# A Public Guide to Storm and Flood Hydrology

Catchments & Creeks

Version 4, 2023

**A Public Guide to Storm and Flood Hydrology**

Version 4, November 2023

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Published by: Catchments & Creeks

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Photos by: Catchments & Creeks, Catherine Cleary, Russell Cuerel, Brisbane City Council (BCC), Australian Bureau of Meteorology (BoM)

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This document should be referenced as:

Witheridge 2023, *A Public Guide to Storm and Flood Hydrology.* Catchments & Creeks, Bargara, Queensland

Key words: hydrology, flood, flooding, drainage management, stormwater drainage, stormwater.

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Cover: Approaching thunder storm, New England Hwy, Bolivia/Deepwater, NSW (4/11/2010).

## Disclaimer

This publication has been prepared as a non-technical, educational, reference document. The general content, and generic nature of the document means that this publication is unlikely to address all of the hydrologic issues relevant to a particular drainage catchment, or provide sufficient information to allow the reader to interpret flood maps. Rather, the focus of this document is on answering many of the questions commonly asked about storm hydrology.

The hydrologic principles presented within this publication are aligned with current Australian practice; however, individual states and territories may adopt flood warning and mapping procedures that differ from those presented within the document.

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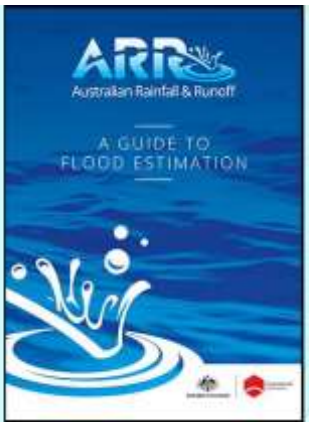


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**Queensland Urban Drainage Manual**

***Queensland Urban Drainage Manual***

4th edition, 2017, Institute of Public Works Engineering Australia, Queensland Division and the Department of Energy and Water Supply. Brisbane, Australia.

**A Public Guide to Living with Floods**

***A Public Guide to Living with Floods***

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**A Public Guide to Stormwater Drainage**

***A Public Guide to Managing Stormwater Drainage on Residential Properties***

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## Purpose of field guide

The aim of this document is to assist the public in their understanding of storm and flood hydrology. It is hoped that by improving the community's knowledge of flood hydrology, there will be a corresponding improvement in the public's understanding of, and response to, future flood warnings.

Further to this, the document aims to:

- answer questions commonly asked by the public (based on the author's experience)
- improve the community's preparation for, and management of, property flooding
- provide the community with an educational document on storm hydrology
- assist government officers in responding to flood inquiries from the public.

This publication does **not** aim to present a comprehensive technical guide to flood and storm hydrology.

## About the author

Grant Witheridge is a retired civil engineer with both Bachelor and Masters degrees from the University of NSW (UNSW). He has over 40 years experience in the fields of hydraulics, stormwater management, creek engineering, and erosion & sediment control, during which time he has worked for a variety of federal, state and local government bodies, and private organisations.

Grant commenced his career at the UNSW Water Research Laboratory operating physical flood models of river floodplains. He later worked for Brisbane City Council on creek engineering and stormwater management issues. He currently works (at his leisure) through his own company Catchments & Creeks.

Grant is the principal editor of the revised Queensland Urban Drainage Manual (2007, 2013 & 2017), Brisbane City Council's Natural Channel Design and Creek Erosion guidelines; the IECA (2008) Best Practice Erosion & Sediment Control documents, and the 2002 engineering guidelines on the Fish Passage Requirements for Waterway Crossings.

## Introduction

According to the Macquarie Dictionary, hydrology *'is the science dealing with water on the land, or under the earth's surface, its properties, laws, geographical distribution, etc.'* However the term is most commonly associated with the prediction of rainfall and flood levels, and the issuing of flood warnings.

The career of a hydrologist is probably no more difficult than any other profession, but it is a job where it can be hard to be 'right' (in the public eye), and easy to be accused of being 'wrong'. The fact is, no matter what prediction of rainfall or flood severity a hydrologist makes, there will always be some degree of 'error', simply because rainfall and flooding are affected by so many factors that are subject to uncontrollable natural variation.

Unlike in the case of a sporting event, where you can choose the 'expert' that you wish to receive tips and predictions from, in the world of hydrology, it is typical for all the advice to originate from a single source, such as a national weather authority with regards to rainfall predictions, and a local council with regards to flood levels.

It is not uncommon for a hydrologist to attach several assumptions to their prediction of an expected flood level. For example, they may say: *'A flood peak of 5.8 m will be reached at the city gauge, at around 9pm on Thursday evening, provided . . .*

- *the rainfall continues as expected*
- *the extent of rainfall across the catchment does not expand*
- *dam releases are maintained at their current programmed rates, and*
- *predicted tide levels are consistent with the predicted storm surge.*

The truth is, flood levels are affected by many variables, all of which are difficult to predict. Only on very large river systems, such as the Darling–Murray rivers, where a 'flood wave' can travel outside the rain-affected area, is it possible to provide accurate predictions of flood levels. In simple terms; if it is still raining, then it is too early to provide an accurate prediction of flood levels.

## A short overview of flood hydrology

**Approaching storm front**

### Storm intensity, duration and extent

- The most critical factor that influences the severity of property flooding is the intensity of the rainfall; however, rainfall intensity is not the only factor.
- The three most important parameters that dictate the likely impact rainfall can have on flood levels are:
  - the **intensity** of the rainfall
  - the **duration** of the rainfall
  - the aerial **extent** of the rainfall.

**Street drainage**

### Surface condition of the catchment

- Most people are aware that the existence of impervious surfaces, such as roads and roofs, can increase the volume of stormwater run-off, but there are other catchment-related influences, including:
  - the type and density of vegetation cover
  - the frequency of burning of bushland
  - the type and depth of soil cover
  - the type of underlying rock
  - the existence of surface depressions that can capture and hold water.

**A widened waterway channel**

### Hydraulic capacity of the waterway

- The severity of creek and river flooding is directly related to the difference between the peak discharge passing down the waterway, and the flow capacity of the waterway channel.
- Similarly, the severity of stormwater flooding (i.e. property flooding caused by stormwater run-off passing over the land on its way to a creek or river), is directly related to the hydraulic capacity of the property's stormwater drainage system.

**Backwater flooding**

### Backwater effects

- Flood levels can sometimes be influenced by flood levels downstream of your property, rather than flows passing through your property.
- This is known as backwater flooding, which can include:
  - tidal flooding
  - flooding within a waterway located downstream of your property
  - low barometric air pressure, which can cause sea levels to rise above expected tide levels.

## Different storms cause different floods in different locations

**Cyclone off the Western Australian coast**

**Overflowing roof drainage system**

### There are many different types of storms

- The media often talks about the 1 in 100 year storm, but what is usually not discussed is that there are many different types of 1 in 100 year storms.
- There are short duration thunder storms, and there are long duration rainfall depressions and cyclones.
- There are storms that start with periods of light rainfall followed by a heavy downpour, and storms that start with a heavy downpour followed by moderate rainfall.

### Storm 'duration' is critical

- Storm duration is a critical factor in determining where the worst flooding will occur along a waterway.
- Short duration storms typically have their greatest impact around the outer edges of large waterway catchments.
- The longer the duration of the storm, the further down a waterway will be the point of worst flooding.
- It does not matter how big a thunderstorm is in Toowoomba, it won't cause a flood to occur in South Australia.

### Understanding 'your' critical storm duration

- Every location along a waterway will have its own critical storm duration, which will ultimately determine the likely severity of flooding during a storm event.
- The critical storm duration for your property is typically based on how long it would take floodwater to travel from the top of the catchment to your property.
- If the critical storm duration for your property is 3 hrs, then stream flows at your property, at any given point in time, will typically be related to the total depth of rainfall that had occurred over the previous 3 hours, even if the storm duration was longer or shorter than 3 hours.
- This means that if a storm lasts for 2 days, then the maximum stream flow passing your property will be largely dependent on the depth of rainfall that occurred during the worst 3-hour period of rainfall throughout that 2-day period.
- It also means that your property will only experience a 1 in 100 year flood event if the rainfall intensity averaged over the worst 3-hour period during a given storm is equal to the predicted 1% probability (i.e. 1 in 100 year), 3-hour average rainfall intensity based on an analysis of historical rainfall records for your catchment (Yes, a lot of contributing factors!).
- Consequently, if your waterway catchment experiences a 1-hour, 1 in 100 year storm burst, then the flooding will be worst for those properties that have a 1 hour critical storm duration, while your property (which has a 3-hour critical storm duration) may only experience a 1 in 20 year, or 1 in 50 year flood level.
- Similarly, if your waterway catchment experiences a 4-day, 1 in 100 year storm, then the flooding will be worst for those properties that have a 4-day critical storm duration, while your property may only experience a 1 in 1 year flood level, or possibly no flooding at all.
- In a waterway catchment the size of the Murray-Darling basin, there would be many, many different types of 1 in 100 year storm events, each causing different flow conditions within different parts of the catchment, which is one reason why so many 1 in 100 year storms are reported—they are just different types of 1 in 100 year storms.

# 1. Commonly Asked Questions

## Commonly asked questions

**Q1. If the 1 in 100 year flood is only expected to occur once every 100 years, then why does it appear that every second flood on our river is called a 1 in 100 year flood?**

A1. Firstly; the term '1 in 100 years' does not mean that such a storm or flood will only occur once every 100 years. A more appropriate term for such an event is the 1% storm, or 1% flood; however, the term '1% flood' is not a term that appears to capture the public's (or media's) attention.

It should be noted that major floods often occur in close proximity to each other, time-wise. So over a period of 100 years, it is not uncommon to find that most of the major floods would have occurred within a period of, say, 50 years. And that several floods may have occurred within a 5-year, or 10-year period within those 50 years.

It is also possible (and it has occurred), that a given town will experience two floods that exceed the 1 in 100 year flood level in just a 2-year period (i.e. consecutive wet seasons).

Finally, it is also worth noting that hydrology is not an exact science. It is difficult to say (with certainty) that a particular storm is a 1 in 87 year storm, or a 1 in 107 year storm. Consequently, it is common for all storms greater than the 1 in 50 year storm, and less than the 1 in 200 year storm, to initially be referred to as a 1 in 100 year storm. This means a lot of storms may initially be called a 1 in 100 year storm, but over time they may be redefined as a 1 in 80 year, or 1 in 110 year storm. However, by the time these storms are fully analysed, the only people that care about their redefined probability are hydrologists and historians.

**Q2. My home is located within our council's 1 in 100 year (1%) flood inundation map; however, last month a 1 in 100 year flood was said to have occurred within our catchment, and my home did not flood. Doesn't that prove that council's flood map is wrong?**

A2. No; it does not mean that council's flood map is wrong. There can be several reasons for such an outcome, for example:

(i) Last month's flood may have been reported as a 1 in 100 year river flood, but you may live on one of the creek tributaries that feeds into the river. A river flood is normally caused by a long-duration storm, possibly occurring over several days. However, a creek flood is normally caused by a high-intensity thunder storm passing directly over the creek. So it may have been a 1 in 100 year storm, but not the type of storm that would flood your property. **OR**

(ii) Last month's event may have been reported by the weather bureau (BoM) as a 1 in 100 year storm, but because this storm happened while the catchment was extremely dry (i.e. after a long drought), and while all the water supply dams were near-empty, the 1 in 100 year storm did not produce a 1 in 100 year flood. **OR**

(iii) The 1 in 100 year storm passed over only part of your river catchment.

Finally, it should be noted that flood maps are based on long-term predictions. A single flood event, such as the one that occurred on your catchment last month, cannot, on its own, prove or disprove such long-term predictions. Data from a single flood event can at best 'add' to our overall data set. It cannot replace the rainfall or flood height data collected over the past 50 to 100 years.

**Q3. Why don't dam operators begin to release water the moment a major storm is predicted to occur? This would allow the dams to be more effective at capturing the floodwater, and therefore reducing downstream flood damage.**

A3. Again this is a question that can have several answers, such as:

(i) The dam in your catchment is currently classified solely as a water supply dam. Given that public money was used to build the dam, government legislation typically dictates that the dam must only be used for the purpose for which it was built. This of course does not stop a government from changing the legislation so that a dam could be used for flood mitigation purposes. However, this change in legislation must occur before any given flood event. It is for the government to make this change. It is not something that engineers operating the dam can choose to do at a moment's notice. **OR**

(ii) There is always the risk that the predicted rainfall will not occur. If a dam releases water prior to a predicted storm, and then the storm changes its direction or intensity, then the authorities can be left with a near-empty water supply dam, which can prove even more damaging to a city than a flood, especially if the city is in the middle of a drought. **OR**

(iii) If the approaching storm is likely to produce several days of heavy rainfall prior to the peak of the storm, such as can occur during a cyclone, then the dam can refill prior to the arrival of the storm's peak rainfall. In such cases, the early release of water may provide minimal flood control benefits to downstream residents, and as a result, the flood's peak will pass over the dam's spillway with minimal flood attenuation. **OR**

(iv) Some dams do not have adjustable spillway gates, so any water released from the dam would be limited to discharges from the main outlet pipe, which would not be able to lower water levels sufficiently over a one or two-day period to have any beneficial effect on downstream flood levels.

**Q4. Why do councils continue to allow new buildings to be built on a floodplain, especially when many of these new buildings are formed on a ground-level slab, and not on piles which could lift them above predicted flood levels?**

A4. The most common reason why new homes are constructed on floodplains is because the land has already been zoned suitable for residential use. The land may have been zoned for residential use during a period when flood mapping was not as refined as it is today. This means the council could be restricted to just two options:

- the council could rezone the floodplain for non-residential use, which means significant amounts of rate-payer's money will need to be used to compensate the current landowners for the rezoning of their land (because they had been paying higher rates on the land based on the old residential zoning); or
- the council could use significant amounts of rate-payer's money to buy back the land.

There can be other reasons why new homes/buildings are constructed on a known floodplain, including:

(i) In some council districts it can be an 'as of right' allowance to build a single detached dwelling on any given allotment, even if the allotment is not zoned as 'Residential'. Such rules were introduced to allow a single farm house, or shed, to be constructed on any given allotment. **OR**

(ii) An existing, elevated, flood-free, pole home is replaced by a new home; and, the home owners have chosen to ignore council's flood warning advice because they can build a bigger home (for the same money) if they build their new home at ground level. **OR**

(iii) The council may require new homes to be built above the 1 in 100 year flood level, which means that the home may be flooded by a more severe flood, such as a 1 in 200 year flood. **OR**

(iv) Pressure may be placed on the council by the state government to increase the amount of land available for residential use in order to achieve current state or federal housing outcomes. This can place a council in a position of having to choose between increasing residential densities on flood-prone land, or on fire-prone land, or on prime agricultural land, or within undisturbed bushland. All of our cities face increased political pressure to increase the number of residential allotments. Unfortunately it is usually only the councils that get blamed for such decisions (I say this as an ex-council engineer).

**Q5. Why don't governments regulate the cost of flood insurance so that flood insurance is affordable and available within all flood prone areas.**

A5. Firstly, what this question is really saying is: Why don't governments force insurance companies to lose money (i.e. for insurance companies to continually pay out more money than they take in as fees)?

There are two options here:

(i) Insurance companies can include flood insurance within all their policies, which means people in non flood-prone areas will be required to pay higher insurance rates in order to subsidise the rates payable by those people living in flood-prone areas, which means those company's insurance premiums may become uncompetitive. **OR**

(ii) Governments can pay part of the insurance premiums for residents in flood-prone areas, which again means people in non flood-prone areas will be required to pay more money (through their taxes) in order to subsidise the rates payable by people in flood-prone areas.

**Q6. Most flood studies recommend a flood levee as a possible solution to a town's flood problems. Why don't governments build more flood levees?**

A6. Unfortunately, investigations into the long-term performance of existing flood levees around the world have shown that:

(i) Flood levees may reduce the amount of flood damage caused by small floods, but often increase the amount of damage caused by those large floods that overtop the levees. **AND**

(ii) A town typically becomes less resilient to flood damage after a levee is installed. Residents typically relax their attitudes to the flood risk, and begin to spend more money on buildings and businesses located behind the levee. **AND**

(iii) It is likely that every flood levee will one day be overtopped.

**Q7. Why do some insurance policies cover storm damage and stormwater flooding, but not creek, river, or backwater flooding?**

A7. Both the engineering profession and the insurance industry treat 'stormwater flooding' and 'waterway flooding' as different types of flooding.

Stormwater flooding is associated with the movement of stormwater run-off flowing overland towards a watercourse (i.e. prior to the water entering the watercourse, or into waters backing-up from the watercourse). Stormwater flooding does not include creek or river floodwater that is backing-up along a stormwater drainage system or sewer. Stormwater flooding includes flooding caused by water seeping from the ground, and rainwater entering a building as a result of roof or building damage.

Waterway (creek or river) flooding is associated with the movement of water along a watercourse, either within the main channel, or along its floodplains. Waterway flooding includes the process known as 'backwater flooding', which can cause creek or river flooding to extend laterally across floodplains, or 'backing-up' into tributaries.

In my opinion, the insurance industry treats stormwater flooding differently from waterway flooding because:

(i) Stormwater flooding within a property or building is not inevitable. It is not a certainty for all properties or buildings to experience such flooding. It can be considered a 'risk based' event. This is an event that any property or building can experience from time to time. Therefore, all policy holders have the potential to benefit from such an insurance policy, and therefore it is fair for all policy holders to contribute to the insurance scheme.

(ii) Waterway flooding of properties or buildings located within a floodplain is considered inevitable. It is an event that flood-risk properties and buildings will experience repeatedly over an extended period of time. It is not a form of flooding that can be experienced by all properties and buildings. Therefore, all policy holders do not have the potential to benefit from such an insurance policy.

**Q8. Who owns rainwater?**

A8. This is a 'legal' question, and I am an engineer, not a legal practitioner.

Firstly, 'rainwater' is the term used to describe rainfall **prior** to its contact with the ground. This is why we refer to water storage tanks directly connected to your roof as 'rainwater tanks'. And 'stormwater' is the term we use to describe rainfall **after** it has had contact with the ground; hence the term 'stormwater run-off'.

To the best of my engineering knowledge, nobody owns 'rainwater'; however, once the rainwater lands on a surface, then the legal owner is likely to be the State Government.

In Australia, state governments own the 'resources' of the state. This means the state owns all water, coal, oil, gas, etc. that originates from the state (unless of course, these assets are sold to a private owner). To the best of my non-legal knowledge, this means the state owns all the water that collects by surface run-off in a dam or rainwater tank.

# 2. Factors Affecting the Severity of Property Flooding

## Introduction

**River flooding**

### What is flooding

- Flooding is the inundation of buildings or land by water.
- Different names can be applied to different types of flooding based on the origin of the water.
- Away from coastal areas, the most common types of flooding are creek and river flooding.
- Homes located outside of a floodplain can still experience flooding as a result of stormwater flooding.

**Stormwater run-off (overland flow)**

### What makes a flood

- Creek and river flooding results from storm run-off passing down a watercourse.
- Stormwater run-off occurs when:
  - the ground or land surface becomes saturated and unable to accept further infiltration, or the surface storage of rainwater; or
  - the intensity of rainfall exceeds the soil's current infiltration rate, even though the soil is not saturated.

**Saturated land**

### Factors affecting the volume of run-off

The factors that affect the volume of stormwater run-off include:

- The size of the drainage catchment.
- The extent, intensity and duration of rainfall across the catchment.
- The ability of the ground to absorb water, which is influenced by land slope, the depth of soil above rock, the type of rock, and the type of vegetation cover.
- The percentage of the land covered by impervious surfaces (e.g. roads & roofs).
- Water retained in surface pools & dams.

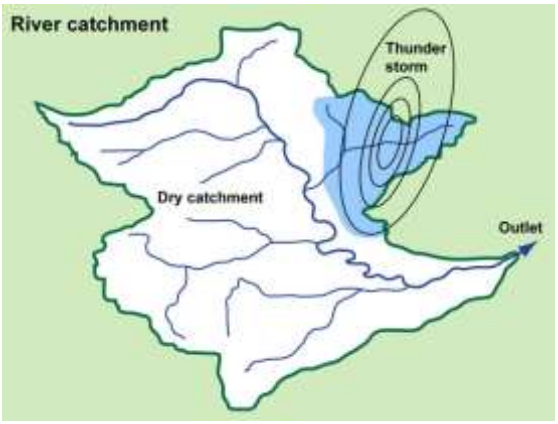
**Debris blockage at a road culvert**

### Factors that affect the height of flooding

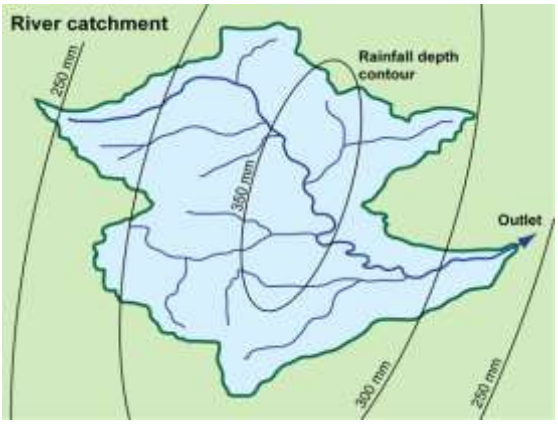
The factors that influence the height of flooding at a particular location include:

- The peak flow rate passing down a drainage system, whether in a pipe, channel, or watercourse.
- The hydraulic capacity of the drainage system.
- The extent of 'blockages' within the floodway (e.g. flood debris, fences, waterway structures, and fallen trees).
- Backwater influences such as tides.

