Understanding floods:

Questions & Answers

Queensland Government

Cover: The flooded Balonne River cuts a road near St George, Queensland, March 2010. Photographer: Michael Marston
Inside cover: The vast floodplain adjacent to the Fitzroy River and its tributaries is inundated by flood waters near Rockhampton, January 2011. Photographer: Michael Marston

Foreword

From December 2010 to January 2011, Western Australia, Victoria, New South Wales and Queensland experienced widespread flooding. There was extensive damage to both public and private property, towns were evacuated and 37 lives were lost, 35 of those in Queensland. Three quarters of Queensland was declared a disaster zone, an area greater than France and Germany combined, and the total cost to the Australian economy has been estimated at more than $30 billion.

Since the beginning of 2011, floods have led to major devastation and personal tragedy around the world. At the same time as the Australian floods, more than 800 people died in floodwaters and mudslides in Brazil and South Africa recorded 70 flood related deaths. Many lives have also been lost due to flooding in the Philippines, Pakistan and Sri Lanka. Most recently, some areas of the Mississippi River recorded the worst flooding since the 1930s.

The Queensland Floods Commission of Inquiry was established to investigate the 2010-11 flood disaster. To support this process, we have convened a comprehensive panel of technical experts, from across Australia and internationally, to provide scientific and engineering perspectives around floods. Our report does not examine the specific events of the recent Queensland floods, but rather focuses on a number of critical, underlying questions relevant to floods generally. These questions include: what do we mean by a 'flood'; what are the causes and consequences; how can we forecast and warn about them; and how do we best plan for floods? We have asked ourselves what processes and technologies are well utilised, what is not being used effectively, and where are the gaps in our understanding.

Finally, recognising that the science and engineering fraternity are often criticised for somewhat inscrutable language, this report has been written with more general communication in mind. We have focused on clarity and brevity, founded on rigour.

I am grateful for the time, enthusiasm and insights from our panel members and other specialists we have consulted. Their diverse and extensive expertise—and challenging yet collaborative style—has been vital to the integrity of this report.

Geoff Garrett

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Chairman, Queensland Floods Science, Engineering and Technology Panel

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Contents

Copies of this publication are available online at www.chiefscientist.qld.gov.au

Introduction

Australia has an extremely variable climate, and is truly a 'land of droughts and flooding rains'. Throughout Australia's long history, the flood-drought cycle has been a natural part of life, with periods of severe drought followed by extensive flooding playing an important and defining role in shaping the Australian landscape and how we live.

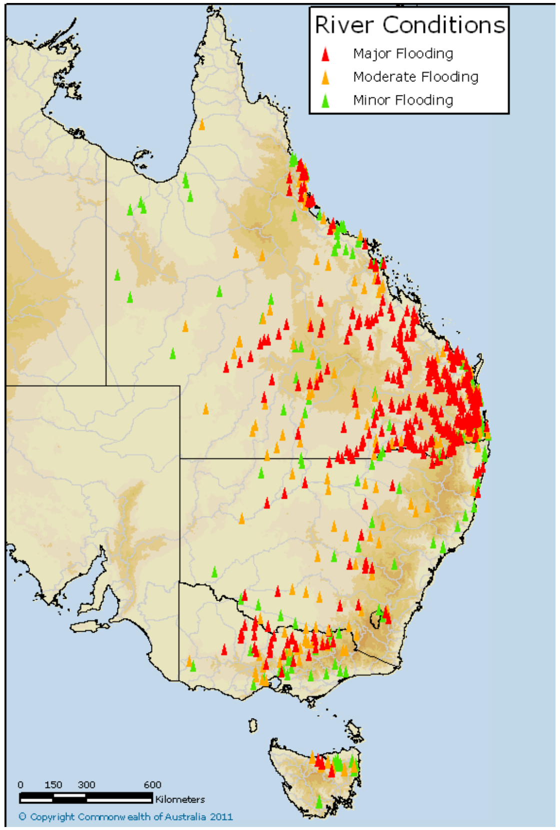
Early Australians typically established settlements on floodplains, along waterways and on coasts, where food and water were plentiful. As a result, floods have had a profound effect on human life and property. As devastating as recent events have been, they are not unique: 77 floods were recorded in Australia in the past 35 years of the 20th century; eight major floods were recorded in Australia in the 19th century; 23 in the 20th century; and six in the first decade of the 21st century. And nature will undoubtedly continue to surprise us into the future.

It is also important to recognise that floods can have some beneficial consequences, for example through replenishing water resources. Most of Australia's unique flora and fauna have adapted to and depend on flood cycles, relying on the floods to trigger breeding, disperse seed, provide food sources and connect habitats.

In order to reduce the risk of floods to communities, economies and environments into the future, it is important that lessons from past floods, and advancements in knowledge and technology, are effectively communicated and applied.

An important contribution the science and engineering community can make is to help reduce this risk, by minimising the chance that communities and infrastructure will be flooded, and mitigating the negative impacts when floods occur. We know a lot about flood risk: more than 1000 Australian flood studies have been conducted, and scientists and engineers have developed a very sophisticated armoury of methods to forecast and manage floods to reduce risk. However, there is still uncertainty about the many interacting factors that influence such an event, how these factors are changing in time, and the consequences of a flood if it occurs. Moreover, nature is unpredictable, so no matter how detailed and clever our calculations and management strategies may be, there will always be a risk of flood.

Of course, social science and government policy also play pivotal roles in reducing the negative impacts of floods, improving emergency responses and optimising recovery of communities following a flood. Improvements in this regard rely not just on social science research, but also on government leadership and community awareness and engagement. Given the science and engineering outlook of this document, flood emergency responses and recovery, which are primarily rooted in social science and policy, will not be addressed. **This report concentrates on floods caused by rainfall and on three key themes to understanding floods. The three themes are floods and their consequences, flood forecasts and warnings, and managing floods. The following paragraphs expand on these three themes, pose the questions we have sought to respond to, and summarise the answers.**



Flood peaks in eastern Australia over the period 26 November 2010 – 20 January 2011.
Courtesy of the Bureau of Meteorology

Summary

Floods and their consequences

Q1: What is a flood?

When water inundates land that is normally dry, this is called a flood. Floods can be caused by a number of processes, but the dominant cause in Australia is rainfall. Floods are a natural process, but mankind's activities affect flooding. Floods occur at irregular intervals and vary in size, area of extent, and duration.

Q2: What factors contribute to floods?

Rainfall is the most important factor in creating a flood, but there are many other contributing factors. When rain falls on a catchment, the amount of rainwater that reaches the waterways depends on the characteristics of the catchment, particularly its size, shape and land use. Some rainfall is 'captured' by soil and vegetation, and the remainder enters waterways as flow. River characteristics such as size and shape, the vegetation in and around the river, and the presence of structures in and adjacent to the waterway all affect the level of water in the waterway.

Q3: What are the consequences of floods?

Floods impact on both individuals and communities, and have social, economic, and environmental consequences. The consequences of floods, both negative and positive, vary greatly depending on the location and extent of flooding, and the vulnerability and value of the natural and constructed environments they affect.

Flood forecasts and warnings

Q4: How do we forecast floods?

Weather forecasts can provide advance warning of a flood, and seasonal forecasts can alert of a heightened chance of flooding in the coming months. However, forecasting river levels and flood extent is a complex process that is continually being improved.

Q5: How do we communicate and warn about floods?

Flood warning systems turn forecasts into messages designed to reduce the negative impacts of floods. Warning systems should be accurate, timely and reliable. Prior community awareness of flood risk can make warnings more effective. Improving our warning systems could reduce social losses from floods.

Managing floods

Q6: How do we estimate the chance of a flood occurring?

Understanding the chance of different sized floods occurring is important for managing flood risk. The chance of a flood event can be described using a variety of terms, but the preferred method is the Annual Exceedance Probability (AEP). A flood with a one per cent AEP has a one in a hundred chance of being exceeded in any year. Currently, the one per cent AEP event is designated as having an 'acceptable' risk for planning purposes nearly everywhere in Australia. However, good planning needs to consider more than just the one per cent AEP flood.

Q7: How do we manage flood risks?

Flood risk includes both the chance of an event taking place and its potential impact. Land use planning informed by floodplain management plans can reduce risk for new development areas. Flood risk is harder to manage in existing developed areas; however modification measures such as dams or levees can change the behaviour of floodwaters. Similarly, property modification measures can protect against harm caused by floods to individual buildings, and response modification measures help communities deal with floods.

Q8: What does the future look like?

Australia's growing population and changing climate patterns imply that the characteristics of the floods we experience will change in the future. Better future land use planning and floodplain management can mitigate the impacts of flooding. Appropriate urban design can reduce the severity of flood impacts. Catchment and waterway revegetation can reduce the impact of flooding. Emerging technologies can improve our ability to predict and manage floods.

Q1: What is a flood?

When water inundates land that is normally dry this is called a flood

Every flood is different. They can occur suddenly and recede quickly, or may take days or even months to build and then discharge. They occur at irregular intervals, and many decades can pass between significant floods. On the other hand, there are many examples of several large floods occurring within short periods of time.

In Australia, many people live on land that is subject to occasional flooding, known as floodplains. Cities and other settlements have been constructed on floodplains to take advantage of access to water and good quality farmland.

Floods in Australia are usually caused by rainfall

Floods can be caused in a number of different ways; however the dominant cause of flooding in Australia is rainfall.

When rain falls over an area of land, some is absorbed by the soil, while the rest becomes ***runoff*** and flows downhill. The area of land that contributes runoff to a particular point is called the ***catchment***.

The amount of rainfall, the intensity of the rainfall over time (the ***temporal pattern***) and the distribution of the rainfall over an area of land (the ***spatial pattern***) can all vary widely. The floods that are produced by this rainfall are therefore equally variable, that is, every flood is different.

Floods can also be caused by other mechanisms. Recent international events have highlighted the risk of flooding from tsunamis. Large tides and storm surges can also flood coastal areas. Inland earthquakes, volcanoes or land slips can also cause flooding, as can breaches/releases in natural or man-made barriers to flooding such as dams and levees.

Floods can occur suddenly

Heavy, intense rainfall can occur suddenly, and the quickly rising floods caused by this in the minutes or hours after the rainfall are known as ***flash floods***. Flash floods are typically associated with relatively small catchment areas where there may be little or no permanent flow of water. As there is little time to react, flash floods are particularly difficult to predict and manage in real time, and this is discussed further in Q4 and Q5.

Floods can occur slowly

In larger catchment areas, rainfall can build up over hours, days or weeks. The runoff from this rainfall flows across land and then down gutters, drains, gullies, creeks and rivers and may create significant floods that inundate large areas of land for days, weeks or months.

With more time to react, flood warning is more effective for these types of floods, as described in Q4 and Q5.

Sometimes, a flash flood in the upper reaches of a river system can evolve into a more general river flood as it joins with other inflows and spreads out as it travels downstream.

Many locations can be affected by both flash floods and the more general river flooding. For example, a particular residence might be potentially affected by a flash flood through the local gully, or a river flood from the nearby major river, or a combination of the two.

Photo: Flash flooding in Toowoomba, 10 January 2011. Image courtesy of Nicole Hammermeister.

