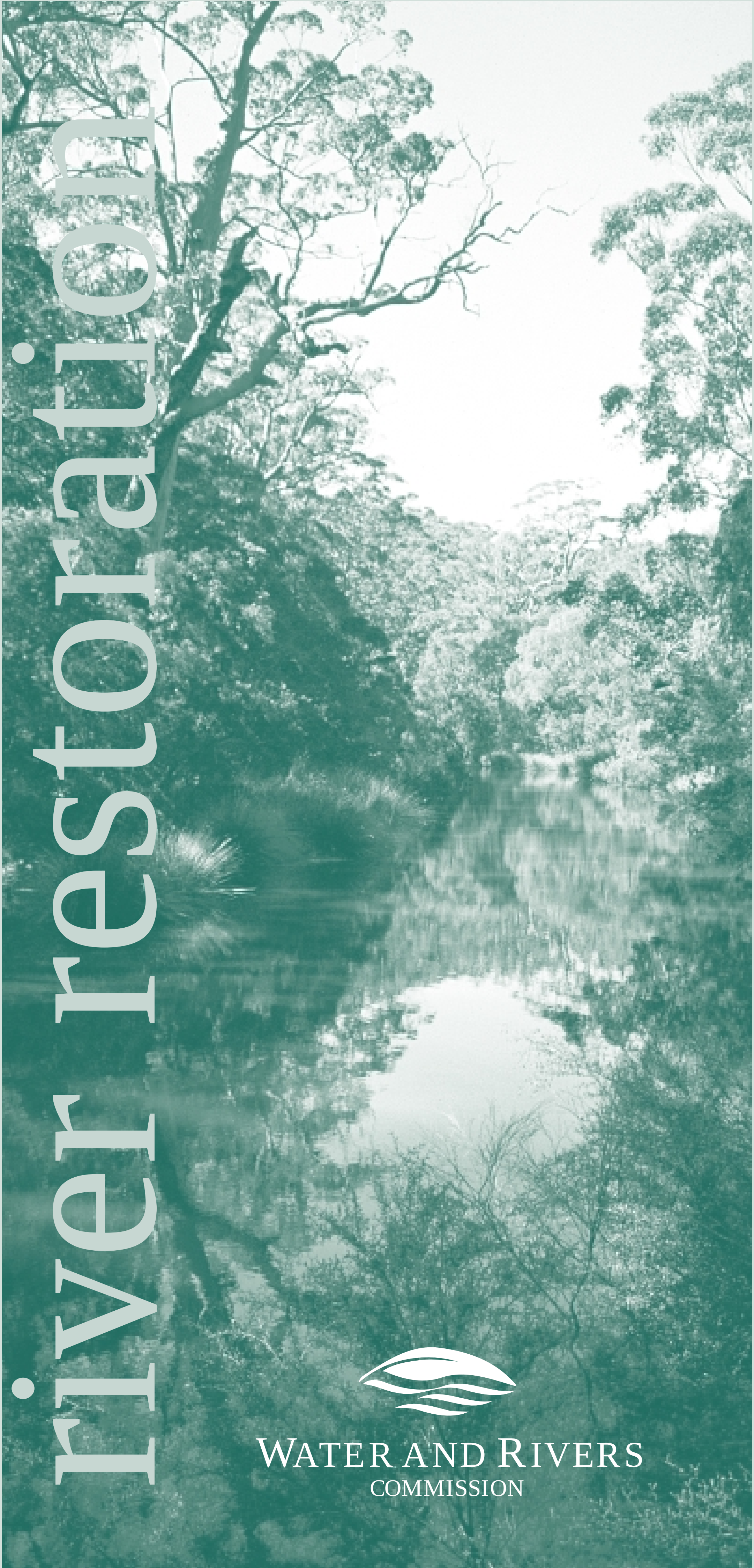

Stream channel processes

Fluvial Geomorphology

July 2000
Report No. RR6

WATER & RIVERS COMMISSION
Hyatt Centre
3 Plain Street
East Perth
Western Australia 6004
Telephone (08) 9278 0300
Facsimile (08) 9278 0301

We welcome your feedback
A publication feedback form
can be found at the back of this publication,
or online at http://www.wrc.wa.gov.au/public/feedback

STREAM CHANNEL PROCESSES

Fluvial Geomorphology

Prepared by
Steve Janicke

jointly funded by

AUSTRALIA
Natural Heritage Trust

WATER AND RIVERS
COMMISSION

WATER & RIVERS COMMISSION
REPORT NO. RR6
JULY 2000

Acknowledgments

This document was prepared by Steve Janicke.

Photos supplied by Steve Janicke.

River Restoration series co-ordinated by Heidi Oswald Water and Rivers Commission.

This document has been jointly funded by the Natural Heritage Trust and the Water and Rivers Commission.

Reviewed by Peter Davies, University of Western Australia and Geraldine Janicke.

Reference Details

The recommended reference for this publication is: Water and Rivers Commission 2000, *Stream Channel Processes: Fluvial Geomorphology.* Water and Rivers Commission River Restoration Report No. RR6.