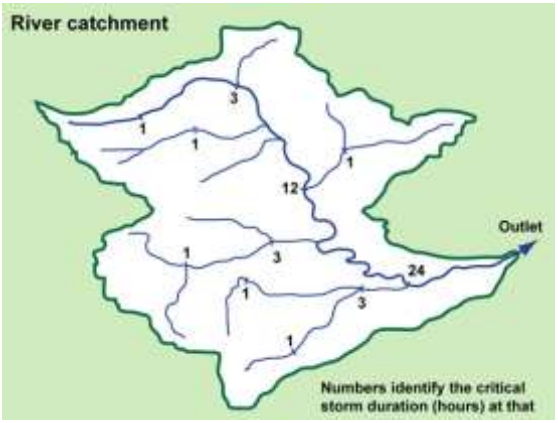
## Impact of storm intensity on flood hydrology



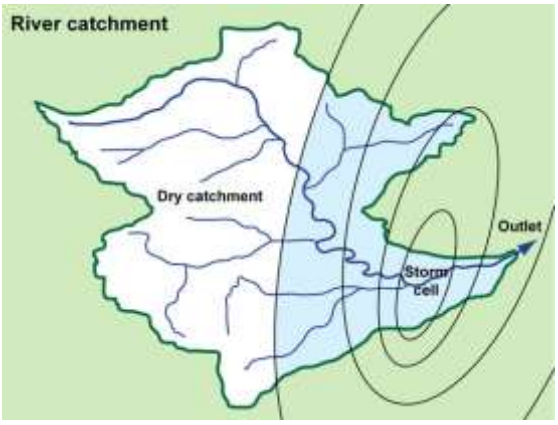

**Thunder storm on a river catchment**




**Storm extending over the whole catchment**




**Critical storm duration along a river**




**Partial catchment storm**

### Impacts of storm intensity

- The severity of flooding is strongly influenced by the severity of the storm.
- The storm severity can be assessed through the following variables:
  - rainfall intensity (measured in mm/hr)
  - the duration of rainfall
  - the extent or coverage of rainfall over the drainage catchment.
- Thunder storms typically have a high rainfall intensity, but a short storm duration, and a small coverage area.

### Intensity of rainfall

- In general terms, the severity of flooding is directly related to the storm's average rainfall intensity ($I_{ave}$), which is averaged:
  - over a specific time period that is unique to a given location, known as the '**critical storm duration'**; and
  - over the **catchment area** (A).
- Even though the relationship between peak flood discharge (Q) and rainfall intensity ($I_{ave}$) can be very complex, in its simplest form it can be expressed as:

$$Q = \text{Constant} \cdot I_{ave} \cdot (A)^{x}$$

### Duration of rainfall

- Each location along a waterway will have a particular 'critical storm duration' that governs the flooding at that location.
- The critical storm duration is a measure of the time floodwater takes to travel from the top of the drainage catchment to any given location along the waterway.
- If the duration of rainfall is less than the critical storm duration, then both the effective 'average' rainfall intensity ($I_{ave}$) and peak flood discharge (Q) will be reduced.

### Extent of rainfall

- The severity of flooding can also be reduced if the storm cell does not extend over the full catchment area.
- If part of the catchment remains dry, then the effective 'average' rainfall intensity will be reduced, and consequently the flood severity will also be reduced.
- In large drainage catchments, such as the Murray River, it is possible for flooding to occur at downstream locations even though no rain has fallen at these locations.

## Impact of land surface conditions on flood hydrology

**Town centre**

### Commercial and city centres

- The volume of stormwater run-off is strongly influenced by the percentage of the land covered by impervious surfaces, such as roads and roofs.
- Areas such as city centres, and industrial and commercial precincts, have extensive amounts of impervious surfaces.
- These surface areas also provide few opportunities for stormwater to pool on the surface of the land (technically referred to as ‘surface storage’).

**Residential area**

### Urban areas

- Urban areas contain significant amounts of impervious roads and roofs interlaced with areas of vegetated soil.
- Modern, high-density residential areas typically consist of around 70 to 90 per cent impervious surfaces.
- Older, low-density residential areas typically contain around 40 to 80 per cent impervious surfaces.
- Effective surface drainage means these areas typically have limited ‘surface storage’.

**Cleared bushland**

### Grassed surfaces

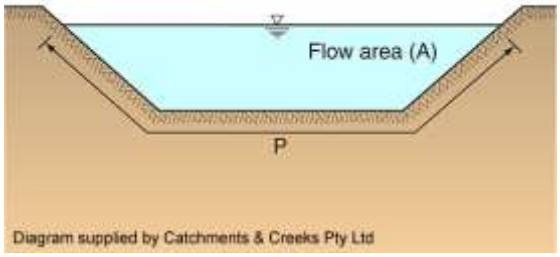
- Land surfaces covered with shallow-rooted vegetation, such as grasses and most commercial crops, typically infiltrate less stormwater than land surfaces covered with dense bushland.
- Land clearing can significantly increase the total volume of stormwater run-off that is expected to discharge from a drainage catchment on an annual basis.
- The impact that land clearing can have on individual storms is complex, and varies from storm to storm.

**Bushland**

### Bushland

- Natural bushland typically has the greatest infiltration capability of all land surfaces, with the exception of sand dunes.
- It takes around 100–200 mm of rainfall to saturate bushland, compared to just 20–50 mm of rainfall to saturate grassland.
- Bushland can also hold large volumes of rainwater on leaf surfaces and within the leaf-litter (mulch) that covers the ground.
- Bushfires can cause significant short-term changes to the run-off characteristics of bushland by removing leaves and mulch.

## Factors affecting the hydraulic capability of waterways




**Channel geometry and flow conditions**

### The flow capacity of a waterway channel

The discharge capacity of simple channels may be estimated using Manning's equation:

$$Q = (1/n)\ A\ .\ R^{2/3}\ .\ S^{1/2}$$

where:

Q = discharge ($m^3/s$)

n = Manning's roughness coefficient

A = cross-sectional area of flow ($m^2$)

R = hydraulic radius (m) = A/P

P = wetted perimeter of flow (m)

S = channel slope (m/m)

**Trees with high branches**

### Channel roughness (n)

- The hydraulic capacity of a waterway channel is inversely proportional to its roughness.
- In engineering, channel roughness is typically defined using the Manning's roughness coefficient (n).
- The type of vegetation that exists along a waterway can have a significant impact on channel roughness and flood levels.
- Trees with branches above the flood level typically represent only minor roughness.

**In-bank vegetation damaged by a flood**

### Impact of low trees and shrubs

- Trees and shrubs with low branches can represent significant channel roughness.
- During severe floods, this low-branch vegetation must bend with the flow, or otherwise be broken and damaged.
- Consequently, the riparian plants that survive best over the long-term are those made from flexible timbers, such as many of the *Callistemons*.
- Plant selection within, and adjacent to waterways, is a complex science.

**Mat-forming grasses in a waterway**

### Grassed waterways

- Grasses can be grouped into two main categories; flexible mat-forming grasses, and stiff grasses.
- Mat-forming grasses generally fold flat during floods, and therefore do not represent significant channel roughness.
- Stiff grasses, such as reeds and *Lomandra*, can represent significant roughness in certain low-flow conditions.
- Stiff grasses can be very important within waterways for fish passage and erosion control.

## Backwater effects

**Backwater flooding**

### Backwater effects

- Flood levels at some locations may not be controlled by the flow capacity of the adjacent drainage channel, but instead by conditions within a downstream waterway (known as the 'backwater effect').
- Floodwaters may 'back-up' along a waterway as a result of tides, debris blockages, or natural channel roughness.
- 'Backwater flooding' is the term used to describe floodwaters that spread laterally into partially-isolated areas of a floodplain.

**Severe debris blockage of a road culvert**

### Blockages at watercourse crossings

- Flood debris can partially or fully block watercourse crossings, such as bridges and culverts, causing an increase in upstream flood levels.
- The extent of these backwater effects (i.e. the distance over which the effects are felt) depends on the gradient of the floodwater, which in most cases is near parallel with the gradient of the waterway.
- In low-gradient waterways, the backwater effect of debris blockages can extend for kilometres upstream of the blockage.

**High tide backing-up into a coastal drain**

### Tidal influences

- Near the coast, flood levels can be strongly influenced by tide levels.
- However, these influences can reduce rapidly as you move away from the coast.
- Tidal effects on flood levels generally:
  - decreases with increasing flood severity
  - extend inland a distance significantly less than the normal (non-flood) tidal limits of the waterway.
- Long-duration floods (> 12 hours) are likely to experience at least one high tide.

**Storm surge inundation**

### Storm surge

- Storm surge is the temporary rise in sea level caused by the extreme surface winds and low atmospheric pressures associated with severe weather conditions, such as a cyclone.
- This rise in sea level is additional to the normal tidal movement.
- Storm surges most commonly impact flood levels within coastal waterways during the occurrence of cyclones.

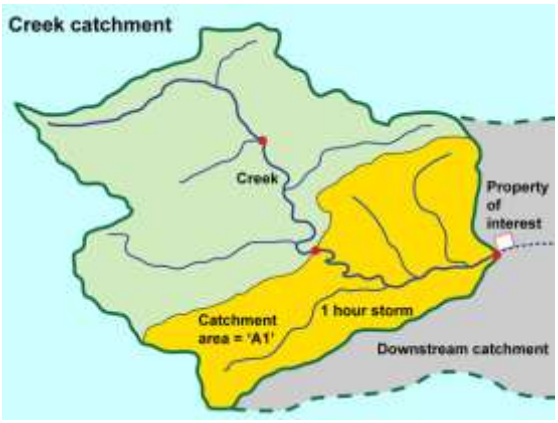
# 3. Understanding the Importance of the ‘Critical Storm Duration’

## Catchment conditions upstream of a given property (the Property)

**Critical storm duration**

### Creek catchment

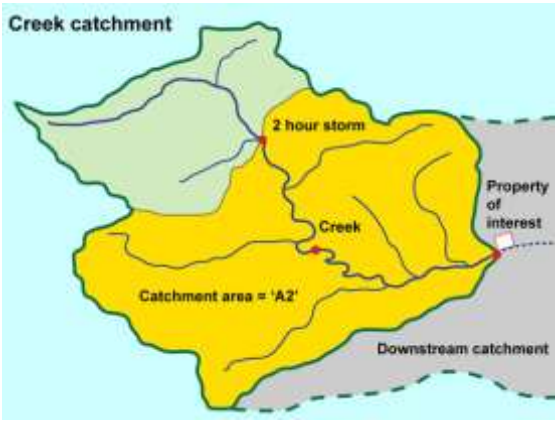
- Let us assume that a flood probability analysis has been requested for a property located on this creek (left).
- A catchment model shows that stormwater run-off will take around 3 hours to travel from the top of the catchment to the property of interest (the **Property**).
- This would suggest that the 'critical storm duration' for the **Property** is 3 hours.




**1 hour storm**

### Contributing catchment area for a 1 hour storm

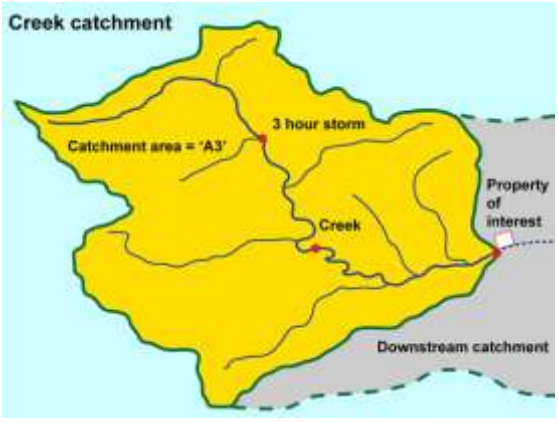
- If a 1 hour, 1 in 100 year (1%) storm were to move over the whole catchment, then:
  - stream flows in the creek adjacent to the **Property** would likely reach a maximum **($Q_{Max-1}$)** after about 1 hour
  - at the time of maximum stream flow, the area of the upstream catchment that would be contributing to this stream flow would be area **'A1'** (shown in yellow).




**2 hour storm**

### Contributing catchment area for a 2 hour storm

- If a 2 hour, 1 in 100 year (1%) storm were to move over the whole catchment, then:
  - stream flows in the creek adjacent to the **Property** would likely reach a maximum **($Q_{Max-2}$)** after about 2 hours (this is not exact)
  - at the time of maximum stream flow, the area of the upstream catchment that would be contributing to this stream flow would be the larger area **'A2'** (shown in yellow).




**3 hour storm**

### Contributing catchment area for a 3 hour storm

- If a 3 hour, 1 in 100 year (1%) storm were to move over the whole catchment, then:
  - stream flows in the creek adjacent to the **Property** would likely reach a maximum **($Q_{Max-3}$)** after about 3 hours (again, this is not exact)
  - at the time of maximum stream flow, the area of the upstream catchment contributing to this stream flow would be the full catchment area **'A3'** (shown in yellow).

## Critical storm duration for the 100 yr storm frequency at the Property

**Contributing area (A) vs. storm duration**

**Rainfall intensity ($I_{100}$) vs. storm duration**

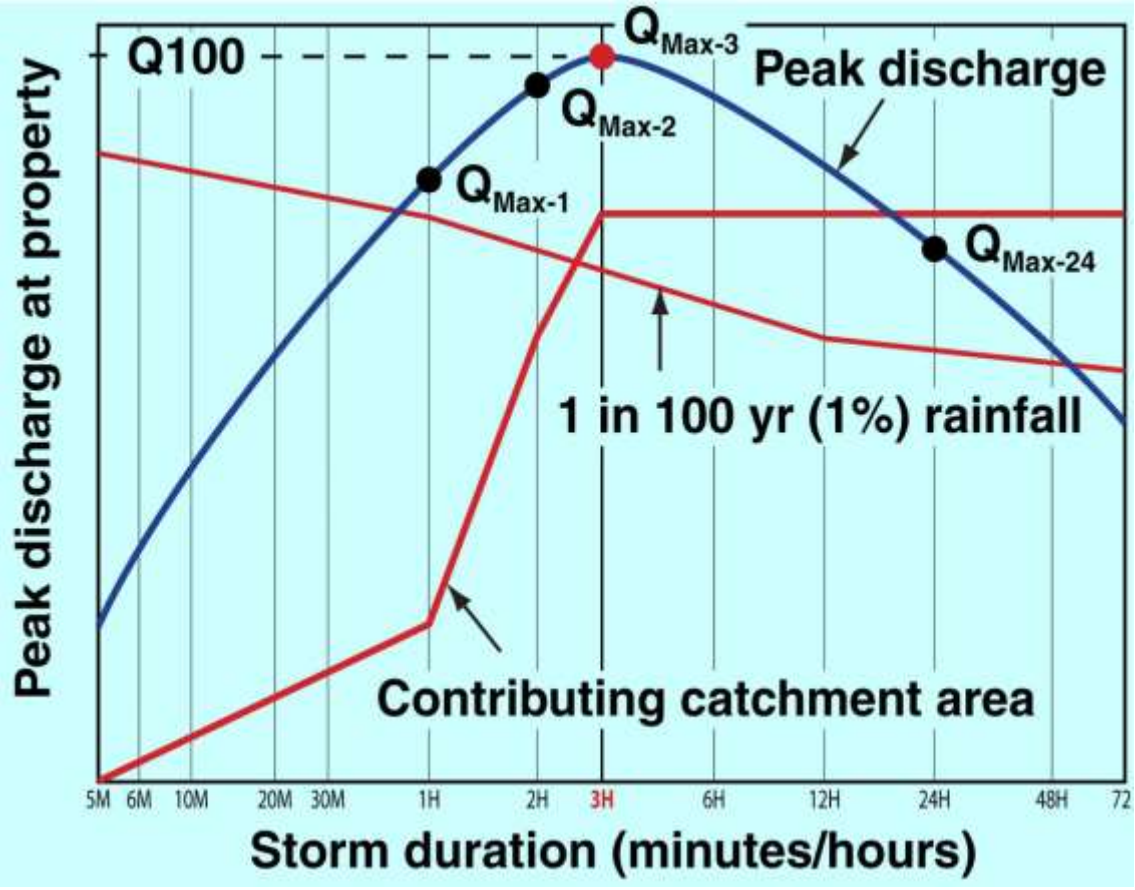
**Changes in the expected peak stream flow for different storm durations**

- This graph (left) demonstrates how the contributing catchment area **(A)** increases as the storm duration increases; however, a maximum is reached once the storm duration equals the 'critical storm duration' for the **Property**.
- The second graph (below, left) demonstrates how the average intensity **($I_{100}$)** of a 1 in 100 year storm decreases as the storm duration increases.
- This rainfall intensity-duration graph would have been developed from an analysis of historical rainfall records from this catchment.
- The large graph (below) combines the first two graphs to demonstrate how the peak flow **(Q)** passing the **Property** becomes a maximum when the storm duration (t) is equal to the critical storm duration ($t_c$) for the **Property** (i.e. t = $t_c$ = 3 hours).

**Q100 = constant . $I_{100}$ . A**

where the catchment area; **A** = **'A3'**

- Thus; Q100 = $Q_{Max-3}$ for the **Property**.




**Plot of the peak discharge generated by 1 in 100 year storms of various durations**

## Critical storm duration for various types of catchments

**Street drainage**

**Short duration thunder storms**

- It is common for road drainage systems to be based on storms that have a very short duration, typically less than 15 minutes.
- Road drainage systems (i.e. pipes under the road) are typically designed to carry run-off from storms up to around the 1 in 2 year storm.
- This means drivers should expect stormwater to pool on, or spill over, the road whenever there is a severe thunder storm.

**Significant overland flow path**

**Typical urban storms**

- Overland flow paths passing through urban areas would typically have a critical storm duration of around 5 to 45 minutes.
- Such storms include thunder storms, and any rainfall event classified as a ‘storm’, rather than as a ‘shower’.

**Flooded creek**

**Rainfall depressions**

- Creek flooding normally results from storms that include a heavy period of rainfall that extends beyond an hour.
- Small creeks may have a critical storm duration of around 1 to 2 hours.
- Larger creeks may have a critical storm duration of around 3 to 12 hours.

**River system**

**Extended periods of rainfall**

- The size of river catchments varies greatly around the country.
- River flooding normally results from long periods of moderate rainfall, possibly including several high-intensity storms.
- Small rivers may have a critical storm duration of around 3 to 5 days.
- Larger rivers may have a critical storm duration that exceeds a week, or even several weeks.

# 4. The Science of Predicting Flood Levels

## Introduction

**Average annual rainfall map (BoM)**

**Physical flood model**

**Rainfall radar map (BoM)**

**River flooding**

### The science of storm hydrology

- Hydrology *'is the science dealing with water on the land, or under the earth's surface, its properties, laws, geographical distribution, etc.'* (Macquarie Dictionary)
- The science of storm and flood hydrology is most commonly associated with the issuing of flood warnings, and the prediction of flood levels.
- The hydrology profession can be viewed as a cross-over between the fields of science-based climatology, and engineering-based hydrodynamics.

### The mechanics of flood hydraulics

- Hydraulics *'is the science that deals with the laws governing water or other liquids in motion and their application in engineering practical or applied hydrodynamics'* (Macquarie Dictionary)
- Both physical and numerical (computer) models can be used to convert rainfall estimates (flood hydrology) to peak flood levels (flood hydraulics).
- Flood hydraulics is primarily an engineering-based profession.

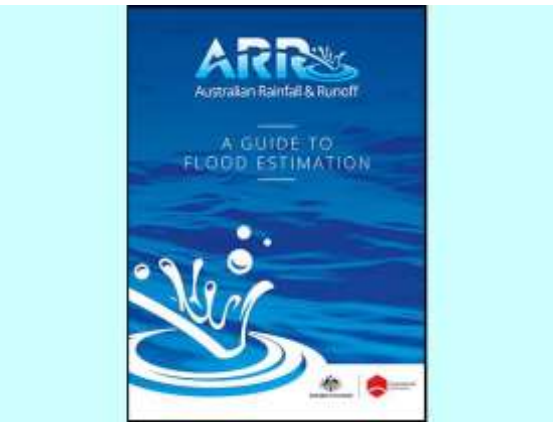
### Flood prediction is not an exact science

- In general there are two types of flood predictions:
  - predictions made while rain is still falling on a drainage catchment
  - flood predictions for large catchments where a known flood wave travels slowly down a river after rainfall has ceased (e.g. Murray River in 2022).
- It is the former case that is the most difficult to predict because these flood predictions must be based on an estimate of future rainfall.

### Confusing terminology

- The terminology used within the science of flood prediction can be confusing.
- A '1 in 100 year flood' does not mean the flood is likely to occur only once every 100 years; in fact it can, and has, occurred in consecutive years at some locations.
- A '1 in 100 year flood' simply means that there is a 1% chance of the flood being exceeded within any 12-month period.
- In hydrology, such a flood is more commonly referred to as the '1% flood'.

## Terminology




**Australian Rainfall and Runoff (2016)**

***ARR, Australian Rainfall & Runoff – A Guide to Flood Estimation,* 2016.** The Institution of Engineers, Australia, Barton, ACT.

- This is the principal flood estimation guideline used in Australia.
- This document presents the preferred terminology for storm and flood events as developed by the Australian Bureau of Meteorology (BoM), and Engineers Australia (EA).