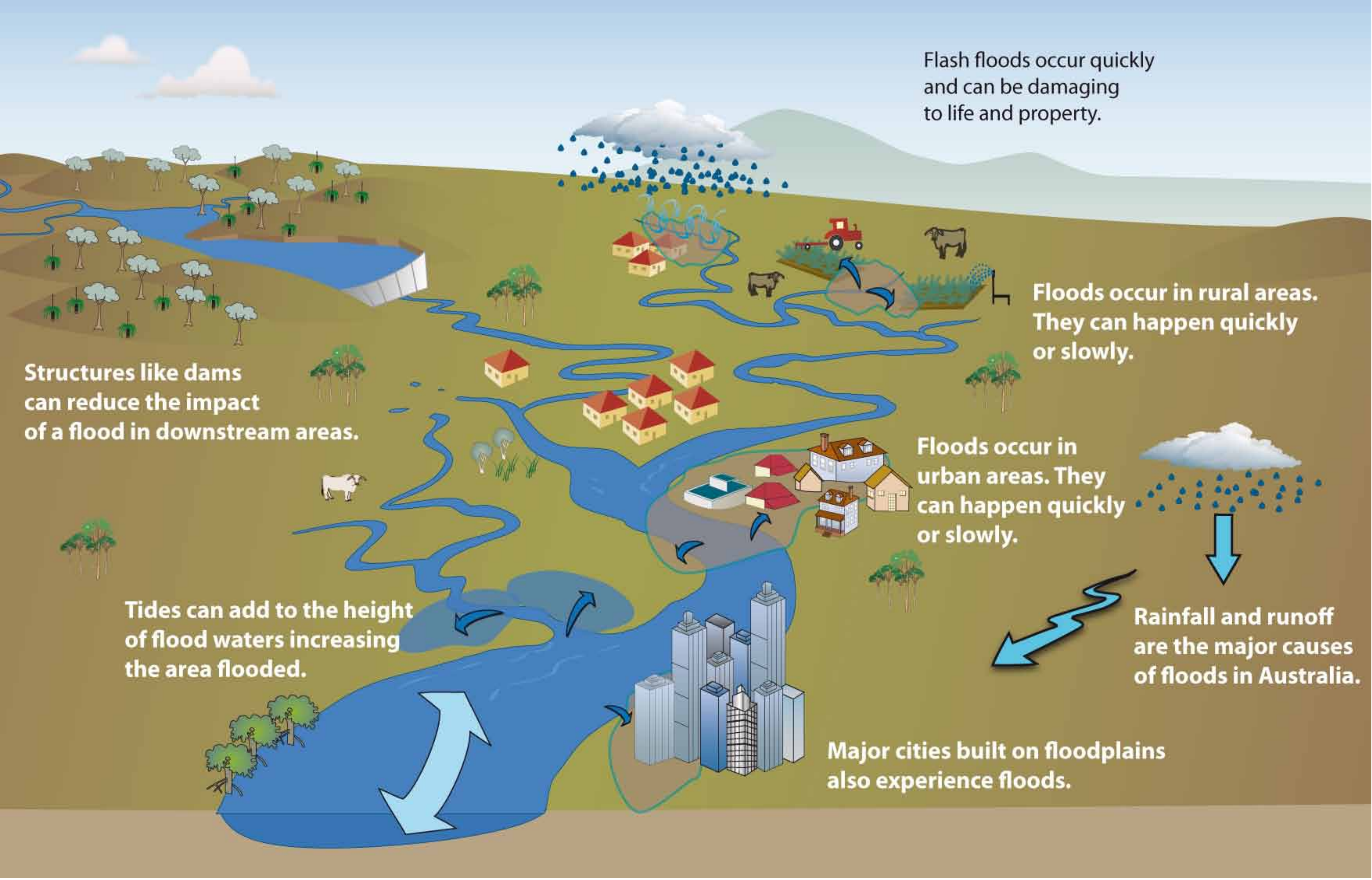


Figure 1. Characteristics of floods. Conceptual diagram developed using the Integration and Application Network (IAN) tool (www.ian.umces.edu/symbols/). The lower sixth represents a sub-surface cross-section.

Charlotte St 1893

Charlotte St 1974

Charlotte and Albert St 2011

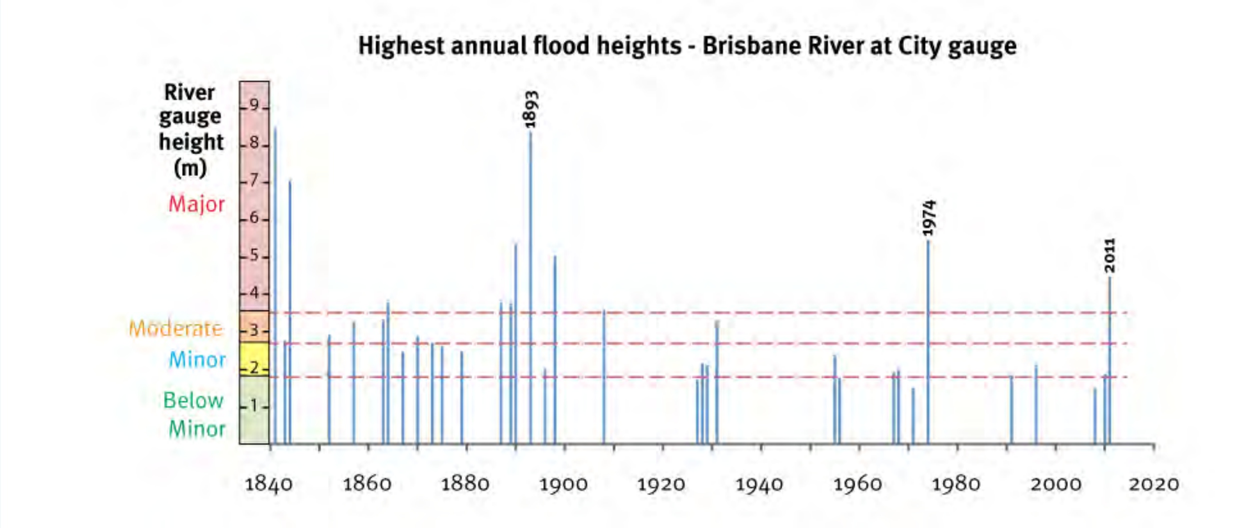


Figure 2. Highest annual flood heights at the Brisbane City gauge, 1840-2011. Minor, moderate and major flooding levels for the Brisbane City stream gauge are highlighted. Sources: Bureau of Meteorology, State Library of Queensland (API-033-01-0016—courtesy of the State Library of Queensland; 181874 © Ross Webster; 27803-0001-0248 © State Library of Queensland).

Floods are a natural process

Floods are a natural process, and our ecosystems, river systems and estuaries have adapted over long periods of time to depend on an irregular pattern of large floods. Many species, such as River Red Gums, rely on Australia's pattern of dry periods separated by periods of intense rain and overbank flooding.

Mankind's activities affect flooding

We make a lot of changes to our catchments including land clearing, urban development and dams, that can change the impact of a flood on the natural environment.

Floods can vary in size

The size of a flood event, or its ***magnitude***, can be expressed in many ways. The peak level of the water at a particular location in a waterway is the most unambiguous way, as it is relatively easy to measure and is the principal driver of flood impact. The flood magnitudes are usually classified by their height, and the Bureau of Meteorology uses three general categories of flooding related to water level:

- **Major**: This causes inundation of large areas, isolating towns and cities. Major disruptions occur to road and rail links. Evacuation of many houses and business premises may be required. In rural areas, widespread flooding of farmland is likely.
- **Moderate**: This causes the inundation of low lying areas requiring the removal of stock and/or the evacuation of some houses. Main traffic bridges may be closed by floodwaters.
- **Minor**: This causes inconvenience such as closing of minor roads and the submergence of low-level bridges and makes the removal of pumps located adjacent to the river necessary.

Figure 2 shows these general categories as they pertain to the main Brisbane stream, or river, ***gauge***. A stream gauge is a device used to measure the height of water in the river, and there is a network of gauges throughout the Brisbane River catchment. The values on this chart are in metres above the reference level defined for this gauge. It is important to note that the river heights for minor, moderate and major flooding are different for different waterways, depending on their individual characteristics.

Other important characteristics of floods that contribute to their severity include:

- The total amount of water in the flood, or the ***flood volume***. The flood volume contributes both to the level and duration of flooding. The flood mitigation ability of dams and detention basins are less for large volume floods.
- How fast the flood rises, or ***rate of rise***. A flood that rises quickly obviously provides less time for warning and evacuation.
- How fast the water is flowing, i.e. the flow ***velocity***. Faster flow causes a higher risk to human life, a higher risk of erosion, and more damage to infrastructure.
- The ***duration*** of flooding. A flood that lasts for a longer time provides a greater impact owing to the increased duration of the disruption to transport, business and personal networks.
- The ***areal extent*** of flooding. Flooding that affects a larger area, either within a river basin or across multiple basins, provides greater impacts.

Floods occur at irregular intervals

Figure 2 also illustrates the sporadic nature of flooding, showing the historic record of river levels at the Brisbane City gauging station since 1840. As illustrated, six major floods occurred in Brisbane between 1885 and 1910, followed by more than 60 years without a major flood.

The chance of a flood of a certain level occurring is usually referred to in terms of the likelihood of that level being exceeded in a particular year, or ***Annual Exceedance Probability (AEP)***. Q6 provides further information on what AEP means, and how it is estimated and used.

Photo: Flooding of the Fitzroy River in Rockhampton, January 2011. Photographer: Michael Marston

Q2: What factors contribute to floods?

Figure 3. An illustration of the factors that contribute to floods. These factors vary between locations and times, meaning that no two floods are the same. Conceptual diagram developed using the Integration and Application Network (IAN) tool (www.ian.umces.edu/symbols/).

Rainfall is the most important factor in creating a flood

Put simply, floods occur when the amount of water flowing from a catchment exceeds the capacity of its drains, creeks and rivers. This process begins with rainfall, but is affected by many other factors (Figure 3).

In Australia, flooding is heavily influenced by our naturally high rainfall variability which, relative to other parts of the world, leads to a much higher variability of the amount of water flowing through our waterways. A major factor in this variability is the El Niño—Southern Oscillation (ENSO) effect (see Figure 4).

In Queensland, average annual rainfall ranges from very low values in the southwest, to very high values exceeding 2000 mm per year along the coast (Figure 5). However, even in those areas with generally low rainfall, relatively heavy rainfall will occur in some years, causing flooding (Figure 6).

Long-term climate change and variability may also be having an influence on rainfall (a matter addressed in Q8).

Catchments convert rainfall into flowing water

When rain falls on a catchment, the amount of rainwater that is converted into flow down rivers and other waterways depends on the characteristics of the catchment.

Some rainfall is captured: A portion of the rain that falls on a catchment is captured by soil and vegetation. Generally, the more rain that falls in a particular area in a given period of time, the lower the proportion that can seep into the ground or be stored on the surface.

Figure 4. El Niño - Southern Oscillation

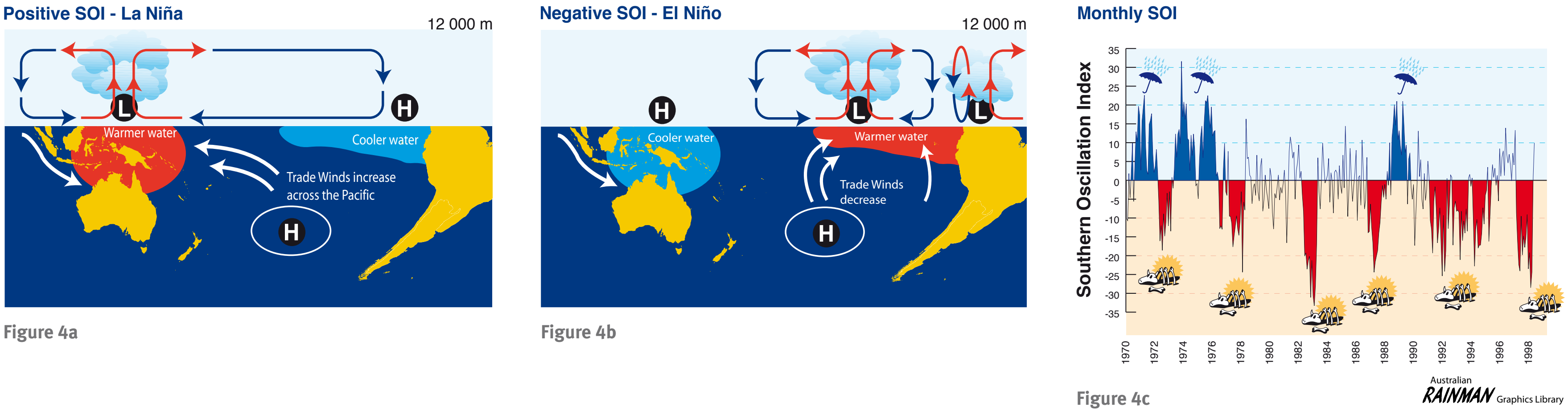


Figure 4a

Figure 4b

Figure 4c

Australian RAINMAN Graphics Library

The atmosphere and the oceans interact strongly to influence our weather.

Much of Australia's rainfall variation from year to year is caused by the natural climate phenomenon known as ENSO, the El Niño – Southern Oscillation. ENSO's 'see-saw' variations are intimately related to variations in the atmospheric vertical circulation along the equator over the Pacific. This circulation, known as the Walker Circulation, is caused by differences in sea surface temperatures between the eastern and western Pacific along the equator.

During 'normal' circulation warm, moist air travels west across the Pacific and rises over Indonesia, producing cloud and rain. The airstream then becomes comparatively dry and moves east at high altitude (approximately 12,000 m) and sinks over the normally cold waters near the South American coast.

There are various measures of the El Niño – Southern Oscillation. One of these, the Southern Oscillation Index (or SOI), measures the difference in air pressure between the eastern Pacific Ocean (measured at Tahiti) and the equatorial area around northern Australia and Indonesia (measured at Darwin).

When the equatorial ocean surface off the coast of South America is abnormally cool, the Walker Circulation is strengthened. In this situation the SOI is strongly positive, and the trade winds blow strongly across the warm Pacific, picking up plenty of moisture (Figure 4a). This increases the likelihood of eastern Australia experiencing above average rainfall, and is called a 'La Niña' event.

On the other hand, when the ocean surface off the coast of South America is abnormally warm, the air pressure between the eastern and western Pacific equalises or becomes a negative value, weakening or reversing the trade winds. This situation, which is a weaker than normal Walker Circulation (Figure 4b), is accompanied by a strongly negative Southern Oscillation Index and is called an 'El Niño'. In Australia this usually results in below average rainfall, and if this trend persists we can slip into drought. The SOI helps tell us how 'strong' a La Niña or El Niño event is. For example, when the SOI is consistently strongly positive (i.e. La Niña and above average rain) we may experience flooding. When the SOI is consistently strongly negative we risk entering into periods of drought (Figure 4c).