ISBN 1-9-209-4719-1 [PDF]
ISSN 1449-5147 [PDF]

Text printed on recycled stock,
July 2000

Foreword

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

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

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

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

Contents

Laws governing water in motion

1. Introduction

This discussion is about the principles that determine the form of stream channels. What is a river? Is it the flowing water, the channel in which the water flows, the overall flood plain or a mixture of these? The proper answer is that the river is a dynamic association of all these components. The water flowing through a stream channel not only shapes the channel but transports all manner of materials such as sediment, leaves, logs, animals, plants and the accumulated rubbish from human activity. This material is repeatedly deposited and relocated to build what we call the floodplain. The floodplain is that part of the landscape that is ruled by the power of flowing water. To understand the changing ‘shape’ or morphology of a stream it is important to understand the way in which a number of natural forces are involved. These are the forces are gravity, friction and fluid cohesion (forces holding the water together).

There are measurements and calculations that should become familiar to you if you are managing rivers. If you can lay aside fearful recollections of algebra classes at school, these mathematical tools can be of use to you to assess the structure of a river and its role in the catchment. The purpose, or at least the hope, of mathematical equations is to be precise in describing the relationship that exists between two or more quantities. In this case the quantities deal with measurements of river features. It is useful to realise that the same physical principles that apply to rivers also apply to streams and quite small creeks, although there are some differences associated with scale. The mathematical relationships are usually approximations that reasonably apply in simple situations. Simple in this context means that the flow has a “steadiness” about it rather than turbulent or chaotic behaviour such as occurs at rapids and waterfalls. The equations provide practical tools to estimate the appropriate size and placement of river features. They may also help to shed some light on the history of the stream. For example, Australian drainage systems were cleared in an era of hydrological ignorance and the capacity of our water resources to coexist peacefully with the urban and agricultural demands placed on them is not yet established.

2. Shear force and resistance to erosion

Before launching into a study of how gravity works to empower stream flow our starting point shall be to introduce the concept of a ‘shear force’. The term has a strong engineering feel about it, perhaps something to do with designing bridges out of steel and concrete. Our senses are constantly alerted to the action of shear forces in the everyday world. A shear force occurs anywhere there is a tearing, wrenching or abrasive motion taking place, typically where one object slides past another. Sweeping floors, sanding a piece of timber, shaving, washing dishes and cutting a slice of bread all involve shear forces.

Streams do not “do their own thing”, they obey rules

Stream channels are shaped as the movement of water and sediment act to apply a shearing action against the channel bed and banks. The soil and rock particles forming the material of the stream channel are glued together by powerful natural forces, these resist the shearing action that attempts to pull them apart. At the inner surface of a channel the shear force of the moving water overcomes this resistance. If this were not so erosion would not occur. Even hard rock can eventually be worn away. You can observe this force in action and it can also be measured.

The resilience or stability of a stream channel will depend on its capacity to resist the effects of the movement of water through it. Any modification that reduces the resistance to erosion will also increase the rate of channel erosion. The removal of vegetation, both surface cover and deep rooted species, reduces the resistance. In a cleared channel, an increase in the rate of erosion will commence at much lower water velocities than in a naturally vegetated channel.

The water itself is compelled to flow down-slope by the force of gravity. We know, usually from personal experience, that the slope and speed of an object down the slope are related, the steeper the hill the faster the bicycle will freewheel. How exact is this relationship?

Gravity acts on an object attracting it towards the centre of the earth (the striped arrows in Fig 1). If it is moving down a slope the slope opposes this fall and as a result a portion of the weight of the object sliding against the slope acts as a shear force. It is the same with water flowing down a channel surface. The steeper the slope the greater the portion of the gravitational force (weight) that acts parallel to the stream bed as a shear force (the dark arrows in Fig 1). The illustration shows that the shear force acts parallel to the surface of contact between the water and the bed. If there is no slope for the water to flow down, and therefore no water movement, there is no shear force. Gravity is then only expressed as a weight of water resting on the bed, as in a lake.

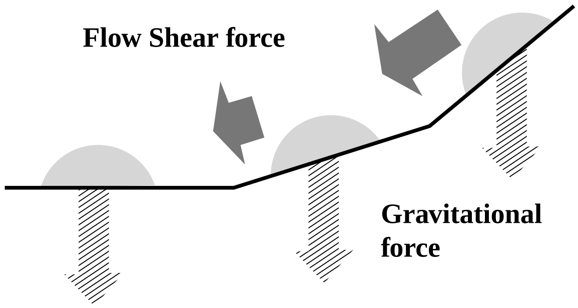

Figure 1: Illustrates that the shear force of flowing water acting on the channel bed increases with slope.

Since gravity accelerates objects we expect that the shear force is also related to the velocity of the water moving past the channel surface. You can experience a shear force effect when putting a hand outside an open car window and sensing the air pressure at different speeds. However the force of gravity is the ‘prime mover’ of streams. The amount of water resting on the channel bed depends on its depth and cross-sectional area. Increasing these increases the weight of water and therefore the shear force on the channel bed. The term tractive force can also be used instead of shear force. You can think of it as the same action that the tracks of a bulldozer exert on the ground as it moves along.

