.

Bank erosion processes

Bank erosion may affect one or both banks of a channel reach, causing the channel to widen. Alternatively it may simply contribute to the migration process of meanders, without necessarily changing the size of the channel. This happens if sediment deposition on one bank offsets erosion on the opposite bank to maintain a stable channel width. In our largely destabilised river channels, the sediment derived from eroding banks is often associated with the infilling of river pools and is of real concern for the health of the river system downstream. Channels become wider and shallower, perhaps even dividing into many minor channels.

Three broad types of bank erosion are discussed here: gradual erosion, erosion due to obstructions and bank collapse.

Gradual erosion

Stream banks can erode away in an even and steady manner along their length, simply by the action of water and sediment rushing past and 'snatching' away loose soil particles. Evidence of general and regular abrasive erosion is a bare soil surface where vegetation has difficulty getting established, or perhaps stain marks, or a lower limit to patches of lichen or moss. Erosion hotspots may be detected by using erosion pins or by applying small patches of paint to the banks and seeing which ones wear away first. Gradual erosion is often natural and acceptable but if it is proceeding too fast, bed or bank protection may be needed, or the flow velocity may need to be reduced.

Slowing the flow can be achieved by increasing the 'roughness' of the channel. The amount of 'slowing' may not need to be very great. Often planting with appropriate plant species or allowing vegetation to naturally re-colonise the banks, perhaps by excluding stock, can be sufficient. The installation of riffles made of local rocks or woody debris may also be appropriate (Figure 8).

Slowing the water by increasing channel roughness also increases the types of habitat available for aquatic life in the otherwise scoured channel bed. It should be remembered that where water flow is slowed, the depth tends to increase and water can take a path around the area of roughness. However since sediment deposition is favoured where water slows down, this will tend to reduce the depth over time. In either case there will be a tendency for the flow to bypass the 'roughened' area if a less resistant path can be found.

Figure 8. An artificial riffle constructed in a straightened section of a creek is intended to slightly slow water and sediment movement, and to create habitat for aquatic fauna.

Obstructional erosion

The second common erosion process occurs where objects within the channel, for example logs, debris, rock or sediment bars, deflect flow into a bank. An object can focus the flow into a more powerful water jet. The erosion rate is increased where the flow is focused, and a 'kink' may form in the channel, perhaps eventually leading to a significant change in the position of the channel. A simple and inexpensive management option may be simply to re-orient the obstruction, rather than removing it completely.

Figure 9 shows a clay bar, exposed by incision and deflecting flow into the bank. The bar was removed in this case and a rocky riffle installed immediately downstream, offsetting the increase in velocity due to the local straightening of the channel.

Figure 9. A clay bar exposed by incision of a modified reach.

Bank collapse

The third type of bank erosion is massive bank collapse. Whereas bed collapse may occur at headcuts, bank collapse is often more widespread and is an important erosion process. The factors that affect rates of bank collapse are:

- the physical cohesiveness and composition of bank soils, particularly water content;
- bank height;
- bank steepness; and
- weight of vegetation.

It should be remembered that collapsing banks may be perfectly natural for the planform of a particular stream and this is usually balanced by rebuilding of the floodplain elsewhere.

A number of different mechanisms for massive bank failure have been identified. For example, *slab failure* occurs when the weight of soil causes slabs to slump, break off and collapse, like a house of cards or books falling over on a bookshelf. *Rotational* slumping occurs where a section of bank slumps along a curved cross-section, like a bar of soap slipping down the curved inside surface of a bathtub. Rotational slumping usually occurs in more cohesive soils. Trees can prevent this through a cantilever strengthening effect.

A slab-like collapse on an incising section of a creek is shown in Figure 10. Waterlogging from substantial sub-surface seepage from up-slope has also weakened the bank and washed away the sandy soil under the cohesive vegetated surface layer. Should it be treated or should the channel be left to adjust itself to the increased catchment discharge?

Figure 10. Bank collapse.

Bank erosion during flooding

When water levels reach the top of a channel, the river exerts its maximum erosive force on the bed and banks. Any further increase in discharge spills onto the floodplain. Bank erosion can occur as flow surges from one side of the channel to the other, impacting at various points, in a manner that is difficult to predict. Obstacles or features that are not a problem during lower flows may become significant flow controls during a flood.