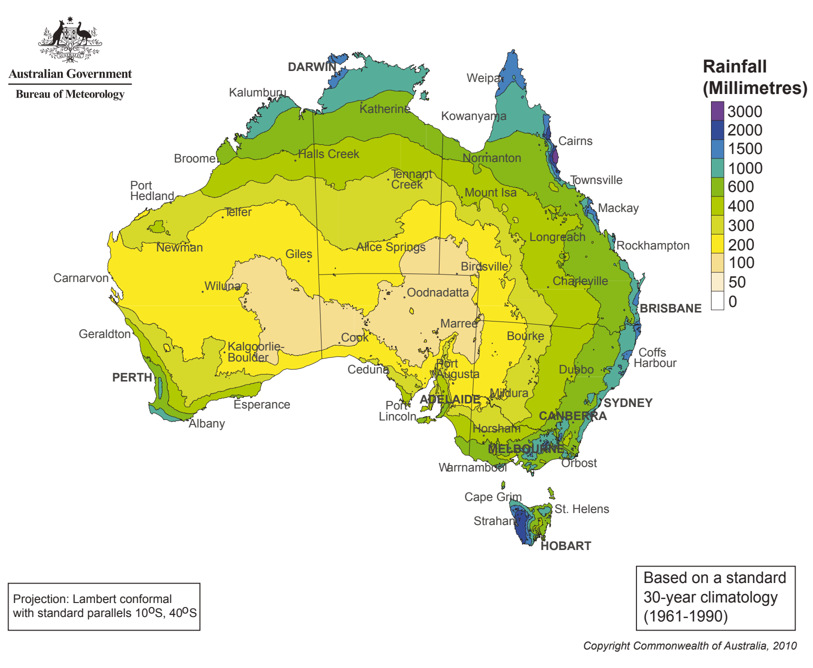


Figure 5. Australian annual average rainfall for the climate period 1961–1990. The period 1961–1990 is the current climate standard ('climate normal') used by the Bureau of Meteorology for climate comparisons through time. Figure courtesy of the Bureau of Meteorology.

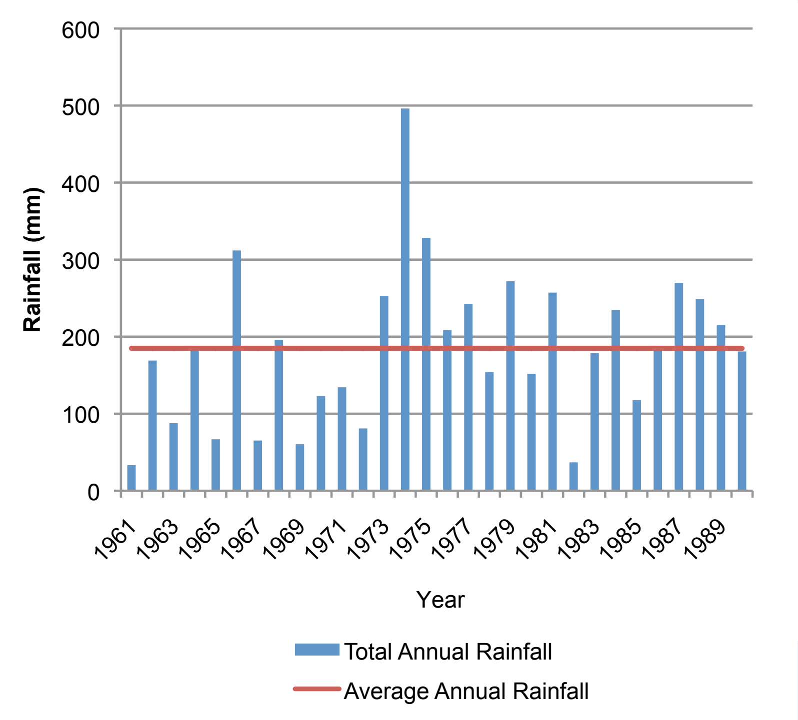


Figure 6. Annual rainfall variability as measured against the long-term average for Birdsville, western Queensland for the period 1961–1990. The period 1961–1990 is the current climate standard ('climate normal') used by the Bureau of Meteorology for climate comparisons through time. Data courtesy of the Bureau of Meteorology.

The greater the rainfall intensity, the greater the potential for runoff. How long it rains, and the area covered by the rain, are also important.

The more vegetation there is in an area, the greater the amount of rainfall that is captured and the less water there is available to flow over the surface. Natural and artificial storages like farm dams and rainwater tanks have a similar effect in reducing runoff.

The soil types in a catchment, land use and weather conditions prior to a rainfall event are also important as they control the amount of rainfall that can infiltrate into the soil, and hence the amount of rainfall which becomes flow. If a large storm is preceded by a period of wet weather, then the ground has little capacity to absorb further rainfall, and a higher proportion of the rainfall will flow across the land surface and into waterways. The construction of areas that cannot absorb water, such as roofs and roads, will also result in reduced infiltration and more rainfall being turned into runoff.

Rainfall that is not captured enters the waterways: Once water begins flowing in a catchment, various factors determine how much flows downhill into successively larger waterways, and how quickly it moves.

Typically**,** larger catchments result in greater streamflow if widespread rainfall occurs for a long time. The steeper the catchment area, the faster the runoff will flow.

Floods are also affected by the roughness of the terrain being passed over. Dense vegetation and artificial obstacles such as fences and houses will slow down water flow, often leading to lower flood levels downstream.

Swamps and natural ponds or lakes have the capacity to store floodwater and release it slowly. Artificial structures such as dams or detention basins (small reservoirs) can also store water for a period of time, and reduce the peak of downstream flows while extending the duration of an event. All such structures have a finite capacity and there is a limit to the volume of catchment flow that can be stored.

River characteristics affect water levels

The capacity of drains, creeks and rivers within a catchment to carry flows depends on a number of factors:

Size and nature of the river: Put simply, the bigger, straighter and smoother a river, creek or other channel, the greater its capacity to carry water and the less prone it is to flooding. Any process that reduces this capacity, such as the placement of structures in the channel, encroachment by development or build up of sediment, contributes to increased flooding.

Vegetation in and around the river: Plants in a river or on its banks slow the speed of the water flowing in it. The slower the water moves, the higher the water level, and the greater extent to which the floodplain surrounding the river will be inundated. This can reduce downstream flood levels and flows. Plants also reinforce river banks, decreasing erosion and increasing the deposition of sediment.

Once a river overtops its banks, the maximum flood level reached depends greatly on the nature of the adjacent floodplain. For example, wide, flat floodplains can store a greater volume of floodwater than steep-sided valleys, and the resulting floods move more slowly. Modifications to floodplains such as clearing of vegetation or the construction of embankments (for example, for a flood free road or rail corridor) can impact natural drainage patterns and processes on river floodplains.

Structures: Structures that are placed in a creek or waterway, for example culverts in an urban drainage system or bridges in a river, reduce the water-carrying capacity of the waterway and may contribute to flooding. Debris can also become entangled on these structures, worsening this process.

Levees along a waterway are designed to protect areas behind the levee from floods up to a certain level, but their constraining influence on flood flows can cause upstream flood levels to be higher than they otherwise would be. Road and railway embankments, with insufficient cross-drainage capacity (for example, use of culverts), can block off parts of the floodplain with a similar effect. Once levees or embankments are overtopped or breached, the way floodwaters spread over a floodplain can alter significantly and the impact of flooding is often severe.

Downstream water levels: The capacity of waterways can also be affected by the water level in the ocean or lake they are flowing into. For example, a king tide or storm surge can hamper the release of water from a river into the ocean. A similar effect can occur near the junction of creeks with rivers, where backwater effects from river flooding can extend a significant distance up the creek.

Photo: Floods can have positive effects on the environment, particularly in wetlands. Photographer: Briony Masters

Q3: What are the consequences of floods?

Photo: Aftermath of a flood: flood damaged household items awaiting collection and cleanup after the Brisbane floods, January 2011. Photographer: Michael Marston

The consequences of floods, both negative and positive, vary greatly depending on their location, duration, depth and speed, as well as the vulnerability and value of the affected natural and constructed environments. Floods impact both individuals and communities, and have social, economic, and environmental consequences (Table 1).

Floods have large social consequences for communities and individuals

As most people are well aware, the immediate impacts of flooding include loss of human life, damage to property, destruction of crops, loss of livestock, and deterioration of health conditions owing to waterborne diseases. As communication links and infrastructure such as power plants, roads and bridges are damaged and disrupted, some economic activities may come to a standstill, people are forced to leave their homes and normal life is disrupted.

Similarly, disruption to industry can lead to loss of livelihoods. Damage to infrastructure also causes long-term impacts, such as disruptions to supplies of clean water, wastewater treatment, electricity, transport, communication, education and health care. Loss of livelihoods, reduction in purchasing power and loss of land value in the floodplains can leave communities economically vulnerable.

Floods can also traumatise victims and their families for long periods of time. The loss of loved ones has deep impacts, especially on children. Displacement from one's home, loss of property and disruption to business and social affairs can cause continuing stress. For some people the psychological impacts can be long lasting.

Can the lost item be bought and sold for dollars?	Direct loss: Loss from contact with flood water	Indirect loss: No contact – loss as a consequence of flood water
Yes – monetary (tangible)	e.g. Buildings and contents, vehicles, livestock, crops, infrastructure	e.g. Disruption to transport, loss of value added in commerce and business interruption, legal costs associated with lawsuits
No – non-monetary (intangible)	e.g. Lives and injuries, loss of memorabilia, damage to cultural or heritage sites, ecological damage	e.g. Stress and anxiety, disruption to living , loss of community, loss of cultural and environmental sites, ecosystem resource loss

Table 1. Types of loss from floods. Modified from *Disaster Loss Assessment Guidelines*, Emergency Management Australia, 2002.

In Australia floods are the most expensive natural disasters

In Australia, floods are the most expensive type of natural disaster with direct costs estimated over the period 1967-2005 averaging at $377 million per year (calculated in 2008 Australian dollars).

Until recently, the most costly year for floods in Australia was 1974, when floods affecting New South Wales, Victoria and Queensland resulted in a total cost of $2.9 billion. The Queensland Government estimates costs for the 2011 floods will exceed this figure for Queensland alone; with the damage to local government infrastructure estimated at $2 billion, and the total damage to public infrastructure across the state at between $5 and $6 billion.

Flooding in key agricultural production areas can lead to widespread damage to crops and fencing and loss of livestock. Crop losses through rain damage, waterlogged soils, and delays in harvesting are further intensified by transport problems due to flooded roads and damaged infrastructure. The flow-on effects of reduced agricultural production can often impact well outside the production area as food prices increase due to shortages in supply. On the other hand, flood events can result in long-term benefits to agricultural production by recharging water resource storages, especially in drier, inland areas, and by rejuvenating soil fertility by silt deposition.

Damage to public infrastructure affects a far greater proportion of the population than those whose homes or businesses are directly inundated by the flood. In particular, flood damage to roads, rail networks and key transport hubs, such as shipping ports, can have significant impacts on regional and national economies.

Short-term downturns in regional tourism are often experienced after a flooding event. While the impact on tourism infrastructure and the time needed to return to full operating capacity may be minimal, images of flood affected areas often lead to cancellations in bookings and a significant reduction in tourist numbers.

Flooding of urban areas can result in significant damage to private property, including homes and businesses. Losses occur due to damage to both the structure and contents of buildings. Insurance of the structure and its contents against flooding can reduce the impacts of floods on individuals or companies.

Floods have significant consequences for the environment

In many natural systems, floods play an important role in maintaining key ecosystem functions and biodiversity. They link the river with the land surrounding it, recharge groundwater systems, fill wetlands, increase the connectivity between aquatic habitats, and move both sediment and nutrients around the landscape, and into the marine environment. For many species, floods trigger breeding events, migration, and dispersal. These natural systems are resilient to the effects of all but the largest floods.

The environmental benefits of flooding can also help the economy through things such as increased fish production, recharge of groundwater resources, and maintenance of recreational environments.

Areas that have been highly modified by human activity tend to suffer more deleterious effects from flooding. Floods tend to further degrade already degraded systems. Removal of vegetation in and around rivers, increased channel size, dams, levee bank and catchment clearing all work to degrade the hill-slopes, rivers and floodplains, and increase the erosion and transfer of both sediment and nutrients.

While cycling of sediments and nutrients is essential to a healthy system, too much sediment and nutrient entering a waterway has negative impacts on downstream water quality. Other negative effects include loss of habitat, dispersal of weed species, the release of pollutants, lower fish production, loss of wetlands function, and loss of recreational areas.

Many of our coastal resources, including fish and other forms of marine production, are dependent on the nutrients supplied from the land during floods. The negative effects of floodwaters on coastal marine environments are mainly due to the introduction of excess sediment and nutrients, and pollutants such as chemicals, heavy metals and debris. These can degrade aquatic habitats, lower water quality, reduce coastal production, and contaminate coastal food resources.

