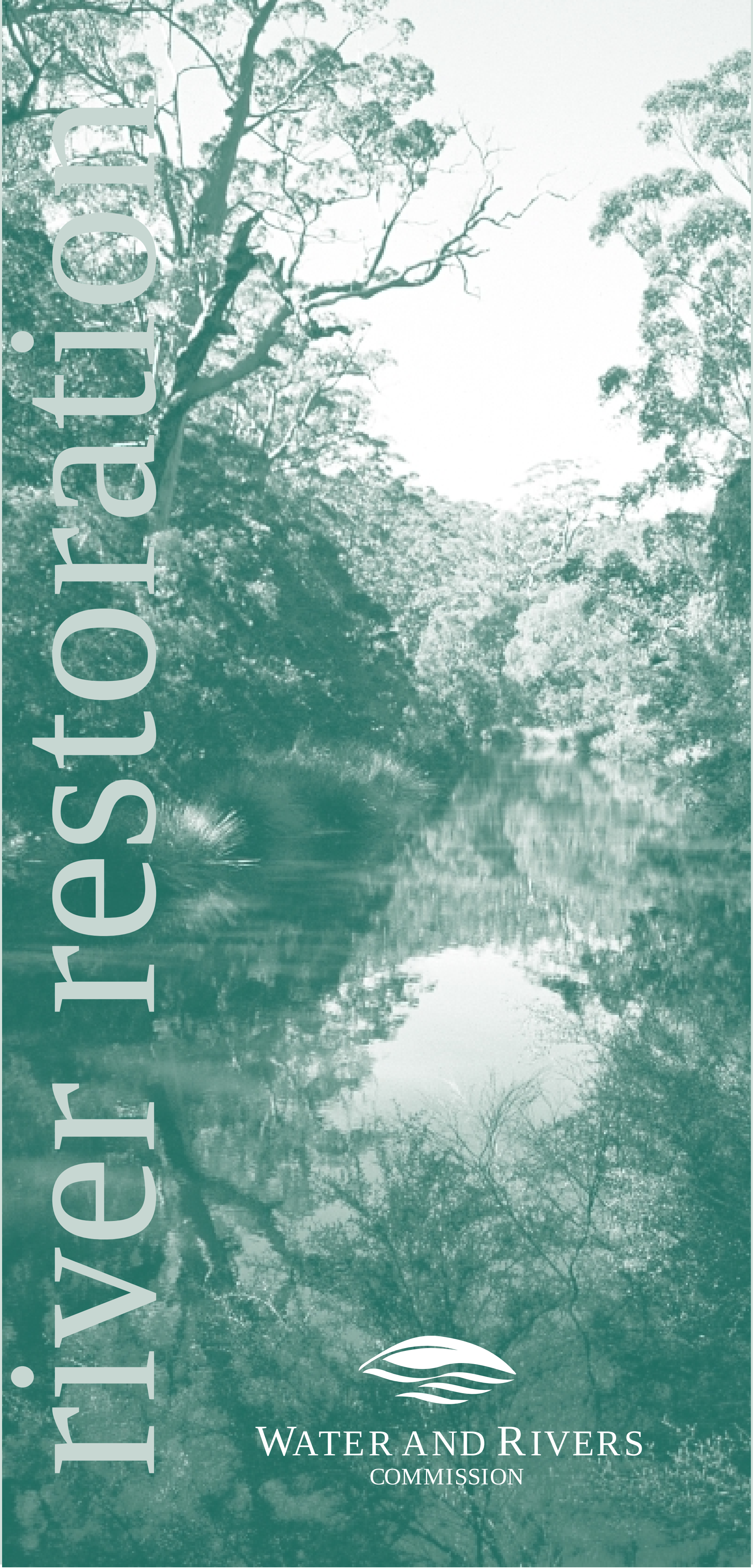

Recognising channel and floodplain forms

September 2002
Report No. RR17

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RECOGNISING CHANNEL AND FLOODPLAIN FORMS

Prepared by
Dr Clare Taylor

jointly funded by

Natural Heritage Trust

WATER AND RIVERS
COMMISSION

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REPORT NO. RR17
SEPTEMBER 2002

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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.

Contents

Figures

1. Introduction

A river, and the sedimentary features it is composed of, can be described in many ways. For instance, you could refer to ‘a small muddy waterway’, ‘a short clay bar on a bend’ or ‘a sandy bedded reach’. However there is more to describing channel and floodplain forms than first may meet the eye.

Being able to recognise the form of a river, and observe the factors influencing this form, helps us to understand how a river behaves. By understanding the behaviour of rivers, we can predict how a river may be influenced by, or respond to, land-use changes, climatic change and restoration activities etc. Armed with this knowledge, we can enhance our ability to protect and restore river health.

To begin to identify the form of a river you can look for various sedimentary features that occur along a river’s length, such as bars, levees and chute channels. These individual, local scale features ‘fit together’ at a reach to subcatchment scale to create distinct river ‘planforms’*.

There are four main types of planform – meandering, braided, straight and anabranching – each characterised by certain combinations of sedimentary features: for example, levees and point bars are common features in meandering systems, but are relatively rare in braided systems. Different planform types occur along the length of a river that then fit together to produce a larger drainage pattern at a catchment scale (Figure 1).

This manual chapter describes local to subcatchment scale channel and floodplain forms. It identifies the factors that influence these forms, and comments on why forms can change over time. The chapter provides suggestions on how to recognise sedimentary forms in your river, any changes in form, and how to apply this knowledge to improve river health.

*The form of a river as seen from above (i.e. from a ‘bird’s eye’ or ‘plan’ view) is known as its ‘plan form’ or ‘planform’.

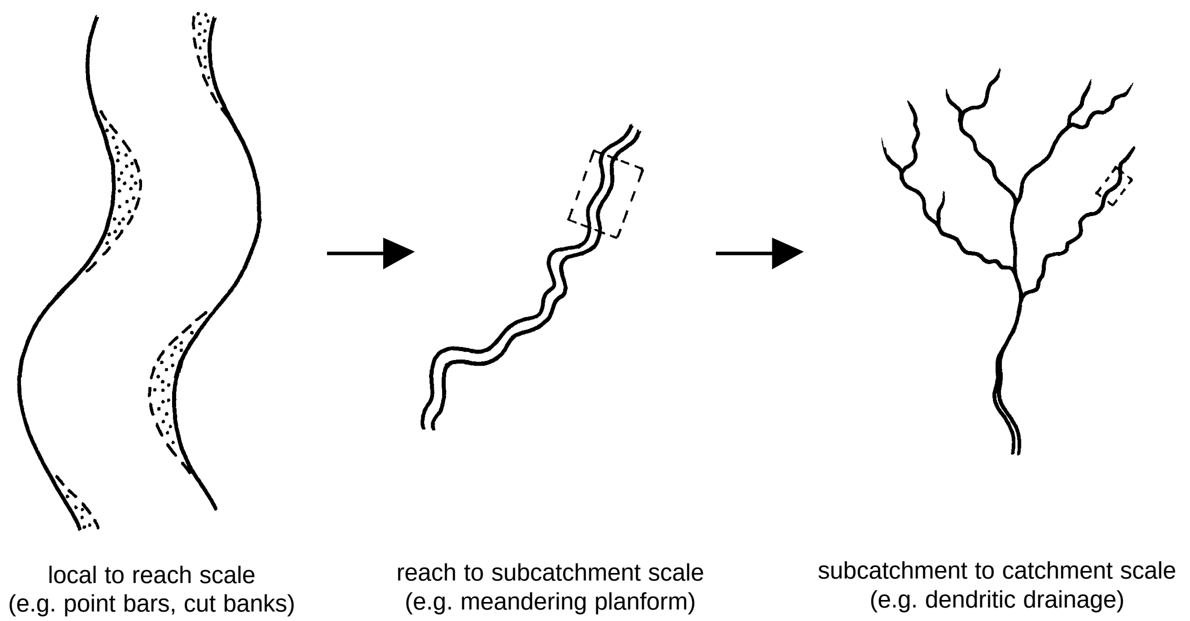


Figure 1. River forms at different scales: how sedimentary forms at local to reach scale ‘fit together’ to produce a river planform, which is in turn part of a larger drainage arrangement

2. River forms at local to reach scale

An overview of the typical types of sedimentary form that may be found at different locations along a river reach is presented below divided into “channel and in-channel forms”, “channel margin forms” and “floodplain forms”. The occurrence, size and detailed shape of any particular form depends on factors such as flow regime, sediment type and vegetation (discussed in Section 4).