The ‘tractive’ force (T) is dependent on both the slope (S) and the cross sectional shape of the stream channel flow. Shape is a difficult thing to specify. A factor called the *hydraulic radius* (R) is defined as the cross sectional area (A) of the stream flow divided by the wetted perimeter (W) length (Fig 2). It is a simple measure of the relative channel shape at a particular flow level. Well rounded channels tend to have a greater R value than wide shallow channels. In principle it is a measure of the ‘nearness’ of the bulk of the water to the bed.

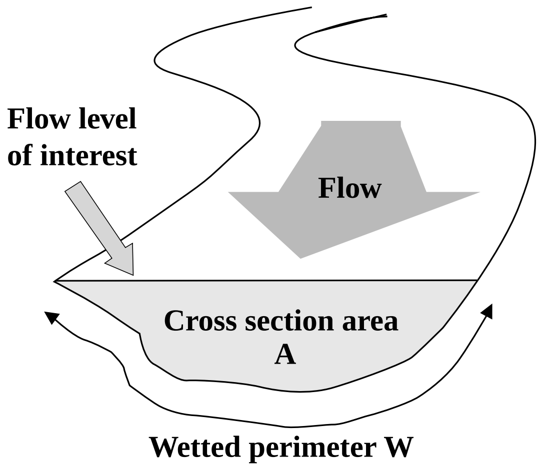

Figure 2: The elements of the hydraulic radius (R).

Hydraulic radius $R = \dfrac{A\ (m^2)}{W\ (m)}$

Symbols used

t	shear force
S	slope
A	cross section area
W	wetted perimeter
R	hydraulic radius
n	roughness factor
V	average stream velocity
$\propto$	is proportional to
Q	discharge

This section explains how the channel dimensions are related to the quantity of water moving through it. The exercise illustrates how natural principles are turned into a practical engineering tool and can also provide an insight into the underlying processes. In 1769 Antoine Chezy developed an equation linking the amount of water flowing in a channel, its dimensions and its slope[i]. He did this by observation and reasoning. In the 1880’s Robert Manning determined a more accurate form of the relationship.

The simplest relationship combining shear force, the channel slope and the hydraulic radius can be expressed as follows:

Tractive Force is proportional to the Hydraulic Radius multiplied by the Slope

$$T \propto R.S$$

This implies that if either the hydraulic radius or the slope increase or decrease, the tractive force T also increases or decreases in a proportional manner.

3. Direct measurement of discharge

The most obvious feature of a flowing stream is the quantity of water flowing in it. This is called the discharge. Stream discharge is the rate at which a volume of water passes through a cross section of a channel in a unit of time. Discharge at a fixed point along the stream is therefore calculated by multiplying the cross-sectional area (A) of the channel by the average velocity (V) of the water. The discharge (Q) is usually measured in cubic metres per second.

A typical bathtub holds about 0.25 cubic metres. If four filled bathtubs were poured out in one second it would correspond to a discharge Q = 1 cubic metre per second. If A is measured in square metres and V is measured in metres per second then Q is calculated as cubic metres per second (cumecs). There is a simple equivalence between mass and volume in the case of water. The mass refers to the amount of water and the volume refers to the amount of space it occupies.

1 tonne (1000 Kg) of water occupies 1 cubic metre (1000 litres) of space. Volume is the preferred measure of water quantity.

Discharge (m^3/s) = Average velocity (m/s) X Area (m^2)

Symbolically $Q = V.A$

1 cubic metre = 1000 Litres = 1000 Kg = 1 tonne

In a stream channel the velocity of the water varies considerably within the cross-section of the flow. At some parts the flow may even be moving upstream. This is the reason that the average velocity is used and not the velocity in the central flow area where it is fastest. The dominant region of downstream flow is known as the *thalweg*. It is often the area towards the centre of the channel, but not necessarily so. The *invert* of a channel is the path in the channel where the last trickle will flow as the stream dries up.

The resistance of the channel bed reduces the velocity of the water. Investigators have found that a relationship also exists between the shear force of the water on the channel bed and the average flow velocity. The average relationship is as follows:

Shear Force is proportional to the average velocity squared or,

$$T \propto V^2$$

It implies that doubling of the flow velocity increases the shear force by four times. Tripling the flow velocity increases the Tractive Force by nine times. In other words a small change in V produces a greater proportional change in T. Relating the two expressions for the tractive force T we obtain.

$$V^2 \propto R.S$$

By reducing V^2 to V we obtain a means of calculating the expected velocity from basic channel measurements.

$$V \propto R^{1/2}.\, S^{1/2}$$

This is the formula developed by Chezy in 1769.

$$V = \frac{R^{2/3}.S^{1/2}}{n}$$

This is Mannings more precise formula introduced in 1889.

The 2/3 power in Manning's version implies that changes in hydraulic radius contribute slightly more to the change in velocity than changes to the slope. The number 'n' is an introduced factor needed to deal with the fact that the "roughness" of the channel also modifies the flow. The effect of increasing 'roughness' will be to slow the water, and increasing the 'smoothness' of the channel will speed up the flow.

The idea of channel roughness is similar to that for any surface, it depends on the amount of unevenness of the surface. In the above relationship stream channels of the same <u>size</u> and <u>slope</u>, but different roughness, will have different flow rates. Notice that as 'n' gets larger in value the velocity must decrease and vice versa. A higher value of 'n' implies a rougher channel surface. Mannings 'n' typically varies between 0.025 – 0.070. Uniform sandy bed channels will probably have an 'n' value closer to 0.025.