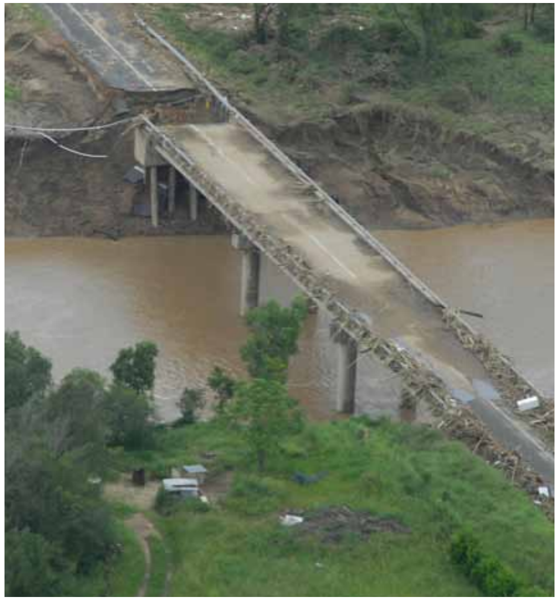


Photo: Flood damage after the Toowoomba flood disaster, January 2011. © APN Regional Media

Q4: How do we forecast floods?

The Bureau of Meteorology (BoM) is the lead national agency for flood forecasting and warning services in Australia, working in partnership with agencies at the state and local government levels. The BoM provides forecasts of the water level in rivers at critical locations during flood events. Local governments and emergency agencies may further interpret the river water level forecasts and provide advice on flood inundation extent. The BoM also provides severe weather warnings that include risk of flash flooding.

In addition, the BoM provides forecasts of rainfall and river flow for the coming three months. These seasonal forecasts may help alert agencies, and the public, of entering a period of heightened chance of flooding.

Weather forecasts provide advance warning of a flood

Reliable forecasts of weather, in particular rainfall, can allow advance warning and forecasting of floods. Weather forecasts for the next one to seven days rely on increasingly accurate computer models of the atmosphere and ocean/atmosphere interactions. Dramatic improvements in the data available to such models (from satellite observations) and in computing power have contributed to this increased accuracy. In some parts of the world, three-day-ahead forecasts of heavy rain are now as accurate as one-day-ahead forecasts were in the mid-1990s (www.hpc.ncep.noaa.gov/images/hpcvrf/hpc20yr.gif).

Radar (and sometimes satellite) images can be useful for tracking areas of heavy rain and their movement (Figure 7). Rainfall in the next one to four hours may be forecast based on these images in combination with computer models. However, such forecasts give only a very short ***lead time*** (the time between when a forecast is made and the forecasted event occurs) for response.

The accuracy of climate and weather forecasts varies with lead time, spatial scale (or size) of the region of interest, the weather or climate variable being forecast (for example, rain, thunderstorm), as well as with latitude. Generally, temperature forecasts are more accurate than rainfall forecasts. The mid-latitudes (in Australia 30°S to 60°S) are easier to forecast than the tropics (so Melbourne has more accurate forecasts than Darwin). It is generally easier to forecast when the lead time of the forecast is relatively short—so a seven-day forecast is usually less accurate than a forecast of tomorrow's weather. Finally, it is generally easier to forecast rainfall over a large area (for example, a large catchment) than local rainfall (for example, a reservoir). This is because the intensity of any rain system varies on small spatial scales, but the variation is somewhat averaged out over a large area.

Rainfall forecasts can be used to extend the lead time for flood forecasts. However, because forecasts of rainfall for specific locations and timing are not fully accurate, flood forecasts based on rainfall forecasts are often subject to significant uncertainty.

Forecasting river levels and flood extent is complex

Flood forecasts are critical to emergency responses to limit property damage and avoid loss of lives.

Flood forecasters rely heavily on real-time data about rainfall and river water levels as well as rainfall forecasts. A network of rain gauges (sometimes combined with radar images) are used to monitor rain that has fallen on the catchment. Water levels (i.e. river height) at stream gauging stations along the river are also measured. A simple river height recorder is shown in the picture. The forecasters then use hydrological computer models to work out how much rainfall will run off different parts of the catchment, how long it will take for runoff to reach the river, how long that water will take to travel from upstream to downstream, and how water from different tributaries converges in the river network.

Flood forecasters estimate the river flow rate at various key locations and lead times and convert the estimates to river water level forecasts (Figure 8). Flood forecasts by the BoM are issued to emergency management agencies and the public through the media and the BoM's website. The forecasters regularly update their forecasts as new observations are made of rainfall and river water level, and as rainfall forecasts become available.

Because rain that has fallen on a catchment takes time to travel to the outlet of the catchment, river flow downstream of the catchment within a certain period will largely be influenced by rain that has already fallen on the catchment and been observed. This means that the river flow forecast for this period will be reasonably accurate. River flow forecasts beyond this period will be less accurate as it is necessary to use rainfall forecasts.

If a critical dam operation is involved in a flood event, the forecasters communicate with dam operators. Decisions about releasing water from dams take into account forecasts about how much water will flow into the dam and assessments of how water releases may affect water levels downstream. In turn, flood forecasts for downstream areas take into account water release decisions.

Forecasts of river water level are most useful when interpreted in terms of where the water is likely to spread beyond the river. Such interpretations may be provided to the public by local governments and emergency agencies, usually based on pre-prepared flood maps using historical flood data and in some cases floodplain hydraulic models (see Q6 for more information).

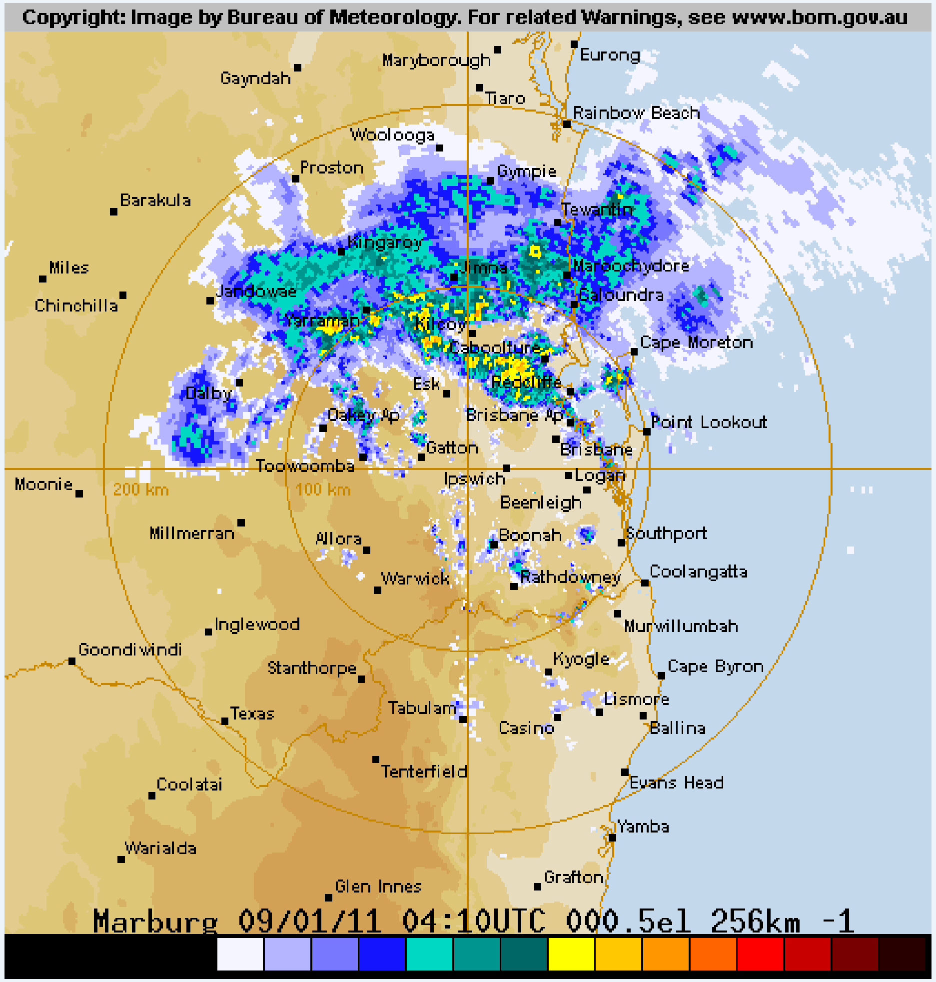


Figure 7. Radar image showing rainfall over the South-East Queensland and New South Wales coast, 9 January 2011. The intensity of the rain (interpreted from droplet size) is indicated by the changing colour scale. Courtesy of the Bureau of Meteorology.

Photo: A manual stream gauging station on the Fitzroy River, Rockhampton, January 2011. Note the historical reference to heights of previous floods: 1918, 1954 and 1991. Photographer: Michael Marston

New technologies are available, but not yet widely used in Australia, for providing near real-time mapping and delivery of forecast flood inundation extent on the internet. These technologies use accurate ground-elevation data, robust floodplain hydraulic models, new spatial information technology and internet map-serving software. Adoption of the technologies would significantly enhance the value of flood forecasts in Australia.

Flash floods are difficult to forecast, although technologies are available and used operationally overseas for flash flood forecasting. These technologies are generally based on monitoring of rainfall using rain gauges and radar images, high resolution rainfall forecasts for the next few hours, understanding of the catchment condition (how much rainfall will run off) and understanding of the local drainage systems (how much water is needed to cause a flood). As flash flood forecasts improve in accuracy and are integrated with communication and response systems over time, they can become highly valuable.

Seasonal forecasts alert of a heightened chance of flooding in the coming months

The BoM regularly issues forecasts of rainfall and temperature for the coming three months (www.bom.gov.au/climate/ahead/). The prospect of a wet season would lead to an increased chance of flooding, so forecasting seasonal rainfall can help alert us of flood risk. The high variability of rainfall across most of Australia from one year to another is largely the result of the El Niño—Southern Oscillation (see Q2 for more information). Computer models are used to predict the development of the La Niña events that are often associated with heavy rains. However, seasonal forecasts are not highly accurate, and are expressed only in probabilistic terms, i.e. percentage chance of occurrence. For example, Queensland may have low rainfall on some occasions even in very strong La Niña events. Nevertheless, such forecasts have been demonstrated to be useful for industries such as agriculture, water resources and finance, indicating that the rainfall forecasts may also be useful for forecasting seasons with an increased chance of flooding.

In December 2010, the BoM commenced a seasonal streamflow forecasting service. This service provides forecasts of probabilities of total flow exceeding various volumes in the coming three months (www.bom.gov.au/water/ssf/). The forecasts are also based on computer models, taking into account how wet and dry the catchments are at the start of the season as well as the climate. Although forecasts of floods are not directly made at the seasonal time scale, it is reasonable to expect an increased chance of flooding when total streamflow volume in the next season is forecast to be high.

In addition to the services provided by the BoM, some state governments and universities also provide seasonal forecast outputs including probabilistic streamflow forecasts in some instances.

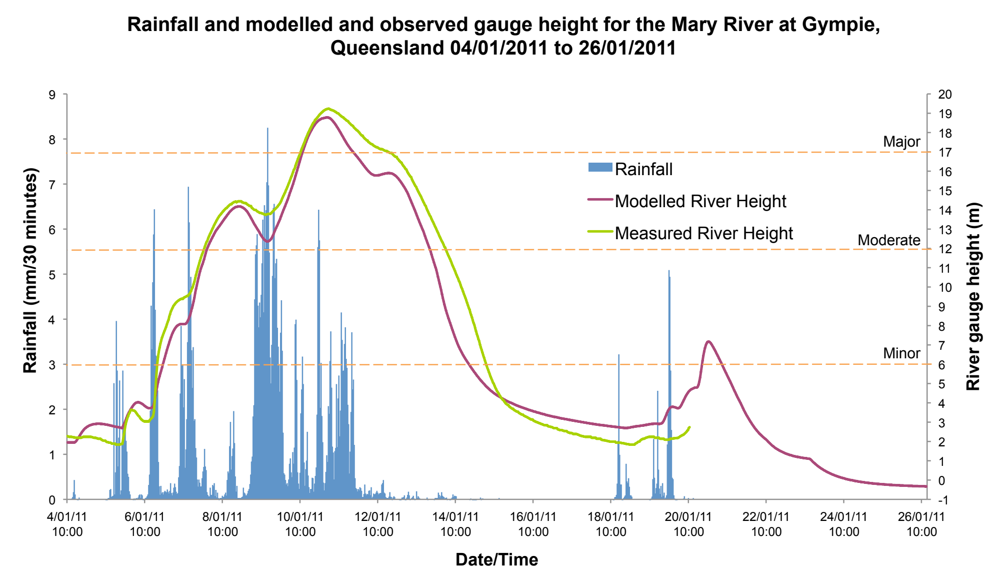


Figure 8. Modelled versus observed water heights for the Mary River at Gympie, Queensland, together with observed rainfall. While there is reasonably good agreement in this instance, as can be seen from the differences between the red and green lines, actual river height can vary from what we expect based on modelled results due to data and model limitations. (This model – red line – was run on 18 January 2011; no further observations – green line – were taken after 20 January 2011 for the above diagram.) Data courtesy of the Bureau of Meteorology.