Channel and in-channel forms

Channel type and shape (Figures 2a & 2b)

– Dominant or main channel
A channel that is better defined than other channels through properties such as width and depth, continuity of flow or continuity of vegetation. The shape of this channel and its banks can vary considerably.

– Low flow channel
A channel within the bed of the main channel which contains the base flow or dry season flow. The location of the low flow channel will vary over time.

– Secondary channel
A channel that is smaller or carries less flow than the main channel. The term is also used to describe minor floodplain channels.

– Chute channel
A short, straight channel formed on the inside of a bend that usually only flows during high flow events. Also known as a chute or neck ‘cut-off’.

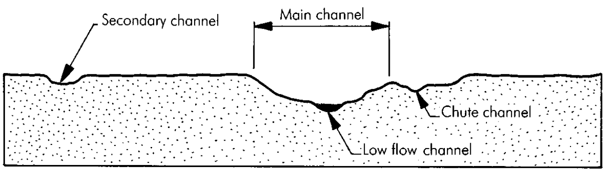


Figure 2a. Channel types.

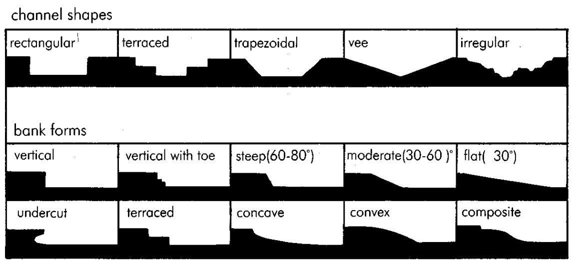


Figure 2b. Channel and bank shapes.

Bar (Figure 3)
A raised sediment deposit within a channel whose shape and size varies with flow and sediment conditions – common bar types include point bars, lateral bars and transverse bars.

– Point bar
An accumulation of sediment located on the inside of a meander bend. Point bars vary in size and sediment detail depending on factors such as sediment supply, bend curvature and flow regime.

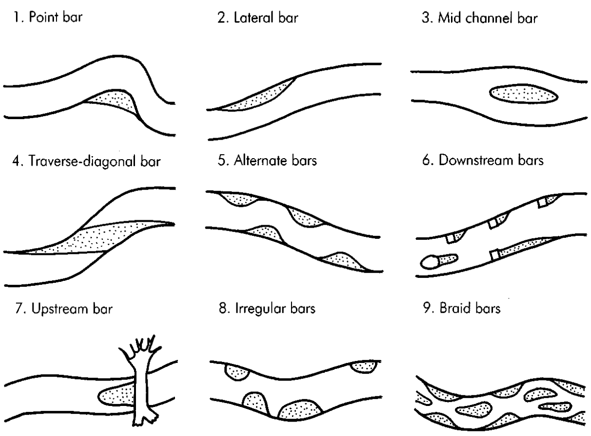


Figure 3. Channel bar types.

Inset deposit (Figure 4)

A sediment deposit within a channel that generally accumulates in vertical layers to infill a backwater or zone of low flow. Layers accrete roughly seasonally rather than within one flow event. Generally found in rivers with strongly seasonal and flood dominant flow regimes.

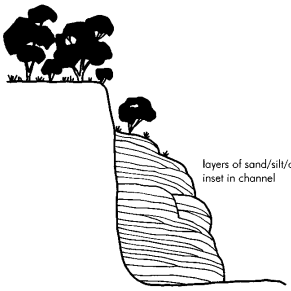


Figure 4. Inset bank deposit.

Oblique bank deposit (Figure 5)

A layer of sediment deposited on sloping channel banks by waning seasonal or flood flow. Different from bars in that sediment character and the slope of the layers is the same as the existing bank.

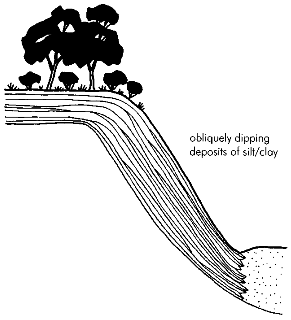


Figure 5. Oblique bank deposit.

Pools and riffles (Figure 6)

Riffles are high points in the channel floor representing bedrock bars or accumulations of relatively coarse material (e.g. sand and gravel). Water flow is typically relatively shallow, fast and rough over riffles. Pools are deeper sections of the channel, usually floored by relatively fine sediment (e.g. clay and silt). Deep pools in seasonally dry rivers are often known as billabongs. Sequences of riffles and pools are best defined in channels carrying a wide range of sediment sizes, though in WA riffle and pool occurrence is typically governed by rock outcrop.

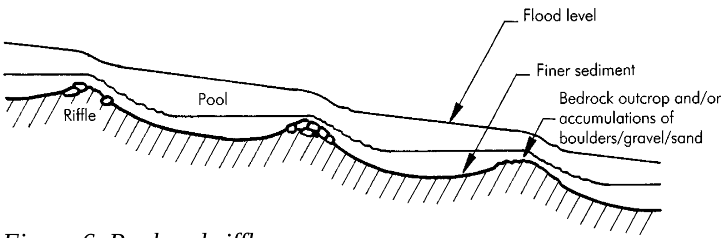


Figure 6. Pool and riffle sequence.

Channel margin forms

Levees (Figure 7)

– Natural levee

An elevated, wedge-shaped, sedimentary form deposited where floodwater slows as it moves from the channel to the floodplain. It consists of fine sand, silt and/or clay, and can vary in height and cross section, and in its lateral continuity.

– Artificial levee

A raised embankment along a channel margin where a channel has been excavated and/or spoil dumped along side.

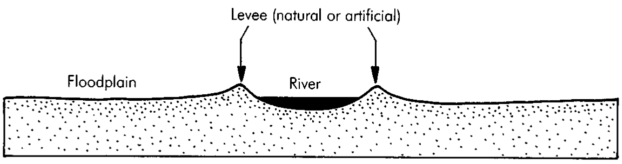


Figure 7. Levees

Crevasse splay (Figure 8)

A localised, typically fan-shaped deposit of sand and/or silt formed when high flows cause a levee bank to break. Water flows onto the floodplain depositing sediment around the break as it spreads out.

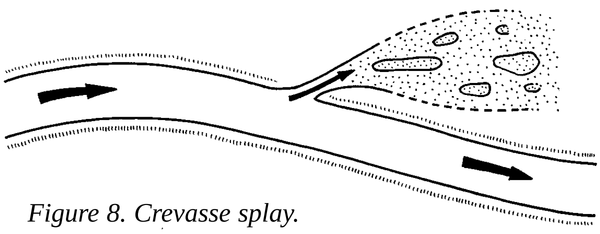


Figure 8. Crevasse splay.

Floodplain forms

Floodplain features (Figures 9, 10, & 11)

– Floodplain
For flood management the floodplain includes the floodway, flood fringe and all typically flood-prone land. A floodplain can be defined in various ways e.g. topographically, hydrologically (i.e. 1 in 50 yr) or legally.

– Floodway
The main flow path of floods. Typically colonised by denser vegetation than the floodplain and surrounds.

