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FLOODING IN LOCKYER VALLEY REGIONAL COUNCIL LGA

ICA HYDROLOGY PANEL

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Water Matters International

SUMMARY OF FINDINGS

Flooding behaviour in the Brisbane River catchment has been discussed in some detail in a previous report, including an overview of flooding in Lockyer Creek and its tributaries (ICA, 2011b). This report presents additional details of flooding in the local government area (LGA) of Lockyer Valley Regional Council (RC), which includes most of Lockyer Creek catchment upstream of Lockrose.

Three distinct flooding episodes occurred in Lockyer Valley RC LGA over the period Sunday-Thursday 9-13 January 2011.

- The first episode occurred over the night of Sunday 9 January and the early morning of Monday 10 January. This was a 'normal', as characterized by 'normal' peak flood levels and rates of water level rise and fall on the rising and recession limbs. This flood was caused by widespread rainfalls and occurred in most tributaries of Lockyer Creek and the Creek itself. This first flood event was 'minor' in nature and did not cause any flooding of substance.
- The second episode occurred on the afternoon of Monday 10 January and was manifest as a flash flood generated in the upper tributaries of Lockyer Creek by intense rainfalls. This flood was manifest as an abrupt flood 'spike', characterized by high rates of water level rise, high flood depths and high (destructive) water velocities.
- The third flood episode occurred over the morning, afternoon and evening of Tuesday 11 January. Again, this was a 'normal' flood that like its 'normal predecessor, was caused by widespread rainfalls and occurred in most tributaries of Lockyer Creek and in the Creek itself.

Over the period 9-13 January, the following daily rainfall behaviour (daily rainfalls to 0900 hours on the indicated day) was recorded across the Lockyer Valley RC LGA:

- There was little rainfall across the catchment in the 24-hour period ending at 0900 hours on Sunday 9 January.
- There were falls of 50–130 mm across the catchment in the 24-hour period ending at 0900 hours on Monday 10 January. The heavier falls were around the lower reaches of Lockyer Creek and to the north into the Brisbane River catchment draining to Wivenhoe Dam.
- The 24 hours to 0900 hours on Tuesday 11 January encompass the rains that produced the flash flood down Lockyer Creek on Monday afternoon 10 January. Daily totals are substantial, amounting to 160-180 mm, with highest falls in the eastern and southern areas of the catchment. These daily rainfall results *mask the flash flooding that occurred in Lockyer Creek* on the afternoon of Monday 10 January.
- Substantial falls occurred in the 24-hours to 0900 hours on Wednesday 12 January (125-150 mm). Again, the heaviest falls were limited to eastern areas of the catchment. Falls up to 75 mm occurred across the middle areas of the catchment.
- No falls of consequence occurred in the 24-hours to 0900 hours on Thursday 13 January.
- Rain of any consequence had ceased across the Lockyer Valley RC LGA by 1800 hours on Tuesday 11 January.

Many of the pluviographs in and around the upper tributaries of Lockyer Creek failed during the intense rainfall events of Monday afternoon. The pluviograph atop The Escarpment at Prince Henry Drive (SPS 42) provided a full record of rainfalls over the 24-hour period 0000-2400 hours on Monday night. Rainfall severities were equal to or greater than 100-Years ARI for rainfall events of 30-minutes to 3-hours duration. The highest severity was for the 1-hour event.

Another pluviograph atop The Escarpment, Toowoomba Alert (540 162), also provided a full complement of data. Severities here were considerably less. It is possible that rainfall severities at other locations within the upper catchment of the Lockyer Creek were higher than those recorded at the official rainfall recording stations. Based on available rainfall data and subsequent flooding behaviour, it is inferred that the greater severities of the Prince Henry Drive pluviograph were representative of rainfalls over the upper catchment areas of Murphys Creek, Rocky Creek and Monkey Waterholes Creek. From these catchments, rainfall severities declined in an easterly and southeasterly direction.

These rainfalls generated flash floods in Murphys Creek, Rocky Creek, Monkey Waterholes Creek and the upper and middle reaches of Lockyer Creek itself. In addition to the intense rainfalls, the following factors exacerbated flash flooding behaviour:

- The wet antecedent conditions and the steep nature of the upper catchments and waterways of Murphys Creek, Rocky Creek and Monkey Waterholes Creek. This maximized the immediacy, volume and speed of surface runoff.
- The response times of these small catchments are about 1-2 hours, which corresponds to the rainfall durations of maximum severity recorded at Prince Henry Drive.
- The drainage network itself, which resulted in the flash flood travelling down Rocky Creek debouching into Lockyer Creek immediately upstream of Helidon, and the flash flood in Monkey Waterholes Creek doing the same immediately downstream of Helidon. These tributary flash floods reinforced and amplified the flash flood travelling down Lockyer Creek. The flash flood in Lockyer Creek reached its greatest size immediately downstream of the confluence of Lockyer Creek and Monkey Waterholes Creek. The following Table provides approximate[1] estimates of the peak discharge at various locations along the Murphys Creek-Lockyer Creek system. The peak flows at Monkey Waterholes Creek and Grantham are seen to be very high, when it is recalled that the peak releases from Wivenhoe Dam that caused the dam release flood in the Brisbane River were about 7,500 m^3/s (ICA, 2011b).