The dominant channel is typically too small for flood flow. This can lead to the formation of a ‘chute’ or channel across the inside of a bend with banks and some foreshore being eroded (note that the pre-flood bend would still have carried part of the flood flow). Figure 11 shows such bank erosion and the creation of a chute.

Figure 11. A chute has been created by the flooding of a meander bend.

Figure 12 illustrates bank erosion due to the existing channel banks not being able to completely contain and govern the path of flood flow. The preferred radius of curvature of the flood flow is greater than the existing channel’s meander radius. The bank erosion seen here is part of the process by which flood flow tends to change the channel dimensions and sinuosity to a scale in harmony with the flood discharge. Over the short duration of most large floods, this change of channel form is generally not completed. The incomplete effect may appear as a local straightening of the channel, as though an extra wide bull dozer was trying to drive down the winding channel but could not quite negotiate the tight bends.

Figure 12. This bank scour was created by severe floods in January 1999 and enhanced again by floods in January 2000.

Managing bank erosion

There is ample evidence that riparian vegetation has a tremendous capacity to resist the 'watery' forces causing bank erosion. Sedges can be seen lining the bank below the near scour shown in Figure 12 and this demonstrates the resilience of certain types of vegetation under extreme flood conditions. The flood overtopped the high bank in the background, but the sedges stayed in place. You can see the massive erosion taking place around the sedge community. Revegetation of banks and exclusion of stock are currently the primary stabilising techniques for unstable banks. Streamline fencing for controlling stock access to channel banks and foreshores is an essential part of a strategy for erosion reduction.

Protection of the base (toe) of the bank may be required if scouring is undermining the bank. Methods to reduce the bank height or slope may be appropriate if the bed is incising. In situations where waterlogging is weakening the soil structure, remedies that address up-slope recharge may be needed. However, as we will see, this restoration strategy does not always work when it comes to extreme flooding.

Floodplain erosion

We now turn to the effect of water that over-tops a channel and moves across the adjacent floodplain. It is clear that the potential for such erosion and sedimentation is an issue that has not been adequately factored into many plans for 'exploiting' floodplains. The infrequency of large floods can lead to a complacent and perhaps overly optimistic approach to floodplain use. Unfortunately the rare, catastrophic flood can have long lasting impacts on the structure of the floodplain.

The clearing of catchments for agriculture and urban development has aggravated floodplain erosion for two reasons, firstly due to changes in surface and groundwater discharge and secondly due to loss of soil strength.

The seasonal pattern of surface and ground water discharge has been dramatically altered in many catchments. This has been summarised as 'more water, more often, moving faster'. In many parts of Western Australia it has also meant saltier water. The net result of these increases is that the pre-existing channel dimensions (width, depth and slope) are insufficient to convey the more frequent flood flows. The channel commences to deepen, widen or to change its planform, and maybe all three.

Extra sediment enters the channel from eroding gullies, banks and hill slopes. Where this sediment is deposited, the channel becomes shallower, forcing more water across the floodplain. The change in discharge pattern is the justification some land managers use for holding those who live upstream responsible for the erosion and sediment problems that are happening downstream.

The second impact of clearing has been to seriously weaken the structural integrity of floodplain and foreshore soils by reducing the surface roughness, lowering its frictional resistance and thereby increasing the water velocity over a reach. The velocity and depth of water flow largely determines its erosive power. During periods when flood waters flow across the floodplain, the degraded ground cover and understorey plants (usually annual pastures or weeds) are no longer sufficient to hold the soil surface in place. In addition, the deeper reinforcing of the soil layers by tree roots is lost as the trees disappear and the roots rot away. High salt levels exacerbate these effects. All these factors combined, lay some of the responsibility for excessive erosion with land managers, regardless of where they live along a waterway.

Managing floodplain flow

Floodplain management methods in rural and urban catchments often do not properly cater for stream hydraulic or ecological function. Most efforts at erosion control are *ad hoc* and a result of 'crisis management' or 'theories', more than informed design or foresight. Highly engineered drains sacrifice almost all ecological function in favour of hydraulic efficiency.