– Backplain or flood fringe
An area of floodplain that is not flooded as frequently as the floodway, where water moves only slowly. A backplain is a flat, fine-grained alluvial deposit distant from the main channel that is formed by sediment settling slowly out of still or waning flood flow. In cross section it appears 'massive', lacking sedimentary features such as bedding or ripple marks.

–Flood channel
A channel that drains excess flow from the floodplain (also known as secondary or distributary channels).

– Floodplain billabong
A pool, usually elongate in shape, formed due to the partial infill of an abandoned channel or cut-off bend. Alternatively, irregularities in geology or valley morphology, or scour due to a flood or series of floods, can lead to billabong formation.

– Ridges and swales
Gentle undulations behind a point bar, formed as point bars accrete when a meander bend migrates across the floodplain. Ridges (also known as 'scroll bars') are relatively higher and drier than swales. Ridges and swales can be difficult to detect on the ground, but may be visible on aerial photographs as alternating light and dark coloured bands.

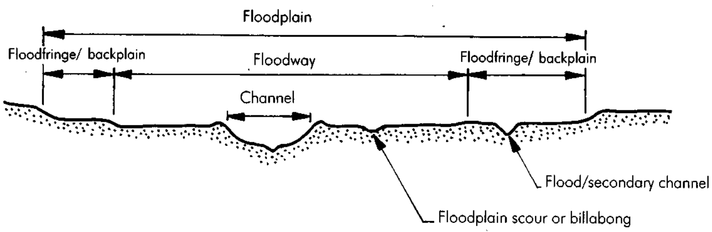


Figure 9. Floodplain features.

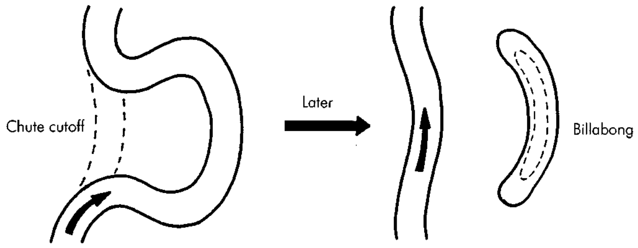


Figure 10. Floodplain billabong.

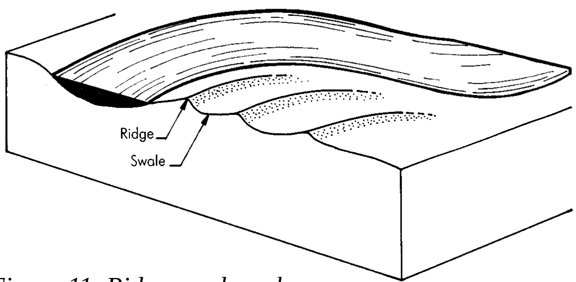


Figure 11. Ridges and swales.

3. River forms at reach to subcatchment scale

Certain sedimentary features are commonly found together, arranged to form particular planform types. Meandering, braided, straight and anabranching planforms are the four classic types, but a whole range of composite planforms exist between them. This concept is illustrated in Figure 12.

We should expect to find an infinite range of planforms because river form is controlled by the interaction of a number of variables (e.g. geology, climate, flow regime, vegetation), and the range of these variables in nature is enormous. Any one planform type may occur over distances ranging from less than a kilometre to several hundreds of kilometres, depending on the size of the catchment and the variation in governing factors.

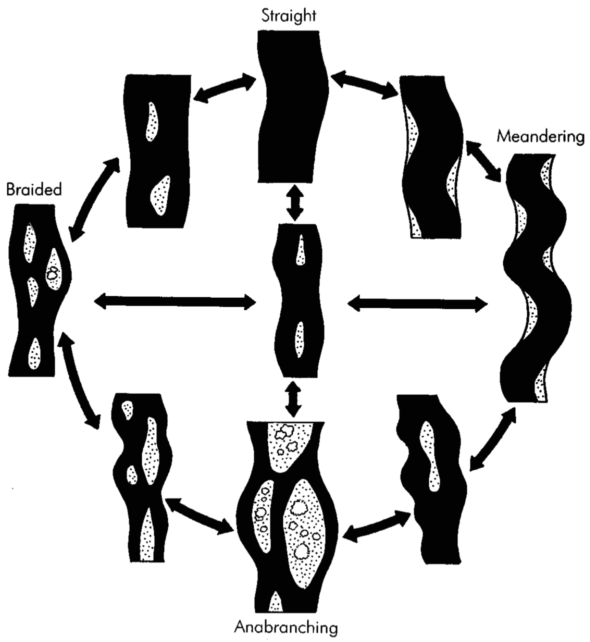


Figure 12. Relationships between the four fundamental types of river planform.

The term 'braided' was formerly applied in a general sense to all rivers with multiple channels. However, anabranching rivers are now recognised as a separate multiple channel planform type. Planforms that alternate between unstable, multiple-channel zones and stable, single channel reaches can be described as 'wandering' but these are not fully recognised as one of the basic planform types.

The four classic planform types are described below. It is important to remember that, for simplicity, only the features classically associated with these planform types have been illustrated and described in the text, and that in reality a wide variety of local to reach scale sedimentary features can be associated with any particular planform type. These four are the end members in the continuum of 'inbetween' types, and provide clues to river behaviour and processes - if your channel section is different, don't worry – what is important is understanding why it looks like it does!

Note also that identifying sedimentary features and reconstructing a three dimensional picture can be difficult since we usually only see features as they are exposed on a one dimensional surface. Things are never as simple as illustrated in the sketches!

Meandering rivers

Meandering planforms are characterised by a single, snake-like or 'sinuous' main channel, usually with well-defined banks. Geomorphic features classically associated with meandering rivers in alluvial environments include point bars, cut banks, levees, crevasse splays and backplains. Pools occur at the apex of meander bends and shallower sections are present on the straight reaches between bends.

Meander bends can become highly sinuous, almost doubling back on themselves (this form is described as 'tortuously meandering'). When it is easier for flow to take a direct path across the inside of a bend rather than travel the distance around the bend, a new straighter channel can form known as a 'chute' or 'neck' cut off. Figures 13a and 13b illustrate features of meandering rivers.

In Western Australia the term meandering is not uniquely associated with rivers having levees, point bars, crevasse splays and well defined clay-rich banks. Meandering is used to describe any channel that has a snake-like planform.

Shannon River, South West. (S. Neville)

Creek near Chapman River, Geraldton Region.

Durack River, Kimberly.

Salmond River, Kimberly.

Figure 13a. Examples of meandering rivers.

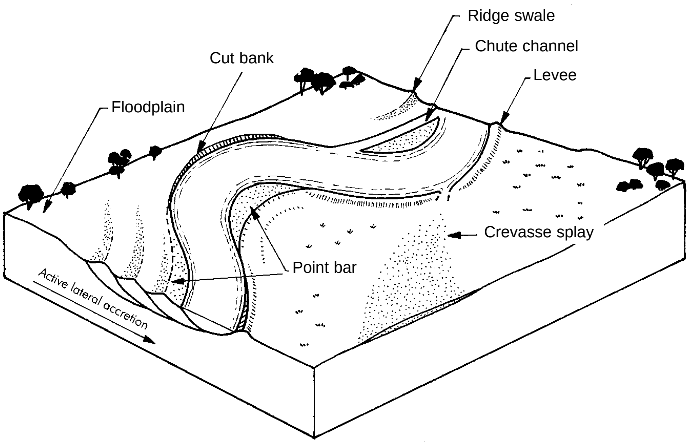


Figure 13b. 3D interpretation of a classic meandering river.

