chapter 2
How south-west catchments and river systems work

- **Rainfall**
- **Surface and Groundwater Movement**
- **Stream Form**
- **Flooding**
- **Case Study - A Comparison of Forested and Cleared Catchments**

This chapter deals with the physical nature of streams, which is largely determined by the laws of physics that govern the motion of fluids. Despite the fact that these laws are universal, the behaviour of streams and the formation of channels are highly variable and complex. This is because of changing climatic and geological conditions, over both time and space, and the contribution that living things, mainly vegetation, make to the nature of stream channels. The south-west has its own unique climatic and geological setting, and its own biological response and contribution to this setting. Therefore, to understand south-west river systems, it is necessary to take a catchment wide approach and to look at the land phase of the water cycle as it expresses itself in the south-west. Thus this chapter follows the main pathways of water through and over the land, and along the way explains the formation and behaviour of the river systems. The story begins with rain.
2.1 Rainfall

Falling rain

When raindrops first form and begin to fall they initially gain speed as gravity pulls them towards earth. But soon they reach what is called terminal velocity, where they stop accelerating and fall at a more or less constant speed determined by the frictional effect of the surrounding air. On the way down drops continually break up and coalesce and the drop size distribution takes on a certain characteristic form. Generally, rain contains a range of drop diameters from about 0.25 mm to 7 mm with the larger drops falling further before reaching a terminal velocity (Troeh et al. 1980). Strong winds can further increase velocity and cause the drops to fall at an angle to the ground.

Reaching the ground

The kinetic energy of the falling droplets is dissipated when the drops complete their atmospheric journey and hit the ground or some object upon it. The magnitude of the impact of each raindrop will be a combination of its size and speed. Large drops have greater momentum and therefore more impact than small ones, and drop size generally increases with storm intensity (Troeh et al. 1980).

While the above explanation may seem obvious, what is not obvious is how significant the energy of falling raindrops is to the erosion of bare soil. Where vegetation is absent, the maximum amount of kinetic energy is delivered to the soil (try tapping your finger on a table and then think of the effect of millions of these little taps on the soil). The pummeling action of the rain breaks up soil aggregates and clods into smaller aggregates or individual particles, moves the soil grains closer together and compacts the soil (Troeh et al. 1980). If rain falls on sloping ground, soil particles tend to be knocked downslope more than upslope and this can lead to downhill soil movement over time.

Rain and vegetation

Vegetation therefore has an important role in dissipating the kinetic energy of rainfall. When rain falls over naturally vegetated catchments, much of it does not hit the ground directly but rather is intercepted by the foliage of the vegetation (Moss and Green 1990). Although much of the rain that strikes the vegetation eventually drips through the foliage, the final fall to the ground is mostly short and thus the drops have low kinetic energy. Other droplets are broken up as they hit the vegetation and fall to the ground as smaller, low energy droplets. Furthermore, much of the rainwater actually runs down the branches and stems of the vegetation (DCE 1984). In heavily vegetated areas, rain that misses the vegetation hits mulch and leaf litter on the ground. In most natural areas of the southwest the soil is well defended from the impact of rainfall by its natural vegetation. Of course, exotic vegetation can also defend the soil, but where annual crops and pastures are grown the soil is dangerously exposed over the summer and autumn and often at the beginning of winter. These are periods when thunderstorms and the break of season rain can result in significant erosion.

Tall gum trees can actually produce high energy raindrops. This occurs firstly because the pointed, relatively broad gum
a) Naturally vegetated catchment

b) Cleared catchment at the beginning of winter

Figure 2.1 The general action and movement of rainwater on the land surface of (a) the naturally vegetated catchment and (b) the cleared agricultural catchment in south-west Western Australia.
Figure 2.2 A comparison of the general flows of water on the land surface in the ground and through the vegetation of (a) the naturally vegetated catchment and (b) the cleared agricultural catchment in south-west Western Australia.
leaves act like microcatchments, gathering water and producing large drops at the tip of the leaves. For tall trees, many of these drops will have uninterrupted falls of many metres, gathering considerable energy on the way and hitting the soil with considerable impact (Moss and Green 1990).

**Where the rain goes**

Once rainwater has reached the earth’s surface it moves in a number of different directions (Fig. 2.1a). Water that remains on the vegetation evaporates. The amount of rainfall which is intercepted and returned to the atmosphere in this way is determined by the surface area of branches and leaves (DCE 1984). In the densely vegetated jarrah forest as much as 28% of rainfall can be intercepted and returned to the atmosphere (DCE 1984), while in the thinner wheatbelt woodlands the amount is about one tenth of this (Nulsen 1992). Rainfall reaching the ground is soaked up by mulch, soaks into the soil or runs across the surface. In natural areas of the south-west virtually all the rainfall that reaches the ground soaks into the soil, with runoff only occurring during intense rainfall events when water cannot infiltrate into the ground fast enough (DCE 1984; WAWRC 1986). Generally, as annual rainfall increases a greater proportion of the rainfall contributes directly to runoff (George et al. 1995; Sadler et al. 1988).

In cleared areas of the south-west, where soils have been compacted by rainfall, livestock and farm machinery, an increased proportion of rainfall contributes to runoff (Schofield 1990) (Fig. 2.1b). Generally speaking, rainfall produces more runoff in cleared areas than in neighbouring naturally vegetated areas. In the south-west, the increase in runoff caused by the clearing of forest and woodlands and their replacement by pastures and annual crops is generally between two and four times (Schofield 1990; Ritson et al. 1995; Muirden unpub. data).

### 2.2 Surface and Groundwater Movement

#### 2.2.1 Water movement in natural areas

Once rainwater reaches the ground it either soaks into the soil or runs across the soil surface. In naturally vegetated areas of forest, woodland and heath, nearly all of the water infiltrates straight into the soil. Only in very high rainfall events when the water cannot penetrate the soil quick enough does water move over the surface (DCE 1984; WAWRC 1986). It is this effect on a large scale that generates flooding. Even then much of the surface runoff will be gathered in depressions or by tiny dams built by washed up leaf litter, to form pools which will slowly soak away. Only a small amount of the water that falls upon naturally vegetated catchments ever reaches creeks by direct runoff (Fig. 2.2a) (DCE 1984).

Nearly all of the rainfall which reaches the ground enters what is known as the unsaturated zone (see Fig. 2.2). This is the zone of the soil between the earth’s surface and the watertable. The watertable marks the surface of the saturated zone, where all the space between soil particles is filled with water (DCE 1984). In the Darling Range and on the Yilgarn Plateau proper the saturated zone overlies impervious bedrock.
Forest, heath and sedgeland of the Deep River catchment near the Weld River.

Photo: J. Alford

An urban catchment of the Canning River, in the City of Gosnells. The two lakes are in Mary Carroll Park.

