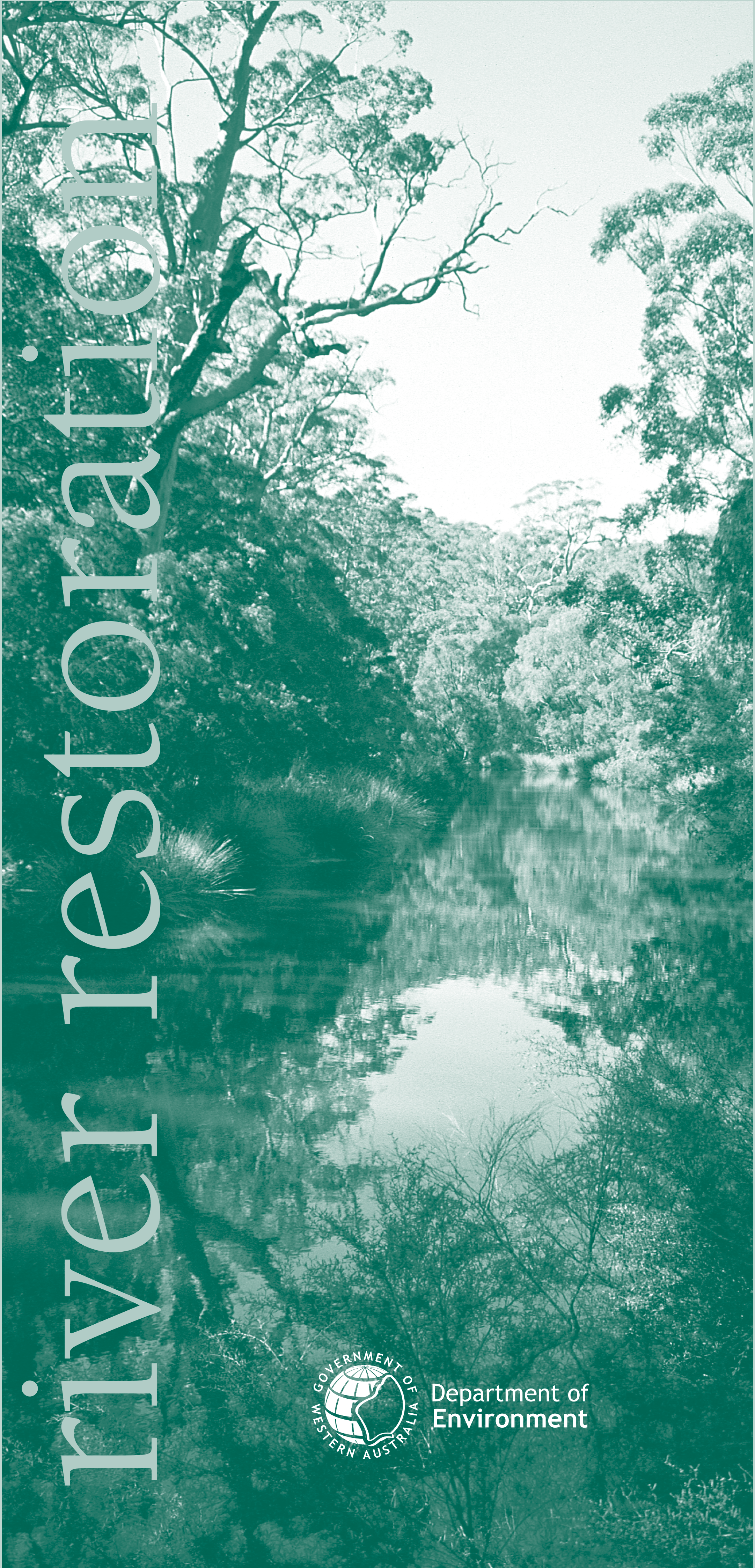

river restoration

Stream and Catchment Hydrology

Government of Western Australia

Department of Environment

June 2003

Report No. RR 19

Stream and Catchment Hydrology

in south west Western Australia

Prepared by
Peter Muirden, Dr Luke Pen and Dr Marnie Leybourne

jointly funded by

Natural Heritage Trust
Helping Communities Helping Australia

Government of Western Australia
Department of Environment

DEPARTMENT OF ENVIRONMENT
REPORT NO. RR19
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We welcome your feedback

A publication feedback form can be found at the back of this publication, or online at http://www.environment.wa.gov.au

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Note: *This is the final chapter in the River Restoration Manual series produced by the Water and Rivers Commission. In 2003, the Water and Rivers Commission merged with the Department of Environmental Protection to become the Department of Environment, hence the change of logo and departmental name for this final chapter.*

Foreword

Many Western Australian streams have become degraded as a result of human activity along waterways and through the effects of catchment land uses. Increased runoff, land and riverine salinisation, erosion of foreshores and infilling of river pools are some of the more pressing issues. Water quality in our streams is declining and many carry excessive loads of nutrients and sediment and, in some cases, are contaminated with synthetic chemicals and other pollutants.

The Department of Environment is responsible for coordinating the management of the State's waterways. Considering that Western Australia has 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 State and Commonwealth governments.

The Department of Environment is the lead agency for the Waterways WA Program, which is aimed at the protection and enhancement of Western Australia's streams and rivers 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 that provides a guide to the nature, rehabilitation and long-term management of waterways in Western Australia. As part of the continuous development and review process, any feedback on the series is welcomed and can be directed to the Catchment Management Branch of the Department of Environment.

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Appendix

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1. Introduction

The majority of waterways in south west Western Australia are ephemeral, ie they have a flood and dry cycle. The Mediterranean climate brings cool wet winters and hot dry summers, so most waterways in the south west only flow after winter rains. In river restoration, it is important to understand the flow characteristics of the waterways you are dealing with.

This Manual Chapter provides an overview of stream and catchment hydrology.

Sections 2 – 4 discuss what happens when rain falls in the catchment, when flow will occur and examines flood events and their impacts on streams and rivers.

Section 5 looks at the impact of clearing and how this has affected flow and salinity. Section 6 outlines water quality parameters influencing river health.

While this discussion on stream hydrology applies to most areas, we have focussed on aspects that relate to the main waterways in the south west of Western Australia (Figure 1).

Other chapters in the River Restoration series provide more detailed information on the flow characterisitics of waterways, such as *RR 6 Fluvial geomorphology*, *RR 9 Stream channel analysis* and *RR 18 Stream channel and floodplain erosion*. These and the other Manual Chapters should also be read before undertaking river restoration works.

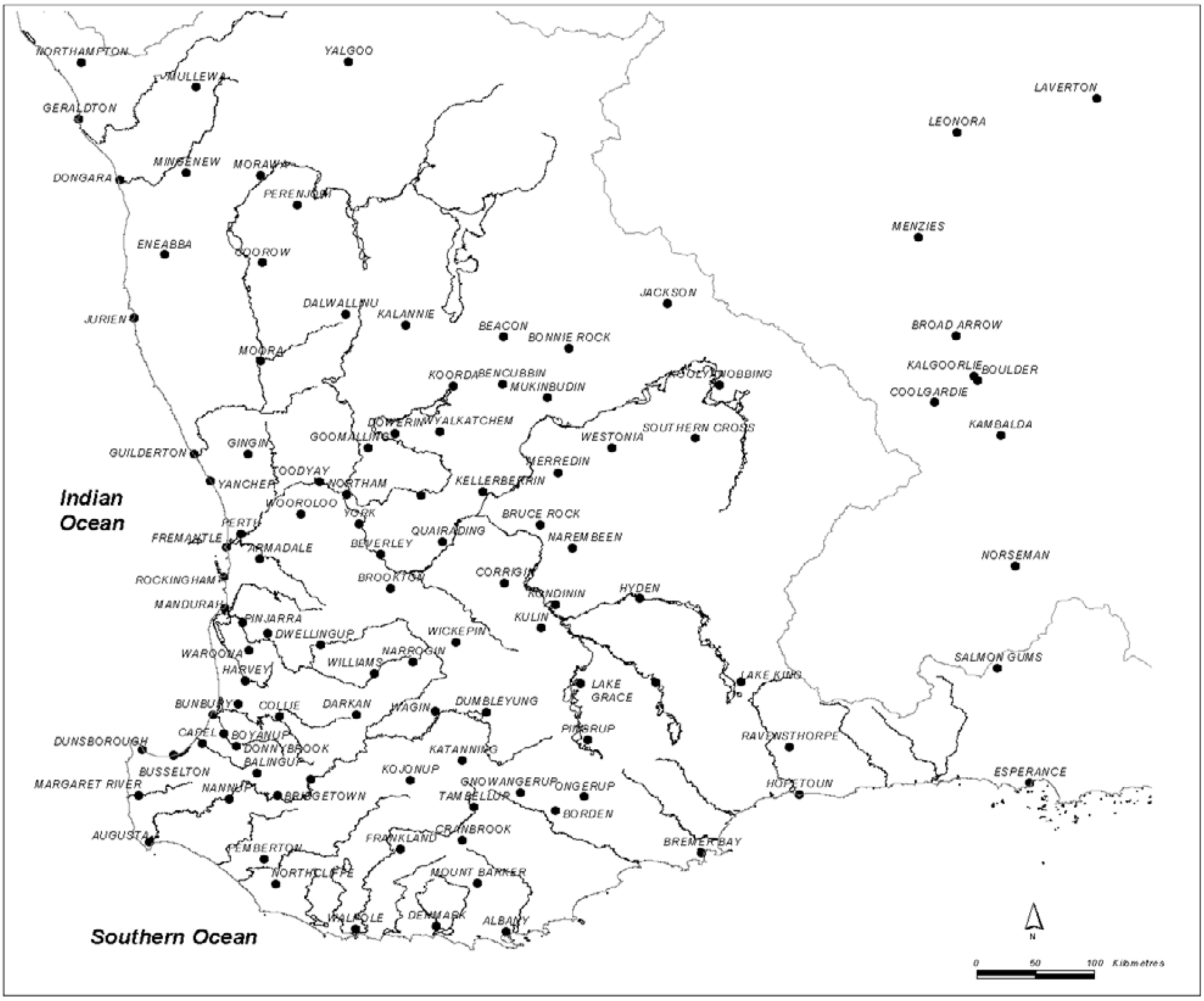

Figure 1. South west of Western Australia.

1.1 What is stream hydrology?

Hydrology is the study of water, particularly in relation to its movement above and below ground. *Stream hydrology* is the study of water in streams, or more precisely how the water behaves once it reaches a stream. The existence of rivers and streams is controlled by the water cycle, which begins with climate and rainfall. We will discuss the water cycle in the next section.

1.2 What is the value of hydrology to river managers?

Understanding and measuring how a stream behaves is critical to designing most river restoration works. This knowledge assists us in ensuring that stream stabilisation works, such as riffles and bank reinforcement, are designed to remain in place through the range of flow conditions of a stream. It is also necessary to understand how climate and the catchment influence stream characteristics.

There is an extensive network of gauging stations throughout WA that provide information and measurement of elements of hydrology such as rainfall, streamflow, flood events and water quality. While this does not provide actual data for every stream in WA, it does enable data from measured sites to be applied to unmeasured sites to describe and understand the broad flow characteristic of a stream.

Understanding the following hydrological components allows rivers to be successfully managed or rehabilitated.

- **Streamflow.** Good relationships exist between annual rainfall levels, catchment clearing, catchment area and flow, including annual variations of flow, flood flows and stream salinity. Awareness and comprehension of these relationships allows a better understanding of river behaviour.
- **Flood hydrology.** Floods are a natural component of stream systems and can determine the way streams are formed and change. Flood waters are responsible for most stream channel erosion and sedimentation as well as deposition of sediments across the floodplain, resulting in these areas being very fertile. Prediction of flood magnitudes and how often they are likely to occur is an important component of stream management.
- **Water quality analysis**. Water quality is an important factor influencing river health. Changes in salinity, nutrients and sedimentation as well as flow can have a major effect on flora and fauna. Analysis of water quality information provides understanding of stream health and trends over time.
- **Behaviour of built structures.** Hydrology helps understand how structures that are placed in or over streams will influence the behaviour of the stream, for example bridges, floodways, riffles and bank stabilisation, or the impact of streamflow on these structures.

1.3 What you will learn

This Manual Chapter will help you appreciate that although streams are complex systems, they follow a set of rules and their behaviour can be measured and understood. After reading this Manual Chapter you will start to understand the relationships between:

- evaporation and rainfall,
- catchment area,
- catchment clearing,
- runoff and flood flows, and
- stream salinity.

This will help you assess and understand a river system before undertaking river restoration and management activities.

2. Understanding the water cycle

The ‘water cycle’ describes in a simplified form, the complex movement of water in the earth’s climatic system. What is interesting is the amount of water involved. About 97 per cent of all water on earth is found in the oceans. While large volumes of water evaporate from the sea to form clouds and then precipitation, much of it falls back into the oceans. Of the three per cent of water not in the oceans, two per cent is frozen in the ice caps at the North and South Poles and nearly one per cent is stored in underground aquifers. Less than 0.2 per cent of all water is held in lakes and rivers and 0.001 per cent is found in the form of water vapour in the atmosphere. Some of this water vapour forms over land and falls as rain, hail, sleet or snow. From there, water flows down streams or through the ground back into the oceans.

The parts of the water cycle of main interest to river managers are when rain hits the ground and the effects of vegetation, leaching to groundwater, surface water runoff and groundwater discharge. This is referred to as the ‘hydrologic balance’ and is described in more detail in section 2.2.

2.1 Climate and rainfall

2.1.1 Climate and evaporation

The south west of Western Australia has a Mediterranean climate, characterised by cool, wet winters and long, hot, dry summers. The average annual temperatures for this region range from 15 degrees Celsius (°C) near Albany, 18°C between Perth and Kalgoorlie and 20°C in the north near Kalbarri. The average daily maximum temperature ranges between 23 and 33°C (in January) and the average daily minimum temperature ranges between 4°C and 10°C (in July).

The Mediterranean climate is also characterised by high evaporation rates. Average annual evaporation rates range from 1000 mm along the south west coast between Cape Leeuwin and Albany, to 2800 mm at Kalgoorlie and Mullewa. Evaporation rates steadily increase further inland from the coast (Figure 2). The average annual evaporation rate for Perth is 1800 mm.

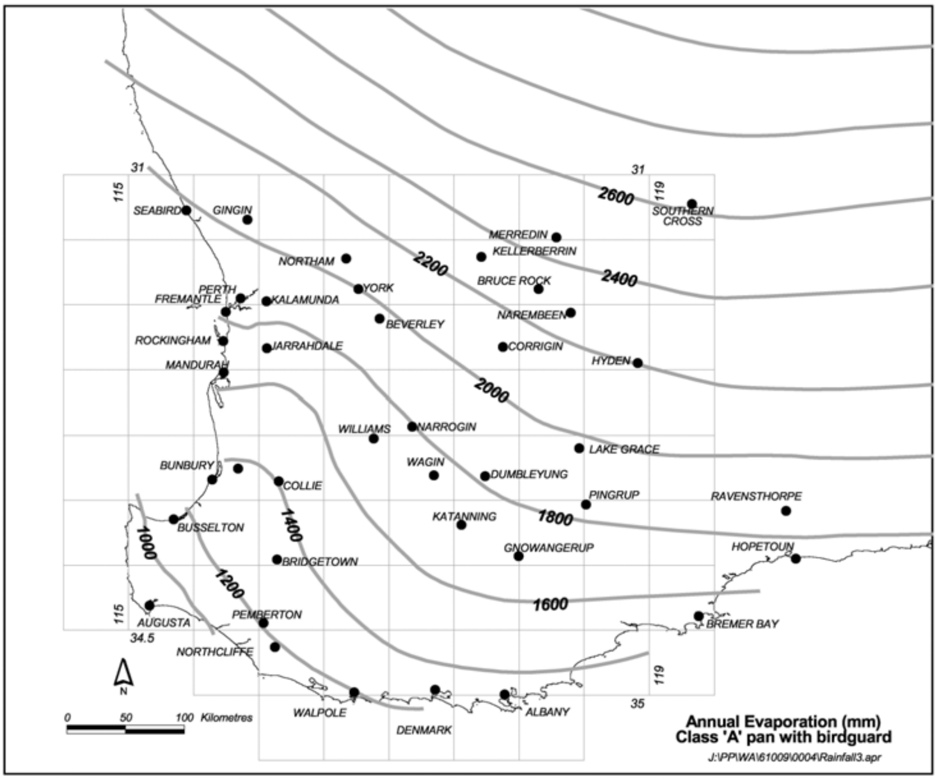

Figure 2. Mean annual evaporation isopleths. See the Appendix for an explanation of how evaporation should be used.

[4] *Numbers accurate for October 2002.*

The annual evaporation rates are higher than the annual rainfall rates throughout the south west region of Western Australia, with the exception of a small area in the extreme south west corner (Augusta to Margaret River). In summer this means that moisture levels in the soil are depleted and open water bodies, such as lakes and dams, lose a lot of water. However, during winter months, rainfall generally exceeds evaporation, allowing seasonal flows in creeks and rivers. Overall, however, more water is lost to evaporation than is received from rainfall.

2.1.2 Rainfall variation

Rainfall variation occurs both spatially (over an area) and temporally (through time). In south west Western Australia rainfall declines with increasing distance from the coast (spatial variation). Rainfall varies from an annual average of 1400 mm on the south coast near Walpole down to less than 300 mm north-east of Merredin. Perth receives, on average, around 820 mm of rainfall per year. Figure 3 shows annual average rainfall over the south west.

