INSURANCE COUNCIL OF AUSTRALIA

THE NATURE AND CAUSES OF FLOODING IN TOOWOOMBA

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ICA HYDROLOGY PANEL

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SUMMARY OF FINDINGS

The severe flooding that occurred in East, West and Gowrie Creeks in Toowoomba on the afternoon of Monday 10 January 2011 was caused by intense rainfalls over the Gowrie Creek catchment between about 1300 hours and 1430 hours. These rains were delivered by a southwesterly tracking storm that originated when a low pressure system off Fraser Island moved north to combine with a monsoonal trough. A high-pressure system off New Zealand drove warm moist air across the western Pacific and onto southeast Queensland.

Short-term rainfall data are available at nine raingauges in and around Gowrie Creek catchment. At six of these nine gauges, rainfall severities were greater than 100-Years ARI for rainfall durations of 30 minutes to 3 hours. At another gauge, rainfall severities were greater than 50-Years ARI. Readings at the remaining two gauges were far less severe (less than 20-Years ARI).

On Monday afternoon, 'heavy rain' (greater than 5 mm in 15 minutes) started falling around 1245-1330 hours. The heavy rain peaked around 1345-1415 hours and generally ceased around 1415-1445 hours, persisting for some 1.5 - 2.0 hours. The time of concentration of East and West Creek catchments is estimated to be 1 – 1.5 hours. Thus, duration of the flood-producing storm was 'critical', providing sufficient time for all the upstream catchment area to contribute to runoff in the CBD and at the junction of East and West Creeks.

The most severe rain fell in a northeast-southwest band that covered the middle and lower reaches of East and West Creeks and included the Toowoomba CBD. The area of most severe rainfall was across the middle and lower reaches of East Creek and the lower reaches of West Creek.

Recorded water levels of relevance to Toowoomba were available at only one streamgauge, the Cranley gauge on Gowrie Creek, which is located about 5 km downstream from the confluence of East and West Creeks. Unfortunately, the gauge malfunctioned after 1400 hours when it had reached a level of 3.67 m GH. The gauge appeared to resume normal functioning at about 1530 hours. Because of this malfunction, the peak water level and time of peak at the gauge cannot be determined from the gauge records. It is inferred that peak level at the Cranley gauge occurred about 1430 hours. It is inferred that water levels peaked in the CBD around 1400-1415 hours, which is in keeping with impressions by Toowoomba City Council representatives. Water levels along the upper and middle reaches of East and West Creeks probably peaked some 15-30 minutes earlier. It was still raining heavily when water levels peaked along East and West Creeks and in the CBD.

Peak flood levels in the CBD and East and West Creeks occurred within 1-1.5 hours of when heavy rain commenced. The resultant flooding was sudden, unexpected and hazardous. The floods that occurred in East, West and Gowrie Creeks are 'flash floods' according to the terminology adopted in this report.

On the basis of flood debris marks, Toowoomba Regional Council surveyed some 700 peak flood levels around the city. This information was used to create an extent of inundation map that showed waterway flooding occurring as a relatively narrow band of inundation, generally some 50-100 m wide, on either side of East, West and Gowrie Creeks. The greatest width of flooding was some 700 m and occurred around the junction of the three creeks (around the 'Flour Mills' on Ruthven Street).

The piped drainage system in Toowoomba can generally cater for about the 2-Year ARI storm event, except in the CBD area where its capapcity is understood to to be up to 5-Years ARI. The piped drainage system will have been completely overwhelmed by the storm of Monday afternoon. Overland flow, as defined in this report will have occurred along streets, gutters and footpaths and across properties, both upslope and downslope of inlet gullies.

On the basis of the rainfall and water level data presented here, it is concluded that:

- Any inundation of property that occurred at locations remote from the area of waterway inundation was caused by overland flow, as defined in this report.
- Given the high intensity of the rainfall, it is possible that properties inundated by waterway floodwaters may have been first inundated by overland flow. In this regard, the 'Dent Street' area is notable, where Toowoomba Regional Council recognizes as a local stormwater drainage problem area.
- The limits of waterway inundation shown on the maps of this report are acknowledged as inexact. Properties around these limits may or may not have been flooded in the first instance, and if flooded, the cause of flooding could be by overland flow, waterway floodwaters or both.

Factors that affected and exacerbated flooding long East, West and Gowrie Creeks on Monday afternoon include:

- Intense rainfalls of around critical duration for East and West Creeks;
- A 'wet' catchment that maximized the volume of surface runoff and resulted in its immediate generation;
- The highly urbanized nature of the catchment also increased the volume and immediacy of surface runoff;
- The steep and narrow nature of East and West Creeks, coupled with rapid and intense surface runoff, generated waterway floods that were sudden, deep, of high velocity and extremely hazardous.
- Waterway obstructions, such as bridges, other waterway crossings and public infrastructure, obstructed waterflows and led to higher flood levels upstream of these impediments. The build up of flood debris in waterway openings of bridges and other waterway crossings further increased upstream flood levels.

In passing, it is noted that all detention basins along West Creek were overtopped but did not breach. It is not expected that the basins had any significant effect in mitigating waterflows passing through them.

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LIST OF ABBREVIATIONS

ARI	Average Recurrence Interval.
BoM	Bureau of Meteorology (Commonwealth).
CBD	Central Business District
DERM	Department of Environment and Resource Management (Queensland).
GH	Gauge Height (water levels).
ICA	Insurance Council of Australia.
TRC	Toowoomba Regional Council.

1 INTRODUCTION

1.1 BACKGROUND TO STUDY

In the aftermath of the devastating Queensland floods of December 2010 and January 2011, the Insurance Council of Australia (ICA) established a 'Hydrology Panel' comprising three experienced flood hydrologists to assess and report on the nature and causes of flooding in various localities across Queensland.

The purpose of these reports is to present a simple, clear and factual description of flooding behaviour that can be used by the general public and individual insurers to better understand 'what happened' and why. The foundation of these reports is rainfall and water level data recorded by federal and state government agencies (the Commonwealth Bureau of Meteorology; the Queensland Department of Environment and Resource Management and SEQWater) and by local councils. Discussions were held with representatives of local councils to hear first-hand of local flooding behaviour during these events.

These reports offer no comment or analysis of the management of 'flood risk' during the flood events, ie flood forecasting and warning, together with flood preparation, response, relief and recovery activities, or the roles played by various agencies in these flood risk management activities. The reports are confined to rainfall and water level behaviour leading up to and during the flood events.

To foster understanding, various technical terms relevant to floods and flooding are defined in the report and a general description is given of the different types of floods and their causes.

1.2 TOOWOOMBA

This report describes the nature and causes of flooding that occurred in Toowoomba on the afternoon of Monday 10 January 2011. This was an unprecedented flood event that rapidly swept down East and West Creeks as a sudden, high velocity flood wave that imperilled people, caused major damage and took two lives.

The Report consists of a further 10 Sections:

- Section 2 introduces the flood terminology used in this Report;
- Section 3 describes the causes and nature of different types of floods;
- Section 4 describes the methodology used to assess and present data in this Report;
- Section 5 provides a description and map of the catchments in Toowoomba affected by flooding;
- Section 6 is meteorological description of the January Storm Event that caused the flooding;
- Section 7 describes rainfall behaviour during the storm event;
- Section 8 describes the resultant water level behaviour;

- Section 9 discusses various factors that affected flooding behaviour in Toowoomba on 10 January 2011;
- Section 10 is a summary of the causes and nature of flooding in Toowoomba; and
- Section 11 is a list of references.

The Report also includes four Appendices:

- Appendix A is a series of radar images showing the storm bands that resulted in flooding;
- Appendix B presents rainfall data recorded in and around the affected catchments;
- Appendix C presents maps of Toowoomba showing the extent of waterway inundation; and
- Appendix D consists of a series of photographs of the flooded areas and waterways.

1.3 ACKNOWLEDGEMENTS AND DISCLAIMERS

Toowoomba Regional Council made available to the Panel rainfall data recorded at council's raingauges and extent of flooding data determined by a post-flood survey of debris marks. The Panel gratefully acknowledges receipt of these data, which have been instrumental in the preparation of this report.

This report has been based on the best data and information available at time of writing. At times, data were not available or incomplete; data used in this report have not been formally quality-checked by the ICA Panel. This report presents an overview of flooding in the various areas of interest; it is not intended to be used and should not be used to ascertain flooding behaviour at the individual property level.

This report has been prepared on behalf of and for the exclusive use of the Insurance Council of Australia (ICA), and is subject to and issued in accordance with the provisions of agreements between the ICA and WorleyParsons, WRM Water and Environment Pty Ltd, and Water Studies International. WorleyParsons, WRM Water and Environment Pty Ltd, and Water Studies International accept no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report by any third party.

2 BACKGROUND 1: FLOOD TERMINOLOGY USED IN THIS REPORT

A somewhat confusing terminology has evolved to describe ‘floods’ and ‘flooding’ that includes words such as ‘stormwater runoff’, ‘watercourse’, ‘drain’ and ‘inundation’, terms that mean different things to different people. For the sake of clarity, this Report adopts the following definitions.

Catchment

A catchment is the area of land that collects and conveys *surface runoff* to a designated point on a waterway.

Surface Runoff

Surface runoff is the rainfall that, after hitting the ground, drains away across the ground surface.

Overland Flow

Overland Flow is the name given to *surface runoff* before it enters a *waterway.* Overland flow is caused by direct local rainfall in the area producing the overland flow. Overland flow may collect in surface depressions, which may or may not overflow.

Overland flow in rural areas can occur across natural ground or over agricultural land. In urban areas, overland flow can occur across grass, gardens, carparks and along streets, gutters and footpaths. Overland flow in urban areas is sustained whenever the capacity of the piped drainage system is exceeded.

Overland flow catchments are generally small in urban areas, but can be large in flat, rural area, where it may be difficult to define their boundaries.

Waterway

A waterway is any physically defined flow path that captures *overland flow* and conveys it down a catchment to the catchment outlet or terminus.

Note that the term ‘waterway’ includes all types of ‘flow channels’:

- We can have ‘urban waterways’ that drain urban areas and ‘rural waterways’ that drain predominately rural areas.
- We can have ‘natural’ waterways and ‘modified’ or ‘improved’ waterways, the latter being physically changed to increase their capacity to convey surface runoff downstream (ie to increase their *discharge capacity*) or to limit flooding. Most urban waterways are modified and can be referred to as ‘modified urban waterways’.
- All watercourses, gullies, streams, creeks, tributaries, rivers and estuaries are ‘waterways’, the principal generic difference being the size of the upstream catchment area.

Waterflow

Waterflow is any flow (discharge), whether natural or managed by human intervention, in a *waterway*.

Consideration was given to using the word 'streamflow' in place of waterflow. However, the former has connotations relating to 'stream' rather than to the more generic 'waterway'.

Flood

A flood is any relatively high *waterflow* that overtops or breaches the natural or artificial banks in any part of a *waterway, lake or dam*. It also includes local inundation caused by *overland flows* and *coastal inundation* resulting from raised sea levels or waves overtopping the coastline.

The above definition of flood is based on the definition given in the Australian Floodplain Management Manual (SCARM, 2000) and the New South Wales Floodplain Management Manual (DIPNR, 2005).

The causes and nature of different types of floods are discussed in Section 3.

Flash Floods

Flash floods are *sudden and unexpected floods* that occur with *little or no warning*. Flash Floods are caused by *short*, *intense rainfalls*, generally falling over a *relatively small, steep catchment area*, often away from the area of interest.

Flash floods have been defined as *"sudden and unexpected flooding caused by local heavy rainfall or rainfall in another area of the catchment. Often defined as flooding that occurs within six hours of the onset of the flood-generating rainfalls".* (DIPNR, 2005).

In the USA, flash floods are defined as floods that peak within 6 hours of commencement of the period of intense rainfall.

Flash floods are characterized by an abrupt and rapid increase in water levels, high waterflow velocities and extreme hazard.

Floodwaters

Floodwaters are the waters causing a *flood*.

Note that floodwaters may originate from inland areas as *overland flow* or as *waterflows,* or as *coastal waters* from the sea.

Inundation

Inundation refers to the covering of land, property and associated infrastructure and possessions by *floodwaters*. Colloquially, 'inundation' can be called 'flooding'.

Thus, we can speak of '*overland flow inundation*', '*waterflow inundation'* and '*coastal waters inundation'*.

These three different types of inundation can occur separately or together. In some cases, it can be difficult to separate out the individual contributions to the overall inundation. In areas of rainfall, *overland flow inundation* and *waterflow inundation* often occur together, properties first being inundated by *overland flow* and then by *waterflow*. In areas where the rain is not falling, *overland flow inundation* will not occur, but *waterflow inundation* from rainfall over upstream areas can occur.

It should be noted that waterflows breaching or overtopping the banks of a channel can inundate areas remote from their source. In these circumstances, waterflow inundation can be confused with overland flow inundation.

3 BACKGROUND 2: CAUSES AND NATURE OF FLOODING

3.1 CAUSES OF FLOODING

There are five separate physical phenomena that cause flooding:

1. Excessive rainfall (overland flow and waterflow);
2. The operation or failure of water storages and flood protection levees (dam release and dam break/levee break floods);
3. Elevated coastal water levels (storm surge floods);
4. Undersea earthquakes (tsunamis); and
5. Geomorphological events (the flood accompanying the collapse of landslip and glacier lakes).

Group 1 floods can be termed '*Rainfall Floods'* because they are caused by flood-producing rainfalls. Group 2 floods are '*Man-made Floods'* because they are caused by the operation and failure of man-made infrastructure (dams and flood protection levees). Groups 3 and 4 floods can be termed '*Maritime Floods'* because they are caused by maritime phenomena (low pressure synoptic systems and undersea earthquakes) and predominately affect water levels along the coastline and in estuaries. Group 5 floods can be termed '*Geomorphological Floods'* because of their underlying geomorphological nature.

The first three groups of floods are commonly experienced in Australia. There is also a small risk of tsunami flooding. Geomorphological floods are unlikely to occur in Australia and will not be discussed further[1]

3.2 RAINFALL FLOODS

3.2.1 <u>Catchment Response</u>

The behaviour of rainfall floods is determined to a large extent by the intensity and duration of the flood-producing rainfalls and by the response of the catchment upstream of the point of interest, which in turn depends upon catchment size and waterway steepness. The smaller and steeper a catchment, the more quickly it will gather and convey surface runoff to the catchment outlet, ie the more quickly the catchment will respond in generating overland flow and waterway flooding.

There is a critical storm duration associated with each catchment that depends upon its size, drainage network and waterway steepness. When a storm is of 'critical duration' or longer

[1] Geomorphological floods occur in highly mountainous regions, such as the Himalayas and the Andes. These floods result from landslips (generally caused by intense rainfall or tectonic movement) into a river channel creating a temporary dam that fills and then breaches, or by the collapse of the ice wall of a glacier lake. Both cases result in a 'dam break' flood. It is also noted that intense rainfalls can cause landslips without forming a temporary dam, where the accompanying landslip can sweep entire villages away. In many cases, the resulting loss of life and damage exceeds that of any accompanying waterway flood. The devastation of such landslips is common in mountainous areas of Asia, but is rare in Australia.

occurs, surface runoff from all areas of the catchment contributes to waterflow at the point of interest, so maximizing waterflow and any resultant flooding. If a storm is of less than critical duration, only some of the catchment is contributing to waterflow when the storm ceases (partial catchment effect), so resulting in less waterflow and flooding at the point of interest.

Smaller, shorter, steeper catchments have a shorter critical storm duration than larger, longer, flatter catchments, ie they respond more quickly to rainfall events.

3.2.2 Overland Flow Floods

Overland flow is the name given to surface runoff (or stormwater runoff) as it makes its way overland towards a defined waterway or before it ends up in a surface depression (see Section 2). An overland flow flood occurs when overland flows inundate property, possessions and infrastructure. In urban areas, overland flow flooding is exacerbated when the intensity of stormwater runoff exceeds the capacity of the piped drainage system, causing surface runoff to flow down gutters, streets, footpaths and across properties.

Overland flow floods are sometimes referred to as 'local floods'.

3.2.3 Waterway Floods

A waterway is any physically defined flow path that captures overland flow and conveys it down a catchment to the catchment outlet or terminus (see Section 2). Waterway floods occur when a waterway overflows or breaches it banks (see Section 2). Waterways include watercourses, gullies, creeks, streams, rivers, etc. The difference between these waterways is principally one of catchment size, the further upstream a waterway one goes, the smaller its tributary catchment area and the steeper its bedslope (in general). This has an effect on flood behaviour, which can be illustrated in terms of tributary flooding and mainstream flooding.

Tributary Floods

A tributary is a waterway that flows into a larger 'receiving waterway'. Tributaries respond more quickly to rainfall events than their receiving waterway: tributary catchment areas are smaller; their waterways are generally steeper, especially the upper reaches. The critical storm duration of a tributary is generally less than that of the receiving waterway. The speed of flow of tributary floodwaters is generally greater than that of floodwaters in the receiving waterway, especially in the steep upper reaches.

We can distinguish three types of tributary flooding behaviour.

- Under intense rainfall conditions, the steep upper reaches and possibly flatter middle reaches can experience *flash flooding* (see Section 2 and below).
- Water levels in the receiving waterway can influence flooding behaviour along lower tributary reaches. A receiving waterway flood passing downstream will increase water levels at the confluence. This *'backwater'* will in turn impede any tributary flood flows entering the receiving waterway and so increase tributary flood levels along lower tributary reaches (the '*backwater effect*'). Note that if there is no upstream tributary flood, receiving waterway floodwaters flowing upstream can flood lower tributary reaches ('*backwater flooding*').
- In the absence of flash flooding and backwater effects and flooding, *'normal'* waterway flooding will occur along the tributary, dictated by waterway steepness, channel capacities and discharges.

Mainstream Floods

Mainstream floods result from the amalgamation of upstream tributary floods. As a mainstream floodwave moves downstream, it is reinforced by tributary floodwaves entering the mainstream and 'piggy-backing' on the passing mainstream floodwave. The resultant mainstream flood depends upon the nature, severity and timing of tributary floods as they enter the mainstream.

Mainstream catchments are generally much larger and flatter than tributary catchments. Accordingly, mainstream floods move more slowly and have more gradual onset and recession (rise and fall) than tributary floods. Note that rainfall may only occur over certain areas of a mainstream catchment and in these circumstances, not all tributaries will contribute equally (or at all) to mainstream flooding. Mainstream floods can influence flooding behaviour along the lower reaches of tributaries through 'backwater' effects (see above).

Flash Floods

Flash floods are sudden and unexpected floods that arise from intense rainfalls, generally over a small, steep catchment area (see Section 2). When flash floods occur in the steep upper reaches of tributary catchments, the resulting flood wave is characterized by very high waterflows and velocities and abrupt water level rises, leading to extremely hazardous conditions. In its behaviour, a flash flood is similar to a minor dam break flood (see below).

3.3 MAN-MADE FLOODS

3.3.1 Dam Release Floods

Dam release floods are caused by the rapid release of large volumes of water from a dam, typically as an emergency response to an incoming flood. If sufficiently large, the release can overtop the banks of receiving waterways and inundate downstream communities.

3.3.2 Dam Break Floods

Dam break floods occur when a dam wall breaches because of overtopping, piping, or the undermining of its foundations, followed by erosion (earth embankments), or by structural failure (non-earth embankments). The resulting dam break flood wave, which consists of a 'wall of water', is highly destructive as it races downstream, generating extreme flood hazard because of its speed of onset and the rapid ('instantaneous') and extreme rise in water levels.

3.4 MARITIME FLOODS

3.4.1 Storm Surge Floods

Storm surge floods are caused by tropical cyclones and other low-pressure weather systems increasing coastal water levels. Such weather systems do this by the action of strong onshore winds and storm-driven waves 'pushing' water against the coast ('wind setup' and 'wave setup' respectively) and by the increase in coastal water levels caused by the low pressure ('inverted barometer effect'). High astronomical tides in affected coastal waters can exacerbate storm surge flooding, especially if highwater coincides with the peak of the storm surge..

Storm surge flooding is a greater risk in the more cyclone-prone areas along the northern coast of Queensland than around the Brisbane coastline.

3.4.2 Tsunamis

A tsunami is a series of fast moving waves generated by undersea tectonic movements (undersea earthquakes). These waves are barely discernible in deep oceans, but rapidly grow into 'walls of water' 5-10 m high or higher as they enter shallow coastal areas. Tsunamis can wreak widespread and enormous devastation on areas within their reach, as the Boxing Day

Tsunami of 2004 demonstrated. Much of the accompanying damage is through the destruction of buildings, property and infrastructure rather than through 'water damage', as in a typical mainstream flood.

It seems that the Queensland coast, especially in Northeast Queensland, is exposed to a risk of tsunami flooding[2].

3.5 COMBINED FLOODING

Many of the above floods can and commonly do occur together, eg dam release floods and waterway (tributary and mainstream) floods. Table 3.1 indicates common combinations of floods.

Table 3.1 Interactions Between Different Types of Flood

	Type of Flood	1.	2.	3.	4.	5.	6.	7.	8.
1.	Overland Flow Floods		✓	✓	✓				
2.	Tributary Floods	✓		✓	✓	✓	✓		
3.	Mainstream Floods	✓	✓		✓	✓	✓	✓	
4.	Flash Floods	✓	✓	✓					
5.	Dam Release Floods		✓	✓			✓		
6.	Dam Break Floods		✓	✓		✓			
7.	Storm Surge Floods			✓					
8.	Tsunami Floods								

3.6 GENERAL FACTORS EXACERBATING FLOOD BEHAVIOUR

A number of factors can worsen flood impacts by increasing peak flood levels and velocities, leading to higher flood damage costs.

3.6.1 Storm Duration and Intensity

A number of storm factors affect the severity of the resultant flooding. As discussed in Section 3.2.1, a storm of critical duration or longer maximizes surface runoff, waterflows and associated flooding at the point of interest. The higher the rainfall intensity, the greater the resultant overland flow and waterflow, and the greater the resultant flooding. The spatial pattern of rainfall and movement of a flood-producing storm can also increase the associated flooding.

3.6.2 Catchment Topography

Steep narrow-sided waterways lead to fast flowing, relatively deep flood flows. The faster the flood flows, the more destructive they are.

2 See for example: http://www.uq.edu.au/news/?article=7153 and http://www.emergency.qld.gov.au/emq/css/tsunami.asp

3.6.3 Antecedent Catchment Conditions

The ‘hydrological’ state of a catchment preceding flood-producing rains can have a marked effect on flood behaviour. If the ground is saturated, the volume of surface runoff is maximized and surface runoff begins shortly after the commencement of rainfall (no ‘initial’ losses to saturate the soil, etc). These effects increase both severity and onset of flooding.

3.6.4 Astronomical Tides

High astronomical tides raise waterflow flood levels along lower waterway reaches draining to the sea. However, this effect diminishes as waterflow flood discharges increase, with waterflows eventually ‘drowning out’ the effects of high tide.

3.6.5 Catchment Urbanization

Catchment urbanization results in the replacement of pervious areas (soil, scrubland, forest) with considerable areas of impervious surfaces (roofs, roads, footpaths, car parks, etc). This increases the volume of runoff and associated flooding. However, the significance of this effect diminishes with increasing rainfall intensity and increasing antecedent wetness, and is probably negligible when rainfall intensities exceed the 1-in-50 ARI event.

Urbanization also results in man-made and other obstructions to waterflow being built across floodplains and in waterways. The resulting loss of floodplain storage and redirection of waterflows caused by road and rail embankments and other floodplain developments can increase water levels and adversely affect flood behaviour in other ways. Unless adequately sized, waterway crossings (bridges, culverts, etc) constrict waterways, impede waterflows and increase flood levels. Conversely, the construction of detention basins along waterways can delay flood peaks and reduce peak flood levels.

4 BACKGROUND 3: METHODOLOGY AND PRESENTATION OF DATA

4.1 METHODOLOGY

The relative timing of 'local' rainfalls and water level rises in areas of interest can indicate the cause of any resultant inundation. Three situations can be distinguished:

1. *In the area of interest, rain is falling, but there is no waterway flooding.* In this situation, it is clear that any inundation will be caused by overland flow floodwaters.
2. *Rain is not falling in the area of interest, but the waterway is flooding.* In this situation, it is clear that any inundation will be caused by waterflow floodwaters.
3. *In the area of interest, rain is falling at the same time as the waterway is flooding.* The cause of flooding in this situation is not immediately clear: it could result from waterway floodwaters, overland flow floodwaters, or a combination of both. Careful assessment of local topography and the relative timing of local rainfall, water level rise and inundation in the area of interest can shed light on the likely cause of flooding.

Thus, the methodology of this Report consists of the assembly, assessment and comparison of recorded local rainfall and water level data, supplemented by discussions with local council representatives to better understand local flooding behaviour.

4.2 RAINFALL DATA

4.2.1 Sources of Data

In Queensland, rainfall data are collected by various commonwealth and state government agencies and by some local councils. The commonwealth Bureau of Meteorology (BoM) is charged with collecting and archiving rainfall data for various purposes, including flood forecasting and warning. A number of state government departments collect rainfall data for their own specific needs: SEQWater for water supply purposes, Sunwater for irrigation management, local Water Boards for water supply, the state Department of Environment and Resource Management (DERM) for catchment management purposes. All of these state agencies make their rainfall data available to BoM. In conjunction with BoM, a number of local councils install rainfall and water level monitoring networks for flood warning purposes (so-called ALERT systems). Both Council and BoM have access to these ALERT data.