Estimated Peak Flash Flood Discharges of Lockyer Creek and Tributaries, 10 January 2011

Location	Waterway	Streamgauge No.	AMTD (km)	Catchment Area (km^2)	Estimated Peak Discharge (m^3/s)
Spring Bluff	Murphys Creek	143 219A	130	18	350
Murphys Creek Township	Murphys Creek	-	-	-	1,000-1,500
Helidon	Lockyer Creek	540 143	99	350	3,500-4,000
D/S Monkey Waterholes Crk	Lockyer Creek	-	95	~ 420	4,000-4,500
Grantham	Lockyer Creek	-	85	-	3,500-4,000
Gatton	Lockyer Creek	540 156	72	1,550	2,500-3,000
Glenore Grove	Lockyer Creek	540 149	52	2,230	2,500-3,000

On Monday afternoon 10 January, after building to its maximum size at the outlet of Monkey Waterholes Creek, storage routing effects then attenuated the flash flood as it surged downstream onto Grantham. However, any attenuation was inconsequential, as witnessed by the devastation and loss of 13 lives wrought in Grantham. After passing Monkey Waterholes Creek, there were no tributary inflows of consequence to Lockyer Creek as the flash flood travelled downstream to the Brisbane River. By the time the flood arrived at Gatton, significant attenuation had occurred, the locals referring to a ‘normal’ flood. Further attenuation had occurred by the time the flood reached Glenore Grove: the flash flood had lost its sting, the

[1] These discharges have been inferred on the basis of discharges estimated from DERM rating curves at Spring Bluff and Helidon and from simple field appraisals. The use of hydrologic models is required to provide more reliable estimates, an exercise beyond the scope of this investigation.

steep rising limb was still apparent, but the peak had become rounded and flattened, and it can be classified as a ‘normal flood’.

The flash flood caused hazardous conditions close to the waterways it travelled down, characterized by deep flows, high (destructive) velocities and rapid rates of water level rise. Buildings adjacent to waterways were swept away in Murphys Creek township, Postmans Ridge and at other locations. Conditions were especially hazardous at Grantham because of the number of dwellings on the floodplain. Water depths of 2.0-2.5 m over the floodplain were realized in perhaps 10-15 minutes; velocities are expected to have been 2-3 m/s.. Nearly every house on the floodplain area of Grantham suffered major damage from inundation and water velocity. A number of houses were washed off their stumps; some houses were totally destroyed; many were rendered uninhabitable.

The flood of Monday afternoon was experienced as a flash flood at Spring Bluff, Murphys Creek township, Withcott, Postmans Ridge, Helidon, possibly Carpendale (on the lower reaches of Flagstone Creek) and at Grantham. However, by the time the flood had reached Gatton, it had attenuated into a more ‘normal’ flood and as such, made its way down Lockyer Creek to the Brisbane River.

After the flash flood behaviour of Monday afternoon, the flood of Tuesday morning, afternoon and evening was a more sedate nature characteristic of a ‘normal’ flood. Tenthill Creek reportedly didn’t break its banks, but significant flooding occurred in Sandy Creek around Forest Hills and in Laidley Creek around Laidley.

Water level behaviour at the Glenore Grove streamgauging station on Lockyer Creek (52 km from the mouth of the creek) was not affected by backwater effects associated with releases from Wivenhoe Dam over the period 0600 hours on Tuesday 11 January to 0300 hours on Wednesday 12 January (see ICA, 2011b, for details of releases from Wivenhoe Dam, the resulting dam release flood wave, and associated backwater effects along Lockyer Creek and the Bremer River). However, backwater effects are perhaps discernible at Lyons Bridge streamgauging station (29 km from the mouth of Lockyer Creek). Water level behaviour along the residual reach of Lockyer Creek downstream of Glenore Grove but within Lockyer Valley RC LGA may have been influenced by backwater effects from the Brisbane River, but these effects were minor.

The following factors influenced flooding behaviour in Lockyer Valley RC LGA on 10-11 January 2011:

- The intense and severe rainfalls that are inferred to have occurred over the upper tributaries of Lockyer Creek, especially Murphys Creek, Rocky Creek and Monkey Waterholes Creek.
- The soil of these catchments was saturated from previous rainfall, especially over Sunday night 9 January. Given the saturated antecedent catchment conditions, the extreme rainfall intensities and the relatively steep nature of the catchments of upper Lockyer Creek tributaries, flash flood events were generated in Murphys Creek, Rocky Creek and Monkey Waterholes Creek.
- As these flash floods pummelled their way downstream as abrupt, rapidly moving flood ‘spikes’, they grew along the way as increasing upstream catchment areas contributed their runoff. Immediately upstream of Helidon, Rocky Creek delivered its flash flood flows to Lockyer Creek, amplifying water levels and discharges as the Lockyer Creek flash flood passed through. Immediately downstream of Helidon, Monkey Waterholes Creek also delivered its flash flows to Lockyer Creek, again reinforcing and amplifying flash flood flows in Lockyer Creek.
- As the flash flood wave travelled downstream along Lockyer Creek from the Monkey Waterholes Creek confluence, it will have begun to attenuate due to storage routing effects along the way. However, any attenuation was inconsequential by the time the floodwave reached Grantham (9 km downstream), as evidenced by the destruction of

property and infrastructure and the loss of 13 lives there. In contrast, significant attenuation had occurred by the time the floodwave reached Gatton, a further 15 km downstream, where its nature was more 'normal' with regard to peak water levels and the rates of water level rise and fall on the rising and recession limbs.