Spatial differences in rainfall can significantly affect land forms and land use patterns. For example, the 'Meckering line', an imaginary line which marks a divide between the rejuvenated landforms to the west (incised valleys with meandering streams) and the ancient landforms in the east (broad flat valleys with local streams ending in terminal lakes), also marks a distinct difference in rainfall-runoff. The 'Meckering line' roughly follows the annual average rainfall isohyets of 400–450 mm (Figure 3) and east of the line, there is only sufficient rainfall to cause runoff once every three to five years.

Temporal variation can occur on an annual as well as seasonal basis, although annual variation is the most well known. From 1970-2002, the average annual rainfall in Perth was 743 mm and is significantly lower than the long term average rainfall from 1878–2002 of 824 mm. The maximum annual rainfall recorded in Perth was 1,312 mm in 1926. The minimum annual rainfall ever recorded for Perth was 496 mm in 1914. Figure 4 illustrates the annual rainfall since 1877. It highlights the marked reduction in rainfall since 1970 with very few high-rainfall years and only one year significantly over 900 mm.

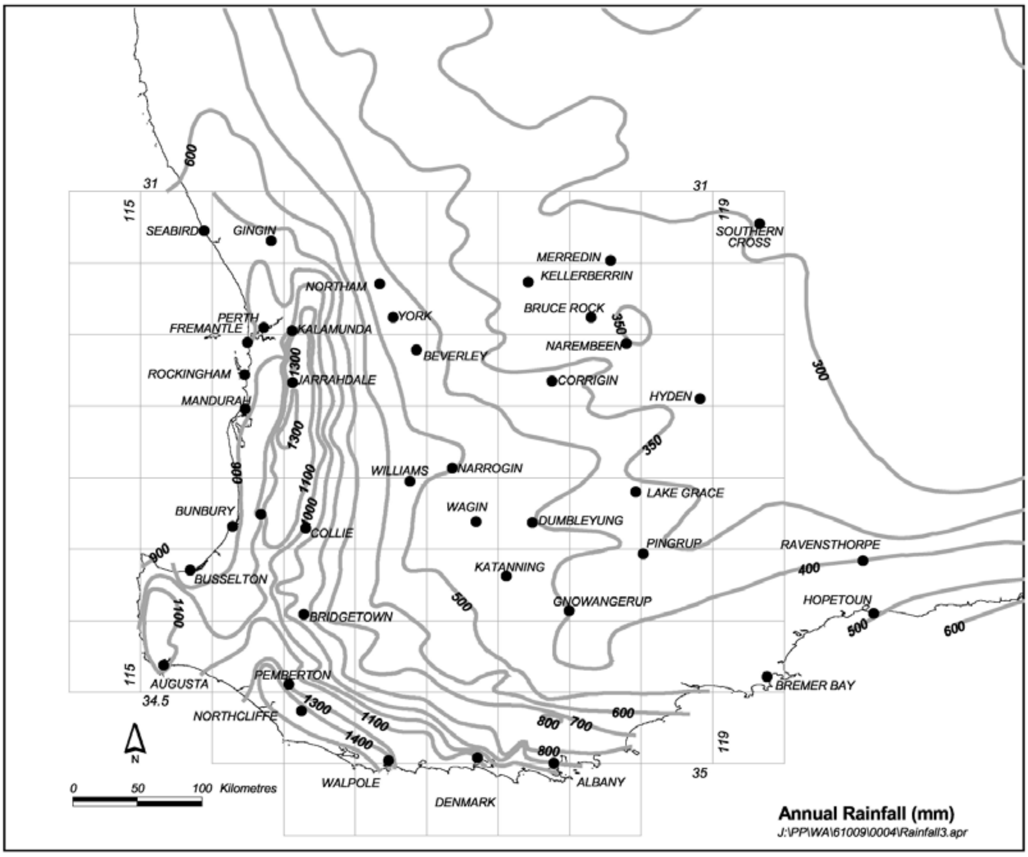

Figure 3. Mean annual rainfall isohyets.

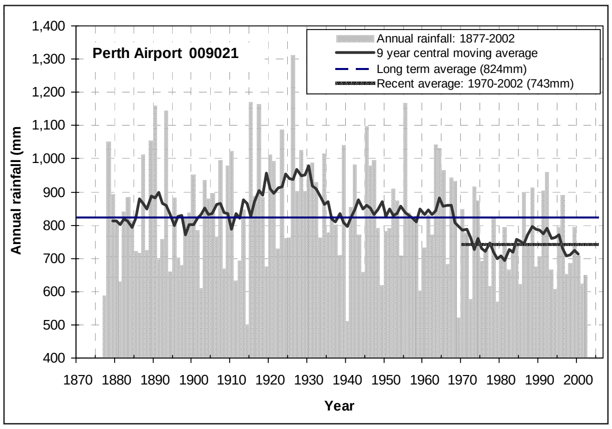

Figure 4. Perth annual rainfall (Source: Bureau of Meteorology).

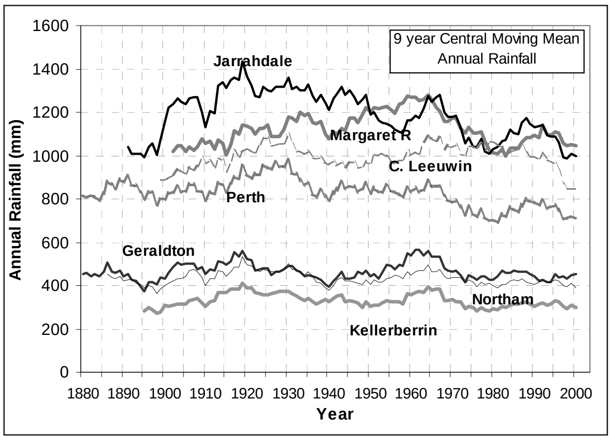

Figure 5. Moving average rainfall of seven south west sites (Source: Bureau of Meteorology).

This low rainfall pattern is also typical of most of the south west for the same period (Figure 5). Note the low rainfall in the late 1800s, higher averages around the 1920s, a dip in 1940, then higher rainfall in the 1960s and a dip around 1980. Cape Leeuwin seems to be unique in that the recent rainfall is higher than the long-term average, while 50 km north at Margaret River, there is a reduction in the recent average rainfall.

A long series of wetter-than-average or drier-than-average years can have significant implications for river and vegetation management. For instance, if there is a long series of wetter-than-average years, there will be an increase in groundwater levels and groundwater seepage, and increase in potential flood flows. Any river restoration works would have to allow for bigger flows. In a long series of drier-than-average years, pools of saline water can form in some areas, and less water will be available to vegetation, resulting in a decline. Any revegetation works would have to account for this, and may have to include a watering program.

Table 1 shows the long-term average rainfall at a series of sites and the average rainfall since 1970. While there has certainly been a reduction in rainfall over the last 30 years, it is still within the range of statistical variability and therefore cannot be referred to as climate change. Hence it is called ‘Climate Variability’. More information on climate variability and rainfall variation over time can be found at the Indian Ocean Climate Initiative website:<www.ioci.org.au>

Table 1. Key long-term rainfall sites

Site Name	Recorded period start	Long -Term (mm)	Recent Average (mm)	Difference
Jarrahdale	1889	1193	1098	-8.0 %
Margaret River	1900	1127	1091	-3.3 %
Cape Leeuwin	1898	1000	1018	+1.8 %
Greenbushes	1893	947	885	-6.5 %
Perth	1877	829	752	-9.2 %
Katanning	1891	484	468	-3.2 %
Geraldton	1877	466	445	-4.3 %
Northam	1884	436	420	-3.8 %
Kellerberrin	1883	331	308	-7.0 %

‘Recent average’ is the mean over the last 30 years (1970-2000). Long-term averages include data to 2000. (Source: Bureau of Meteorology)

2.1.3 Seasonal patterns

Winter

In the south west of WA, winter rain is generally associated with cold fronts that have been created as a result of Antarctic low pressure systems in the Southern Ocean that sweep across the south west corner of the State (Figures 6 and 7). When a cold front combines with moist tropical air, it can produce heavy rainfall and major winter storms.

In winter large high pressure cells, or anticyclones, are centred over Australia. The anticlockwise rotation of these systems blocks frontal systems and forces them to slide south-eastward. This produces rainfall in the south west and limits the amount of rainfall reaching inland areas.

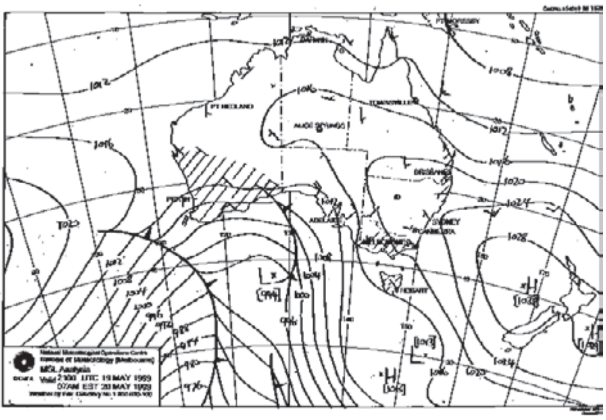

Figure 6. Typical frontal synoptic chart (Source: Bureau of Meteorology). In this system, most of the moisture in the eastern front is being drawn down from the tropics. The second front (still off the coast), holds little moisture (ie. rain clouds).

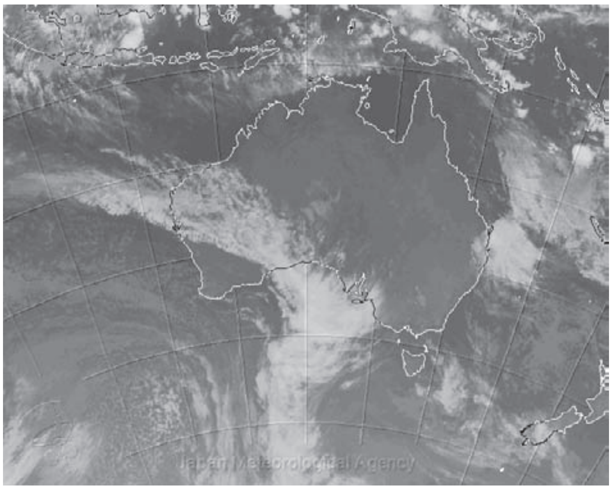

Figure 7. Typical frontal satellite photograph – same day as Figure 6 (Source: Bureau of Meteorology).

Summer

In summer large high pressure cells in the Great Australian Bight force frontal systems south, away from the coast, resulting in limited rainfall. Thunderstorms can occur throughout the year, although they occur more often in summer. Thunderstorms are caused by moist air moving upwards above freezing level creating a thickening of cloud of typically short duration. In the south west of WA, thunderstorms can be an important source of summer rainfall. In most cases, thunderstorms are very localised, causing intense rainfall on very small catchments and any flooding is also localised. However, there are exceptions. For example, on 21-22 January 2000, widespread thunderstorm activity on the upper Avon River basin caused flooding over thousands of square kilometres and was the biggest flood event in the region since 1963.

Other significant summer storms in the south west include decaying tropical cyclones. Cyclones originate in the warm water off the Pilbara and Kimberley Coasts, generally tracking in a south westerly direction before turning to the south-east, usually crossing the coastline somewhere between Wallal and Exmouth. However, cyclones are unpredictable and can occasionally move right down into the south west region of the State (Figure 8), causing widespread damage and flooding.

The remnants of cyclones have reached as far as the Southern Ocean, eg Cyclone Alby in April 1978 and Cyclone Steve in March 2000. They can also weaken to become tropical lows or rain-bearing depressions, such as Cyclone Bruno in January 1982 and Cyclone Elaine in March 1999.

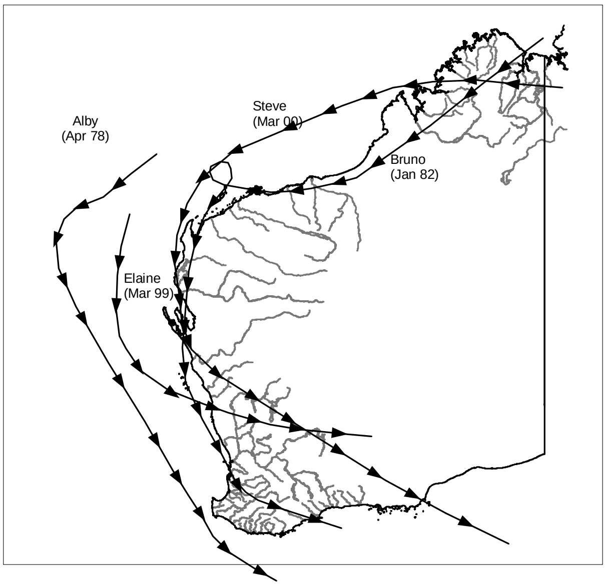

Figure 8. Selected cyclone tracks (Source: Bureau of Meteorology).

2.1.4 Drought

Given that much of Australia is arid, it could be suggested that a drought condition exists permanently over much of the continent, however, native flora and fauna are well adapted to these conditions. Australia is therefore termed ‘arid’ rather than ‘drought-stricken’.

Any year in which rainfall is significantly less than the average could be called a drought year. However, climatologists tend to define a drought year as one in which the annual rainfall is within the range of the driest 10 per cent of years for that location. Under normal conditions, this would tend to occur about one year in ten.

Of course, droughts become serious if more than one year in a row has below average rainfall, which has occurred in the south west during 2001 and 2002 with poor winter rainfall. Some towns received their lowest two-year total rainfalls since records began over 100 years ago, and in 2001 others had their lowest annual rainfall ever recorded.

The other issue with reduced rainfall is that it has a proportionally larger impact on runoff. Analysis of the relationship between catchment rainfall and subsequent runoff has shown that 10% less rainfall can result in 30–40% less runoff (see section 2.3).

2.2 The hydrologic balance

Our main area of interest as river managers, is what happens to rain once it falls. This is the key part of the water cycle, referred to here as the 'hydrologic balance' (Figure 9).

When rain falls, it can be intercepted by vegetation and structures such as dams, evaporate from the land surface or seep into the ground. Once in the ground, the water may be taken up by plants and transpired back into the atmosphere. It may also percolate through the soil until it joins a groundwater source or move laterally through the soil until it discharges into a watercourse.

Surface water runoff occurs when a large amount of rain falls, and there is too much water to infiltrate into the ground or evaporate. This may be in addition to water already in the stream as baseflow or groundwater discharge.

The interaction between rainfall, groundwater levels, baseflow seepage and runoff means low winter rainfall can lead to creeks drying up earlier in the spring or summer. And in dry years, the amount of 'rainfall' available to enter creeks may be too little to provide much, if any flow.

The final phase in the hydrologic balance is the flow of water down river channels to the ocean. Accumulation and evaporation processes still occur in this phase. Direct rainfall as well as merging tributaries may add to the volume of the stream. Water will be used by aquatic flora and fauna and evaporate into the atmosphere to cycle again.

The hydrologic cycle is the same throughout the world, although the rate at which water moves through the cycle and the path it takes differs depending on climatic conditions and land characteristics. A temperate region with a high rainfall, for example, would experience proportionally less transpiration and have more water in lakes and rivers than a drier environment.

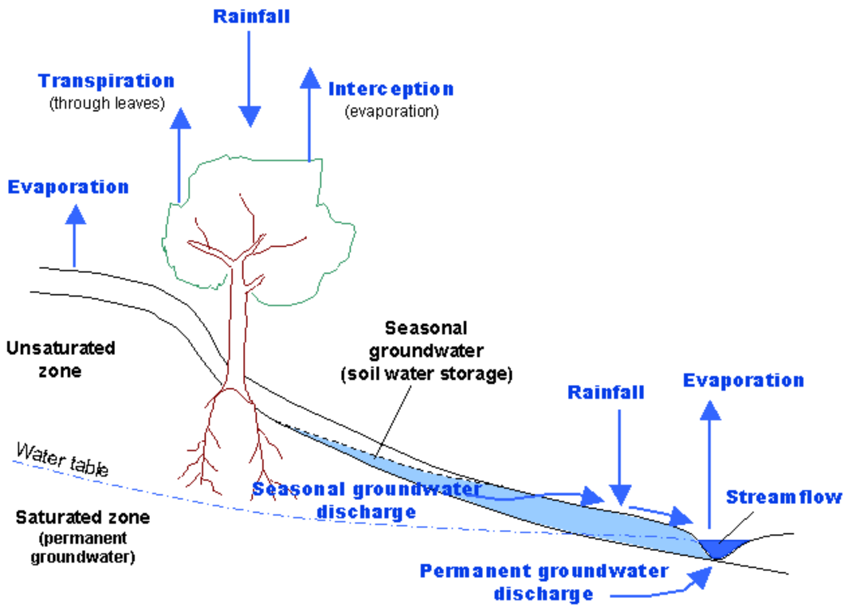

Figure 9. The land-based hydrologic balance.