Rainfall stations are generally of two types: daily-read stations that report 24-hour rainfalls for the period ending at 0900 hours each day, and event-based 'short duration' stations (pluviographs) that record the time at which small increments of rainfall occur (typically 1 mm or 0.5 mm increments). Daily rainfall data, which are readily available from the BoM website, are useful for examining the spatial distribution of rainfall and antecedent catchment wetness, but daily data are often too coarse to meaningfully interpret the cause of inundation. Pluviograph data, with its much finer time resolution, is needed, especially in smaller catchments.

In passing, it is noted that rainfall intensity and duration can vary significantly with distance (and in an unknown manner) as one moves away from a raingauge. Thus, care needs to be taken in implying rainfall behaviour away from the closest raingauge.

4.2.2 Presentation of Data

Pluviograph data can be presented as either incremental rainfalls or as cumulative rainfall. Figure 4.1 shows the rainfall recorded by the gauge at Roma Airport over the period 1-3 March 2010. The plot of incremental rainfall clearly shows the timing and duration of the heaviest falls; the steepness of the plot of cumulative rainfalls indicates intensity and the final plateau indicates total rainfall for the event.

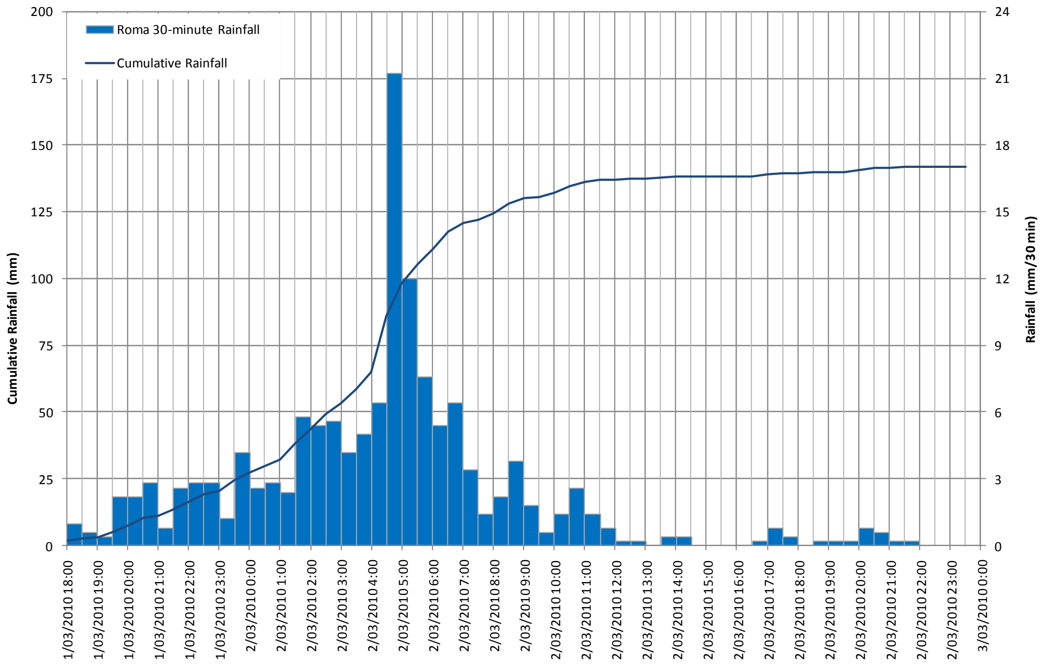


Figure 4.1 30-Minute Rainfalls at Roma Airport Station, 1 to 3 March 2010

The spatial distribution of rainfall is most easily depicted as isohyets, or lines (or bands) of equal rainfall plotted over the area of interest. Figure 4.2 shows 24-hour rainfall isohyets for Queensland on 10 January 2011.

4.3 WATER LEVEL DATA

4.3.1 Sources of Data

In Queensland, water level data are collected by the same agencies that collect rainfall data (see Section 4.2.1). When a flood has passed, many local councils collect peak flood level data to define the extent of inundation, depths of overtopping at roadways and bridges, etc.

4.3.2 Presentation of Data

Streamgauges are used to measure water levels in a waterway. Water levels are recorded more-or-less continuously and the resulting graph of water level versus time (the stage hydrograph) indicates water level behaviour. Figure 4.3 shows the stage hydrograph for Bungil Creek at Tabers for the period 3-7 December 2010. The ‘rising limb’ of the hydrograph defines the onset of flooding (the arrival of floodwaters and their spilling onto the floodplain); the ‘recession limb’ defines the retreat of floodwaters off the floodplain and back into the waterway.

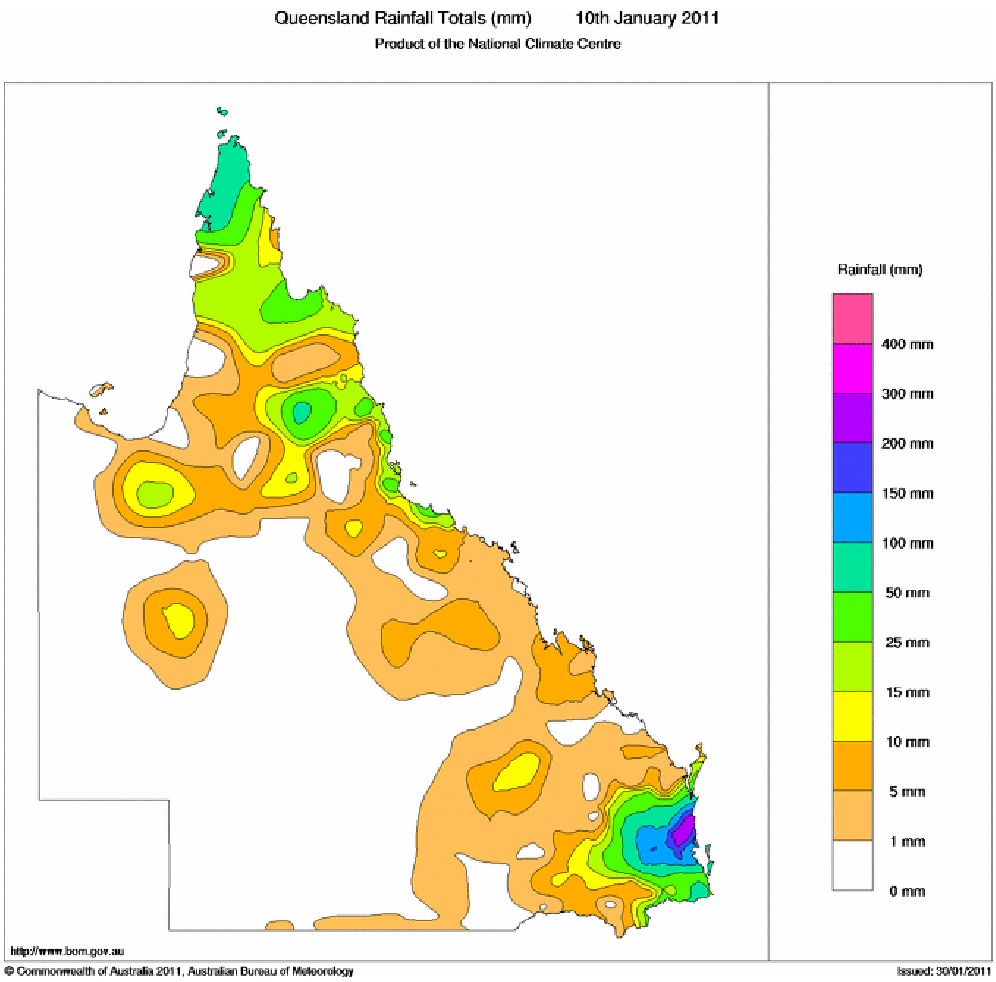


Figure 4.2 Rainfall Isohyets for Queensland on 10 January 2011

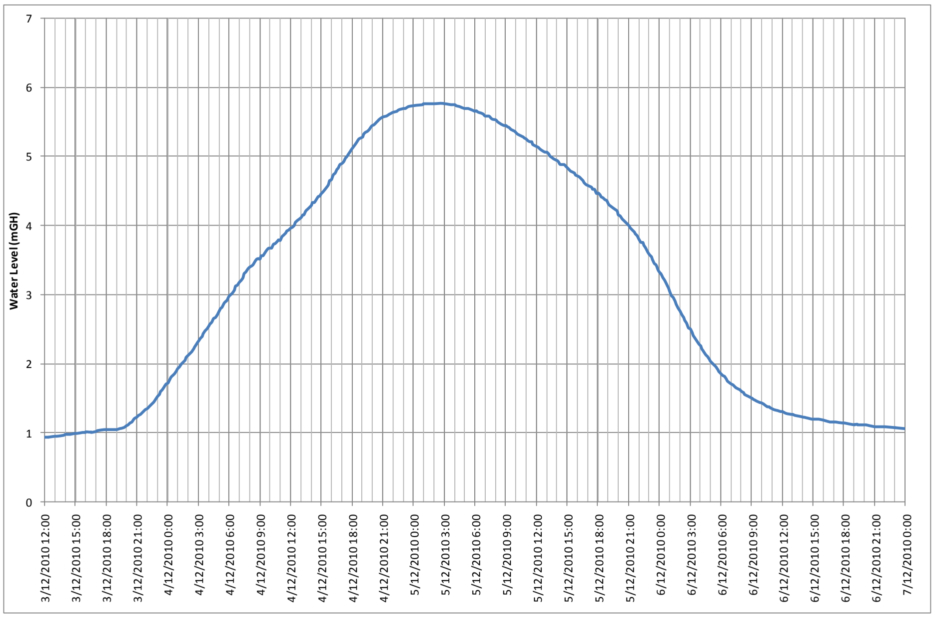


Figure 4.3 Stage Hydrograph, Bungil Creek at Tabers, 3 to 7 December 2010

4.4 EXTENT OF INUNDATION DATA

Where possible, the Report includes a map showing the 'extent of inundation' for the area of interest. Estimates of the extent of inundation are based on peak flood levels, either recorded at streamgauges or provided by local councils. If a digital elevation model (DEM) is available for the area of interest, peak flood level data – supplemented by design flood surface data[3] – can be used to generate an extent of inundation map. Figure 4.4 shows an extent of inundation map for Roma for the flood event of 7 March 1997.

[3] As part of their flood mapping program, local councils generate extent of flooding maps for standard flood events (eg the one-in-100 year flood). This information can be used to assist in estimating the extent of inundation in areas where there a few or no recorded peak flood levels.

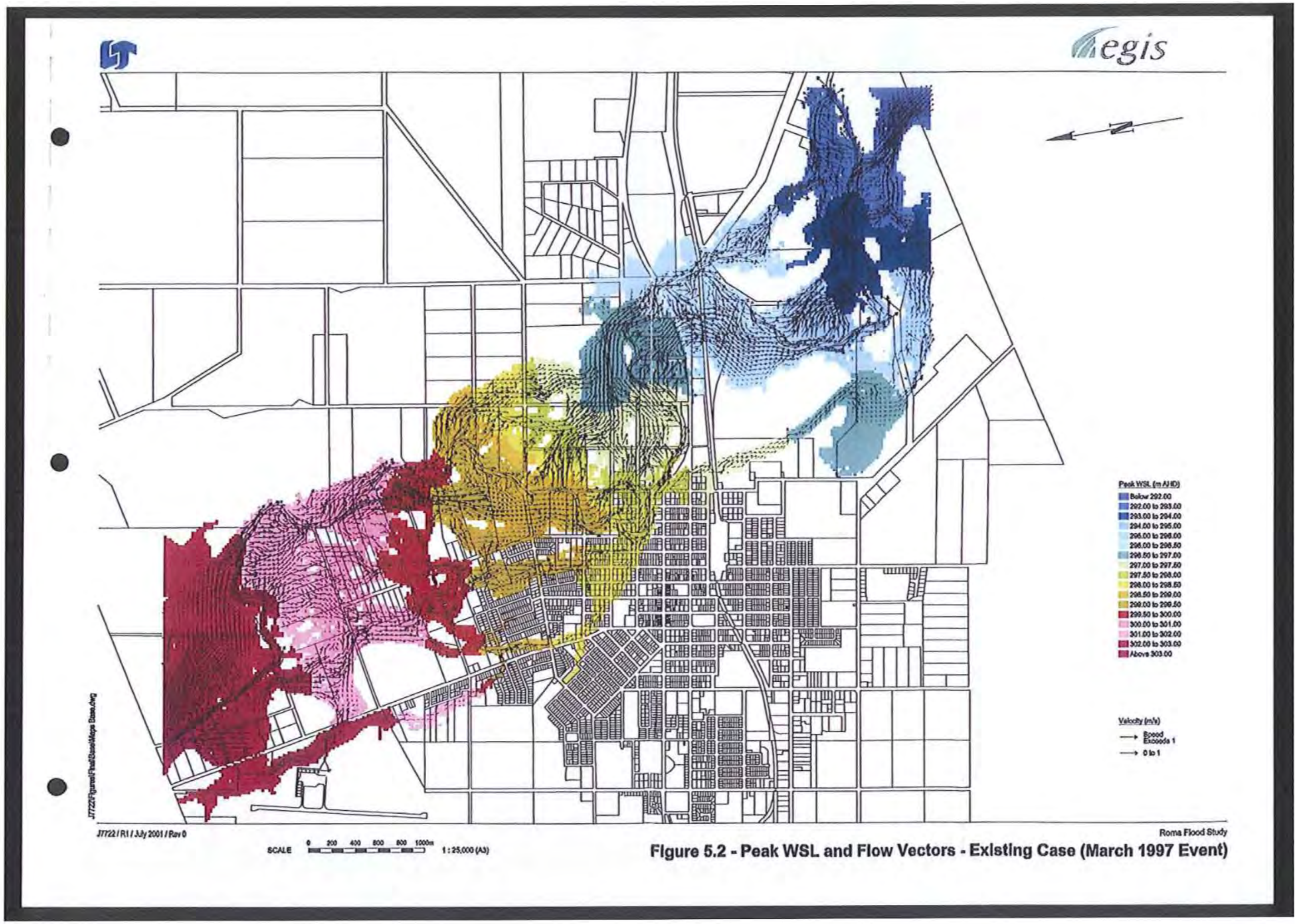


Figure 4.4 Extent of Flood Inundation, Roma Flood Event on 7 March 1997(Source: Egis, 2002)

5 CATCHMENT DESCRIPTION

5.1 DRAINAGE NETWORK

The City of Toowoomba is drained by Gowrie Creek and its tributaries (East Creek, West Creek and Black Gully) as shown in Figure 5.1. East and West creeks rise in the southern part of the city and converge just to the north of the Central Business District (CBD). Black Gully joins Gowrie Creek approximately 2 km downstream (north) of the confluence of East and West Creeks. The catchment area of Gowrie Creek to the northern boundary of the Toowoomba City is approximately 51 km^2. Of this, East Creek, West Creek and Black Gully catchments command areas of about 14.6 km^2, 16.2 km^2 and 7.3 km^2 respectively.

Gowrie Creek and its tributaries have steep channel gradients and also catchments that are quite steep. Typical gradients of the catchments draining towards East, West and Gowrie Creeks and Black Gully are of the order of 3 to 5 percent, with the longitudinal gradients of the waterways themselves of the order of 0.5 to 2.0 percent (WBM, 1998). Therefore, Gowrie Creek catchment is likely to respond quickly to heavy rainfalls and the water level rise in its waterways is likely to be quite rapid.

The waterways of the Gowrie Creek catchment, especially East and West Creeks, have been significantly modified over the years. Gowrie Creek itself (downstream of the Confluence of East and West Creeks) presently appears to be in a relatively natural state. East and West Creeks have been heavily modified with concrete and grass lined channels, on-line detention basins, water features, drop structures, etc. A number of photographs taken along these creeks during a site visit is shown in Appendix D.

5.2 IMPACT OF URBANIZATION

Most of the catchment of Gowrie Creek has been urbanised (see Figure 5.1), mostly for residential purposes, along with significant areas of commercial and industrial land use. The urbanisation of the catchment has often allowed development up the edge of waterways, reducing the flow capacity and flood storage along sections of these waterways.

Urbanisation has significantly changed the pre-development drainage characteristics of Gowrie Creek catchment. Surface runoff from the developed parts of the catchment is now conveyed to Gowrie Creek and its tributaries via a piped drainage system, with any surface runoff in excess of the capacity of the piped drainage system flowing into the respective waterways as overland flow along roads, open spaces, etc.

Urbanisation has also resulted in the construction of a significant number of road crossings (e.g. culverts, bridges) across Gowrie Creek and its tributaries. These structures constrict flows and have the potential to significantly impact on the flood behaviour of these waterways, particularly if blocked by debris during a flood event.

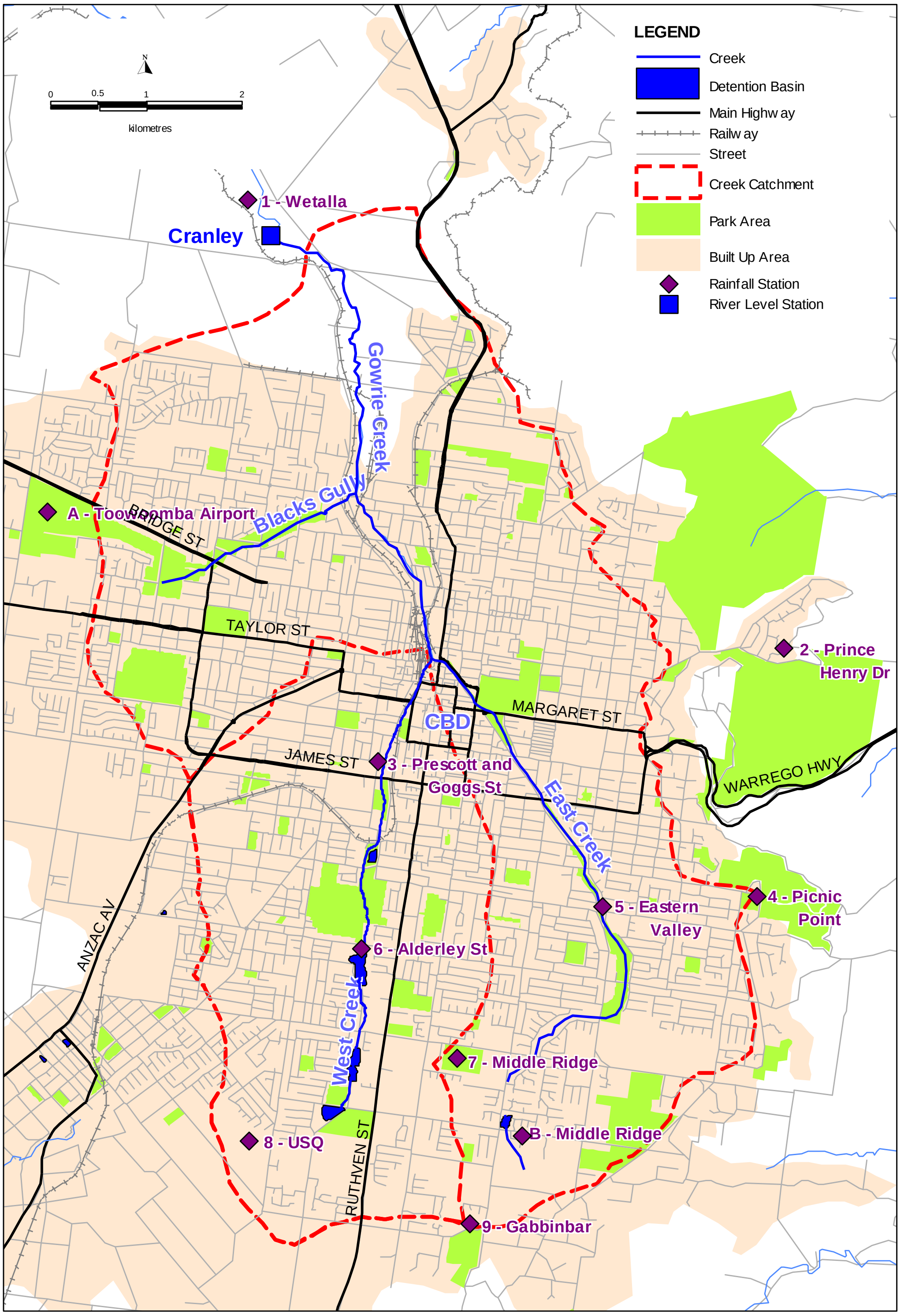


Figure 5.1 Gowrie Creek Catchment and Drainage Characteristics

6 METEOROLOGY OF 10 JANUARY 2011 STORM EVENT

6.1 SYNOPTIC SITUATION

The rainfall event that caused flooding in Toowoomba on 10 January 2011 culminated from the interaction of a low-pressure system (1000-1005 hPa) off the mid and south Queensland coasts and upper level and monsoonal troughs. The low-pressure system travelled south from Mackay (Friday 7 January) to an area northeast of Fraser island (Saturday, Sunday 8-9 January), before moving closer to the coast (Monday 10 January).

Early on Sunday 9 January, the low-pressure system combined with an upper level trough to deliver heavy rains to southeast Queensland over much of Sunday. (A high-pressure system off New Zealand forced warm moist air into the upper level trough). In Toowoomba, about 80 mm of rain fell to 0900 hours on Monday 10 January (see Table 7.3).

The upper level trough dissipated early on Monday 10 January, but the low-pressure system intensified (1000 hPa) and moved north to combine with a monsoonal trough, which was moving south. This again led to heavy rainfalls across the southeast corner, warm moist air being delivered by the high of New Zealand. In Toowoomba, 120-150 mm of rain fell to 0900 hours on Tuesday 11 January (see Table 7.3)

Over the latter part of Monday 10 January, the low-pressure system and monsoonal trough moved north and west, with rainfall declining and ceasing (see Table 7.3 for daily rainfalls to 15 January).

6.2 BUREAU OF METEOROLOGY

BoM has released a Special Climate Statement pertaining to the weather, rainfall and flooding that occurred over the period November 2010 to January 2011 (BoM, 2011). The following extracts are quoted from this Special Climate Statement.

6.2.1 Synoptic Situation

‘*10 to 12 January.* An upper-level low combined with a humid easterly flow to bring very heavy rain to southeast Queensland and northeast New South Wales. The heaviest falls were in the areas north and west of Brisbane (Figure 1e). Three-day totals exceeded 200 mm over most of the area bounded by Brisbane, Gympie and Toowoomba, including the majority of the Brisbane River Catchment. Further south, totals exceeding 100 mm extended to the coast and adjacent ranges of New South Wales north of Coffs Harbour, locally approaching 200 mm on parts of the Northern Tablelands, and also extended into inland southern Queensland as far west as Dalby. The heavy rain covered a smaller area than was the case in the late December event. The highest daily totals observed in the Bureau’s regular network were 298.0 mm at Peachester and 282.6 mm at Maleny on 10 January, while the highest three-day totals were 648.4 mm at Mount Glorious and 617.5 mm at Peachester. Intense short-period falls also occurred during the event, with one-hour falls in excess of 60 mm occurring on both 10 and 11 January at numerous stations in various locations north and west of Brisbane. It is possible that higher short-period falls occurred in areas between observing sites.’

6.2.2 Comparison with Previous Events in Southeast Queensland

'While all of the data is yet to be compiled, a preliminary comparison can be made between the three-day rainfall totals from the 10-12 January 2011 event with those of 25-27 January 1974 is shown in Figure 5. Peak rainfalls from the 1974 event were substantially heavier than those in 2011. A number of stations had three-day totals from 25-27 January 1974 in excess of 1000 mm, the highest being 1215.0 mm at Mount Tamborine, compared with the 2011 event peak of 648.4 mm. Many stations in the 1974 event experienced daily totals which exceeded 400 mm; the highest were 563.2 mm at Mount Tamborine and 561.5 mm at Wundurra, in the Gold Coast hinterland, while in the Brisbane area 475.8 mm fell on 26 January at Enoggera Reservoir. 1974 also saw much heavier rainfall in metropolitan Brisbane than 2011, with Brisbane's three-day and peak one-day totals of 600.4 mm and 314.0 mm in 1974 comparing with 166.2 mm and 110.8 mm in 2011. However, in 1974 the heaviest rains were close to the coast, whereas in 2011 heavy falls spread further inland, and on the western fringe of the Brisbane River catchment and on the Great Dividing Range 2011 was the wetter of the two events (Figure 5, right). The weeks prior to the 1974 event, whilst wetter than normal, were also less wet than the equivalent weeks prior to the 2011 event. Over the Brisbane River catchment as a whole, average three-day rainfall in the 1974 event was 348.5 mm, compared with 286.4 mm in 2011, and all four major sub-catchments were also wetter in 1974 than in 2011, although by small margins in the cases of the Bremer (1974 442.1 mm; 2011 417.1 mm) and Lockyer (1974 331.3 mm; 2011 292.0 mm) sub-catchments.

Insufficient rainfall data exist for a comprehensive assessment of the 1893 event. However, the available station data indicate that peak rainfalls in the region during the 1893 event were much heavier than those during either the 1974 or 2011 events. Crohamhurst, in the Glasshouse Mountains inland from the Sunshine Coast, received 907.0 mm on 3 February 1893, which remains an Australian daily record, whilst three-day totals included 1715.0 mm at Mooloolah and 1680.3 mm at Crohamhurst.'