Q5: How do we communicate and warn about floods?

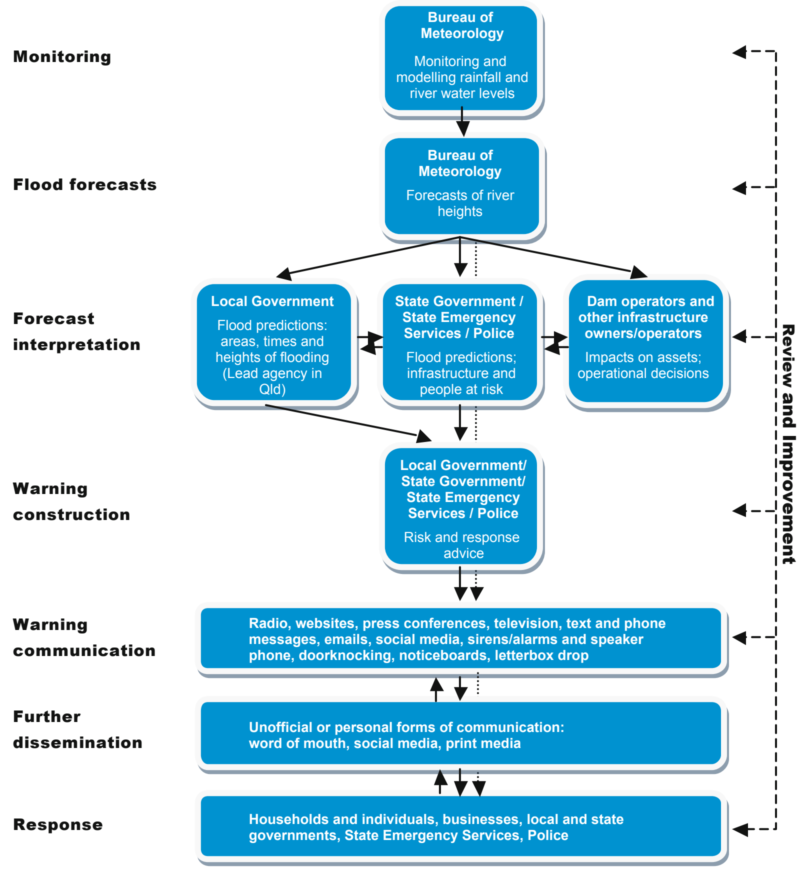


Figure 9. Components of a flood warning system, noting that the precise arrangements vary between states. While flash floods are not covered in this figure, the Bureau of Meteorology also provides severe weather warnings, which can include general warnings of potential flash flooding, via its website. Compiled by the Science, Engineering and Technology Panel.

Flood warning systems turn forecasts into messages designed to reduce losses

A warning system consists of a number of key steps: monitoring rainfall and river flow rate; making forecasts about river water levels and flood extent; interpreting forecasts for their meaning in terms of impact on those at risk; composing and disseminating warning messages; response by those at risk and emergency services; and review and improvement (Figure 9).

In Australia, flood warning systems for rivers involve the BoM, which provides forecasts of river water heights at specified locations to relevant authorities, and to the public via broadcast media and the BoM's website. Local government or State Emergency Services then interpret the BoM's forecasts to provide local information on areas likely to be affected, potential impacts and action advice to those at risk. Messages are also disseminated throughout the community, particularly by personal or informal networks. Social media (for example, Facebook, Twitter) will almost certainly play an increasingly important role in the future. This will also raise challenges due to the potential risk of mis-information.

Flash floods account for most flooding fatalities in Australia and currently present the most challenges due to the limited warning time. While the BoM provides severe weather warnings, which can include the risk of flash flooding, specific flash flood forecasts and warnings (i.e. including specific location and timing information) are not generally provided. However, some local governments have warning systems for these events.

Warning systems should satisfy a number of technical and communication attributes

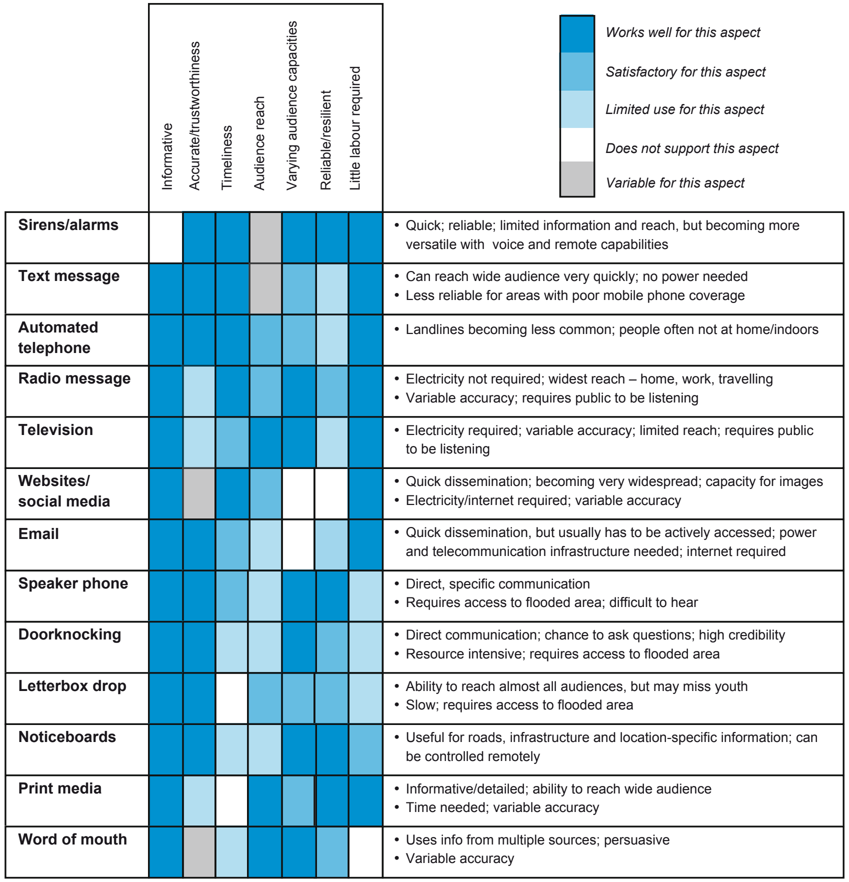
They should be informative: Warning messages should indicate what the threat is, what action should be taken, by whom and when, in understandable, unambiguous and consistent language. A warning also needs to have personal meaning for those at risk (whether individuals, agencies or businesses). This means going well beyond a specified river height to indicating the area likely to be covered by the flood, its depth and speed in terms of locally relevant landmarks. In turn, this requires understanding of the relevant river systems.

They should be accurate: As warnings are predictions about the future, there is inevitably some uncertainty. Uncertainties can also arise from the construction and wording of warning messages themselves. Engaging with the community and business groups affected has been shown to improve understanding of the issues and reduce the chance that future warnings will be ignored.

They should be timely: Warnings need to allow enough time for appropriate action. This is particularly a challenge for flash floods.

They should be trustworthy: Warnings are more likely to be heeded if they come from multiple trusted sources.

They should reach the appropriate audiences: The audience for a warning will typically consist of many sub-groups, each with its own needs and expectations, preferred way of receiving warnings, and own ways of interpreting messages. No one warning source will reach, or be understood by, everyone. Warning systems work best when designed with the needs and expectations of the ultimate users in mind—something best achieved with their input. The capacity of individuals to receive or respond to



- ■ *Works well for this aspect*
- ▓ *Satisfactory for this aspect*
- ░ *Limited use for this aspect*
- □ *Does not support this aspect*
- ▒ *Variable for this aspect*

	Informative	Accurate/trustworthiness	Timeliness	Audience reach	Varying audience capacities	Reliable/resilient	Little labour required	
Sirens/alarms	□	■	■	▒	■	■	■	• Quick; reliable; limited information and reach, but becoming more versatile with voice and remote capabilities
Text message	■	■	■	▒	▓	░	■	• Can reach wide audience very quickly; no power needed • Less reliable for areas with poor mobile phone coverage
Automated telephone	■	■	■	▓	▓	░	■	• Landlines becoming less common; people often not at home/indoors
Radio message	■	░	■	▓	■	▓	■	• Electricity not required; widest reach – home, work, travelling • Variable accuracy; requires public to be listening
Television	■	░	▓	■	■	░	■	• Electricity required; variable accuracy; limited reach; requires public to be listening
Websites/ social media	■	▒	■	▓	□	□	■	• Quick dissemination; becoming very widespread; capacity for images • Electricity/internet required; variable accuracy
Email	■	■	▓	░	□	░	■	• Quick dissemination, but usually has to be actively accessed; power and telecommunication infrastructure needed; internet required
Speaker phone	■	■	▓	░	■	■	░	• Direct, specific communication • Requires access to flooded area; difficult to hear
Doorknocking	■	■	░	░	■	▓	░	• Direct communication; chance to ask questions; high credibility • Resource intensive; requires access to flooded area
Letterbox drop	■	■	□	▓	▓	▓	░	• Ability to reach almost all audiences, but may miss youth • Slow; requires access to flooded area
Noticeboards	■	■	░	░	■	■	▓	• Useful for roads, infrastructure and location-specific information; can be controlled remotely
Print media	■	░	□	■	▓	■	■	• Informative/detailed; ability to reach wide audience • Time needed; variable accuracy
Word of mouth	■	▒	░	■	■	▓	□	• Uses info from multiple sources; persuasive • Variable accuracy

Table 2. Pros and cons of different flood warning communication methods. Compiled by the Science, Engineering and Technology Panel.

warnings may be reduced because of disabilities, age, language, or other commitments.

They should be reliable: Warnings need to work under extreme conditions (for example, in inundated areas, in the absence of electricity), as this is when warnings are most needed. A variety of warning sources increases the likelihood that warnings will be maintained throughout a flood event.

Prior awareness of risk can make warnings more effective

For warnings to achieve their aims, people need to know about their community's flood risk, what actions will improve their safety, and how they will receive a warning to implement those actions. Prior awareness and preparation are key to success.

Those issuing warnings and advice need to know what sorts of actions are feasible for those who are being warned. This requires mutual learning between government agencies with formal responsibility for the warnings, and the people who need to respond to warnings. People need to see the personal relevance of the warnings to their situations—this is a major gap in many communities.

Community education programs can use a wide range of approaches, including community and industry facilitated climate, weather and flood workshops that identify community and industry risk and key management decisions. Another option is to run flood rehearsals or drills. A challenge is to maintain flood awareness and preparedness during the periods between floods.

Photo: Warnings should be accessible to the whole community. Here, government and emergency personnel provide warnings for the community during a live television broadcast, January 2011. An Auslan interpreter translates these warnings for the deaf community. Photographer: Hugh O'Brien

Improving our warning systems could reduce losses

Improvements in warning systems, in particular in community response, is one of the most cost-effective means by which we could reduce the economic and social losses from floods and save lives.

Areas where current systems could be improved include:

- Persuading people to take effective protective action once a warning has been issued. We know how to raise awareness, but not how to ensure action. This is a significant knowledge gap.
- Using more locally relevant information so that people relate personally to warning messages, and know what to do for their own safety.
- Reducing uncertainty in predictions while providing enough time for effective action, by harnessing the promise of advances in flood modelling and communication technologies. To date, the advances in modelling and modern information and communication technologies have had limited impact on overall warning system effectiveness.
- Communicating the uncertainties in warnings, possibly through a mix of verbal qualifiers like 'may', 'could', 'be at least' and probabilities. However, public appreciation of numerical probability statements is understandably limited.
- Providing effective warnings for flash flooding. This is currently a major gap across Australia. Technical advances may now make flash flood warnings feasible, but the issues of rapid decision making by all the agencies involved and by those at risk would need to be addressed.
- Improving methods to evaluate warning performance.

Q6: How do we estimate the chance of a flood occurring?

Understanding the chance of different sized floods occurring is important for managing flood risk

The best method for calculating the chance of different sized floods occurring is statistical analysis of long-term flood records from stream gauging stations. Where a long-term flood record exists, and no significant changes have occurred to the catchment, a statistical technique known as ***flood frequency analysis*** can be used to determine the likelihood of floods of different sizes occurring at a specific site in the future (Figure 10). However, Australia's flood records do not extend far into the past, and flood events are highly variable, meaning there is still a level of uncertainty in defining such flood estimates. Climate change may also affect how much we can rely on past flood records.

Where sufficient flood records do not exist, or a very rare flood needs to be estimated, ***rainfall based techniques*** are used. These use statistical analyses of rainfall records, together with computer models based on the geographical characteristics (for example, catchment area, waterway length) of the region being studied, to determine the chance of different sized floods occurring. These models can be set up to take account of changes that affect runoff, such as new dams and urbanisation, but the computer models used to convert rainfall to runoff are not perfect, making rainfall techniques generally less reliable than the use of long-term flood records.

Both of these techniques result in predictions for peak water flows at key locations in rivers. These predictions are translated into flood levels at any point of interest in the floodplain, through the use of further computer models known as floodplain hydraulic models.