Since $Q = A.V$ Then $Q = \frac{A.R^{2/3}.S^{1/2}}{n}$

Channel slope, cross section, surface roughness and discharge intimately influence each other

Manning's equation is useful for estimating the stream discharge using measurements from a survey of the stream channel. The relationship is not exact and should only be applied in situations of reasonably steady and smooth flow. Where rapids, waterfalls and extreme turbulence occur, the relationship is quite unreliable.

If a steady stream flow is measured and the discharge determined, the equation could also be used, in reverse, to calculate a value for 'n'. Tables of 'n' values for various 'typical' situations are available.

Table of mannings n values (Newbury and Gaboury 1993).

Mannings n channel resistance factors	**n**
Clean straight, few boulders	0.03
Clean winding, cobble bed, riffles	0.04
Sluggish weedy, pools	0.05
Large woody debris, vegetation	0.08

4. The concepts of potential energy and stream power

The structure of a stream channel is 'carved' into the landscape through the action of the shearing force of water flow. Another way of considering stream processes is through the concept of energy and energy changes. As the sun's radiation beats down upon the surface of the oceans, the radiant energy enables molecules of water to break free of the sea surface and to be mixed into the atmosphere. High above the earth's surface complex processes bring the molecules together, usually to form ice crystals.

When the crystals are large enough they overcome the buoyant uplift and turbulence of the air and commence to fall towards the ground under the influence of the earth's gravity. They grow, melt and turn into raindrops. Clouds are like gigantic solar charged batteries that power our rivers.

If you imagine an elastic band attached between the earth and the raindrop as representing the gravitational attraction between them, the energy is stored in the stretched elastic and is available to be converted to motion. The gravitational tension between the earth and a raindrop can be thought of in terms of stored energy. It is called Potential Energy (PE). The greater the altitude (separation between the earth and the raindrop) the greater is its potential energy.

An accepted and crucial property of energy is that it cannot be created or destroyed but can only change in form. As the raindrop falls to a lower altitude it will have less Potential Energy and the difference must be accounted for. We have noticed that as an object falls its speed increases. As the raindrop falls its potential energy is available to increase the velocity of the drop. The Potential Energy becomes energy of motion. Environmental change will be produced when the motion of the drop encounters resistance.

February 1998

January 1999

January 1999

[Photos: A. Maughan, S. Janicke]

Figure 3: Effects of flooding on Neridup Creek, Esperance.

The reason for describing all this is that once the rainfall accumulates in creeks and rivers the same principles continue to dominate the process. The raindrop hitting the ground still has altitude and hence a reserve of potential energy. As drops come together and commence their flow back to the sea their energy is literally ‘pooled’ and any resistance is an opportunity to produce further environmental change. In the terminology of physics, the water particles do 'work' on the environment.

Stream flow remains the "slave" of gravity and carves and shapes the landscape into the form of creeks and rivers. The more we understand this the more we will appreciate the inner workings of our streams. At all stages energy is being lost back into the environment in the form of low level heat, movement and even sound. The channel keeps the coalesced raindrops together. If a stream flows over a high enough waterfall the lack of confining resistance allows the water to separate back into individual droplets.

The same thing happens if you observe water flowing from a hose. This demonstrates the intimate relationship between the way in which water flows and the medium that confines it. The water flowing in a creek or river is no longer the loosely interacting collection of drops found in the rain shower but a new and unusual object, a liquid ribbon. The river manager can view the stream as an entity in its own right. It is not hard to attribute a lifelike quality to this pulsating, twisting, object. The Rainbow Serpent of Aboriginal tradition is in many ways an apt name for the forces creating the rivers, describing the origin of the river water and its impact on the earth’s surface.

The total potential energy of a quantity of water depends on the amount of water and its relative altitude, usually taken to be its height above sea level. The river is constantly being depleted of its store of potential energy and this depletion produces the features that we see in the picturesque pristine river as well as the degraded drain.

Important physical principles suggest that the flow will follow the path, which offers a minimum expenditure of energy but with maximum effect on the channel. In other words the flow takes the path of least resistance or we might say the path of minimum effort, while causing irreversible changes to the channel. This path is rarely a straight line. A river will have to be forced to conform to a straight channel for any distance. This will cost money for robust design and perpetual maintenance. Without constant maintenance the river will inevitably override the engineering works.

5. Stream power

Power is defined as the rate at which energy changes its form. The work of rivers is shifting the landscape, grain by grain, to the lowest parts of the earth’s surface, the oceans. It takes power to do this. Power (P) is calculated as force times velocity. Stream power relates to Shear Force times the Average Flow Velocity.

$P = T . V$

Changes that increase either T or V will increase the stream power. Increased Steam Power will mean greater changes to the channel are possible. We usually observe these changes as excessive erosion, redistribution of sediment and vegetation, alterations to the geometry of the stream channel and damage to man-made structures (usually more man-made than woman-made).