6.2.3 Resulting Floods

'The most destructive floods during the period occurred during the second week of January in the southeast corner of Queensland and adjacent border areas of New South Wales. There was major flooding through most of the Brisbane River catchment, most severely in the Lockyer and Bremer catchments where numerous flood height records were set (Table 4), along with the Toowoomba area just outside the Brisbane catchment. In Brisbane it was the second-highest flood of the last 100 years, after January 1974. The flooding caused substantial loss of life, and thousands of properties were inundated in metropolitan Brisbane and elsewhere. Major flooding with inundation of properties also extended inland to the upper Condamine-Balonne catchment, with Chinchilla and Dalby being severely affected for the second time in less than a month. Other rivers which experienced major flooding during the period included the Mary River around and upstream of Maryborough and Gympie, the Macintyre River around Tenterfield and Goondiwindi, and the Clarence around and downstream of Grafton.'

6.3 RADAR IMAGES

Appendix A contains snapshots of radar images from the Mount Stapylton weather radar operated by BoM. These images show the inferred rate of rainfall over the period Saturday 8 January to Wednesday 12 January. The following aspects of these images are noted:

- A westerly travelling storm passed to the south of Toowoomba late on Saturday night (8 January) - see Figure A1.
- A southwesterly travelling storm passed to the north of Toowoomba around daybreak on Sunday morning (9 January) – see Figure A2.
- Two major westerly travelling storms passed over Toowoomba on Sunday (9 January), the first between 1000-1300 hrs (see Figure A3) and the second between 1500-2400 hours (see Figures A4 and A5). These storms accounted for the high rainfalls in Toowoomba in the 24-hour period ending at 0900 hours on Monday 10 January (see Table 7.3).
- Southwesterly moving storms again passed over Toowoomba between 0500-0900 hours on Monday morning (10 January) – see Figure A6. The rain from these events will also be included in the rainfall totals to 0900 hours on Monday morning.
- On Monday at 1100 hours, a major storm cell has developed to the northeast of Toowoomba (see Figure A7). This storm cell travels southwesterly and blankets Toowoomba between 1200 to 1500 hours (see Figure A7). Intense rainfalls occur between 1300 and 1400 hours (the yellow areas in Figure A7). *This is the storm that caused flooding in Toowoomba on Monday afternoon 10 January.* After the flood-producing storm has passed, little rainfall occurs, except around 2000-2100 hours (see Figure A8).
- On Tuesday morning (11 January) another series of southwesterly moving storms passes over Toowoomba between 0500 and 0800 hours (see Figures A9 and A10). From 0900 to 1600 hours on the Tuesday, major storm clouds cover the area to the east of Toowoomba along a northeasterly-southwesterly axis (see Figures A10 and A11).
- From 1900 hours onwards on Tuesday evening, the rain has disappeared (see Figures A11 and A12).

7 RAINFALL BEHAVIOUR DURING THE 10 JANUARY 2011 STORM EVENT

7.1 AVAILABLE DATA

7.1.1 Toowoomba Regional Council

Short duration rainfall (pluviograph) data are collected by Toowoomba Regional Council at 11 locations within and in the immediate vicinity of the Gowrie Creek catchment. On 10 January 2011, two stations malfunctioned. The locations and details of the nine functioning stations are shown in Figure 5.1 and Table 7.1.

Table 7.1 Available Short Duration Rainfall Stations

Station No	Station Name	Station Location
1	Wetalla	Wetalla Sewerage Treatment Plant
2	Prince Henry Dr	Prince Henry Drive
3	Prescott St	Corner Prescott and Goggs Streets
4	Picnic Point	Tank at Picnic Point
5	Eastern Valley	Eastern Valley at South Street and Mackenzie Street
6	Alderley St	Alderley Street at West Creek
7	Middle Ridge	Middle Ridge Pump Station
8	USQ	University of Southern Queensland
9	Gabbinbar	Gabbinbar Reservoir at Nelson Street

7.1.2 Bureau of Meteorology

There are two other short duration rainfall stations operated by the Commonwealth Bureau of Meteorology (BoM) within the Gowrie Creek catchment, namely Toowoomba Alert (Middle Ridge) and Toowoomba Aero. These two stations are designated A and B on Figure 5.1. Details of these stations are shown in Table 7.2. Short duration data for these two stations were not available at the time of preparing this report. However, 24-hour data at these stations were available from the BoM website.

Table 7.2 Available Daily Read Rainfall Stations

Station No	Station Name	Station Location
A	Toowoomba Aero	Toowoomba Airport, 4 km to west of CBD
B	Middle Ridge	Toowoomba ALERT, close to Council’s Middle Ridge Stn.

7.2 RECORDED RAINFALLS

7.2.1 Daily Rainfalls

Table 7.3 shows the daily rainfalls recorded at the BoM stations at Toowoomba Airport and Middle Ridge for the period 1-15 January 2011. These data were obtained from the BoM website. The high rainfalls of the storm event are evident (rainfall to 0900 hrs on 11 January). Major falls also occurred on 3 January, 6 January and on the day preceding the storm event (to 0900 hours on 10 January), when some 80 mm of rain fell. Thus, Gowrie Creek catchment was well and truly ‘primed’ with saturated soils and a high level antecedent wetness immediately before the flood-producing storm event.

Table 7.3 Daily Rainfalls, Toowoomba, 1-15 January 2011

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Toowoomba Airport	0	7.6	46.8	0.8	0	67.8	16.8	22.6	5.2	83.6	123.4	26.6	1.0	0.2	0
Middle Ridge	0	14.4	9.2	1.0	24.8	54.6	16.2	16.6	3.4	80.8	149.6	42.2	1.6	0	0

7.2.2 Rainfall Intensities

Figure 7.1 shows cumulative rainfalls recorded at the rainfall stations listed in Table 7.1. Appendix B shows 15-minute rainfalls recorded at the various stations between 0900 hours and 1600 hours on 10 January 2011. These data indicate that flooding in Toowoomba was caused by intense rain that fell on the Gowrie Creek catchment between approximately 1200 hours and 1500 hours on 10th January. The most intense rain burst occurred during a 75-minute period 1330-1415 hours.

Table 7.4 shows the recorded maximum rainfall intensities at the rainfall stations listed in Table 7.1. Table 7.4 also shows the severity, represented as the average recurrence interval (ARI), of rainfalls recorded at the above stations for a range of storm durations from 5 minutes to 12 hours. Design rainfall ARI’s were determined using data given in Australian Rainfall and Runoff (IE Aust, 1998). Appendix B, which shows plots of rainfall severity-intensity-duration, also shows how the severity of rainfall varies with duration over the storm event. The results of Table 7.4 and Appendix B indicate that:

- The most intense rainfalls (with ARIs of greater than 100-Years) occurred in a *northeast-southwest band across the centre of the catchment*, specifically encompassing raingauges at USQ, Middle Ridge (TRC), Eastern Valley, Alderly Street, Prescott & Goggs and Prince Henry Drive. This zone of *extreme rainfall* is shown on Figure 7.2. Rainfall intensities in the southeast corner of the catchment (Picnic Point and Gabbinbar) were less that 20-Years ARI. Rainfall intensities at Wetalla in the northern extremity of the catchment were above 50-Years ARI, but below 100-Years ARI. Note that the zone of extreme rainfall includes the CBD.
- The difference between the rainfall intensities and totals at Picnic Point and Gabbinbar is considerable compared to the band of extreme rainfalls to the immediate northwest of these gauges, and the functioning of these two gauges must be questioned. Alternatively, the reduced rainfall at Picnic Point and Gabbinbar may reflect local factors associated with the nature of the storm and orographic effects of the escarpment.
- The highest rainfall severities were recorded for storm durations of between 30 minutes and 3 hours, with 1-2 hour duration events being greater than 100-Years ARI at all stations in the extreme band of rainfalls across the middle reaches of the catchment.
- Prince Henry Drive station recorded the most intense rainfalls with ARI’s significantly greater than 100 years for durations ranging from 30 minutes to 3 hours.

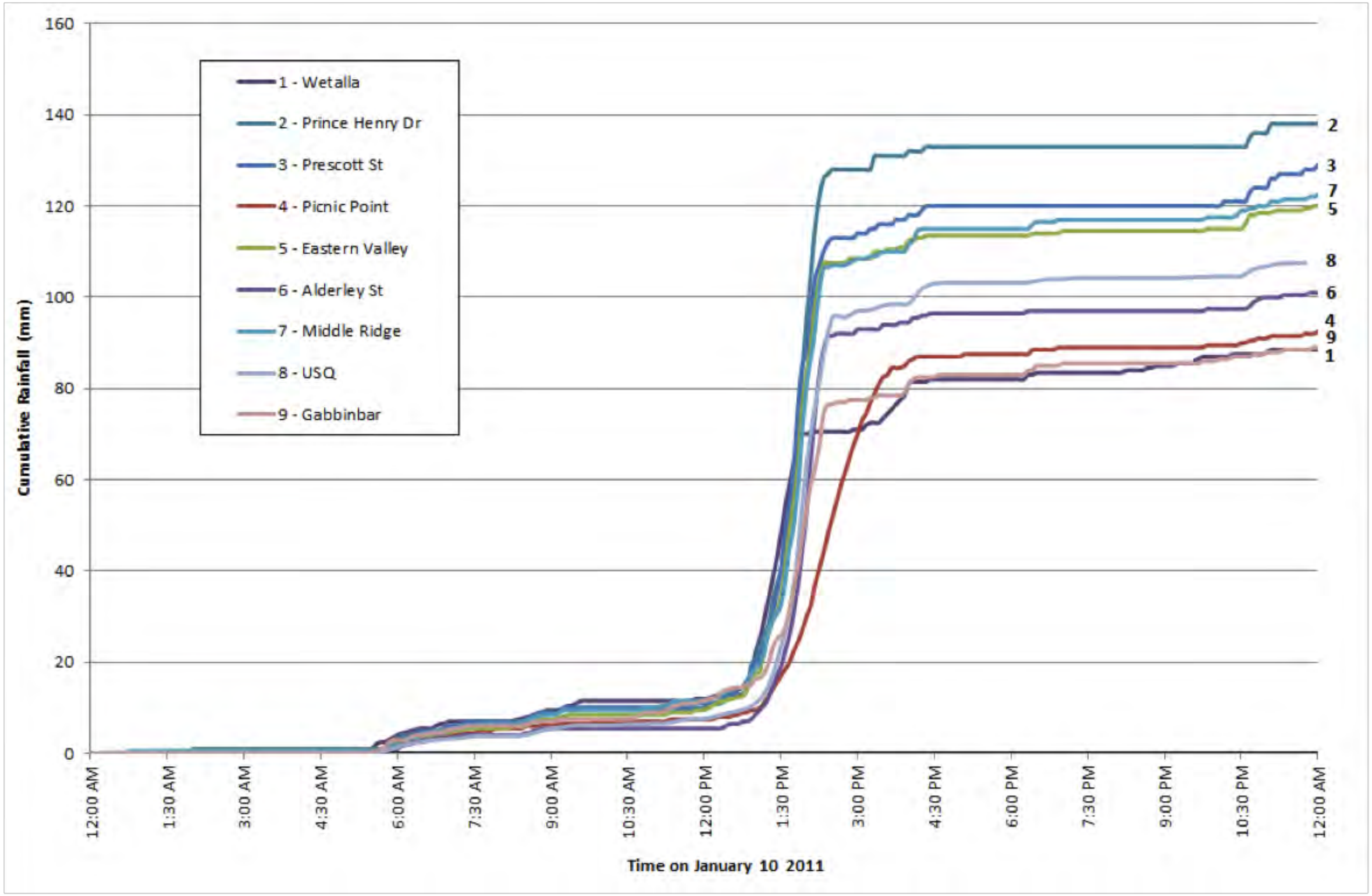


Figure 7.1 Cumulative Rainfalls, Toowoomba on Monday 10 January 2011

Table 7.4 Recorded Maximum Rainfall Intensities and Severities in Toowoomba, 10 January 2011

Storm Duration	1 Wetalla		2 Prince Henry Dr		3 Prescott St		4 Picnic Point		5 Eastern Valley		6 Alderley St		7 Middle Ridge		8 USQ		9 Gabbinbar	
	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)	Intensity (mm/hr)	ARI (Yrs)
5min	72.0	6	144.0	4	156.0	7	54.0	<1	150.0	5	138.0	4	144.0	5	106.4	2	84.0	<1
10min	69.0	12	144.0	18	132.0	14	48.0	<1	126.0	10	129.0	12	132.0	14	106.4	4	75.0	1
15min	66.0	17	140.0	38	120.0	18	46.0	<1	112.0	12	120.0	18	122.0	19	106.4	10	72.0	2
20min	63.0	21	135.0	89	108.0	29	46.5	<1	105.0	22	115.5	42	109.5	31	93.0	13	67.5	2
30min	61.0	31	128.0	>100	100.0	67	45.0	1	98.0	51	104.0	86	103.0	82	90.0	38	67.0	6
1hr	52.5	53	94.0	>100	81.0	>100	40.5	4	78.5	>100	74.5	>100	77.5	>100	72.0	>100	51.5	15
2hr	29.3	59	57.5	>100	50.5	>100	32.8	14	48.0	>100	42.8	81	46.8	>100	43.2	>100	31.3	13
3hr	20.7	62	40.0	>100	34.7	>100	25.5	17	33.0	80	29.2	43	32.3	94	29.8	61	22.2	9
6hr	11.8	71	20.5	59	18.3	48	13.4	7	17.5	33	15.3	17	17.6	45	16.1	31	12.6	6
12hr	6.8	82	11.0	23	10.0	20	7.3	4	9.4	13	8.0	6	9.5	19	8.6	12	6.9	3

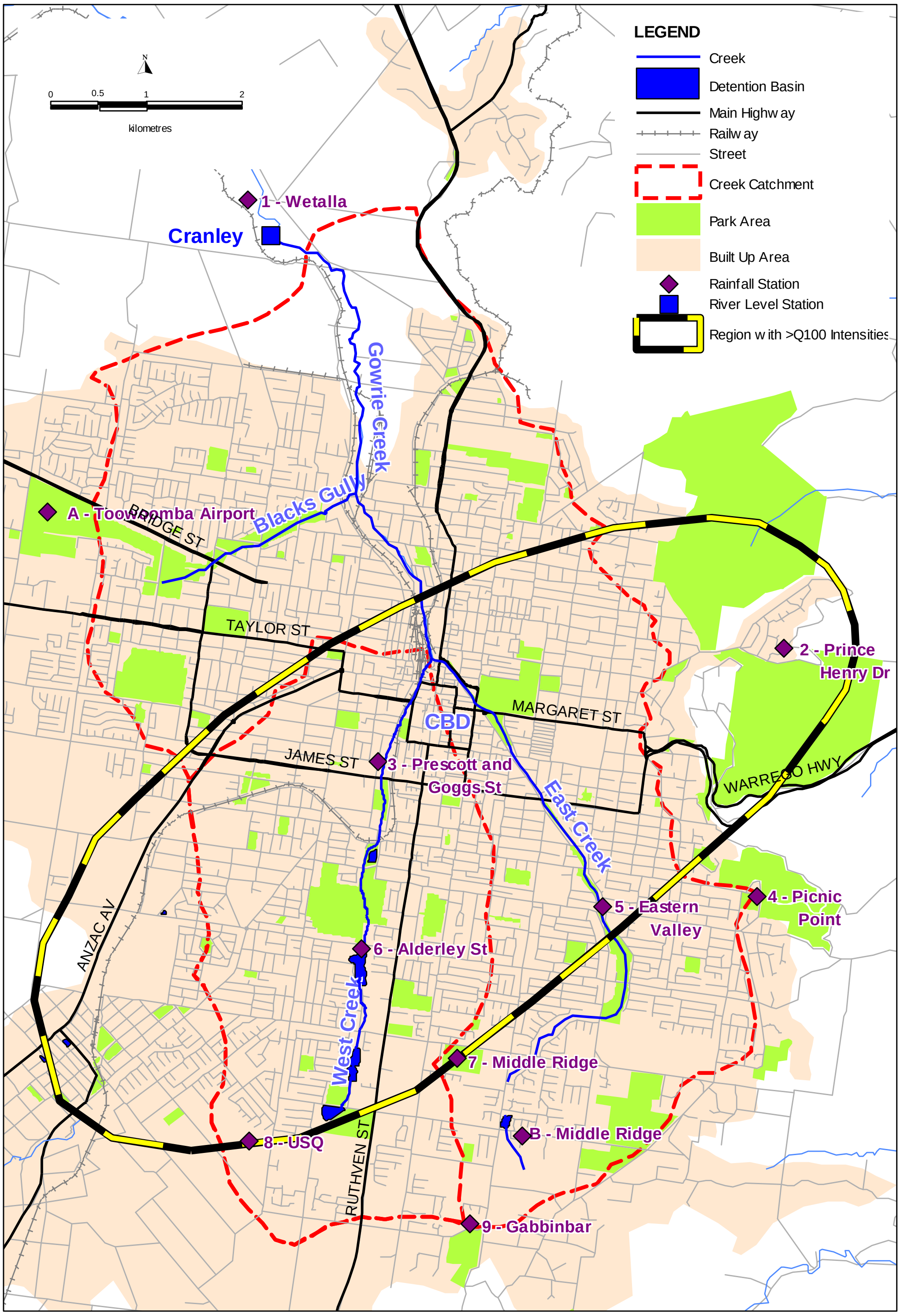


Figure 7.2 Area of Extreme Rainfall, Toowoomba, 10 January 2011

Inspection of the rainfall hyetographs in Appendix B indicates that the heaviest falls generally occurred between 1300 and 1430 hours, with peak falls occurring just before or just after 1400 hours. The highest 30-minute falls, all of which occurred in the period 1330-1430, ranged from 60 mm at Prince Henry Drive to 45-50 mm at all other stations except Picnic Point (22 mm), Gabbinbar (32 mm) and Wetalla (30 mm).

7.3 RAINFALL ISOHYETS

Figure 7.3 to Figure 7.9 show isohyets of cumulative rainfall across Toowoomba, as measured from 1200 hours on Monday 10 January. The southwest passage of the storm across the City is clearly apparent, as is the central zone of high rainfall. The following aspects of rainfall behaviour are noted:

- Little rain fell between 1200 and 1300 hours (see Figure 7.4) and that which did was limited to the northeast side of Gowrie Creek catchment (10 -20 mm total).
- By 1330 hours, widespread rain had fallen over the northern part of the catchment (see Figure 7.5), bringing the total rainfall since 1200 hours to 30-40 mm over the northern area of the catchment and 10-20 mm in the south.
- The main burst of heavy rain fell between 1330 and 1400 hours (see Figure 7.6), increasing the total fall since 1200 hours over the central eastern area of Gowrie Creek catchment to 80-90 mm. The heaviest falls were over the lower reaches of West Creek, the lower and middle reaches of East Creek, and the Reach of Gowrie Creek from the confluence of East and West Creeks downstream to Blacks Gully. The area of heavy rainfall includes the CBD.
- Heavy rain continued to fall through to 1430 hours (see Figure 7.7), the heaviest falls occurring over the middle eastern area of the catchment (total rainfall since 1200 hours of 100-120 mm) and the escarpment (total rainfall of 130 mm).
- Comparing Figure 7.7 and Figure 7.8, it is seen that little additional rainfall occurred between 1430 and 1500 hours.
- Additional rain fell between 1500 and 1600 hours, increasing the area of heavy rainfall and driving the total rainfall the rainfall band further to the southwest (compare Figure 7.8 and Figure 7.9).