Meander bends form as a result of the non-uniform, turbulent nature of flowing water. As flowing water spirals around a slight curve, sediment is carried up the inside slope of the bend and accumulates to form a 'point bar'. Concurrent erosion of sediment on the outside of the bend forms a 'cut-bank'. These two processes result in a bend growing and moving or 'migrating' across a floodplain to produce the sinuous path that characterises meandering channels (see also River Restoration Report RR 18, *Stream channel and floodplain erosion*).

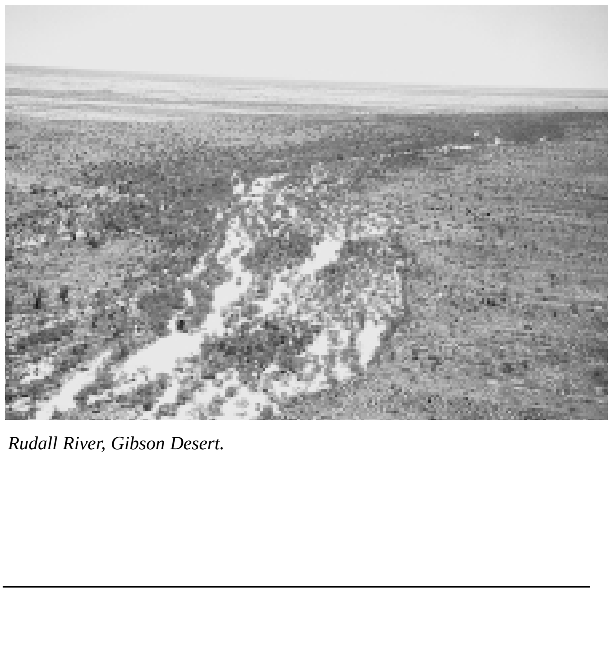
For a given average flow, the actual shape of a meander bend, and the rate of bend migration, varies with the cohesiveness of the channel banks. Bank cohesiveness can vary considerably depending on factors such as the amount of clay relative to sand in the floodplain profile (the higher the clay content the more cohesive the bank), soil weathering history, rock outcrop, and the type, structure and density of riparian vegetation.

Poorly cohesive and thus easily eroded bank material typically allows a high rate of migration, a wide channel cross section and a long distance between bends (i.e. a long 'meander wavelength'). More cohesive banks offer a higher resistance to erosion that typically results in a relatively slow rate of meander migration, a narrow cross section, steep banks and a relatively shorter meander wavelength. Meander bends with very cohesive banks are not free to migrate and these systems are known as 'passively' meandering systems. An extreme example would be the sandstone gorges in the Murchison River near Kalbarri known as the 'Loop' and the 'Z Bend'.

The style, rate and history of meander migration influence whether the floodplain is made up of deposits that have accumulated side by side (e.g. accreting point bars) or vertically (e.g. accreting backplain deposits). Recognising meander behaviour is helpful for understanding river behaviour and therefore for locating fences, roads, bridges and other forms of infrastructure, and for planning river restoration works.

Braided rivers

A braided river planform is characterised by numerous, interlaced channels that divide and rejoin around unstable bars and small islands. Channel banks may also be unstable. Bars, islands and sometimes even channel floors can be colonised by vegetation that can bind sediment and increase stability. These features can be seen in Figures 14a and 14b.



Rudall River, Gibson Desert.

Yule River, Pilbara.

Figure 14a. Examples of braided rivers.

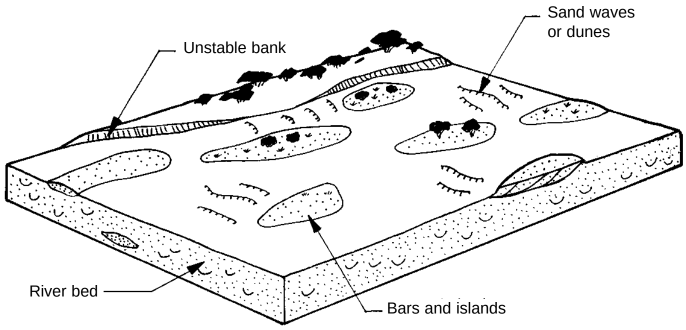


Figure 14b. 3D interpretation of a classic braided river.

Braiding develops in rivers carrying large amounts of coarse sediment (typically sand-sized in Western Australia). This sediment forms mid-channel bars that divide a channel and deflect flow to either side. As a bar grows, water coming from upstream is diverted and may cause other bars and channel banks to erode, thus mobilising sediment. The mobilised sediment can then be re-deposited to form new bars or extend existing bars.

Individual channels within a braided planform tend to be variable in width and depth, and their banks are easily eroded. Bars are continually forming, growing and eroding, though the rate and extent to which this happens varies greatly from system to system. The degree to which a channel is braided can be expressed by the percentage of a reach length that is divided by one or more bars or islands.

The floodplains of braided rivers vary in extent and architecture. They are not as stable as the floodplains of meandering rivers and sediment mainly builds up vertically. Braided rivers typically move across their floodplain in sudden 'jumps' or avulsions, rather than by gradual migration.

Straight rivers

A channel is classified as straight if its length is very similar to the length of the valley floor that it runs along or, to be more exact, if its sinuosity is less than 1.1 (the sinuosity of a channel is its degree of curvature as measured by channel length divided by valley length). The banks of straight channels are typically well-defined. Examples of straight rivers can be seen in Figures 15a and 15b.

Dempster River, South Coast. (J. Alford)

Charnley River, Kimberly.

Figure 15a. Examples of straight rivers.

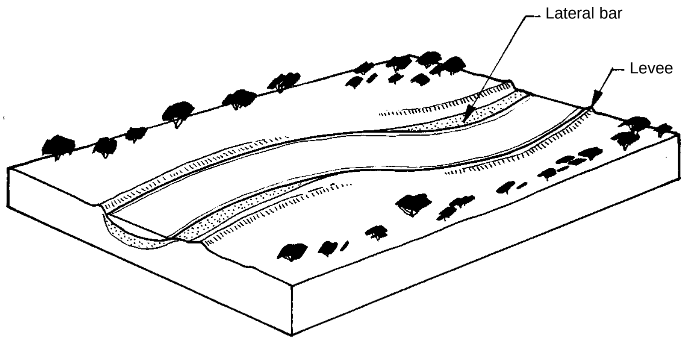


Figure 15b. 3D interpretation of a classic straight river.

Naturally straight channels in alluvial environments are uncommon. Some channels can appear to be straight at high flow levels, for example, when the bars in a braided channel are submerged. Also, some channels appear straight because they have been modified artificially, for example to create drains in the south-west of Western Australia. Naturally straight channels commonly occur in rocky terrain where linear fractures or other weaknesses have been eroded by flowing water.

Naturally straight alluvial channels are uncommon because the non-uniform and turbulent nature of flowing water, combined with variations in the resistance to erosion of channel banks, cause channels to bend and/or branch. Even where channel banks are straight, the deepest part of the channel bed (known as the thalweg) typically wanders from one bank to another, with sediment accumulating in the shallows.

Anabranching rivers

Anabranching rivers are characterised by a network of diverging and converging channels separated by large, long-lived islands that are inundated only by floodwaters (Figures 16a and 16b). This contrasts with braided rivers whose relatively small, more unstable bars and islands are frequently covered by in-channel flows. Individual reaches of anabranching channels can be meandering, straight or braided.

Coongan River, Pilbara.

Fortescue River, Pilbara.

Figure 16a. Examples of anabranching rivers.