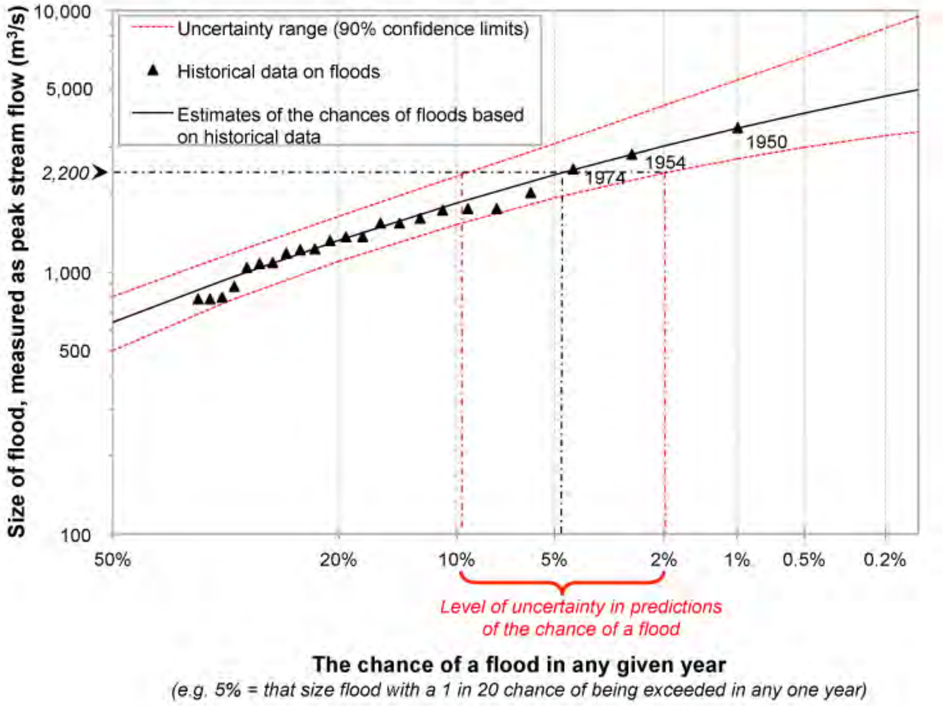


Figure 10. Estimating the chance of floods of different size based on flood frequency analysis of historical flood records at Bellingen, NSW. There is always a level of uncertainty inherent in such analyses. For example, the chance of a flood with a stream flow of 2,200 m^3/s (as arrowed, left hand axis) in any year is estimated to be between 1 in 50 (2%) and 1 in 10 (10%). This is said to be 'within 90% confidence limits', i.e. we are 90% sure that it will be in this range – with a 10% chance we will be wrong, and it will be outside this range, higher or lower. The more confidence there is in the data the closer the confidence limits (red dashed lines) will be to the estimate (black line). Courtesy of WMAwater.

Floodplain hydraulic models are virtual representations of the river and its surrounding land, or floodplain. They incorporate things such as ground levels, roads, embankments and river sizes to estimate predicted flood flows. The output of the models includes representations of predicted flood levels and the predicted speed of water flow.

It should be noted that any actual flood event will vary in some manner from the theoretical events from floodplain computer models (Figure 11). Such variations are primarily due to differences in the rainfall pattern, along with other factors such as how wet the catchment was before the event, and whether the centre of the storm was over the lower or central reaches of the catchment. (See Q2 for more on these variations.)

The chance of a flood event can be described using a variety of terms

Floods are often defined according to their likelihood of occurring in any given year. The most commonly used definition in planning is the ‘1 in 100-year flood’. This refers to a flood level or peak that has a one in a hundred, or one per cent, chance of being equalled or exceeded in any year. Similarly, a ‘1 in 200-year flood’ has a one in two hundred, or 0.5 per cent, chance of being equalled or exceeded in any one year.

Other terms that express the same idea, such as one per cent ***annual exceedance probability*** (or one per cent AEP), are preferred because they avoid the common misconception that a ‘1 in 100-year flood’, for example, can only occur once every 100 years; or that you are ‘safe’ for another 100 years after you experience such an event. For example, in Kempsey, NSW, major floods approaching the one per cent AEP level occurred in 1949 and then again a year later in 1950.

In reality, the chance of experiencing different sized flood events in a given period of time can be estimated mathematically (see Table 3). If you lived for 70 years in a location that had a one per cent chance of flooding in any one year (that is, it would only flood if a ‘1 in 100-year flood’ occurred), then there would actually be a 50 per cent chance, or one in two odds, of you experiencing at least one flood during that 70 year period. The way we calculate this is: 100 per cent minus the chance of a flood not happening 70 times in a row, i.e. $0.5 = 1 - 0.99^{70}$.

It is also important to remember that the chance that you will be affected by a flood is not only dependent on the likelihood of your own property flooding. Floods can disrupt transport networks, impact tourist destinations and prevent food from reaching markets. With more than 100 rivers and creeks in Queensland the chances are good, when flooding occurs, that many people will be affected, either directly or indirectly (see Q3 for more information).

Good planning needs to consider more than just the one per cent AEP flood

In nearly all but a few locations, even the best plans are not able to fully eliminate the chances of a flood.

Nevertheless, for planning purposes, it is important to decide what level of flood risk is acceptable for individuals and the community. This should take into consideration both the chance of a flood happening and the consequences of a flood (see Q7 for more information).

Until about 30 years ago, it was common to use the largest historical flood in an area for planning purposes, and this is still used in some rural locations.

However, currently nearly everywhere in Australia the one per cent AEP event, or ‘1 in 100-year flood’, with an appropriate additional height (or freeboard) for buildings is designated as having an ‘acceptable’ risk for planning purposes, regardless of the potential consequences of the flood.

Chance of a flood of a particular size being exceeded in any one year	Chance of experiencing a flood in a 70 year period	
	at least once	*at least twice*
10% (1 in 10 odds)	99.9%	99.3%
5% (1 in 20 odds)	97.0%	86.4%
2% (1 in 50 odds)	75.3%	40.8%
1% (1 in 100 odds)	50.3%	15.6%
0.5% (1 in 200 odds)	29.5%	4.9%

Table 3. Probabilities of experiencing a given size flood once or more in a lifetime. Modified from *Floodplain Development Manual: the management of flood liable land,* NSW Government, 2005.

There are often strong social and economic reasons for considering a higher standard than the one per cent AEP flood. For example, in some locations flood levels associated with rarer floods are significantly higher and are likely to cause significant devastation; inundation of a particular location may have significant economic and social consequences for a much wider region.

For example, London is moving to a planning level above the '1 in 500-year flood' (0.2 per cent AEP) for land adjoining the Thames estuary. Also, many parts of the Netherlands use planning levels above the '1 in 1000-year' coastal flood event (0.1 per cent AEP), because inundation of large, low lying areas would have major consequences.

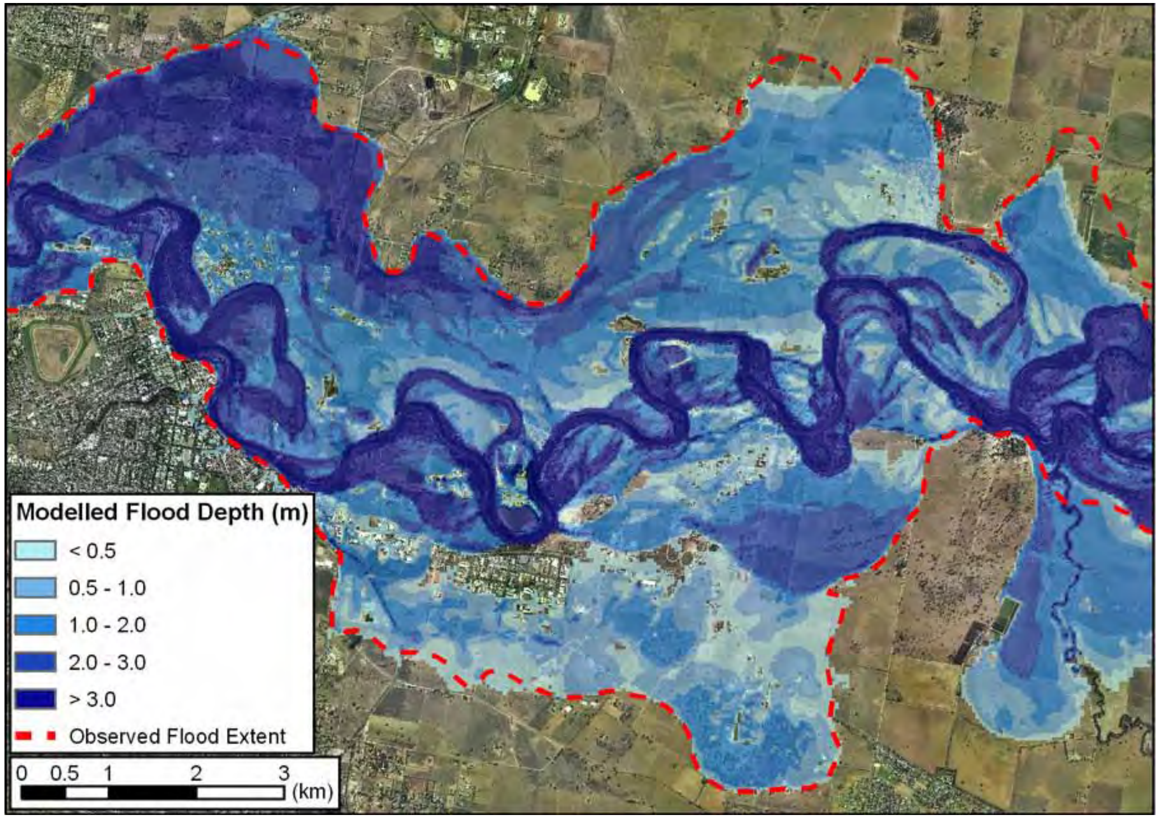


Figure 11. Post event comparison of flood extent modelled (predicted) by a floodplain hydraulic model (blue) and an actual flood event (red line) in Wagga Wagga, NSW, 1974. While predictions are mostly very good, some variations can be observed between predicted and actual (observed) flooding, e.g. in the right hand side of the image. Courtesy of WMAwater.

Q7: How do we manage flood risks?

Flood risk includes both the chance of an event and its potential impact

Flood risk is a combination of the chance of a flood occurring and the consequences of the flood for people, property and infrastructure (Figure 12). The consequences of a flood depend upon how exposed the community is to flooding and how vulnerable its people, property and infrastructure are to the flood's impacts.

Managing risks from floods may involve altering the chance of flooding affecting a community; and/or reducing the impacts of flooding by reducing the community's vulnerability and exposure to flooding. The methods that are effective in reducing flood risk are very location specific. There is no one-size-fits-all solution and a variety of measures are generally necessary to reduce risk.

Flood risk management is a partnership between government and the community using a range of measures to reduce the risks to people, property and infrastructure. Decisions on managing flood risk should be made in consultation with the community that may be impacted by floods.

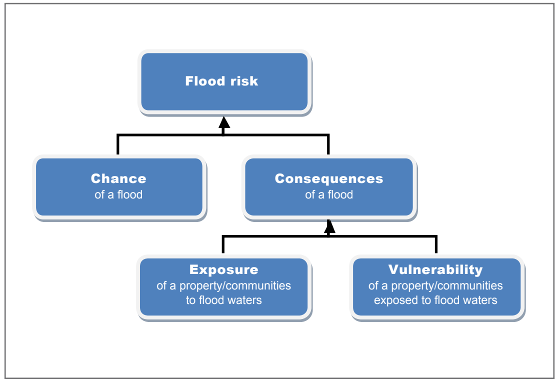


Figure 12. Components of flood risk.

Preparing a floodplain management plan that outlines how flood risk to existing and future development can be managed for a particular location can inform these decisions. This process involves more than simply ensuring that building floors are above a particular flood level. It also considers how flood behaviour and hazard may vary in different parts of the floodplain and how different sized flood events might have an impact on people, property and infrastructure.

Floodplain management plans can reduce risk for new development areas

Managing flood risk is generally simpler in new development areas. Preparing a floodplain management plan enables strategic decisions about where, what and how to develop the floodplain while reducing residual flood risk (i.e. the risk left after management measures are put in place) to an acceptable level.

Local councils can use local planning instruments to influence the long-term development of an area in consideration of flooding, by restricting the location of development (zonings) and placing conditions (controls) on development.

Zonings can limit the impacts of new development on flood behaviour in other areas and the exposure of people and property to risk by locating new development away from areas where:

- The main floodwaters flow. Development in these areas may alter flood behaviour affecting other properties. Maintaining these flowpaths can also provide green corridors through cities.
- The speed and depth of water make it hazardous to people, property and infrastructure.
- It is not possible to evacuate people to flood free areas and there is no practical alternative.