2.2.1 Changes to the hydrologic balance

In the south west of Western Australia, the hydrologic balance has changed considerably over the past 170 years. Prior to European settlement, most of the south west of WA was vegetated, and rainfall tended to be intercepted and re-evaporated. Rain that did reach the ground tended to be taken up by the vegetation, used and then returned to the atmosphere through evapotranspiration. Very little percolated into the ground and there was little runoff. Due to high evaporation rates, most river systems in the region dried out in summer.[1]

As most catchments in the south west now have less vegetation due to clearing, less water is being taken up by vegetation and more water is entering the groundwater systems or flowing over land, both resulting in increased stream flows and causing a rise in groundwater levels. Around Perth, the rise in groundwater levels has been, to some extent, ‘controlled’ through abstraction by bores. However, in other parts of the south west the rise in groundwater levels due to clearing has caused much of the salinity and waterlogging currently being experienced, particularly in the wheatbelt region. Section 5 explores the hydrologic impacts of clearing in more detail.

2.3 Rainfall, runoff and flow

In the south west of WA, the spatial and temporal variations in rainfall, runoff and stream flow mean that the systems are not easily predictable. However, there are some basic factors that influence these systems, such as:

- how wet or dry a catchment is at the time rainfall is received – a saturated catchment will produce greater runoff;
- the amount of rainfall received – usually higher rainfall areas have higher runoff rates; and
- the size of a catchment – the larger the catchment the more rainfall it can capture.

Understanding these factors helps in the management of river systems.

The sponge analogy opposite shows the strong influence that catchment wetting can have on stream flow. This is illustrated by the seasonal variability of rainfall and runoff in the Wooroloo Brook catchment shown in Figure 10. Here most rainfall occurs in June and July, while generally most flow/runoff occurs during the months of July and August. Effectively, the catchment is ‘wetted-up’ early in winter and it takes proportionally more rainfall to cause runoff, while later in winter less rainfall is required to produce runoff. Also, the peak percentage of flow is higher than that for rainfall because much of the summer rainfall is lost to evaporation, so the proportion of summer rainfall as runoff is minimal.

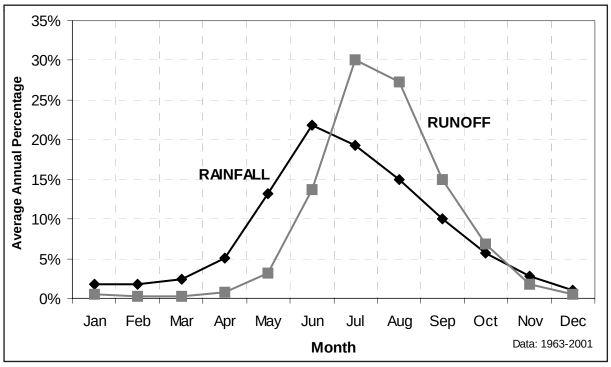

Figure 10. Monthly variation of flow and rainfall.

Flow and runoff

The volume of water that moves through river channels is called the ‘flow’. The flow in a channel, stream or river is simply the volume of water travelling down the channel over a period of time. Its volume is generally measured in either cubic metres (m^3) or megalitres (ML = 1,000,000 litres or 1,000 m^3) and the time period, added to produce daily flow (ML/d) or annual flow (ML/a). Instantaneous flow is generally expressed as cubic metres per second (m^3/s) or litres per second (L/s).

The term ‘runoff’ is used to compare the flows from different sized catchments. It is defined as a volume per unit catchment area (measured in millimetres), and represents the amount of water leaving the catchment.

The amount of water leaving the catchment can never be more than the amount entering it and will usually be only a small proportion - due to evaporation and infiltration. The runoff from any particular catchment will vary depending on the amount and timing of the rainfall.

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[1] *In one natural catchment east of Lake King, where there has been no clearing, and has an annual rainfall of 300 mm, there has been only one recorded flow event over the past 25 years.*

Sponge analogy

We can demonstrate how water runs off a catchment very simply by using a sponge to represent the catchment area. At the end of summer the catchment (sponge) would be dry. Add some rain (or water) and both the catchment and the sponge begin to get wet. With only a light rainfall or only some water, the catchment and the sponge are able to soak the moisture up and there is little or no runoff or seepage (Figure A).

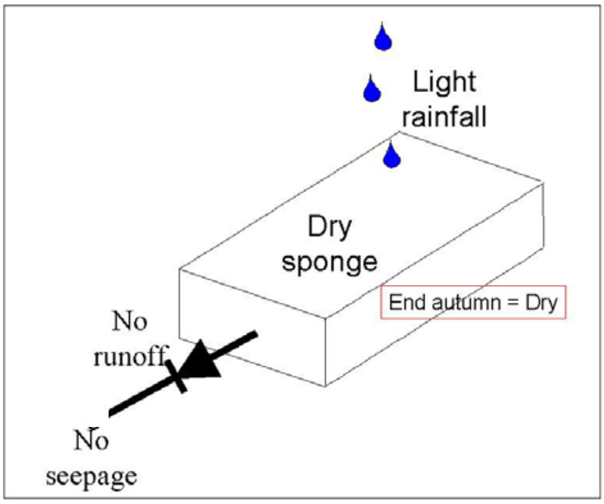

Figure A. Dry catchment, light rain.

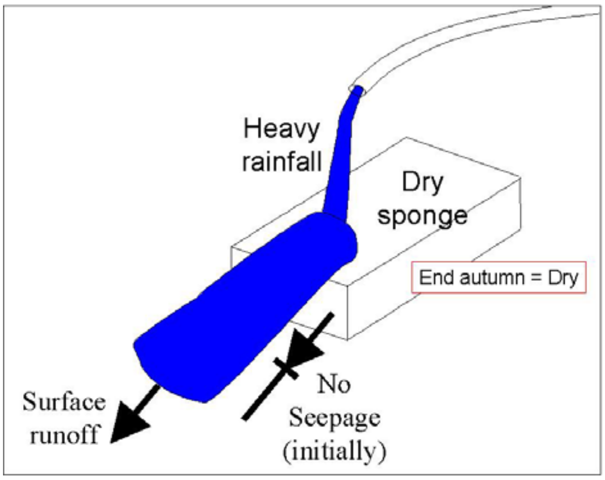

Figure B. Dry catchment, heavy rain.

Take the same catchment or sponge and give it a hard, heavy soaking (a heavy rainfall). While the catchment or sponge is dry, only so much of the water can infiltrate into the soil (or sponge). The remainder will run over the surface, causing runoff. Depending on the amount of water or rain, this can cause flooding (Figure B).

In winter, a catchment will normally be saturated due to frequent rain events. There will be seepage out of the catchment (or sponge) even with no rainfall or additional water added. However, with some rain or additional water, an overland flow will tend to occur (Figure C).

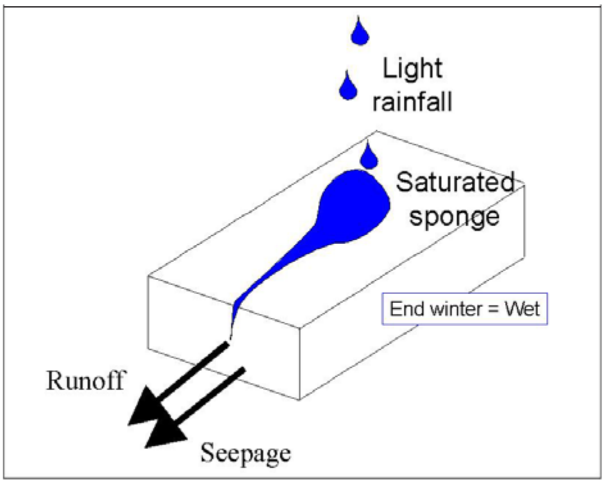

Figure C. Saturated catchment, light rain.

'Runoff' is usually understood to be an annual total depth, but may also be used to express the runoff in a particular event. Both flow and runoff vary on a seasonal basis and are dependent on rain events. In the south west of WA, many rivers dry up during summer months resulting in no flow at all.

We use runoff and the percentage of the annual rainfall that becomes runoff (called percent runoff) to compare discharge from different sized catchments. We can also compare what the typical runoff may be for catchments in a given region, where climatic conditions are similar.

For example, consider a catchment with an area of 10 km² that receives an average of 800 mm of rain per year. The flow of the river leaving the catchment has been measured at 1000 ML/a.

- The runoff (or runoff depth) is calculated as:

1000 ML/10 km² **= 100 mm**

- The percentage runoff is:

100 mm (runoff) / 800 mm (annual rainfall) **= 13%**

There is a relationship between the location of rainfall and the amount of runoff. Locations where the proportion of runoff is high correspond to locations of high rainfall. Conversely, it is the low rainfall areas of the eastern wheatbelt that have only small proportions of runoff – the majority of rainfall being evaporated or going into the groundwater.

In terms of annual runoff, the south west of WA is divided into four distinct areas:

Area	% Runoff
Coastal Plain (between Perth and Busselton)	25–40%
Forested areas (Serpentine to Denmark)	8–20%
Moderate rainfall agricultural areas (generally west of the Meckering line)	2–8%
East of Albany and the low rainfall, dryland areas of the wheatbelt	less than 2%

Therefore, the previous example catchment (with 800 mm pa and 13% runoff) would be found in the forested areas between Serpentine and Denmark, where the percentage runoff from catchments is generally between 8–20%.

Rainfall variability

Annual rainfall totals vary considerably over time and space. In Figure 11, the actual and average runoff and rainfalls are shown for Thompson Brook (south-east of Bunbury). Both rainfall and runoff varies from year to year with runoff varying by up to 50 per cent each year, but both curves closely follow each other.

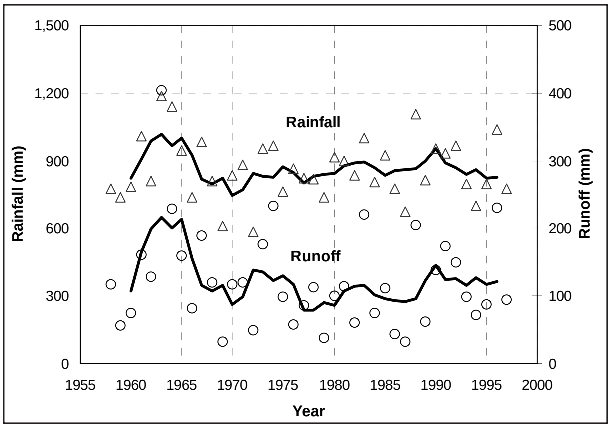

Figure 11. Rainfall and runoff comparison for Thompson Brook (using actual and central moving – 5 years - average data).

In areas of higher rainfall, the variability in the amount of runoff (or flow) from year to year is not as great as in lower rainfall area. In areas of low rainfall, a lower-than-average rainfall in any year may not be sufficient to produce a flow. Figure 12 shows the annual variation in total flow on the Lockhart River at Kwolyn Hill (north-west of Corrigin); where there is flow every year but in some years is negligible, and the actual lowest annual flow is in 2002 with 42 ML. It is also interesting to note that the two largest annual flows on record (1990 and 2000) are dominated by single rainfall events.

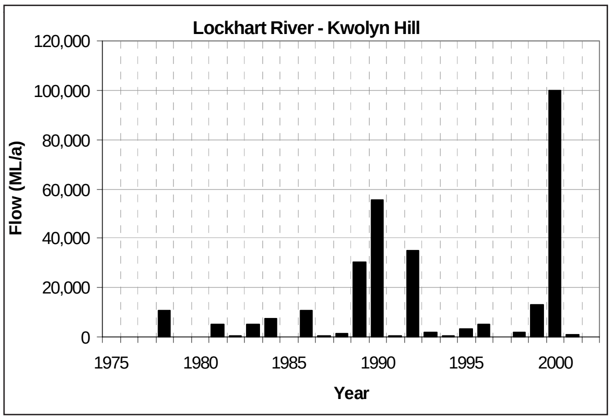

Figure 12. Variability of flow in low rainfall areas (average annual rainfall is 300 mm).

The impact of a reduction in rainfall is more than you might think. This is because runoff is always only a small proportion of total rainfall (a typical wheatbelt catchment may have 500 mm rainfall per year, but only 30 mm runoff), and a 10% reduction in rainfall will produce a much larger reduction in runoff. Consider the Dombakup Brook catchment near Northcliffe as an example. This catchment has experienced a 15% reduction in annual rainfall between 1960 and 2000. This equates to a 40% reduction in runoff for the same period, as shown in Figure 13.

2.4 Catchment area

Annual flow volume is also influenced by catchment area, with increasing catchment area resulting in increasing annual flow. As a catchment area increases, there is an increasing opportunity to capture rainfall, resulting in more water available to flow. Figure 14 illustrates this variation of annual flow with catchment area for a group of 180 gauging station sites in the south west of WA.

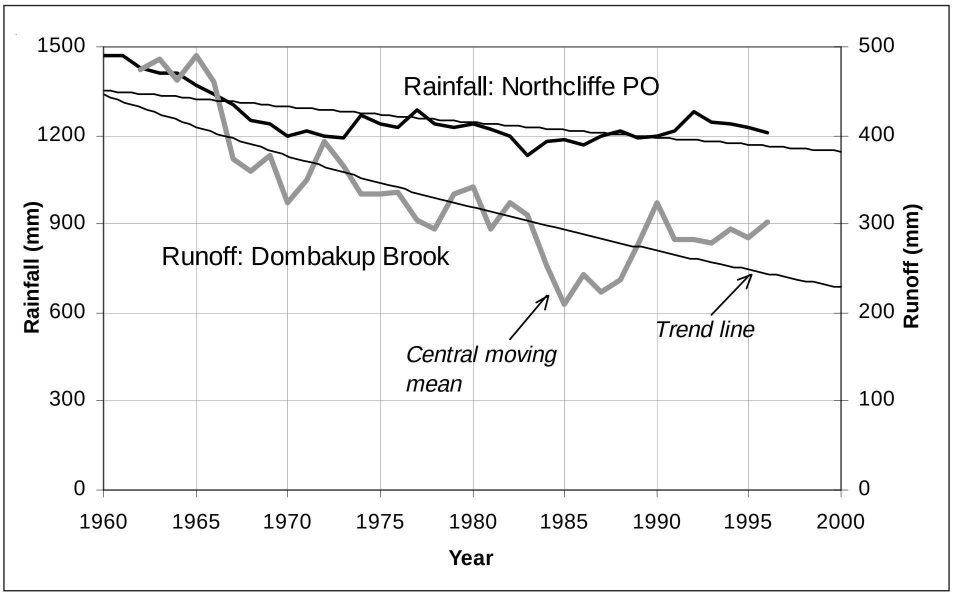

Figure 13. Relationship between rainfall and runoff (using central moving mean data and a trend-line).

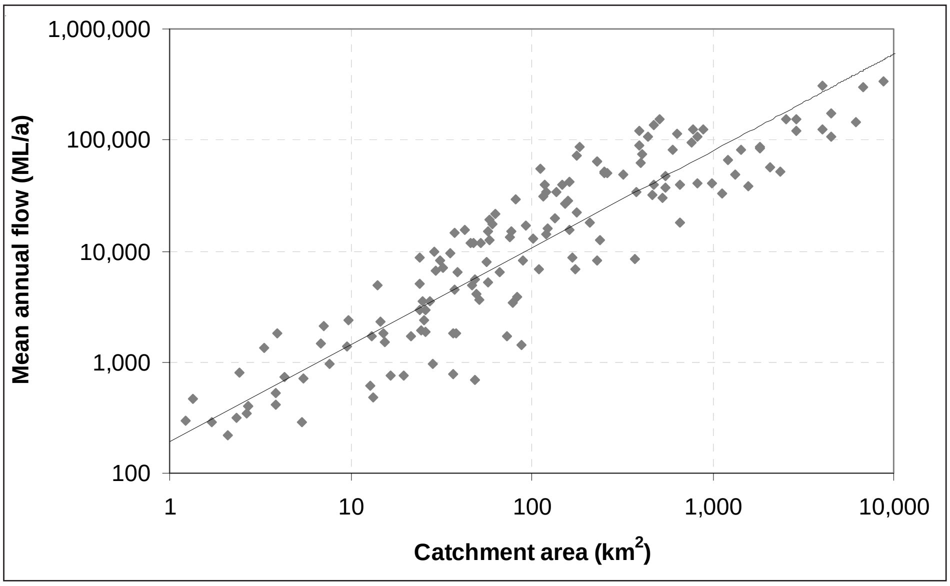

Figure 14. Mean annual flow for catchments of south west WA (NB: the data is represented on a logarithmic scale).

3. Streamflow characteristics

Under natural conditions, there tends to be a period of rainfall, followed by a time delay where water flows off the land into the small streams and then into the larger ones before reaching a peak at the catchment outlet (eg estuary). River flows can be measured over time and illustrated on a hydrograph (Figure 15). The hydrograph is made up of two components: the ‘quickflow’ which is the surface runoff part, and the ‘baseflow’ which is the component of the flow that seeps out of the groundwater. The amount of ‘quickflow’ is related to the losses in the system, but basically the more intense the rainfall or the wetter the catchment, the less the losses are likely to be, the greater the runoff and the higher the peak will be, ie the larger the event, the greater the proportion of ‘quickflow’.