Photo: L. Pen
A rural catchment in the Shire of Manjimup. Photo: S. Neville - Ecotones.
The unsaturated zone is where most of the action takes place. Here water is either taken up by plants which eventually return it to the atmosphere via evapotranspiration, or moves laterally slowly downslope to eventually seep into surface streams or lakes or slowly downward to the saturated zone (Fig. 2.2a). In high rainfall areas of the Darling Range, the water of the saturated zone typically discharges to streams in deep valleys, the base of which is bedrock. A small amount of water also evaporates directly from the upper parts of the soil profile. However, most of the water which enters the unsaturated zone is consumed by plants. In fact, in the wheatbelt, where average annual rainfall is less than 500 mm, about 99% of rainfall was once intercepted and consumed by the indigenous woodland, mallee and heath plant communities (George et al. 1995). In natural catchments very little water escapes the unsaturated zone to flow either to creeks, rivers or lakes or to the saturated groundwater zone. Indeed, some of the water which reaches the streams can actually re-enter the groundwater by percolating through the stream bed (Fig. 2.2a).

Some of the water which does make it to creeks, rivers and lakes will be consumed by fringing vegetation, although some recent research suggests that fringing plant species in certain circumstances make little use of this water (Thorburn et al. 1992, 1994).

In contrast, the large trees, shrubs and mallees of upland dry forest, woodland and mallee communities send their root systems as far down as 40 metres to tap the deep groundwater of the saturated zone and to exploit fully the soil water of the unsaturated zone (DCE 1984; Schofield 1990) (see Fig. 2.2a).

### 2.2.2 Water movement in cleared agricultural areas

Where the soil has been compacted by rainfall, livestock and vehicles, a greater proportion of rainfall moves from the land as surface runoff (Fig. 2.2b) (DCE 1984; Schofield 1990). Nevertheless, most still enters the unsaturated zone. However, much less is consumed by agricultural plants, especially pastures and annual crops, and therefore more water is left to evaporate from near the soil surface or move through the soil to streams and lakes or to the saturated groundwater zone. As a result, streams carry more water today, relative to rainfall, than they did in the past and watertables are rising (Fig. 2.2b) (Schofield 1990). The latter effect is compounded by the enormous loss of deep rooted perennial plants which once consumed vast quantities of the soil water and some deep groundwater (Fig. 2.2a).

The broad impact of rising groundwaters and salinisation on the environment is beyond the scope this book, but it should be noted that agricultural clearing is not the only cause. Clearing of native perennial vegetation also occurs for other reasons.

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1. The movement of water in the unsaturated zone depends on the material that comprises the subsoil. For example, duplex soils (e.g. shallow sand over clay) will force water to move in particular ways because of the difference in hydraulic conductivity. Macropores, which form where plant roots rot away, may give the dense clayey soil profile an uncharacteristically high conductivity.

2. The decline in rainfall over recent years (see Chapters 1, 7 and 10) by 10-20% has reduced river flow by about one third in natural areas in the south-west and would have reduced the increase in river flow brought about by greater runoff and lateral soil water flow in cleared areas.
such as sand and gravel quarrying, residential development and road building. There is also clearing for open-cut mining and clear felling for wood production, but in these cases clearing is often only temporary and groundwater rise is mostly carefully managed (DCE 1984). Poorly executed irrigation is another cause of land salinisation (White 1997). (See Chapter 7 for the impact of rising groundwater and salinisation on river ecosystems.)

### 2.2.3 Water movement in urban areas

A large proportion of the land surface of urban areas is rendered impermeable and smooth by roads, parking lots, pathways and buildings. This has the effect of increasing both the volume and speed of runoff, far above that of cleared rural areas (Rhoads 1995). In other words, in an urban catchment for a given rainfall event, there is much more water moving off the land surface than in an equivalent size rural area, and it is moving faster. Furthermore, for a given volume of water, the faster runoff means that peak discharge is greater in the urban area than in rural areas, because the movement of the same amount of water in the urban catchment is compressed into a shorter period of time. To prevent flooding in urban areas, artificial drainage systems are essential. For this reason urban drainage systems are generally constructed to move water quickly and to be large enough to contain the very high peak flows. Compared with rural catchments, the lag time between rainfall and the resultant runoff is very short and even small rainfall events which would produce no runoff in rural areas, can produce considerable flows in urban areas. Thus drainage density, the length of drainage line (including road gutters) per unit area, is much greater in urban than in rural areas (Rutherford and Ducatel 1994). Interestingly, runoff from the heaviest of storms is about the same for urban as cleared rural catchments, because the saturated soil conditions that quickly result from the heavy rainfall render the land surface as impenetrable as the impervious land surfaces of urban areas (Rutherford and Ducatel 1994).

### 2.2.4 Surface flow and soil erosion

The actual flow of water over the land surface can take one of two forms. Usually it starts out as a uniform sheet of water which is seldom more than a few millimetres deep (Troeh et al. 1980), but soon becomes channelled to form minor streams along both ill defined and well defined drainage lines. These drainage lines may form small temporary pools or eventually join to form larger streams which are part of a much larger drainage system.

**Water flow velocity**

Water basically flows under the force of gravity. It either spreads out over a flat surface or runs down a slope. The greater the slope the greater the acceleration. The longer the slope the greater velocity the water will have, until a terminal velocity is achieved as a result of friction with the land surface. A slope may be straight, in which case acceleration is uniform along its length; it may be convex, with water starting out slowly but gaining velocity as it moves downhill; or conversely, the slope may be
concave with decreasing acceleration of the water as it moves downhill (Fig. 2.3 a & b). The shape of the contour lines on a hill slope is also important. Convex contours, as you would see with water running down from the top of an inverted bowl, cause the water to diverge (Fig. 2.3c), whereas concave contours, as you would see with water running from the rim to the bottom of the inside of a bowl (Fig. 2.3d), cause it to converge, resulting in the concentration of water and therefore an increase in depth.

In channelised flow, depth in addition to slope is an important factor in determining the velocity of the water (Marsh and Dozier 1981). This is because the channel bed has a large frictional effect, slowing the water and dissipating its energy as heat or as work in the erosion and transport of sediment. In effect the water drags on the channel bottom and carries some of the bottom sediment along with it. Water away from the stream bed is less affected by it and therefore is free to flow faster. A view of the water column in cross section shows that flow velocity increases with distance from the stream bed (Fig. 2.3e). Therefore, as stream depth increases and a smaller proportion of the water is actually in contact with the bed, the overall average flow rate increases. The water just below the surface of the deepest part of the stream moves the fastest of all (Fig. 2.3e). At the water surface, the frictional effect of the air slows the water very slightly (Fig. 2.3e) (Marsh and Dozier 1981).

Often the river bed supports vegetation which is many times rougher than the bed itself. Aquatic and fringing vegetation are very significant elements in the natural channel in slowing the movement of water (Thorne 1990).

The river reach

A section of streamline along which the kinetic energy of the flowing water more or less remains constant is known as a reach. Here the flowing water is established in an equilibrium between the forces of acceleration and friction and there is no increase in the volume of water (Marsh and Dozier 1981). A reach would appear as a section of streamline of more or less uniform slope and channel roughness between tributaries.