- During the Monday afternoon flash flood event, any inflows from the northerly draining tributaries of Lockyer Creek (Flagstone, Ma Ma, Tenthill and Laidley Creeks) were small and played no significant role in flood behaviour as the flash flood wave travelled downstream. However, inflows may have prolonged the subsequent recession.
- Flooding in Grantham was especially hazardous because of the combined depth and velocity of floodwaters across the floodplain, the rate of rise and the population at risk. Floodwaters were some 2.0-2.5 m deep across the northern floodplain with a maximum velocity of perhaps 2-3 m/s, and probably higher at some locations through the town. The rate of rise was inferred to be some 12 m/hour, indicating that it would have taken only 10-15 minutes to rise to full depth.
- Flooding was especially hazardous adjacent to waterways experiencing flash flooding because of high water depths and velocities (perhaps to 3-4 m/s). Houses built adjacent to waterways were washed away in Murphys Creek township, Postmans Ridge and possibly elsewhere. Nearly every house in the 'southern development' area of Grantham sustained structural damage caused by the velocity of the floodwaters. Some were washed off their stumps and completely destroyed. Others were rendered uninhabitable.

The following Table summarizes flooding behaviour at specific locations of interest in Lockyer Valley RC LGA on Monday 10 and Tuesday 11 January 2011.

Summary of Flooding Behaviour, Lockyer Valley RC LGA

Location	Waterway	Site Visit	Nature of Flooding	Date of Flooding	Onset of Flooding	Time of Peak Flood Level	End of Effective Rain	Overland Flow Inundation
Spring Bluff	Murphys Creek	No	Flash Flood	Monday 10 Jan	1220 hours	1340 hours	1400[a] hours	Possible
Murphys Creek Township	Murphys Creek	Yes	Flash Flooding	Monday 10 Jan			1400[a] hours	Possible
Withcott		No	Flash Flooding	Monday 10 Jan			1400[a] hours	Possible
Postmans Ridge	Rocky/Six Mile Creeks	Yes	Flash Flooding	Monday 10 Jan			1400[a] hours	Possible
Helidon	Lockyer Creek	Yes	Flash Flooding	Monday 10 Jan	1420 hours	1530[a] hours	1400 hours	Possible
Carpendale	Flagstone Creek	No	Backwater/Flash Flooding[2]	Monday/Tuesday 10-11 Jan			1600[a] hours	No[3]
Grantham	Lockyer Creek	Yes	Flash Flooding	Monday 10 Jan	1500-1530[a] hours		1600 hours	No
Gatton	Lockyer Creek	Yes	Normal Flooding[4]	Monday/Tuesday 10-11 Jan	1630 hours (Monday)	0430 hours (Tuesday)	1600 hours (Tuesday)	No.
Laidley	Laidley Creek	Yes	Normal Flooding	Tuesday 11 Jan	0600[a] hours		1400 hours	Possible
Forest Hill	Sandy Creek (S)	Yes	Normal Flooding	Tuesday 11 Jan	0200[a] hours		1600 hours	Possible
Glenore Grove	Lockyer Creek	No	Normal Flooding	Tuesday 11 Jan	1900[a] hours (Monday)	1700 hours	1400 hours	Possible
Lyons Bridge	Lockyer Creek	Yes	Normal Flooding[5]	Tuesday 11 Jan	2100[a] hours (Monday)	1800 hours	1500 hours	Possible
Rocky Creek and Tribs	-	Yes	Flash Flooding	Monday 10 Jan				Possible
Monkey Waterholes Crk	-	No	Flash Flooding	Monday 10 Jan				Possible
Flagstone Creek	-	No	Normal Flooding	Tuesday 11 Jan				Possible
Ma Ma Creek	-	No	Normal Flooding	Tuesday 11 Jan				Possible
Tentthill Creek	-	No	Normal Flooding	Tuesday 11 Jan				Possible
Sandy Creek (S)	-	No	Normal Flooding	Tuesday 11 Jan				Possible
Laidley Creek	-	No	Normal Flooding	Tuesday 11 Jan				Possible

[a] Inferred/estimated

[2] If flooding in Carpendale occurred on Monday afternoon 10 January, it will have been caused by backwater flooding upstream along Flagstone Creek as the flash flood passed down Lockyer Creek. If flooding in Carpendale occurred on Tuesday 11 January, it will have been caused by a 'normal' flood in Flagstone Creek.

[3] Overland flow inundation is most unlikely to have occurred if flooding in carpendale occurred on Monday afternoon 10 January.

[4] The streamgauge at Gatton failed on the rising limb of the flash flood. It is not known whether the Tuesday flood at Gatton was higher than the Monday flood.