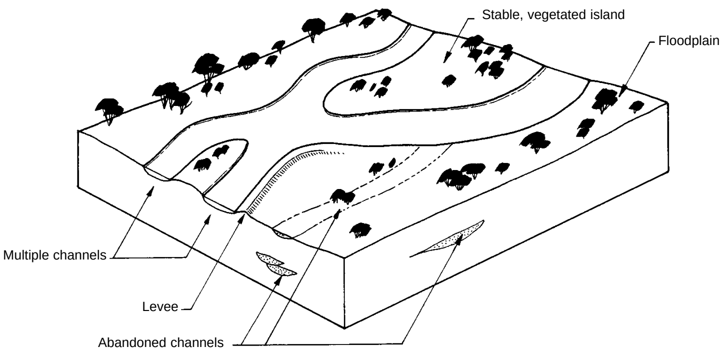


Figure 16b. 3D interpretation of a classic anabranching river.

Anabranching planforms consist of a range of individual sedimentary features. For example, some anabranching rivers are characterised by prominent levees and clay-rich, damp, fertile backplains. These are known as anastomosing rivers and are usually associated with low stream power regimes. Higher energy anabranching rivers are associated with subtle levees, a coarser sediment load and flood-scoured pools on floodplains.

The channel networks that characterise anabranching systems typically develop when new channels form due to flood flow finding a more efficient path to drain a floodplain. This can happen by flood flow:

a) breaking through a levee of the main channel to cause a sudden channel avulsion;

b) gradually eroding low points in the floodplain that eventually connect together; or

c) creating a head-cut like feature out of the main channel that works its way up-valley.

The formation of new channels is usually accompanied by the infilling of existing channels with sediment and their colonisation by vegetation.

Other planforms

As mentioned earlier, many rivers in Western Australia do not fall neatly into one of the four classic planform types. Often some kind of hierarchical and composite arrangement exists linked to factors such as irregular flow regimes, vegetation colonisation and landscape features inherited from the past.

Also our classification and use of the terms meandering, braided, straight and anabranching, depends on the scale we are working at and whether we are describing a form or a process. For example:

- Braided and anabranching channels can bend or curve (ie ‘meander’) over a landscape.
- Within braided, meandering, straight and anabranching channels, the low flow channel typically meanders from side to side.
- One branch of an anabranching channel can have a meandering character while another branch may have a more braided character.
- Braided channels can appear straight when flow is at bankfull level, and meandering and anabranching channels can appear straight during flood flows.

• Some meander bends actively meander or migrate across their floodplain whilst others are 'fixed' in bedrock.

So it is important to understand the 'big picture' context when these terms are used! The photographs in Figure 17 illustrate channels that exhibit a mixture of planform types.

Near Nullagine, Pilbara. Meandering form at reach to subcatchment scale, but channel exhibits braided characteristics (abundant coarse sand bedload, high width/depth ratio, unstable bars) rather than classic meandering characteristics.

Upper Ord River, Kimberley. Mix of braided characteristics (unstable bars, abundant sand bedload, high width/depth ratio) and anabranching characteristics (some stable, vegetated, linear islands separating multiple, interconnected channels). Fairly straight form at reach to subcatchment scale.

Ponton Creek, Goldfields (J. Alford). Meandering to straight form at reach to subcatchment scale, but channel exhibits braided characteristics (abundant sand bedload, high width/depth ratio, unstable bars). Note meandering form of low flow channel.

Turner River, Pilbara. Anabranching form at reach to subcatchment scale (multiple, interconnected channels separated by stable alluvial islands) but channel exhibits braided characteristics (abundant sand bedloads, high width/depth ratio, unstable bars).

Figure 17. Examples of composite planforms.

4. What factors influence river form?

River form at all scales is controlled by a complex interaction of many environmental variables. The relative importance of any particular variable in shaping channel form depends on the time and geographic scale being considered (see Table 1).

Some important and interrelated variables are discussed briefly below.

The **geology** of a catchment can influence river form both directly and indirectly. A direct influence may occur when bedrock or a fault system confines, diverts or cuts across the course of a channel and its floodplain. Geology indirectly influences river form through its effect on soil type, landforms, vegetation and the characteristics of sediment available for transport by the river.

The **geological and tectonic history** of a region can also affect the form of a river by changing its slope and sediment supply, both gradually (e.g. by slow uplifting or tilting of the landscape) or through sudden geological events such as landslides.

Relief (the variation in height of a landscape) and **valley dimensions** affect river form in several ways. For instance, a steep, narrow valley can generate higher stream power in a channel than a flat broad valley, and therefore a large capacity to move sediment.

Valley dimensions also control the degree to which a channel is constrained in its sideways, or lateral movement. For example, a narrow valley floor can curtail meander development or avulsion, whereas an unconfined valley floor provides more scope for water and sediment movement.

Relief and valley dimensions affect sediment supply. For example, a rugged terrain with narrow valleys would typically have an abundant supply of coarse, angular material available for transport, whereas a flat, low relief terrain would generate a different supply of sediment.

The **present climate** of a region influences channel form through its effect on rainfall, evaporation and temperature regimes. These influence stream flow, sediment transport, bank cohesiveness and vegetation density and distribution (both catchment-wide and riparian).

The **climate history** of a region can also influence river form through factors that still affect modern processes. These include soil properties, weathering rates and hence sediment supply, bank/bed cohesiveness and vegetation associations (both catchment-wide and riparian). For example, in some locations past aridity and water table fluctuations have cemented former soils. These now resist erosion and restrict channels adopting their preferred form. Former glacial and interglacial periods have also influenced the form of some channels in Western Australia via associated changes in rainfall, temperature, vegetation, sediment supply and sea level

(as well as through their influence in shaping valley dimensions and relief in the more distant past).

Present hydrology, that is the amount of water entering a river system and how it is distributed over seasons and from year to year, affects channel form. It affects the average and extremes of flow velocity and stream power and hence the amount and type of sediment that can be moved down a river system at any given time. This influences the shape, width and depth of a reach (in association with bank cohesiveness). Present stream hydrology also influences the type, structure and density of riparian and floodplain vegetation.

Past flow regimes (closely related to past climate regimes) influence channel form. For example, if higher flows in the distant past scoured wider and deeper channels, these may still exist with today's flows lying within them. Past flow regimes may also have influenced the sediment deposits that today's channels flow through, over or around.

The type of **sediment** (grain size, shape and mineralogy) that is carried by a river and that makes up its bed, banks and floodplain, influences channel form through factors such as bank strength and cohesiveness, and its ability to be eroded and deposited. The amount of sediment available for transport, and being transported, also influences channel form. Sediment type, amount and capacity for transport is a product of several variables already mentioned (geology, climate, flow regime etc).

Vegetation affects river form because it influences the relationship between rainfall and runoff for a catchment, as well as bank and floodplain cohesiveness and 'roughness'.

A well vegetated catchment reduces the amount and rate of conversion of rainfall into runoff by reducing the amount of rain that hits the ground, slowing the flow of water across the landscape and assisting water to infiltrate into the ground via pores and root spaces. This decreases the erosive capacity of water and the amount of new sediment entering a channel, both of which affect channel form.

The type, structure and density of riparian vegetation influences bank and floodplain cohesiveness and roughness, and each tier of vegetation - understorey, midstorey and upperstorey – is important. For example, dense deep rooted vegetation adds cohesiveness to channel banks, and bushy shrubs with an understorey of rushes create more roughness to slow flow than cut grass.

The opportunistic colonisation of channel floors by vegetation during low flow periods stabilises sedimentary deposits and can encourage further deposition by increasing roughness and reducing flow velocity. Note that vegetation, depending on its size, position and the flow regime, can also initiate or accelerate channel bank erosion as well as promote deposition.

The influence of river variables at different time scales

The relative significance of different variables in influencing river form is shown in Table 1. Variables which are 'independent' or 'dependent' are listed for three time scales. The time scales are approximate, but help us to appreciate the scale of changes we are dealing with and what this might mean for river management.

- Independent variables are those that are not significantly influenced by others, but they may influence other variables, which are then said to be dependent.
- Dependent variables are significantly influenced by other variables.