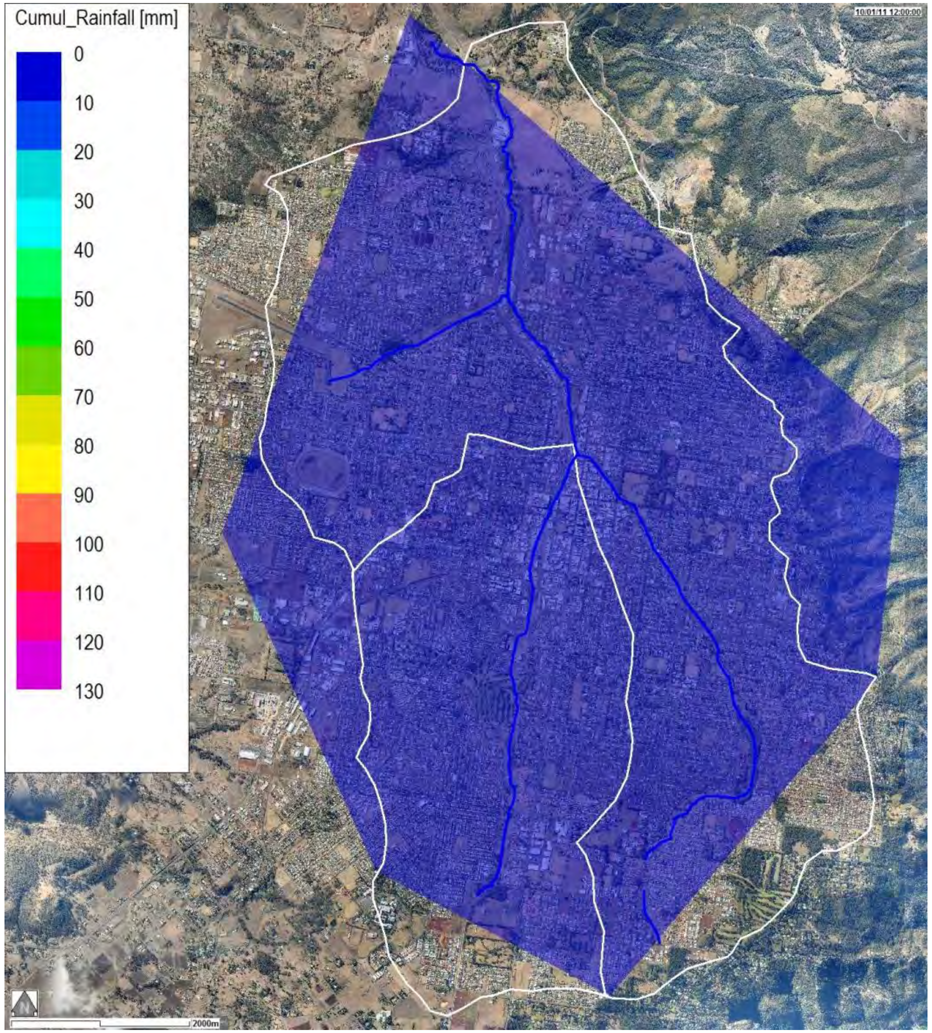


Figure 7.3 Cumulative Rainfall to 1200 Hours, Monday 10 January

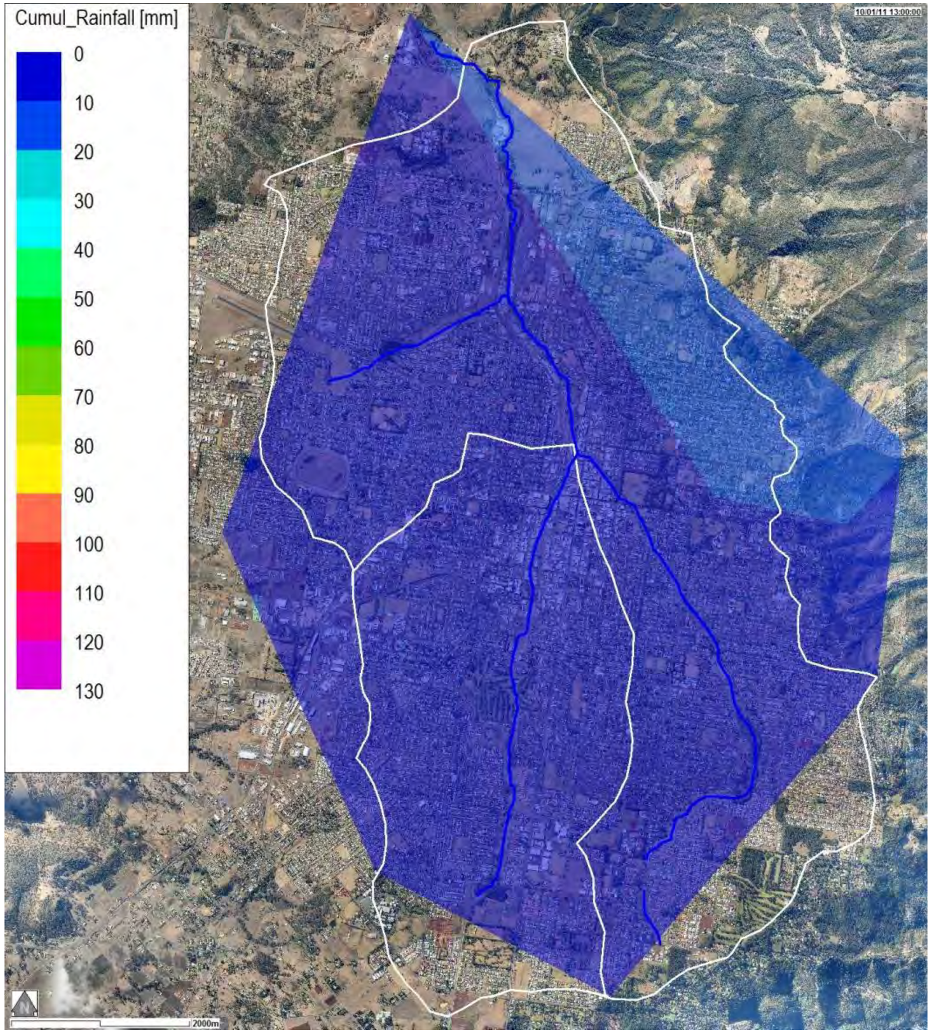


Figure 7.4 Cumulative Rainfall to 1200-1300 Hours, Monday 10 January

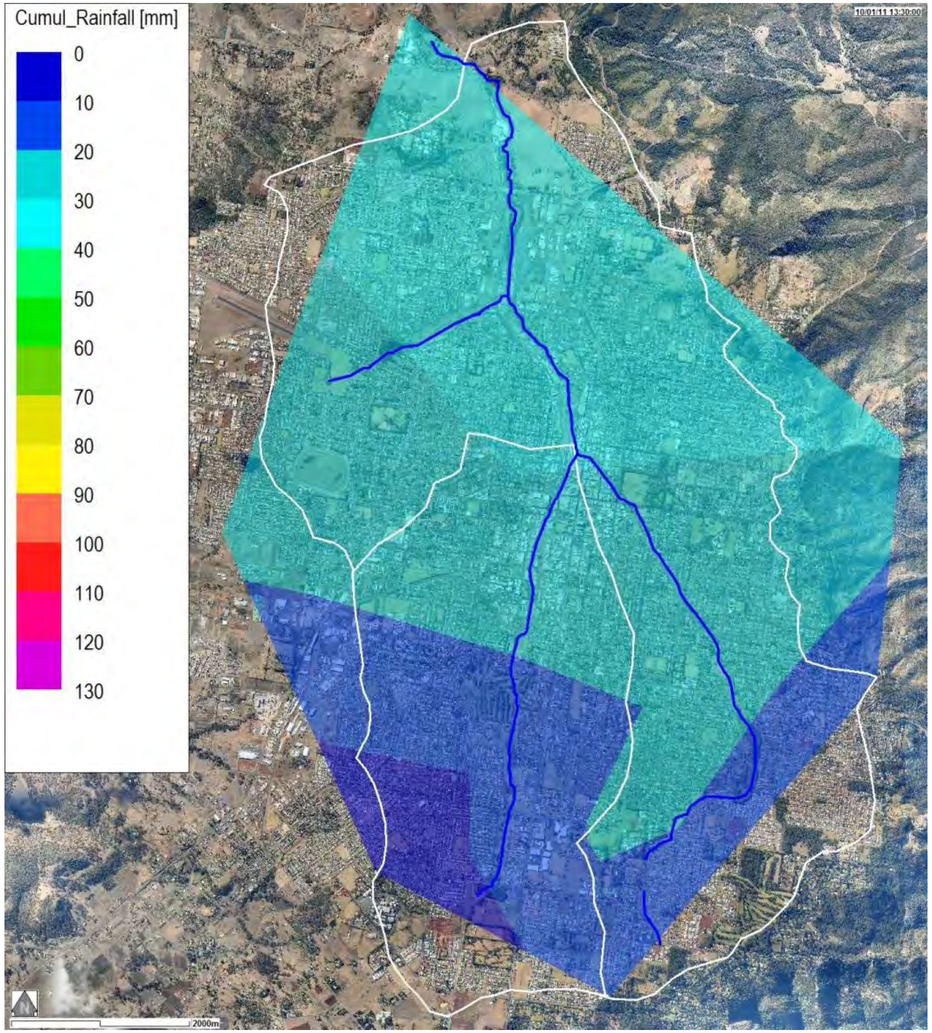


Figure 7.5 Cumulative Rainfalls to 1200-1330 Hours, Monday 10 January

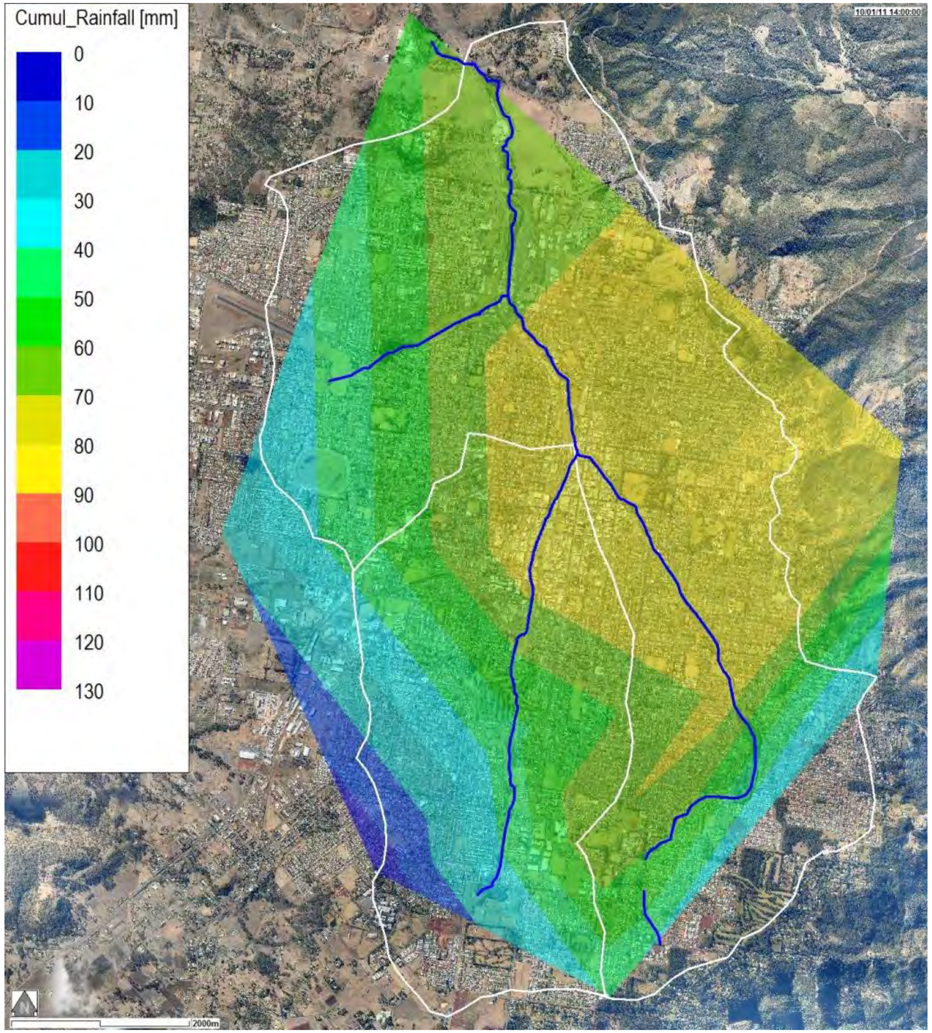


Figure 7.6 Cumulative Rainfalls to 1200-1400 Hours, Monday 10 January

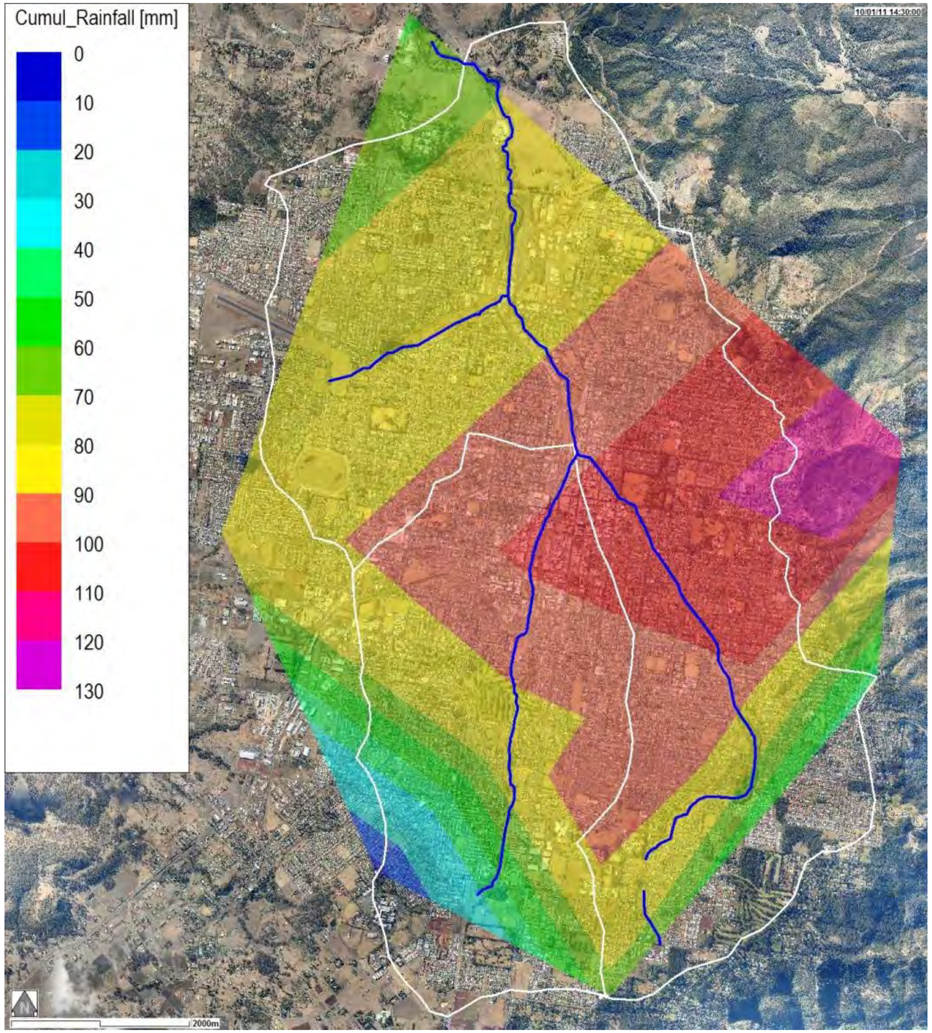


Figure 7.7 Cumulative Rainfalls to 1200-1430 Hours, Monday 10 January

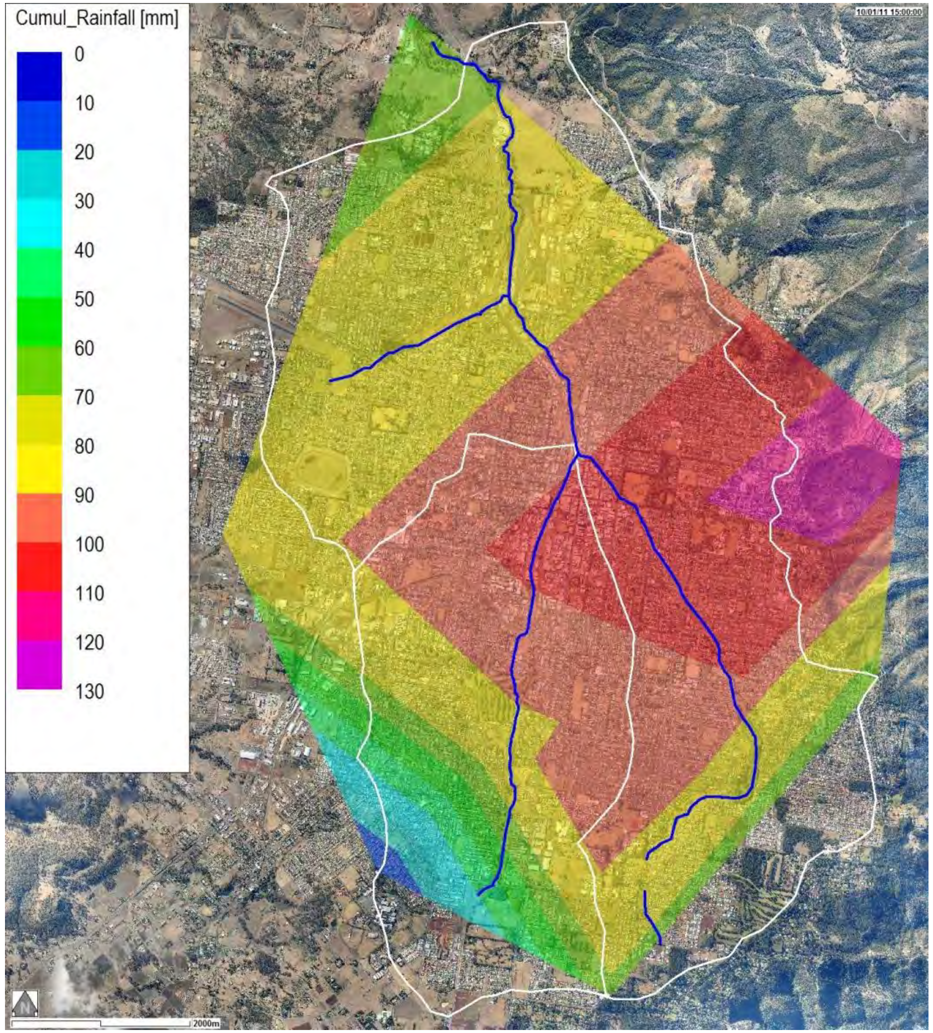


Figure 7.8 Cumulative Rainfalls to 1200-1500 Hours, Monday 10 January

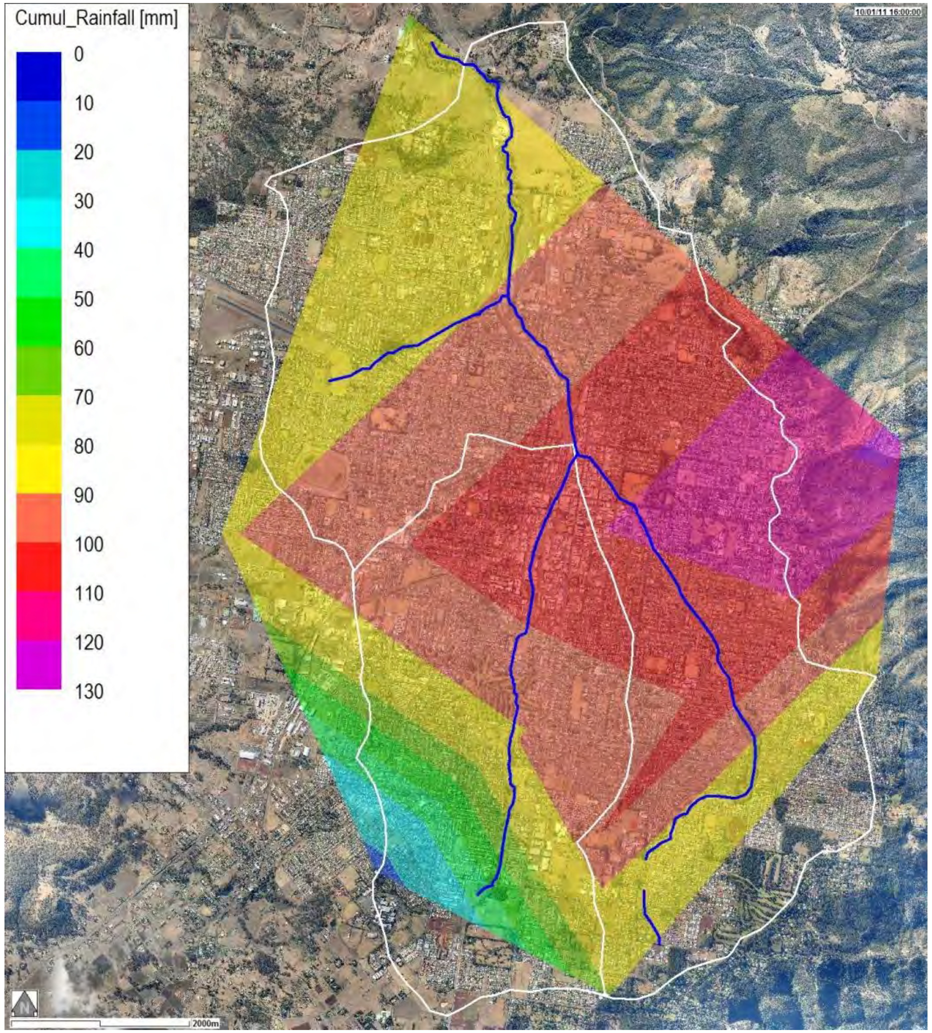


Figure 7.9 Cumulative Rainfalls 1200-1600 Hours, Monday 10 January

8 WATER LEVEL BEHAVIOUR DURING THE 10 JANUARY 2011 FLOOD EVENT

8.1 AVAILABLE DATA

8.1.1 Department of Environment and Resource Management

There is only one stream gauging station in the Gowrie Creek catchment of relevance to Toowoomba[4], namely the Cranley streamgauge (Station No 422326), which is located about 6 km north (downstream) of the Toowoomba CBD and is operated by the Department of Environment and Resource Management (DERM). The catchment area at the Cranley streamgauge is 47 km^2. The location of this station is shown on Figure 5.1.

8.1.2 Toowoomba Regional Council

Toowoomba Regional Council has estimated peak water levels along Gowrie Creek and its tributaries by surveying debris marks left by the 10 January Flood Event.

8.2 WATER LEVEL HYDROGRAPHS

Figure 8.1 shows recorded water levels in Gowrie Creek at the Cranley streamgauge on 10 January 2011. Figure 8.1 also shows the recorded 5-minute rainfalls at Prescott Street within the Toowoomba CBD, over the same time period. The data shows that there was a rapid rise in the recorded water levels at Cranley between 1300 hours 1400 hours on 10 January, up to a water level of 3.67 m gauge height (GH). The erratic trace at the Cranley gauge between 1400 hours and 1600 hours indicates that the gauge malfunctioned during that period. Rainfall-runoff modelling is required to clarify the bahaviour of the discharge and stage hydrographs at Cranley (which is beyond the scope of this study). Notwithstanding the cause of this behaviour, the data shows that the water level at Cranley peaked *within an hour or so after the most intense rain burst*. It should be noted that the water levels in East and West Creeks through the City Centre area *would have peaked earlier* than the Cranley stream gauge and therefore within a shorter period after the most intense rain burst. This is discussed in greater detail in Section 9.1.

On the basis of this behaviour, the floods that travelled down East and West Creeks and Gowrie Creek itself are *'flash floods',* as so-defined in this Report (see Section 2).

[4] There is another gauging station on Gowrie Creek further downstream at Oakey. This station, which is also operated by DERM, has a catchment area of 142 km^2. Data for the Oakey Station were not available at the time of writing this report.

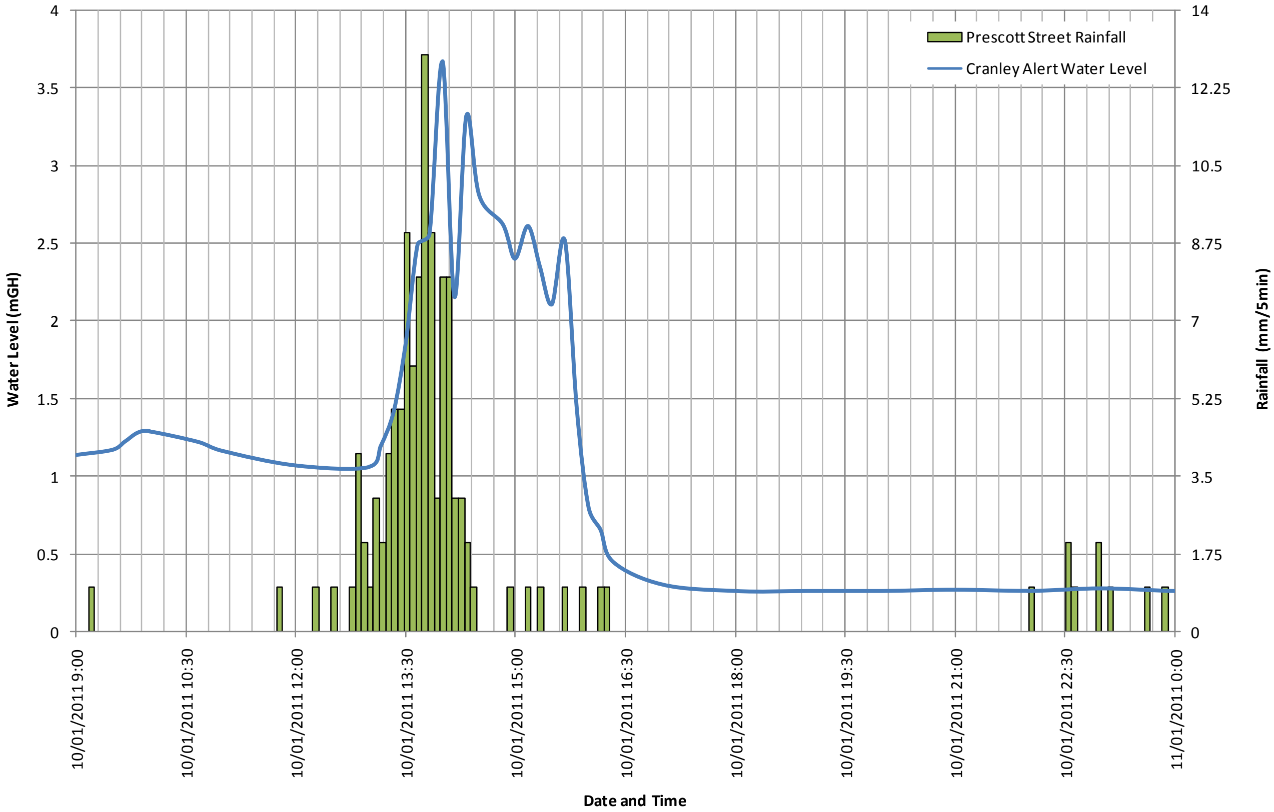


Figure 8.1 Recorded Gowrie Creek Water Levels at Cranley Streamgauge, 10 January 2011

8.3 EXTENT OF INUNDATION

Figure 8.2 shows the approximate extent of inundation caused by floodwaters from Gowrie Creek and its tributaries, as estimated by Toowoomba Regional Council (TRC) on the basis of flood debris marks. The four diagrams in Appendix C show the estimated extent of inundation in more detail. Regarding the estimated extent of inundation:

- The extent of inundation was limited to a relatively narrow strip some 50 - 100 m wide on either side of the waterways (see Maps B, C and D of Appendix C). The limited width of inundation reflects the relatively steep and narrow nature of the waterways.
- The width of inundation was greatest (some 700 m – see Map A of Appendix C) in the area around the confluence of East and West Creeks between Margaret Street to the south and Bridge Street to the north.
- The severity (ARI) of the 10 January flood in Toowoomba has not been assessed in this Report. However, based on the recorded rainfall intensities, catchment antecedent conditions and flood modelling undertaken by TRC, the flood event appears to have had an ARI significantly greater than 100 years.

The extent of inundation shown in Figure 8.2 and Appendix C is *indicative* only. Flooding at individual properties, especially around the limits of inundation, can be influenced by a number of local factors that may not be properly refected in the survey of flood debris marks. In supplying the data used to construct the extent of inundation map, Toowoomba City Council made the following observations (quoted):

- 'Because of the nature of the flooding this map has been based predominantly on debris levels (and also with assistance of the local residents). There are nearly always issues with the accuracy of debris levels as they can sometimes 'slump' after the water has passed or they may have been disturbed. Nevertheless this map represents the best possible information available.

- The map includes some interpolation using the DEM data (refer the second shapefile showing the flood levels used). As with any interpolation, particularly in and around buildings, there will be some areas that aren't as accurate as others.
- This only represents what we call 'creek flooding'. This has been difficult to distinguish in some locations where roads carrying significant stormwater volumes intersect the creeks. Because of this distinction this map may not correspond exactly with some residents perception of where the floodwater rose to.'

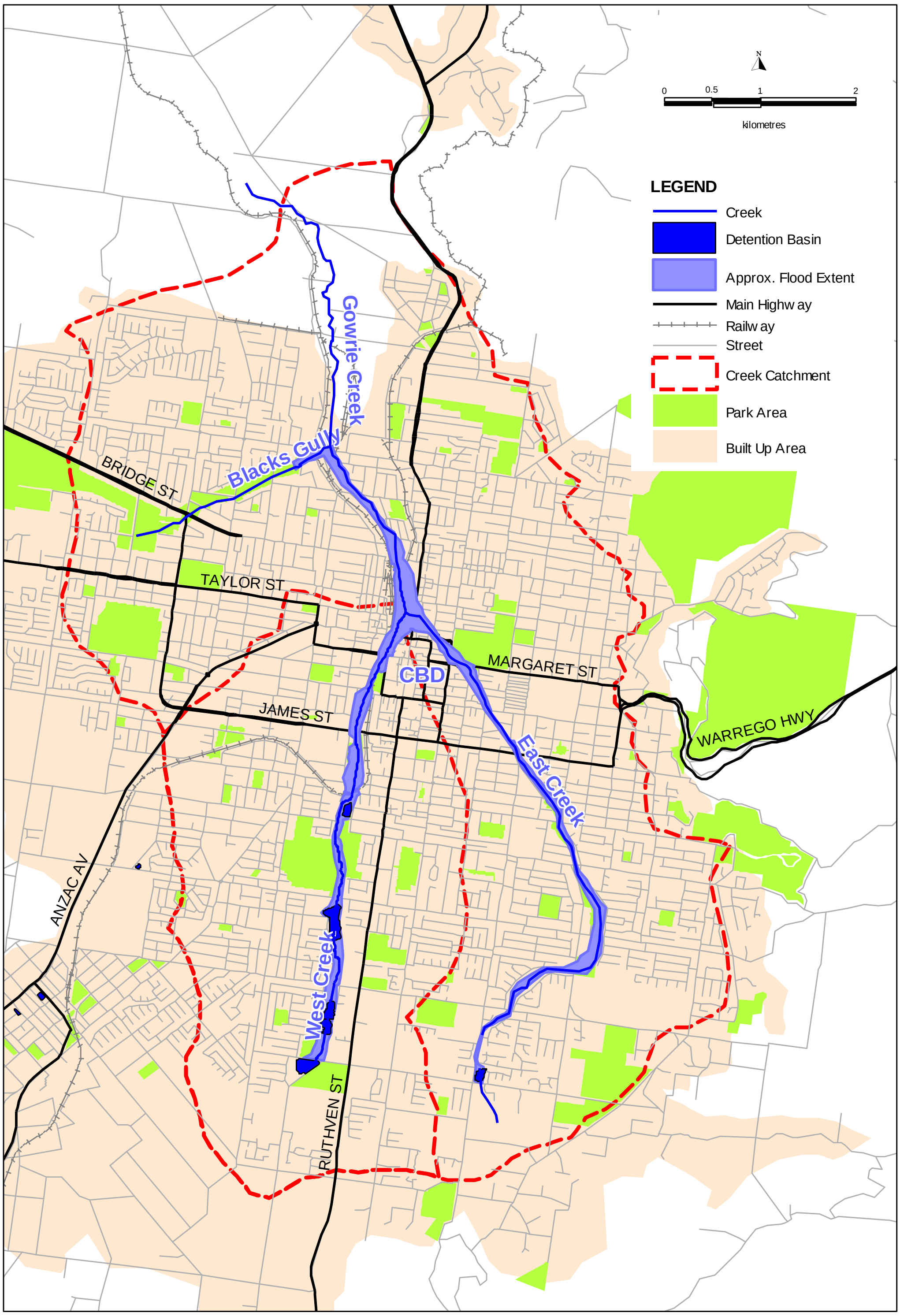


Figure 8.2 Extent of Inundation, Toowoomba, 10 January 2011 (Source Toowoomba Regional Council)

9 CAUSE AND NATURE OF FLOODING IN TOOWOOMBA ON 10 JANUARY 2011

9.1 RAINFALL AND WATERFLOW TIMING

9.1.1 Timing of Heavy Rainfall Bursts

Table 9.1 shows key times in the rainfall history recorded at the nine short duration raingauges described in Section 7.1. Three times are shown: start of heavy rainfall, start time of most intense rainfall (peak rainfall) and time the heavy rainfall ended. 'Heavy rainfall' was defined as being greater than 5 mm in a 15-minute period.