The action of flowing water

Just as falling raindrops have kinetic energy, so does water as it moves across the land surface. Therefore it can do work. It can detach and lift soil particles, hold them in suspension or at least cause them to jump or tumble (a process called saltation) and carry or push them along. The more kinetic energy water has, that is the faster it flows, the larger and heavier the particles it can detach and carry. If the flow of water becomes turbulent, as for example through the action of falling raindrops on shallow sheet flow, its kinetic energy is increased dramatically and so is its erosive capacity (Troeh et al. 1980). Furthermore, the particles moving around in the water generally have greater density than the water itself, and thus they impart greater energy to the muddy fluid, making the fluid more abrasive and heavier, and therefore more erosive, than clean water (Troeh et al. 1980).

In naturally vegetated areas of the southwest, where surface flow of water is very limited and much of the soil is protected by vegetation, soil erosion and therefore sediment transport is probably insignificant. However, in cleared agricultural areas
Figure 2.3 The relationships between flow velocity and slope form for (a) convex and (b) concave slopes, for (c) diverging (hill) contours and (d) converging (valley) contours and for (e) stream channel depth (NB. the longer the arrows the faster the flow).
where surface flow is much greater and the soil far more exposed, especially at the end of summer, soil erosion can be considerable (White 1997; SCEP 1991). The turbulent movement of abrasive muddy water over exposed soil can quickly break up soil aggregates and clods and put them into motion. Generally the lighter or smaller the particles the further they are carried (Marsh and Dozier 1981). In this way the soils of our agricultural lands are slowly being sifted of their finer fractions with only the coarse fractions remaining on the farmlands (Troeh et al. 1980). It is the finer fractions that contain most of the nutrients and organic matter needed for highly productive soils.

The nature of the material of the stream bed itself also has a great effect on the work that flowing water can do. For example, silts and clay particles are cohesive and are held in the stream bed principally by molecular attraction, requiring a relatively large amount of energy to detach individual particles. However, once dislodged, their tiny size means that they are easily carried in suspension. In contrast, larger sands and gravels which are held in the stream bed by gravity alone, while being relatively easy to detach, require more energy to transport.

Dissipation of the energy of flowing water

The energy of flowing water is dissipated in a number of ways. Firstly, as explained above, the channel bed itself imparts a large resistance to the flow of water. And when water does work in the channel by eroding and carrying sediment it loses some of its energy and slows down (Marsh and Dozier 1981). Similarly energy is lost when the water is slowed because of increased friction due to aquatic vegetation, or when it is forced to spread out over a large relatively flat area, such as a wide channel or floodplain where the water is in greater contact with the ground. A constriction or barrier may also slow upstream flow. The damming up of water by washed up leaf litter or a log jam along a river, are examples of the latter form of energy dissipation. When this occurs, water loses some of its capacity to erode and to carry sediment, with the result that the coarser fractions, previously held in suspension, will settle out. If the energy of flowing water is not dissipated in some way, gravity ensures that as the water accelerates downstream it gains increasing power to erode and carry sediment.

Vegetation, probably more than any other factor, plays an important role in dissipating the energy of flowing water, especially along creeks and rivers (Thorne 1991). It imparts greater roughness along streamlines, slowing the water and holding it up. In this way vegetation protects the land from erosion and filters out sediment. On floodplains, where floodwaters come to a near halt, even the fine clay and silt fractions have an opportunity to settle out. Unfortunately, the fringing vegetation of streamlines and their floodplains has been lost or thinned in most agricultural catchments, enhancing the capacity for flowing water not only to carry sediment from the farmlands but also to erode exposed beds and banks of creeks and rivers, often leading to severe sedimentation of downstream waterways (Frankenberg 1992).
Incision

The downward cutting action of the stream on the land is called incision. The rate of incision is determined by the cohesive strength or the size of the sediment of the stream bed and the amount of energy the stream brings to bear upon it. Where a stream has little energy through flowing along a slight slope or where the stream bed is very cohesive (e.g. clay), incision is very slow. Similarly, where most of the stream’s energy is dissipated by vegetation or in the transport of sediment, incision is slow or does not occur. Where a stream bed is covered with sediment too large to be eroded quickly, the stream bed is said to be armoured. But incision can be dramatic on soft sandy channel beds during high flow periods. Interestingly, where incision cuts a deep channel the steep banks often collapse and contribute sediment which armours the bed. For a while net incision of the channel will cease, until the sediment is transported downstream.

Stream power

Stream power is the capacity of a flow of water to do work, to dislodge, lift and carry material. It is also referred to as tractive force. The factors that go into determining stream power are many and interact in complex ways. For the purposes of this book the main factors are slope and depth of flow. Slope has great bearing on the speed at which water moves, and the faster water is moving the deeper it is, the greater is its stream power.

2.3 Stream form

When rainfall gathers on the land surface and begins to move downslope, it initially flows as a thin sheet. However, flow soon becomes concentrated into streams of faster moving water. This occurs where converging sheet flow creates deep water and where flow naturally moves along paths or lines of least resistance. Channels form along these lines as the stream erodes the ground beneath it. Channelised drainage lines intercept one another and combine successively to form a system of stream channels which grow fewer in number but larger in width and depth as the water progresses downstream and the system gathers more and more water. As drainage lines are low points in the landscape they also receive water via seepage along their banks from the lateral flow of soil water. While groundwater seepage generates the low base flows of creeks and rivers, it is the surface runoff flows, generated by high rainfall events, that excavate and maintain stream channels.

The physical forces which act on the movement of water in channels determine the form of drainage systems. These forces are as much in play on tiny streams as they are on the largest rivers.

2.3.1 Channel width and depth

The width and depth of a channel along a particular reach is determined by the amount of water that flows in an average regular flood, known as the channel forming flow, when heavy rains fall in the catchment and direct runoff is significant (Marsh and Dozier 1981). In south-west
Australia this mostly occurs in mid-winter when the soils are very wet from earlier rains in the season. For most of the time however stream flows are small and in many cases there may be no flow at all for months or even years.

The channel forming flow can be recognised because it fills or more than fills the channel from bank to bank. On average this occurs once every one to two years (Leopold et al. 1964; Leopold 1995; Newbury 1995). The size of this bankfull flow (also known as bankfull flood or discharge), and hence the channel, increases downstream as the river system gathers more and more water via its tributaries from an increasing catchment area. Generally, the width of the channel increases more than the depth as the bankfull flow or channel forming flow increases in magnitude (Leopold et al. 1964; Leopold 1995; Newbury 1995).