The erosion potential of a channel and floodplain is influenced, in part, by the degree of bed, bank and floodplain 'roughness'. Roughness is often specified by a factor known as 'Manning's n' (for more information on 'Manning's n', see *Stream channel analysis* Report No RR 9). The roughness and/or dimensions of the channel should be maintained at a level (or equivalent Manning's 'n' value) appropriate to its long term flood history. Typically the threshold dimensions of a channel are those corresponding to the flood that occurs, on average, every 1 to 2 years. The effect of catastrophic floods, that is those rare events that can produce major failure of the channel system, must also be considered in our recently cleared catchments.

A channel with high roughness compared to its adjacent floodplain – for example a channel congested with vegetation, excess sediment and debris accumulated over many years of low annual floods, but cleared in the flood fringe - is a potential site for an erosion feature called an *avulsion*. An *avulsion* occurs when water escapes out of one channel and creates a new channel or scour. The eroded sediment is dumped somewhere downstream. Natural restrictions in the channel can also cause avulsions. Man made structures, including crossings and restoration works, which restrict or focus flow into unstable areas, should be avoided.

A closer look at Figure 1 reveals an avulsion where flood waters failed to negotiate an irregular meander on the Dalyup River, cutting across in a straight line to its junction with the West Dalyup River. In order to maintain optimum discharge capacity or water conveyance, and therefore reduce the risk of an avulsion, some sensitive re-arrangement may be an option. Channel conveyance can be maintained by selectively repositioning debris, pruning vegetation and excavating accumulated sediment if it is causing significant congestion. Any proposal to remove vegetation, sediment or large woody debris from the channel should be assessed in context with the entire stream reach. For example, large woody debris could be perceived to be congesting the channel, when actually a causeway downstream is causing back flooding. Removal of obstructions should be localised and large scale clearing using bull dozers should not be undertaken, although this action is often and seriously suggested.

When water is flowing over the floodplain, the distribution and nature of vegetation patches, pasture, hedges, plantations and barriers is an important factor in influencing the location and degree of floodplain erosion. Vegetation is the most basic and preferred 'engineering' material for management of floodplain erosion and sedimentation. Less obvious native plants (the ones without large brightly coloured flowers) such as sedges and samphires may emerge as the key ingredients for stabilising our waterways, even in highly saline areas. Concrete, rubbish and old car bodies are relegated to the bottom of the list of useful resources. Vegetation is likely to be the cheapest option and the most flexible and efficient in its application. It may not be necessary to revegetate an entire floodplain to prevent excessive erosion. Agricultural activities can coexist with natural river processes with an acceptable level of risk, provided a design approach is taken.

There is a good case for maintaining alternate or secondary channels formed by previous floods, as a form of 'safety valve' for future events. These channels, usually of smaller dimensions than the main channel, are a common feature and may be short cuts across bends or diverge from the main channel for some distance (anabranch), even competing with the main channel during lesser discharges. The cross-sectional shape of the channel determines where floodwaters exit and enter the main channel and these points are often critical erosion sites. A knowledge of the likely pathways that flood flows may take across a floodplain is an essential basis for good protection and maintenance measures.

A farm management or restoration plan should consider old channels and the potential for new channel formation, as well as the existing planform of the river. Features that were initiated in earlier floods, such as depressions, sediment highs and obstacles to the flows should also be taken into account. These features may be assessed by inspecting aerial photographs, walking the river, and if necessary, by conducting a cross-section level survey of the floodway. Figure 13 gives a perspective of the path of a flood that may not be fully appreciated at ground level.

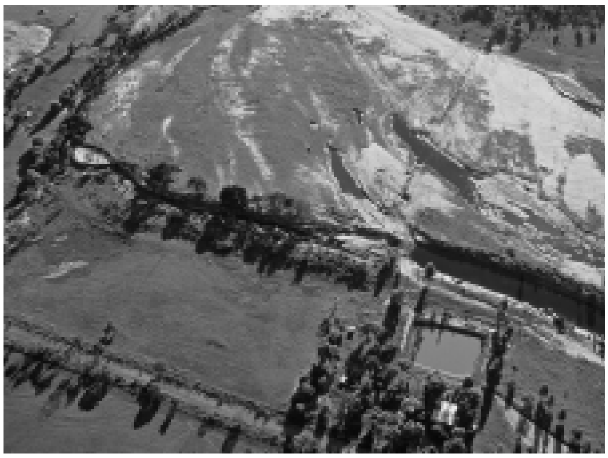

Figure 13. The Dalyup River Bridge area shortly after the floods of January 2000. The path and effects of the flood across the floodplain are clearly seen from the air.