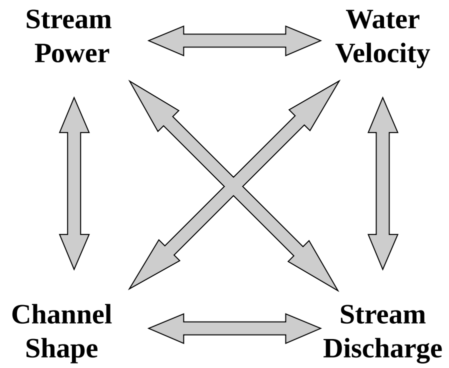

Figure 4: Demonstrates the key relationships.

For example when a winding section of river is straightened potential energy of water rushing along the channel is released over a shorter distance and in a shorter time period. The stream power is increased and the bed resistance is further overcome thus accelerating erosion. The channel may deepen, widen and commence reforming bends.

Erosion will proceed rapidly until the channel forming forces come to a balance with other factors that impact on the character of the river. The ‘other factors’ include vegetative colonisation, soil structure, groundwater levels and land use.

While this is happening the entire stream reach is relatively unstable, at least to the extent that it produces unwanted outcomes for human activity and the native plant and animal inhabitants living in the riparian zone. Stream power, water velocity, discharge and channel-shape are all intimately connected as Figure 4 illustrates.

The river manager must understand that a change in one of the factors discussed above will bring about adjustments in the others. All energy must be accounted for. History is littered with examples of humans meddling with river flows without an understanding of these connections, to the detriment of many a community.

It should also be remembered that the stream is a dynamic system, never completely static, but steadily changing and also subject to sudden, unpredictable and dramatic modifications. Conditions in a river are, literally, as changeable as the weather. The common features found in streams of all sizes, worldwide are evidence that natural laws underlie even apparently arbitrary forms.

6. Sinuosity and minimum effort

Solid objects show certain characteristics such as flexibility, a capacity for bending and stretching under tension and resisting alterations in shape. They take on a shape that reflects a balance between competing forces that are internal and external. The river, a liquid ribbon, has a flexibility and a capacity to bend and stay together also, but being a liquid its shape is very sensitive to its container, which is the channel, and its movement down slope, sloshing as it were from one side to the other. The water upstream is connected to the water downstream and the energy of these connections is described by 'pressure heads'. The 'heads' are elevation head (potential energy), pressure head (due to depth) and velocity head (energy of movement). All these add together to empower the stream to take on its characteristic geometry. Nature suggests that three heads are better than one.

The fact that the flow in a stream generally stays intact and there is a pattern for its path suggests that indeed there are 'watery equivalents' of the flexibility and tensile characteristics of long thin solid objects. The liquid undulates and pulses, swirls and rolls in a manner that has defied exact analysis by mathematical experts. Its chaotic behaviour nevertheless occurs within confining boundaries and these boundaries appear to adhere to certain predictable measures.

The evidence for these assertions lies in the observed shape and form of streams and rivers of all sizes and environments throughout the world. There are recurring numerical ratios between channel width, depth, radius of curvature and the distribution and spacing of common river features. There is a similar appearance to bends and features at many scales.

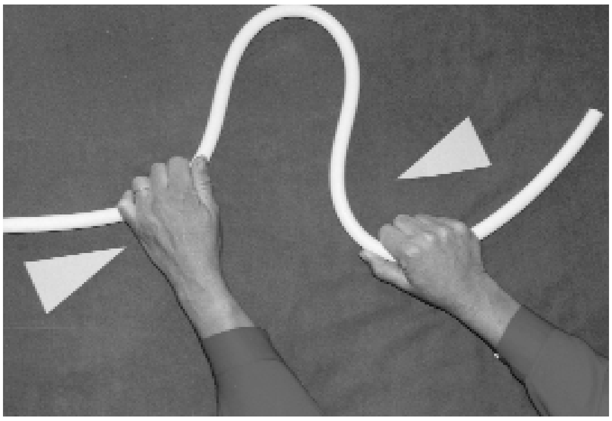

Figure 5: Compression producing meander-like curves.

Meanders of the Amazon River look similar and have the same features, apart from size, as meanders on the Gairdner River near Bremer Bay.

If an isolated stream feature is redesigned, or even eradicated, the repercussions will produce changes upstream and downstream. You can obtain a length of flexible hose of length at least 20 times its diameter, lay it on a table and push from each end as if trying to shorten it. The hose will distort into a loop. This curve has a wavelike shape in appearance not unlike a river bend. Increasing the compression causes the bend to take on the appearance of a fully-fledged stream meander.

The shape of the curve is related to the degree of compression and the resistance of the material of the tube. The distribution of stress along the length of the bend is not even, as will be seen if you continue the compression. The turns of the bends will kink first.

The final shape reflects the 'best' response to pressure. Someone may say, "OK but how does this apply to a river, how do you push or pull water?" The force of gravity acting on the entire stream length causes the 'pushing and pulling'. The channel ensures that the water particles stay together but it is not able to totally dictate the shape or the flow.

The capacity of the water particles to attract each other, to stay together, is called its viscosity. The pressure heads provide the source of energy to sculpture the channel and the extent of the curvature is limited. The evidence suggests that the forms of the bends and curves of any creek or river also represent a path of minimum effort at this larger scale.