2.3.2 Meandering

Water does not flow in a straight line, but rather flows in a wave form. This is due to the water being bent up as it drags on the channel bed and banks. (The effect can be likened to the gathering up of a piece of paper ribbon, standing on one edge, as it is pushed from one end upon a table surface.) Consequently, natural streamlines are seldom straight and for the most part meander across the land. On average the length of a single meander turn is six times the bankfull width of the channel, with a full meander of two bends being twelve times the bankfull width (Fig. 2.4) (Leopold et al. 1964; Leopold 1995). Furthermore, the average radius of curvature of a meander bend is 2.3 times the bankfull width. This is the most energy efficient form of the stream. (Think of this like a stroll through a forest and the path you would take to walk around a tree. You would not wait until you were right up against the tree before you moved around it and you would not begin to walk around it when you first saw the tree, tens of metres away. Also, you would not take a detour that added unnecessarily to the distance you would need to travel. At some point the most energy efficient, or least effort, course would present itself and you would deviate from your straight line course. The least effort course through a forest is a meandering one and one where the meander wave length and amplitude is just right.)

One interesting effect of meandering is that the speed of water increases as it passes around the outside of a bend and decreases on the inside (think of the wheels of a car going around a corner). Erosion occurs at the outside and slightly downstream of the meander bend, while deposition of sediment occurs on the inside, forming what is known as a point bar (see Fig. 2.4) (Newbury 1995). For this reason, the outside of the channel bend usually runs along a steep bank or even a cliff, while the inside of the channel runs along the low lying land formed by the point bar (Fig. 2.4).

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3 An exception to this is the rare occurrence of heavy cyclonic rain during summer. Cyclone Errol caused many rivers to flood throughout the south-west in January 1982 and the exceptional flood levels it produced are often marked at bridges. Look out for them when you are next out and about in the lower south-west.

4 The analogy can be stretched a little further by considering the desire of the bushwalker to walk at a more or less constant rate and thus minimise unnecessary high effort ‘bursts’ of energy or the need for rapid changes in course.
Figure 2.4 Stream channel form: (a and b) pool and riffles and (b and c) meanders and point bars.
A second interesting effect of meandering is to increase the length of the stream between two points, thus reducing channel slope and increasing bed area. The result is reduced acceleration due to slope and increased stream bed friction, both of which reduce the velocity and hence kinetic energy of the flowing water. Consequently, water flowing in a meandering channel has a reduced capacity to erode and carry sediment compared to that flowing in the straight channel. Therefore, a meandering channel is more stable and less likely to be eroded than is a straight one between the same two points (Marsh and Dozier 1981).

### 2.3.3 Pools and riffles

Just as water undulates from side to side it also undulates up and down, forming a stream bed which has alternating deep and shallow zones, known as pools and riffles⁵. Some scientists believe that these zones are formed as a result of the movement of water as it passes round a meander bend (Newbury 1995). As water moves through a bend, centrifugal forces cause it to sweep to the outside edge (think of the lean of a car as it goes around a corner), causing a build-up of water towards the surface of the outside of the bend which displaces the water beneath it. This displaced lower water is forced to move towards the inside of the bend as it moves downstream. The overall effect is that water moves in a spiral form, like a corkscrew, around the bend. Between the bends, where the flow of water straightens up again before the next turn, are shallow areas known as riffles. Because of pool/riffle form, stream beds do not have a constant slope as would be found along a freshly constructed drain, but rather a step form, where water flows from one pool to another as shown in Figure 2.4.

This is one reason why most of the rivers in south-western Australia have large deep pools which retain water over the summer and autumn when river flow is reduced to a trickle or ceases altogether and most of the river channel is dry. During low to moderate flow periods between floods, water appears to flow from one pool to another in a step fashion as each pool overflows into the next pool downstream. At this time, not all the water that can be seen in the channel is actually flowing. Most is impounded within the pools. If not for these pools the river bed would hold much less water and there would be far less habitat for aquatic animals. When the stream channel is in flood, all the water that can be seen is actually flowing, and it is at this time that the deep pools are scoured of sediment that has built up in them during low and moderate flow periods (see Section 2.3.6) (Marsh and Dozier 1981).

As mentioned above, at times of low to moderate flows water is moving only on the riffles, causing them to be scoured of fine sediment which settles out in the pool downstream. In times of flood when water is moving throughout the system, stream power is actually greatest over the pools where the water is deepest. For this reason anything like a decent size rock or log that is washed off a riffle is quickly swept through the pool onto the next riffle where stream power is less than over the pool. Fine sediment which collected in the pools during times of low flow is carried far.

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⁵ Note that a riffle is also the name given to a zone of flowing water where the water surface is uneven due to rocks on the stream bed, but where these rocks do not break the surface.
downstream and swept up onto the point bars. Studies elsewhere in the world have shown that the length of a single pool riffle sequence is, on average, six times the bankfull width of the stream (Leopold et al. 1964; Gregory et al. 1994; Newbury 1995). A full meander, with two complete riffles (one half at each end and a full riffle in the middle) and two pools, is on average twelve times the width of the channel (Fig. 2.4).

Note that classic pool/riffle form only occurs in streams where channel bed particles are pebble size or larger (Church 1992). Sandy bed creeks and rivers tend to be braided and mainly form pools at constrictions in the river valley, due to scouring by accelerated flow. Pools may also form where dolerite dykes cross rivers creating a rifflle/pool sequence for reasons yet to be clearly understood.

### 2.3.4 Step pools

Along the channels of many upland creeks of the Darling Range, the roots of trees cross the channel and provide for ‘steps’ which mimic on a small scale the pool/riffle effect seen on larger creeks and rivers (Church 1992; Growns and Davis 1994).

### 2.3.5 Low flow channel

During moderate to low flows the water in the pools will appear quite still and the water in the riffle zone is often confined to a narrow channel winding from one pool to another. This second stage channel contained within the main channel or floodway of the river is typical of many rivers in south-western Australia. It is formed by the longer lived low to moderate, groundwater fed flows which occur between floods (Myers and Lynes 1994). This second stage channel is often known as the low flow channel, main channel or active channel, and it will also carry water when the flow is reduced to a trickle. The last term applies where the low flow channel mostly does not support vegetation and is actively eroding and transporting sediment, if only slightly. The broad river channel, when well supported by protective fringing vegetation, may be considered inactive.

#### 2.3.6 Changing form: erosion and deposition

The stream channel is a dynamic system; it is constantly changing its form through erosion at certain points and deposition at others (Marsh and Dozier 1981; Dept. Water Resources 1993). In the most stable of rivers, erosion and deposition are virtually limited to meander bends and point bars, respectively. With erosion at the outside and slightly downstream of the meander bend and deposition on the inside and slightly upstream of the bend, each meander is slowly moving laterally downstream (Dept. Water Resources 1993). Thus the wave form of the stream slowly progresses downstream; where the channel once ‘zigged’ it will eventually ‘zag’, and so on. Where a stream is well protected by vegetation, changes in channel form may be hardly detectable in hundreds of years, but where vegetation is sparser or has been removed the channel may undergo dramatic change in only a short time.