The natural tendency of stream flow to wander

Bends in rivers of all sizes are such common features that their nature and relationship to erosion and sedimentation processes needs some explanation. This section discusses some critical aspects of the development of river bends.

Bends in rivers occur in single or multiple channels and at many scales. Bends within bends are a common occurrence. They are not simply a result of diversion of flow around particular obstacles, but are more fundamentally a result of the behaviour of a stream of water interacting with a resistive but erodible pathway.

Persistent and developing river bends can over-ride or enhance local ‘wiggles’ caused by obstructions, to produce the smooth, snaking path we usually associate with a stream. Once a flow pathway is established there are a number of factors that determine how persistent that particular path is, and the manner in which it shifts. The mechanisms influencing the formation of river bends are only now being more clearly understood to the extent that they can be modelled and their theoretical movement predicted. It is also clear that river restoration efforts need to work with, and not against, stream meandering if erosion is to be well managed.

The ‘wiggliness’, or sinuosity of stream channels

We define stream *sinuosity* as a measure of the curvature of a section of stream channel. At one extreme, a channel can be straight (lowest sinuosity) and at the other extreme it can have many gathered loops (extreme sinuosity). A measure of the sinuosity between two points along a channel is found by dividing the actual channel length, as the fish swims, by the length of a straight line joining the two end points, usually measured as the down valley distance.

$$\text{Sinuosity} = \frac{\text{Channel length}}{\text{Straight line distance}}$$

The lowest practical measure of sinuosity is one (1) and this means that the channel is straight or takes the most direct path down the valley.

Figure 14 shows a short, steep, but nevertheless sinuous channel carved in solid granite. It illustrates the tussle between the capacity of the water to pursue a sinuous path, even on a steep slope, and more subtly how the channel once established also influences the subsequent behaviour of the flow. This mutual influence between water and channel material is difficult to predict and so any channel modifications should be undertaken with care.

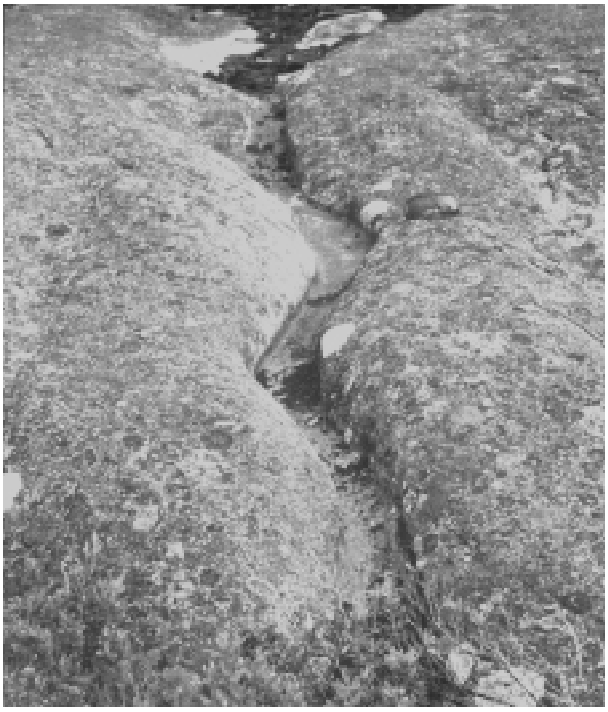

Figure 14. Water flowing from a tiny catchment, perhaps 0.1 Ha, has managed to erode a channel in solid rock.

When stream channels have a reasonably regular ‘wavy’ path, we can define wavelength and amplitude as measures of the amount of channel curvature. The wavelength is the straight-line distance between two points at either end of a stream ‘zig’ and ‘zag’. The amplitude of a bend sequence is a measure of how far the channel wanders from the centre-line of its overall direction. Although bends in streams are not generally circular it is convenient to assign a *radius of curvature* to the bend. Figure 15 illustrates these concepts.