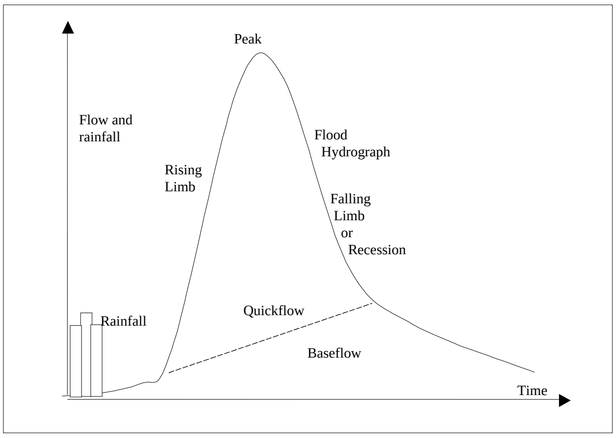

Figure 15. Standard flood hydrograph.

There are four stages during the life of a flood event:

1. The ‘rainfall’ stage that initiates the event in the first place.
2. The ‘rising limb’ that is often quite steep (eg. river level rising at 0.5 m/hr); however, it is rarely a wall of water unless there has been a ‘dam break’ or embankment failure. The rising limb carries with it most of the debris and sediment and causes most of the erosion.
3. The flood ‘peak’ is the highest flow rate (volume of water flowing past a point of the river per second) during a flood event and is also the highest river level. This is also the point at which the average velocity of the stream peaks.
4. The ‘recession’ stage is the falling limb of the event but in a natural stream is never as steep as the rising limb due to the storage in river reaches, floodplains and shallow groundwater. A single rainfall event may take months to recede.

3.1 Channel flow

There are many factors that can influence the type, form and velocity of the water flow in a river or stream. These include:

- rainfall, evaporation, surface runoff, groundwater discharge;
- cross-sectional geometry and bed slope of the channel, bed and side slope roughness;
- meanders, obstructions and changes in shape;
- hydraulic control structures and impoundments; and
- sediment transport and channel stability.

These factors need to be taken into account when designing river restoration works. More information on their measurement and analysis can be found in *RR 6 Fluvial geomorphology* (WRC 2000) and *RR 9 Stream channel analysis* (WRC 2001).

Low flows have a marginal but steady impact on 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 floodplains. However, most of the channel forming work is done by more intermediate bankfull flows.

3.2 Bankfull flow

While typical south west stream flows will vary throughout the year, from none or minimal during summer, to significant flows in mid-winter, the annual total is usually consistent - especially in the higher rainfall areas. However, a significant flow event occurs on average every year or two, where the water in a stream just overtops the channel banks – this is bankfull flow. These regular ‘floods’ or channel forming flows can change the shape of a channel over time.

When undertaking river surveys, the bankfull level can generally be easily distinguished by changes in vegetation. Vegetation below the bankfull level is usually only species that can survive regular submersion. Otherwise it may be the same vegetation as that which occurs higher up the bank, but it will be younger and will drown and/or be swept away by the current every year or two. In moderate rainfall areas, the bankfull flow is understood to have an average recurrence interval (ARI) of 1.5 years. In lower rainfall areas, bankfull flows occur less regularly and the ARI is higher. Section 4.2.1 explains ARI in more detail.

The design of river restoration works must be robust enough to at least handle a bankfull flow. Engineering for rarer, high flood flows will be more extensive and expensive. Bankfull flow therefore needs to be calculated for your river reach before undertaking river restoration works. It can be estimated using a river’s catchment area and flow records (Figure 16), and confirmed by conducting a river survey to measure the size and shape of the riverbed. *RR 9, Stream channel analysis* explains how to do this.

Figure 16 shows bankfull flows varying with catchment area and shows a similar relationship illustrated in Figure 14 of increased catchment area linked to increased flow.

A more accurate method for determining bankfull flow (or any peak type flow) is using nearby gauging station data and using the relative catchment area to calculate the flow. The formula to calculate the bankfull flow at an ungauged site is:

$$Q_1 = Qgs \times (A_1 / Ags)^{0.7}$$

where: Q_1 = bankfull flow at site of interest

Qgs = bankfull flow at gauging station

A_1 = catchment area of site of interest

Ags = catchment area at gauging station

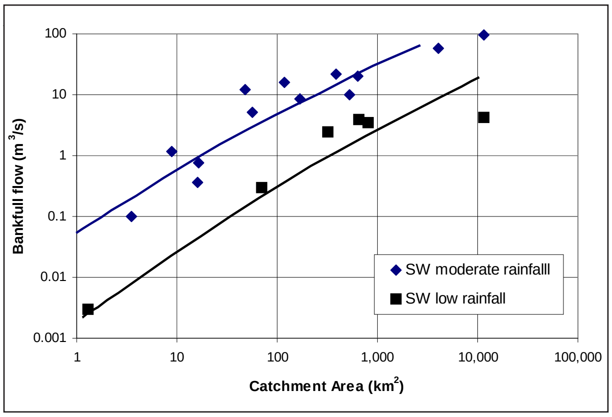

Figure 16. Relationship between catchment area and bankfull flows for the south west of WA.

3.3 Flow velocity

Velocity of flow affects the extent of erosion and the movement of debris downstream. Any object within the river (such as sediment, riffles, logs, vegetation and weirs) will be affected by the moving water. The larger the velocity, the larger the force. This is logical if the impact of velocity on channel formation is considered. If velocities are high, there is scour and erosion and the channel will enlarge itself. If velocities are low, then sedimentation will occur and the channel will shrink.

To simplistically demonstrate the general impact that velocity has on a channel, imagine a stream with a flat sandy bed. Add a heavy log (say 500 kg) sitting loose in the stream, directly across the flow path (Figure 17). Assuming it is partially waterlogged and has neutral buoyancy, at a flow velocity of 0.5 m/s the log is unlikely to move as this flow rate only exerts a force strong enough to move about 50 kg. At 1m/s the force of the water has increased, moving up to about 220 kg, so the log is likely to start moving (probably by rolling). With a velocity of 2 m/s, the water is strong enough to move up to about 850 kg and the log will flow downstream easily.

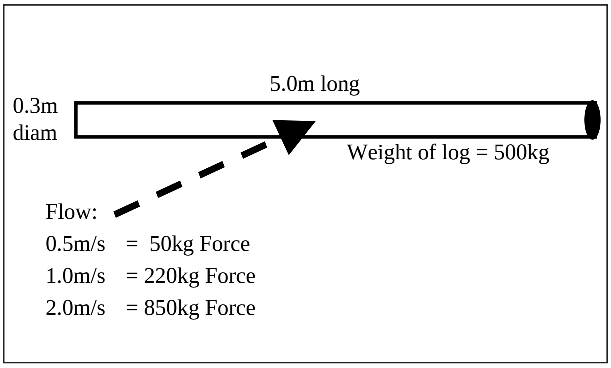

Figure 17. Force on a log in a flow.

The velocity of water flow is typically not constant across or along a section of a river or channel. For example, an obstruction such as a log would change the flow paths near the log and velocities would be slower as the water banks up behind it. Around the log, velocities would increase to 2–5 times the average stream velocity, before slowing down (or flowing backwards) in a turbulent area immediately downstream of the log. In fact, micro-areas of a channel or river behind obstructions such as logs, are important areas for aquatic life, which is why leaving woody debris in rivers is so important.

Flow velocities are measured as an average per cross section and tend to be similar for low, medium or high flows, irrespective of the catchment area and actual flow rate. To demonstrate this phenomenon, the flow velocities of three very different rivers, at low, medium and high flows, were analysed:

1. Blackwood River at Darradup (catchment area of 10,400 km²).
2. Collie River at James Crossing (catchment area of 169 km²).
3. Coolingutup Brook at Pesconeris Farm (catchment area 3.7 km²).

Figures 18a, b and c show the velocity versus flow for each river channel over a range of flows. Consider the similarities in velocity across all three locations, despite the wide range of catchment areas and the actual value of the flow:

- As flow increases, velocity increases.
- At low flow, velocities are about 0.2 m/s.
- At high flows, velocities can rise to over 1m/s and to greater than 1.4 m/s.

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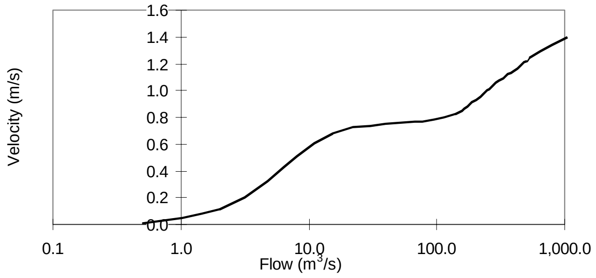

Figure 18a. Flow velocities for the Blackwood River at Darradup (catchment area of 10,400 km²).

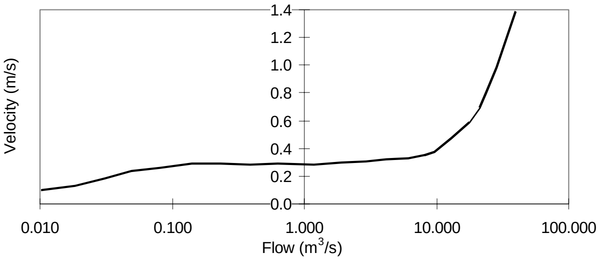

Figure 18b. Flow velocities for the Collie River East at James Crossing (catchment area of 169 km²).

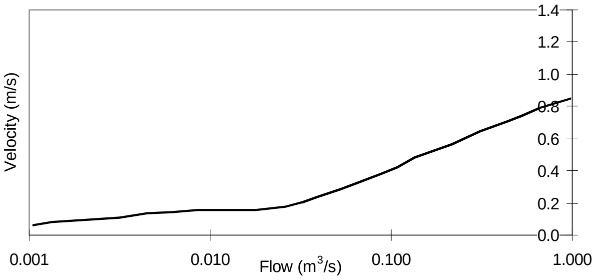

Figure 18c. Flow velocities for Coolingutup Brook at Pesconeris Farm (catchment area of 3.7 km²).

3.4 Sediment in streams

Rivers can move sediment of a variety of sizes, from clay size particles to large boulders. Boulders as large as one metre in diameter can sometimes be moved if the velocity of the water is sufficiently high. The faster the velocity of the water, the larger the particle size that can be moved. This is why the beds of fast-moving shallow streams are relatively clear of sediment, often with only large rocks or boulders, while those in slower moving, flat reaches have more sediment. This concept is illustrated in Figure 19.

Sediment is defined as anything carried by the stream other than water. It can be divided into three categories according to its size:

1. Dissolved particles (too small to be seen), tend to stay in the flow and move downstream as far as the water travels. These particles are so small that they mostly consist of dissolved salts.
2. Sediment can also be ‘suspended’, with material varying in size from fine clays to gravel. The material will continue to move downstream providing there is sufficient water velocity, and tends to drop to the riverbed as water flow slows.
3. Sediment that is too heavy to be ‘suspended’ in the water may also roll and/or jump along the channel bed. This is known as ‘bed load’.

When a stream is slow moving (when it is in low flow), the movement of sediment is small with no bed load and usually no suspended load. The only sediment movement will be of dissolved particles.

There is a strong relationship between flow and suspended solids, which is shown in Figure 20 with the levels of suspended solids (< 0.063 mm) and flow for a particular event in June 1988 on the upper Warren River. However, the relationship between flow and suspended solids is highly variable. For instance, it is very poor for low flow conditions but will be very different for a large flow event occurring on a dry catchment (as in Figure 20), compared with the same flow on a wet catchment later in the winter.

During a flood event, the majority of the sediment is mobilised on the rising limb of the hydrograph, as in Figure 20. This is where topsoil is initially mobilised and banks are being ‘wetted-up’. It is also the time when there will be no backwater effect[2] in the river and so velocities will be the highest. In the Warren River example, the highest average velocity at this location would have been on the 26/06/1988 when the flow was 70–75 m³/s. After the flow hydrograph flattened out, the river rose further due to backwater effect.

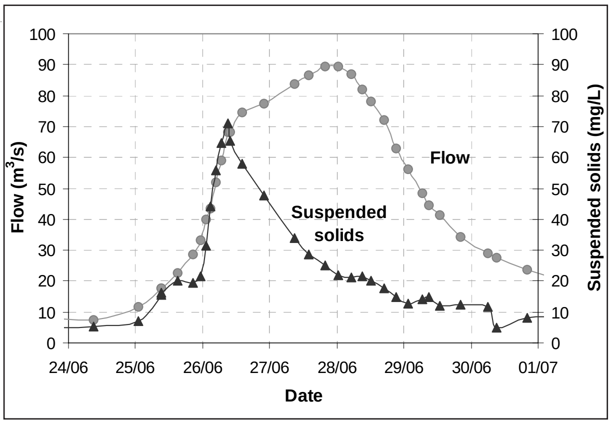

Figure 20. Sediment on Warren River 1988. Note: This suspended solids data is only that passing through a 0.063 mm sieve, commonly called ‘colloidal’ material.

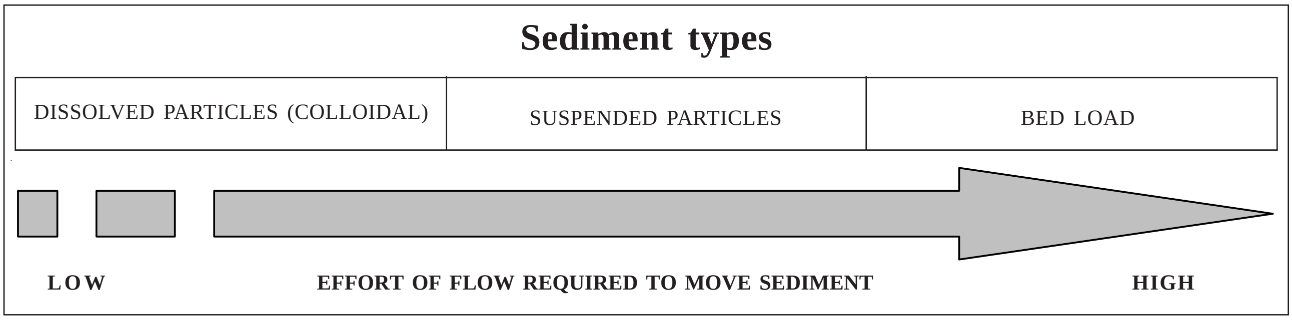

Figure 19. Simplified stylised relationship between water velocity and movement of sediment.

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[2] *Once water in a stream reaches a certain height, any structures associated with a stream, like a roadway crossing, will cause the water to constrict, resulting in an increase in water levels upstream of the structure. This is referred to as the backwater effect.*

4. Floods

Floods are natural events that are important in the formation of rivers and have some positive benefits, eg. dropping silt on flood plains to increase fertility of the soil. Flooding occurs where the rates of flow are more than the river channel can handle, and where water cannot be intercepted by vegetation or soak into the groundwater. The stream overflows its banks and begins to spill out onto the floodplain. Sometimes floods are slow moving and simply inundate large areas of a floodplain, however, in a confined river channel, they can be very fast moving causing major changes to the channel. Floods help shape the meanders, pools and riffles of a river channel and help maintain or control vegetation.

Large rainfall events, whether they originate from tropical events or from frontal activity, can cause flooding at any time of the year, but in the south west of WA they usually occur during the months of January to March or July to September. Figure 21 illustrates flood flow in the Gascoyne River. Floods often behave unpredictably, and the larger the flood, the more unpredictable it may be. Our understanding of the behaviour of floods has increased tremendously, but they can still be surprising!

Tropical summer events tend to be very intense and a significant amount of rain can fall in a short time. However, flood risk is lower in summer because catchments would generally be dry at this time resulting in water being infiltrated into the soil (whereas winter events tend to occur over wet catchments that may already be saturated). There are exceptions – cyclones such as Ex-Tropical Cyclone Bruno in January 1982 caused severe flood damage in the Collie, Blackwood and Pallinup catchments. Ex-tropical Cyclone Elaine, in March 1999, caused the highest flood levels on record in the Moore River.

Figure 21. Flood flow in Gascoyne River at the old Nine Mile Bridge – March 2000.

Significant streamflows will occur at any time of the year when steady rain falls over long periods, and may have the same effect as intense rainfall events of short duration.

4.1 Flood magnitude

The size of a flood (known as flood magnitude) will be dependent on the combination of catchment size, rainfall intensity, duration and distribution. The way in which a dry catchment can limit the potential flood risk has been explained in the sponge analogy (see section 2.3).

There are three variables that determine the size of a peak flow[3]:

1. **The rainfall in the catchment.** In general, the more the rainfall, the greater the peak. However, the size of the peak also depends on the distribution in space and time of rainfall across a catchment. For instance, the peak may be greater if 60% of the rainfall in an event fell in the lower part of the catchment than at the top of the catchment. Similarly, 60% of rain falling in the last half of the event might cause a larger peak than if 60% fell in the first half.

2. **The size and shape of the catchment.** In general, the larger the catchment area, the larger the flow (see section 2.4).

3. **Flow velocity.** The quicker the floodwaters run off a catchment, the larger the flood will be. However, the types of river channel in a catchment affect the velocity of flow. This can be simply explained by comparing two channel types:

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[3] *Maximum flow rate in a flood, measured in m^3/s.*

a) A meandering thickly wooded channel and floodplain would restrict the rate that water can travel down a river, so that while floodwaters stay in the system longer, the flow is spread out so that it cannot reach a very high peak downstream.

b) A channel with no obstructions would allow a flood to travel quickly and therefore peak in a relatively short period of time.