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*A dolerite dyke is a long narrow sheet of igneous rock that cuts discordantly through the land. Often the rock is less erosive than the surrounding land through which it cuts.*
A well vegetated channel of the lower Kalgan River. The vegetation has been buffeted by recent flood flows. Photo: L. Pen

A meander bend on the middle Kalgan River. Photo: S. Janicke
A river pool on the Collie River South Branch near the hamlet of Collie-Cardiff.  Photo: L. Pen

The low flow channel of the Collie River South Branch in the vicinity of 'Hunter's Bridge'.  Photo: S. Janicki
The stream channel will also change form slightly between short periods of low to moderate flow and floods. During low flows, sediment will tend to be stripped from the riffle zones where water is flowing quite rapidly and deposited in the pools where the water is comparatively still. In contrast, during floods the pools are well scoured and sediment is thrown up onto the riffle zones (Marsh and Dozier 1984).

With long term changes in flow magnitude, changes to channel form will be more pronounced. For example, between the 1910s and 1980s, the south-west has experienced a major reduction in rainfall of the order of 20%. This resulted in much lower river discharges in most natural areas, of about 45% for rivers near Perth (Schofield 1990). This means that sediment would have accumulated in most stream channels, reducing their depth and width. In effect, with less water and hence energy the stream channels have contracted in size (Rutherford and Ducatel 1994). With a return to average rainfalls or greater, this accumulated sediment will be scoured from the streams and the channels will deepen and widen (Rutherford and Ducatel 1994). Clearing and hardening a catchment can also increase discharge significantly, causing dramatic deepening and widening of channels, far in excess of what would occur naturally. This is why severe gullying along minor drainage lines is often seen on farmland and in urban areas.

Erosion and sedimentation in urban areas

Erosion and sedimentation go through two phases in urban areas. In the initial construction phase, vegetation is cleared and the ground is disturbed as buildings and infrastructure are established (Thorne 1990; James 1995; Urbanas and Benik 1995). In this stage the land surface is highly exposed to erosion, with the effect that large quantities of sediment are delivered to streams in surface runoff. Because runoff rates have yet to increase dramatically, sediment collects in the streams and is often colonised by weeds. Accumulated sediment may reduce channel capacity and perhaps cause flooding.

In the post-construction phase the catchment has been rendered relatively hard, smooth and impervious. In this condition catchment erosion is low, but runoff is high. High energy flows can cause channel incision and widening and even channel shift, as the channel grows and alters its meander radius to accommodate the much larger channel forming flows of the urbanised catchment (Leopold 1995; James 1995). This process can be sudden and dramatic and involve damage to drainage infrastructure and adjacent property, especially if protective fringing vegetation has been removed (Rutherford and Ducatel 1994; Leopold 1995). After a number of years, sediment which accumulated in the stream during the construction phase may be entirely flushed downstream, and with the decline in new sediment from the consolidated urban catchment, bank and bed erosion may become an ongoing problem (Wolman 1967).
2.3.7 Floodplains, terraces, billabongs and double channels

Floodplains are broad flat low lying areas adjacent to rivers. They are not formed initially by floods, as the name would suggest, but rather by the accumulation of sediment on point bars and the slow lateral movement of the river channel away from the areas of accumulation. Floodplains are so called because they help to contain and to some extent carry floodwaters during major floods when rivers burst their banks and the floodwaters spill over onto the land. By holding water for a time and slowly releasing it to the river channel, floodplains stretch out the flood over time and thereby reduce peak flows. In so doing, floodplains reduce the amount of water the river channel must carry during the height of the flood, and hence the amount of energy it must bear during major flood events. Floodplains can be looked upon as a form of protection against channel incision and widening. Furthermore, because water only moves slowly across floodplains, very fine sediment, which would otherwise be in suspension in the more rapidly flowing water of the channel, is deposited on the plains and thus removed from the floodwaters. In this way floodplains may build up in time through the accumulation of sediment, often creating rich red loamy soils.

A terrace is an old floodplain which is no longer or very seldom inundated by river floods. Terraces form as a result of slow downward movement of the river bed as it cuts deeper into the land over many thousands or millions of years, leaving old floodplains stranded above typical flood levels.

A billabong is an old river pool which has been cut off from the main channel of the river. This occurs where the meandering of the river is highly convoluted and a meander bend progresses downstream faster than the one below it, cutting through to the channel below the next downstream meander. Because this short cut has a greater slope than the old channel, it represents the more energetic route and takes most of the water. As the old section of channel no longer carries much water, it becomes filled with sediment and its pool isolated. True billabongs are uncommon in the south-west, suggesting that river channel change has occurred only very slowly in this region. Some old billabongs remain near the end of the Preston River’s natural course near Bunbury. Sometimes secondary channels in braided rivers like the Avon become disused and form long pools which are referred to by local people as billabongs. Backwaters would probably be a more accurate term.

Sometimes rivers in the south-west have two channels for short distances. Usually one channel is dominant, carrying water for most of the time when there is flow, with the second channel only flowing during floods. It is difficult to explain why two channels should form, but one reason may be that vegetation in the main channel slows the water down, causing it to build up upstream and to overflow across the top of a point bar where the more upland vegetation is sparser or across higher ground to a tributary. The process of forming a ‘break-out channel’ is called an avulsion and the resultant channel is known as an anabranch or distributary. Whatever is the cause of an avulsion, during periods of high flow, the secondary channel apparently
A section of the lower Waychinicup River showing the alternating sequence of pools and rocky riffles.

Photo: S. Neville - Ecotones
A SMALL FLOODPLAIN ON THE MIDDLE WAREN RIVER. PHOTO: L. PEN

A VIEW OF THE LOWER KALGAN RIVER, AT THE SITE OF THE WATER AND RIVERS COMMISSION GAUGING WEIR. HERE THE KALGAN RIVER HAS FORMED A 'CLASSIC' RIVER VALLEY. PHOTO: L. PEN
becomes another efficient route for the water to take, and in some cases a more efficient route. Mostly, double channels occur for only short distances and generally lie close together. However, sometimes they may cover long distances. A good example is the Young River near the Stirling Ranges. Minor double channels may also form as second stage channels within the broader major channel.

2.3.8 Braided streams, levees, bars and deltas

In highly eroding catchments, river systems will carry large quantities of sediment. These will be seen as many small heaps or large plumes of sediment on point bars, behind obstructions or amongst vegetation; as sand bars on the edge of pools; or as levees along the edges of floodplains where floodwaters first slow down and deposition is heaviest. Where the sediment load is not particularly large it will be moved downstream quite efficiently, mostly from point bar to point bar, without compromising the general form of the stream channel. However, if the amount of sediment is excessive it will begin to clog the channel, filling river pools and covering the riffle zones until the stream appears as a long plume of sand known as a slug. In this situation the stream often becomes braided into a series of channels weaving from one to the other through the sand; the stream channel will be seriously compromised and the behaviour of the stream will change dramatically, possibly causing serious erosion of the bank or upstream flooding. Today the Palinup and Moore Rivers are examples of south-west rivers whose lower to middle reaches carry large sediment loads (Olsen and Skitmore 1991; Select Committee on Land Conservation 1990).