Table 9.1 Time of Start, Peak and End Rainfall Bursts

No.	Station Name	Time of Start of Heavy Rainfall Bursts (10 January)		
		Start	Peak	End
1	Wetalla	1245	1330	1400
2	Prince Henry Dr	1300	1400	1445
3	Prescott St	1245	1345	1430
4	Picnic Point	1330	1415	1530
5	Eastern Valley	1245	1345	1415
6	Alderley St	1315	1400	1430
7	Middle Ridge	1300	1345	1445
8	USQ	1315	1345	1445
9	Gabbinbar	1315	1345	1445

Figure 9.1 shows the frequency across the nine gauges of the start, peak and end times of heavy rainfall. It is seen that the time of heavy rainfall generally commenced between 1245 and 1330 hours, the time of peak rainfall generally occurred between 1345-1415 hours, and heavy rainfall generally ceased around 1415-1445 hours.

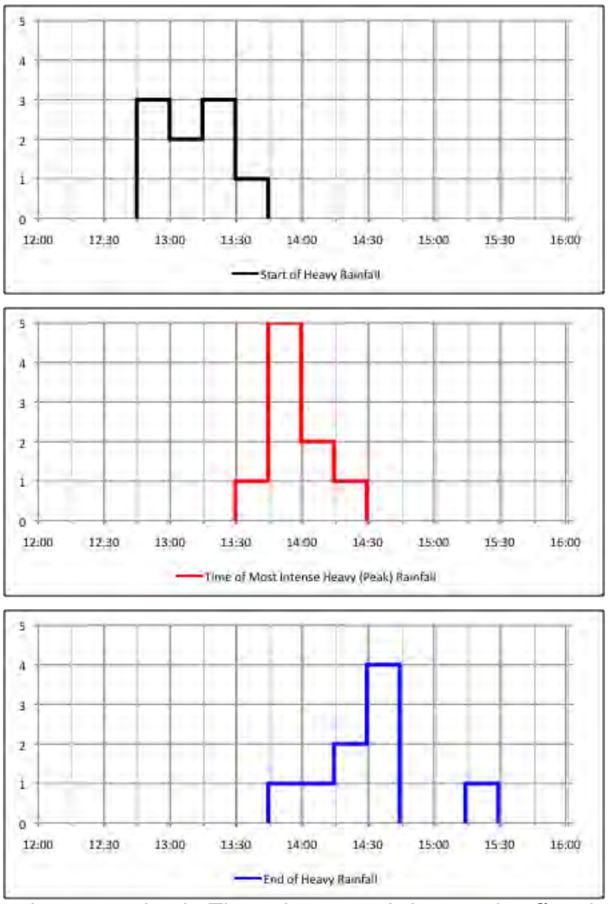
9.1.2 Water Level Rise

As discussed in Section 8.1, the only available water level data of relevance to flooding in Toowoomba were recorded at the Cranley streamgauge, which is located some 5 km downstream from the junction of East and West Creeks. As noted earlier, this gauge malfunctioned during the flood event, but inspection of Figure 8.1 indicates that the peak water level at Cranley would have occurred sometime between 1400 and 1530 hours, probably around 1430-1445 hours, or some 1.5–2 hours after heavy rainfall commenced in Toowoomba and some 0.5-1 hours after the peak rainfall burst.

The flood wave is estimated to have taken about 30 minutes to travel the 6 km from the CBD to Cranley gauge. Thus flood levels in the CBD are estimated to have peaked around 1400-1415 hours, or some 1–1.5 hours after heavy rainfall commenced (1245-1330 hours). This timing of

CBD peak flood levels is in keeping with TRC's understanding of what happened. Peak flood levels would have occurred some 30-minutes earlier along the upper and middle reaches of East and West Creeks (especially East Creek, where the heaviest falls occurred), or around 1330-1345 hours.

It is noted that heavy rainfall was generally occurring until around 1430-1445 hours (see Figure 9.1), ie *during and after the time at which water levels in East and West Creek and the*



CBD are estimated to have peaked. Thus, it was raining at the flood peak.

Figure 9.1 Distribution of Times of Start, Peak and End of Heavy Rainfalls

9.2 OVERLAND FLOW INUNDATION

The Toowoomba stormwater drainage system in the catchment of East, West and Gowrie Creeks delivers stormwater to the creeks. The piped stormwater drainage system has a capacity to handle storm events up to about 2-Years ARI, except in the CBD where the capacity of the piped drainage system is some 5-Years ARI. The flood-producing storm event of 10 January 2011, which was greater than 50-Years ARI in the northern areas of the catchment, greater than 100-Years ARI in the central band of extreme rainfall, and greater than 20-Years ARI in the south-east area of the catchment, will have overwhelmed the piped drainage system, leading to overland flow down streets, gutters, footpaths and across property both upslope and downslope of stormwater inlets.

Hence any inundation that occurred in areas clearly remote from the limits of inundation shown in Figure 8.2 and Appendix C *will have been caused by overland flow*.

It is considered likely that overland flow *may* also have caused initial inundation in areas that were subsequently flooded by waterflow down East, West and Gowrie Creeks. This initial inundation would have been caused by overland flow from the overloaded stormwater system making its way to the creeks before creek flows rose sufficiently to flood areas with waterflow. The intensity of the storm-producing rainfalls and the rapid response of the catchments meant that surface runoff and water level rises in the creeks would have occurred quickly after rain commenced. Thus, the window for initial inundation by overland flow in areas subsequently flooded by waterflow would have been short.

TRC notes that the 'Dent Street, which runs between Herries Street and Margaret Street has 'local drainage problems'. Dent Street lies to the west of the railway line, which in turn lies to the west of West Creek. It is probable that this area experienced initial overland flow flooding before waterflow flooding from West Creek subsequently occurred.

9.3 WATERFLOW INUNDATION

The extent of waterflow inundation is shown in Figure 8.2 and Appendix C. Properties in the defined area *were flooded by waterflows* from the creeks, with the following caveats:

- Initial flooding by overland flow may have occurred, especially in properties further away from the creeks, where the window of opportunity for initial flooding by overland flow is greater (as discussed above).
- The estimated extent of inundation, as shown on Figure 8.2 and in the maps of Appendix C, is necessarily inexact. Properties outside the limits of inundation may also have been flooded, by either waterflow or overland flow. (Rain continued during, up to and after water levels had peaked).

9.4 UNCERTAIN

Thus, uncertainties exist as to whether properties flooded by waterflows also suffered initial inundation from overland flow flooding. To resolve this issue requires investigation of 'local' factors (such as local topography and the area of overland flow characteristics) and, preferably, numerical modelling of the storm event and stormwater drainage system in Toowoomba, which is beyond the scope of this report.

10 FACTORS AFFECTING FLOODING IN TOOWOOMBA ON 10 JANUARY 2011

The following factors affected and exacerbated the nature of flooding in Toowoomba on 10 January 2011:

- The intense rainfalls that occurred over Gowrie Creek catchment. At six of the nine rainfall stations for which data were available, the ARI of 30-mimute to 3-hour falls were greater than 100-Years, at one other station, the ARI was greater than 50-Years.
- Given the saturated antecedent catchment conditions, the extreme rainfall intensities and the relatively steep nature of the catchments and waterways draining Toowoomba, the time of concentration of East and West Creeks is estimated to be some 1-1.5 hours for the Monday afternoon storm. This corresponds closely to the 1.5-2 hour period of 'heavy rainfalls', ie the storm was of critical duration to maximize catchment runoff.
- Almost the entire catchments of East and West Creeks are urbanized, contributing to the fast, immediate conversion of rainfall to surface runoff.
- Antecedent rainfalls had 'primed' the catchment for runoff; catchment soils were saturated. Some 80mm of rain fell in the 24-hour period immediately preceding the flood-producing storm (to 0900 on 10 January). Catchment response to the flood-producing storm would have been immediate, with surface runoff generated as soon as rain fell.
- The most intense band of rainfall was centred over the middle and upper reaches of Gowrie Creek catchment, ensuring a rapid rise in water levels along East and West Creeks and in the CBD.
- The steep and relatively narrow nature of the waterways (bedslopes of 0.5-2 percent), coupled with the intense rainfall, resulted in high velocity, deep and extremely hazardous floodwaters surging down the creek systems.
- Almost all bridges and waterway crossings along East and West Creeks were overtopped during the flood event. These structures will have impeded waterflow and raised upstream flood levels. This effect was compounded by the large volume of material swept into the creeks, such as motor vehicles, logs, walls, roofs and other elements of buildings, etc, much of which was caught in the openings of bridges and waterway crossings, further impeding flows and raising upstream flood levels. Other man-made structures situated along the banks of the waterways and flooded buildings and urban infrastructure will also have impeded flood flows and raised water levels.
- The detention basins built along West Creek were overwhelmed; all were overtopped but none breached. It is expected that the capacities of these basins are too small to have exerted any meaningful mitigating effect on waterflows passing through them.

11 REFERENCES

BoM (2011) ‘Frequent heavy rain events in late 2010/early 2011 lead to widespread flooding across eastern Australia’, Special Climate Statement 24, Updated 25 January 2011. Commonwealth Bureau of Meteorology, 25 January 2011.

DIPNR (2005) ‘Floodplain Development Manual: the management of flood-liable land’, NSW Department of Infrastructure, Planning and Natural Resources, April 2005.

IEAust (1998) ‘Australian Rainfall and Runoff’, Institution of Engineers, Australia, 1998.

SCARM (2000) ‘Floodplain Management in Australia, Best Practice principles and Guidelines’, Standing Committee on Agriculture and Resource Management, SCARM Report No. 73, 2000. (CSIRO Publishing)

WBM (1999) ‘Gowrie Creek Toowoomba Catchment Management Strategy’, Report prepared for Toowoomba City Council by WBM Oceanics Australia and Hassell, November 1999.