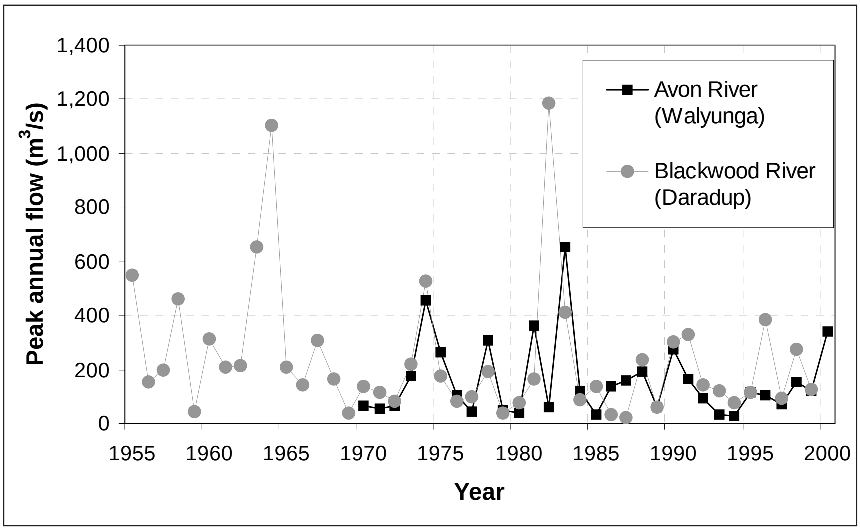


Figure 22. Floods on the Avon and Blackwood rivers.

Both channel types would have approximately the same total flow volume. However, type a) would take days to travel and only be a small peak, while type b) would be over in hours but have a very high peak with high velocities and potentially cause more damage.

4.2 Flood frequency

Floods occur in a random pattern that is statistically predictable. This means that while any particular year's peak flow is unpredictable, it is possible to predict that over a given period, a particular flow or river level is likely to be exceeded. Figure 22 shows an example of the annual variation of floods on the Avon River at Walyunga and the Blackwood River at Daradup (as peak annual flow rate).

The longer the measurement record, the more accurate the estimate of maximum flood will be. Generally, a record of five years is considered an absolute minimum, though it is preferable to have more than 20 years of record. It is possible to extend a short 5-year record by mathematically comparing it with the peaks at a long term site nearby.

Measurement may take the form of a continuously recorded stream gauging station or simply annual flood marks on the side of a building, tree or gauge board. Even a single flood mark of a known large event is useful in predicting the impacts of large floods.

The analysis process in its simplest form is to take the highest flow rate (or flood level) in each recorded year (even those of zero flow) and then rank the year from the highest to the lowest flow rate. For example, consider a series of annual peak flows on the Ludlow River at Ludlow from 1991–1998 (8 years), as shown in Table 2.

Table 2. Flow analysis

Annual flows						*Calculations – described in 4.2.1*	
Year	**Flow rate (m^3/s)**		**Sorted flow rate (m^3/s)**	**Year**	**Rank**	**Probability of not being exceeded**	**Average Recurrence Interval (yr)**
1991	19.1		67.8	1997	1	0.889	9.00
1992	14.3		49.7	1995	2	0.778	4.50
1993	13.0	Sort by flow	23.2	1996	3	0.667	3.00
1994	6.1	→	19.1	1991	4	0.556	2.25
1995	49.7		14.3	1992	5	0.444	1.80
1996	23.2		13.0	1993	6	0.333	1.50
1997	67.8		7.6	1998	7	0.222	1.29
1998	7.6		6.1	1994	8	0.111	1.13

The data in Table 2 can also be extrapolated, using calculations described below, to work out the probability of when a certain size flow will re-occur. This is called the ‘recurrence interval’ of a flood (see 4.2.1).

With more statistical detail, probability curves, such as those shown in Figure 23 for the upper Vasse River and lower Wilyabrup Brook, can be drawn. Probability calculations allow the size of a flood at a particular point to be estimated. It should be noted that floods cannot be predicted, but the likelihood of a flood level reaching a certain height over a certain period of time can be predicted. Also, knowing the relationship between flow and river level allows a similar analysis to be undertaken for flood level prediction.

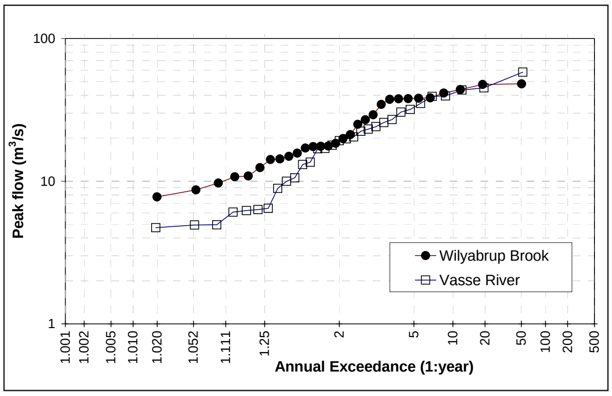


Figure 23. Probability curve for floods.

It is important to appreciate that flood flows, levels and velocities affect rivers and any river restoration activities that may be undertaken. For instance, any vegetation planted above the flood level should normally be safe from being washed away. However, remember that floods are unpredictable and extreme events can exceed the usual flood level.

4.2.1 Average recurrence interval

When floods are described, they are usually described as occurring every ‘x’ years (for example, a 20-year flood or a flood with a 20-year return period). This is called the *average recurrence interval* (ARI) and is defined as how often a flow, river height, or rainfall event is likely to be exceeded. For example, a flood with an average recurrence interval of 100 years, is one that would be expected to occur, on average, once in every 100 years. An ARI of 1 year indicates that this flow level would be exceeded in all years.

The ARI has sometimes been incorrectly understood to mean that one and only one event should occur every 100 years. In fact, the probability of the 100-year flood occurring twice in 100 years is over 60%. The ARI is really a simplified way of presenting a flood’s probability of occurrence.

The flow probability can be calculated in a series of steps, using the Rank (Table 2 sorted high to low), the probability of flow not being exceeded and the ARI. For example:

Step 1: Data ranked (eg Table 2)

Step 2: Calculation of the probability of peak flow in a single year not being exceeded is:

$$p = 1 - \frac{[Rank]}{(N+1)}$$

Where: *N* is the number of years of data.
[*Rank*] is the ranked number assigned a sorted list of all years.

For example, using the data from Table 2 for the year 1996:

$$p = 1 - \frac{[\ 3\ ]}{(8+1)} = 0.667$$

Step 3: Calculation of the Average Recurrence Interval.

$$T = \frac{1}{(1-p)}$$

Where: *T* is the ARI in years.
p is the probability of the flood not being exceeded (%).

For example, using the above calculation with a 66.7% probability of a flood not being exceeded:

$$T = \frac{1}{(1 - 0.667)} = \frac{1}{0.333} = 3 \text{ year ARI}$$

4.3 Major events

In recent times, one of the major flood events in the south west was the January 1982 flood caused by Ex-Tropical Cyclone Bruno. Figure 24 shows the rainfall spread across the south west by the tropical low. The rainfall caused major flooding in the Collie, Blackwood and Pallinup catchments. It should be noted that some of the worst flood damage occurred in

Nannup, which received only 52 mm of rainfall. This is because the Blackwood River catchment is so large, that when heavy rain fell in the upper catchment, the flow had a large area to source by the time it arrived many kilometres downstream to flood Nannup.

The resultant hydrograph from this rainfall on the Blackwood at Winnejup, just upstream of Bridgetown, is shown in Figure 25. This hydrograph and other information tells us that:

- The catchment area at this point of the river is 8,700 km^2. If square, this would be 95 km by 95 km. The catchment area is the area of land surface where rainfall could reasonably be expected to fall, runoff and flow to the specific point.
- The total river flow here during the event was 385,000 ML.
- The peak flow rate was 1,300 m^3/s, equal to an Olympic sized pool flowing past every second, and had a peak river level of 5.7 m which is the maximum depth of water at that point.

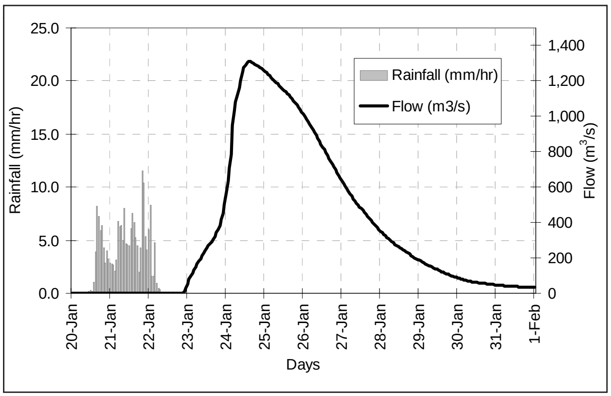


Figure 25. Blackwood River hydrograph upstream of Bridgetown – January 1982.

- The average rainfall over the catchment during the event was 200 mm.
- The average runoff over the catchment during the event was 44 mm (=385,000 ML / 8700 km^2), which is more than the average annual runoff of 32 mm.
- Hence the runoff was 22% of the catchment rainfall. This compares with the usual annual percentage runoff 6.5%.
- The river flowed strongly (greater than 1 m^3/s) for 8 days and did not stop before winter rains arrived.

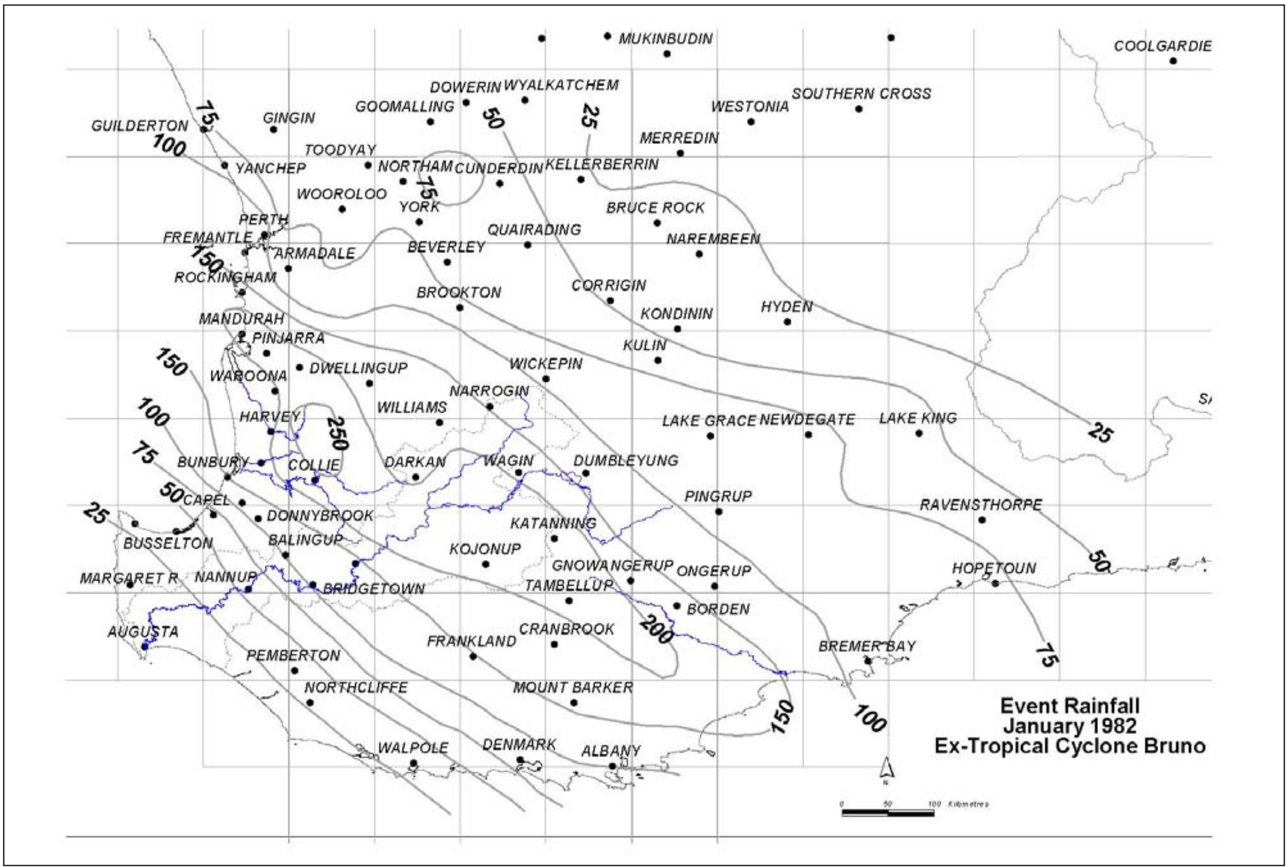


Figure 24. Catchment rainfall from Ex-Tropical Cyclone Bruno – January 1982 (numbered lines show the total amount of rainfall in mm received over two days).

5. Effects of clearing

There are few areas in the south west of WA that could still be considered to be in their natural state. Most catchments have been altered to some degree and the greatest change has been clearing of native vegetation. This in turn has affected factors such as runoff, salinity, erosion and sedimentation. The clearing of catchments is most dramatic across the broad flat valleys of the wheatbelt where few catchments have more than 20% native vegetation cover. Several shires, including York, have only around 3% of the original vegetation.

The hydrologic balance (section 2.2) shows that vegetation intercepts rainfall by using the water directly, soaking it up when it leaches into the root zone and returning it to the atmosphere through transpiration (or evapotranspiration). Native vegetation developed and flourished as it used all the available water entering the root zone, with little water entering the groundwater systems. Revegetation with annual species such as wheat and barley, or even pasture for grazing by livestock, does not have the same effect as native vegetation. Less moisture is taken up by annual species than native vegetation or deep-rooted perennial vegetation; and annual species provide little vegetative cover over the winter when most of the rain falls.

Clearing has altered the hydrologic balance throughout the agricultural region of the south west of WA, so that more rain now percolates into the soil, groundwater levels have risen and runoff (streamflow) has increased. The effect that clearing has had on increasing surface water runoff into waterways is of interest to river managers, because the channels must widen or deepen to adjust to the new amount of flow. This process often leads to an oversized channel where there is little vegetation to protect and support the banks. Deposition of sediment from the channel or through broad catchment erosion can cause the filling of river pools, smothering of aquatic habitat, reduction of channel capacity and channel avulsions (a new channel breaking out adjacent to the old channel).

When planning to restore channel stability, the current and possible future characteristics of the catchment must be considered. River restoration designs should be developed to restore stability to a waterway rather than attempt to replicate the original natural system. More information on channel stabilisation can be found in *RR 10 Stream stabilisation* (WRC 2001).

5.1 Changes in flow and runoff

Vegetation clearing has resulted in significant changes in streamflow characteristics. Analysis of data from streamflow gauging stations between Esperance and Geraldton shows a strong relationship between rainfall, runoff and catchment clearing. Runoff increases with annual rainfall, and it also increases with catchment clearing. This relationship is presented in Figure 26 and shows that the annual average runoff in streams of the south west of WA varies from 0 mm to more than 500 mm.

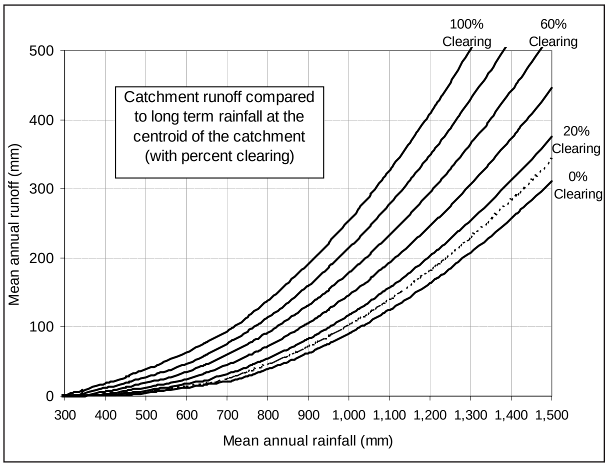


Figure 26. Mean annual relationship between rainfall, clearing and runoff. Data based on long term flows over period 1963-1996. (Note this is a generalised relationship accurate to +/- 20%)

Note that the relationship calculates the ‘average annual’ runoff in a catchment, while in individual years this may vary considerably. In low rainfall areas of less than 400 mm per annum, an uncleared catchment may only produce runoff in intense rainfall events.

The impact of clearing on runoff is shown in Figure 27, which summarises the results of analysis of a set of three small catchments near Munglinup where the annual rainfall is 440 mm. For the first seven years of the study, from 1975, the catchments remained undisturbed. Seven years later (in 1981/2), two of them

(Munglinup and Cascades) were significantly cleared (between 10 and 25%), while the third (Meleluka) remains uncleared. The increase in runoff is startling with the average runoff before clearing being approximately 1.0 mm/yr and after clearing 10-15 mm/yr. The impact of the clearing only took two years to be clearly seen in the streamflow runoff.

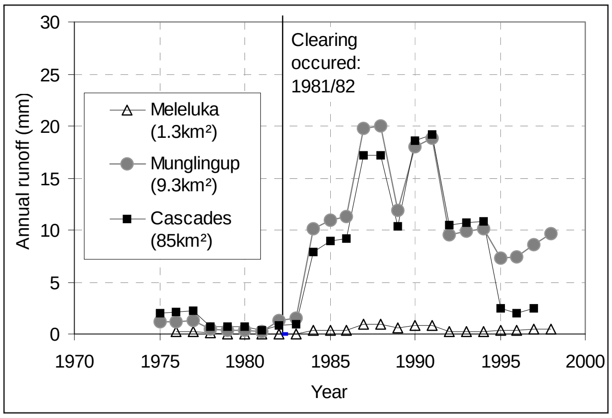


Figure 27. Comparison of the effect of clearing vs: no clearing on runoff in low rainfall catchments.