**Recommended terminology (BoM)**

**Recommended terminology for storm and flood events**

- The table (left) developed by the BoM and EA presents the preferred terminology (shown in blue, pink & green highlight) for use in the description of different storm and flood events.
- The table recommends a different set of terms to be used for minor storm (< 1 in 5 years) storms, large (< 1 in 100 years), and severe storms (> 1 in 100 years).
- Below (in pink) is the flood terminology commonly used by councils & the media.

| Frequency | EY | AEP (%) | (1 in X) | ARI | Engineering Design |
|---|---|---|---|---|---|
| Very frequent | 12 | | | | Stormwater treatment |
| | 6 | 99.75 | 1.002 | 0.17 | |
| | 4 | 98.17 | 1.02 | 0.25 | |
| | 3 | 95.02 | 1.05 | 0.33 | |
| | 2 | 86.47 | 1.16 | 0.50 | |
| Frequent | 1 | 63.20 | 1.58 | 1 | Drainage design |
| | 0.69 | 50.00 | 2.00 | | |
| | 0.50 | 39.35 | 2.54 | 2 | |
| | 0.22 | 20.00 | 5.00 | | |
| | 0.20 | 18.13 | 5.52 | 5 | |
| Infrequent | 0.11 | 10.00 | 10 | 10 | Floodplain management |
| | 0.05 | 5.00 | 20 | 20 | |
| | 0.02 | 2.00 | 50 | 50 | |
| | 0.01 | 1.00 | 100 | 100 | |
| Rare | 0.005 | 0.50 | 200 | 200 | |
| | 0.002 | 0.20 | 500 | 500 | |
| | 0.001 | 0.10 | 1000 | 1000 | |
| Extremely rare | 0.0005 | 0.05 | 2000 | 2000 | Major infrastructure |
| | 0.0002 | 0.02 | 5000 | 5000 | |
| | | | | | |
| | (EY = Expected exceedances per year) | (AEP = Annual Exceedance Probability) | (1 in X year probability) | (ARI = Average Recurrence Interval) | |
| | | | (PMP = Probable Maximum Precipitation) | (PMF = Probable Maximum Flood) | |
| | | | | | |
| Extreme | | | PMP | PMF | |

**Table 1 – Storm and flood terminology commonly used by councils and the media**

## Terminology

**Stormwater treatment system**

**Stormwater drainage system**

**Flood map**

**Emergency services building**

### Reasons for different terminology

- The reason why different forms of terminology are used within the hydrology profession is because each form of terminology (EY, AEP, ARI) is based on a different method of analysing rainfall data.
- Depending on what type of drainage system is being designed, there is a preferred way of analysing the rainfall.
- Unfortunately, because of the different ways rainfall can be analysed, comparing EY values with AEP or ARI values, is a bit like comparing apples with oranges.
- Similar issues can exist in other industries. Consider, for example, a system for ranking high schools. You may prefer the schools to be ranked according to:
  - the highest Year-12 student score achieved within each school, or
  - an average of the top 10% of Year-12 students in each school, or
  - an average of all Year-12 students in each school.
- Similarly, rainfall data can be analysed based on the worst storm in each year, or the top X% of storms independent of which year they occurred.

### How the different systems are used in engineering design

- The EY-system is a measure of the expected number of storms that are likely to exceed a given rainfall intensity over a 12-month period.
- This terminology is useful in the design of stormwater treatment systems that have a flow capacity less than a 1 in 1 year storm, such roadside stormwater filters.
- The AEP-system stands for Annual Exceedance Probability, which is presented as either a percentage (%), or as a '1 in X years' value.
- This terminology is commonly used in the generation of flood maps.
- The ARI-system stands for Average Recurrence Interval.
- This terminology is often used when councils specify the design standard for new and upgraded drainage systems on roads and subdivisions.
- In the ARI-system, the 'design storms' are often referred to as Q1, Q2, Q5, Q10, etc., where the 'Q' term stands for 'quantity' or 'discharge'.

## How hydrologists predict flood levels during a flood

Doppler weather radar

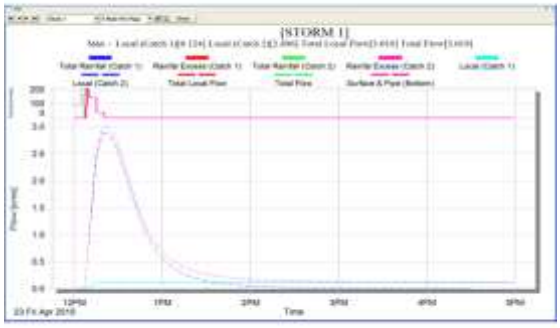
### Measuring distant rainfall

- A combination of weather balloons, fixed gauging stations, and Doppler radars are routinely used to develop weather maps.
- As a storm approaches a particular drainage catchment, special radars can measure the variations in rainfall intensity across the storm front.
- This radar data can then be compared with the 'actual' rainfall data collected from rainfall gauges located within the drainage catchment.

Rainfall monitoring station

### Measuring actual rainfall data

- Automatic rainfall gauges measure the rainfall intensity and send this data back to a central office for processing.
- The data collected from these rainfall gauges is processed to determine if the rainfall depth (mm), or intensity (mm/hr), exceeds any of the pre-determined 'trigger values'.
- If any of the trigger values are exceeded, then a flood warning is generated and issued to the public.




Output from numerical hydrology model

### Turning rainfall data into flood predictions

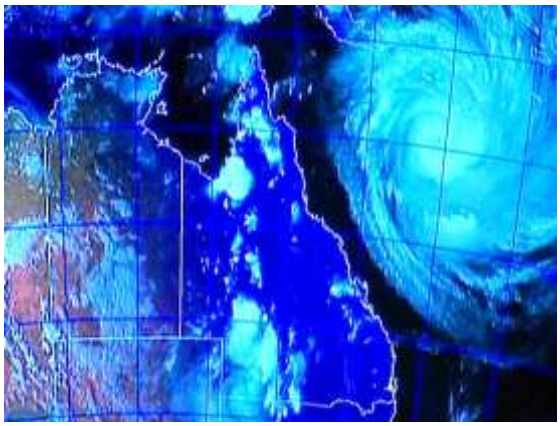
- Well before any flooding occurs, computer models are set up and calibrated for each drainage catchment.
- As a storm approaches an area, early rainfall **'predictions'** can be used within these computer models to provide **'preliminary'** flood level predictions.
- As rain begins to fall on the catchment, these computer models can be updated (in real time) using a combination of actual and predicted rainfall data.

Manual flood height gauge

### Measuring actual flood levels

- Finally, as flood levels rise along the waterway, a combination of automatic and manual flood height gauges record and report on river flood levels.
- These measured river flood levels are used to further update and refine flood predictions until the flood has passed.
- Consequently, flood level predictions are continually updated as the 'predicted' storm data used within the computer models is slowly replaced with 'actual' rainfall and flood level data.

## Why it is so difficult to accurately predict flood levels during a flood



**Satellite imagery (BoM)**

### Trying to predict a moving target

- It is relatively easy for computer models to predict the height and timing of floods once the rain has stopped and the floodwaters are moving slowly down a long river system.
- However, it is usually necessary for flood levels to be predicted well before the rain has stopped.
- In such cases, flood level predictions need to be based on 'predicted' rainfall, rather than 'actual' rainfall.

**Flood release from a dam**

### Not just a case of predicting rainfall

Predicting flood levels is not just a simple case of knowing if rainfall will continue over the next few days—hydrologists also need to know the following:

- estimated rainfall **depths** at various locations across the drainage catchment for each day that rain is likely to occur
- soil moisture conditions
- predicted discharges from any dams located within the catchment
- coastal tide and storm surge information.

**Approaching storm front**

### What can go wrong in flood prediction

The following are some of the problems that can be faced when predicting flood levels:

- Weather systems can change very quickly. If you think that predicting tomorrow's weather is hard, then try predicting the likely depth of rainfall in three days time.
- Sometimes rainfall gauges can record unusually high or low rainfall readings, which could mean a high-intensity storm burst is actually occurring, or that the rain gauge has been damaged by the storm.
- As the flood moves down a river, hydrologists use automatic river-height gauges to confirm that their numerical models are accurately predicting flood levels. Occasionally these gauges can give unusual readings. The hydrologists will therefore need to determine if:
  - there is a problem with their model, or
  - the high water levels are being caused by excessive debris blockage of a downstream culvert or bridge, or
  - the gauging station has been damaged by floodwaters.

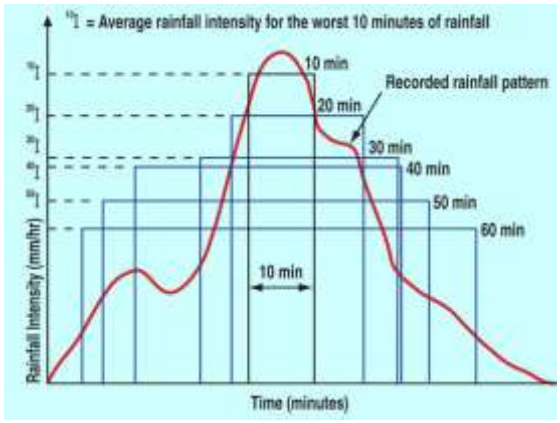
**Automatic river flood level gauge**

## Production of flood maps

**Physical river and floodplain model**

### Physical models

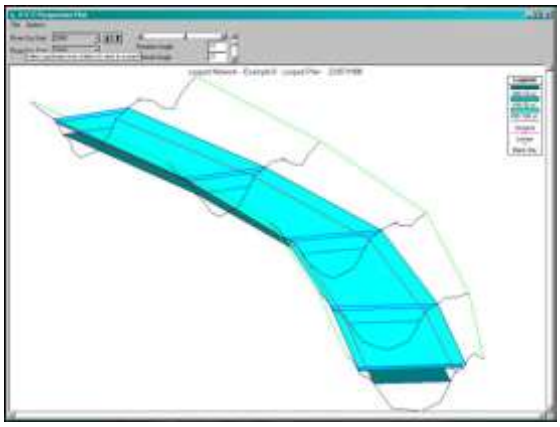
- Historically, flood maps were produced through the operation of large physical models.
- These days computer models are quickly replacing the more expensive physical flood models.
- Today the role of physical models is limited to the study of complex hydraulic conditions such as the design of dam spillways, and investigations into some coastal engineering projects.




**Analysis of a real storm**

### Analysis of historical rainfall data

- Flood mapping starts with the analysis of historical rainfall data.
- From this data hydrologists determine the statistical probabilities of various rainfall intensities for different storm periods.
- When interpreting this information, hydrologists need to consider the duration of the recording period in order to account for known climatic cycles (e.g. the period 1950–2000 contained more severe flooding than the period 1900–1950).



**Numerical modelling**

### Computer models

- A separate computer model must be prepared and calibrated for each waterway.
- In large river systems there is usually one model that incorporates the full catchment, and several smaller models prepared for key locations and important tributaries.
- The full catchment model is typically used for flood predictions, while the smaller models can be used for detailed flood mapping and hydraulic design.

**Flood map (Brisbane City Council)**

### Plotting flood inundation maps

- Flood maps can provide two forms of information; flood levels (usually to Australian Height Datum, AHD) and the expected extent of flood inundation.
- Converting a ‘flood level map’ to a ‘flood inundation map’ requires accurate land topography information. Only with recent advances in aerial survey technology have hydrologists had access to such data.
- The ‘actual’ extent of the flood risk can also change from time to time as a result of ongoing property development.

## Why authorities focus on the 1 in 100 year flood

**Another C&C free publication**

### Living with floods

- It is unrealistic to expect everyone to live and work above the **maximum** flood level.
- People need to regularly interact with waterways and floodplains for many reasons, including:
  - movement of goods by ships
  - farming on highly-productive floodplains
  - recreational pursuits.
- This means authorities need to define specific flood levels that can be used to regulate various land use activities.

**River flooding**

### Social importance of the 1 in 100 year flood

- The 1 in 100 year (1%) flood level has been favoured by governments because, rightly or wrongly, it is considered to be the maximum flood that a person is **likely** to experience within their lifetime.
- Statistics show that there is approximately a 50% chance of a 1 in 100 year flood being exceeded at least once, at a given location, over a period of 70 years.
- There is also a 15% chance of the flood being exceeded at least **twice** in 70 years.

**Flood marks on building**

### Definition of a 1 in 100 year flood

- A 1 in 100 year flood is defined as a flood that has a 1% probability of being equalled or exceeded within any 12 month period.
- However, this does **not** mean that there is a 100 % probability of the flood occurring within a 100 year period!
- Historical records indicate that in Australia there is approximately a 63% probability of a 1 in 100 year flood being exceeded over a 100 year period, and a 39% chance of exceedance over a period of 50 years.

**River flooding**

### Likelihood of a 1 in 100 year (1%) flood

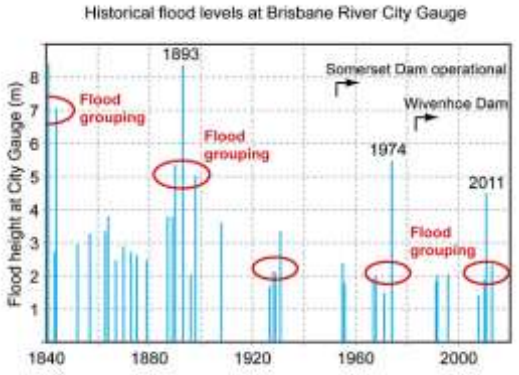
- The following table outlines the probability of the **1 in 100 year (1%)** flood occurring at least once over a specified period.

| Time period | Probability |
|---|---|
| 1 year | 1% |
| 10 years | 10% |
| 50 years | 39% |
| 70 years | 50% |
| 100 years | 63% |
| 200 years | 86% |
| 500 years | 99% |

## Maximum possible flood

**Flood map, Mt Ommaney, Brisbane (BCC)**

**River flooding**




**Historical flood records, Brisbane**

**Stormwater flooding**

### Probable Maximum Flood (PMF)

- The maximum expected flood level is normally defined by the Probable Maximum Flood (PMF).
- A PMF is the outcome of the maximum probable rainfall precipitation coupled with the worst possible flood-producing catchment conditions that could reasonably be expected to occur simultaneously within a given catchment.
- It is the PMF that defines the full extent of the floodplain.

### The likelihood of a PMF

- The PMF has a likely occurrence of once in 10,000 to 10,000,000 years.
- Australia may have existed as a continent for millions of years, but our **current** climatic conditions would have only existed for possibly a few hundred, or thousands of years.
- Even though the world's climatic conditions are constantly changing, some parts of Australia would have already experienced a PMF.

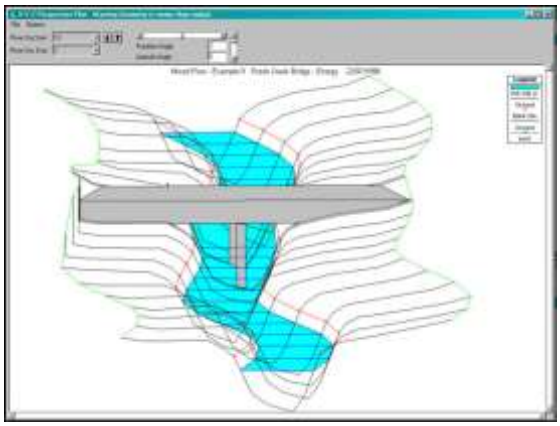
### Flood grouping

- Most hydrology text books indicate that the probability of a 1 in 100 year flood occurring within any given year is 1%, and that this probability is independent of what flooding occurred in the previous years.
- However, severe floods have a tendency to group within 'wet years', while non-flood years group within periods of drought.
- Consequently, it is common for two or more severe floods to occur within a relatively short period of time.

### Flooding <u>above</u> the PMF

- A common error found in some publications is the statement that homes located above the nominated PMF are effectively 'flood free'.
- It would be unwise to suggest that any building is truly 'flood free'.
- Property flooding can originate from a variety of sources, including groundwater and local stormwater run-off.
- Even a home built on the top of a hill could be subject to flooding if appropriate stormwater drainage was not installed.

## Why it is so difficult to predict the 1 in 100 year flood level



**Computer modelling of creek & bridge**

### Flood mapping assumptions

- Flood mapping is based on predicted storm and catchment data, including:
  - expected travel path of the storm
  - soil moisture levels at the start of rainfall
  - degree of debris blockage at crossings
  - tidal and storm surge conditions.
- If the 'actual' conditions are different from the 'assumed' conditions, then a different flood level will be reached.

**Automatic rain gauge**

### A problem of insufficient rainfall data

- It would be a mistake to assume that predicted 1 in 100 year (1%) flood levels will always be correct.
- The reality is that in Australia we have only been collecting rainfall data of around 100 years. This means that there is only around a 63% chance that a 1 in 100 year rainfall event has actually been recorded at any given weather station.
- It would take hundreds of years to confirm the true 1% flood level, by which stage the world's climate would have changed.

**Partial catchment storm**

### Extent of rainfall

- The severity of flooding is strongly influenced by the extent and uniformity of rainfall across the drainage catchment.
- It is possible that a severe storm would only impact upon a part of the drainage catchment.
- For a catchment the size of the Murray-Darling basin it would be highly unlikely for a single storm to extend over the whole catchment. In such cases, flood mapping may rely upon historical flood levels rather than rainfall-runoff modelling.

**Woody debris in a rural stream**

### Waterway conditions

- Flood levels in minor waterways can be highly dependent on the vegetation roughness that exists within the waterway at the time of the flood.
- If two floods occur in close proximity, then the flood levels achieved during the second flood can be affected by the vegetation damage that occurred during the first flood.
- Waterway vegetation also has a tendency to change over time, sometimes from season to season.

## The 1 in 100 year storm does not always produce a 1 in 100 year flood

**Low water level within dam**

### 1 in 100 yr storms, and 1 in 100 yr floods

- It should be noted that a 1 in 100 year storm will not necessarily produce a 1 in 100 year flood level.
- If the storm occurs when the tides are low, or the catchment is very dry, or the dams are nearly empty, then a lower flood level would be expected to occur.
- If the storm occurs when the tides are high, or the catchment is wet, or the dams are full, then a higher flood level would result.

**Dry soil**

### Soil moisture conditions

- If a severe thunderstorm occurs after a long period of dry weather, then creek flooding may not even occur.
- However, if the same thunderstorm was to occur after several days of moderate rainfall, then the risk of creek flooding is significantly increased.
- The ability of the soil to absorb and infiltrate large quantities of rainwater greatly influences the occurrence and severity of downstream flooding.

**Severe debris blockage of a road culvert**

### Debris blockage

- Flood levels are not only influenced by the flow rate, but also the hydraulic conditions that exist within the watercourse.
- For example, a minor 1 in 1 year stream flow approaching a fully blocked road culvert can result in higher flood levels than the predicted 1 in 100 year flood level based on a clean (non-blocked) culvert.
- Debris blockage is usually random, highly variable, and not necessarily related to the severity of the storm.

**Storm surge**

### Tidal conditions

- Tidal conditions can significantly influence flood levels in coastal regions.
- In the case of large rivers, there is a high probability that peak tidal conditions will occur during the flood peak.
- However, for the smaller creeks, there is only about a 50% chance that the flood peak will occur during a high tide.
- In addition to tides, there is also the risk of a storm surge adding to flood levels.

## How the flood risk can change over time

Control burning

### Changes to bushland hydrology

- If the hydrologic response of a catchment changes over time, then so will the flood risk.
- There are many activities that can change the hydrologic response of a catchment, including bushfires, land clearing, dam construction, and channel works.
- The risk of flooding normally increases for a period of 5 to 10 years after severe bushfires—the shorter time frame typically applies to tropical regions.

Land clearing

### Changes in vegetation cover

- Land clearing can significantly increase the frequency and severity of minor floods.
- The influence of land clearing on flooding is less pronounced if the rainfall extends over several days, or weeks.
- Deep-rooted plants, such as trees, help to lower the watertable, thus increasing the quantity of rainfall required to saturate the catchment.
- Vegetation along the waterway channel helps to hold back floodwaters and reduce the severity of downstream flooding.

Urban catchment

### Changes in urban density

- Urbanisation not only clears the drainage catchment of its vegetative cover, but also covers much of the earth with impervious surfaces such as roads and roofs.
- Urbanisation has its greatest impact on the frequency and severity of minor floods.
- A significant impact on major flooding is only likely to result from changes to the flood storage capacity of the floodplain, either due to the construction of flood-control levees, or the filling of floodplains to create flood-free urban land.

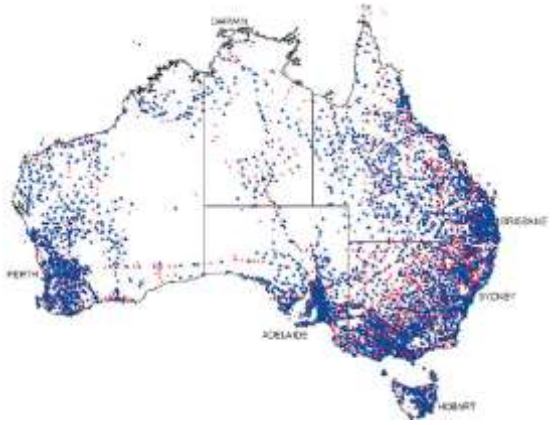
Effects of climate change

### Climate change

- The risk of flooding also varies over time as a result of changes to the world's climate.
- Ongoing climate change is a natural phenomenon; however, there is ample evidence to support the claim that human activities are significantly increasing the 'rate' of this change.
- Climate change is likely to increase the frequency of severe flooding within those catchments primarily affected by thunderstorms.