7. Bankfull discharge and channel forming flow

There is a basic but important question that arises from investigations of river channel forming processes. What are the useful measurements of a stream? For example how wide is a river? How deep is it? How long is a piece of string? Flow does not stay the same and the level is constantly changing. In fact Western Australian rivers and creeks stop flowing altogether for substantial periods of time. Since flow measurements are changing in time, the relationship between the changing discharge and the channel dimensions has been of particular interest.

Low flows have a marginal but steady work of erosion and sediment transport and deposition. On the other hand rarer extreme floods can produce major rearrangements of sediment, create new channels or drastically modify existing channels and flood plains. Under what conditions is most of the work done? If this is known then the stream can be realistically protected or modified to cope with the changes produced by settlement and clearing.

Observations in other countries have suggested that channels are predominantly maintained by an intermediate flow referred to as bankfull (Q_{bf}). It is not the same as the average flow. The width and depth at the bankfull discharge are useful measurements. If a flow record is obtained for a long enough period of time the bankfull flow is considered to be that maximum flow rate that occurs every 1.5 to 2 years, on average.

This definition is based on investigations of rivers worldwide. Its exact relevance to Western Australian rivers is not fully known since Australian rivers appear to have average discharges that are less than rivers of comparable catchment area on other continents. In addition the flows are often intermittent and intense or ‘flashy’.

If you take the time to carefully observe natural river channels you will see that the active channel of creeks and rivers is often highlighted by distinct changes in the appearance of the banks at a certain water level, not necessarily at the very top of the bank. Some of these features are undercutting, change of vegetation density, water marks on rocks, a boundary level for mosses or lichens and changes in deposited sediment particle size and the height of the point bar on the inside of the meander bend. These levels are considered indicators of bankfull flow, ie the dominant channel maintaining flow.

An extreme example demonstrating that in some situations bankfull flow is more important than bank-top flow is the Murchison Gorge. The river has cut down, we say incised, through the rock leaving vertical channel sides fifty metres or more high in places. The bankfull level is definitely not at the top of the cliffs and flow levels at this height have never been observed, yet the channel continues to deepen. Many Australian streams are considered incised, although not to the extent that they are considered to be gorges. Incision has been aggravated through land clearing and rising water tables and even many smaller streams do have gorge like features.

The encroachment of vegetation may provide one of the best indicators of primary channel forming flow, at least over a period of several decades. Vegetation colonises and over a period of time changes the effective structure of the stream channel environment. The degree to which colonisation will proceed into the channel will be related to the ability of the plants to live in the watery environment and to coexist with the shear stresses imposed by bankfull flows that occur in the stream. Where pre-existing vegetation is not coping with increased flows due to land clearing there will be evidence of bank and tree collapse.

The design of river restoration works must be robust enough to at least handle a bankfull discharge. Since the dimensions of channels can be shown to be related more intimately with bankfull discharge, changes to channel geometry are more likely to be maintained if they conform to these values.

Catchment clearing has produced greater surface run off, groundwater recharge and more frequent flows in streams. The bankfull or dominant flow has therefore been increased. The channels no longer reflect a slow and steady evolution but may have rapidly changing dimensions.

The susceptibility of the channel to higher than bankfull flows will depend on the discharge at which the flow spills over onto the floodplain where the energy can be spread out and flow power is lower. An incised channel, that is deeper than the bankfull depth, will be capable of carrying flood flows. The channel will contain most of the power of these flows even if the bank is overtopped. The process of erosion and deposition will be accelerated as the stream power increases. If the flow overtops the bank the extra power will be dissipated onto the flood plain. Engineering for rarer high flood flows will, however, be more extensive and expensive. The works must be weighed against measures that will simply enable the riparian zone to 'bounce' back during periods of more moderate conditions.

8. The effect of vegetation

The landscape surface throughout much of Australian agricultural land consists of well-eroded and redistributed sediments in the form of large undulating plains. These areas have only been cleared, cultivated and grazed for a short space of geological time. The natural channel forms were in an intimate 'give and take' relationship with the native vegetation cover.

Sand and clay soils are common in the riparian zone but they had an in-built added resilience through an extensive network of tree and shrub roots. Channel 'roughness' was dramatically increased by the numerous fallen trees and branches. Sedges and grasses added protective clothing to the soil surface. The evergreen forest, woodland and scrub cover was efficient in intercepting rainfall and reducing the annual surface runoff. The native vegetation and the large woody debris falling into streams acted as a very effective hydrological 'shock absorber' for the fragile soils.

[Photos: S. Janicke]

Figure 6: The photographs above were taken along the same drainage line . Photo A shows the slowly changing meandering channel in an upstream patch of remnant vegetation. The channel is probably wider and deeper than prior to clearing upstream, but it is still held together by the remnant vegetation and a rock chute 100 metres downstream. Photo B is taken approximately 500 metres downstream. A straightened shallow channel was created and this has deepened and widened dramatically. Stock have uncontrolled access and the vegetation is largely gone. Photo C is a further 250 metres downstream. Here the channel has remained narrow and this probably reflects a more cohesive sub-surface soil profile that compensates for the lack of vegetative bank reinforcing.

Work carried out by the CSIRO suggests that having both stream banks well vegetated has a significant effect on channel dimensions. If both banks are well vegetated the bankfull width may be 25% lower, the channel 25% deeper and the flow velocity twice that of an uncleared channel, on average. It is not uncommon for rivers to widen by a factor up to 5 or 6 times the original width, after land clearing has taken place.