[5] Water level behaviour at Lyons Bridge displays some evidence of backwater effects from the Brisbane River.

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LIST OF ABBREVIATIONS

AHD	Australian height datum
AMTD	Adopted Middle Thread Distance
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).
RC	Regional Council
ICA	Insurance Council of Australia.
LGA	Local Government Area.

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 LOCKYER VALLEY REGIONAL COUNCIL LGA

This report describes the nature and causes of flooding that occurred in the Lockyer Valley Regional Council (RC) Local Government Area (LGA) on the afternoon of Monday 10 January and Tuesday 11 January 2011. The most devastating flooding was caused by a flash flood passing down the upper and middle reaches of Lockyer Creek and its tributaries. The lower reaches of Lockyer Creek were subject to backwater flooding by releases from Wivenhoe Dam. Lesser, but still significant, 'normal' flooding occurred along Laidley Creek and more southern and westerly creek systems.

An overview of flooding in the Lockyer Creek catchment is provided in an earlier Report (ICA, 2011b), which should be read in conjunction with this report.

Exceptionally intense, short-duration rainfalls (1-2 hours) over the upper catchment of Lockyer Creek and the catchments of its upper tributaries generated an unprecedented high velocity floodwave that rapidly swept down Lockyer Creek, imperilling people and causing massive damage to public and private property and infrastructure. This Lockyer Creek flood event on Monday 10 January took 20 lives: townships where lives were lost were Spring bluff (2), Murphys Creek (2), Postmans Ridge (2), Helidon (1) and Grantham (13). Forest Hill and Laidley suffered significant 'normal' flooding on Tuesday 11 January. A number of other towns in the

Lockyer Valley RC LGA suffered lesser flooding over the period 10-11 January. These towns include Withcott (Monday afternoon), Carpendale[6] and Gatton (Tuesday).

1.3 REPORT STRUCTURE

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 Lockyer Valley RC LGA affected by flooding;
- Section 6 provides a 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 Lockyer Valley RC LGA on 9-13 January 2011;
- Section 10 is a summary of the nature and causes of flooding in Lockyer Valley RC LGA; 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 consists of a series of photographs of the flooded areas and waterways.

1.4 ACKNOWLEDGEMENTS AND DISCLAIMERS

Lockyer Valley Regional Council made available to the Panel information on the depth of flooding at various locations throughout the LGA. This information was provided in the form of GPS coordinates of each point, along with the depth of flooding at that point. This information proved unsuitable for estimating the extent and depth of flooding, as was done in earlier Reports (ICA, 2011a; ICA, 2011c; and ICA, 2011d). However, the information was used to gain a better understanding of flooding behaviour at Grantham. The Panel gratefully acknowledges receipt of these data.

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 Worley Parsons, WRM Water and Environment Pty Ltd, and Water Matters International. Worley Parsons, WRM Water and Environment Pty Ltd, and Water Matters

[6] Hydrologists of the ICA Panel did not inspect Carpendale, for which we apologize. It is unclear whether flooding in Carpendale occurred on the Monday afternoon, and was associated with the flash flood down Lockyer Creek, or on the Tuesday, and was associated with a ‘normal’ flood event passing down Flagstone Creek.

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. Various cases of flooding in relation to ‘free flow’, ‘impeded flow’ and backflow’ in piped drainage systems are discussed later in this Section.

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.

'Normal' Floods

Floods that do not fall within the definition of flash floods, irrespective of its magnitude, are referred to as 'normal' floods ie. floods that are not 'sudden and unexpected' and are not characterized by an abrupt and rapid increase in water levels.

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.

Piped Drainage

'Piped drainage' refers to the system of inlet gully pits, sumps and pipes used to collect overland flow and convey it to nearby waterways. Piped drainage systems are common in urban areas. As far as piped drainage flow is concerned, three situations can be distinguished, as shown in Figure 2.1:

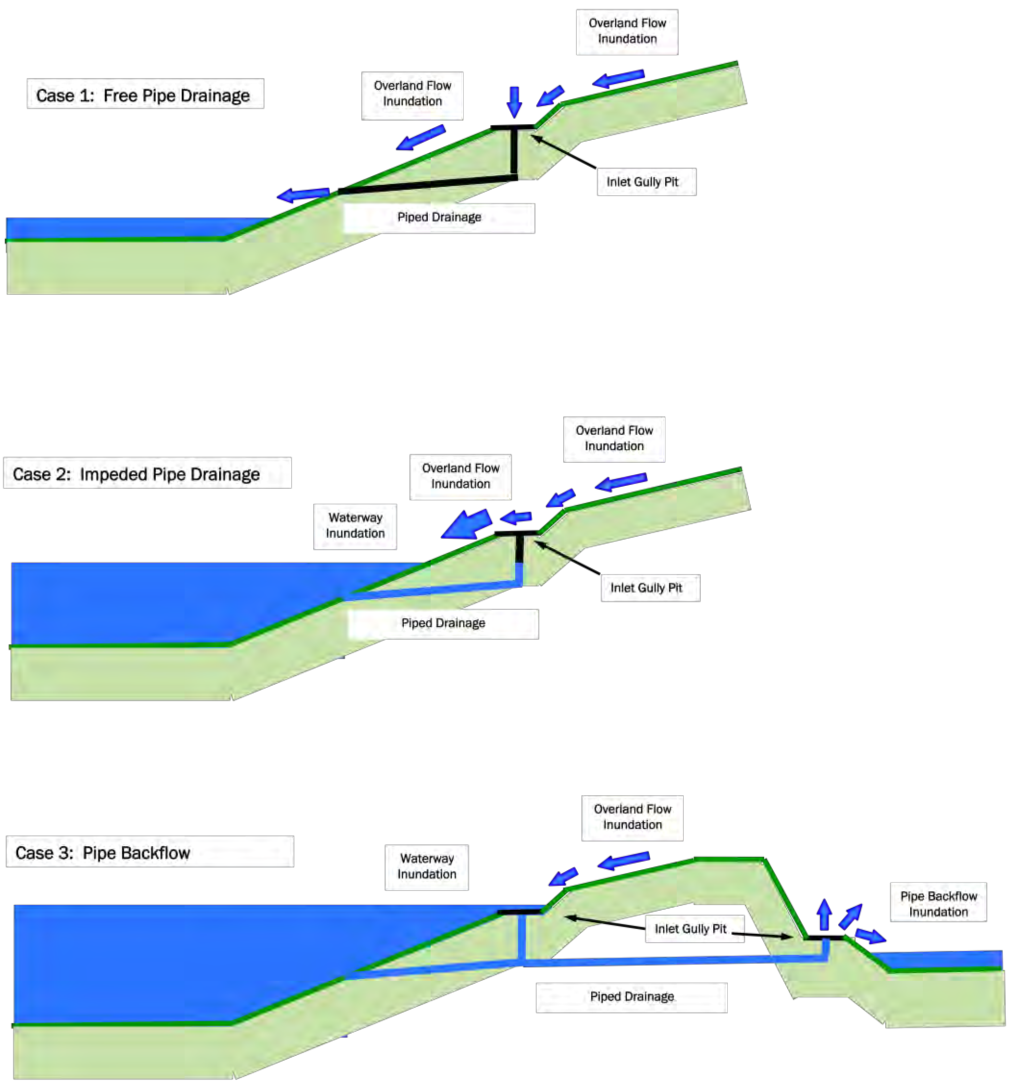

Figure 2.1 Piped Drainage Flow Situations

Free Pipe Drainage

Overland flows enter and drain freely through the piped drainage system, as shown in Case 1 of Figure 2.1. Water levels in the receiving waterway (tail water levels) are below the level of the outflow pipe and do not impede pipe outflows; inlet gullies do not become blocked during the storm event. If the overland flow rate exceeds the capacity of the piped drainage system to collect and discharge the water, inlet gullies will 'choke' and some 'upslope' overland flow will bypass the gully and continue to flow downslope as 'overland flow'. Overland flow inundation can occur both upslope and downslope of the inlet gully.

Impeded Pipe Drainage

Overland flow in the piped drainage system is impeded by high tailwater levels in the receiving waterway, or by blockages to inlet gullies or to the pipes themselves, commonly caused by debris (see Case 2 of Figure 2.1). In this situation outflows issuing from the piped drainage system are reduced and an increased volume of overland flow bypasses the inlet gullies. Again, overland flow inundation can occur both upslope and downslope of the inlet gully.

Pipe Backflow

In some situations, a low-lying area of land may be separated from a waterway by an intervening ridge of higher land (see Case 3 of Figure 2.1). If the tailwater level in the receiving waterway rises above the level of inlet gullies in the low area, backflow up the piped drainage system can occur, causing inlet gullies to discharge water onto the area they were constructed to drain. In these circumstances, pipe backflow inundation can occur in the low area and in contiguous downslope areas. If pipe backflow inundation occurs while rain is falling, inundation in the low area will be from a combination of waterway floodwaters entering the low area as pipe backflow and overland flow trying to enter the piped drainage system.

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 'Dam-*Related 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[7]

3.2 RAINFALL FLOODS

3.2.1 Catchment Response

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

[7] 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 generally occur within six hours of the onset of the flood-generating rainfalls (see Section 2). Flash floods are caused by intense rainfall, generally over small, steep catchment areas. When flash floods occur in the steep upper reaches of tributary catchments, the resulting flood wave is characterized by abrupt water level rises and high waterflows and velocities, leading to extremely hazardous conditions. In its behaviour, a flash flood is similar to a minor dam break flood (see below).

3.3 DAM-RELATED 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[8].

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.

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

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.

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.