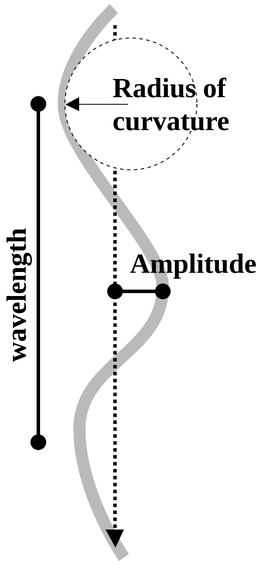

Figure 15. Defining wavelength, amplitude and radius of curvature.

For example, if the channel length shown in Figure 15 is 1.8 km long and the straight-line distance (dotted line) is 1.2 km, then the sinuosity (S) of the reach can be calculated as:

$$S = \frac{1.8}{1.2} = 1.5$$

If significant change in channel form is evident, then changes in sinuosity may be used as a measure of the response of a stream to pressures from the shift in the hydrological balance.

The path of high velocity flow

Turbulent behaviour in streams is influenced by such factors as flow velocity and channel roughness. The result is that the water does not move at the same speed at all points throughout any cross-section of the flow. Figure 16 illustrates this.

Figure 16. The path of high velocity flow.

Slowing of the water by friction or drag near the stream bed and banks, creates a core region away from the channel perimeter of greater than average velocity. The position of this ‘core’ and its size will, of course, vary with the flood level, but it is an important characteristic of any stream, large or small. This path of highest velocity is not constrained to stay along the centre-line of the channel and in fact it is most unlikely to maintain such a position due to the many hindrances which nudge it one way or the other. The path of highest velocity is usually associated with the channel thalweg, the line joining the lowest points of successive cross-sections of a channel (see also Figure 20).

The behaviour of the ‘core’ or ‘thread’ of high velocity is considered a critical factor in the initiation and development of river bends. Since water is incompressible, the deflection of a few litres around any one obstacle is felt throughout the entire cross-section, much as someone blocking your path along a busy footpath causes you to veer to one side and you in turn cause others to veer. At the same time the shop windows and the roadway confine the meandering. The winding path of the high velocity thread can be thought of as an average response of the water particles to all obstacles including other faster or slower parts of the water body itself.

In addition, loose material forming the bed and banks not only deflects the water but is itself swept to quieter areas of the channel. Thus a pathway for the higher velocity flow may be able to persist for a long period of time. The persistence of a feature is a measure of its ‘stability’. An important factor here is the cohesiveness of the material of which the channel and floodplain are constructed.

Figure 17 shows a ‘wiggle’, or scour, in the path of river. It was created in a few days by a major flood event. This change in the curvature of the meander would undoubtedly have continued if the floods had persisted, but may not lead to a long lasting change to the position of the main channel during normal periods of flow.

Figure 17. A bank scour demonstrates that the sinuous motion of the flood flow was not in harmony with the old channel.

Bend development

As water moves along a newly created, straight drainage channel, sinuous 'wiggles' are present in the turbulent flow. These promote the accumulation of sediment in bars whose position typically alternates from one side of the channel to the other. These bars can become colonised by vegetation if conditions are favourable. Erosion is strongest at the outside of the bend in between bars. The development of stream sinuosity is thought, by some researchers, to be intimately tied to the development of sediment deposits within a channel. Figure 18 gives an example of a common alternating pattern of sediment deposition.

Understanding the relationship between both deposition features and erosion features is therefore important to restoration design. For example, although an eroding outer bank of a stream bend may attract your initial attention, erosion control may be achieved by manipulating the sediment deposited on the inside of the bend or *point bar*. This may be a simpler and adequate solution to an immediate problem.

Figure 18. A section of a small channel showing the formation of alternating sediment bars after a storm event. This suggests there were areas of high velocity and low velocity associated with the sinuous path of the high flow.