For example, on a time scale of more than 1000 years, the table indicates that geology, past climate and past hydrology influence relief and valley dimensions. Over this time scale, the form of alluvial channels can change and hence is regarded as indeterminate. At very short time scales (1 to 10 years), channel form is independent, and influences flow hydraulics. Over historic times (10 to 100 years) channel form depends on relief, valley dimensions, modern climate, vegetation and flow regime as well as the geology, past climate and past hydrology.

*Table 1. The varying significance of river variables over different time scales**

River variables	**Significance of variables during designated time spans**		
	(>1000 yrs) Long	**(10 - 100+ yrs) Historical**	**(1 - 10 yrs) Present**
Geology (lithology, structure)	Independent	Independent	Independent
Past climate	Independent	Independent	Independent
Past hydrology (long term discharge of water & sediment)	Independent	Independent	Independent
Relief	Dependent	Independent	Independent
Valley dimensions (width, depth, slope)	Dependent	Independent	Independent
Climate (rainfall, temperature, seasonality)	-	Independent	Independent
Vegetation (type & density)	-	Independent	Independent
Hydrology (mean discharge of water and sediment)	-	Independent	Independent
Channel form (shape, width, depth, local slope, pattern)	**(Indeterminate)**	**Dependent**	**Independent**
Hydraulics of flow (local scale)	-	-	Dependent

*for equilibrium alluvial channels, modified from Richards 1982 after Schumm & Lichty 1965.

Relationships between form, flow discharge, slope and sediment

Understanding the factors that control river form at a range of time and space scales, and understanding the relationships between different variables, is vital for effective river management. It enables us to model river processes and predict changes that might occur in response to engineering works, land use changes and changes in climate.

Relationships between planform and factors such as slope, sediment supply (load and grain size), flow velocity and stream power are illustrated in Figure 18.

The diagram indicates that meandering rivers are typically deeper and narrower than braided systems (i.e. have a lower width/depth ratio) and are generally associated with low gradient terrains. Meandering systems typically carry finer sediment (clays and silts) and less sediment than braided systems, and typically transport it in suspension rather than by moving it along the river bed as 'bed load'. The amount of sediment carried as bed load is, therefore, only small compared to the total amount of sediment transported (the 'total load' as indicated in Figure 18). Meandering rivers generally have a relatively lower flow velocity and a less 'flashy' discharge regime than braided systems, and are therefore typically more stable.

Actively meandering systems are, therefore, most common:

- in low to moderate gradient landscapes;
- where clay and silt are more abundant than sand; and
- where rainfall is fairly regularly distributed in time and across a catchment, and is adequate enough to support permanent vegetation.

In contrast, braided rivers are typically associated with environments having one or more of the following characteristics:

- an abundant supply of relatively coarse sediment (usually sand or gravel); and/or
- moderate or steep slopes; and/or
- irregular discharge regimes (flashy high flows, floods and/ or strongly seasonal flows).

In Western Australia, braided rivers are most commonly associated with high sediment loads and/or irregular discharge regimes rather than with moderate or high gradients.

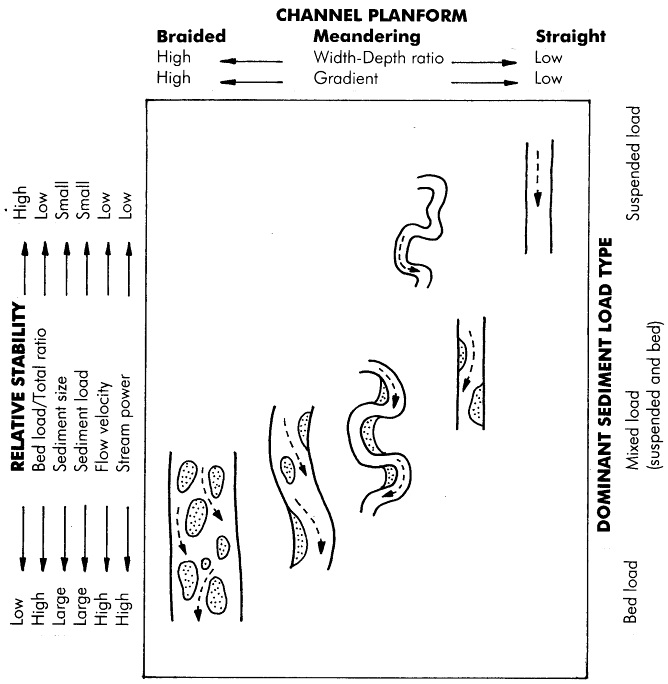


Figure 18. Controls on river form based on planform type and dominant sediment load type. The relative stability of a planform and the characteristics of associated variables are indicated.

Looking in even more detail at controls on channel form... in meandering rivers that are free to move across their floodplain, meander wavelength has been found to be related to flow discharge and to channel width:

- meander wavelength ≈ 54 x the square root of bankfull discharge.
- meander wavelength ≈ 12 x channel width.

5. Changes in river form over a catchment

A word of caution and excitement: Western Australia's rivers are different

Many river systems in Western Australia do not follow classic 'text book' examples about how a river's form might vary from its source, to its exit at a coast. This is because in North America and Europe, where the early text book concepts were derived, the arrangement over a catchment of the factors that control river form – e.g. slope, flow, rainfall and sediment supply – is different to their arrangement in Western Australia.

In the classic text book examples, the upper parts of a catchment (traditionally known as 'youthful' landscapes) are usually associated with braided planforms, steep slopes, narrow valleys, and abundant angular boulders, gravels and/or sands. The regular rainfall and seasonal snowmelt associated with these high relief environments generate high flow velocities which abrade and round off the coarse sediment as it is transported downstream. The lower part of a catchment (traditionally known as 'mature' landscapes) is associated with meandering planforms; gradients are low and sediment is relatively fine after having travelled long distances from headwaters, with much having been stored in floodplains. The main channel is now wider since water discharge has increased due to tributary inflows. Valley floors are also wide. Water flows throughout the year and supports mature, but often relatively shallow rooted, riparian vegetation.

Four main interrelated differences between these traditional concepts and river systems in Western Australia are outlined and explained below:

1. **Many Western Australian rivers have their head waters in low or moderate gradient landscapes** rather than in steep gradient terrains. In the south-west the steepest gradients typically occur in the middle to lower reaches of river systems, when rivers pass through the Darling Scarp or down the Ravensthorpe Ramp (Figure 19). Since slope affects channel form, this difference in longitudinal profile from classic catchments is one reason why WA has a different distribution of channel forms over a catchment. This difference also means that concepts such as the lower parts of catchments being more 'mature' than upper parts, or being preferred sediment storage zones, are often not appropriate in Western Australia.

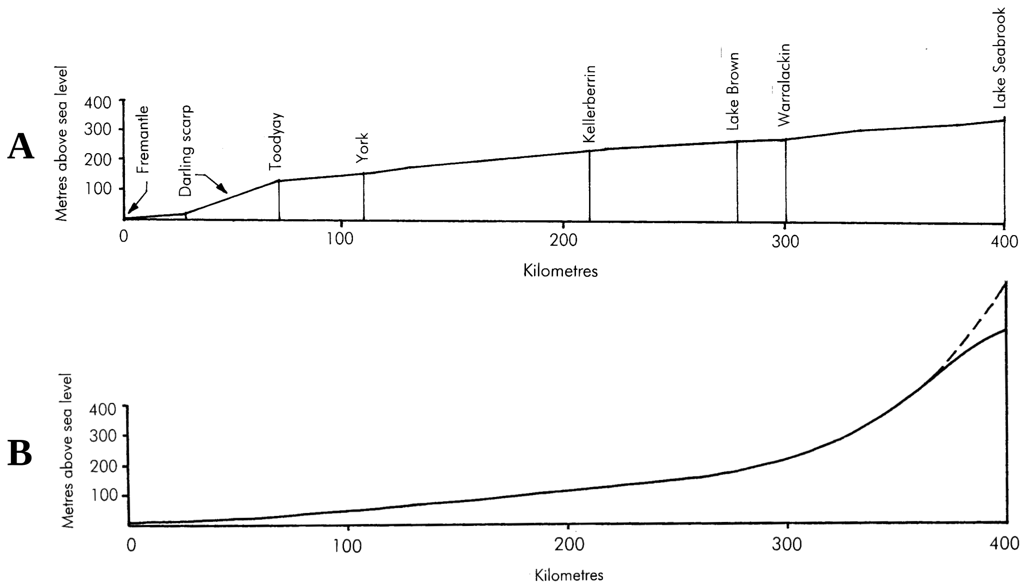


Figure 19. Difference between river profiles in A) from west to east across the Darling Scarp and, B) a classic text book profile.