5.2 Salinity

Salinisation is a direct result of altered catchments and is currently the most significant environmental issue faced by governments and the community across Australia. At present, approximately 1.8 million hectares in the south west agricultural region is affected by salinity. Without intervention, about three million hectares will be affected by 2015, rising to six million hectares (or 30 per cent of the region) when a new groundwater balance is reached. This new groundwater balance may take anywhere between 15 to 80 years to be reached (State Salinity Council, 2000).

The Salinity Strategy (2000) asserts that significant changes to current land management practices are required across most of the 18 million hectares of cleared land within the south west agricultural region to achieve only a moderate level of control on salinity. Deep-rooted perennial shrubs and trees integrated into farming systems are seen as an important mechanism to utilise rainfall and prevent further rising of groundwater levels.

There are three distinct types of salinity.

1. Primary Salinity; is a natural occurring salinity sourced from rainwater that contains low levels of salt, but once on the ground is concentrated by evaporation. It is leached into the soil or runs off into terminal lakes.

2. Secondary Salinity (or dryland salinity); is caused by rising groundwater levels as a result of land clearing, bringing salt from deep groundwater to the surface.

3. Tertiary Salinity (or irrigation salinity); is caused by the accumulation of salt from irrigation water that has already been impacted by secondary salinity (this most often occurs on the coastal plain).

Secondary and tertiary salinity produce the same results – elevated levels of salinity in the soil as well as ground and surface waters, rising groundwater levels, increasing runoff, waterlogged land and salt scalds.

5.2.1 Salinity classifications

The extent to which dissolved salts are found in water is an important gauge as to the suitability of water for drinking, irrigation and industrial use. Total Dissolved Salt (TDS) concentrations increase as water moves over the land surface and through soils and aquifers. Reuse of water used for human consumption, industrial activities and farming further increases TDS as it is returned to surface waters. Eventually TDS may increase until the waters are no longer satisfactory to support wildlife habitats. Table 3 lists a classification for salinity levels in terms of TDS (over page).

5.2.2 Stream salinity

In natural watercourses, after the effects of interception and evapo-transpiration, the concentration of primary salinity is generally about 100–300 mg/L. When land has been cleared, secondary salinity changes the groundwater levels and groundwater seepage increases stream salinity (or salt concentration) over time until the system reaches a new equilibrium.

Two typical examples of changes in salinity levels over time are shown in Figures 28 and 29 – in the Denmark River catchment where significant revegetation has taken place since the late 1970s (Figure 28), and in the Frankland River catchment where very little revegetation has been undertaken (Figure 29). There is an increase, followed by a gradual lowering of salinity levels in the Denmark River catchment, illustrating the effect that revegetation can have. However, the impact of revegetation on salinity levels is slow.

Table 3. Recommended categories for salinity as measured by Total Dissolved Salts

Water quality *	TDS (mg/L)	Comment
Fresh	Less than 500 (<90 mS/m)	Regarded as good quality drinking water. Rainwater is < 25 mg/L.
Marginal	500 – 1,000 (90 – 200 mS/m)	Acceptable for most uses.
Drinking range	500 – 750	Acceptable as drinking water based on taste. Acceptable for most irrigation.The acceptable level for irrigation will with type of crop, type of soils and level of drainage.
Irrigation	500 – 1,000	Direct adverse biological effects become more apparent in river, stream and wetland ecosystems as salinity increases to 1,000 mg/L.
Brackish	1,000 – 3,000 (200–880 mS/m) 1,000 – 1,500 1,500 – 3,000	Acceptable for most stock and some irrigation. The acceptable level for irrigation will range with type of crop, type of soils, and level of drainage. Upper limit for human consumption. Limited irrigation and some livestock (pigs, poultry & dairy cattle). Most grasses and plants.
Saline	3,000 – 35,000 (880 – 5000 mS/m) 5,000 – 10,000 10,000 – 14,000	Limited farm use – unacceptable for most stock unless as an emergency supply. Hardy livestock, including beef and dry sheep. Some very salt tolerant plants.
Hypersaline	>35,000 (>5000 mS/m)	Industrial and mining use. Levels can be up to 300,000 mg/L.
Seawater	35,000	

* *Categories are defined based on the National Water Quality Management Strategy report series (ANZECC & ARMCANZ 2000). Note: 100 mS/m = 1mS/cm*

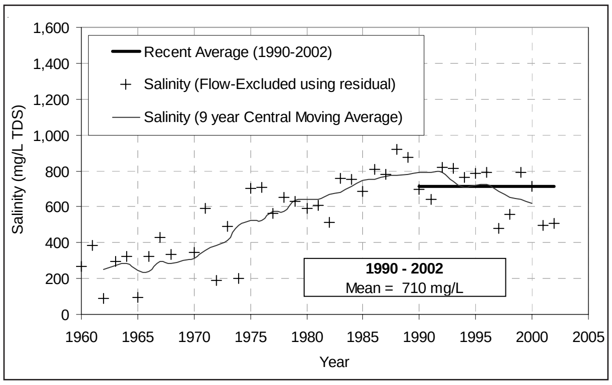


Figure 28. Denmark River - increasing salinity before a turnaround with revegetation. Smoothed curves use a 9-year central moving average.

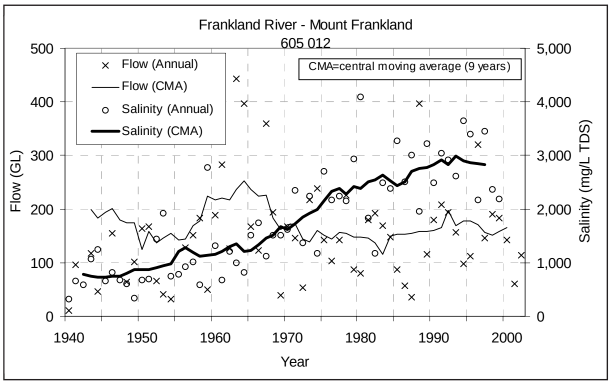


Figure 29. Frankland River - increasing salinity with little revegetation work.

Note that overall, there has been little change in flow rate but a steady rise in salinity. However, in years with low flow, salinity is high and in years of high flow the salinity is low. Note also the high variation in actual flow and salinity from year to year.

Levels of stream salinity vary from slightly fresh in cleared land in high rainfall areas, to highly saline in cleared areas of low rainfall. The relationship between annual rainfall and average stream salinity is shown in Figure 30. The relationship is most significant when a catchment has been more than 5% cleared because clearing of more than 5% changes the hydrologic balance of the catchment (Figure 9). Above 5%, there is little obvious relationship between the proportion of clearing and stream salinity, ie stream salinity is directly related to mean annual rainfall, not the degree of clearing.

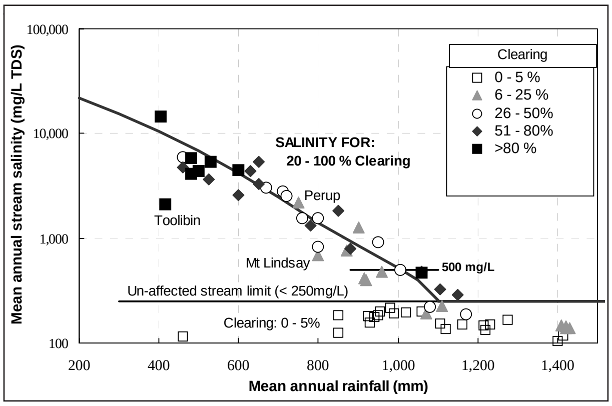


Figure 30. Salinity relationship with annual rainfall.

A stream in a fully cleared catchment with 400 mm annual rainfall is likely to have salinity levels of up to 20,000 mg/L. But as the annual rainfall increases, the stream salinity levels decrease so that at 1200 mm/yr, the average stream salinity is likely to be less than 500 mg/L (whether the catchment is cleared or not). Conversely, uncleared catchments in all rainfall bands are likely to have average stream salinity levels of between 100 and 200 mg/L.

It is not clear why the relationship outlined in Figure 30 occurs. However, it is likely to be a function of:

- increased evaporation with decreasing rainfall;
- a larger percentage of runoff with increasing rainfall; and
- a greater amount of surface water to provide dilution.

5.2.3 Annual variation in salinity levels and salt loads

On a much shorter time scale, there are significant and continuous variations of stream salinity levels with flow, as shown in Figure 31. It is driven by the differences in salinity between groundwater discharge and surface water runoff (as described in section 2.2, Figure 9). When groundwater dominates, salinity levels are high and when surface water dominates they are low. There is often a huge range of variation. For instance, on the same river at trickle flows, salinities can be well in excess of seawater; at normal flows salinities can be 'saline' (say 4000 mg/L); while at the peak of a major flood salinities may be fresh (ie. less than 500 mg/L).

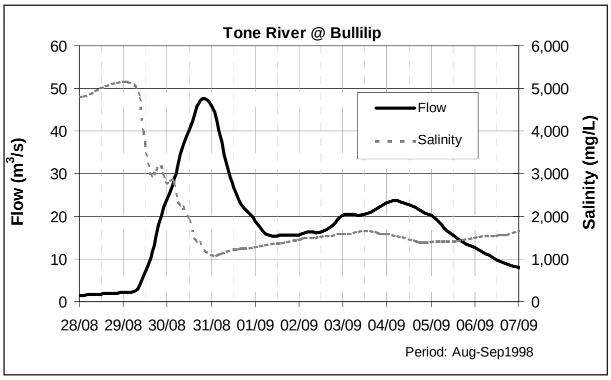
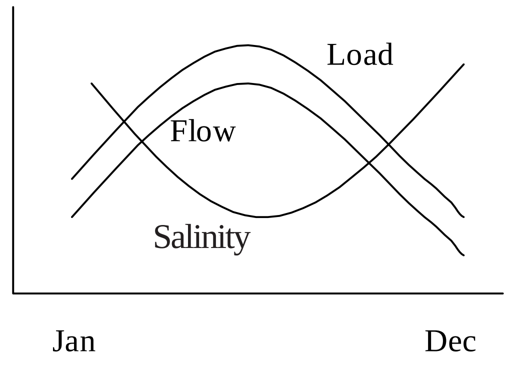


Figure 31. Short-term flow and salinity variation.

Stream salinity is usually the opposite, with the freshest flows occurring during winter and the saltiest during summer. However, the salt load (mass or weight of salt) generally follows the same shape as the flow shown in Figure 32, so that even when salinity is freshest with the higher flows of winter, the load (weight of salt flowing downstream) is the highest.



Flow, Q = (Volume / Time) (ML/a)

Salinity, C = (Weight / Volume) (mg/L = kg/ML)

Load, M = (Weight / Time) (kg/a)

Where: **M = C.Q**

Figure 32. Idealised annual variation of flow, salinity and salt load.

A typical case is the Collie East Branch River (Coolangatta), where the annual flow is 60,000 ML/a, the average salinity is 2,100 mg/L and the load 125 kt/a. The highest average monthly flow (August) is 17,000 ML at 1,400 mg/L salinity which is 24 kt of salt. The lowest monthly flow occurs in January when there is 86 ML of flow at 4,200 mg/L and 0.4 kt of salt.

This typical distribution works well for short streams or rivers in the same rainfall zone. However, in large rivers that traverse many rainfall zones, the result can be more complicated. For example, the Blackwood River originates in the low rainfall and highly salt-affected land of the wheatbelt, but flows through the forested high rainfall zone near Nannup. The annual flow at Hut Pool (near the mouth) is 700,000 ML, with an annual average salinity of 2,000 mg/L, and an average salt load of 1,400 kt.

At Hut Pool, the highest average monthly flow occurs in August at 220,000 ML, with a salinity of 1600 mg/L. The highest average salinity occurs in July at 2400 mg/L while the lowest, 1100 mg/L, is in April. The lowest average flow and load is in February with 2000 ML and 1.4 kt at 1400 mg/L. These unusual conditions are caused because most of the salt load comes from high in the catchment and this dries up in summer. In April, there is likely to be some early rainfall in the high rainfall areas causing relatively fresh runoff, but this is unlikely to occur in the upper catchment area. Hence this is an exception to the generalised relationship in Figure 32.

5.3 Erosion

Another effect of altering catchments through clearing is increased erosion. Vegetation binds soil particles together and creates resistance to flow by slowing stream velocity. Without the protection of vegetation, topsoil is often eroded by wind and water and transported to streams. Overland flow forms tiny streamlets, with higher velocities, and they rapidly cut into the topsoil, resulting in gully formation. From there, the increased runoff flows into larger creeks where unprotected river banks scour and collapse or waters in floodplains race down firebreaks and cause deep scouring.

In rural areas, livestock can also cause erosion even in uncleared catchments. Livestock, particularly cattle, graze and trample unprotected vegetation, often on the banks of streams where they gain access for water. This also increases sedimentation and turbidity of the water (see section 6).

Eroded sediment is initially transported along a stream before being deposited on riverbeds, banks and floodplains. It should be noted that streams have always eroded and deposited sediment, however, the extent of this has increased by many orders of magnitude since clearing began in Western Australia 170 years ago.

6. Water quality

Water quality is an important factor influencing river health. Activities in the catchment such as clearing and landuse practices can result in changes to the quality and quantity of water discharging into streams. We often see these changes expressed as a deterioration of water quality and stream stability. This can include algal blooms (resulting from excess nutrients), streambank erosion, sedimentation of river pools and changes in flow regimes. More subtle changes that are not easily seen are experienced by aquatic organisms.

The size of a waterway and its flow rate affect water quality. For example, discharges containing contaminants will have less effect on large fast flowing rivers than on small slow streams. It is particularly valuable to know if flows are at low, moderate or high level and if the level is rising or falling because the concentrations of nutrients, turbidity and contaminants tend to be higher when the stream level is rising than when it is falling (Waterwatch Australia 2002). Understanding the quality of water in a river enables river managers to develop a broader understanding of stream health.

This section provides a brief overview of aspects of water quality and how this influences river health. Particular focus is given to nutrients (nitrogen and phosphorus and resultant algal blooms), temperature and dissolved oxygen. A brief overview of the relevance of pH, biological oxygen demand, metals and pesticides is also covered. More information on water quality can be found in the Appendix and other publications such as *RR 7 Stream ecology* (WRC 2000), Waterwatch Australia (2002) and Pollington (2002).

6.1 Nutrients and plant productivity

Water transports a wide range of nutrients. Many of these are in very low levels and have relatively minor impacts on overall water quality. However, two nutrients, nitrogen and phosphorus, have quite dramatic impacts on water quality. Both of these are made of up soluble and particulate components. The main impact of changes in nutrient levels, usually an increase, is the generation of excessive plant growth. Most often in the south west this is seen as massive phytoplankton blooms that sometimes result in waterways being closed for recreational activities. In some estuaries though, the excessive plant growth is not by algae but by macrophytes or vascular aquatic plants.

Algal blooms also change water quality. Because plants (like algae) photosynthesize (trap energy from the sun and convert it to food) during the day, they release oxygen as a by-product of this process. This can result in oxygen levels increasing to well above the normal saturation level. At night, respiration becomes the dominant process, with both plants and animals using up oxygen in the water, so oxygen levels are often lowest first thing in the morning.

It would appear that algal blooms with their production of oxygen, are good for maintaining stream health. In small concentrations this is true, and small algal blooms did occur in estuaries prior to European settlement. The catastrophe occurs, however, when the millions of cells in these large blooms die. Oxygen is used up when the cells begin decomposing, and sudden crashes in oxygen levels often result. Lack of oxygen can cause massive fish and aquatic organism deaths.

Algae have long been used as indicators of water quality. Some noxious species of phytoplankton flourish in nutrient rich water causing offensive taste and odours, generating toxins that kill or affect aquatic organisms, and in some cases, being toxic to humans resulting in the waterway being closed to direct contact.

6.2 Understanding nutrients

6.2.1 Nitrogen

The nitrogen cycle is important to water quality for several reasons. The nitrification process causes dissolved oxygen in the water column and stream bed to be consumed. Ammonia and nitrate are also important nutrients for the growth of algae and other plants. Excessive nitrogen can lead to eutrophication, while the availability of nitrogen can frequently limit algal productivity.