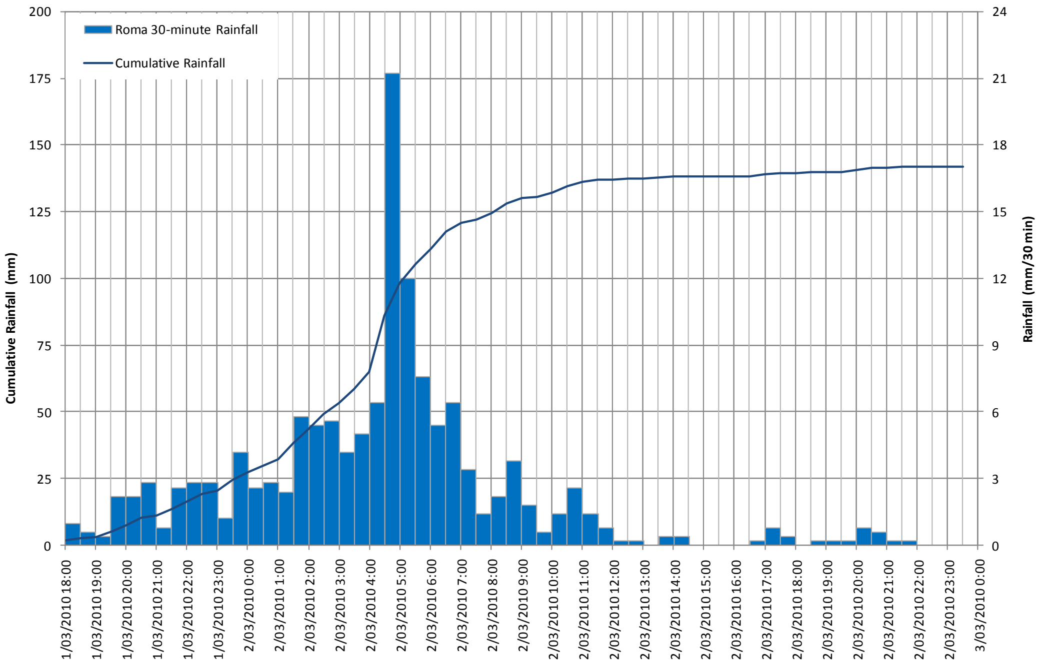

Figure 4.1 30-Minute Rainfalls at Roma Airport Station, 1 to 3 March 2010

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.