# 5. The Determination of Flood Level Probabilities

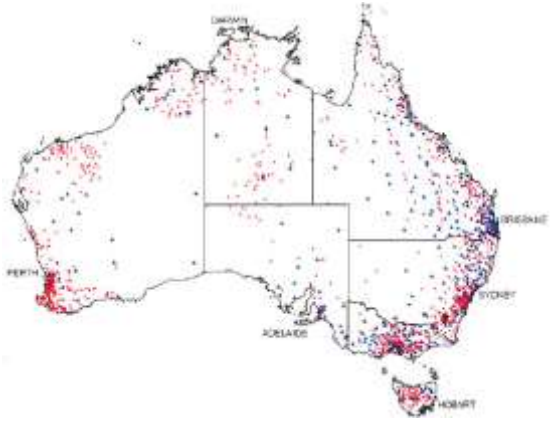
## The determination of flood level probability



**Daily-read rainfall stations (ARR, 2016)**

### Daily-read rainfall data

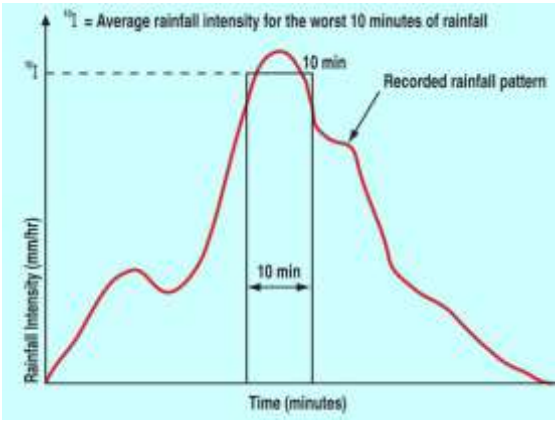
- Rainfall data is collected and analysed from a wide range of weather stations located around Australia.
- Daily-read rainfall stations provide only the depth of rainfall over a 24 hour period.
- Daily-read rainfall stations are numerous in their number, and generally provide rainfall data over a longer period than the automatic, continuous-recording, rainfall stations.



**Continuous rainfall stations (ARR, 2016)**

### Continuous rainfall stations

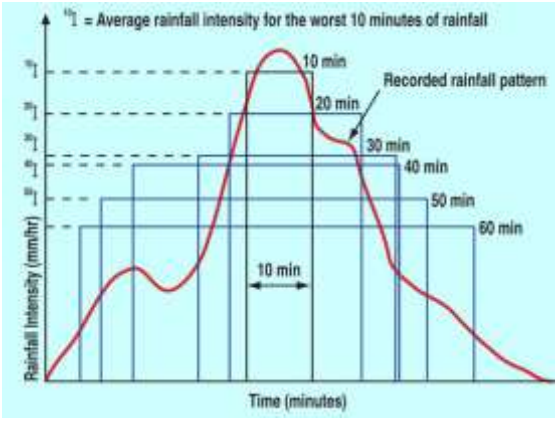
- Automatic, continuous-recording, rainfall stations are capable of recording rainfall data throughout a storm event.
- In most cases, this rainfall data is sent automatically (i.e. in real time) to a central recording station, usually a council, or the Bureau of Meteorology.
- It is the data from these stations that is used to determine the statistical probability of average rainfall intensities for various storm durations (known as IFD data).




**Worst 10 minutes of rainfall**

### Analysis of historical storms

- The Australian Bureau of Meteorology has taken the recorded rainfall data from each weather station, and then analysed each recorded storm event for:
  - the 'worst' 5, 10, 20, 30, 40, 50, 60, etc. minutes of rainfall
  - the average rainfall intensity for each of these time periods
  - the statistical probability of the average rainfall intensity for each time period.

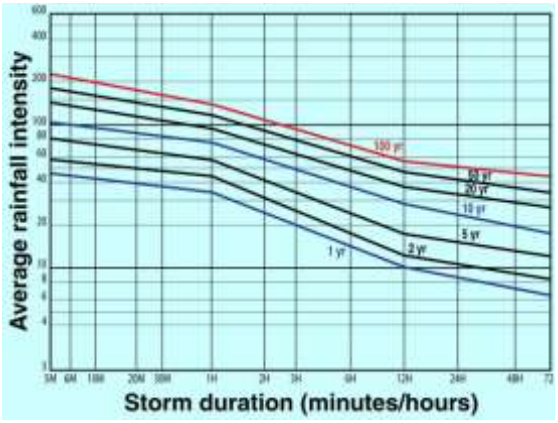



**Analysis of rainfall intensities**

### Analysis of storms for a range of storm frequencies

- An analysis of all the rainfall records from around Australia allowed the Bureau of Meteorology to determine some consistent patterns for Australian rainfall data.
- With the aid of these known rainfall patterns, the Bureau was able to:
  - make best use of the rainfall data at each weather station
  - identify and remove erroneous rainfall data.

## The determination of flood level probability




**Example IFD data from a given location**

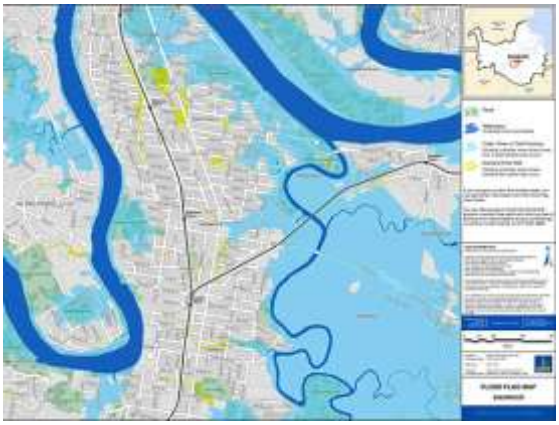
### The determination of rainfall intensity probabilities for each rainfall station

- The final outcome from the statistical analysis of all the storm data is a rainfall Intensity-Frequency-Duration (IFD) chart for each weather station.
- This data is then used to develop a rainfall map that allows councils to determine an IFD chart for any location within Australia.
- This IFD data is used for both flood mapping and engineering design.

**Rainfall over part of a river catchment**

### The determination of the likely storm and catchment conditions

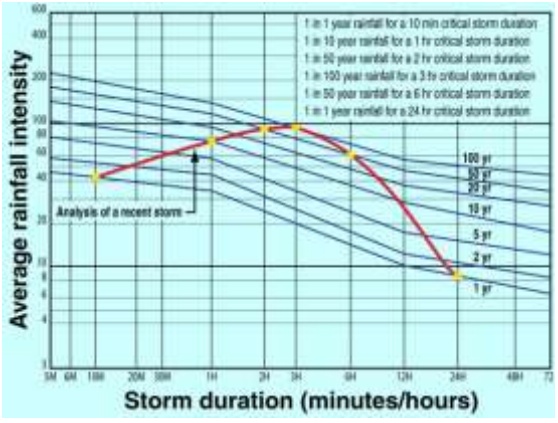
- In addition to the rainfall intensity data, the Bureau of Meteorology, in association with Engineers Australia, also determined:
  - possible rainfall patterns (i.e. variations in the rainfall intensity during a storm)
  - the probable extent of a storm event over large river catchments
  - the probability of debris blockages of waterway structures during flood events
  - the probability of storm surges in coastal regions.



**Flood map (Brisbane City Council)**

### The determination of flood level probabilities from numerical flood models

- Councils and state governments use this rainfall data to:
  - calibrate numerical flood models such that the frequency of flooding generated within the model is consistent with flood level data recorded at various river gauging stations
  - generate flood maps that identify the extent of flooding for various flood level probabilities (1 in 100 yr, etc.) at various locations.

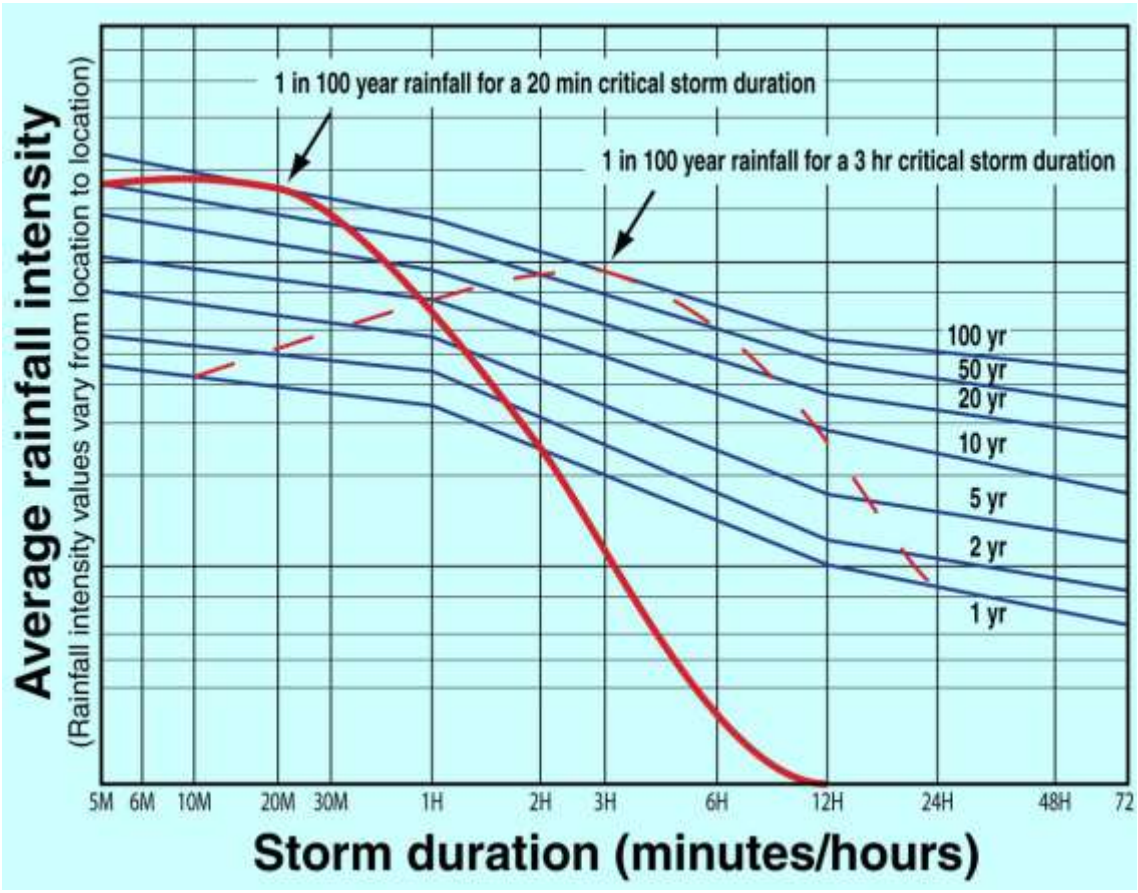



**Analysis of a recent storm**

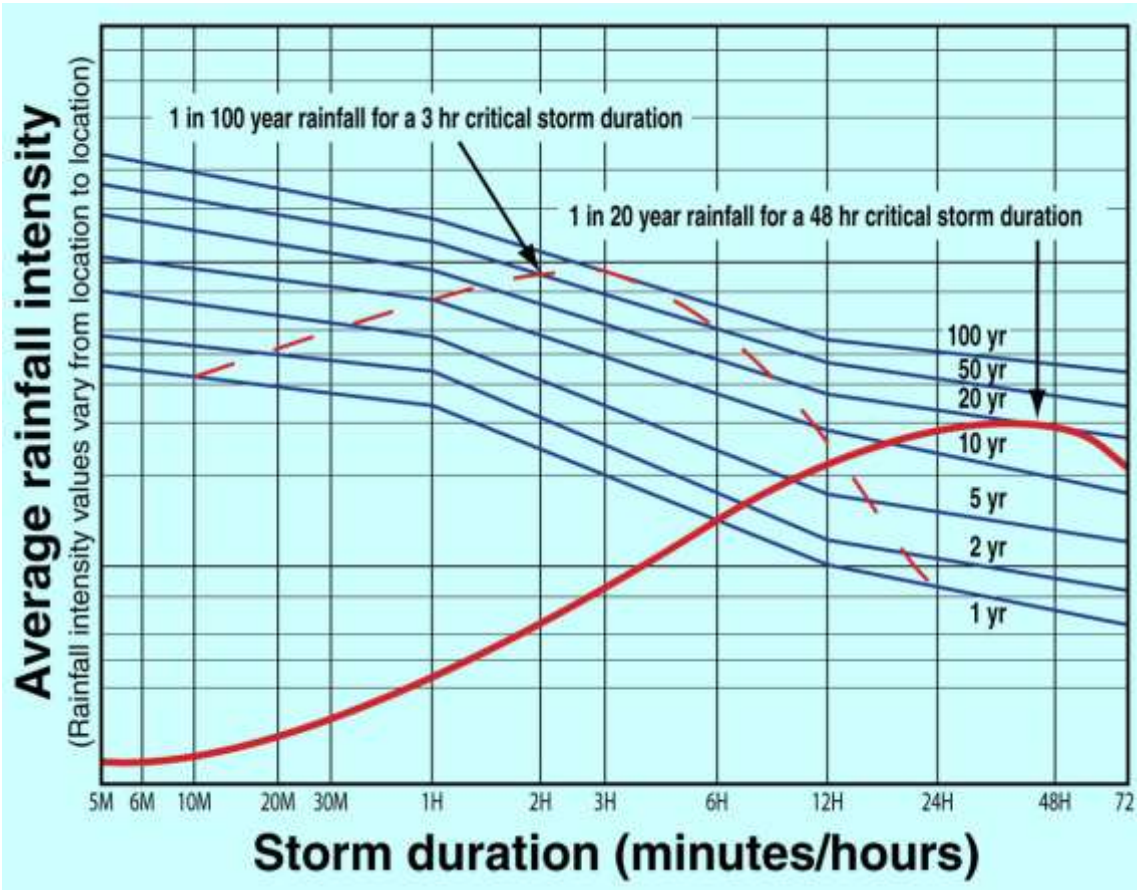
### The real-time analysis of rainfall data during a storm

- During a storm event, actual rainfall data can be compared with long-term averages in order to determine if a flood warning needs to be issued.
- This plot (red line) shows an example of a storm event that is likely to produce:
  - 1 in 100 yr flooding at any location that has a 3 hour critical storm duration
  - 1 in 10 yr flooding at any location that has a 1 hour critical storm duration, etc.

**Example storm frequency curves for various individual storms**




**Example of a short-duration, 1 in 100 yr thunder storm (shown as solid, red line)**



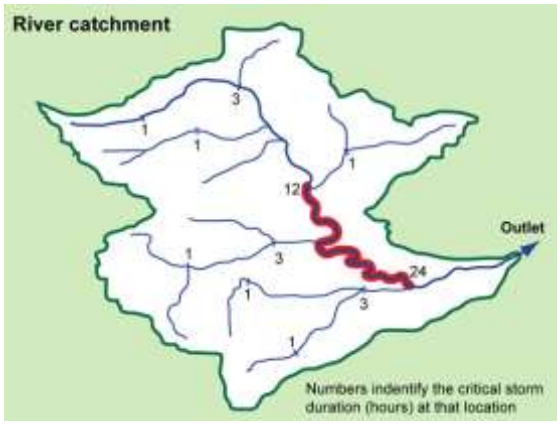

**Example of a possible 1 in 20 year, 48 hour storm event (just one possible example)**

# 6. Why Does a 1 in 100 Year Flood Appear to Occur So Often?

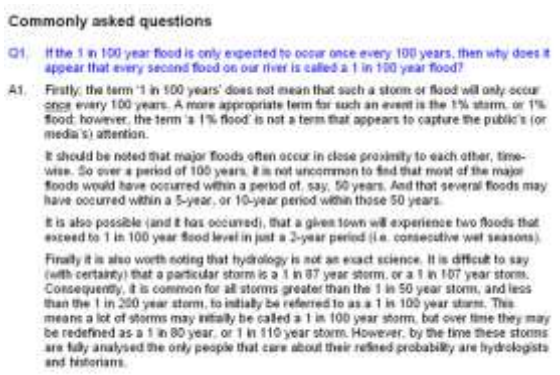
## Introduction

**River flood marker**

**Murray–Darling river catchment**




**Region of 12-24 hr critical storm duration**



Commonly asked questions

Q1. If the 1 in 100 year flood is only expected to occur once every 100 years, then why does it appear that every second flood on our river is called a 1 in 100 year flood?

A1. Firstly, the term '1 in 100 years' does not mean that such a storm or flood will only occur once every 100 years. A more appropriate term for such an event is the 1% storm, or 1% flood; however, the term 'a 1% flood' is not a term that appears to capture the public's (or media's) attention.

It should be noted that major floods often occur in close proximity to each other, time-wise. So over a period of 100 years, it is not uncommon to find that most of the major floods would have occurred within a period of, say, 50 years. And that several floods may have occurred within a 5-year, or 10-year period within those 50 years.

It is also possible (and it has occurred), that a given town will experience two floods that exceed to 1 in 100 year flood level in just a 2-year period (i.e. consecutive wet seasons).

Finally it is also worth noting that hydrology is not an exact science. It is difficult to say (with certainty) that a particular storm is a 1 in 97 year storm, or a 1 in 107 year storm. Consequently, it is common for all storms greater than the 1 in 50 year storm, and less than the 1 in 200 year storm, to initially be referred to as a 1 in 100 year storm. This means a lot of storms may initially be called a 1 in 100 year storm, but over time they may be redefined as a 1 in 80 year, or 1 in 110 year storm. However, by the time these storms are fully analysed the only people that care about their refined probability are hydrologists and historians.

**Chapter 1. *'Commonly Asked Questions'***

### Introduction

- People can begin to mistrust the science of hydrology if they hear repeated predictions of the 1 in 100 year flood.
- Logic would suggest that a 1 in 100 year flood would occur just once in a person's lifetime (if they live their entire life in one town).
- However, there can be many reasons why several 'reports' of a 1 in 100 year flood are issued.

### Explanation No.1

- Hydrology is a complicated science, and it is a science that relies heavily on mathematics and statistical analysis.
- Given the complexity of the mathematics associated with the 1 in 100 year flood I have decided to present three different explanations to this common public question.
- Explanation No.1 (next chapter) is based around the Murray–Darling river catchment.

### Explanation No.2

- Explanation No.2 is based around a fictitious river catchment.
- This explanation involves a bit more mathematics.
- It is important to note that there is **not** just one type of 1 in 100 year storm or flood, in fact there is an infinite number of different types of 1 in 100 year storms and floods.
- Every flood is different, even if two floods reach the same maximum river level at a given location, over the length of a river the two floods will be different.

### Commonly asked questions

- Explanation No.3 was provided in an earlier chapter titled *'Commonly Asked Questions'* (Chapter 1).
- It is not necessary to read all three explanations—just focus on the explanation that best aligns with your way of thinking.

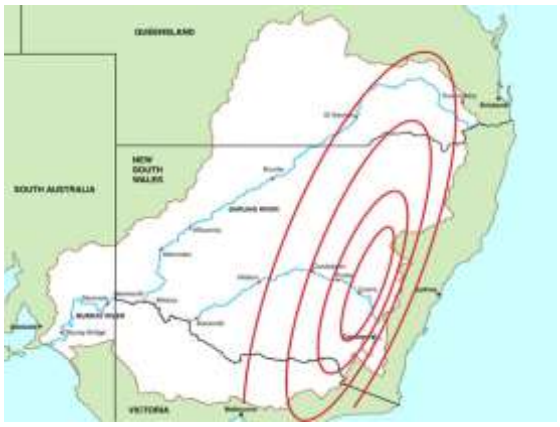
# 7. Why the 1 in 100 Year Flood Appears to Occur So Often

## Explanation No. 1

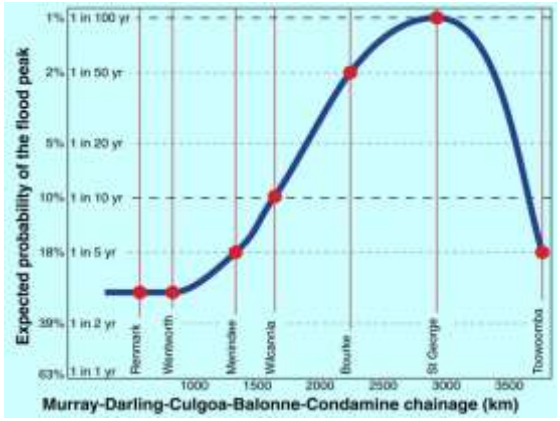
# Introduction

**Murray–Darling river catchment**

**Storm in the upper catchment**




**Storm in the eastern catchment**




**Severity of river flooding (example)**

### Introduction

- The Murray–Darling river catchment (or Murray–Darling basin) is the largest river catchment in Australia.
- The river system has a length of 3,375 km, and a catchment area of 1,061,469 km$^2$.
- Given the size of the catchment it is highly unlikely that:
  - a single storm will extend over the whole catchment
  - the rainfall intensity will be uniform over the whole catchment.

### Storm in the upper catchment

- Storms can centre around the upper, lower, western, or eastern regions of the catchment.
- A major 1 in 100 year storm located in the upper Darling River catchment can cause 1 in 100 year flood levels in the upper, central, or lower catchment depending on the storm's duration.
- Short-duration storms have their greatest impact in the region where the storm occurred.