2. **Rainfall in Western Australia is generally lower over river headwater areas** than over downstream reaches because of our subdued topography inland and long distances from any coast. This contrast with the classic text book story has implications for concepts based on relationships between flow discharge and variables such as channel width, catchment area and sediment availability and transport. For example, channels in Western Australia do not always get wider with distance down a river because flow discharge is not always higher and more constant in downstream reaches. Rather, at catchment scale, channel width depends on the rainfall distribution across the catchment as well as factors such as valley width, bank cohesiveness and vegetation.

3. **Rainfall and flow in Western Australia are also more variable** than in most other countries, both within a year and between years. Variability in rainfall is reflected in stream flow, with most rivers having very seasonal flow regimes, and with floods and droughts being fairly common occurrences. Variability in stream flow affects sediment processes and therefore channel and floodplain forms. For example, large floods can scour floodplains and re-shape channels. Years of very low flow can allow vegetation to colonise channel floors and stabilise sediment deposits that might otherwise be washed away. Our high variability in rainfall can also mean that theoretical calculations which assume that bankfull flow occurs every 1 to 2 years are inappropriate in some cases.

4. **In Western Australian rivers, sediment is not always more abundant and coarser in the upper parts of catchments** relative to the lower parts. The old age of our landscapes and their typically low, flat relief means that sediment supply can be limited and/or composed dominantly of sands, silts and clays throughout a catchment. In classic text book catchments the size and angularity of sediment typically gradually decreases downstream. In WA however, these properties are more dependent on the distribution and type of bedrock outcrop in a particular catchment. Boulders and/or coarse angular gravels can occur wherever bedrock outcrops along or adjacent to a watercourse. Since sediment characteristics influence channel form, this difference in bedrock weathering and distribution equates to further differences between Western Australia's river forms and the classic examples and concepts.

In conclusion, care should be taken in applying concepts of river form derived from older textbooks that are based only on rivers located in the temperate climates and landscapes of Europe and parts of North America. Rivers worldwide are influenced by the same factors, but these factors are arranged differently in different biophysical environments.

Overview of the typical rainfall, flow, sediment and planform characteristics associated with different Western Australian landscape types. *(Note – little work has been done in this area and more is needed to refine this dataset!).*

Landscape unit	**Landscape characteristics**	**Rainfall and flow regime**	**Sediment type**	**Typical planform characteristics**
Blackwood Plateau	Low to moderate gradients through laterites or sandy soils.	Regular winter rainfall, dominant winter flow.	Moderate to high sediment loads, dominantly sand and clay sized.	Dominantly meandering (passive and active).
Darling Scarp	Moderate to steep gradients, narrow valleys, undulating hills.	Regular winter rainfall, dominant winter flow.	Range of sediment sizes available (cobble to clay).	Bedrock / structure controlled, passive meandering.
Gascoyne - Murchison	Moderate to low slopes, some gorges.	Episodic summer flood events due to dissipating cyclones with weak winter season flows.	Abundant sand bed load with cobble lags.	Meandering, braided, anabranching. Broad floodways, no distinct banks.
Inland and northern deserts (Canning, Victoria, and Officer Basins)	Low gradients, vegetated dunes, sand sheets and minor alluvium.	Irregular rainfall and flow events mainly due to dissipating cyclones.	High sediment loads. Dominantly sand sized.	Meandering, braided, anabranching. Broad floodways, no distinct banks.
Kimberley Block	Moderate gradients. Gorges or broad valleys depending on rock type.	Regular summer flow due to monsoon rainfall with frequent large summer floods of cyclonic origin.	Generally moderate to high sediment loads. Range of sizes available.	Bedrock and fault controlled, straight, meandering, braided, anabranching. Tidal reaches strongly meandering.
Pilbara Craton	Steep to low slopes, narrow gorges with rocky beds in upland areas.	Episodic flood events due to dissipating cyclones.	Moderate sediment loads. Range of sizes available including cobbles.	Bedrock and fault controlled (straight) or broad braided, sand dominated channels.
Ravensthorpe Ramp (South Coast)	Moderate to steep slopes.	Regular winter rainfall flow, ephemeral to weakly seasonal flow. Occasional summer floods.	Moderate to high sediment loads, dominantly sand and clay sized.	Meandering, minor anabranching and braided.
Swan Coastal Plain	Low to moderate gradients, dominantly alluvium or dune sand.	Regular winter rainfall, dominant winter flow. Significant baseflow component.	Moderate to high sediment loads, dominantly sand and clay sized.	Meandering. Straight (drains).
Yilgarn Craton	Low gradients, wide unconfined shallow valleys, buried palaeochannels.	Regular but low rainfall, and occasional summer floods. Seasonal and ephemeral flow regimes.	Limited loads in many areas, generally sand to clay sized material.	Braided, meandering, poorly defined channels. Chains of salt or playa lakes.

6. Changes in river form over time

Rivers tend to organise themselves into forms that require the minimum amount of energy or effort to maintain (see River Restoration Report RR 6, *Fluvial geomorphology* for more discussion). For rivers that have achieved this 'comfortable' or 'equilibrium' state, although erosion and deposition occur at a local scale, there is no overall change in channel planform, and the sediment load supplied from upstream is transmitted through the system without net erosion or deposition.

When external variables change, rivers adjust themselves to attain a new equilibrium state. Sometimes the imposed changes cause rivers to adopt a significantly different planform. The magnitude of the imposed changes required to tip the balance depends on the 'sensitivity' of the system in question. Alluvial rivers can adjust their:

- Curvature or sinuosity.
- Degree of braiding.
- Number of channels.
- Average/maximum/minimum width.
- Depth (by bed erosion or increasing bank height).
- Slope.
- Type/size of ripples, dunes etc on sandy channel beds.

In Western Australia, two major landuse changes associated with our settlement activities over the past 100 years or so – the clearing of native vegetation and urbanisation - have caused changes to the form of many channels.

Changes in channel form can be recorded in the sediments deposited by streams. Interpretation of a sequence of sediment layers frequently indicates that different channel and floodplain forms and even planform types, and different environmental conditions, existed in the not so distant past.

Clearing of vegetation

The extensive clearing of both hill slope and riparian vegetation, and its replacement by shallow rooted crops and/or grasses, has increased the proportion of rainfall running directly into river systems and increased the amount of sediment entering and moving down rivers.

Such impacts have manifested in changes to river planform such as:

- increase in channel width (bank erosion);
- decrease in channel depth (filling of pools);
- increased tendency towards braiding; and
- increased rates of meander migration.

Clearing of vegetation has also resulted in increased levels of nutrients and salinity in water bodies which can indirectly influence channel form.

Urbanisation

After construction of buildings and infrastructure, there is an increase in impervious surfaces such as roads, roofs and car parks. As a result, sediment input levels decrease below natural levels, and the proportion and speed of runoff entering a stream typically increases. The greater amount and speed of flow through the system leads to erosion and an increase in channel capacity by incision and/or widening. Note that during construction the amount of sediment in streams temporarily increases leading to local aggradation and reduced channel capacity.