Zonings can also limit the development of the remaining available land by considering:

- **The use of community facilities during a flood.** Critical facilities, such as emergency hospitals, should ideally be located in areas where they will not flood and can operate during a flood event (see Figure 13).
- **The vulnerability of occupants to flooding.** Aged care and disabled facilities should generally be located in areas where they can be readily evacuated to dry land.
- **The vulnerability of buildings and contents.** Homes and their contents are generally more vulnerable to flooding than industrial and commercial buildings and therefore should be located in less vulnerable areas.

Conditions on development can include: minimum fill levels for land and minimum floor levels for buildings (to reduce how often people and property are exposed to flooding); building regulations (that reduce the potential for structural building damage); and the ability to evacuate people to flood free areas (which may affect the way land is developed).

Flooding can also have significant impacts on infrastructure, which needs to be considered when designing infrastructure. Appropriate design standards for infrastructure exposed to flood risk can reduce its vulnerability to flooding.

Figure 13. Land use planning should consider flood behaviour and risk. Probable Maximum Flood (PMF) is an estimation of the largest possible flood that could occur at a particular location. Critical public infrastructure such as hospitals and emergency management centres are ideally located outside the influence of the PMF. From Q6 we note that a 10% flood is a '1 in 10-year flood' and a 1% flood is a '1 in 100-year flood'. Courtesy of WMAwater.

Flood risk is harder to manage in existing developed areas

Flood risk is harder to manage where development, or the right to develop, already exists. Flood risk to existing infrastructure is usually altered through improvements to protection as part of any upgrade. However, for people and property there are basically three ways of managing flood risk to reduce the consequences of flooding: by modifying flood behaviour, property, or community response.

None of these measures is a stand-alone solution for addressing flooding issues. The preferred option is often a combination of flood-, response- and property-modification measures to reduce risk to an acceptable level and to manage this residual risk appropriately.

Flood modification measures change the behaviour of floodwaters

Flood modification measures aim to reduce flood levels, velocities or flows, or exclude floodwaters from areas under threat for events up to their designed capacity. They are a common and proven means of reducing damage to existing properties under threat from flooding. They tend to be more expensive than response or property modification measures but will often protect a larger number of properties.

Flood mitigation dams can reduce downstream flood levels by temporarily storing and later releasing floodwaters. Most dams are used to supply water to the community, but they can, when purpose built, also provide some flood mitigation for events up to their flood storage capacity. In larger floods, this mitigation capacity can be exceeded and floods pass through with little, if any, reduction. On the negative side, dams can cause disruption to existing communities, loss of valuable land and negative environmental impacts, and good sites for dams are difficult to locate. ***Detention basins*** act like dams but at a much smaller scale and are most suitable for 'green field' developments, where sizing constraints tend not to exist.

Levees are generally raised embankments built to eliminate inundation of the areas protected by the levee up to a certain size event. In larger floods, levees can be overtopped with water flooding into and inundating areas protected in the smaller events. Levees can trap local stormwater, causing damage unless flood gates and pumps are provided. However, levees, whether temporary or permanent, can increase flood levels in areas not protected by the levee (as noted in Q2).

Waterway or floodplain modifications such as widening, deepening, realigning or cleaning rivers and flowpaths can improve the transport of floodwaters downstream and reduce the likelihood of blockage, but can increase velocities and erosion and cause negative environmental impacts. The benefits of cleaning and clearing are only temporary unless these continue to be maintained.

Other structures such as roads, railways and embankments also have an impact on flood risk management because they can alter flood flows and behaviour. Floodgates can also be used to prevent backflow from river systems into drains.

Property modification measures can protect against harm caused by floods

In addition to the zoning and development controls for new and re-developments mentioned above, modifications to existing property are also essential if the growth in future flood damage is to be contained.

Land filling involves building up low-lying areas and can improve the flood immunity of structures constructed on that land, but can adversely affect flood behaviour elsewhere and therefore is generally limited to the fringes of the floodplain.

Flood proofing involves the sealing of entrances, windows, vents, etc. to prevent or limit the ingress of floodwater. Generally it is only suitable for brick commercial buildings with concrete floors and it can prevent ingress for outside water depths up to approximately one metre. Ideally, new developments would use flood resilient designs and materials, as addressed in Q8.

House raising is widely used to reduce the frequency of inundation of habitable floors, thereby reducing flood damage. This approach provides more flexibility in planning, funding and implementation than removal of development. However, its application is limited as it is not suitable for all building types and only becomes economically viable when above-floor inundation occurs frequently (for example, on average at least once in every 10 years). It also does not remove the risk to people who occupy the house, particularly in larger flood events.

Removal of development is generally only considered where there is significant potential for fatalities to residents and/or potential rescuers due to flooding, and where other measures are not able to reduce these risks. There are instances where a large proportion of, or an entire town has been relocated due to flooding. For example Clermont, Queensland, was relocated to higher ground after the flood of 1916. This approach generally involves voluntary purchase and demolition of the residence to remove it from the floodplain. Voluntary purchase has no environmental impacts, although the economic cost and social impacts can be high. Communities often oppose such schemes due to the impact on their community, surrounding property values and way of life.

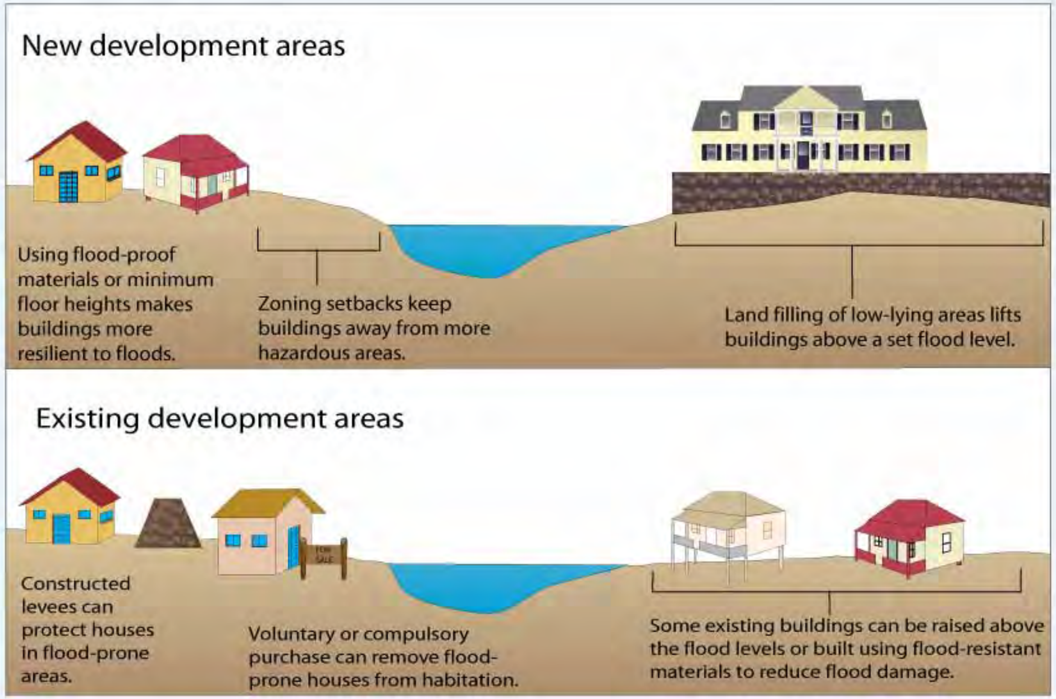


Figure 14. Property modification measures to manage flood risk in new and existing development areas. This schematic was developed utilising the Integration and Application Network (IAN) tool (www.ian.umces.edu/symbols/).

Response modification measures help communities deal with floods

Measures to modify the response of the community to a flood are essential to deal with residual flood risk, because development controls and flood mitigation works generally cannot deal with all possible floods. Response modification measures can include: flood warnings, upgrading flood evacuation routes, flood evacuation planning, flood emergency response and flood education programs.

Implementing effective flood response within the community can reduce the danger and damage associated with floods. Flood warning and evacuation plans can be very cost effective and may, in some cases, be the only economically justifiable risk management measures. However, like all mitigation measures, they require ongoing maintenance and support. This is discussed further in Q5.

Photo: In flood prone areas, houses with habitable floors built above the potential flood height can reduce the loss and damage associated with floods. Photographer: Michael Marston

Q8: What does the future look like?

Climate change will affect flooding patterns

Because flood events are influenced by a number of factors, based on the current science it is difficult to confidently state that, overall, extreme flood events in Queensland will increase in intensity or frequency as a result of climate change. However, increased coastal inundation from sea level rise and increased chance of flash flooding because of an increase in short-term heavy rainfall events both seem highly likely, based on current assessments of projected climate change.

There are four specific questions about climate change that have relevance to future flooding in Queensland:

Will the systems that drive our regional climate be affected? This question is relevant because of the strong tendency for widespread flooding to occur during La Niña events, the 'wetter' extreme of the El Niño—Southern Oscillation, ENSO (see Q2 for more information). If La Niña events, or their effects on Queensland rainfall, became more frequent or more intense because of global warming, we can expect more frequent flooding. Currently it is projected that, in the future, ENSO variations may be different from those in the recent past. However, we are not currently able to project confidently what those changes will be.

Will average rainfall and short-period rainfall events change? Average rainfalls in South-East Queensland are projected to increase in summer and decrease in winter. Regarding short-period (e.g. less than 24-hour) rainfall events, the Intergovernmental Panel on Climate Change recently concluded that it was likely such heavy precipitation events would become more frequent over most land areas. This could lead to increased flood risk, especially for flash floods. A re-evaluation of probable maximum precipitation could be required, along with flood resilience capacity for critical infrastructure such as dams and bridges.

Will the sea level rise? Global warming is expected to lead to sea level rise, increasing the risk of flooding near the coast, including the lower reaches of coastal rivers.

Will changes in 'storminess' affect coastal flooding? Any increase in the frequency or intensity of storms could lead to increased storm surge risks, and this would exacerbate the increased likelihood of coastal inundation arising from projected sea level rise. However, it is very difficult at present to predict how storms might change. Current predictions are for a decrease in the global number of tropical cyclones, but with a possible increase in the intensity of the strongest cyclones and more intense rainfall.

Better land use planning and floodplain management can mitigate the impacts of flooding

The future will see Australia's population continue to grow, placing increased pressures on our waterways, many of which already experience high levels of flood risk. A growing population will result in increased development on the floodplain and the temptation to build in flood corridors. Rising land prices and a resulting move to smaller block sizes are expected to result in our cities becoming more densely populated, increasing the chance of flooding in the cities. More houses built closer together increases the number of houses potentially exposed to flood damage.

Better strategic land use planning will be essential to limit the growth of flood risk

This will require improved flood studies and floodplain management plans to enhance our understanding of how floods will behave under changing climate and catchment conditions.

Implementing the findings of these studies and management plans will help constrain development from areas where it would increase the negative impacts of floods on other properties, including the delineation of flow corridors to support the safe passage of floodwaters through urban areas. Improved flood studies and management plans would also help restrict development from areas where there would be an intolerable flood hazard to people or property, or where people could not be readily evacuated to dry land, or a practical alternative, in the case of a flood.

In areas that are deemed suitable for development, these improved flood studies and management plans can help identify the types of developments that will be suitable for specific locations and the development controls necessary to reduce any residual flood risk in these areas to an acceptable level. These controls could include minimum fill and floor levels, assessing and delineating flood evacuation routes to flood free land, designing subdivision layouts to facilitate staged evacuation and providing innovative building designs. Information from these studies can also inform regional land use planning, local environmental plans and development control plans.

Future development should also be guided by detailed flood models (Figure 15). These models would enable all impacts of proposed new urban land uses to be quantified, and for issues such as flood evacuation strategies, the impacts of infrastructure and the need for compensatory works to be assessed. These models should also be used to assess how infill development and the increasing density of our urban environments can be managed from a flood perspective.