APPENDIX A

RADAR IMAGES OF JANUARY 2011 STORMS

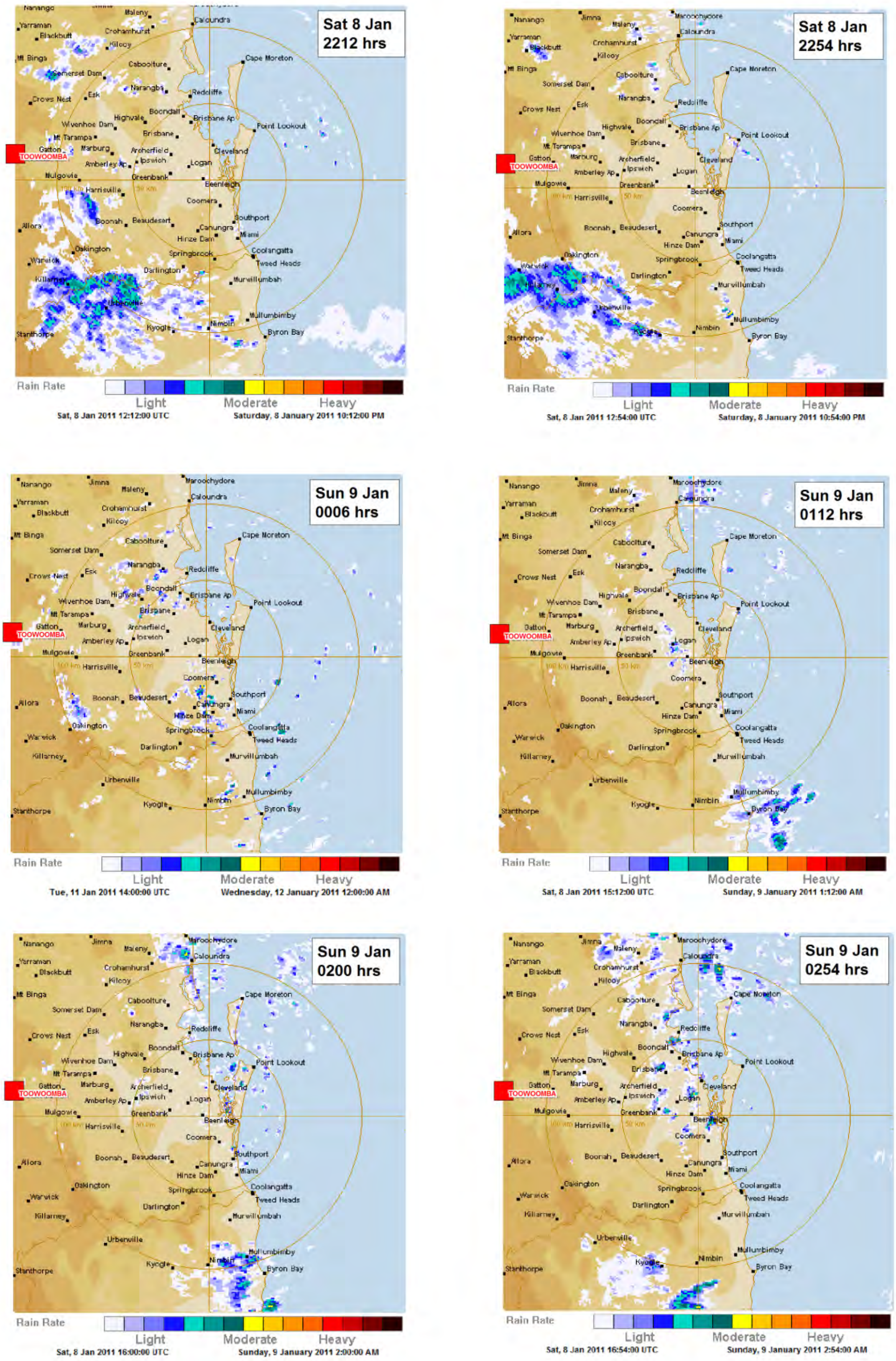


Figure A1 Radar Images Saturday 8 January 2212 hrs to Sunday 9 January 0254 hrs

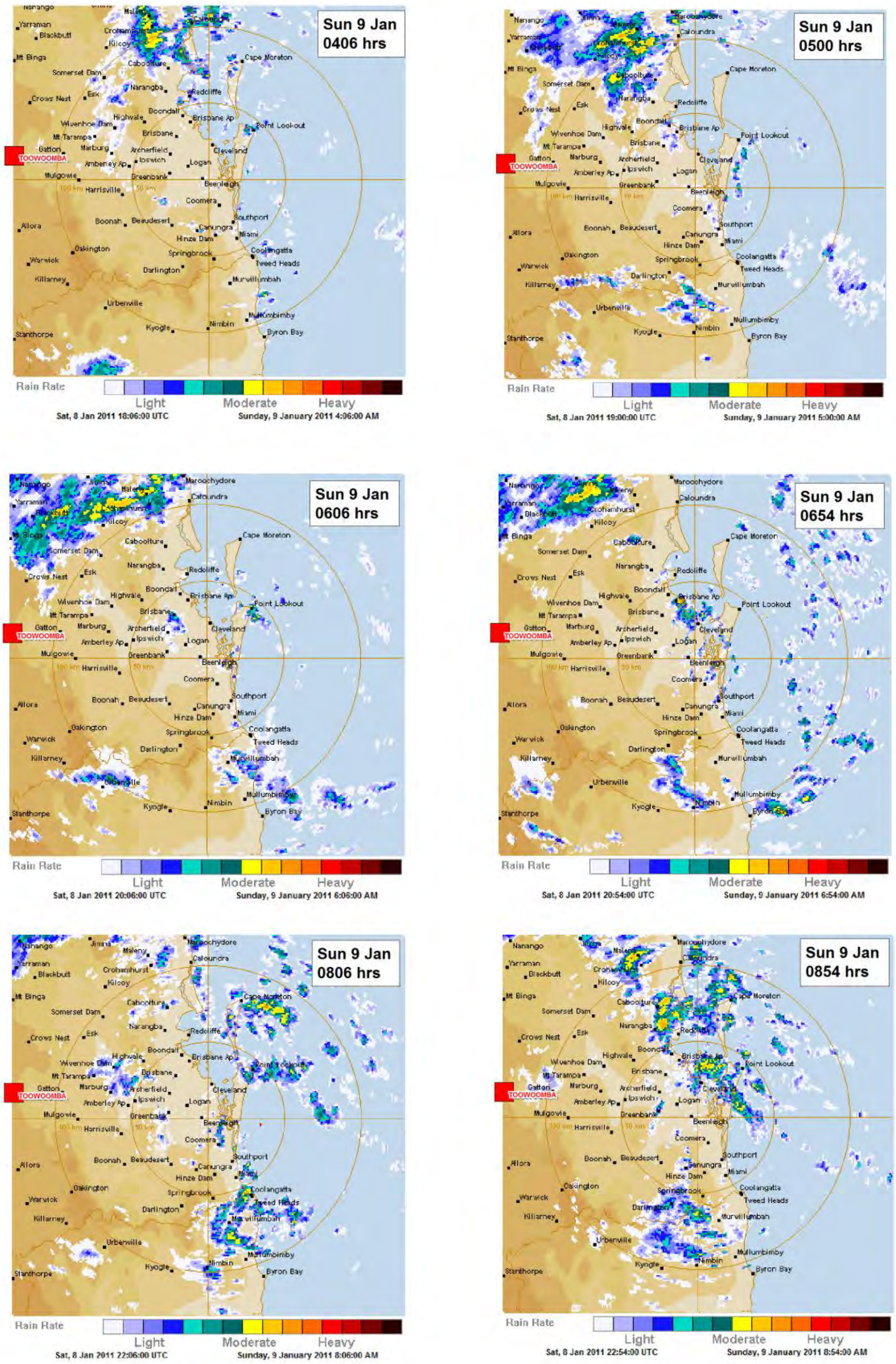


Figure A2 Radar Images, Sunday 9 January 0406 hrs to Sunday 9 January 0854 hrs

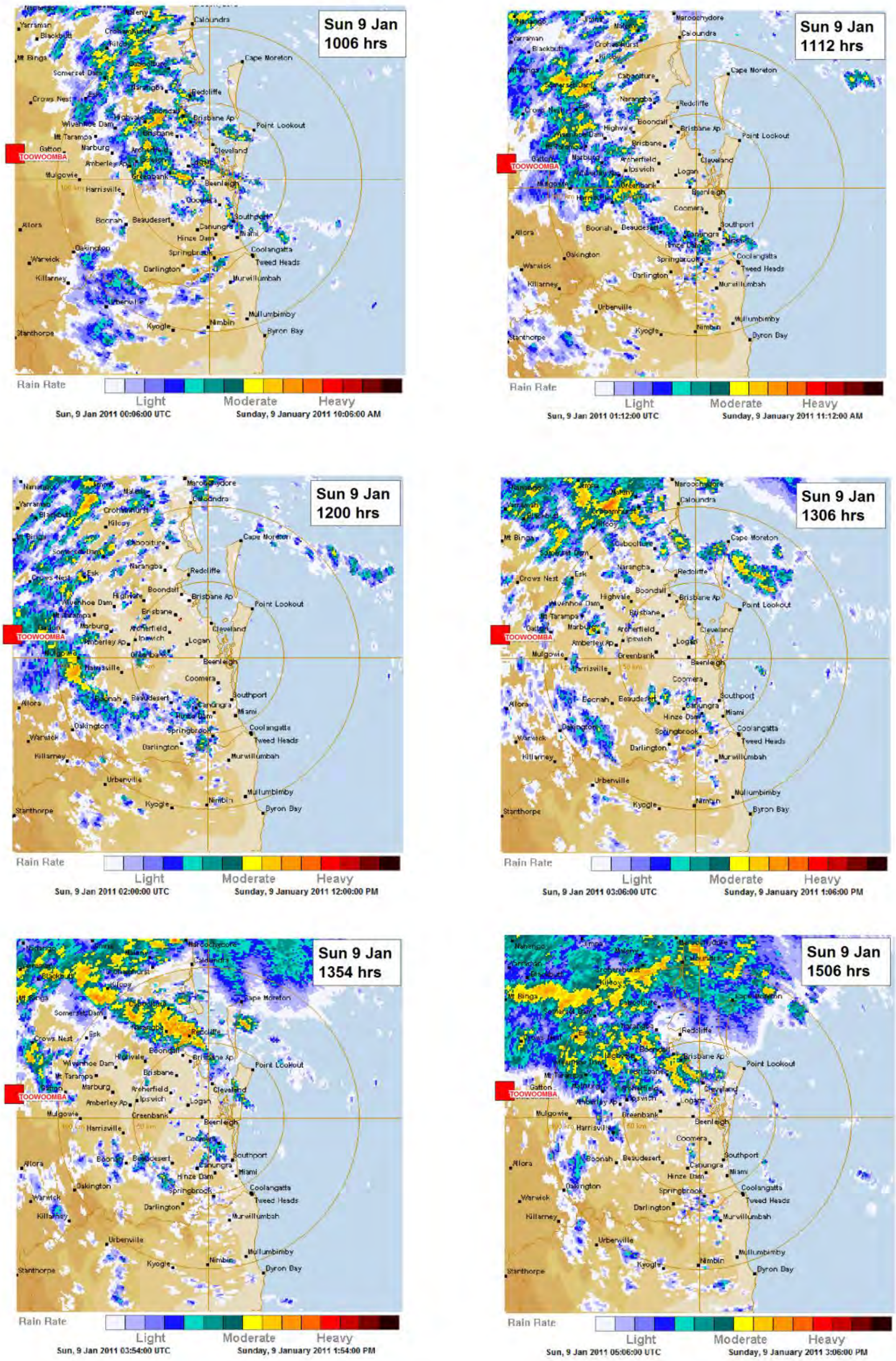


Figure A3 Radar Images, Sunday 9 January 1006 hrs to Sunday 9 January 1506 hrs

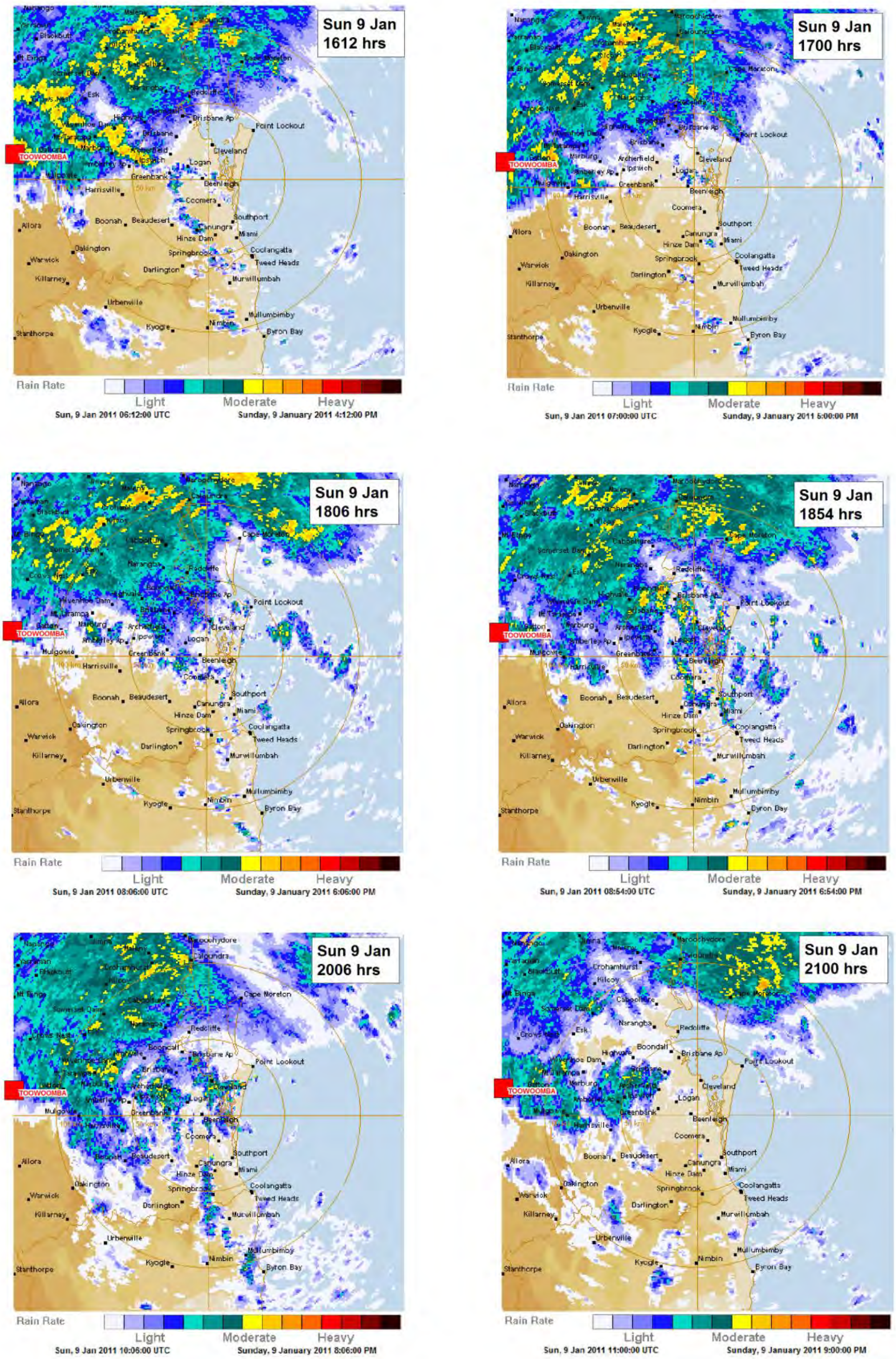


Figure A4 Radar Images Sunday 9 January 1612 hrs to Sunday 9 January 2100 hrs

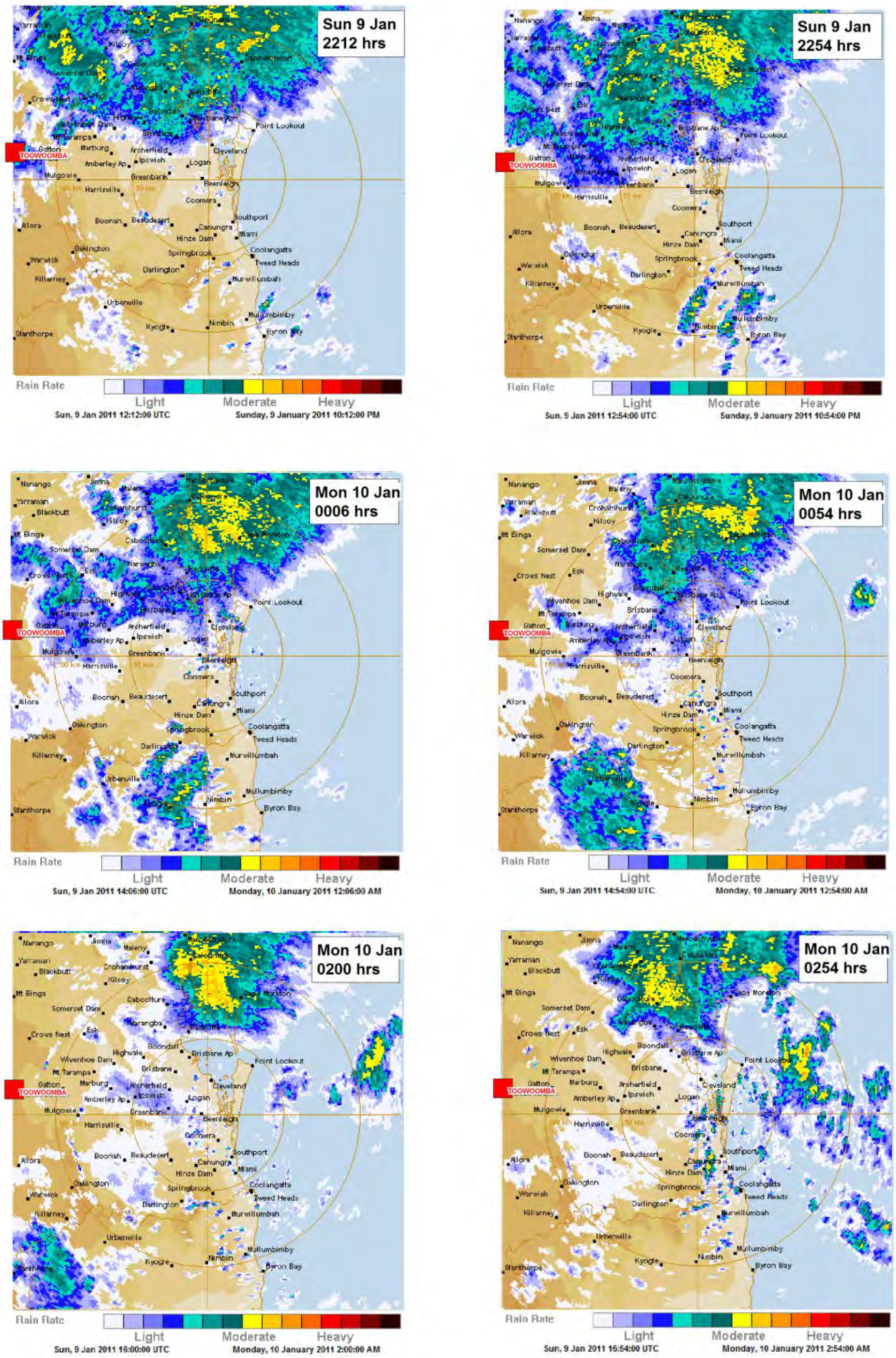


Figure A5 Radar Images Sunday 9 January 2212 hrs to Monday 10 January 0254 hrs

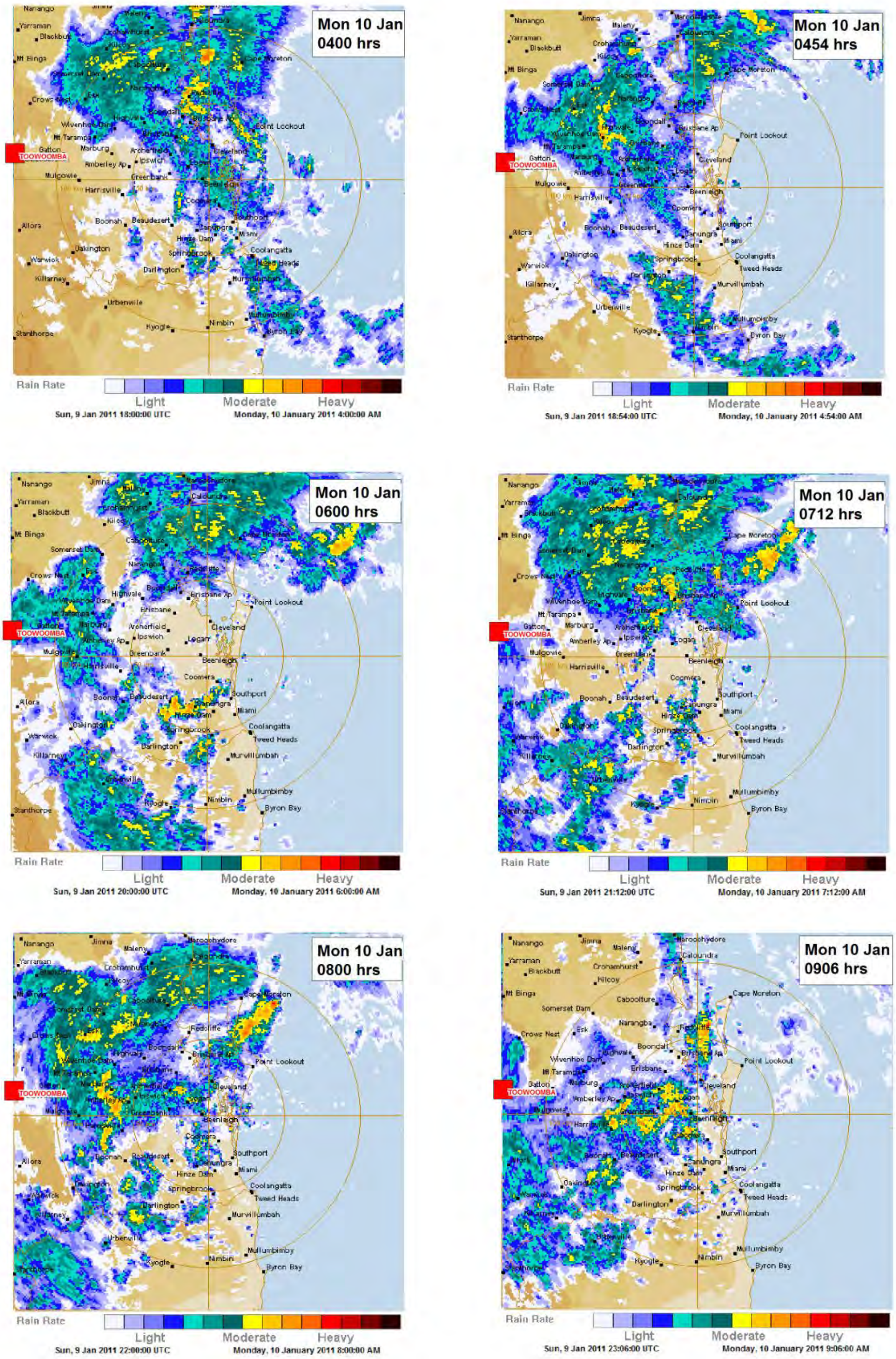


Figure A6 Radar Images Monday 10 January 0400 hrs to Monday 10 January 0906 hrs

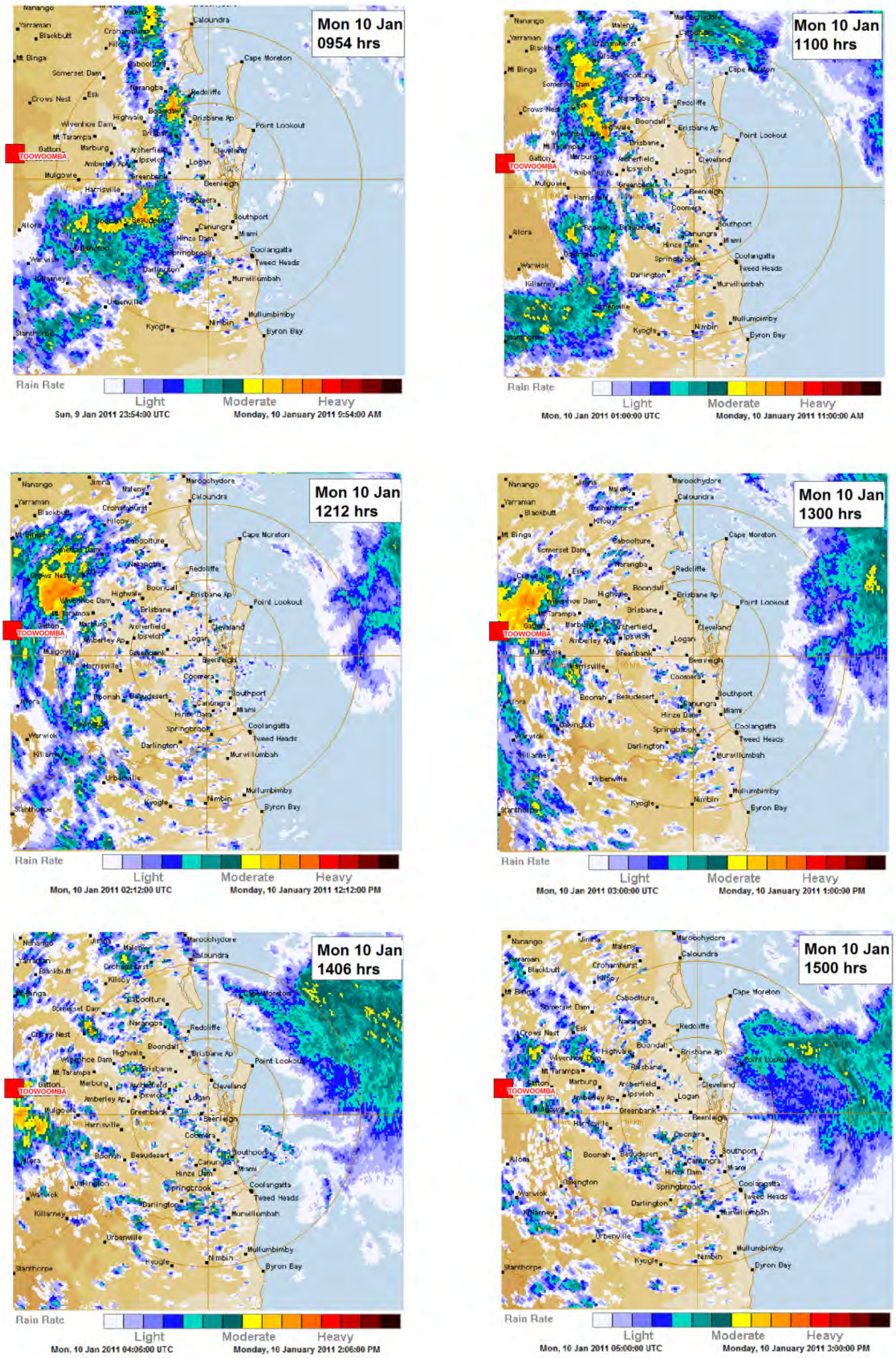


Figure A7 Radar Images Monday 10 January 0954 hrs to Monday 10 January 1500 hrs

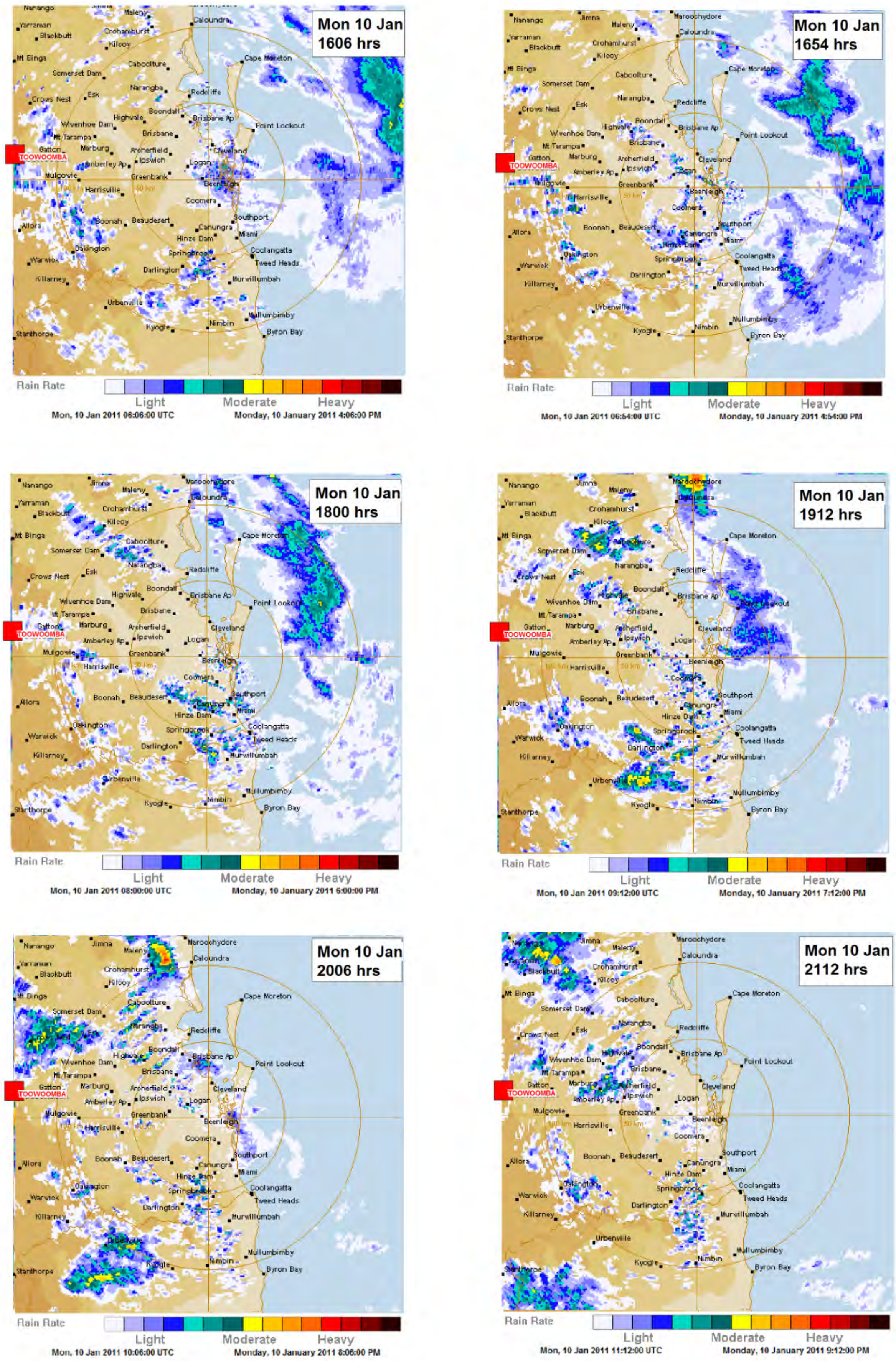


Figure A8 Radar Images Monday 10 January 1606 hrs to Monday 10 January 2112 hrs

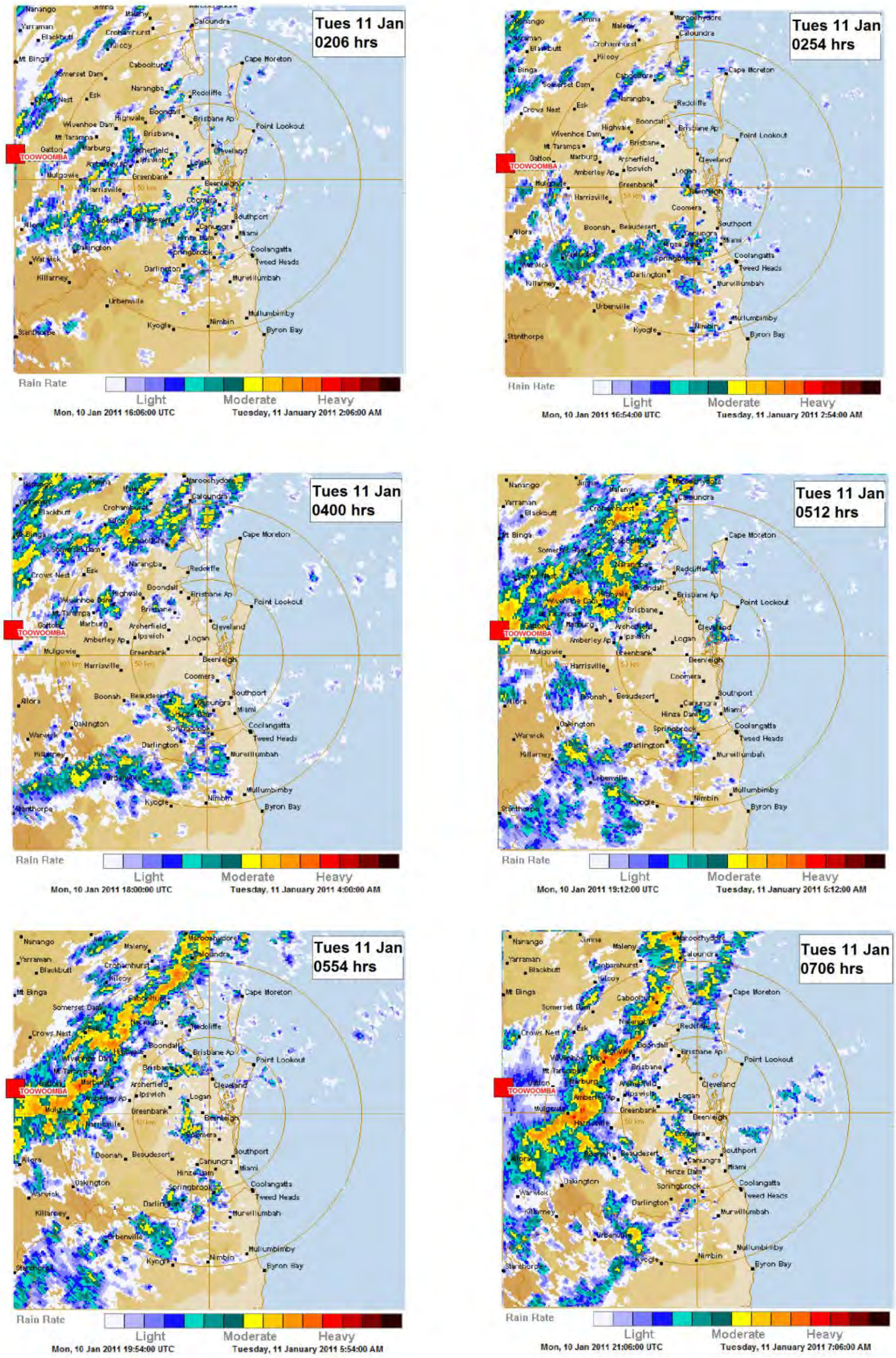


Figure A9 Radar Images Tuesday 11 January 0206 hrs to Tuesday 11 January 0706 hrs

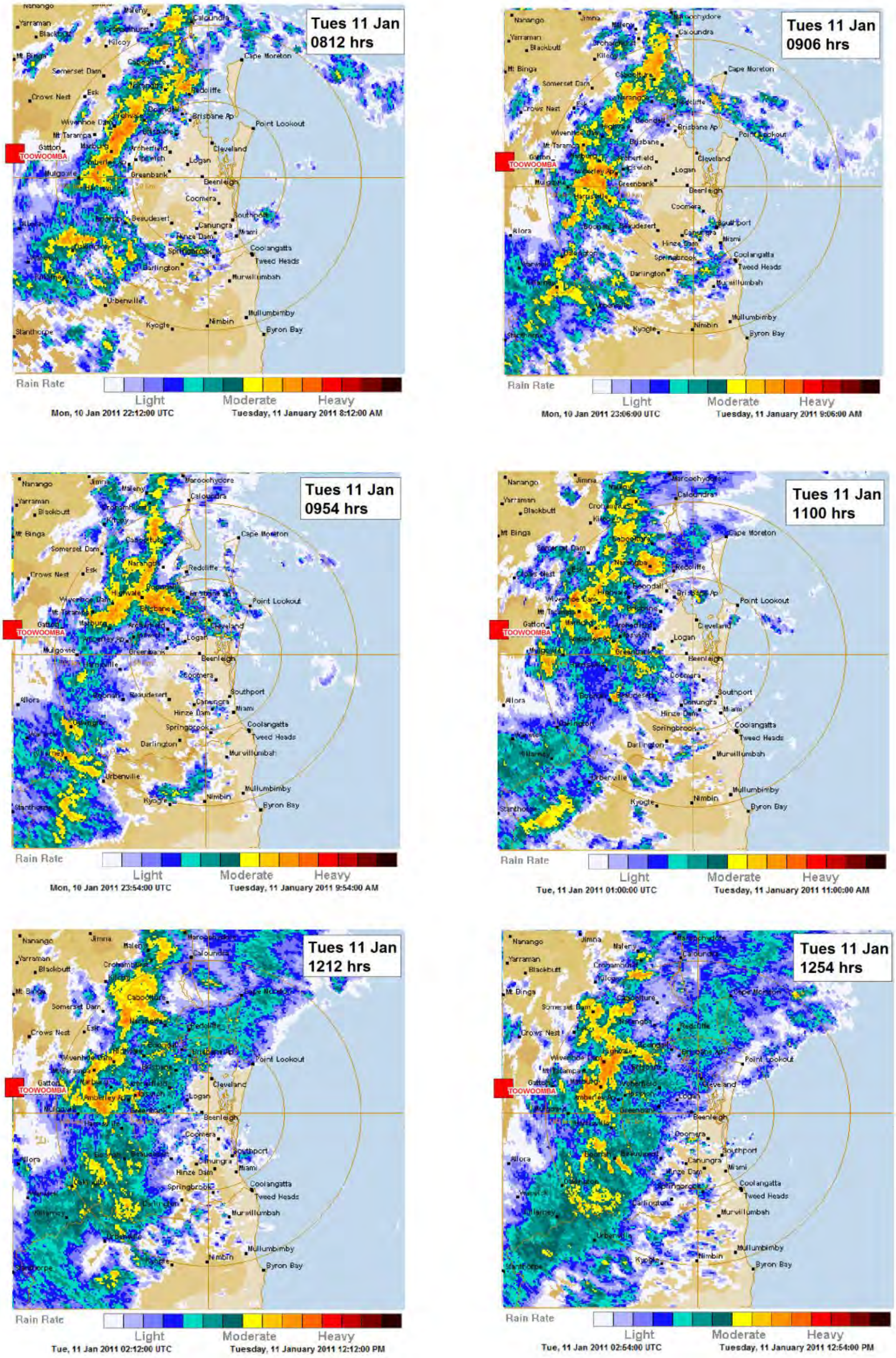


Figure A10 Radar Images Tuesday 11 January 0812 hrs to Tuesday 11 January 1254 hrs