When the water of a river or creek enters a lake, estuary or ocean inlet or bay, the water slows abruptly and most of the sediment is deposited, forming islands, spits and bars known as deltas. Deltas mark the end of the creek or river system, although in the wheatbelt some lakes will occasionally overflow into downstream river systems. Heirisson Island on the Swan Estuary marks the end of the Swan-Avon river system. It is not a natural island, but was made from the dredged material of the original deltaic islands, bars, mudflats and salt-marshes.

Bars, levees and deltas provide opportunities for colonisation by vegetation which may in time stabilise them, forming permanent islands and levees. These in turn may affect the behaviour of the water within the channel, leading to further channel alterations to accommodate the new form. Before it was trained the Avon River had a heavily forested braided form. A short section about 300 metres long, between the Ballardong Bridge and railway bridge at York, retains its original form.

2.3.9 Waterfalls, cascades, rapids, riffles and runs

Waterfalls are found where water is in free fall or near free fall on a very steep slope. They often form where the flow of water passes from hard ground to relatively soft ground, the softer downstream land eroding away more quickly. In the south-west most waterfalls are found along the Darling Scarp where streams drop from the plateau to the sandy coastal plain, although one of
the most spectacular examples, Fernhook Falls, is in the lower south-west on the Deep River.

Seldom, however, do south-west waterfalls actually have one or two true long falls, as in the case of the Mitchell Falls on the Mitchell River in the northern Kimberley. Mostly they are simply the combination of many small short falls and the fast flow of water over steeply sloping rock. They would better be described as steep cascades (Church 1992), where the water falls or flows quickly and with much turbulence over a series of rocky steps along a steep or moderate slope. Gooralong Brook, a scarp tributary of the Serpentine, has a good example of a series of drops, which includes both vertical drops and steep cascades. The Cascades picnic site on the Lefroy Brook near Pemberton is another example. Rapids differ from cascades in that the water is seldom ever in free fall or near free fall, but rather flows rapidly over and between rocks so that the water surface is boiling and broken into froth. Where water flows rapidly over boulders or pebbles and the water surface is uneven but not broken, the stream zone is called a riffle (Church 1992). This is because, in the northern hemisphere where this term comes from, riffle zones between the pools often have flow which resembles this form. Finally, a run or glide is where the flow of water is swift but the water surface is more or less even.

Waterfalls, cascades, rapids and ripples have two very important functions. Firstly, they help to oxygenate the water column. Turbulent flow, often with broken water, increases the surface area of the water in contact with the air which increases the aeration and hence oxygenation of the water, essential for aquatic life.

In the south-west this is all the more important because, for reasons outlined in Chapter 3, there are few other opportunities in the natural river ecosystem to oxygenate water. The second function is the creation of sound: the babbling of brooks and the roaring of rapids. Normally the flow of water makes no sound; only when it is accelerated suddenly by an abrupt increase in slope or through having to flow over an obstruction, is noise produced (Newbury 1995). It occurs because of the breaking of bubbles of air which are entrained in the water during initial acceleration. For aquatic animals this noise is important, as it enables some species to find their preferred habitats. For example, in North America it is known that trout find their way to feeding and breeding habitats by moving towards the sound of breaking bubbles (Newbury 1995).

2.3.10 The river valley and riparian zone

The river channel lies within a valley which the stream has dug over many thousands of years. Here we are not talking about the broad valley of the catchment such as the Avon River valley or the Blackwood valley which have been eroded by countless drainage lines over millions of years, but rather the immediate valley of the river which is usually characterised by the presence of wetland plant species such as flooded gums, paperbarks and sedges and rushes. Figure 2.5 illustrates the typical cross sectional form of the river valley and the terms used to describe it.
Figure 2.5 Typical river valley form and the riparian zone
In cross section, the river valley consists of a number of zones: the valley embankments, the broad floodplain\(^7\), the broad river channel, also appropriately known in Western Australia as the floodway, and perhaps a central, main or low flow channel. The floodway may be in the form of a riffle (see Fig. 3.2) or a pool (see Fig. 3.2). The actual shape of the valley can vary considerably depending on its location in the landscape. In the Darling Range river valleys are narrow and V-shaped with a small floodplain. In these situations floods are vertical in nature, with water rising to great depths in the narrow river valley. On the other hand, river valleys on coastal plains are relatively shallow with moderate embankments and occasional floodplains (see Fig. 3.2). And at the very extreme, some rivers, such as the Cobbline and the Gordon in very flat areas of the wheatbelt, appear to be all floodplain with no identifiable valley embankments or even floodway.

Another useful zone to recognise, at least for the management of river systems, is the verge. The verge is an area of upland of indefinite width above the crest of the valley embankment on either side of the river (see Fig. 2.5). While this zone is not actually of the river valley itself, it may nonetheless have great influence upon it (see Chapters 3 and 4).

For river management, the entire river valley and the verge areas on either side are known collectively as the riparian zone (see Fig. 2.5). For ecological considerations the verge would not necessarily be included.

### 2.3.11 Drainage or branching patterns and stream order

In south-western Western Australia most river systems have what is called a dendritic pattern (Marsh and Dozier 1981); where most branches have between two and three tributary branches, with the overall branching form of the stream system resembling that of a gum tree. Figure 2.6 illustrates the branching pattern of the Gardiner River on the south coast near Northcliffe. Minor order streams which have no tributaries are called first order streams. Where two or more first order streams come together they form a second order stream; two or more second order streams combine into a third order stream, and so on (see Fig. 2.6) until the branches combine into a single trunk which discharges into a lake, inlet or the ocean, perhaps as a high fifth or sixth order stream.

In headwaters of coastal river systems of the Darling Range the steps of the pool riffle sequence are small and closely spaced within a narrow channel. But further downstream, as the streams combine and drainage area and discharge increase, the steps grow longer and the pools and riffles widen and deepen in a broader channel. Finally, in the lower reaches where all the water of all the tributary branches has gathered, the river is widest and meanders lazily across low gradient broad valleys or coastal plains.

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\(^7\) Note that the term broad floodplain, defined and mentioned only in this section, refers to the broad area that is inundated during major floods, which includes the river channel, and is not to be confused with floodplain, as a geomorphic unit or habitat type adjacent to the river channel. The term is introduced here to distinguish floodplain as considered by flood managers.
Figure 2.6 Stream system branching pattern and stream order
2.3.12 Complications of climate, terrain and vegetation

Having read the above sections the reader could be excused for thinking that stream channels in the south-west will typically have a form which fits the textbook description. But in fact this is rarely the case. If a stream was to have a consistent flow pattern and flow along a uniform slope and over ground with a uniform particle size and weight, then in time it would build a perfect channel which appears to obey all the rules. But natural environments are much more complicated, with great variations in rainfall, catchment discharge, slope, ground cohesiveness and sediment size, weight and quantity, produced by changing weather pattern, land form and land use over both space and time (Church 1992). As a result, natural stream channels represent an 'average' of changing conditions. Scientists have come to understand channel form, as governed by catchment discharge, through the study of natural systems and through experimentation using laboratory models of stream systems (Leopold et al. 1964; Leopold 1995).8

Channel form is further complicated by vegetation, especially in areas with periods of aridity. Because south-western Australia has very long dry summers, channels tend not to be inundated with water for much of the year, so vegetation which is tolerant of periodic inundation has colonised river channels in most areas.