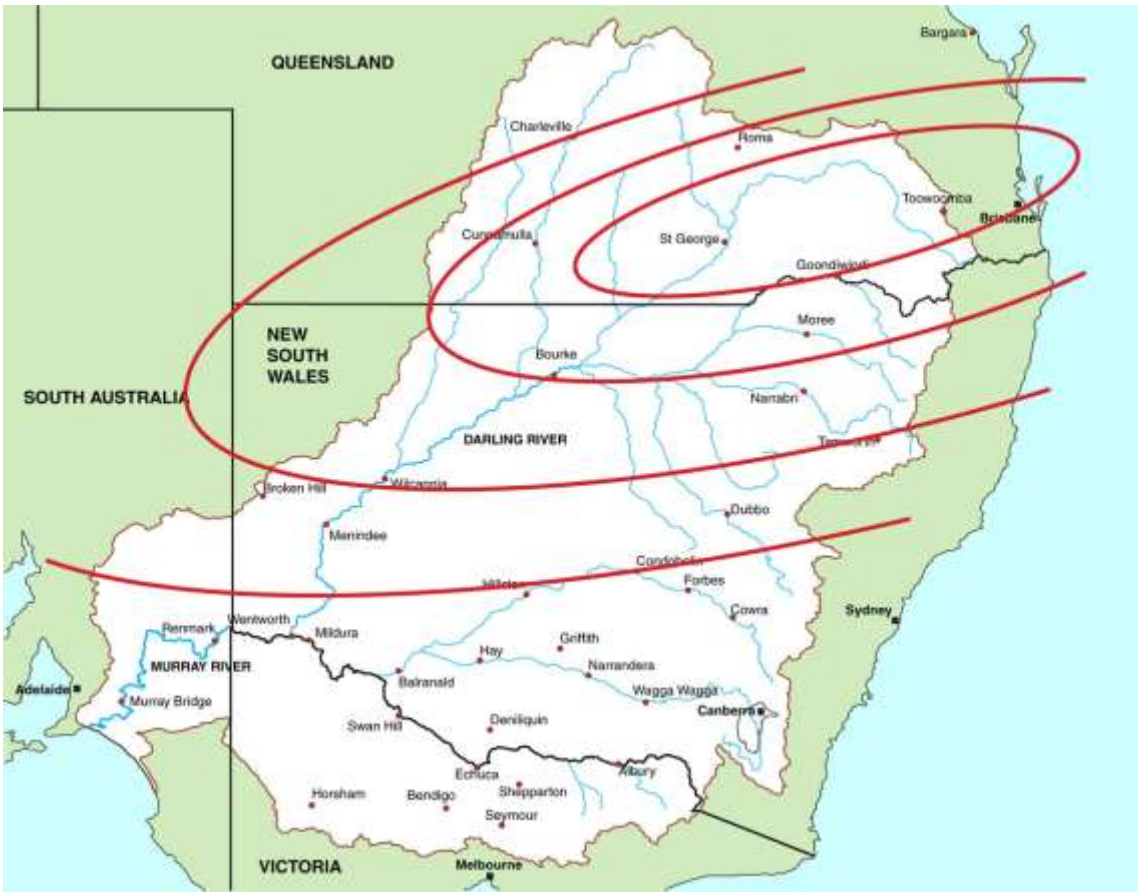
### Storm on the eastern region

- A 1 in 100 year storm centred in the eastern catchment can cause 1 in 100 year flood levels in the rivers of central NSW, or in the lower Murray River depending on the storm's duration.
- Short-duration storms would have their greatest impact in the eastern region of NSW.
- Long-duration rainfall depressions, such as the storms experienced in late 2022, can cause severe flooding along the Murray River.

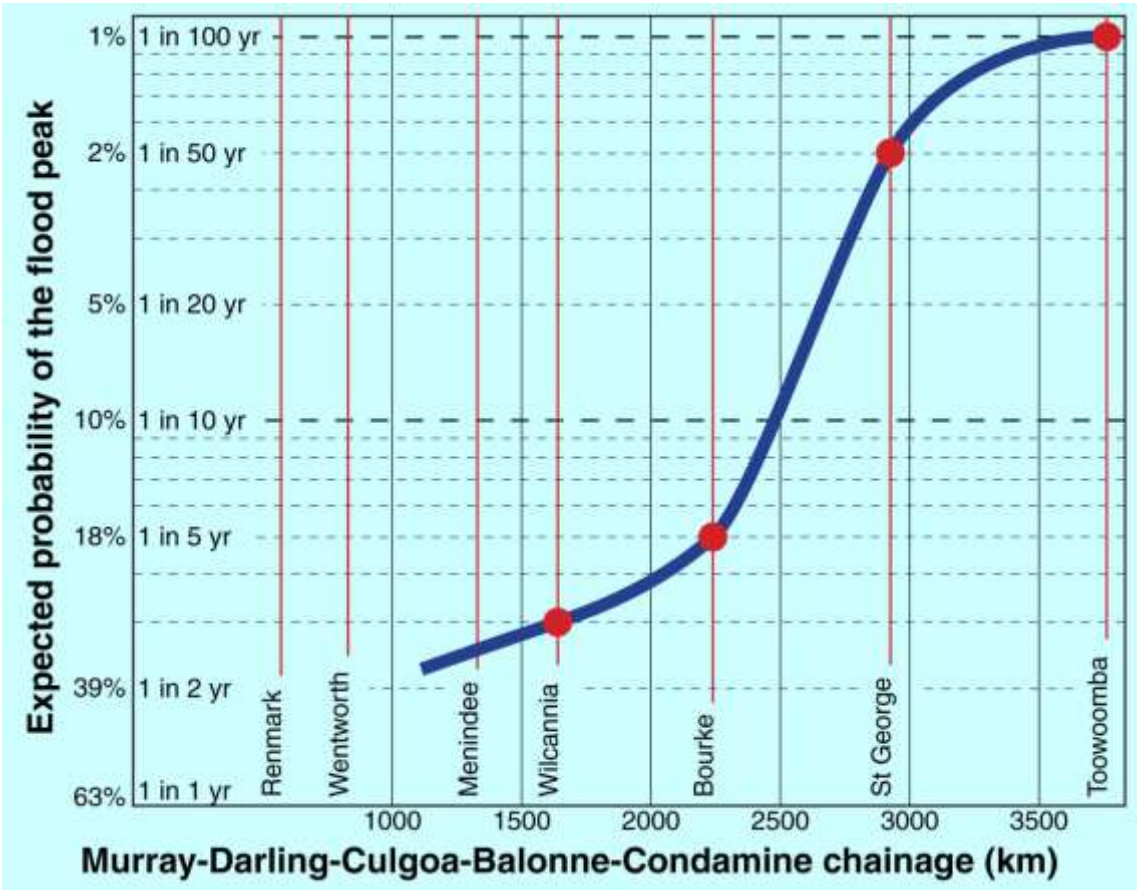
### Storm in the lower catchment

- In order to demonstrate how the severity of flooding can vary along the river, graphs such as this (left, and following pages) show the possible flood frequency (i.e. 1 in 100 yr, 1 in 50 yr, etc.) at various chainages (distances) along the river.
- For most storm events there will be just one region of the river that will experience the most severe flooding.
- However, it is possible for 1 in 100 year flooding to occur at more than one location during a given storm event.