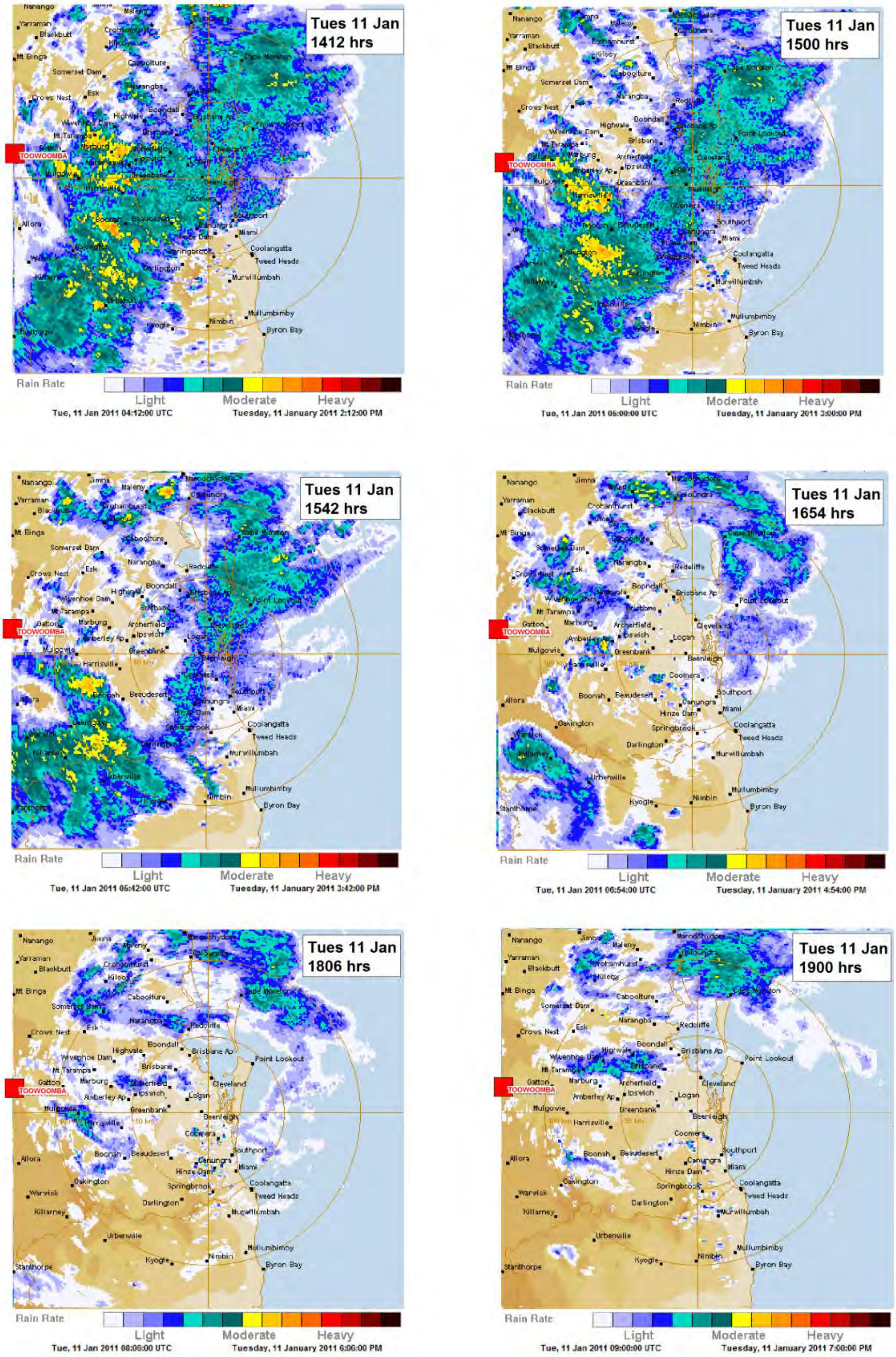


Figure A11 Radar Images Tuesday 11 January 1412 hrs to Tuesday 11 January 1900 hrs

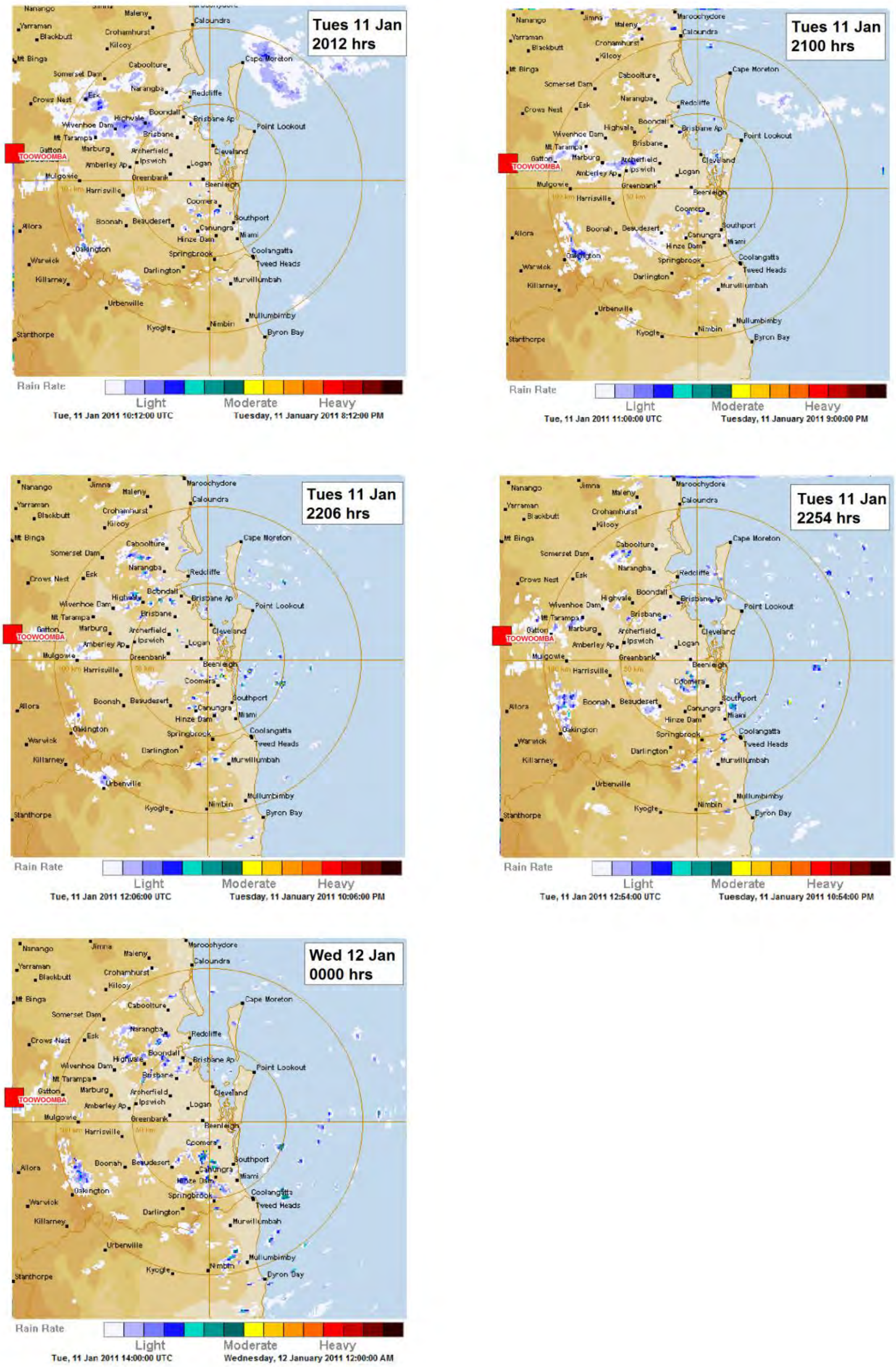
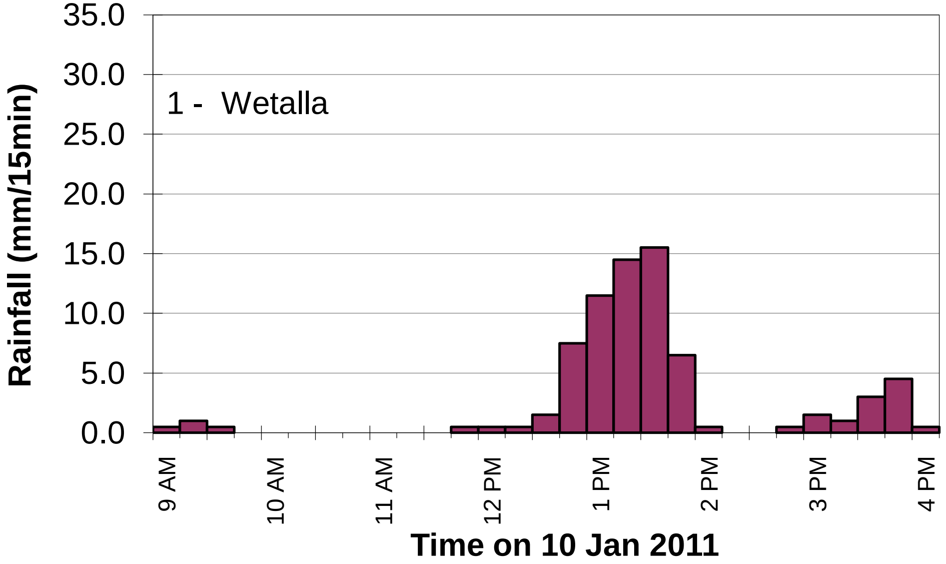
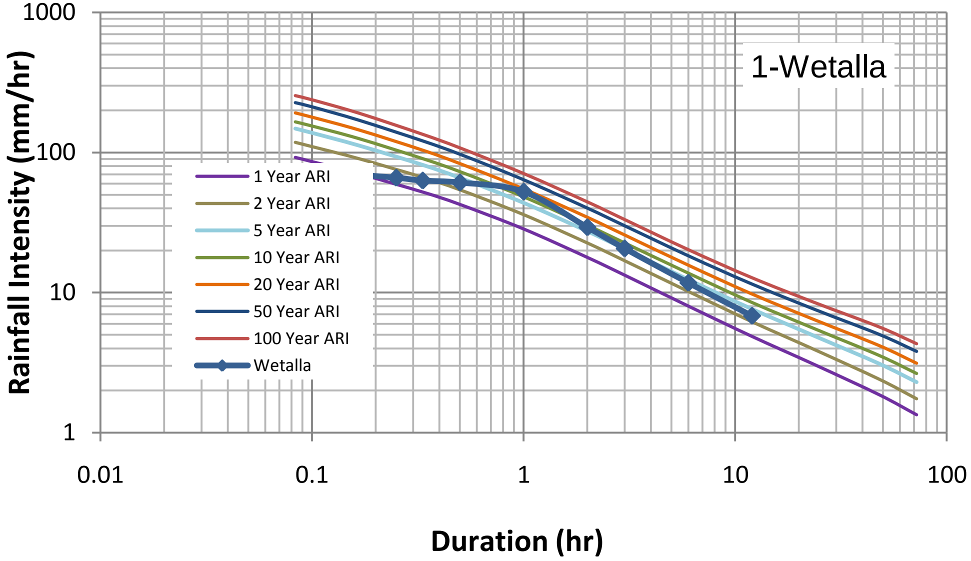


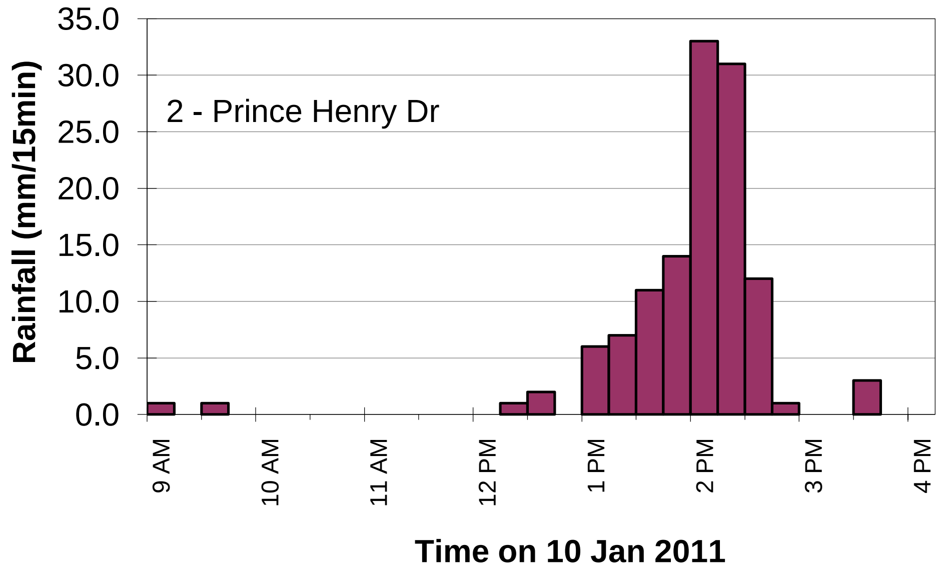
Figure A12 Radar Images Tuesday 11 January 2012 hrs to Wednesday 12 January 0000 hrs

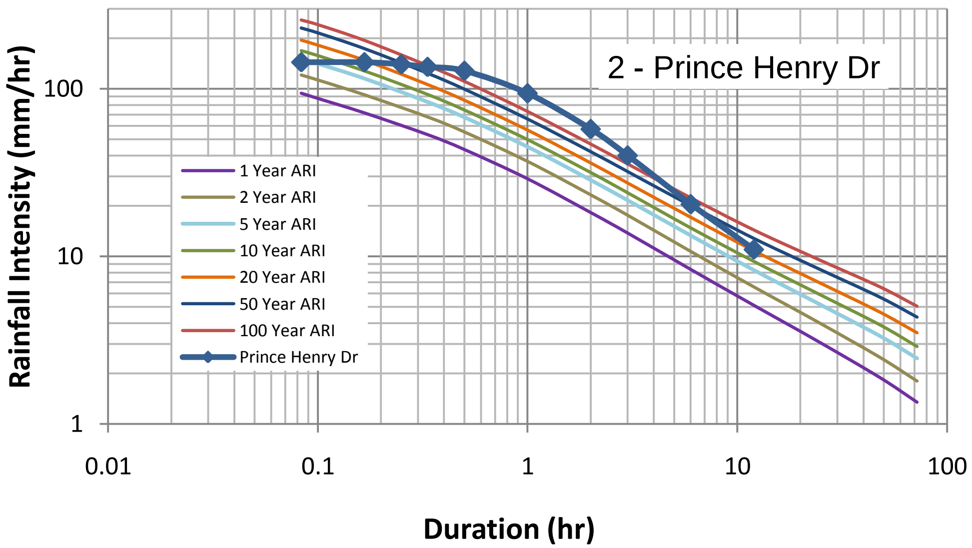
APPENDIX B

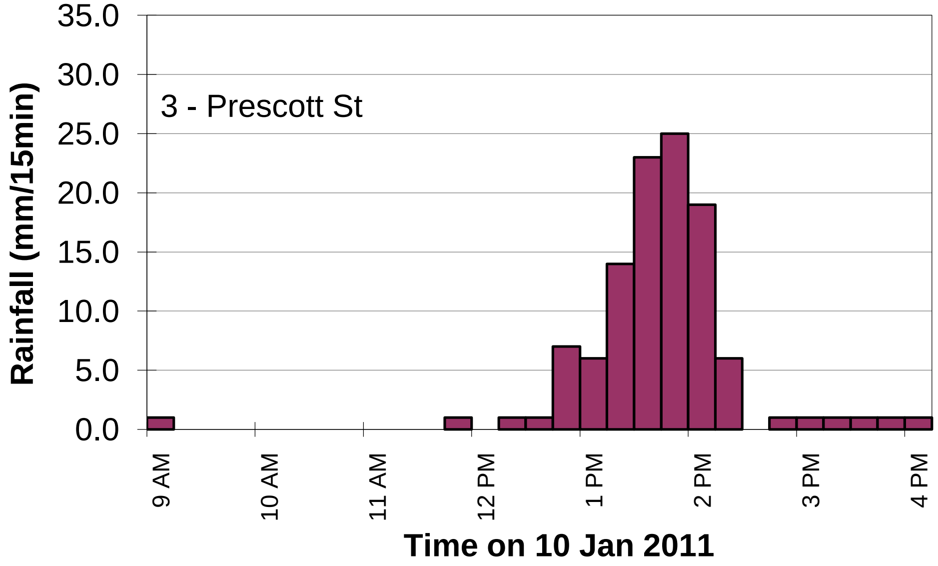
RAINFALL HYETOGRAPHS AND INTENSITIES

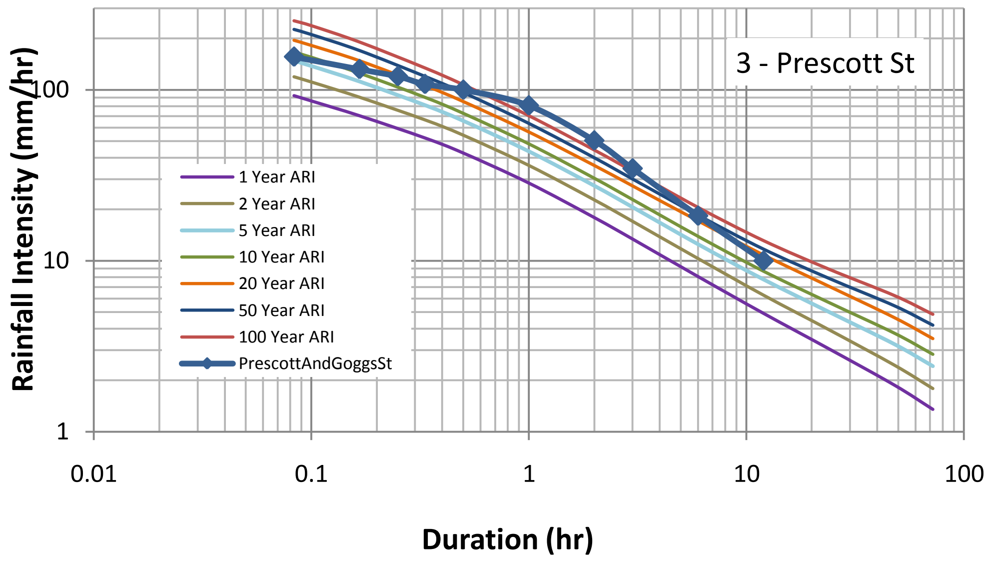

1 - Wetalla
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

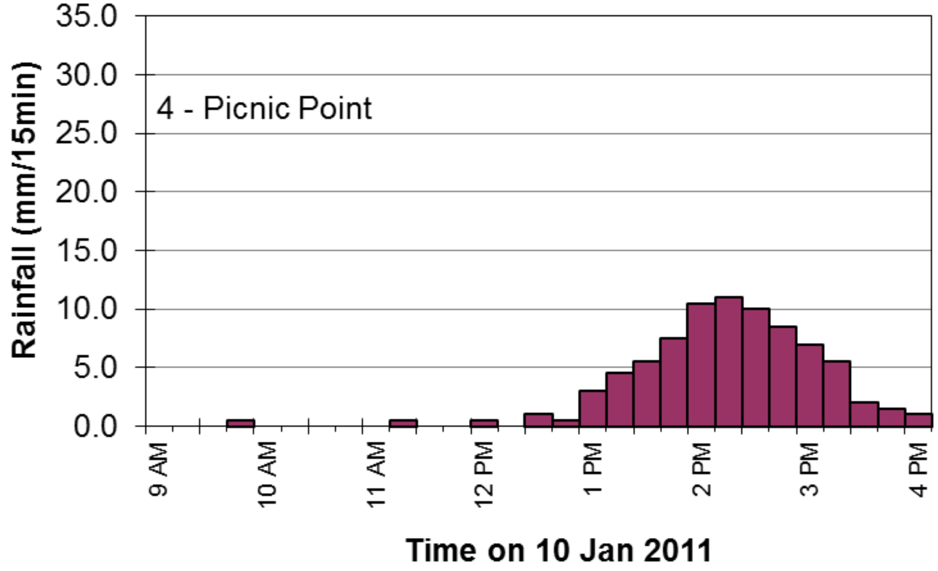

1-Wetalla
Rainfall Intensity (mm/hr)
1000
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Wetalla

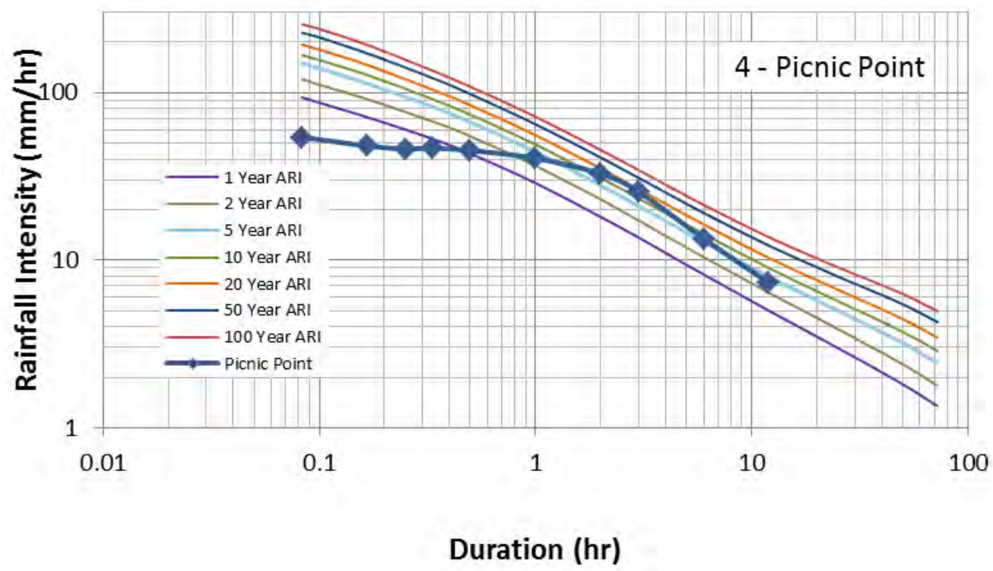

2 - Prince Henry Dr
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

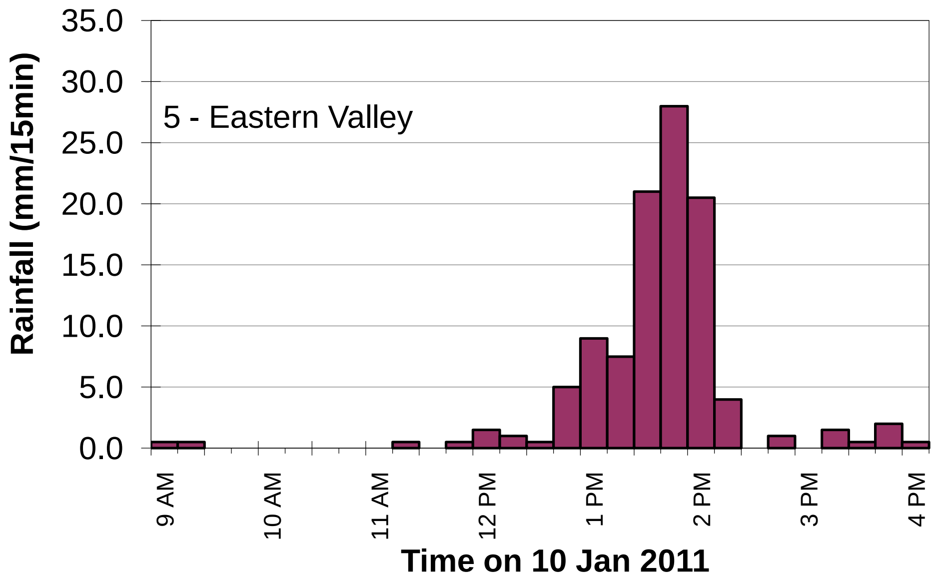

2 - Prince Henry Dr
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Prince Henry Dr