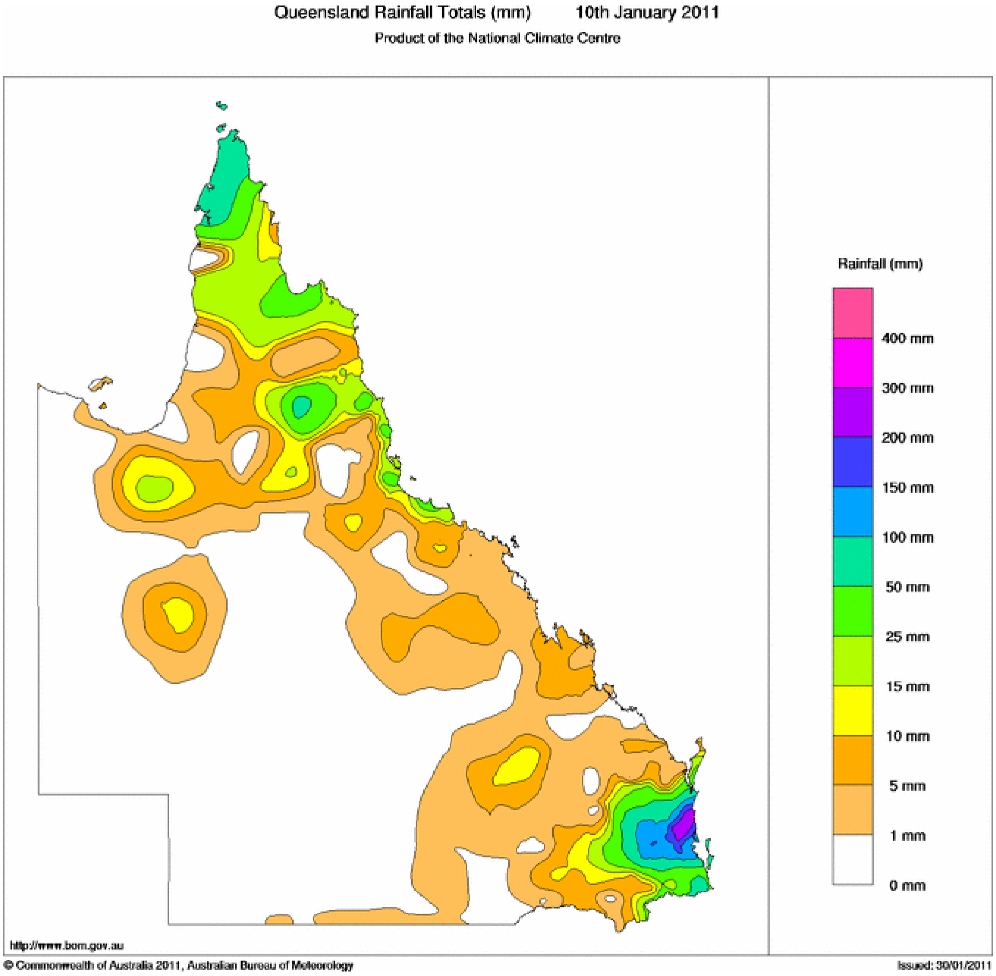

Figure 4.2 Rainfall Isohyets for Queensland on 10 January 2011

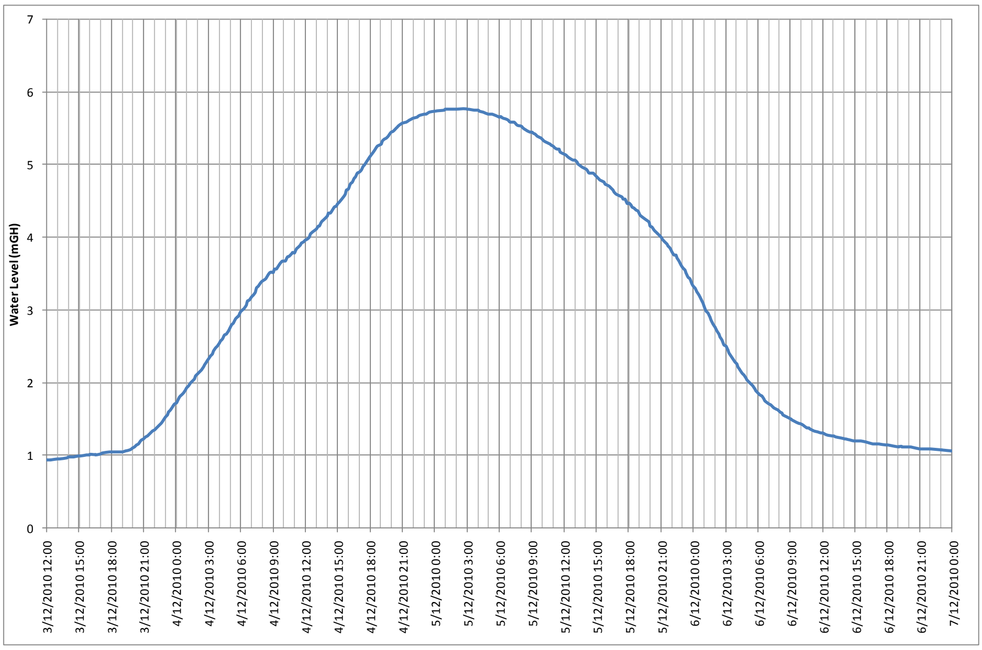

Figure 4.3 Stage Hydrograph, Bungil Creek at Tabers, 3 to 7 December 2010

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[9] – 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.

[9] 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.