Motion around a bend

There is a distinctive 'feel' about driving a car around a tight bend (on a road, not in a river, although that is quite distinctive also). You instinctively grip the wheel and exert energy to maintain your balance by leaning towards the inside of the bend. This is because your body is objecting to changing course and inclined to continue in a straight line. To moderate this effect we apply the brakes to achieve a more comfortable speed. There is an optimum bend radius that balances allowable speed against the effort you expend when turning. Road engineers design the radius and cross-sectional slope of the road bend with this speed in mind.

The situation is similar for river flow, but the erodible banks allow the flow to partly design its own highway. The channel cross-section moves to the form that is the most efficient conserver of energy. In one sense, the bed and bank of the channel itself, applies the brakes to the flow. For a car, the brake pads and tyres and to a lesser extent, the road, wear away, but in a stream it is only the bed and banks that wear away, not the water.

And as a car has a tendency to roll on a bend, water is also inclined to tumble, but being a liquid, the tumbling motion results in a spiralling secondary current. The secondary current is able to move sediment sideways across the bed as well as downstream.

The fact that the water, like a driver, does not respond easily to a change in direction, can be seen where flow is constrained to move around a tight meander and there is active erosion at the outside exit end of the bend. In floodplains that are easily eroded, the position of the bend tends to move down and/or across the valley, producing asymmetrical meanders, as illustrated in Figure 19.

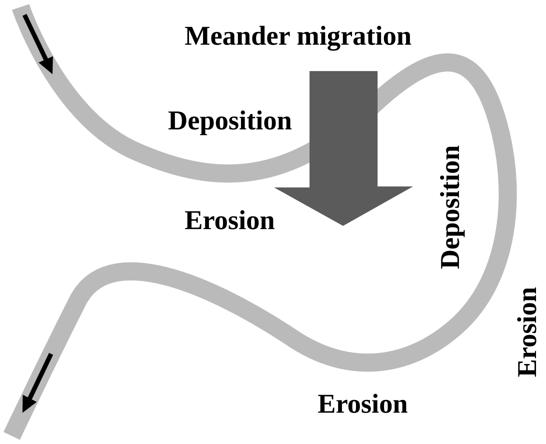

Figure 19. Bend migration in alluvial channels.

Understanding this process helps the river manager to appreciate where the erosion stress points are likely to be along a channel. The relative position of the path of highest flow velocity in the cross-section, and the strength of the secondary currents, are important in any particular reach. It is the relationship between the curvature of the path of high water velocity and the curvature of the channel that really influences the process of bend erosion and deposition. This relationship varies for different flood levels.

The stress on a stream channel, at a bend, does not occur where the 'rubber meets the road', but where the 'water meets the bed'. This tussle tends to be concentrated in the area at the base or *toe* of the bank. If the soil cohesion is able to resist the abrasive power of the flowing water-sediment mixture, the bank is robust. If not, then bank scouring, and perhaps collapse, will be very active.

The eroded material will fall to the toe of the bank and eventually be removed by the faster flow. This material will be carried by the secondary currents toward the inside of the bend and be deposited on the point bars of bends downstream.

At a bend, the cross-sectional area of an alluvial channel takes on a characteristic asymmetric shape that can be seen clearly in Figure 20. This highlights the powerful partnership that exists between the velocity profile and the stream cross-section.

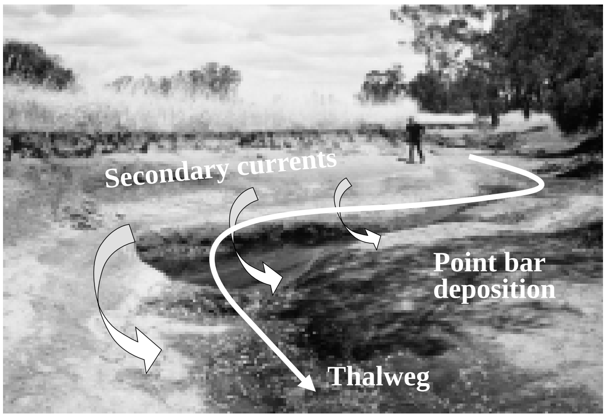

Figure 20. Shows the bend features, namely the incision along the path of high velocity and the scouring and deposition effects of the secondary current, that create this common cross-sectional shape.