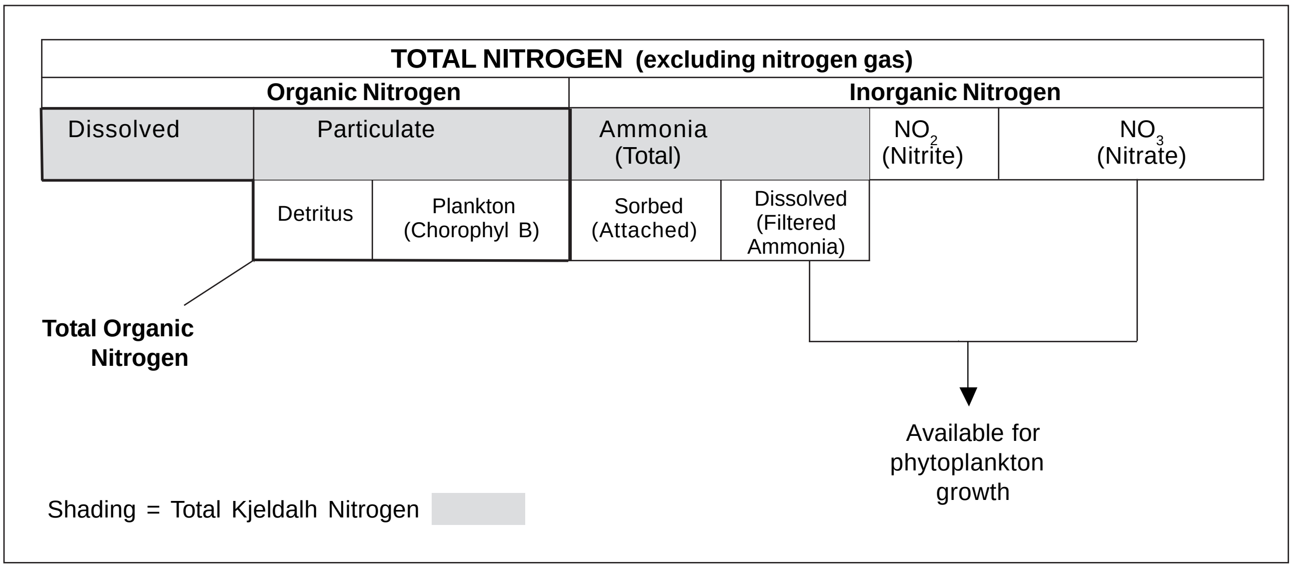


Figure 33. Nitrogen components within water (from McCutcheon et al *1992).*

Nitrogen may be present in water naturally at quite high levels, depending on the type of vegetation. The component make-up of nitrogen is shown in Figure 33. In WA, Total Nitrogen (TN) for natural streams will be below 1.0 mg/L, while in agricultural areas streams often have levels of more than 2.0 mg/L. Where there are large point sources of nitrogen, TN levels can be in excess of 6.0 mg/L.

6.2.2 Phosphorus

Phosphorus is an important component of organic matter and is vital for all organisms. In many rivers, phosphorus is the limiting nutrient that prevents additional productivity. The origin of phosphorus in streams is the mineralisation of phosphates from the soil and rocks, or drainage containing fertiliser or other industrial products. Phosphorus concentrations are normally reported in mg/L, especially when polluted waters are sampled.

Phosphorus in water is normally categorised as being either dissolved or particulate depending on whether it passes a 0.45 mm membrane filter (Figure 34). Dissolved phosphorus may therefore include a substantial colloidal component. Within the dissolved fraction, there are two major components, reactive (orthophosphate) and complex organic. Only the reactive component is available for phytoplankton growth. Particulate phosphorus includes phosphorus incorporated into mineral structures, adsorbed on to surfaces, primarily clays and incorporated into organic matter. Concentrations of suspended particulates vary greatly with land use and the erodibility of the catchment. They also increase dramatically with storm flows.

In WA, natural streams will have Total Phosphorus (TP) levels of less than 0.05 mg/L while in agricultural areas they may be in excess of 0.25 mg/L. Point source TP levels can be well in excess of 0.3 mg/L.

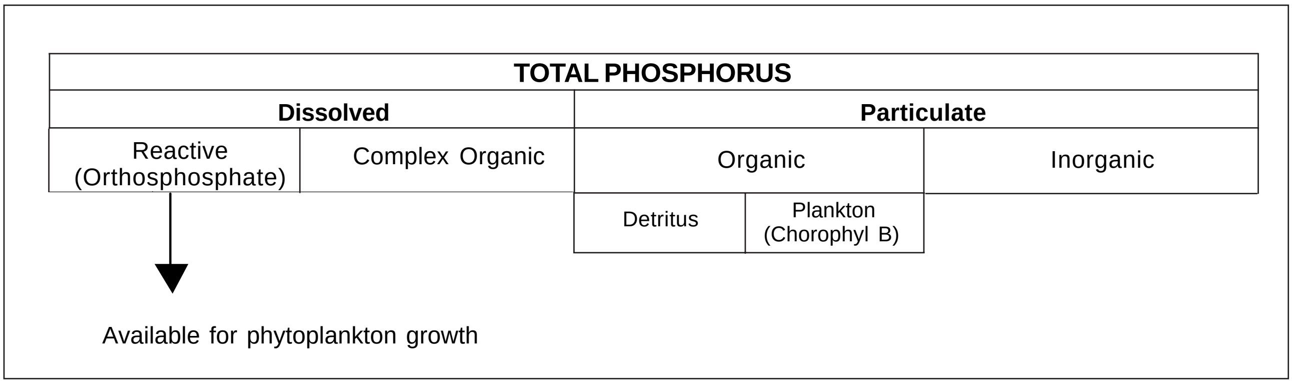


Figure 34. Phosphorus components within water (from McCutcheon et al *1992).*

6.3 Understanding dissolved oxygen, temperature, pH and turbidity

6.3.1 Dissolved oxygen

Dissolved oxygen (DO) content is a measure of the ability of surface waters to support aquatic life. Oxygen is poorly soluble in water and the oxygen saturation concentration is dependent on three basic parameters - temperature, atmospheric pressure and dissolved salts. Natural streams aerate themselves when they flow over riffles and through large woody debris. However, in altered catchments, clearing, river training (straightening and dredging of rivers) and sedimentation have significantly reduced this process.

Dissolved oxygen concentrations in rivers can vary markedly in space and time. A stream of fast moving water flowing over riffles will have much more dissolved oxygen than a stream in a flat landscape. Also, shallower flowing streams will usually have more dissolved oxygen than deeper, stiller waters, where the mixing of oxygen between water layers is poor (Waterwatch 2002). A river in summer will tend to use more oxygen than in winter, and hence have lower dissolved oxygen levels. In winter when water temperatures are less than 10^{o}C, dissolved oxygen levels may be up to 11 mg per litre. Dissolved oxygen levels at night are generally lower than during the day time. In addition, the annual regime of dissolved oxygen is typically inversely related to the annual cycle of water temperature, ie warm water, less oxygen.

Supersaturated conditions can occur due to aeration in highly turbulent waters such as in turbines and at spillways, and also on sunny days in waters experiencing algal blooms or with many aquatic plants, because of photosynthesis (photosynthesis increases the amount of dissolved oxygen around plants). In this supersaturated environment, the oxygen concentration in fishes’ blood rises. When the fish swim out into water that has less dissolved oxygen, bubbles of oxygen quickly form in their blood, harming the circulation (Waterwatch 2002). In contrast, low oxygen levels can also be lethal. Dissolved oxygen levels below 5 mg per litre are generally lethal to fish and in summer when water temperatures are about 25^{o}C, oxygen levels may be as low as 8 mg per litre, often making the summer pools a harsh refuge (Pen 1999).

6.3.2 Temperature

Temperature is important for its relationship with parameters such as conductivity, pH, and oxygen. For instance, salts are more soluble in warmer water, so temperature can affect the water’s salinity. However, temperature is also important in its own right. High temperatures generally increase the use of oxygen by aquatic organisms, leading to a rapid decline in oxygen levels in water. Also, many aquatic organisms have temperature thresholds (ie a temperature above or below which they die).

Water temperature is regulated by overhanging vegetation (trees and shrubs). Water temperatures in winter usually range from 5–15°C, and in summer they generally range from 15–25°C. The shading reduces water temperatures and can reduce the daily maximum by as much as 10^{o}C (Land and Water Australia 2002). Streams with little shading vegetation are usually significantly warmer (up to 40^{o}C) than those with shading. In summer, when river flow has ceased and only river pools are left, shading by large trees helps to maintain water temperatures and therefore aquatic organisms can continue to survive.

6.3.3 pH

pH is the simplest measure of acidity and is technically the concentration of hydrogen in water. A value of 7.0 is regarded as neutral, lower values as acidic, and higher values indicate alkaline waters. Many aquatic organisms are adapted to specific ranges of pH, generally between 6.5 and 8.0, and any changes can have serious implications such as stress or death to an organism (Waterwatch 2002). Most fish eggs will not hatch below a pH of about 5 (Pollington 2002).

In WA, low pH (acid) is usually associated with groundwater discharges of sulphate soils. The water reacts with oxygen forming a highly acidic solution that will dissolve any heavy metals in the soil and often causes high levels of iron, lead, magnesium and molybdenum. Most incidents of low pH have occurred along the coastal plain in swampy areas that have been disturbed, but more incidences are being recorded in the wheatbelt where soils are disturbed by drainage projects aimed at managing salinity.

Algal blooms can also increase pH of the water. The process of photosynthesis generates slightly alkaline byproducts which can increase the pH of water, particularly during a large phytoplankton bloom.

6.3.4 Turbidity

Turbidity is caused when fine suspended matter such as clay, silt, colloidal particles, plankton and other microscopic organisms are present in the water. High turbidity can result in a water sample having a muddy or milky appearance. Turbidity is a measure of the attenuation, or reduction in intensity, of an artificial light source by suspended sediment.

Turbidity is actually an optical effect that not only reflects the presence of suspended solids, but their fineness, colour and shape. Consequently, although there is usually a good relationship between turbidity and suspended solids, it is not a constant linear relationship and varies with location. There is, however, a very good relationship between turbidity and flow, similar to that between flow and suspended solids.

Increased turbidity silts up the stream bed habitat, making it unsuitable for some stream fauna, and it reduces the amount of light for plant growth. In addition, pollutants such as nitrogen, phosphorus, pesticides and metals attach to fine sediment particles and therefore an increase in turbidity will usually result in an increase in the levels of pollutants.

6.4 Other water quality parameters

6.4.1 Colour

Turbidity should not be confused with the natural appearance of water in south west streams. Water in many well-vegetated streams in the south west is naturally a dark tea colour. This is mainly due to the leaching of tannin from the leaves that drop into the water from the overhanging eucalypts and paperbarks. Eucalypts drop more leaves in summer, so by early winter, the stream water is dark brown and some pools and backwaters can become inky black. There is little growth of algae or aquatic plants in these waters as the dark colour and shade from the trees prevent light penetration (Pen 1999). Highly coloured waters are usually free of salinity issues.

Colour is usually used as one measure of the suitability of a waterbody for use as drinking water and is measured in Hazen units.

6.4.2 Biochemical oxygen demand

Biochemical oxygen demand (BOD) is the amount of oxygen consumed by microorganisms while stabilising or degrading carbonaceous and nitrogenous compounds. The BOD test is widely used as an indicator of the amount of industrial and municipal waste in the water and is an important test used in protecting aquatic life from oxygen deficiency. BOD is measured as the amount of dissolved oxygen consumed over a five-day period and is reported in mg/L. Unpolluted water would have a BOD of <5 mg/L. To put this in perspective, treated sewage has a BOD of between 20 and 30 mg/L (Reference:

www.huonvalley.tas.gov.au/healthyrivers waterquality/ parameters/bcdemand).

6.4.3 Microorganisms

Microorganisms are present in all surface waters. The significant microorganisms in water quality studies are viruses, bacteria, fungi, algae, and protozoa. Coliform bacteria are present in the intestines of all warm-blooded animals and are excreted with faeces. Their presence is an indicator that other pathogenic (disease causing) bacteria would also be present. The *E. coli* is generally accepted as a microbiological indicator of human contamination.

6.4.4 Metals and pesticides

Metals occur naturally in water, however, there are set levels in potable water that are acceptable for human consumption. Often activities that disturb the soil such as drainage or mining can cause metals to be exposed and they leach out into local streams and lakes. They can be of particular concern where coastal plain wetlands are disturbed or in discharge waters from some wheatbelt deep drains.

In intensive agricultural areas, streams often have trace levels of pesticides, however the concentration is highly variable depending on the type and breakdown processes involved.

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Glossary

Annual vegetation	Vegetation that is planted and cropped within one year.
Backwater effect	Once water in a stream reaches a certain depth, any structures associated with a stream, like a roadway crossing, will cause the water to constrict, resulting in an increase in water levels upstream of the structure. This is referred to as the backwater effect.
Bankfull flow	The flow rate at a point just before a stream is in flood and when the main channel is full. This event usually occurs once every 1-2 years.
Base flow	The part of the total flow in a stream derived from groundwater discharge.
Catchment	An area of land with a single outflow point. This is the same as a watershed. Also related is a basin, which is a defined catchment for a major river system.
Conductivity	A measure of the amount of current that passes through water. Closely related to salinity.
CV	Co-efficient of variation = Std Dev / Mean. Indicates how variable a data set is, where a value below 0.5 indicates little variation and a value greater than 1.5, high variation. It is usually used to assess annual flows.
Dam break	A flood caused by a dam or embankment failure. Usually at a local (rural) level when dams overtop; major dams are designed to cope with extreme events.
Discharge	See flow.
Evaporation	The depth of water that could potentially be lost to a body of water. Usually measured using a standard ‘Class A’ pan, filled with water and refilled daily with whatever has been lost to evaporation. The pan is covered by a birdguard, a mesh which stops birds bathing in the water and which will increase the measured evaporation (Figure 2) by 7%.
Extrapolated	Adding extra points to a ‘line of best fit’ that has been extended beyond known data, usually using theoretical analysis.
Flow	Streamflow in terms of m^3/a, m^3/d or ML/a. It may also be referred to as ‘discharge’. Sometimes means ‘flow rate’ or ‘discharge rate’ which is in terms of m^3/s.
Flood	Defined when a river rises high enough to leave the main channel and flow over its banks into the floodplain.
Grab sample	Manual water sample obtained in a bottle for the purpose of analysing its water quality. Usually taken in flowing water just below, but not touching the surface.
Hydrograph	Graph of river level or flow over time (eg. Figure 15).
Hydrology	The study of how water behaves on land, including both surface and groundwater.
In-situ	Direct and instantaneous measurement taken at a site.
Interpolated	Adding extra points to a ‘line of best fit’ between known points.
Isohyet	Line or contour of equal rainfall calculated over a period (eg. Figure 3).
Isopleth	Line or contour of equal evaporation (or other climate variable) calculated over a period (eg. Figure 2).

Mean	Same as average = sum of values / number of values.
Median	The middle value in a ranked series of values. It is often a better indicator of ‘normal’ flow than the mean in highly variable series.
Peak	Maximum level, flow rate, concentration or load during an event.
Perennial vegetation	Permanent vegetation that does not have a period of dormancy.
Pluviograph	A rain gauge that records in 0.2 mm increments, effectively making it a continuous recorder. Usually linked to a logger to record the information automatically and is sometimes telemetered.
Precipitation	Usually rainfall in WA, but also encompasses hail, sleet and snow.
Pump sample	Automatic sample obtained in a bottle for the purpose of analysing its water quality.
Quickflow	The part of the total flow in a stream derived from surface water runoff.
Rank	1) to sort a series of data from maximum to minimum; or 2) the integer order number of a particular sorted item.
Rating curve	A conversion curve. Often between river level and flow (as stage-discharge), but also used between: reservoir level – outflow; lake level – volume; conductivity – TDS.
Rising limb	Part of a hydrograph where the water level of flow is rising.
River level	Water level of a stream where the base datum for no flow is 0.00 m.
Riverine pool	A natural pool within a stream, which is usually much longer than it is wide. Many river pools are permanent.
Recession	Part of the hydrograph where the water level or flow is falling.
Runoff (mm)	Streamflow leaving a catchment expressed as a depth per catchment area: Runoff (mm) = flow (ML/a) / area (km^2).
Runoff (%)	Runoff (%) = runoff / rainfall.
Salinity	The concentration of salt within a stream, usually expressed as TDSalts in mg/L. Also used for expressing the whole salinisation issue.
Salt load	The unit weight of salt within a stream (usually in t/a or equivalent units).
Sediment	Anything other than water, carried by the stream. Includes dissolved solids, suspended solids and bed load.
Stage level	Water level of a stream, pool or lake where the base datum for no flow is approximately 10.00 m.
Stream	Generic name for a natural or constructed river, creek or brook. Does not include drains or lakes, but will include riverine pools.
Stream salinity	Same as salt concentration (in mg/L). Also can be expressed as a conductivity (mS/m).
Suspended solids	Particles of earth within the water in a stream. Can be course sand, fine clay or colloidal.
Transpiration	Evaporation of water from a plant through the leaves.
TDS (TDSalts)	Salinity as Total Dissolved Salts.
TDSolids	Total Dissolved Solids. Is TDS plus the small amount of carbon-based components.