7. Tools for recognising and understanding river form

Field visits, data sets and maps, and discussions with people can help you recognise, describe and understand the various forms of your river channel and floodplain.

Field visits

Field visits and field surveys are crucial for identifying and interpreting sedimentary features and channel planforms. For example, sediment size and type can be noted, local rock outcrops can be mapped, and vegetation characteristics can be identified. Field activities can also include:

- Sketching plan views and cross-sections through individual sedimentary features.
- Measuring the size of features and the frequency of their occurrence.
- Interpreting a three dimensional picture of the channel and floodplain using sites where recent bank erosion, a tributary junction, or excavation has exposed soil profiles.

- Noting where sediment is building up and eroding within a channel and mapping any factors (local or regional) you think may be responsible.

Signs you can look for in the field that indicate *changes* to channel form include the following:

- Buried tree trunks, fence posts, logs, soil horizons and historical artefacts (e.g. bottles, scrap metal, etc) indicate a trend towards deposition. Rates of deposition can be estimated from knowing the age of buried artefacts or by placing pegs (e.g. star pickets) at a site and recording how fast they are buried – the more points sampled, the better the estimate. Alternatively, if funds are available, rates can be calculated by analysing the activity of radioisotopes in a sediment sequence (e.g. using techniques such as ^{14}Carbon, ^{137}Caesium, and thermoluminescence dating).
- Exposed tree roots or bridge/fence/pole footings indicate a trend towards erosion. River bank characteristics can indicate active and past erosion. For instance, signs of active erosion include fresh bank faces, minimal colonising vegetation, an absence of lichens, annual weeds, spider webs, etc.
- Changes in the character of a vertical sequence of sediment layers, such as loose sand overlying hard clay, suggests a change in flow and/or sediment regime (e.g. a flood event or channel avulsion).
- Different ages and successions of floodplain vegetation can indicate trends of deposition or erosion and provide an idea of the rate of change. Dating tree-rings and examining patterns of lichen growth on river cobbles or banks (lichenometry) can help quantify rates of change.

Data sets and maps

Useful data sets and maps that you can access through government agencies, Shire offices and/or the Internet include:

- Topographic maps (use a range of scales).
- Geology maps.
- Cadastral maps (land use, dams etc).
- Vegetation maps.
- Aerial photos laid out to form a mosaic.
- High resolution satellite imagery.
- Shire plans and engineering reports (e.g. reports on road or rail works).
- Oral histories/diaries from Aboriginal elders and long-term residents.
- Historical data (e.g. surveyors field books) on cross sections, slope/longitudinal form or pool depths.
- Rainfall and flow data (seasonal distribution and historic record) and flood marks.

Comparing maps, photographs etc from the same river reach over time can indicate changes in channel form and even provide quantitative data. It must be remembered that maps and written records provide only ‘snapshots’ in time and that care must be taken when interpreting changes and averaging rates of change between two dates.

Discussions with people

It is often helpful to talk to people who live near waterways, or work on waterway issues, about why certain geomorphic features might look like they do, and how they have changed over time. Farmers, rivercare officers. Aboriginal people, engineers, landcare coordinators, university academics, hydrologists, local land holders, geomorphologists, and long term riverside residents are just a few types of people you could speak to about river form (but don’t be surprised if you get a range of views!).

8. River forms and river management activities

Recognising river forms and understanding how they behave and change over time and space is vital for managing and protecting river systems, and especially vital for planning river restoration activities. As discussed throughout this document, in order to be most useful, recognising river forms needs to:

- be made in the context of Australian conditions;
- be framed in a catchment context;
- include an understanding of underlying sedimentary processes and their controls; and
- incorporate the condition of the river, and reflect the direction of possible changes in condition.

There are various ways in which knowledge of river forms can be translated into river management to improve river health. One approach could be to identify the range of sedimentary features and hence planform types across a catchment. Since similar planform types usually reflect similar sedimentary processes and controls, variation in planform can be used to divide a catchment into management units. Each planform type can then be subdivided into shorter reaches using other criteria such as land use or vegetation associations. In recognising these spatial changes in river form, you can also assess the present condition of the river, the management practices that may have impacted on its form, and any changes or trends in form over time. This will help you determine the major controls on river form which will provide a good basis for identifying and prioritising management options including assessing the recovery potential of degraded reaches, and the protection priorities for reaches in good condition.

Questions you could ask and address to help you understand your river form and plan your river management activities include:

- What are the characteristics of the catchment, for example in terms of climate, geology, landscape, flow regime, land uses, groundwater etc?
- What are the dominant, local to reach scale sedimentary forms of the channel and floodplain system that you are interested in?
- What planform type does the system most closely resemble and how does this planform type change over the catchment? Why?
- What are the dominant controls on channel and floodplain form? For example does bedrock constrict meandering? Does the shape of the floodway confine flow in certain reaches? Does vegetation quickly colonise new in-channel deposits? Are there any features that may reflect past (>10,000 years ago) flow or climate conditions and if so could these influence modern river processes?
- How have human land use changes impacted on the river system? What is the present condition of the reach in question? Does it appear unstable?
- How should fencing, tracks or other infrastructure be best positioned for a particular planform type?
- If more major work is envisaged, what type of channel and floodplain features are planned by stakeholders and the general community, and are these realistic and appropriate?
- How do particular channel and floodplain forms and their controls relate to ecological process, habitats, water quality, recreational opportunities, etc?

A well-developed approach to translating an understanding of channel and floodplain form into management initiatives to improve river health is the 'River Styles' procedure. This approach is demonstrated on the CD 'Rehabilitating Australian Streams' and at www.es.mq.edu.au/courses/RiverStyles

In terms of river management, the river styles procedure:

- Helps to develop proactive, rather than reactive, management strategies, to effectively prioritise resource allocation to management issues.
- Enables realistic 'target conditions' to be determined for river rehabilitation based on a geomorphological understanding of river processes.
- Ensures that site-specific strategies are linked within a reach and catchment-based 'vision'.
- Can be used to guide a selection of 'representative' sites in programs to monitor river condition, recovery potential and to audit the effectiveness of river management strategies.

By extension, river styles can provide a catchment-framed biophysical template for water resource planning and decision making. For example, river styles provide a natural basis for monitoring programs to examine the impacts of water allocation strategies.

The River Styles approach was developed by Gary Brierley and Kirstie Fryirs at Macquarie University. Further information can be obtained from the developers of the framework at Macquarie University.

9. Glossary

Alluvial environment, channel etc An environment made up of, or a channel cut into, alluvium. Alluvium is material deposited by running water, typically rivers. It displays characteristics such as stratification and size sorting. The term is usually restricted to relatively young sediment and does not include lithified material such as sedimentary rock.

Avulsion The diversion of a river channel to a new course.

Bankfull discharge The discharge that fills a river channel to the bankfull level without spilling over to the floodplain.

Base level The lower limit to the operation of surface erosion processes. Sea level is the overall base level for continents, though an individual channel can have several local base levels defined by bedrock bars, waterfalls or dams.

Bedforms Features such as ripple marks and sand waves formed by flow over a deformable bed, e.g. stream flow over a sandy river bed.

Dendritic A branching form that is on of several forms that a river can exhibit at catchment scale. Other forms include trellis, parallel, rectangular and centripal.

Geomorphic Of, or relating to, the forms of the earth's surface and the processes associated with them (e.g. erosion, weathering, transport and deposition). Fluvial geomorphology relates to river form and process.

Lag A desposit of relatively coarse sediment that has been produced by the removal of finer material by water or wind.

Palaeochannel A channel that is no longer part of the contemporary fluvial system, i.e. has been abandoned or buried.

Playa lake A closed depression in an arid area that is periodically inundated by surface water.

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