The presence of large woody debris (LWD) has been shown to create greater diversity of flow structure through the complex effects of turbulence. This structural variation also provides opportunities for a diversity of animal and plant species by providing many different types of habitat.

Many agricultural area streams now have the appearance of arid zone rivers. These are characterised by broad, shallow sandy channels transporting massive quantities of sediment. In these areas vegetation is sparsely distributed and only the massive river eucalypts with their impressive root systems are capable of standing in this volatile environment.

9. Branching patterns and stream order

In the above discussions the term minimum effort has arisen in two contexts relating to the scale of the process discussed. Firstly in the movement of water at any locality in a river and secondly in terms of the larger scale bends and loops of the channel. At a catchment wide scale it has been postulated that the entire drainage pattern also represents the most efficient means of draining water from a large area. Models, simulations and calculations of path lengths for varying arrangements also suggest that this is so.

If you look down upon a catchment, from a good vantage-point, the stream channels often appear as a treelike (dendritic) branching pattern perhaps modified by large scale geological features. Geology is certainly the main factor that determines the extent of the overall drainage pattern. As the water flows down to the sea the stream channels extend like tendrils ‘upward’ towards the higher parts of the catchment, dissecting the landscape.

To describe the position that a particular channel has in the entire system various schemes for numbering the channels have been developed. Most ordering systems recognise reaches between confluences (where separate channels meet) as the fundamental unit of a drainage pattern. Streams are usually numbered on a map. As a result ordering number systems are specific to a particular map scale only and are limited by the detail shown.

Horton (1932) proposed that the first distinct channels to arise, those that have no tributary shown on a catchment map, be labelled as first order streams. In his system, a stream of any particular order could only receive channels of a lower order. Thus a third order channel is one that receives input from first and second order streams only.

[K. Parker]

Figure 7: A new first order stream – gully erosion.

Strahler (1952) proposed that any stream order is produced by the junction of two streams of identical order, but a unit lower. Thus a third order stream is the sum of two second order streams converging and a second order stream of two first orders. Again first order streams are the most basic channels with no other registered channel input.

Shreve (1967) proposed that a stream order be simply the sum of all upstream orders, with a similar definition of 1st order channels as that proposed by Horton and Strahler. This system more closely relates to the catchment area of any particular reach. Of course different maps scales could lead to the situation of a particular stream section being assigned a different order. The river manager does not simply deal with maps and a walk across a typical farm will reveal many small but distinct valleys that might be considered as containing true first order streams even though the available map does not show their existence.

From a ground perspective, the point at which water flowing from a storm event first enters a stable channel may be subject to differences of opinion. However with increased runoff in agricultural areas these formerly indefinite channels are now becoming permanent fixtures with all the attributes of a proper persistent channel. Stream ordering schemes are an outcome of attempts to find the 'hidden' rules governing drainage formation. Their use is less critical to river managers, but stream order is often used for orientation and descriptions of the relative importance of catchment and river management works.

One exception to this, that may become important, is the introduction of artificial drainage works, particularly higher up in a catchment. Works that are of a size inappropriate to the natural scale of channels at neighbouring stream orders in the sub-catchment may prove less efficient, a waste of money and effort. They may prove extremely destructive to the downstream environment creating a freeway for topsoil. This is an area of study that has by no means been fully and satisfactorily investigated. What is clear is that drainage systems are being added to and modified in an ad hoc manner with some managers not looking past the fence line.

10. Channel dimensions, catchment scale and discharge

This section summarises some of the general relationships between features in the drainage system of a catchment. Surveys may reveal discrepancies from the expected 'norm' that should be explained.

Discharge and catchment area

Catchment area is an important measurement since it is related to stream discharge and the structure of the entire drainage system. Larger catchments will have more tributaries and a greater range of channel sizes than small catchments. Discharge is influenced by many other factors in the catchment and the relationship between catchment area and discharge is more general. A relationship between area and average discharge can be determined by field observations for a particular river or perhaps a group of rivers in a particular type of landscape.

A useful predictive model of discharge will have to incorporate land use, rainfall, vegetation type and extent of cover, soil structure, drainage pattern, surface and groundwater storage. For example inland drainage lines, in Western Australia, often consist of strings of salt pans that only link up under rare flood flows. The areas are large but discharge at the lower end may be small.

Channel width and discharge

Various studies have shown a good relationship between channel width, particularly at bankfull and the stream discharge. Departures from this may indicate a stream channel in a state of accelerated change. The average relationship as it applies to Western Australian streams is not well described.

Excess sediment and channel shape

Sediment transport in Western Australian dryland rivers is of major concern to water resource managers. Massive quantities of sediment have been mobilised due to increased discharge and destabilisation of channels throughout the agricultural catchments. Tracking down the source of sediments is difficult, but studies suggest that banks are the primary source. Topsoil sheet erosion and bed incision also contribute to a greater or lesser extent. A feature of dryland areas is the many smaller creeks that have become filled with sand.