Mathematical modelling has implied that the rate of meander development is influenced by the local channel curvature, particularly upstream, as well as by the cohesiveness of banks. This suggests that alterations to the channel curvature may speed up or slow down bank erosion nearby. If this type of research has any message for river managers it is that 'works that modify channel curvature must remain in harmony with channel curvature upstream and downstream'.

As stream sinuosity increases, the average bed slope is reduced. This results in a slower flow and reduced turbulence. We observe this condition in sequences of looping meanders on broad alluvial floodplains, where the channel width is fairly constant and the 'old man river', though sedate, is still powerful. Straightening a channel, even when the flow has only moderate stream power, may demand a commitment to heavy reinforcement of banks along the entire reach. An understanding of channel bend formation is at the very heart of an appreciation of river erosion and sediment deposition processes.

Manipulating sinuosity to control stream erosion

A number of erosion control techniques may be applicable to a situation where the migration of a channel, through bend erosion, threatens infrastructure. Figures 21 and 22 show two local stabilisation measures to control bank erosion. These techniques are explained in detail in River Restoration Report No RR 10, *Stream stabilisation*. It is also suggested that undesirable erosion and bend development might be minimised, in some cases, by maintaining stream curvature within a certain range. In single channels that are free to migrate across their floodplain, there is a tendency for the radius of curvature of a meander bend to be between 2.3 and 2.7 times the bankfull width (see also River Restoration Reports No RR6, *Fluvial geomorphology* and RR 9, *Stream channel analysis*).

Allowing for natural stream sinuosity goes against the desire of many landowners' to shorten creek channels with a view to increasing the rate of discharge to prevent water logging or flooding of paddocks. The price, usually paid in full, for straighter and hence steeper channels is increased stream power and more destructive erosion and sediment deposition as the flow starts to rebuild bends.

Figure 21. Groynes diverting flow from fragile sandy banks.

Figure 22. Bank armouring. Note that armouring a bend with rock, for low flows, may aggravate turbulence and erosion during high flows.

Conclusion

Stream channel erosion is a natural product of river flow, but our activities can magnify the process of erosion and it can cause problems for us when we undertake works within a catchment. When large amounts of sediment are eroded, further trouble results from increased turbidity levels and the infilling of river channels, pools and even estuaries, which affect river ecology as well as channel structure. Understanding how water and sediment interact to cause erosion and deposition is crucial for good river management.

River bends are erosion and deposition 'hot spots' and their complex and elegant behaviour often attracts our attention and even our wonder. Floodplains play an integral role in river function and these areas should not be overlooked when dealing with erosion and sedimentation processes.

Two basic variables, water velocity and water depth, can be influenced to reduce channel and floodplain erosion. Vegetation and channel form have a significant influence on these variables. Therefore river restoration activities need to balance and maintain a variety of hydraulic, ecological and management functions. They require, as does any farm or urban undertaking, a commitment to ongoing, adaptive and informed management.

Human intervention in waterway processes, where some degree of hydrological 'balance' previously existed, must be accompanied by a commitment to a management process to achieve a new balance without excessive erosion. If we place a high demand on river products and services, it is unrealistic to interfere with their functioning and then expect them to naturally work things out, without unwanted impacts. The 'do nothing' option is likely to be unacceptably costly and unproductive in the long run.

Managers at all levels need to understand how erosion and sedimentation processes work. This will help to us find a balance between drainage hydraulics and ecological stream function, as well as any other demands we place on a waterway. A better understanding will also help overcome any controversy about what constitutes appropriate river management.

Glossary

Avulsion In the context of this chapter, an avulsion refers to the cutting off a section of land by flood flow, or a change in the course of water flow often accompanied by erosion activity.

Bankfull level Height of the channel forming flow, that is, flow that shapes the channel and leaves its mark. Marks or clues to the height of level include the upper edge of generally exposed soil, lowest extent of lichens or annual grasses, grooves in the bank and upper edge of water stains on the bank.

Discharge The rate at which water flows. It is often measured in cubic metres per second (cumecs) or litres per second.

Meander The turn of a stream channel, a bend, often associated with a distinct loop.

Planform The characteristic structure of a stream channel, specifically in the way the channel appears in plan view.

Thalweg The line joining the lowest points of successive cross-sections of a channel. Usually associated with the path of highest velocity.

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