The presence of vegetation in river channels is a hugely complicating factor. Vegetation supports the bed and banks and acts to dissipate the energy of flowing water, thereby reducing erosion and increasing sediment deposition. Furthermore, by causing water to back up, it often increases depth with the effect that water can flood adjacent land and flow over higher ground where there may be less obstruction to flow. While the function of vegetation in the stream channel is relatively well understood, and is discussed in Chapter 4, just what is its contribution to overall stream form, other than to further complicate it, is a subject which is only now being investigated (Thorne 1990; Gregory 1992; Masterson and Thorne 1992).

2.3.13 Sediment: the currency of rivers

A river reach is said to be in equilibrium when erosion and sedimentation are in balance. This is reflected by the stable form of the channel. Essentially a balance is struck between the stream’s capacity to erode its bed and banks and transport material out of the reach, and the resistance to erosion and transport of new material being washed into the reach (James 1995). As the net movement of sediment is downstream, outgoing sediment must be equalled by incoming sediment from the catchment and from the gradual incision into the landscape of the stream system over time. Some streams may be rich in sediment and others may be poor, but in either case they can still be in equilibrium.

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8 One of the greatest of these scientists is the American engineer, Luna B. Leopold. The author recommends his book *A View of the River* for a 'simplified' understanding of the physical nature of rivers.
A section of the upper Blackwood River exhibiting a somewhat eroded, but still braided channel form.

Photo: L. Pen

Small rapid on the southern branch of the Margaret River. Note the oxygenation of the water and the green colouration of natural algae growth in the open conditions.

Photo: L. Pen

Fernhook Falls on the lower Deep River.

Photo: L. Pen
Wild branching pattern exhibited by rivers in the south-eastern part of the Pilbara region.

Photo: L. Pen

A bankfull flow on Spencer's Brook, a tributary of the Avon River, in the winter of 1996.

Photo: L. Pen

Floodwaters on a floodplain of the middle Moore River during the March 1999 floods that inundated the town of Moora upstream from this point.

Photo: L. Pen
providing outgoing sediment equals incoming. The stream system can be thrown into disequilibrium when the supply of sediment from the catchment increases, which often occurs with changing land use such as when land is cleared or undergoes urban development (Leopold 1995). Conversely a channel may be starved of sediment, for example when a catchment is effectively sealed through urban development or when sediment is excavated from the channel. In this case the consequences involve channel incision and subsequent widening through bank collapse, mostly where the channel is not well protected by vegetation (Rutherfurd and Ducatel 1994).

2.4 FLOODING

2.4.1 What is flooding?

Flooding occurs when a catchment delivers more water to a stream channel system than it can contain. Ordinarily a stream channel system has a great capacity to store water and this capacity generally increases downstream at a greater rate than catchment area (Leopold 1995). For this reason flooding generally declines as the flood pulse moves downstream and more and more of the river valley is available to contain the floodwaters.

Flooding generally occurs following unusually heavy rainfall. In the low rainfall wheatbelt region, flooding often occurs from surface runoff following intense summer rainfall of cyclonic origin (WAWRC 1986). This was the cause of flooding on many rivers in the south-west in January 1982 (Bretnell pers. comm.). On the other hand, flooding in high rainfall, typically forested catchments usually only occurs in winter following heavy rainfall on catchments that are already wet from preceding rainfall (WAWRC 1986).

2.4.2 Flooding and floodplains

Floodplains are very important in controlling the power of floods. They provide an area in which to contain floodwaters for a time and thus to draw out the period over which the water moves off the land, reducing peak discharge and peak stream power. In V-shaped river valleys, flooding causes the water depth to rise and rise, and thereby increases stream power. But where floodplains occur, floodwaters can rise only slightly above the active channel and floodway before spreading out over the land. This prevents stream power from rising to a level that could cause serious channel incision and bank erosion. It is important to note that floodplains are often formed by the meandering of rivers themselves and that this means that rivers have an intrinsic capacity to dampen the destructive power of floodwaters over time\(^\text{10}\). We should learn from this and protect floodplains wherever possible.

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\(^9\) Some scientists believe the Avon River training program has been effective in reducing flooding, simply because of the increased storage capacity that was brought about by one to two metres of channel incision, an intended consequence of removing the vegetation and ripping the bed (Jim Davies and Ass. 1997).

\(^{10}\) There is an important exception to this and it is the very broad floodplains of the wheatbelt, which have largely been formed from the filling of ancient deep river valleys with sediment over many millions of years (see Chapter 1).
Often floodplains which are used for farming or urban development are leveed off, raising water level over the channel, and hence stream power, in times of flood.

2.4.3 Flooding and changing catchments

While heavy rainfall is the main cause of flooding, human activities can increase the frequency of flooding by changing the behaviour of catchments. Catchment clearing can increase runoff rates by two to four times that of natural catchments (DCE 1984), and urbanisation by many times greater than this (Rutherfurd and Ducatel 1994). Rising groundwaters will increase the proportion of catchments wetted-up in winter, with a consequent increase in runoff. The result is that rainfall events which once represented no flood risk may in certain catchments, now or in the future, generate problematic flooding. As an example, Watts Creek in the State of Maryland, USA, exhibited nineteen flood flows between 1958 and 1967, when urbanisation in the catchment was not significant, compared with seventy-three between 1978 and 1987, when urbanisation covered much of the catchment (Leopold 1995).

2.4.4 Flood forecasting

On the basis of long term stream flow and rainfall monitoring records, the frequency of floods of various magnitudes can be forecast. Generally the key flood level frequency is that which is only exceeded once in every hundred years on average. The accuracy of these forecasts depends on the length of record and the degree to which the catchment involved has changed. With catchment clearing, rising groundwaters, drainage, damming and urbanisation the long term record becomes less and less a reflection of the hydrological nature of the present catchment. All this must be taken into account when assessing the risk of flooding and the damage and heartache involved.
It is late autumn and the winter season is broken by a powerful frontal system sweeping up from the south-west. The first front is only moderate in intensity and drops only a small amount of rain but the second front is strong and drops a large amount of rain.

**Forested catchment and the moderate front**

Some of the rain is intercepted by the foliage of the vegetation and lost quite quickly from the catchment through evaporation. Still most of the rain either misses the foliage, drips from the leaves or runs down the stems of the plants to reach the ground. Some of it is soaked up in leaf litter or evaporates and the rest percolates into the soft soil where it begins its slow journey towards the groundwater or downhill towards the nearest stream line. But before it can do so, the vegetation, with its deep root systems and thirsty from a long hot dry summer, takes up all of the water and none reaches the groundwater or dry creek beds.