The result has been to broaden the flow into a braided network along the valley floors. Pools have become filled and the wetlands and estuaries at the end of the catchments are threatened with infilling also. In pre-clearing days the small first order streams probably had ill-defined channels and the runoff percolated through the native vegetation and leaf litter taking little of the soil with it. The newly fashioned channels now resemble the pattern of a stream flowing across a sandy beach on the coast. It makes sense to deal with sediment inputs from the top of a catchment first.

[S. Janicke]

Figure 8: Sediment mobilisation in the Dalyup River, Esperance.

The concept of fencing off these smaller tributaries, which may be only a kilometre or two in length and revegetating the channels is not yet seen as being of great importance by the rural community in general, although some landowners are being quite innovative in this respect.

11. Down cutting, successive head-cuts, widening and discharge

[S. Janicke]

Figure 9: A headcut moving upstream in the Dalyup River and deepening the channel bed.

In the case where the flow effectively transports the sediment, increased discharge has resulted in an increase in 'head-cut' activity. A head-cut is a waterfall that erodes its way upstream. The rate at which this progression occurs depends on the material the channel is made of.

Head-cuts can move imperceptibly or at the rate of tens of metres or more each year. Trees and ground cover adjacent to the head-cut cannot guarantee that deepening and widening will not continue.

The control of head-cutting will require some form of channel bed stabilisation. In recent years there has been a growing interest in the installation of large woody debris (LWD) and rocky riffles to achieve this, even in streams that did not have well developed riffles in pre-clearing times. In consolidated clayey soils the channel may become a narrow slot in the broader, shallower pre-existing channel. Widening will occur when the channel depth is such that the bank loses sufficient support and collapses into the stream. This is an all too common observation around the countryside these days.

The role of fallen timber (ie large woody debris) has now been recognised as a critical component of pristine Australian streams, a component that controlled the width, depth and discharge to a significant extent. Woody debris was originally removed to speed up the stream flood conveyance. At the same time that stream power was increased habitat diversity was also decreased. It has been shown that correctly placed woody debris has little effect on drainage efficiency and offers a means of stabilising stream banks and beds and preserving aquatic habitat.

River processes have a certain simplicity about them, but predicting the exact outcome of alterations is not at all easy. The Figure below illustrates the interconnectedness of the factors discussed in this article. Any system of this sort is likely to be sensitive to change and dynamic in its behavior, but the important message is that ...

Streams obey rules...
so before attempting riparian restoration,
get the stream hydraulics correct!

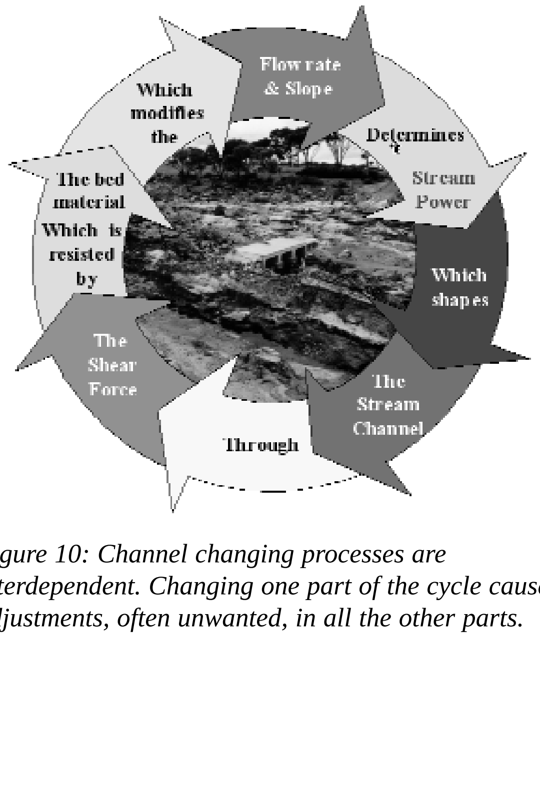

Figure 10: Channel changing processes are interdependent. Changing one part of the cycle causes adjustments, often unwanted, in all the other parts.

12. References

1. Gordon, N. D. McMahon, T. A. Finlayson, B.L. 1992, *Sream Hydrology: an introduction for ecologists*, John Wiley & Sons, ISBN; 0-471-930 84-9.

2. Heady, G. & Guise, N. 1994, *Streamlining, (an environmentally sustainable drainage network for the Swan Coastal Plain),* Community Catchment Centre, Pinjarra, Western Australia.

3. Horton, R. E. 1932, *Drainage basin characteristics*, Trans. Am. Geophys, Union 13, 350-61.

4. Leopold, L. B. 1994, *A view of the River,* Harvard University Press, London.

5. Newbury, R. W. & Gaboury, M. N. 1993, *Stream analysis and Fish Habitat Design (a field manual)*, Newbury Hydraulus Ltd, ISBN; 0-969-6891-0-1, Australia.

6. Rutherford, I. & Bartley, R. 1999, *Second Australian Stream Management Conference, Conference Proceedings, Vols I & II,* Co-operative research Centre for Catchment Hydrology, ISBN 1-876006-37-4, Australia.

7. Shreve, R. L. 1967, *Infinite topologically random channel networks*, J. og Geology, 75, 178-86.

8. Strahler, A. N. 1952, *Hypsometric (area-altitude) analysis of erosional topography*, Bull. Geol. Soc. Am. 63, 1117-42.