Abbreviations

a	annum (ie. year)
ARI	Average Recurrence Interval (year)
BOD	Biochemical oxygen demand
BoM	Bureau of Meteorology
$CaCO_3$	Calcium Carbonate
CSIRO	Commonwealth Science Industrial Research Organisation
°C	degrees Celsius
DO	Dissolved Oxygen
DoE	Department of Environment
GL	gigalitre (1 000 000 000 litre or 1 000 000 m^3)
ha	hectare
hr	hour
kg	kilogram
kL	kilolitre (1 000 Litre or 1 cubic metre)
km^2	square kilometre (unit of area)
kt	Kilotonne
L	litre (0.001 cubic metre)
mm	millimetre (0.001 metre)
m^3	cubic metre (unit of volume)
m/s	metres per second (unit of velocity)
m^3/s	cubic metre per second (flow rate)
ML	megalitre (1 000 000 litre or 1 000 m^3)
ML/d	megalitres of flow per day
mg	milligram
mS/m	milli-Seimon per metre
mg	microgram (10^{-6} gram)
NTU	nephelometric turbidity unit
PVC	plastic pipe (poly vinyl chloride)
s	second
t	tonne
TDS	Total Dissolved Salts (mg/L)
TSS	Total Suspended Solids (mg/L)
WA	Western Australia
WRC	Water and Rivers Commission

Appendix

Brief overview of aspects of hydrologic measurement in Western Australia

The first stream gauging in Western Australia began in 1897 on the Canning and Helena Rivers during the planning for the Goldfields water supply scheme, however only limited measurements were undertaken during the early part of the 20th century. Serious data collection in the south west of WA began in about 1940 with 22 gauging stations in operation from the Denmark River in the south, to the Avon River in the north. Since then there have been many improvements to the coverage and the technology used and data collection now covers the coastal drainage divisions from Esperance to Kununurra.

Stream flow information is collected by the Department of Environment and other organisations at many sites throughout WA. This information is collected to assess:

- flood warning and floodplain management;
- allocation and licensing water use;
- regional assessment and water resource planning;
- climate variability;
- stream salinity and the impact of drainage and remediation assessment; and
- river restoration design requirements.

The number[4] of operating stations of various types run by the Department of Environment throughout the State are:

- Streamflow (level)	290
- Rainfall (pluviograph)	180
- Evaporation	0
- Climate	1
- Conductivity and temperature	95
- Turbidity	3
- pH	1
- WQ sampling sites (regular)	125

Details of DoE measurement data can be viewed at www.environment.wa.gov.au.

In addition to these, there are some gauging stations run by the Water Corporation that are mostly located on regulated (controlled/dams) rivers and drains, and by other agencies including the Department of Agriculture and CSIRO. The Bureau of Meteorology collects rainfall data throughout the State and has approximately 1050 daily and 180 pluviograph (continuous rainfall) sites. For more information see <www.bom.gov.au/weather/wa>.

Measurement of river level and flow

Continuous measurement of flow is really a continuous measurement of river level with a flow calculation. Figure 35 shows a typical gauging station recording river level. The water in the floatwell (similar to a street drainage manhole) is connected to the river by a set of PVC pipes that balance the water levels so that they are the same inside and out, except that any surges or waves are smoothed out. A float on a weighted pulley rises and falls with the water level and a ‘shaft encoder’ (or analog to digital converter) connected to the pulley picks up changes in water level which are stored on a logger.

One third of stream gauge sites in WA are telemetered and those sites are ‘polled’ (or communicated with) at set times (normally before 7am each day and more often during moderate to high rainfall events) by a computer in the Department of Environment office in Perth. The system uses the telephone network to download all the river level data (and water quality data) collected on the logger since the last poll. This data is processed and placed on the Internet (look on the DoE home page <www.environment.wa.gov.au> under ‘Flood Warning’).

There are 121-telemetered gauging stations in WA, designed mainly to monitor the progress of floods along significant rivers. During actual flood events, the data is updated more regularly, depending on the size of the river (eg. six-hourly for the Fitzroy River; hourly for the Vasse River). While these stations mainly show river levels, there are some stations (eg. Blackwood River at Hut Pool, 609019) which show more detailed information (daily flows, stream salinity and loads) and there is calculated monthly flows for all DoE gauging stations over their recorded period.

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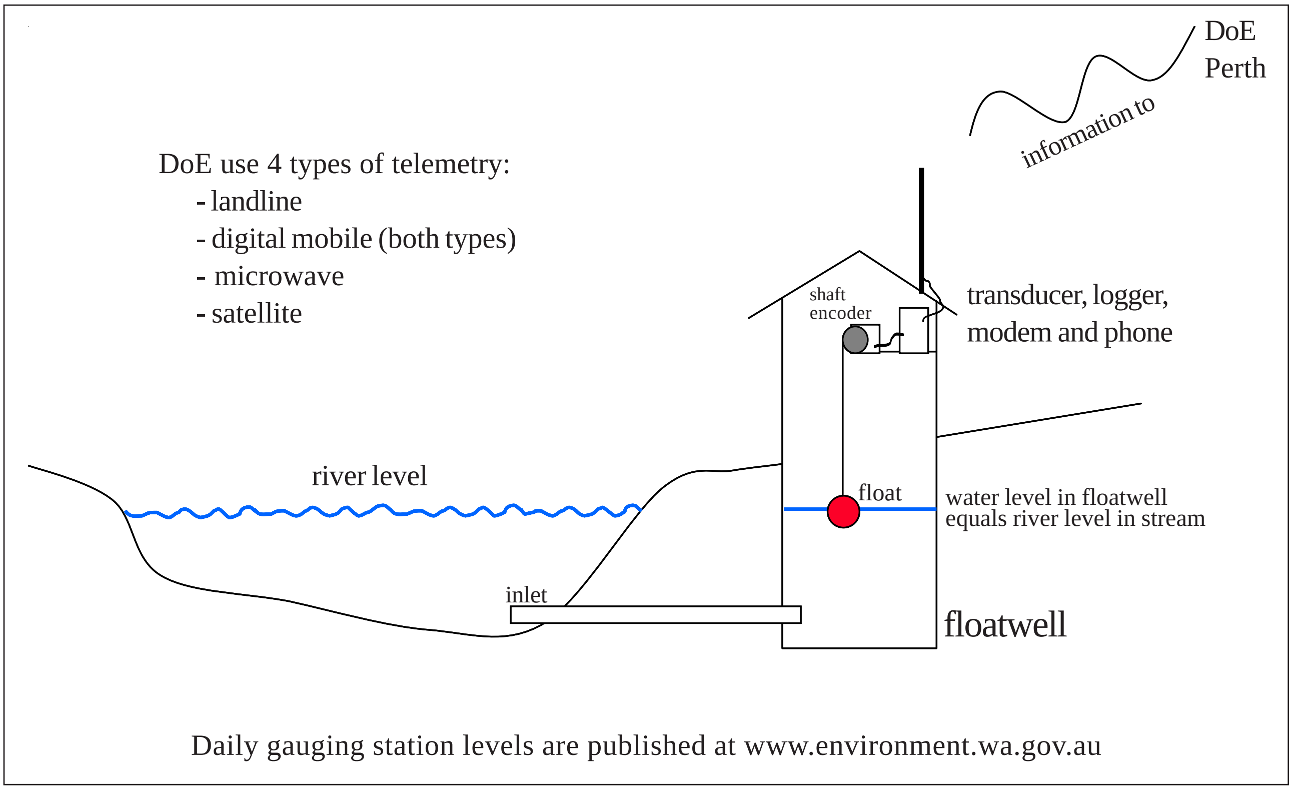
[4] *Numbers accurate for October 2002.*



Daily gauging station levels are published at www.environment.wa.gov.au

Figure 35. Telemetered stream gauging station schematic.

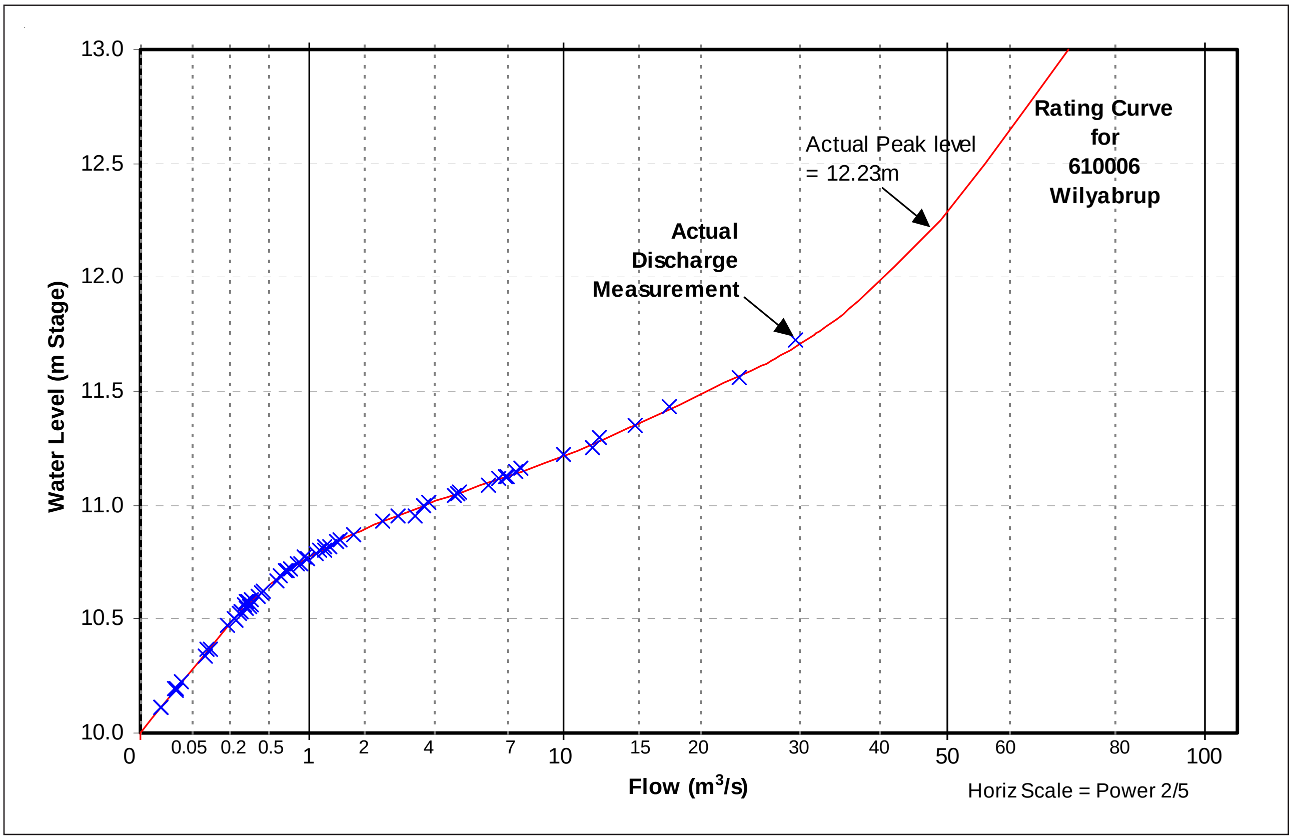


Figure 36. Example rating curve for gauging station.

A continuously recording gauging station takes the average river level every five minutes. Over a period of many years, measurements of flow called discharge measurements (many measurements of velocity over a cross-sectional area) are taken at many different river levels, allowing a *rating curve* to be developed that is unique to the site; an example of which is shown in Figure 36. This method allows calculation of the:

- instantaneous river level at any time;
- instantaneous flow at any time; and
- total flow for a period (day, month, year).

The length of record is an important factor in the analysis of flow. A single year of flow measurement has only limited use because of the variation of rainfall and hence flow between individual years. Five years is considered an absolute minimum length of record for use and this small length of record would mainly be used for estimation of total annual flow. As discussed in section 4.2, it is possible to extrapolate from other longer-term records.

Simple flow measurement

Flow measurement can be undertaken at almost any site. For 'one-off' sampling, a simple flow estimate is relatively easy to do. For a regular sampling site, it is best to install a 'gauge board' (simple board showing a graduated scale, similar to those Main Roads WA has on some floodways), and read a level each visit. When individual flow estimates from each level are plotted, a rating curve can be developed for the site.

For a regular site it is best to choose a place where there is 'all weather' access and some form of constriction like a culvert with a small pool upstream to place the gauge board, and a good flow away from the downstream side of the constriction.

Measurement should be undertaken at weekly intervals while the stream is flowing, and extra measurements should be taken, if possible, during flood events. It is also important to return and estimate the peak level that occurred during the flood event.

Note: permission from landowners is required before taking measurements.

Rainfall and evaporation

Rainfall is the easiest climatic parameter to measure. Rain gauges are relatively inexpensive and easy to operate. Ideally, they need to be placed in a broad clearing near ground level, and read and emptied at 9am each day.

Continuous rainfall measurement is undertaken using an instrument called a pluviometer which measures and records each 0.2 mm of rainfall onto a logger (the output of the pluviometer is called a pluviograph). The pluviometer allows analysis of rainfall intensities in floods (eg. rainfall causing flooding in a small catchment might have a rainfall rate of 50 mm/hr for 15 minutes, however rainfall causing flooding in a large catchment might have a rainfall rate of 8 mm/hr for 12 hours).

Evaporation measurement is quite complex. It is undertaken using a standard evaporation 'Class A' pan, a 4-foot diameter tank of water 10 inches deep (1.22 m x 0.254 m). The amount of evaporation (in mm) is recorded daily (at 9am) and then the pan refilled with water to a prescribed level. Any rainfall needs to be added to the recorded daily evaporation amount.

Because the pan site is above ground, it is subject to sunshine on its sides and this <u>increases</u> the evaporation compared to reality. This needs to be accounted for by multiplying the evaporation rate by a pan co-efficient. In south west WA, this pan co-efficient is approximately 0.80 times the recorded value (but varies across the region). In addition, most pans have birdguards fitted to stop birds bathing in the water. The birdguard stops bird access but results in a <u>reduction</u> of the amount of evaporation recorded by the pan. To allow for this, the recorded value needs to be multiplied by 1.16 (Shaw 1983). Taking into account both of the above variables, the total pan factor in south west WA is approximately 0.90 (times the evaporation rate).

Sediment

Sediment is a difficult parameter to measure accurately. Samples taken at the surface of the water will be very different to those taken near the riverbed and those on the bank will be different from those mid-stream. This is due to velocity changes across a stream bed from one bank to the next, but there are also changes along a river's length between the constrictions and pools.

The common unit of measure for turbidity is the nephelometric turbidity unit (NTU). Suspended sediment is best measured by taking samples from the middle of the river (where the flow is usually uniform), and at about two-thirds of the depth from the water surface.

Bed load measurement can be undertaken by measuring (surveying) the amount of sediment filling a (large) hole in a river over the course of a year. Major movement of sediment will only occur in flood flows. Floods will mobilise material from paddocks, gullies, riverbanks and riverbeds, transferring it many kilometres downstream.

Salinity

Salinity is usually defined in terms of its Total Dissolved Salts (TDS) in mg/L. The actual 'salts' are filtered ions (or chemical element components) that are present in the stream. The main ones are Chloride and Sodium, but there are several others that are major contributors including Magnesium (Mg), Sulphate (SO_4) and Calcium (Ca). It would be difficult and expensive to undertake a laboratory analysis every time we wanted to know the salinity of a stream, so the close relationship between salinity (TDS) and conductivity is used instead – that is, an increase in TDS correlates with an increase in conductivity. Conductivity is recorded in units of milli Seimen per metre (mS/m) using an *in-situ* probe, which is inexpensive and relatively simple. Conductivity is recorded either as a 'one-off' or a continuous measurement.

Two issues need to be considered when collecting conductivity. First, conductivity is highly variable with water temperature. Most probes will attempt to correct for temperature (called 'temperature compensation'), but despite this, water temperature should always be recorded whenever conductivity is measured. The second issue is that the relationship between conductivity and TDS varies slightly between streams (by up to 10%), and relationships have been determined for most areas of WA. For example, the TDS for a particular water sample from bores near Carnarvon is about 10% higher for a specific conductivity than would the TDS from the Blackwood River at the same conductivity.

More information on these relationships can be obtained from the Resource Information Branch of the DoE.

Planning measurement

Measurement of hydrologic information, including water quality, should always be undertaken to a plan. The plan may be a simple understanding of what is going on in the stream at one point now, or a long-term catchment scale assessment of a system.

The measurement plan will need to define:

- why it is being undertaken;
- what it is looking for - the parameters that are to be collected (eg. conductivity, temperature, total nitrogen, chloride);
- where it is looking - where they are to be collected (specific sites and what needs to be done at each one);
- frequency of sampling (eg. a once-off snapshot, or regular period sampling - two weekly to annual);
- length of sampling period (eg. once, over a 3, or 5-year period or permanently); and
- what resources are needed.

Water quality parameters that cannot be measured *in-situ* (ie. there is no probe developed for measuring metal concentrations) are generally measured by collecting a 'grab' sample and sending it to a recognised laboratory for analysis. Grab samples should always take the water just below the surface (never the actual surface water), in a moving body of water. Samples should rarely be taken in streams that are not flowing as the parameter concentration may be affected by evaporation. The date, time and stage level or estimated flow should be recorded for each sample. Even if the collector has no confidence in their own abilities in flow estimation, a comment of high, medium, low, trickle or none is very useful in understanding the results.

Note: Permission is required to access private land for sampling.

While the Department of Environment collects water samples in targeted areas throughout the south west of WA, community groups are now often involved in sample collection and flow or level measurement, such as those involved in the Waterwatch Ribbons of Blue Program. More information on water quality sampling and methodology can be obtained from other sources, such as the *Waterwatch Australia National Technical Manual Module 4 Physical and Chemical Parameters* (Waterwatch 2002) and the *Waterwatch Tasmania Data Confidence Guidelines* (Pollington 2002). More information on monitoring and evaluating projects can be found in *Water Note 28*, *Monitoring and evaluating river restoration works (WRC 2002)* and *Monitoring and evaluating biodiversity conservation projects* (Coote *et al* 2002).

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