## Example short-duration storm

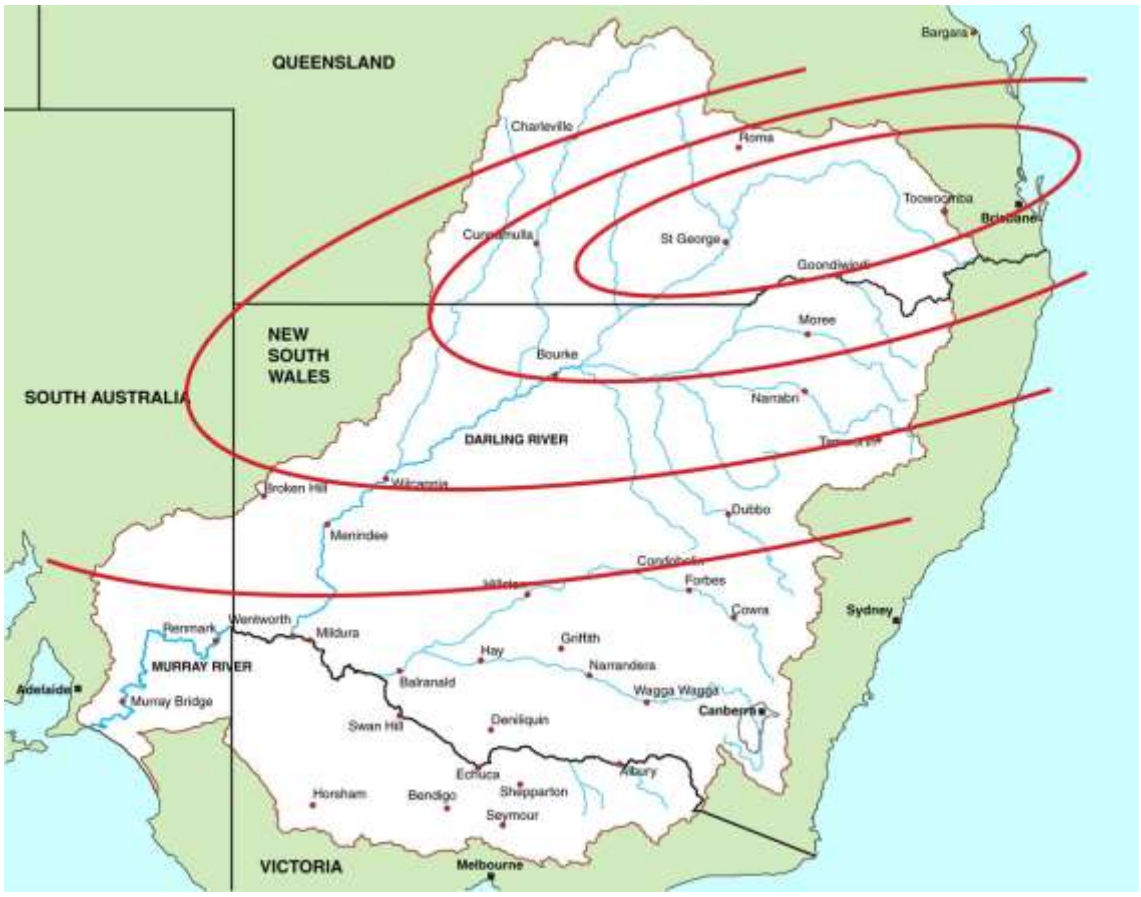



**A short-duration storm centred in the upper Darling River catchment**

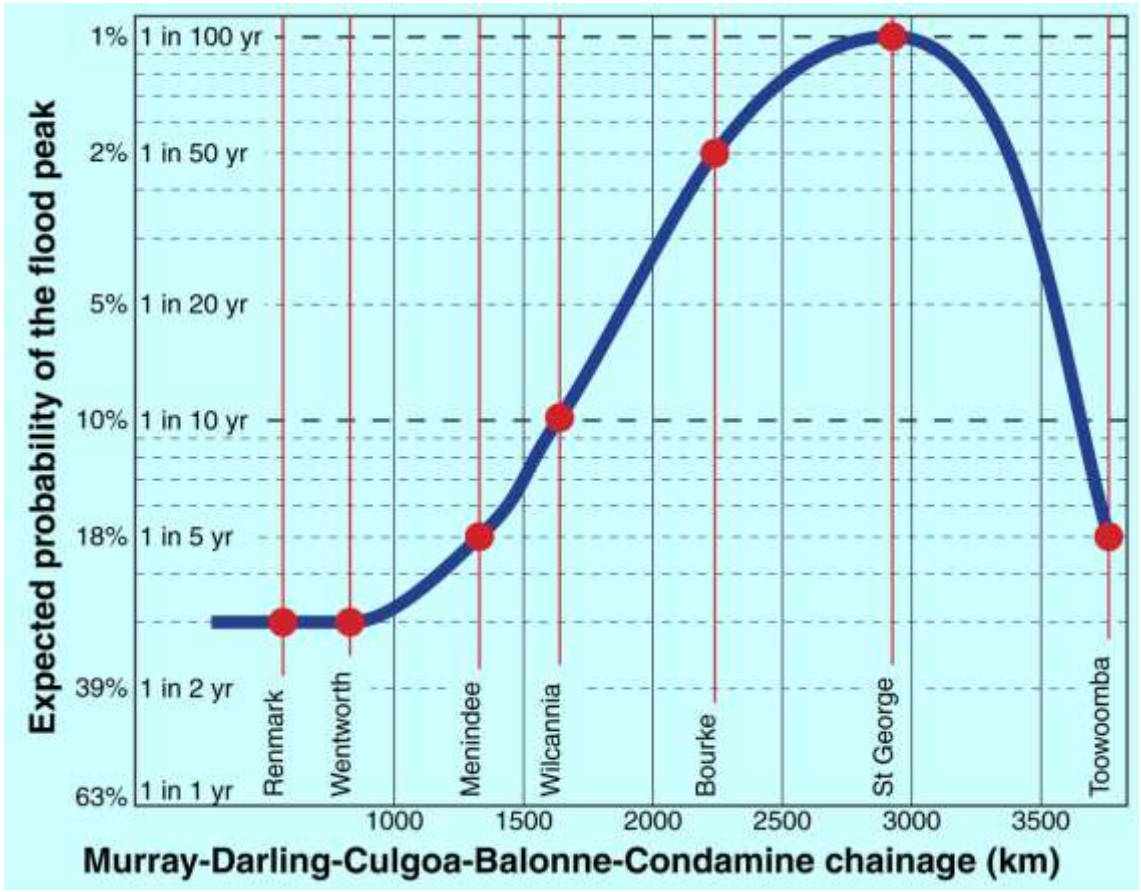



**Possible flood severity resulting from the above storm (example only)**

## Example long-duration storm

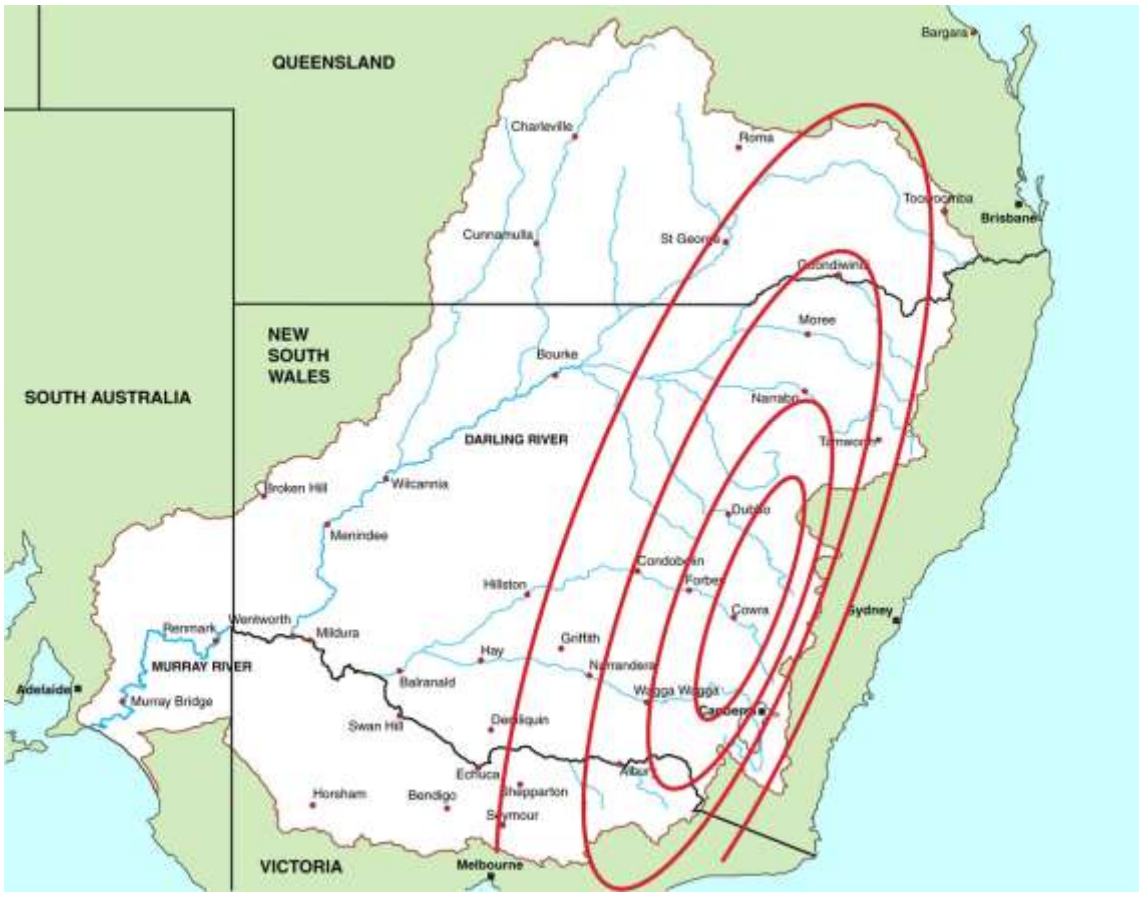



**A long-duration storm centred in the upper Darling River catchment**

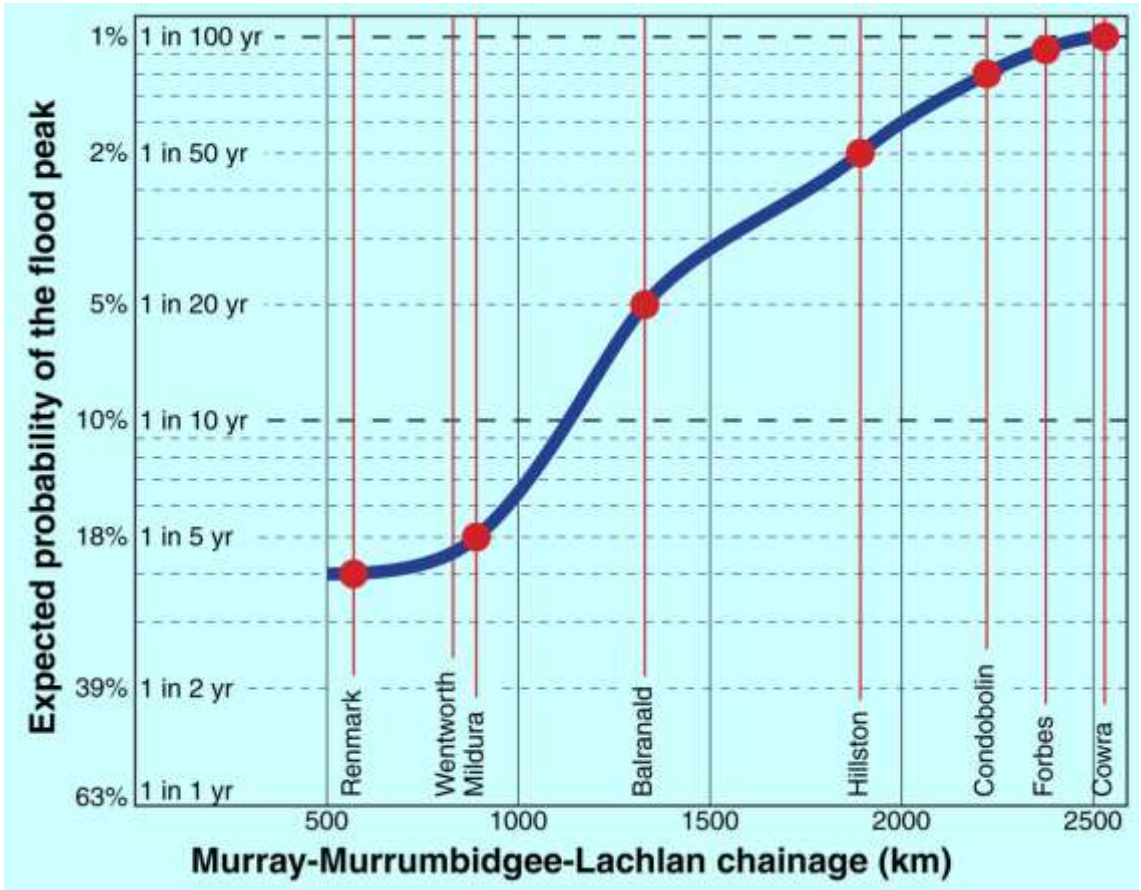



**Possible flood severity resulting from the above storm (example only)**

## Example short-duration storm

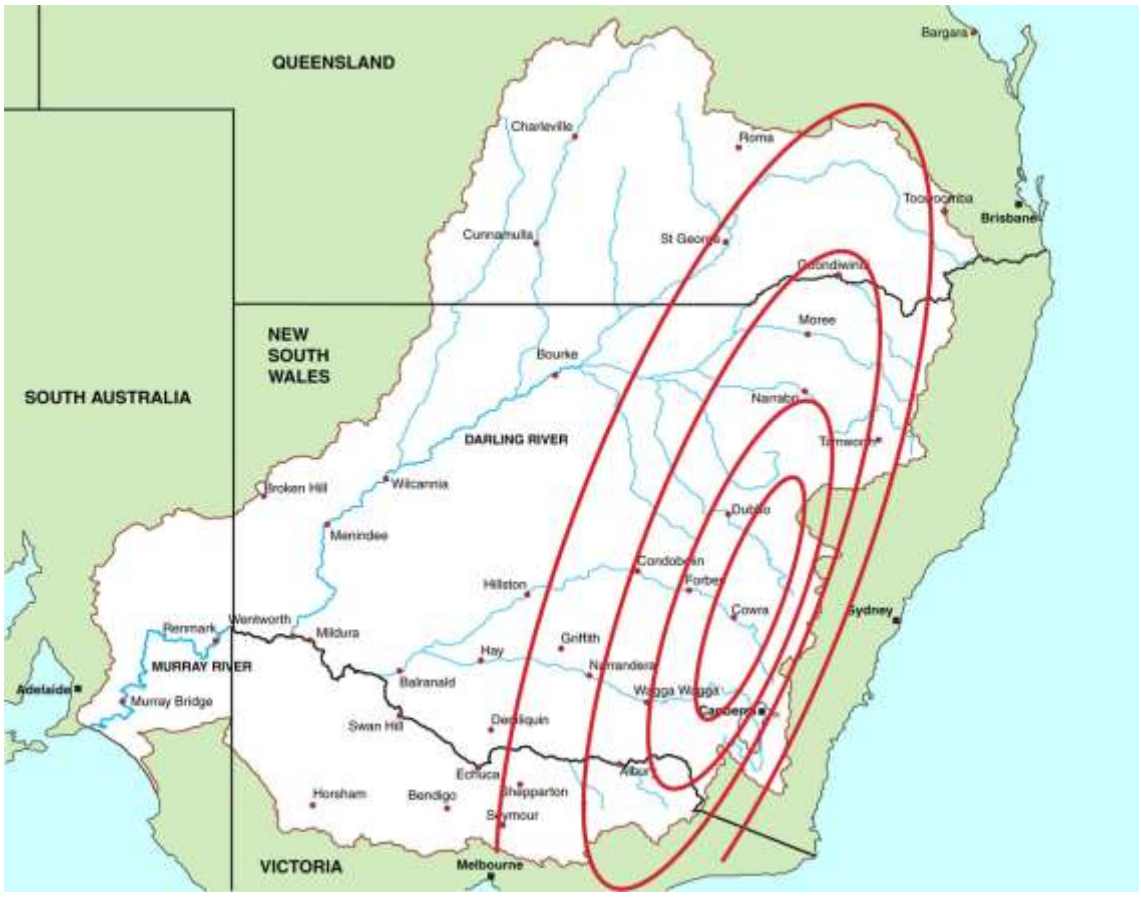



**A short-duration storm centred in the eastern Murray–Darling catchment**

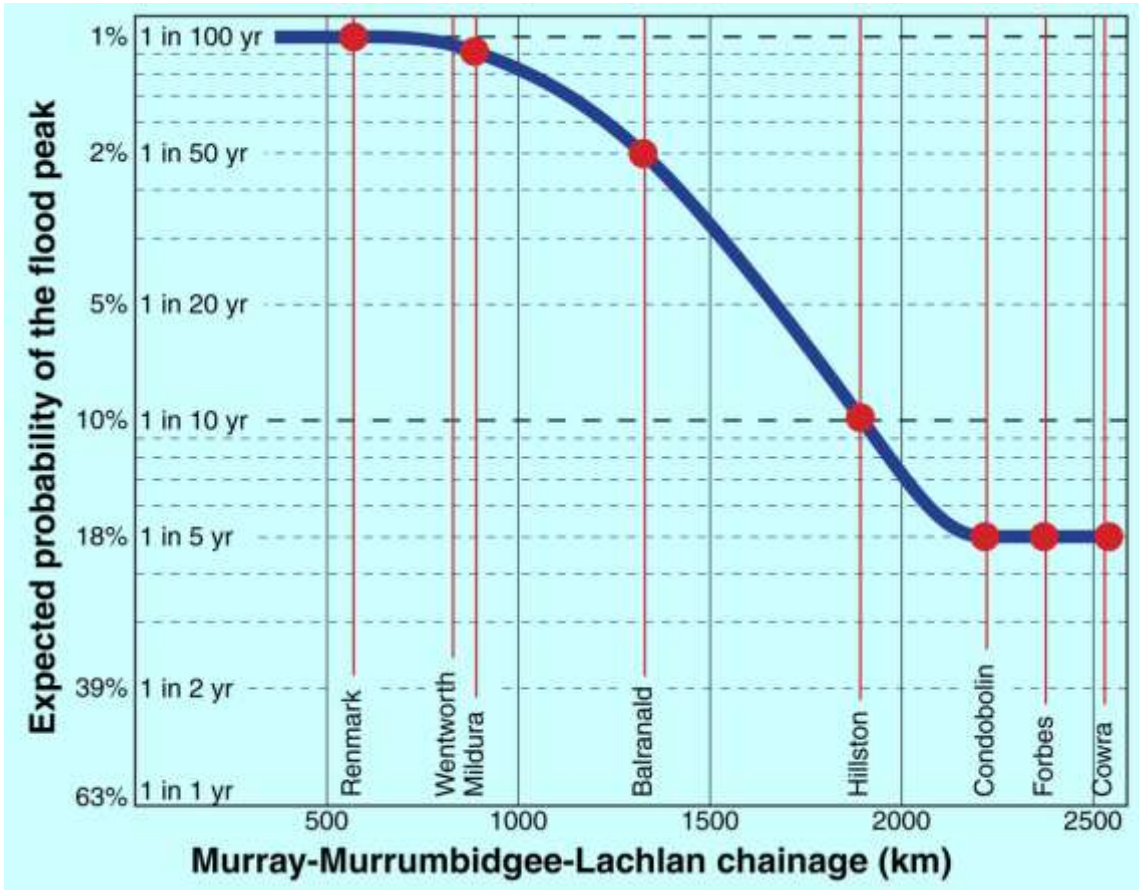



**Possible flood severity resulting from the above storm (example only)**

## Example of a very long-duration storm

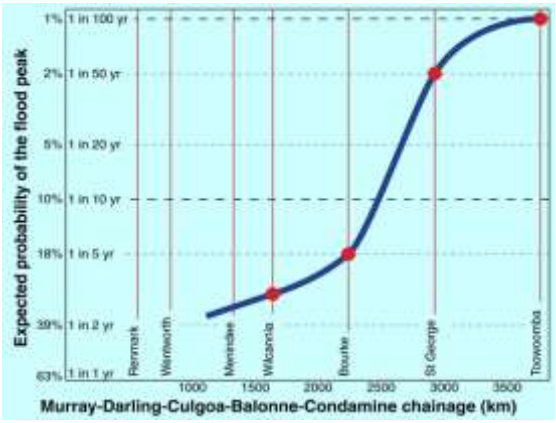



**A very long-duration storm centred in the eastern Murray–Darling catchment**




**Possible flood severity resulting from the above storm (example only)**

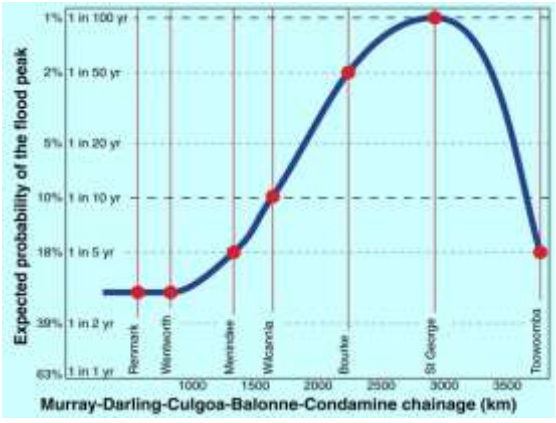
## Analysis of these four 1 in 100 year storm events




**Severity of river flooding**

### Short-duration upper catchment storm

- A short-duration storm, similar to what was experienced in 2011, may cause:
  - 1 in 100 year flooding in Toowoomba
  - 1 in 50 year flooding at St George
  - 1 in 5 year flooding at Bourke.
- If the residents of St George were unaware of the flood damage that had just occurred in Toowoomba, they may be wondering why such a storm was announced over the radio as a 1 in 100 year event.




**Severity of river flooding**

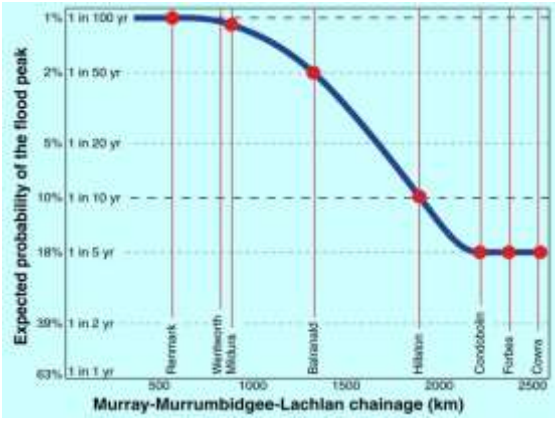
### Long-duration upper catchment storm

- A long-duration storm may cause:
  - 1 in 5 year flooding in Toowoomba
  - 1 in 100 year flooding at St George
  - 1 in 50 year flooding at Bourke
  - 1 in 10 year flooding at Wilcannia
  - 1 in 5 year flooding at Menindee.
- Similarly, if the residents of Toowoomba were unaware of the flood damage that was about to occur at St George, they may be wondering why such a storm was called a 1 in 100 year event.

**Severity of river flooding**

### Short-duration eastern catchment storm

- A short-duration storm in the eastern catchment may cause:
  - 1 in 100 year flooding at Cowra
  - 1 in 50 year flooding at Hillston
  - 1 in 20 year flooding at Balranald
  - 1 in 5 year flooding at Mildura.




**Severity of river flooding**

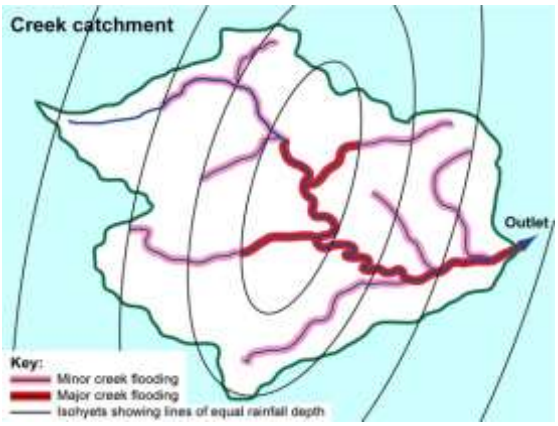
### Long-duration eastern catchment storm

- A very long-duration storm may cause:
  - 1 in 5 year flooding at Cowra
  - 1 in 10 year flooding at Hillston
  - 1 in 50 year flooding at Balranald
  - 1 in 100 year flooding at Renmark.
- **All of these storms can be classified as 1 in 100 year storms even though they only produce 1 in 100 year flooding at one region along the river system, thus many storms can officially be called 1 in 100 year events.**

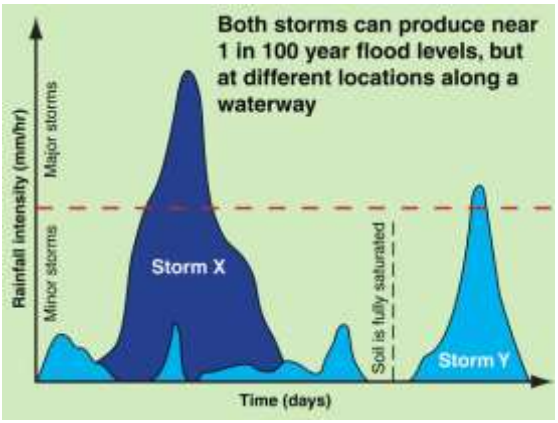
# 8. Why the 1 in 100 Year Flood Appears to Occur So Often

## Explanation No. 2

## Introduction




**Variable flooding along a waterway**




**Storm hydrographs**

**Upper catchment flooding**

**Lower catchment flooding**

### Different storms cause different outcomes

- During any given flood there will always be one location along a waterway where the severity of flooding will be the worst.
- In one flood it will be **Town X** that suffers the worst flooding, while in the next flood it may be **Town Y**.
- The fact that one town experiences 1 in 100 year flood levels during a particular flood does **not** mean that 1 in 100 year flood levels will have been reached at all locations along the waterway.

### Many different types of 1 in 100 year floods

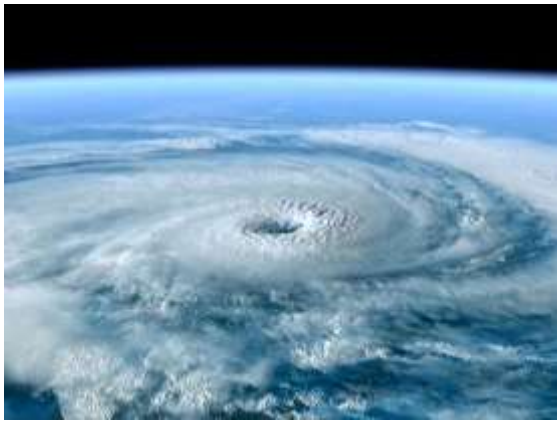
- One of the most important things to know about storm hydrology is that there is **not** just one type of storm that can be called a 1 in 100 year, or 1%, storm.
- Severe storms come in all different shapes and sizes.
- If we consider a large river catchment the size of the Murray–Darling basin, then there will never be just one storm that produces 1 in 100 year flood levels at all locations along the waterway.

### Critical storm duration

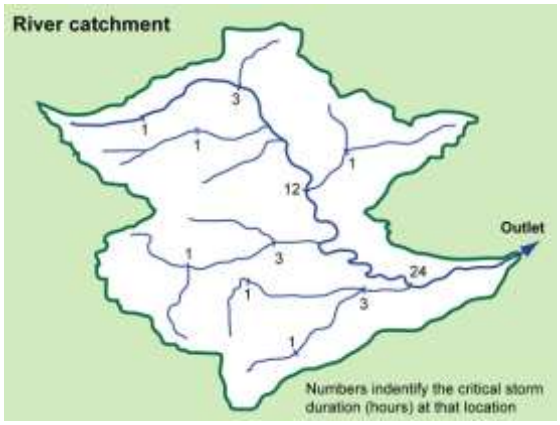
- Each **storm** has its 'worst-case' storm duration—that being the period of the storm where the rainfall intensity (averaged over this time period) is considered to be the most severe.
- Similarly, each **town** along a waterway will have its own critical storm duration—that being the storm duration that governs the severity of flooding at that town's location.
- In the hydrology profession, the term 'critical storm duration' is used to define that period within a storm where the rainfall intensity (averaged over that period) is directly related to the severity of the flooding that can be expected at a given location along a waterway.
- For homes or towns in the upper part of the catchment, the critical storm duration may be less than one hour.
- For homes or towns in the lower part of the catchment, the critical storm duration may be several hours.
- In large river catchments the critical storm duration can be several days, or even several weeks.

## Why the 1 in 100 year flood appears to occur so often

**Thunder storm**



**Cyclone**




**Example river catchment**

| | Time period | | | | |
|---|---|---|---|---|---|
| | 30 min | 60 min | 3 hours | 12 hours | 24 hours |
| Storm A | 80 mm | 103 mm | 145 mm | 150 mm | 155 mm |
| Storm B | 72 mm | 113 mm | 140 mm | 165 mm | 170 mm |
| Storm C | 60 mm | 98 mm | 160 mm | 170 mm | 180 mm |
| Storm D | 30 mm | 57 mm | 109 mm | 246 mm | 304 mm |
| Storm E | 47 mm | 47 mm | 113 mm | 237 mm | 320 mm |

Total rainfall depths for different periods of rainfall

**Cumulative rainfall over different periods**

### Different storms affect different waterways

- It is common for severe thunderstorms to cause significant flooding along minor waterways; however, thunderstorms are short duration storms that cannot release enough rain to cause river flooding.
- River flooding usually requires long duration storms, such as those produced by cyclones, or widespread low pressure cells.
- The larger the river system, the longer the rainfall event that would be required to cause flooding.

### Many types of 1 in 100 year storms

- For any given waterway there is not just one type of 1 in 100 year storm, but several different types of storms that are required to achieve 1 in 100 year flood levels along the length of the waterway.
- Thus a 30-minute 1 in 100 years storm may flood the upper foothills one year, then several years later a 2-hour 1 in 100 year storm may cause severe flooding further downstream.
- Unfortunately, each of these storms will still be reported as a 1 in 100 year storm!

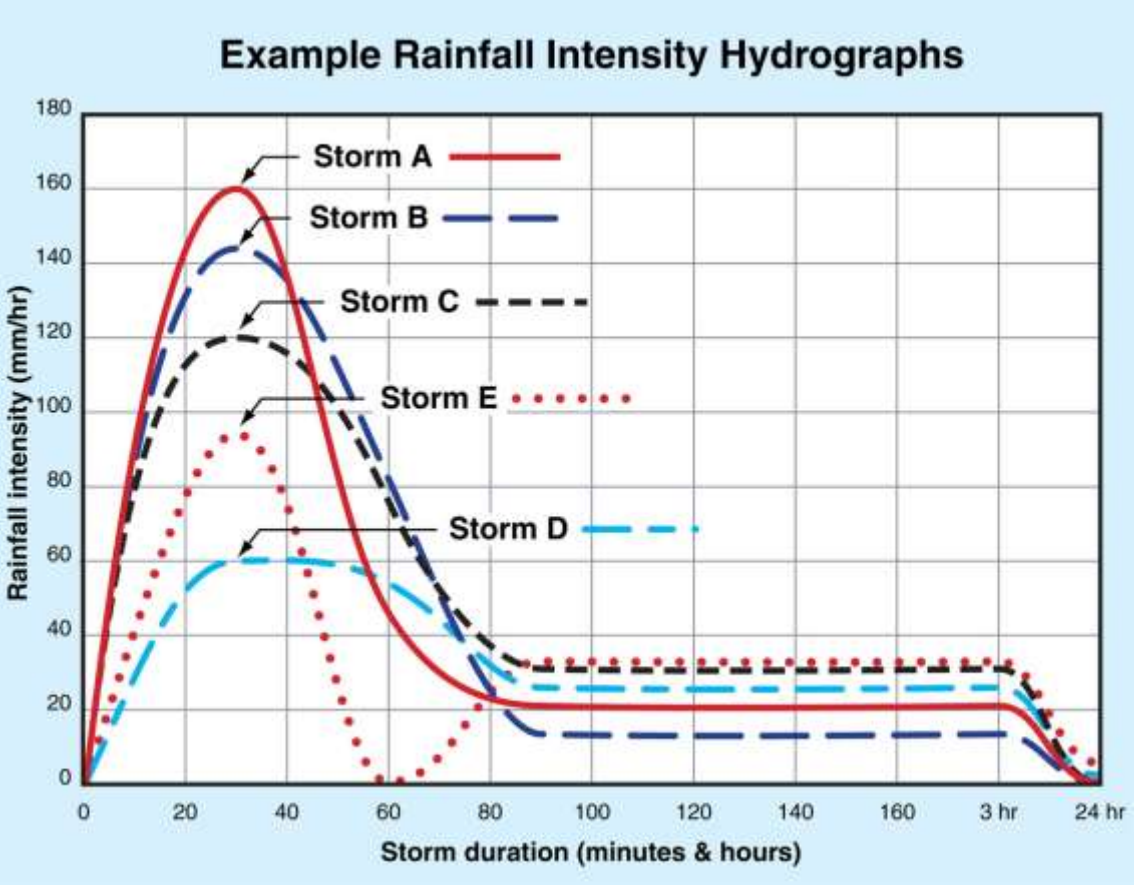
### Example river catchment

- It would be extremely rare for a single 1 in 100 year (1%) storm to be able to produce 1 in 100 year (1%) flood levels at <u>all</u> locations along a large river system.
- The diagram (left) shows an example **<u>river</u>** catchment with the critical storm duration (in hours) identified at various locations along the river.
- Different types of 1 in 100 year storms would produce different flood level peaks at each of these locations.

### Example 1 in 100 year storms

- The table opposite shows rainfall depths for a variety of 1 in 100 year storms for the Brisbane region, each having a different critical storm duration.
- In each case the rainfall continues for 24 hours; however, the duration of the main ‘storm burst’ is different for each storm.
- Even though all of these storms (A to E) would be classified as ‘1 in 100 year’ or 1% storms, each storm would produce different flood levels at different locations along the Brisbane River.

## Why the 1 in 100 year flood appears to occur so often




**Rainfall hydrographs for example 1 in 100 year storms A to E**

| | Time period over which rainfall intensities were averaged | | | | |
|---|---|---|---|---|---|
| | 30 min | 60 min | 3 hours | 12 hours | 24 hours |
| Storm A | 160mm/hr | 103mm/hr | 48.3mm/hr | 12.5mm/hr | 6.46mm/hr |
| Storm B | 144mm/hr | 113mm/hr | 46.7mm/hr | 13.8mm/hr | 7.08mm/hr |
| Storm C | 120mm/hr | 98mm/hr | 53.3mm/hr | 14.2mm/hr | 7.50mm/hr |
| Storm D | 60mm/hr | 57mm/hr | 36.3mm/hr | 20.5mm/hr | 12.7mm/hr |
| Storm E | 94mm/hr | 47mm/hr | 37.7mm/hr | 19.8mm/hr | 13.3mm/hr |
| Average rainfall intensities for different periods of rainfall | | | | | |

**Average rainfall intensity vs duration**

| | Critical storm duration | | | | |
|---|---|---|---|---|---|
| | 30 min | 60 min | 3 hours | 12 hours | 24 hours |
| Storm A | 1 in 100 | 1 in 63 | 1 in 60 | 1 in 10 | 1 in 4 |
| Storm B | 1 in 57 | 1 in 100 | 1 in 48 | 1 in 15 | 1 in 5 |
| Storm C | 1 in 20 | 1 in 47 | 1 in 100 | 1 in 17 | 1 in 7 |
| Storm D | 1 in 2 | 1 in 4 | 1 in 15 | 1 in 100 | 1 in 80 |
| Storm E | 1 in 7 | 1 in 2 | 1 in 17 | 1 in 85 | 1 in 100 |
| Assessed storm frequencies for different periods of rainfall | | | | | |

**Storm frequency vs storm duration**

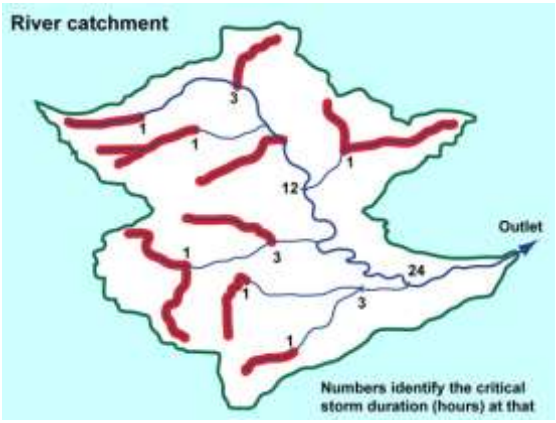
### Maximum average rainfall intensity measured over a specified duration

- In reality, a 1 in 100 year (1%) storm **should** be defined not just by its rainfall intensity, but also by the duration of the critical rainfall period.
- The table opposite provides the average rainfall intensities for different periods of rainfall for each of the above storms.
- Storm A has the most severe 30 minutes of rainfall intensity, while Storm E has the most severe average rainfall intensity measured over a 24 hour period.

### Storm frequency vs storm duration

- The table opposite provides the approximate storm frequencies if the worst 30 min, 60 min, 3 hr, 12 hr and 24 hour periods of rainfall intensity are considered for each storm.
- In very simplistic terms, if a person lived at a location along a river where the critical storm duration was 60 minutes, then 'Storm B' would likely produce a 1 in 100 year flood level, while 'Storm D' would only be expected to produce about a 1 in 4 year flood level.