**Cleared catchment and the moderate front**

Here most of the pastures and annual crops have all but withered away over the long summer and soil has been compacted and roughed up by the trampling of livestock. Thus nearly all of the rainfall hits the ground, delivering a punch of kinetic energy which further breaks up soil aggregates and compacts the soil. The compacted and non-wetting nature of the soil at the beginning of winter causes the
Figure 2.7 Comparison of surface water flow on a forested catchment, cleared agricultural catchment and the 'streamlined' catchment (NB. the longer the arrows the faster the flow)
water to lie on the ground for a time, where some evaporates and much begins to flow overland carrying fine soil particles with it. But since the rainfall was only moderate little makes it to the creeks and there is only a cloudy trickle of flow along the creeklines for a short time. Some water gathers in natural sinks, such as depressions, wetlands, dams and soft soils, to evaporate or soak away during the ensuing dry weather. So, as with the forested catchment, most of the water soaks slowly into the ground, but since there is virtually no live vegetation nearly all of this soil water will eventually reach the creeklines or the groundwater, which through years of recharge is close to the surface.

**Forested catchment and the strong front**

Heavy prolonged showers fall on the catchment. The foliage is quickly soaked with water but only a small proportion of the rain is intercepted and held on the leaves and branches. Although a large volume of water reaches the ground, the foliage continues to absorb much of the kinetic energy of the falling raindrops and the ground is well protected. The soft soils of the forest have a considerable capacity for infiltration of the rainwater, but such is the intensity of rainfall the water cannot soak into the ground fast enough and begins to form pools which slowly drain away. Even so this is only a small proportion of the water which fell, with most of the water still penetrating the ground. Too much water enters the soil to be taken up by the vegetation and so some will eventually discharge to the groundwater or seep laterally into creeklines.

Much of the water that does run off is dammed up by thousands of tiny damlets formed by leaf litter or accumulates in thousands of small depressions, to be held up long enough for the water to soak away once the heavy rains have finished. A small amount of the runoff reaches minor drainage lines, but because they support dense aquatic vegetation the water is once again held up and prevented from flowing quickly downstream. After a number of days the slow drawn-out movement of the water along the creeklines discharges into the main channel of the river, which likewise is densely vegetated. The river will begin to flow, but only slightly. It will only flow strongly after a number of heavy rainfall events have soaked the catchment and seepage is widespread and more or less constant.

The presence of vegetation along the entire route of the surface flowing water dissipates its energy, reducing erosion and promoting the deposition of what small amount of sediment is in transport. The result is that the water leaving the catchment is filtered of its sediment and is very clean, although it may be darkly stained with the tannins which have leached out of the hard dead leaves deposited in the stream beds by the native vegetation.

**Cleared catchment and the strong front**

The rain falls heavily on the cleared farmland for days. The powerful large fast-falling raindrops pummel the soil, breaking up the soil aggregates further and causing soil particles to fly high in the air. Even though the previous rains dampened the catchment and reduced non-wetting, the soil remains compacted. After some hours the infiltration rate of the soil is exceeded in some areas and water begins to accumulate in shallow pools and then to drain away.
The initial sheet flow is made turbulent by raindrops which increases the capacity of the sheet flow to pick up and carry soil particles. The muddy water soon forms into channels which further erode the soil and carry heavy abrasive water to the exposed creeks. With little vegetation to slow the water the denuded creeks are quickly swollen with rushing muddy water which erodes the banks at meander bends and scours sediment which had accumulated in the channels.

From all over the catchment swollen and bursting minor creeks discharge their loads of muddy water into the river. Because more water has been discharged from the catchment in a shorter period of time than would have occurred under natural conditions, the floodwaters often exceed the natural capacity of the channels. This causes the river to burst its banks in some sections and to dig a larger channel in others, especially where livestock have denuded the bed and banks of their protective vegetation. With further erosion of the banks and scouring of the bed the floodwaters pick up even more sediment. In some downstream sections, where dense riparian vegetation has been protected, the floodwaters are caught up, slowing the water for a time and causing flooding of adjacent land and heavy siltation of the channel and the floodplain. After this the floodwaters proceed downstream, ultimately to discharge their muddy loads into the estuary and the ocean.

Sediment is not all that the river carries. Large amounts of salt, dead plant material, recently applied fertiliser and manure are flushed from the catchment. Soil particles washed from the paddocks are rich in nutrients, and some may be contaminated with pesticides. All of these materials that are washed into the river and estuary place a huge burden on the natural ecosystem's ability to break down the organic material, assimilate the nutrients and tolerate (or not) the rising salt levels and toxic chemicals. Ultimately this burden will become overwhelming.

But this is less than half the story. Much of the water still enters the ground and as there has been little time for pastures and crops to grow, little is taken up by plants. Some water will evaporate in the coming days of dry weather. Most of the water moves slowly towards creeks or to the groundwater where it makes a major contribution to groundwater rise. This in time will bring salt to the land surface and ultimately cause salinisation and contribute to waterlogging over large areas.

The landcare catchment

In the lower part of the river system, a landcare group in a small sub-catchment is leading the way in achieving a hydrological balance by controlling drainage and groundwater recharge. Greater use is made of perennial pastures, fodder crops, minimum tillage, contour cultivation and contour banks. Remnant vegetation has been protected and every available space has been planted to native trees and shrubs and some paddocks or strips of land have been given over to wood and oil crops (e.g. blue gums and oil mallees). To reduce groundwater recharge strategic areas have been planted with deep rooted trees and shrubs. All of the minor drainage lines have been strengthened with perennial pasture or fodder crops and where necessary have been managed or simply fenced-off to protect both planted and
native vegetation over the harsh summer period when grazing pressure is greatest. Finally, broad well vegetated and fenced-off riparian zones have been created along the lower reaches of the main creek and along the adjoining part of the river to protect the major drainage lines from erosion.

In this catchment, much of the rain is intercepted by vegetation and the soil is better protected from the impact of raindrops. The softer soils increase infiltration and the perennial vegetation is present to make instant use of the winter-breaking rainfall, and thus reduce groundwater recharge. New and remnant native vegetation is also present to tap the deep groundwater.

Although runoff is greater and swifter in this catchment than the naturally vegetated one, it is slowed significantly by the perennial vegetation of the paddocks and the drainage lines. Consequently, less soil and other material is carried from the paddocks and a greater proportion of it is deposited amongst vegetative buffer strips and the vegetated drainage lines. While slowing the water on the paddocks causes some minor short term local flooding in times of very high rainfall, the slow release of water from the wider catchment reduces the severity of flooding downstream and the damage it can cause to the river and adjoining land. Overall the landcare group has created a catchment which draws out the water of high rainfall events and dissipates its energy, to both reduce erosion and control serious flooding. It also has sufficient vegetation to drink that portion of rainfall which entered the ground.

The quality of water flowing from this catchment does not compare with that from the forested one. It still contains quantities of sediment, organic material and nutrients, sufficient to degrade natural habitats and render the water unsuitable for human domestic use. But it is of adequate quality to support livestock, the irrigation of crops, recreation and many if not most of the elements of the original aquatic ecosystem. In this case the river and its tributaries represent a sophisticated drainage system which can produce a renewable water resource. This sort of catchment is the south-west’s future.
Chapter 2

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