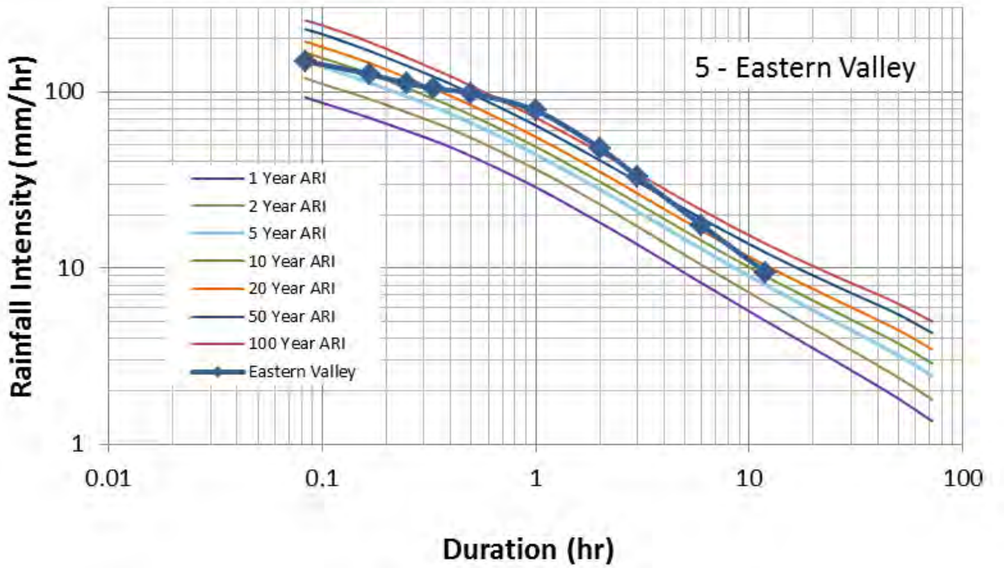

3 - Prescott St
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

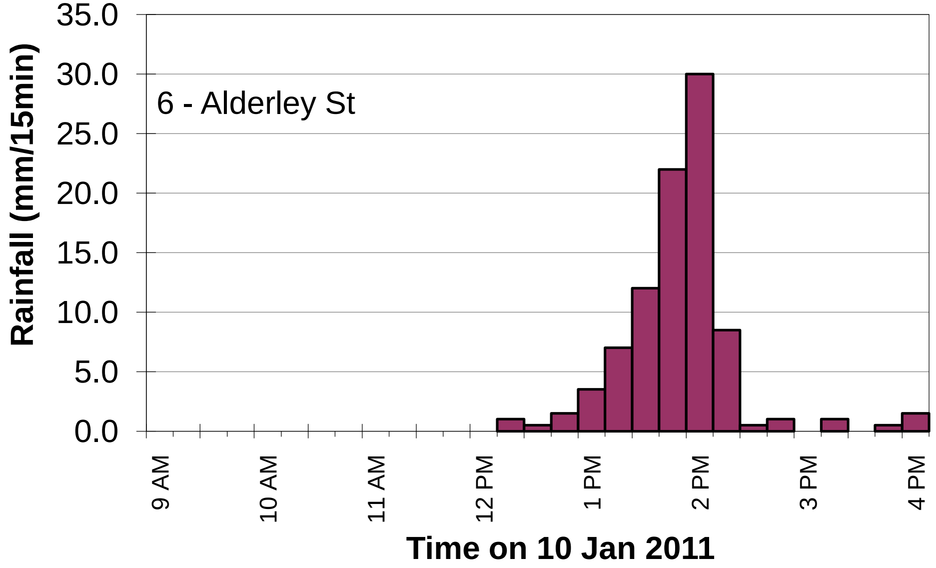

3 - Prescott St
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
PrescottAndGoggsSt

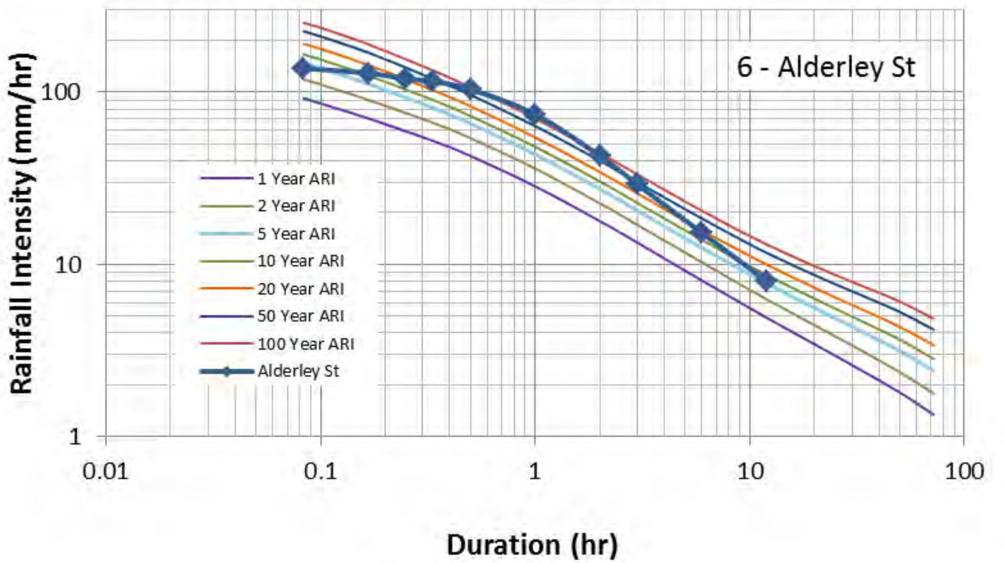

4 - Picnic Point
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

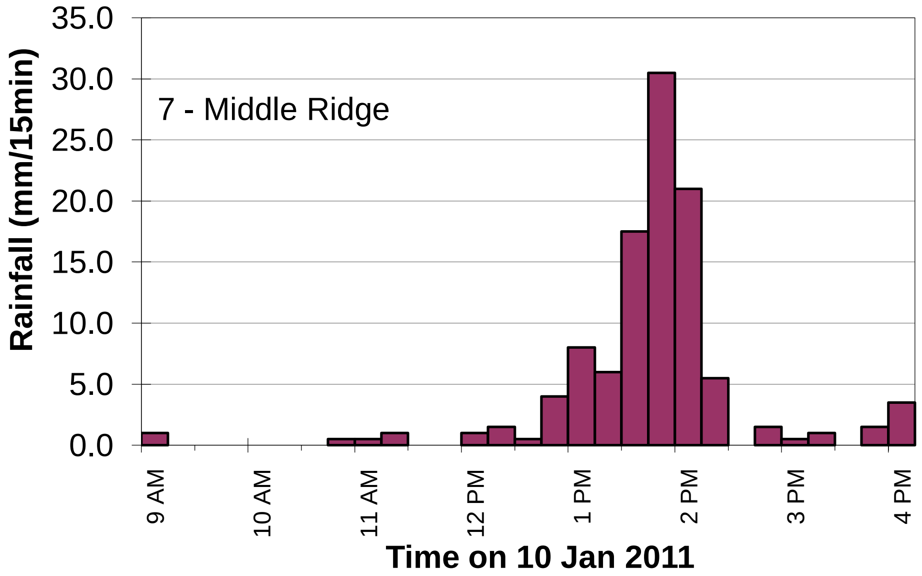

4 - Picnic Point
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Picnic Point

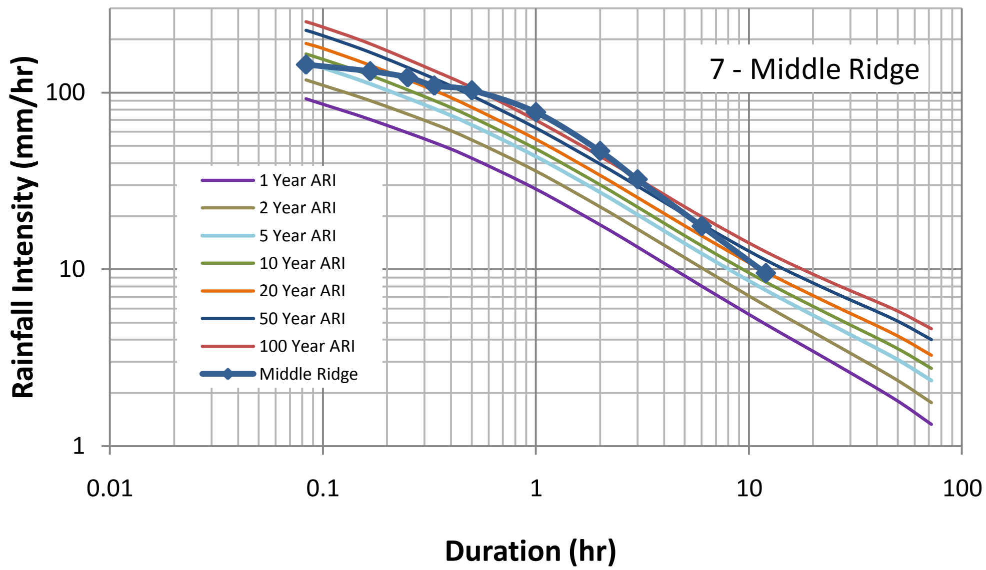

5 - Eastern Valley
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

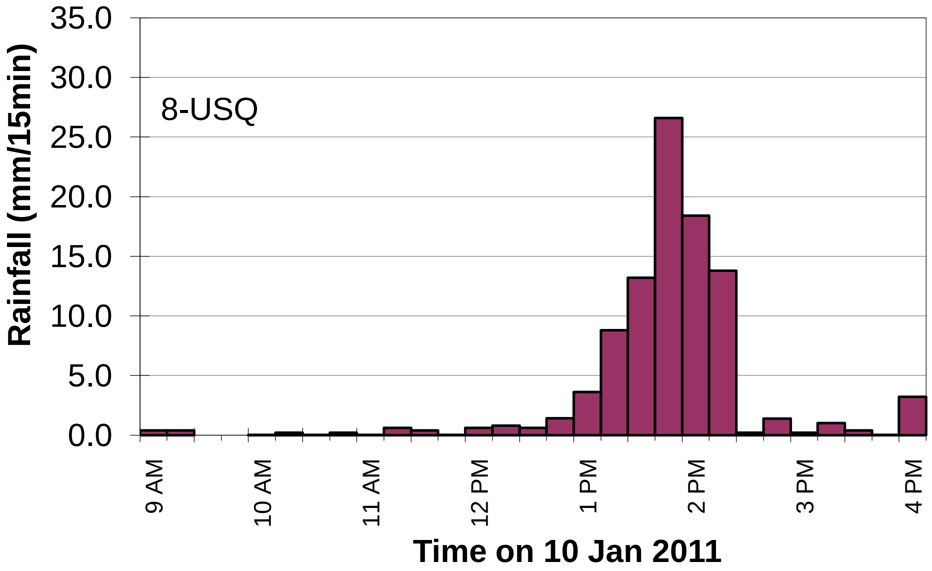

5 - Eastern Valley
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Eastern Valley

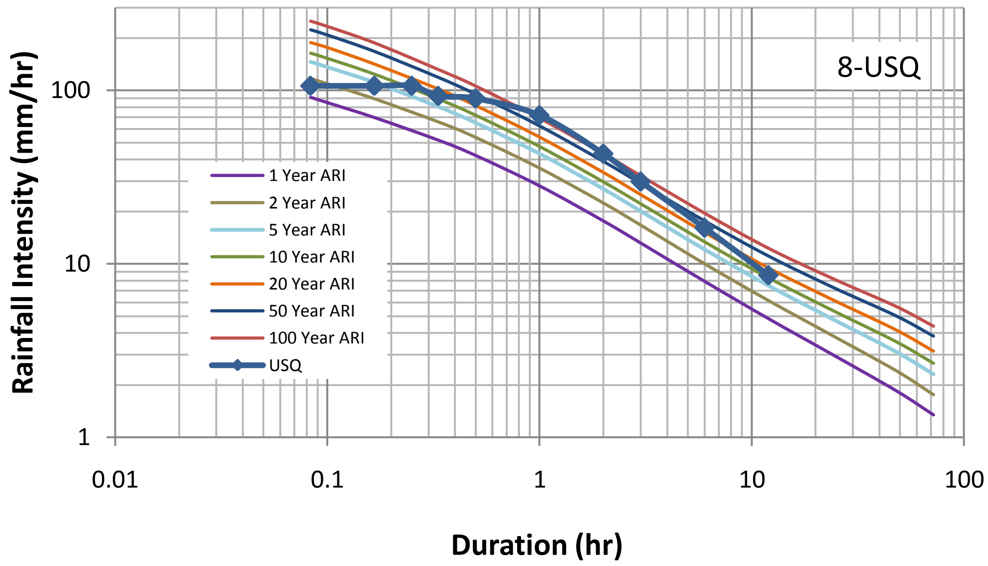

6 - Alderley St
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

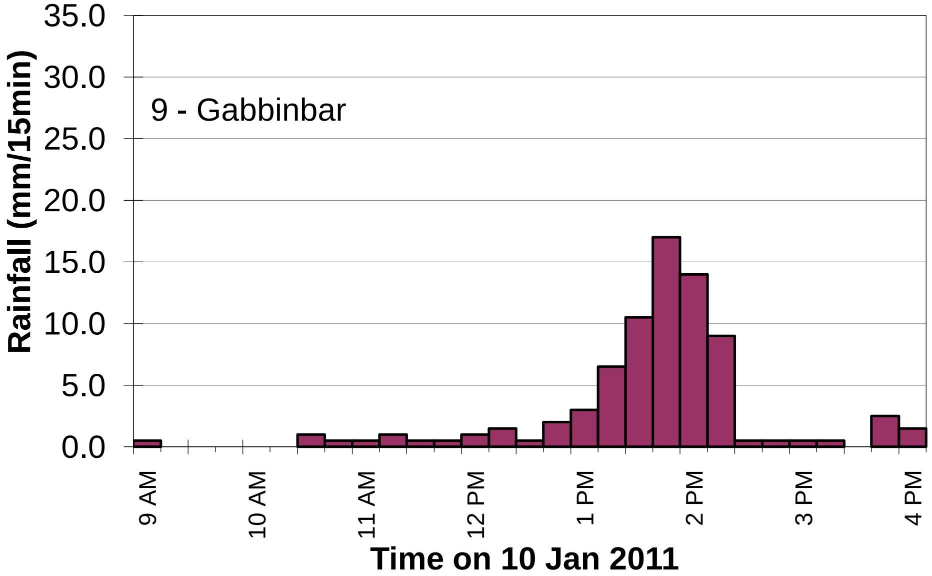

6 - Alderley St
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Alderley St

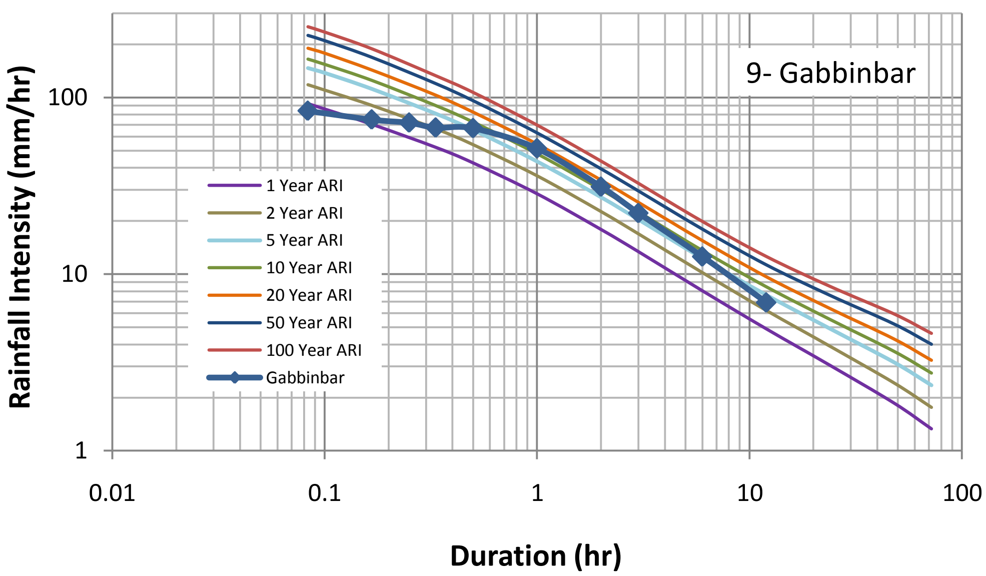

7 - Middle Ridge
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011


7 - Middle Ridge
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Middle Ridge
Duration (hr)


8-USQ
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011

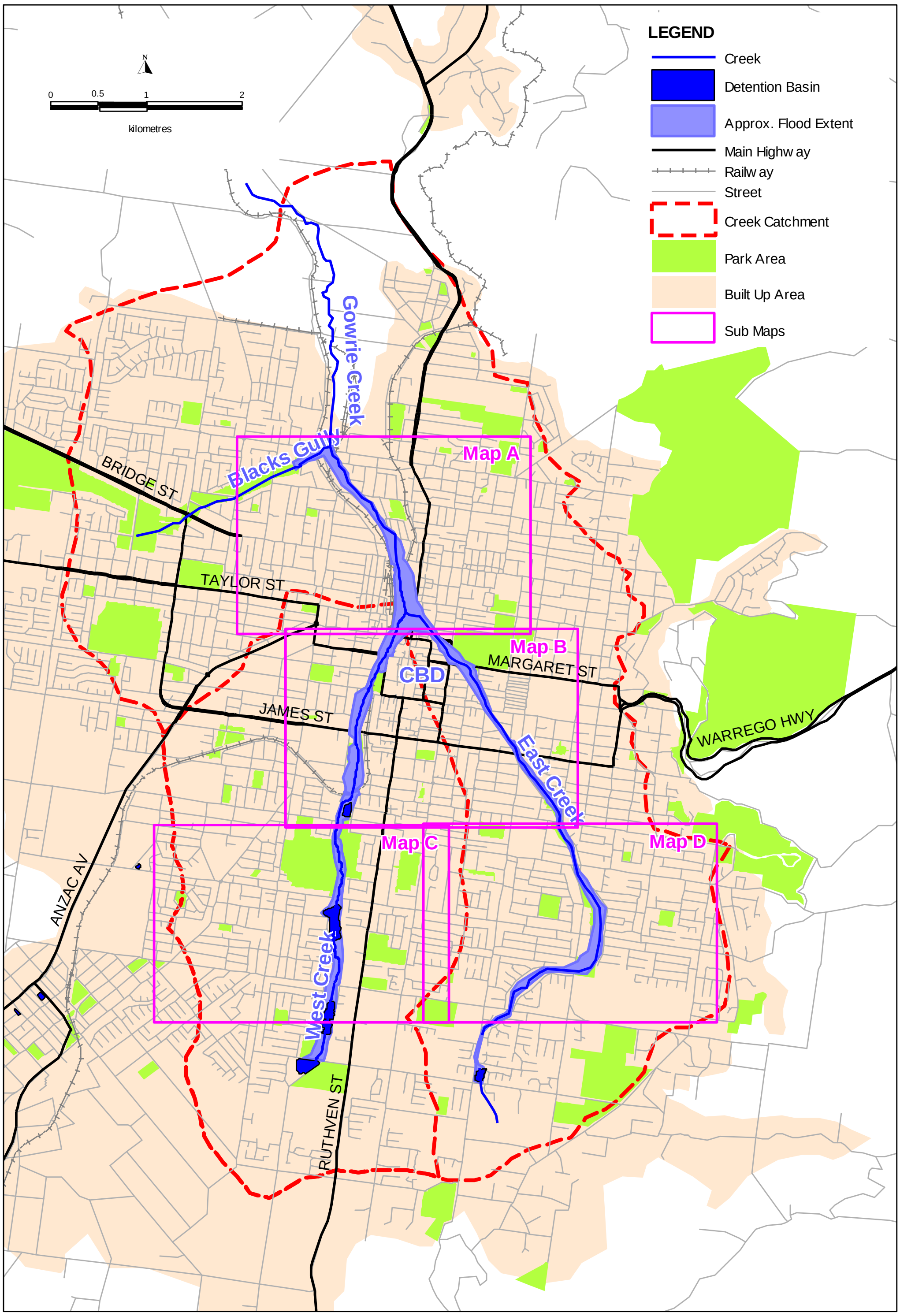

8-USQ
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
USQ
Duration (hr)


9 - Gabbinbar
Rainfall (mm/15min)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
Time on 10 Jan 2011


9- Gabbinbar
Rainfall Intensity (mm/hr)
100
10
1
0.01
0.1
1
10
100
Duration (hr)
1 Year ARI
2 Year ARI
5 Year ARI
10 Year ARI
20 Year ARI
50 Year ARI
100 Year ARI
Gabbinbar

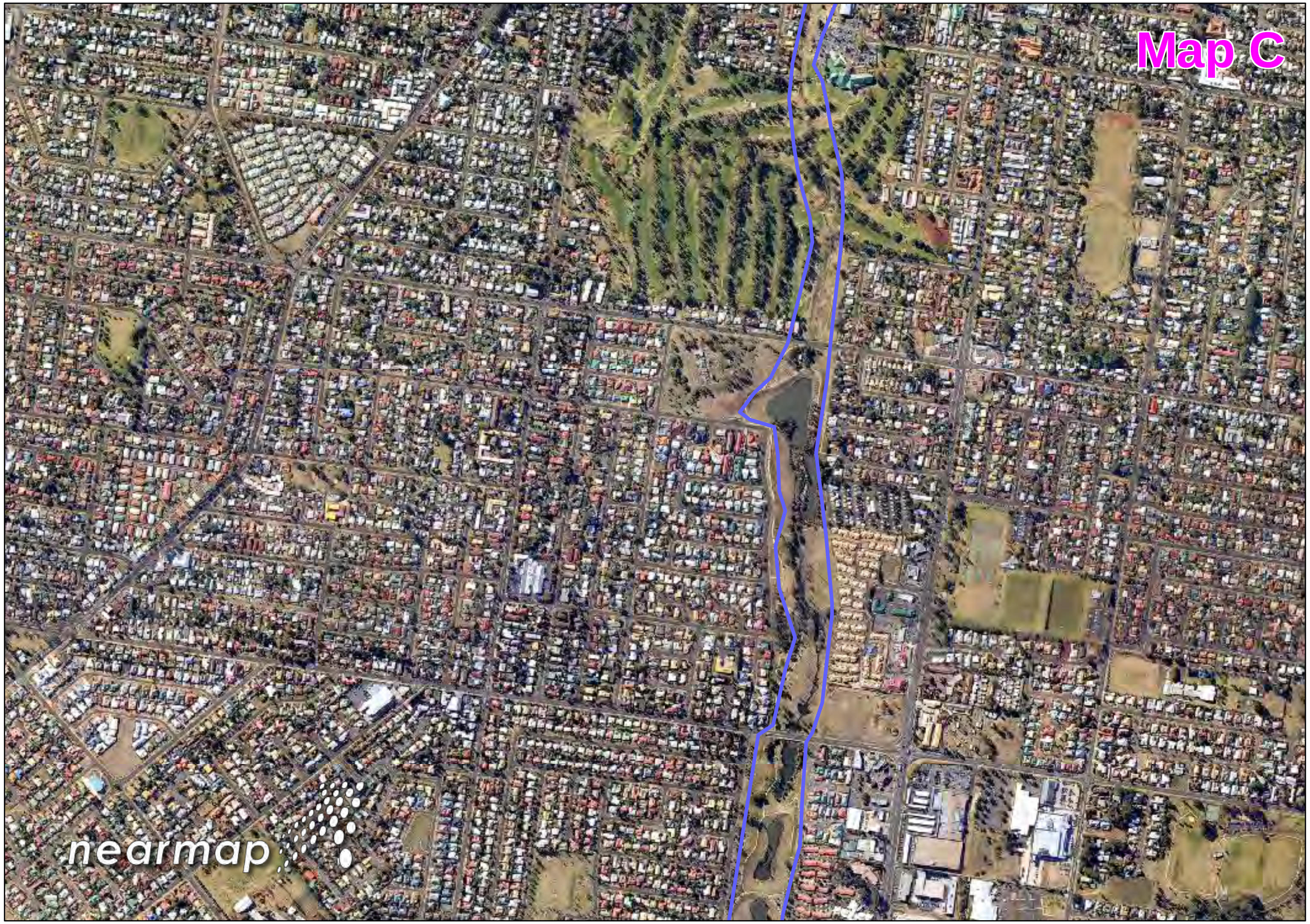
APPENDIX C

EXTENT OF INUNDATION MAPS


LEGEND
Creek
Detention Basin
Approx. Flood Extent
Main Highw ay
Railw ay
Street
Creek Catchment
Park Area
Built Up Area
Sub Maps
0
0.5
1
2
kilometres
N
Gowrie Creek
Blacks Gully
Map A
BRIDGE ST
TAYLOR ST
Map B
CBD
MARGARET ST
JAMES ST
East Creek
WARREGO HWY
ANZAC AV
Map C
Map D
West Creek
RUTHVEN ST


Map A
nearmap


Map B
nearmap


Map C
nearmap


Map D
nearmap

APPENDIX D

PHOTOGRAPHS

Photo No. 1 *East Creek at Spring St Looking Upstream: Debris Indicates Depth of Flow Over Road*

Photo No.2 *East Creek at Spring St Looking Downstream: Bank Erosion Along Grassed Waterway*

Photo No. 3 East Creek at Bowen St (US from Junction with West Creek): Depth of Flooding Over Road

Photo No. 4 East Creek Looking US at Neil St Culverts: Grassed Waterway with Concrete Low Flow Channel, Erosion on RH Bank, Depth of Flooding 1.5-2 m above Neil St

Photo No. 5 East Creek Outlet Under Ruthven St: Note Flood Debris on Fence; Floodwaters were some 2m Above Deck Level

Photo No. 6 West Creek at Spring St, Looking Upstream: Spring St overtopped by 0.5-1 m, Erosion on RH Bank Caused by Floodwaters Overtopping Road

Photo No. 7 West Creek at Spring St Looking Downstream: Grassed Waterway with Concrete Low Flow Channel.

Photo No. 8 West Creek at James St Looking Downstream into James St Detention Basin: Outlet Works Under James St Destroyed.

Photo No. 9 Looking North Along Railway Line Opposite Dent St (LHS), Russell St Crossing in Background: Northward Flowing Floodwaters from Dent St Flowed Eastwards across Railway Embankment and Back into West Creek (RHS Out of View)

Photo No. 10 Looking South Along Railway Line Opposite Dent St, West Creek to LHS: Easterly Flowing Floodwaters that Overtopped the Embankment Destroyed Fence When Returning to West Creek

Photo No. 11 West Creek North of Russell St, Looking Downstream (Flour Mills in Background): Extensive Inundation Along Russel St.

Photo No. 12 Gowrie Creek at Junction of East and West Creeks From East Creek Waterway Crossing: Floodwaters 2 m Above Deck Level

Photo No. 13 Disused Bridge Immediately DS of Junction of East and West Creeks (Flour Mill in Background): Floodwaters 1.5-2 m Above Deck Level of Bridge, Flood Debris Readily Apparent in Creek.