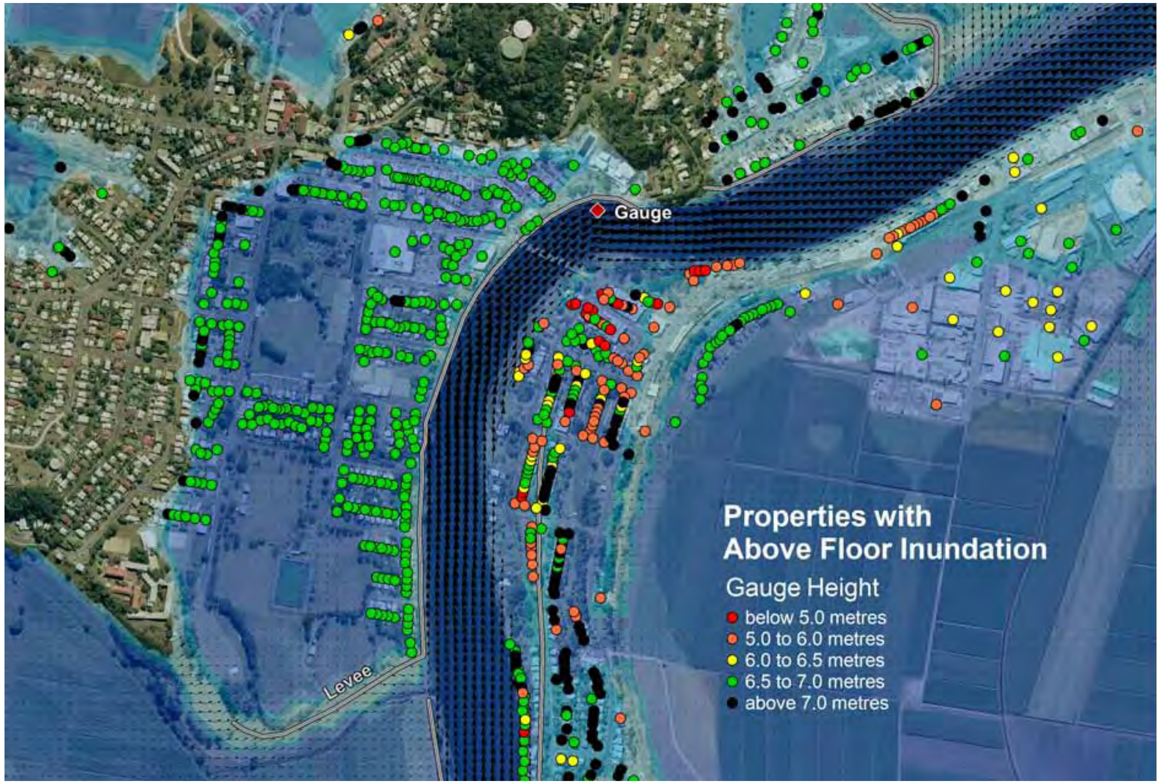


Figure 15. Example of a contemporary urban flood model from the Tweed River at Murwillumbah, NSW. Yellow dots, for example, are areas where houses will be inundated when the river gauge reads between 6.0-6.5 m; black dots illustrate properties that will flooded once the gauge reading exceeds 7.0 m. TUFLOW model image courtesy of BMT WBM.

Appropriate urban design and integrated water management can reduce the severity of flood impacts

Historically, we have managed flooding, water supply and wastewater separately. In the future, it is highly likely that more ***integrated water planning*** will occur to better deal with Australia's flood-drought cycle, minimising human impacts on the environment, and helping manage the impacts of our growing population and changing climate on water resources and flood risks.

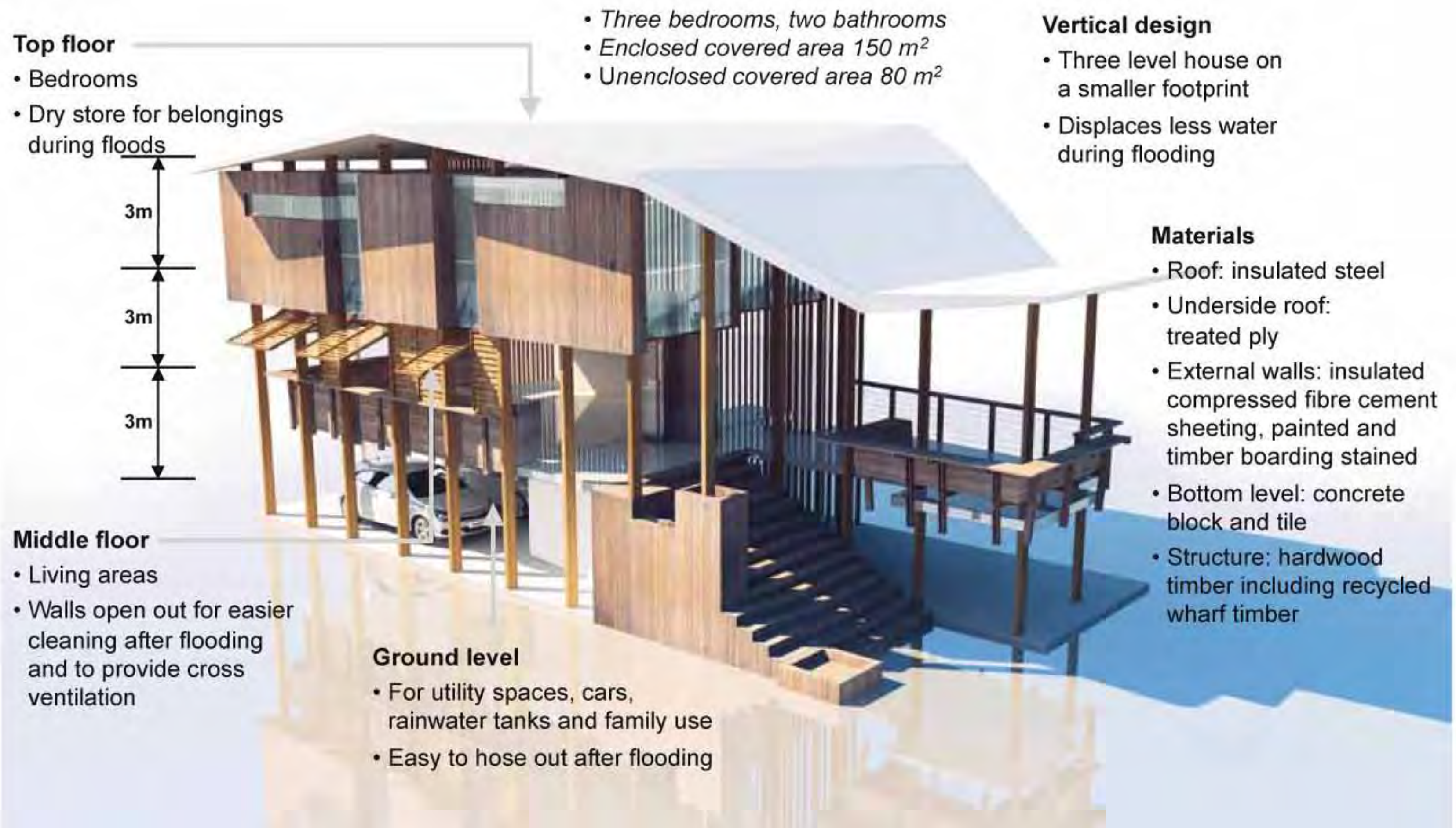
Further, if appropriate urban development takes place—adopting approaches such as water sensitive urban design—it may be possible to reduce some of the increases in the severity of frequent urban flood problems associated with future increased urbanisation.

Water sensitive urban design, while having little effect on larger storm events such as those that occurred recently in Queensland, has the potential to reduce the volume of local flooding in smaller storm events through the capture and reuse of water in storages such as tanks and groundwater systems. This approach is one in a suite of techniques that will enable future towns and cities to be more flood resilient.

In the future, cities and towns designed in a water sensitive manner and using integrated water planning may use less drinkable water, potentially allowing us to manage our dam water levels with more flexibility. For example, dams could potentially be operated at lower levels before predicted wet seasons, thereby providing additional flood mitigation capacity. This issue will need to be balanced with the additional pressures on water supply security from population growth.

In flood prone areas, where residents can be effectively evacuated to dry land during a flood, and where the predicted speed and depth of flooding are within accepted limits, existing dwellings could be redeveloped in the form of modified 'Queenslander' style dwellings (Figure 16).

These houses would use more appropriate flood resilient materials, which can withstand the effects of inundation and be readily cleaned after a flood, and would be designed in a way that allows household contents to be quickly moved above flood levels within the house before evacuation.



Top floor

- Bedrooms
- Dry store for belongings during floods

- *Three bedrooms, two bathrooms*
- *Enclosed covered area 150 m^2*
- *Unenclosed covered area 80 m^2*

Vertical design

- Three level house on a smaller footprint
- Displaces less water during flooding

Materials

- Roof: insulated steel
- Underside roof: treated ply
- External walls: insulated compressed fibre cement sheeting, painted and timber boarding stained
- Bottom level: concrete block and tile
- Structure: hardwood timber including recycled wharf timber

Middle floor

- Living areas
- Walls open out for easier cleaning after flooding and to provide cross ventilation

Ground level

- For utility spaces, cars, rainwater tanks and family use
- Easy to hose out after flooding

Figure 16. Flood resilient Queenslander, designed to ‘live’ with flooding and incorporating water sensitive urban design techniques. Image courtesy of Cox Rayner Architects.

Catchment and waterway revegetation can reduce the impact of flooding

Although it is unlikely that the way we use rural land in Australia will change dramatically in the future, our understanding of how these areas should be managed to minimise their adverse effects on downstream environments, and especially on water quality, is improving. Many of these management techniques also have significant potential to help with downstream flood mitigation. One technique being piloted in the South-East Queensland region is the creation of a dense band of vegetation 30 to 50m wide along the banks of major upper and mid-catchment waterway corridors. While these techniques appear to have merit, careful consideration needs to be given to the potentially adverse upstream flood impacts of such measures.

Photo: Example of a rehabilitated waterway corridor in the upper reaches of the Brisbane River catchment. Courtesy of Professor Jon Olley

Emerging technologies can improve our ability to predict and manage floods

Better weather modelling and improved forecasting systems*:* The accuracy of weather modelling has improved substantially during the past decade. This improvement will continue as more accurate computer models are developed, and as these models are informed with better observational data. Real-time radar observation of rainfall and satellite monitoring of inundation will also improve.

As the science of weather modelling improves, we should be able to more reliably predict the near term—in the order of several days into the future—patterns and magnitudes of rainfall on our catchments. In the not-too-distant future, this should enable us to develop near real-time flood forecasting systems that link predictions of rainfall with the flow of water from our catchments and the resultant flood levels and velocities in our creeks and rivers and on our floodplains. These systems, which could potentially provide forecasts in near real time via the internet, will be able to provide flood forecasts with greater accuracy and longer lead times than today.

Better flood warning systems: The improved predictive systems described above will increasingly be linked to real-time flood warning systems. Such systems could realistically have several categories of alert that may significantly reduce damages associated with flooding by giving residents more time to prepare. Real-time flood models could be linked to interactive (internet based) maps that provide residents with detailed information on key issues such as:

- predicted peak flood levels, rates of rise for their location, and escape routes together with predictions of evacuation time and the provision of staggered 'get out' warnings to isolated residents
- traffic network advice that assists with escape route planning to minimise congestion
- the locations and availability of emergency centres and whether space is available.

These systems may have a simulation capability to allow disaster training and practices.

Glossary

Catchment - The surface area of land that collects and drains water into a river or other waterway. Catchments can include both rural and urban areas.

Channel - The physical course of a river, creek, stream or drainage line in which water flows (see also *waterway*).

Detention basin - A small, man-made reservoir connected to a waterway that provides a temporary storage for floodwaters, potentially reducing or delaying the likelihood or magnitude of downstream flooding.

Flash flood - Flooding that is sudden and unexpected and of short duration; flash floods are often caused by heavy rainfall, but can also result from other events within a catchment. For example drain blockages or bursts. Flash floods are defined by the speed of flooding, not the source of water.

Floodplain - Land adjacent to a waterway, subject to occasional flooding (up to and including the *probable maximum flood*). Floodplains can be narrow, steep, wide and/or flat, and can extend several kilometres from the waterway.

Flood forecast - Estimation of river height, streamflow, time of occurrence, and duration of a flood, especially of *peak flow rate*, at a specified point on a waterway, usually resulting from rainfall.

Flood inundation extent (or flood areal extent) - The area under floodwaters.

Inundation - The covering of land, property and associated infrastructure and possessions by floodwaters.

Levee - Raised embankments or earthworks along the floodplain that reduce the frequency of inundation of areas adjacent to the waterway. They are designed to withstand certain river heights, and will be overtopped if floodwaters exceed this level.

Peak flow rate/peak water flow - The maximum flow of water in a waterway—typically measured in cubic metres of water per second. This is a measure of the size (or magnitude) of a flood.

Peak water level/flood peak - The highest level that water in a waterway reaches during a flood. This is a measure of the size (or magnitude) of a flood.

Probable Maximum Flood (PMF) - An estimate of the largest possible flood that could occur at a particular location, under the most severe meteorological and hydrological conditions as they are currently understood.

Risk - Risk is a combination of likelihood (or chance) of an event occurring, and the consequences of that occurrence. Consequences are in turn determined by the level of exposure to the occurrence and the vulnerability of people, property and infrastructure to the occurrence.

River flow/streamflow - The flow of water in a waterway, as measured at a particular location, usually expressed in terms of cubic metres of water per second.

River height/water level - The level of water in a waterway as measured by a stream/river gauging station for a particular location along a waterway, expressed in metres above the *Australian Height Datum* (i.e. mean sea level), or an alternative arbitrary 'zero' level.

Runoff - The water flow that occurs when either (1) soil is infiltrated to full capacity; or (2) rainfall occurs at a rate greater than the rate at which it can infiltrate the soil. The resultant 'excess' water from rain and other sources flows over the land.

Stream/river gauging station - Measures the height of the water in a river at a particular location. It may be manual or automated.

Waterway - Any physically defined water flowpath such as a river, gully, creek, tributary, estuary or stream, that captures runoff and conveys it towards an outlet or terminus for example, the ocean or a dam (see also *channel*).

Photo: When flood waters rise quickly it can sometimes be difficult to move possessions to higher ground in time. Photographer: Michael Marston

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Working group

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