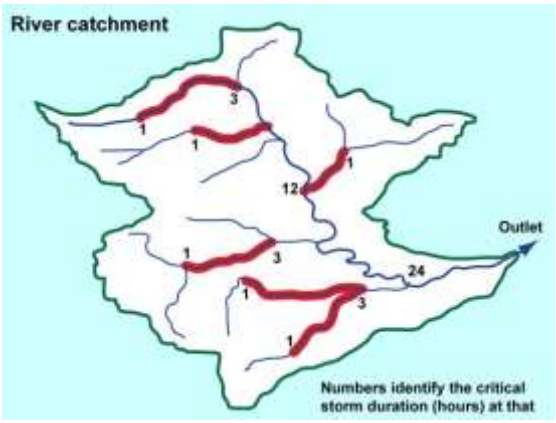
## Why the 1 in 100 year flood appears to occur so often




**30 to 60 minute critical storm region**

**Areas with a 1 hour critical storm duration**

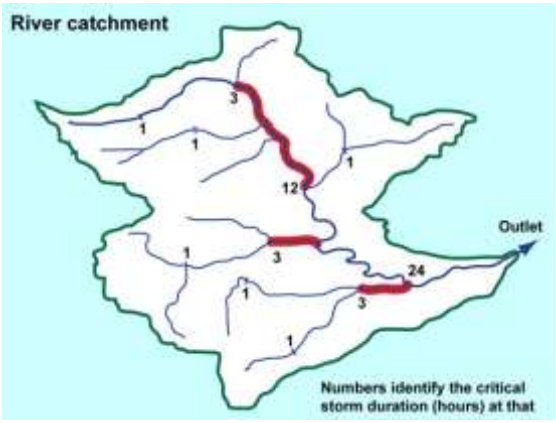
- This diagram identifies those areas along the waterway where the severity of the flooding is likely to be a direct response to the worst 30 to 60 minutes of rainfall within any given storm.
- In the example provided over the page, only storms A or B would likely produce near 1 in 100 year flood levels within the regions shown in red.




**1 to 3 hour critical storm region**

**Areas with a 1 to 3 hour critical storm duration**

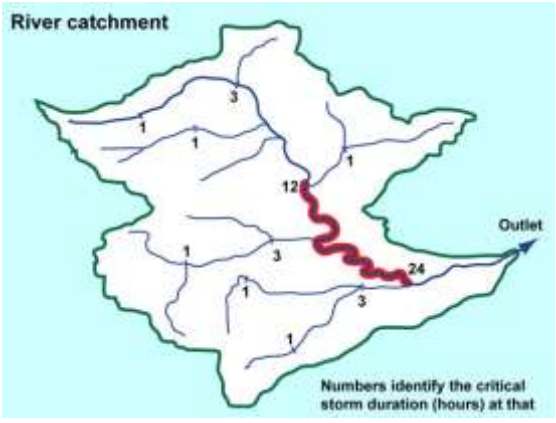
- This diagram identifies those areas where peak flood levels are likely to be directly related to the severity of the worst 1 to 3 hours of rainfall within a given storm.
- Only storms B or C would likely produce near 1 in 100 year flood levels within these regions.



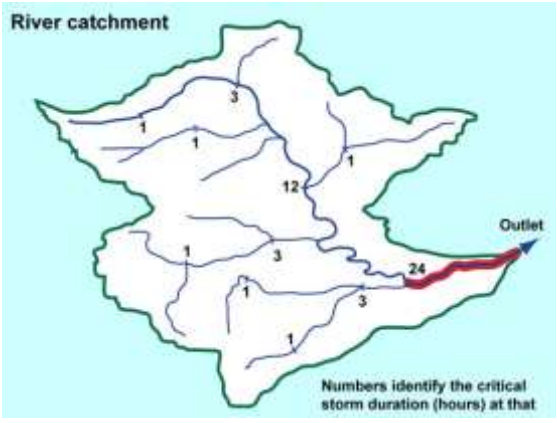

**3 to 12 hour critical storm region**

**Areas with a 3 to 12 hour critical storm**

- The diagram (left) identifies those areas where the severity of the flooding is likely to be related to the worst 3 to 12 hours of rainfall within a given storm.
- The diagram (bottom-left) identifies those areas where the severity of the flooding is likely to be related to the worst 12 to 24 hours of rainfall.
- The diagram (bottom-right) identifies those areas where the severity of the flooding is likely to be related to the worst 24 hours of rainfall.




**12 to 24 hour critical storm region**




**24 hour critical storm region**

## Why the 1 in 100 year flood appears to occur so often

**ABC Australia**

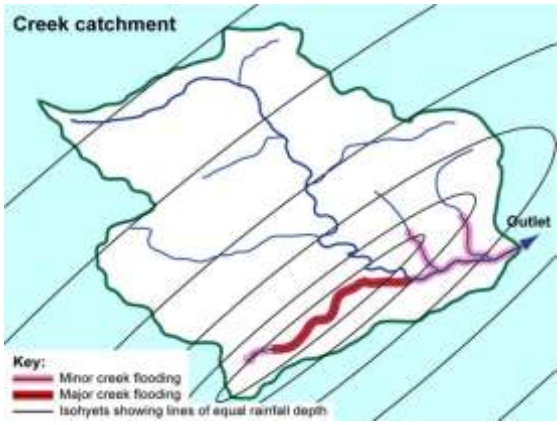
### Media coverage of storms

- The public generally learns about the occurrence of severe storms through the media.
- The wide coverage area of most media outlets means they can report on storm activities across several waterway catchments.
- Consequently, the frequent reference to the occurrence of 1 in 100 year (1%) storms is a reflection of the media's broad coverage area, rather than the frequency of such storms at a single location.

**Example creek catchment**

### Creek catchments

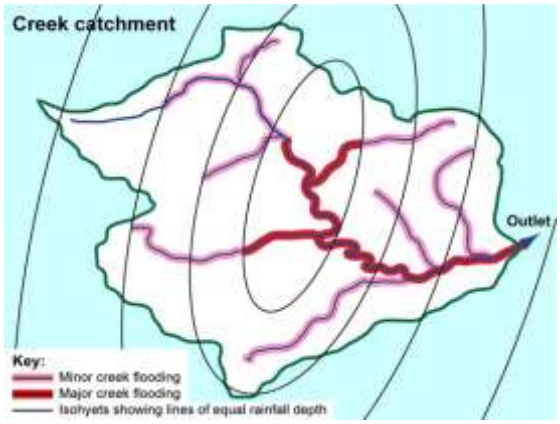
- Creek catchments are generally much smaller than river catchments, and their critical storm duration is normally less than a few hours rather than days or weeks.
- Even in creek catchments, 1 in 100 year storms can often appear to occur more frequently than most people would expect.
- Because of their small size, creeks are more likely to experience flooding as a result of high-intensity thunderstorms.



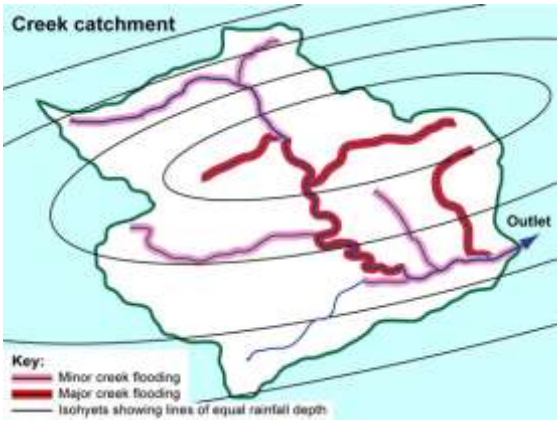

**Example 1 in 100 year storm**

### Example 1 in 100 year storm events

- In small creeks, it is common for a 1 in 100 year storm to produce 1 in 100 year flood levels along the full length of a creek.
- However, in large creeks a 1 in 100 year storm may cause 1 in 100 year flooding along isolated sections of the creek.
- These three diagrams (left & below) show various 1 in 100 year storms passing over a large creek catchment. Each storm produces severe flooding along different parts of the creek, but each storm will still be reported as a 1 in 100 year event.




**Example 1 in 100 year storm**




**Example 1 in 100 year storm**

# 9. Recommendations from the ‘Queensland Floods Commission of Inquiry’, 2012

## Introduction

In 2011 a Commission of Inquiry was held into the various floods that had occurred across Queensland during late 2010 and early 2011. The 'Queensland Floods Commission of Inquiry' (QFCI) presented its final report, along with its 177 recommendations, in 2012. This chapter reproduces only those recommendations that directly relate to storm and flood hydrology.

## Recommendations from the Queensland Floods Commission of Inquiry that directly relate to storm and flood hydrology

**Chapter 2 Floodplain management**

2.4 A recent flood study should be available for use in floodplain management for every urban area in Queensland. Where no recent study exists, one should be initiated.

2.9 Elected representatives from councils should be informed of the results of each flood study relevant to the council's region, and consider the ramifications of the study for land planning and emergency management.

2.13 For urban areas or areas where development is expected to occur:

(a) councils with the requisite resources should develop a flood map which shows 'zones of risk' (at least three) derived from information about the likelihood and behaviour of flooding

(b) councils without the requisite resources to produce a flood behaviour map should develop a flood map which shows the extent of floods of a range of likelihoods (at least three).

2.14 For non-urban areas or areas where limited development is expected to occur councils should consider, on a risk basis, what level of information about flood risk is required for the area, and undertake the highest ranked of the following options which is appropriate to that need and within the capacities (financial and technical) of the council:

(a) a map showing 'zones of risk' (at least three) derived from information about the likelihood and behaviour of flooding

(b) a map showing the extent of floods of a range of likelihoods (at least three)

(c) a flood map based on historic flood levels that have been subjected to a flood frequency analysis to estimate the annual exceedance probability of the selected historical flood

(d) a historic flood map without flood frequency analysis.

2.15 Councils should ensure that areas for which there has been no assessment of the likelihood of flooding are indicated on a map and that, as part of the development assessment process for these, there is at least some enquiry into whether a site proposed for development could be subject to flooding.

2.17 Flood maps, and property specific flooding information intended for use by the general public, should be readily interpretable and should, where necessary, be accompanied by a comprehensible explanatory note.

2.19 The Queensland Government should consider implementing a mechanism by which prospective purchasers of property are alerted to the issue of flood risk. To that end, the Queensland Government should consider consulting the Real Estate Institute of Queensland and the Law Society of Queensland as to the appropriateness of amending standard contract conditions so as to include a 'subject to flood search' condition, or other means of achieving the same objective.

**Chapter 4 State planning instruments**

4.3 The Department of Community Safety should put in place administrative arrangements which ensure it can readily ascertain whether its comments are being reflected in council planning schemes. If the Department of Community Safety becomes aware that its comments are not being adequately addressed, it should take steps to follow this up with the Department of Local Government and Planning.

4.6 Councils should consider using the limited development (constrained land) zone in their planning schemes for areas that have a very high flood risk.

**Chapter 5 Local planning instruments**

5.6 The Queensland Government should include in the model flood planning controls a model planning scheme policy that:

(a) for development proposed on land susceptible to flooding, outlines what additional information an applicant should provide to the assessment manager as part of the development application, or

(b) for development proposed on land where the potential for flooding is unknown, requires an applicant to provide:

- as part of the development application, information to enable an assessment of whether the subject land is susceptible to flooding, and
- upon a determination the subject land is susceptible to flooding, more detailed information, to allow an assessment of the flood risk.

**Chapter 7 Development and flood considerations**

7.1 The Queensland Government should consider extending the application of a state planning policy dealing with flood to the types of community infrastructure which are identified in the Sustainable Planning Regulation 2009 and which the community needs to continue functioning, notwithstanding flood.

7.2 The Queensland Government should draft assessment criteria to be included in the model flood planning controls that require community infrastructure (including the types of community infrastructure which are identified in the Sustainable Planning Regulation 2009 and which the community needs to continue functioning, notwithstanding flood) to be located and designed to function effectively during and immediately after a flood of a specified level of risk.

7.11 The Queensland Government should draft assessment criteria to be included in the model flood planning controls that require that:

(a) the manufacture or storage of bulk hazardous materials (as defined in State Planning Policy 1/03) take place above a certain flood level, determined following an appropriate risk based assessment, or

(b) structures on land susceptible to flooding and used for the manufacture or storage of bulk hazardous materials (as defined in State Planning Policy 1/03) be designed to prevent the intrusion of floodwaters.

7.13 When approving applications for development which involve the manufacture or storage of hazardous materials, councils should not restrict the conditions imposed to ones which are solely reliant on human intervention to remove the materials in the event of flood.

7.16 The Queensland Government should consider drafting assessment criteria to be included in the model flood planning controls which require that works in a floodplain:

(a) do not reduce on-site flood storage capacity

(b) counteract any changes the works will cause to flood behaviour of all floods up to and including the applicable defined flood event by measures taken within the subject site (for example, use of compensatory works, detention basins or other engineering mechanisms)

(c) do not change the flood characteristics outside the subject site in ways that result in:

- loss of flood storage
- loss of/changes to flow paths
- acceleration or retardation of flows, or
- any reduction in flood warning times elsewhere on the floodplain.

7.19 Levees should be regulated.

7.23 There should be a common set of considerations in the decision whether to approve an application to build a levee, including:

(a) the impacts of the proposed levee on the catchment as a whole

(b) the benefits of the proposed levee to the individual or entity applying to build the levee and to any nearby community as a whole

(c) any adverse impacts on other landholders, including the risk of levee failure

(d) the implications of the proposed levee for land planning and emergency management procedures

(e) whether any structural, land planning or emergency management measures can be taken to mitigate the adverse impacts of the proposed levee.

**Chapter 8 Development assessment in practice**

8.1 Councils should, resources allowing, maintain flood maps and overland flow path maps for use in development assessment. For urban areas these maps should be based on hydraulic modelling; the model should be designed to allow it to be easily updated as new information (such as information about further development) becomes available.

8.7 Councils should not rely on a condition requiring an evacuation plan as the sole basis for approving a development susceptible to flooding.

**Chapter 9 Building controls**

9.3 The Queensland Government should consider amending the 'Limitation' section of the proposed new part of the Queensland Development Code, Mandatory Part 3.5 'Construction of buildings in flood hazard areas', to allow for the possible application of 'acceptable solution A1' to a building located on a lot if:

(a) it is reasonable to expect the part of the lot on which the building work is proposed to be subjected to a maximum velocity of less than 1.5 metres per second, or

(b) the part of the lot on which the building work is proposed is located in an inactive flow or backwater area.

**Chapter 10 Essential services**

10.6 Queensland Urban Utilities, and other distributor-retailers and councils, that have identified a practice of stormwater drains being connected to sewerage infrastructure, should conduct a program of education to raise public awareness that this practice is illegal and impedes the operation of the sewerage infrastructure.

10.9 All councils should, resources allowing, map the overland flow paths of their urban areas.

10.10 Councils should consider amending their planning schemes to include provisions directed to consideration of the flood resilience of basements as a factor in determining the appropriateness of a material change of use.

10.11 In assessing and determining development applications for material change of use in areas susceptible to flood, councils should consider whether the new developments locate essential services infrastructure above basement level, or, alternatively, whether essential services infrastructure located at basement level can be constructed so that it can continue to function during a flood.

10.15 Councils should conduct education campaigns directed to ensuring that all residents and property owners in areas identified as being at risk of backflow flooding are aware of the circumstances in which backflow flooding can occur, the hazard it presents and what should be done if it occurs.

10.20 The Queensland Government should consider whether there should be a legislative requirement that customer dedicated assets be built at or above the applicable defined flood level and if so, the Queensland Government should consider which legislation should contain such a requirement.

**Chapter 12 Performance of private insurers**

12.1 When a policy-holder makes a claim, the insurer should ascertain the policy-holder's preferred method of contact and ensure that it is used (with other modes of communication if necessary) to keep the policyholder informed about the progress of the claim. However, important decisions regarding the claim – for example, determinations about the outcome of the claim and settlement sums – should always be confirmed in writing.

12.2 Insurers should review their existing systems and processes and implement any improvements necessary to ensure that accurate and complete records of conversations with policy-holders are made.

12.3 Letters notifying policy-holders that their claims have been denied should, at a minimum, state the information upon which the insurer has relied in making the decision. These letters should also advise policy-holders that copies of the information will be made available upon request (in accordance with clause 3.4.3 of the General Insurance Code of Practice) and indicate how policy-holders can make a request.

12.4 The Insurance Council of Australia should consider an amendment to Part 3 of the code which requires insurers to notify policy-holders of the information on which they relied in assessing claims.

12.5 The Insurance Council of Australia should amend clause 3.4.3 of the General Insurance Code of Practice so that it requires insurers to inform policy-holders of their right to request a review of an insurer's decision to refuse to provide access to information on which it relied in assessing claims.

Chapter 15 Emergency response and other interim report issues

15.8 Emergency Management Queensland, in consultation with councils, should develop clear directives about:

(a) the communication and reporting that should take place between the SES and disaster managers, including in relation to task allocation and completion, once disaster management groups have been activated

(b) the communication and reporting that should take place between the SES and disaster managers, including in relation to task allocation and completion, once disaster management groups have been activated

(c) the process for dealing with requests for assistance that exceed an SES unit's capacity to respond them

(d) the process for seeking extra support for an SES unit that has been overwhelmed by a disaster (whether by way of Emergency Management Queensland or the disaster management arrangements or both)

(e) the role of SES liaison officers in communications with disaster managers about SES disaster operations

(f) the role of incident controllers, and their teams, relative to those SES (or Emergency Management Queensland) personnel charged with the command of SES operations.

# 10. Lessons Learnt from the Class Action taken after the 2011 Brisbane River Flood

## 10.1 Background

Following the Brisbane River flood of 2011, a Class Action was brought against the owners and operators the Wivenhoe and Somerset dams in relation to the operation of these dams during the flood.

This class action occurred in two stages; the Common Law Division, Supreme Court of NSW [2019 NSWSC 1657] by the 'primary judge' during 2017-19, and the Court of Appeal, Supreme Court of NSW in 2021 by the 'appeal judges' [2021 NSWCA 206].

This chapter outlines my **personal** observations of the court case. This chapter does not provide legal advice.

## 10.2 Potential conflict of interest

I must point out that I know, on a professional level, some of the engineers that were involved in the operation of these dams. In the early 1990's I worked, on a voluntary basis, with one of the engineers on an Engineers Australia, Queensland Division, committee. And, some of the Flood Operations Engineers have attended hydrology conferences that I had also attended. I was also employed by the Department of Energy and Water to complete a review of the Queensland Urban Drainage Manual following the release of the Queensland Floods Commission of Inquiry's 2012 report.

However, I have not worked with any of these engineers on a professional basis (outside my membership of the Engineers Australia, Queensland Division, Water Panel); and, I do not know any of these engineers well enough to have their phone number in my Contacts List.

## 10.3 Reviewed information

In preparing this chapter I have read the following documents:

- Court of Appeal, Supreme Court, New South Wales, Queensland Bulk Water Supply Authority t/as Seqwater v Rodriguez & Sons Pty Ltd, [2021] NSWCA 206 (8/9/2021)
- 'Queensland Flood Victims Still Waiting for Payout as Appeal Launched', A Current Affair, Nine News (2021)
- '2011 Qld Flood Victims Lose Final Appeal Against Dam Operator', by Toby Crockford and Tony Moore, Brisbane Times (12/4/2022)
- 'Qld Flood Victims Lose High Court Fight', Pandora, 7-NEWS (12/4/2022)
- 'Victims of 2011 Queensland Floods Lose Fight for $440m in Compensation', Australian Associated Press, The Guardian (12/4/2022)
- 'Victims of 2011 Brisbane Floods Lose High Court Appeal to Reinstate Findings Against Dam Engineers', Elizabeth Byrne, ABC News (12/04/2022)
- 'Sliver of Damages Awaits Victims of 2011 Queensland Floods', Liam Walsh, Financial Review (17/05/2022)
- 'Brisbane 2011 Flood Class Action Win of $450 Million to be Distributed by Early 2023', Alicia Nally and Steve Austin, ABC News (2/06/2022)
- 'Angry Residents Consider Class Action Over Brisbane Flash Flooding', Tony Moore, Brisbane Times (21/07/2022)
- Queensland Floods Class Action, Appeal update, Maurice Blackburn Lawyers (28/9/2022)
- 'Lessons Learned' Case Study: Wivenhoe Dam (Australia, 2011), by Seth Thompson, Association of State Dam Safety Officials, Lexington, KY, USA (27/9/2022)

## 10.4 Introduction

In my opinion, court cases are not about determining who is 'right' and who is 'wrong', or about determining a 'fair' outcome. Court cases are about following the law. If however, the law requires the court to determine who is right, or what is fair, then so shall the court.

Nothing that I present in this chapter should imply any form of failure by the courts. Such an implication is not for me to say. I have absolute confidence that the various courts correctly followed the law in coming to their conclusions. The purpose of this chapter is to review those findings, and to discuss what lessons a person (engineer) may gain from the findings.

I need to stress that I do not have legal training. I am a civil engineer. At best I can only provide an indication of how an engineer could possibly interpret the findings of the court. If you require a legal interpretation, then you need to seek advice from a legal expert, not this publication.

I would also like to acknowledge my admiration of these judges and their ability to develop such a detailed understanding of the flood operations of dams in such a short period.

## 10.5 My initial reaction to hearing of the proposed class action

When I first heard of the proposed class action I did not believe that it would be successful because I believed that the flood engineers would have followed the Flood Manual rigorously. However, I also believe that such class actions are necessary from time to time to hold authorities accountable for their actions, and to help maintain the community's confidence in such authorities.

A key aspect of floodplain management is 'people management'. You cannot have a 'natural disaster' without people, or the structures that people built. In the absence of people and structures, a flood is just a flood, a bushfire is just a fire, and a cyclone is just a strong wind. Disasters only occur when people and their assets interact with wind, water, earth and fire.

The **key** to understanding people management during a flood is different from managing people before or after a flood. During a flood many people enter into a state of shock. Their degree of shock typically depends on:

- The amount of experience the person has with floods (hence, residents of northern Australia generally are more relaxed and organised during a flood because such floods are regular events).
- The amount of knowledge the person has of flood behaviour, and flood hydrology (consequently, flood engineers and SES workers are often calm during a flood).
- The degree of responsibility the person feels for others around them. Typically, one parent will remain calmer than the other parent, which can mean that communication between the two parents will be difficult, and generally not consistent with their 'normal' communication pattern. The parent in shock will generally struggle to receive information and instructions compared to the parent that takes on the 'lead' role.
- The person's mental strength and their recent stress history.

After experiencing a major flood event, many people enter into what is known as the Five Stages of Grief, those being: denial, anger, bargaining, depression and acceptance. For many people there is the strong need to deny their contribution to the tragedy. Many people find it very difficult to accept that their purchase or rental of a home could have contributed to their family's current situation.

Some people deal with their guilt and grief by deflecting their anger towards someone else: 'The government should have given us better warnings'. 'The government should not have allowed housing at this location'. 'The government should have built a levee, or operated the dams correctly'.

For many people it is important to deny that the flood was a natural event, because that means it could happen again. If they can believe that the flood was the result of negligence, then that means the cause of the flood can be fixed, which means they can continue to live in their home without the concern of another flood event.

A ‘class action’ can be seen as part of the bargaining process. It is a process of figuring out how much of their flood damage is attributable to their decision to buy this particular home, and how much can be attributed to the actions of the government. The main intention of a class action is to obtain compensation, but for many it is also about laying blame.

The outcome of a class action can result in either depression or euphoria, but eventually there needs to be acceptance of the situation. This is where I can see problems with the outcomes of some class actions. If the plaintiffs get a favourable result, they are quick to move to the point of acceptance; however, if the result is unfavourable, then it can be difficult to move from the state of depression into a state of acceptance.

In respect to the 2011 Brisbane River flood, I have the following concerns:

- If people believe that the findings of the initial court action, and the out-of-court settlement by the State of Queensland and SunWater Limited, confirmed their ideas that the operation of the dams was negligent, then they are likely to believe that such a flood is unlikely to occur again.
- Based on the outcomes of the Court of Appeal, it is my engineering (i.e. non legal) belief that if the State of Queensland and SunWater Limited joined the appeal process, they also would have been found to be largely free of any negligence. It is my engineering (i.e. non political) belief that the out-of-court settlement by State of Queensland and SunWater Limited was a (wise) political decision, and not an admission of guilt.
- If people continue to believe that the 2011 Brisbane River flood was the result of government negligence, then in my engineering opinion, they are remaining in a state of denial. This flood was a natural event. The flooding occurred because of heavy rainfall. The NSW Court of Appeal found that the flood model simulations used in the primary court case were not based on decisions that ‘a reasonably competent flood engineer’ would likely have made at the time.

Statements in the media, such as: ‘In November 2019, the Supreme Court in New South Wales found flood engineers operating the Wivenhoe and Somerset Dams in Queensland were negligent and failed to follow the manual they had helped draft’ (ABC News, 2/6/22) help to reinforce in people’s mind that the flood engineers were ‘negligent’. The later finding of the NSW Court of Appeal puts such claims of negligence in some doubt.

My concern is that if the community is not correctly informed of the facts, this will likely increase the future flood risk to people and property. Those that don’t learn from the past are likely to confront the past all over again.

Given all the damage and heartache experienced during the flood, possibly the worst thing that could happen would be for people to continue to believe that such a flood could not happen again. The fact is, if the same rainfall were to fall once again on the catchment, then the same flood would likely result. Our only saving grace is that every year ‘our’ ability to predict imminent rainfall gets better, which means ‘our’ ability to operates dams during a flood event also gets better.

## 10.6 My observations of what can be learnt from the class action taken against the dam operators

The outcome of the Court of Appeal appears (from my point of view) to turn on five key issues:

(i) The statutory duty of care applicable to Seqwater.

(ii) Whether a reasonably competent flood engineer would have determined the maximum forecast water level in Wivenhoe Lake based on the assumption that the dam’s flood gates would remain closed.

(iii) Whether the flood engineers gave adequate consideration to forecast rainfall, and not just ‘rain on the ground’.

(iv) Whether a reasonably competent flood engineer would have continued the first ‘declared flood event’ beyond the 2 January 2011, thus avoiding the need to declare the commencement of a second flood event on 9 January 2011.

(v) Whether a reasonably competent flood engineer would have continued to lower water levels in Wivenhoe Lake below 67.0 m (FSL) between the 2nd and 9th of January 2011.

It would appear that the primary judge came to the conclusion that a reasonably competent flood engineer would not have made such decisions. However, the appeal judges arrived at the opposite conclusion.

Having read the findings of the appeal judges I found their conclusions to be consistent with what I believe a reasonably competent flood engineer would have done given the information available to the flood engineers at the time.

Based on an engineering-based understanding of the findings from the two court cases, I do not believe that an initial judgement should have been made against Seqwater (First Defendant), SunWater Limited (Second Defendant) or the State of Queensland (Third Defendant). However, as a Queensland tax payer I do not mind that SunWater Limited, and the State of Queensland, settled out-of-court, and that some tax-payer's money did pass onto some of the flood victims.

I can see that it would have been politically damaging for the Queensland Government to have appealed the primary judgement. Under 'normal' circumstances, it is common for governments to provide financial assistance to victims of natural disasters. And this was a **natural** (not man-made) disaster. So the out-of-court settlement is possibly no different from the normal government assistance flood victims could expect (except in regards to how the settlement was distributed amongst the flood victims).

The first of the key Appeal issues deals with issues that are beyond my understanding. The only comment I can make is that the Court of Appeal accepted Seqwater's claim that a different legislated standard should been applied to the actions of Seqwater.

The second issue appears to centre around the meaning of the word 'maximum'. The primary judge appeared to treat this term as meaning the 'maximum possible water level'. In engineering we would tend to use the term 'maximum possible', or 'theoretical maximum', if we wished the term 'maximum' to have such a meaning. In engineering, the term 'maximum' generally means the actual maximum, or the maximum foreseeable.

As an example, in engineering, the maximum car speed on a stretch of road would mean the maximum lawful (i.e. posted) speed, not the maximum possible speed a car could travel if the speed limit was ignored.

The Court of Appeal concluded that: 'It was not unreasonable for the engineers to have regard to the water which was being released'. The appeal judges further added that 'none of the witnesses, including Dr Christensen, had ever encountered a flood mitigation system which required engineers to disregard the effect of releases of water'.

In dealing with the third issue, the Court of Appeal referenced several e-mails sent between the flood engineers during the flood event that discuss possible changes to their strategy in light of forecast rainfall. In other words, the dam operators did consider the likely impacts of forecast rainfall.

The fourth issue appears to centre around the fact that the 'end of the first flood event' was declared on 2 January 2011 when Wivenhoe Lake was at a recorded elevation of 67.1 m, and not the 67.0 m required in the Flood Manual. It was reported that the flood engineer declared the end of the flood event in order to allow authorised volunteers to rescue lung fish from the pond at the base of the spillway.

Given that locally-generated wind waves on Wivenhoe Lake would exceed a height of 0.1 m, I would suggest that a reasonably competent flood engineer would have declared an end to the flood event on 2 January in order to achieve the outcomes that the flood engineer indicated he wished to achieve. I therefore concur with the logic presented by the appeal judges that the flood engineers were not negligent by calling an end to the first flood event.

The fifth issue appears to centre around the idea that the Flood Manual only required the water level in Wivenhoe Lake to be at the designated Full Supply Level (FSL, at 67.0 m) at the end of a flood event. It was therefore suggested that the Manual allowed the flood engineers to lower the lake level below 67.0 m prior to the arrival of the second storm front. However, the further lowering of the lake level would **only** have been allowable if the first flood event remained active between 2nd and 9th January.

Because the appeal judges agreed that the flood engineer could rightfully end the first flood event on the 2 January, this meant this fifth issue was no longer relevant because the Flood Manual specifically prevented any further lowering of the lake levels after a flood event had ended, and while the lake level remained below 67.25 m.

The Court of Appeal did conclude that: '. . the engineers were not obliged to make releases in such circumstances . .'.

I concur with the appeal judges that the flood engineers were not negligent in maintaining lake levels above 67.0 m prior to the second storm event.

Even though both courts observed that the Flood Manual was worded in a manner that could result in several different interpretations, the Court of Appeal accepted that if the five flood engineers discussed and agreed on a course of action, then this suggests that their actions were consistent with what a reasonably competent flood engineer would have determined. In other words, with regards to the possible interpretation of the Flood Manual, each flood engineer did not act in isolation from the collective decision of the group.

Claims were made on social media after the 2011 Brisbane River flood that the flood was a 'man-made' flood, and that the flood could have been prevented if the various government agencies had acted correctly. In my opinion, such claims are wrong and very misleading. The idea that all the flood engineers had to do was 'look out the window' is wrong, unlawful in its intent, and degrading to the flood engineers. Nowhere in the Flood Manual are the flood engineers told to 'look out the window'. They are required to consider the best available rain forecasts, which means Bureau of Meteorology forecasts.

Based on my reading of the NSW Court of Appeal (2021), and my engineering-based understanding of the issues, I believe that it would be false for someone to claim, today, that the flood engineers were negligent in their operation of the dams during the 2011 Brisbane River flood. However, given that the Court of Appeal did not address the issues faced by the State of Queensland and SunWater Limited, it is impossible (based on my knowledge) to be absolute in the exoneration of the flood engineers.

## 10.7 My comments on the reported 'controversy' associated with the distribution of funds to flood victims following the class action

Various media reports indicated that the class action participants were offered payments that appeared to be larger for those homes that experienced the least damage, and lesser for those homes that experienced greater damage. Such financial payouts may appear to go against common sense, but there is a logical and (I believe) fair reason why such a payment system exists in these cases.

When support payments are made directly by governments during a natural disaster, the payments are normally distributed equally to all victims. However, in a class action, the payments may be (in my opinion):

(i) based on the recommendations of the court

(ii) based on the directions of the court

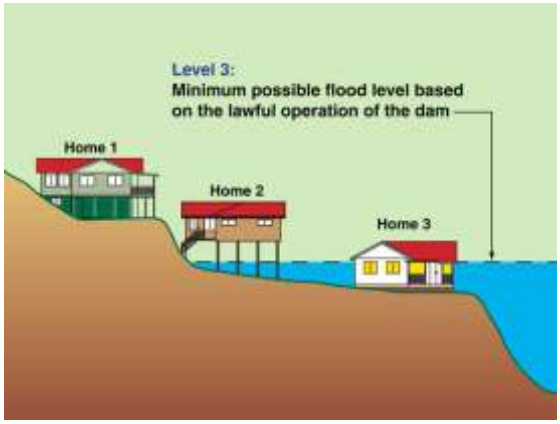
(iii) based on the assessed increase in damages, or repair costs, incurred by the owner and/or resident as a consequence of the determined negligence (i.e. excluding those damages or costs that would have occurred in the absence of any negligence).

In the case of (iii) above, the distribution of payments typically requires a complex hydraulic analysis. It is important to note that payments need to be based on the assessed 'increase' in damages as a consequence of the determined negligence, not the total damage bill.

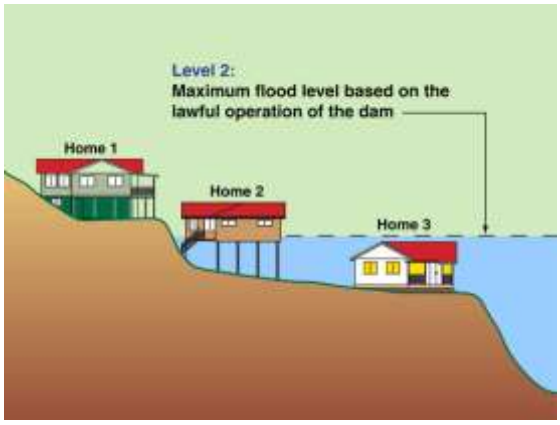
Media reports following the flood event appear to suggest that some residents held the attitude that if any negligence was found to occur in the operation of the dams, then the dam operators will be liable for all the flood damage, not just part of the flood damage.

The following is a general discussion, and does not necessarily represent the process adopted by the 2011 Brisbane Flood class action.

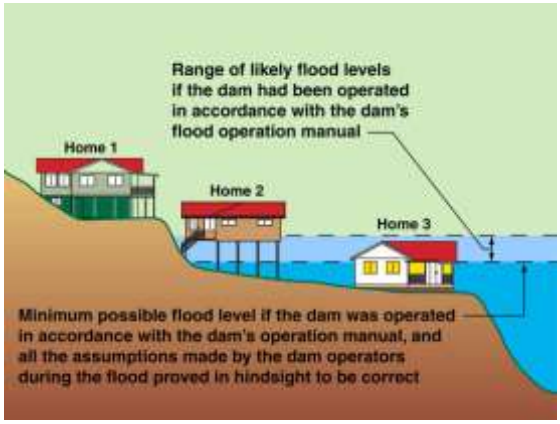
## 10.8 Possible distribution of funds resulting from a class action




**Minimum possible flood level**




**Maximum possible flood level**




**Range of 'compliant' flood levels**

**A potentially flood-free home**

### Minimum possible flood level

- In some cases a hydraulic analysis will be performed to determine the lowest possible flood level (Level 3) based on the best possible (in hindsight) decisions that a flood engineer could have made.
- The fact that a reasonably competent flood engineer could have achieved this lower flood level does not mean that a reasonably competent flood engineer could not have achieved a higher flood level (e.g. Level 2) while still complying with the approved Flood Manual.

### Maximum possible flood level

- A hydraulic analysis can also be used to determine the highest possible flood level (Level 2) while still complying with the Flood Manual.
- This upper-range water level represents a flood condition that would not have been considered a product of negligence.
- Ideally, damage claims under the class action should be linked to the difference between the actual flood level (Level 1) and this upper-range, flood level (Level 2).

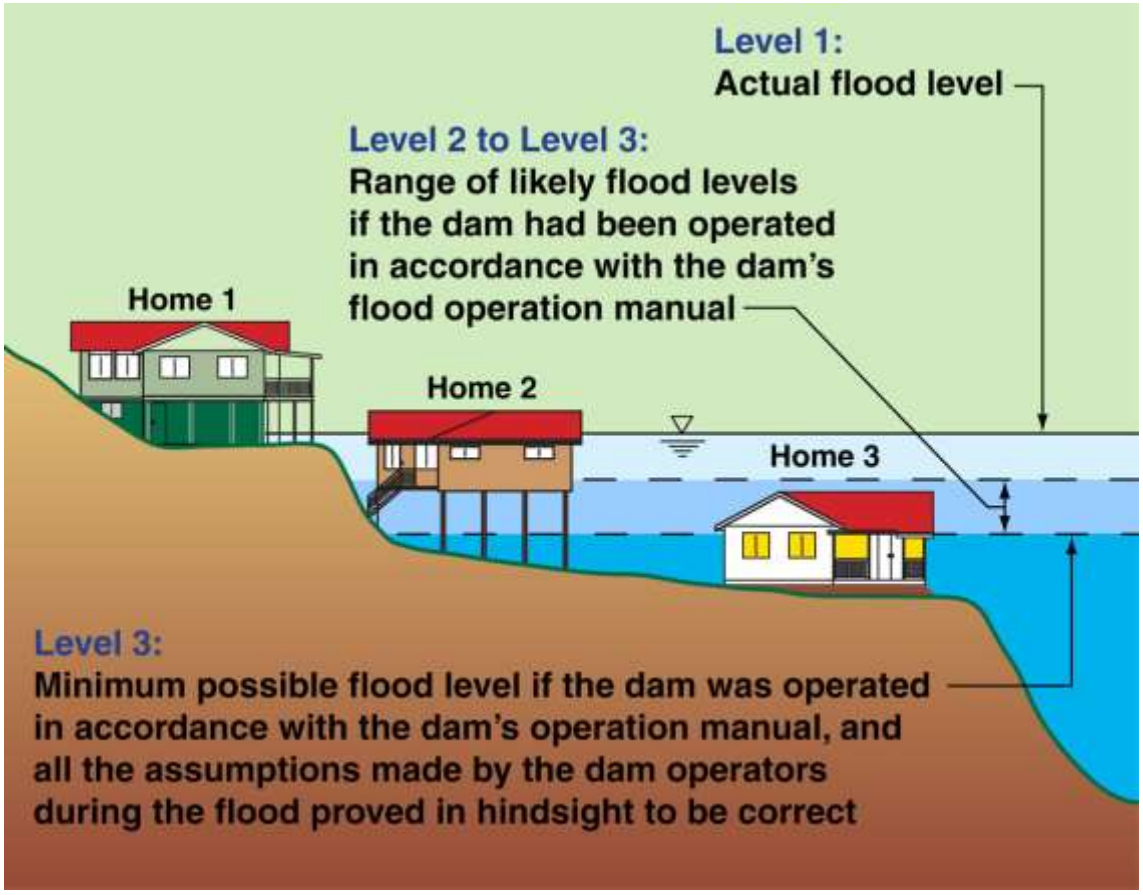
### Range of 'compliant' flood levels

- The maximum and minimum flood levels that are consistent with the aims of the approved Flood Manual provides the court with a range of flood levels that could have resulted from the actions of a reasonably competent flood engineer.
- The reason why a 'range' of flood levels are considered as 'acceptable' outcomes is because most Flood Manuals are not strictly prescriptive, but instead allow the flood engineer to make choices that best align with the intent of the Manual.

### Home 1

- A hydraulic analysis (i.e. a numerical flood model) should be able to identify those homes that should have remained flood free during a flood event (i.e. property assets that are above flood Level 2).
- Ideally, such properties would receive a payment that is proportional to their total damage bill.

## Possible distribution of funds resulting from a class action (continued)




**Actual and 'best practice' flood levels**

**Partially flooded home**

**Fully submerged home**

**Home 2**

- There will be homes that experience significant damage during a flood event, but would still have partially flooded in the absence of any negligence by the flood engineers.
- If the court accepts Level 2 as the reference flood level, then only a partial payment would be expected.
- If the court accepts the lower Level 3 as the reference flood level, then the building should have been flood-free, and thus due for full payment of any flood damages.

**Home 3**

- There may be homes that would still have flooded in the absence of any negligence by the flood engineers.
- In such cases, these home owners, and or residents, may not receive any payment, particularly if the funds available from the class action do not fully cover all the potential claims.
- In all cases, if the property is a rental home, then there will be two claimants: the home owner's building claim, and the resident's contents claim.

## 11. Glossary of terms

| | |
|---|---|
| **1 in 100 year flood** | A flood that has a 1% probability of being equalled or exceeded within any 12 month period at a given location. |
| **Australian Height Datum** | A level datum, uniform throughout Australia, which is based on observations of mean sea level at 30 tide gauge stations around the Australian coastline. |
| **Backwater** | The water of a stream kept above an otherwise expected elevation due to some downstream influence such as floodwaters within a downstream reach or tributary. |
| **Blockages** | Flood debris trapped in and around hydraulic structures in such a manner that cause either a reduction in the maximum flow capacity of the structure, or an increase in upstream water levels. |
| **Critical storm duration** | The storm duration that will likely cause the most severe flooding at a given location, of any given storm frequency.<br><br>It is possible for the 'critical storm duration', at a given location, to be different for the 1 in 10 year, 1 in 50 year, 1 in 100 year, etc. flood events. |
| **Flooding** | The inundation of normally dry land or structures by water. |
| **Floodplain** | Land area adjoining rivers, streams, artificial channels, lakes, dams, bays, or oceans, that is inundated during flood events due to over-bank stream flows or abnormal high tides resulting from severe storms. Their extent is defined by tidal limits, or the expanse of the probable maximum flood (PMF). |
| **Floodplain storage** | The volumetric flood-holding capacity of a floodplain defined over a specified reach length and to the peak elevation of a specified flood. |
| **Floodway** | A channel or passage through which floodwaters pass. |
| **Isohyet** | A contour of constant rainfall depth shown on a rainfall map. |
| **Manning's equation** | A formula used to predict the velocity of uniform fluid (water) flow in an open channel or other conduit. |
| **Manning's roughness** | The numerical representation of the hydraulic roughness of a conduit, flow path or channel as used in the Manning's formula. |
| **Probable maximum flood (PMF)** | The largest flood that could conceivably occur at a particular location, resulting from the probable maximum precipitation (PMP) and, where applicable, snowmelt, coupled with the worst flood-producing catchment conditions that can be realistically expected in the prevailing meteorological conditions. The PMF defines the extent of flood-prone land. |
| **River gauge** | A device for measuring water levels at a given location. |
| **Run-off** | That part of rainfall, snow or hail not lost to infiltration, evaporation, transpiration or depression storage that flows from the catchment area past a specified point. It includes that portion of precipitation that appears as flow in streams; and drainage or flood discharges that leave an area as surface flow or as pipeline flow, having reached a channel or pipeline by either surface or sub-surface routes. |
| **Storm duration** | In hydrology, 'storm duration' is the duration of the most severe (with respect to its probability) period of rainfall intensity within a single storm, or a series of connected storms. As such, a 10 minute duration thunder storm can occur in the middle of a 24 hour rainfall depression, or, a 5-day storm duration may involve the total rainfall from several individual storm events that occur over a continuous 5-day period. |

| | |
|---|---|
| **Storm surge** | An atmospherically driven rise in sea level caused by extreme surface winds and low atmospheric pressure associated with severe weather conditions, usually cyclones. |
| **Surface storage** | The volume of stormwater retained on the surface of the catchment and within minor surface depressions causing a reduction in expected stormwater run-off. |