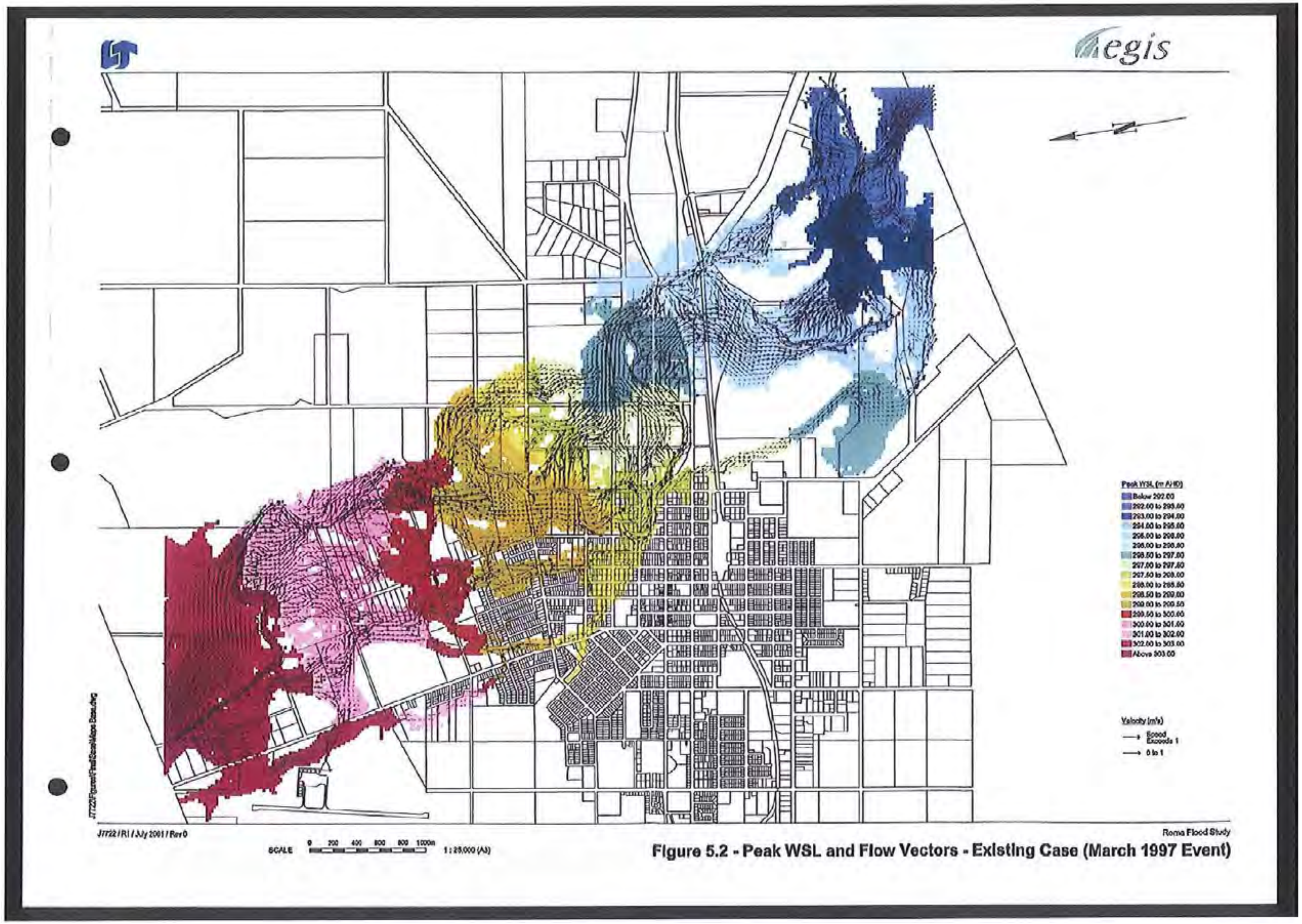

Figure 4.4 Extent of Flood Inundation, Roma Flood Event on 7 March 1997(Source: Egis, 2002)

5 CATCHMENT DESCRIPTION

5.1 DRAINAGE NETWORK

Figure 5.1 shows the drainage network of Lockyer Valley RC LGA, which essentially comprises Lockyer Creek and its tributaries. To the west, the catchment area of Lockyer Creek is bounded by 'The Escarpment' of the Great Dividing Range (elevation 600 m ASL), atop of which sits Toowoomba; to the south by the Little Liverpool Range; to the north by Mount Hallen; and to the east by the low area of intervening land separating the Lockyer Creek and Bremer River catchments.

Lockyer Creek flows in a generally easterly direction, entering the Brisbane River at Lowood. It is the largest tributary of the Brisbane River, having a catchment area of 2,600 km^2. Major southern tributaries include Flagstone Creek, Ma Ma Creek, Tenthill Creek and Laidley Creek. Important tributaries entering from the north include Murphys Creek, Fifteen Mile Creek and Alice Creek. Buaraba Creek, another tributary of Lockyer Creek, flows in a generally easterly direction before joining Lockyer Creek a short distance upstream from its confluence with the Brisbane River.

To the west and south, the upper areas of Lockyer Creek catchment are steep and mainly forested. The extensive lower floodplains are used intensively for agriculture, with a number of small population centres scatted across them. The intervening areas between the steep upper areas and the lower floodplain consist of rolling hills and are generally used for grazing.

5.1.1 Upper Lockyer Creek Catchment

Figure 5.2 shows details the drainage network of the upper catchment of Lockyer Creek. Rainfall generated over this area was responsible for the flash flood that tore down Lockyer Creek on the afternoon of Monday 10 January.

The upper tributaries of Lockyer Creek include Murphys Creek, Fifteen Mile Creek (including Paradise Creek) and Alice Creek. Murphys Creek rises at the base of The Escarpment, then flows north for some 5 km to around Spring Bluff, from where it flows eastwards for some 7 km to the township of Murphys Creek. These upper tributaries of Lockyer Creek meet some 5 km to the southeast of Murphys Creek township and some 7 km to the northwest of Helidon township to form Lockyer Creek proper. A series of easterly flowing creeks (Six Mile Creek, Little Oaky Creek and Gatton Creek) combine around the Postmans Ridge area to form Rocky Creek (catchment area 85 km^2), which enters Lockyer Creek some 2.5 km to the west and upstream of Helidon. Downstream of Helidon, another major easterly flowing creek, Monkey Waterholes Creek (catchment area 70 km^2), joins Lockyer Creek about 1 km to the south of the Warrego Highway.

Moving further downstream, a series of northerly flowing creeks enter Lockyer Creek. The creeks include Flagstone Creek (catchment area 174 km^2), Ma Ma Creek (catchment area 266 km^2) and Tenthill Creek (catchment area 466 km^2). It is noted that Flagstone Creek enters Lockyer Creek immediately upstream from Grantham (about 2.5 km) and that Ma Ma Creek enters Lockyer Creek immediately downstream of Grantham (about 2 km). The confluence of Tenthill Creek with Lockyer Creek is somewhat further downstream, but Tenthill Creek and Ma Ma Creek run down opposite sides of Back Flagstone Road, and in times of flood, it is expected that their floodwaters inundate the road, merge and flow downstream to Lockyer Creek as a broad, combined flow.

It is noted that Sandy Creek (N)[10] drains a small catchment (61 km^2) to the immediate north of Grantham, flowing in a southerly and easterly direction before passing under the railway bridge at Grantham and flowing south to join Lockyer Creek some 3 km to the south of the railway bridge.

5.2 IMPACT OF URBANIZATION

Urban areas within Lockyer valley LGA are limited to small, scattered townships. These areas will have no significant effect on flooding behaviour; however, many of these areas are exposed to the risk of flooding.

[10] There are two ‘Sandy Creeks’ in the Lockyer catchment, the northern tributary under discussion, which has been labelled ‘Sandy Creek (N)’, and the other, which forms a northward flowing tributary of Laidley Creek (see Figure 5.1) and which has been labelled ‘Sandy Creek (S)’.

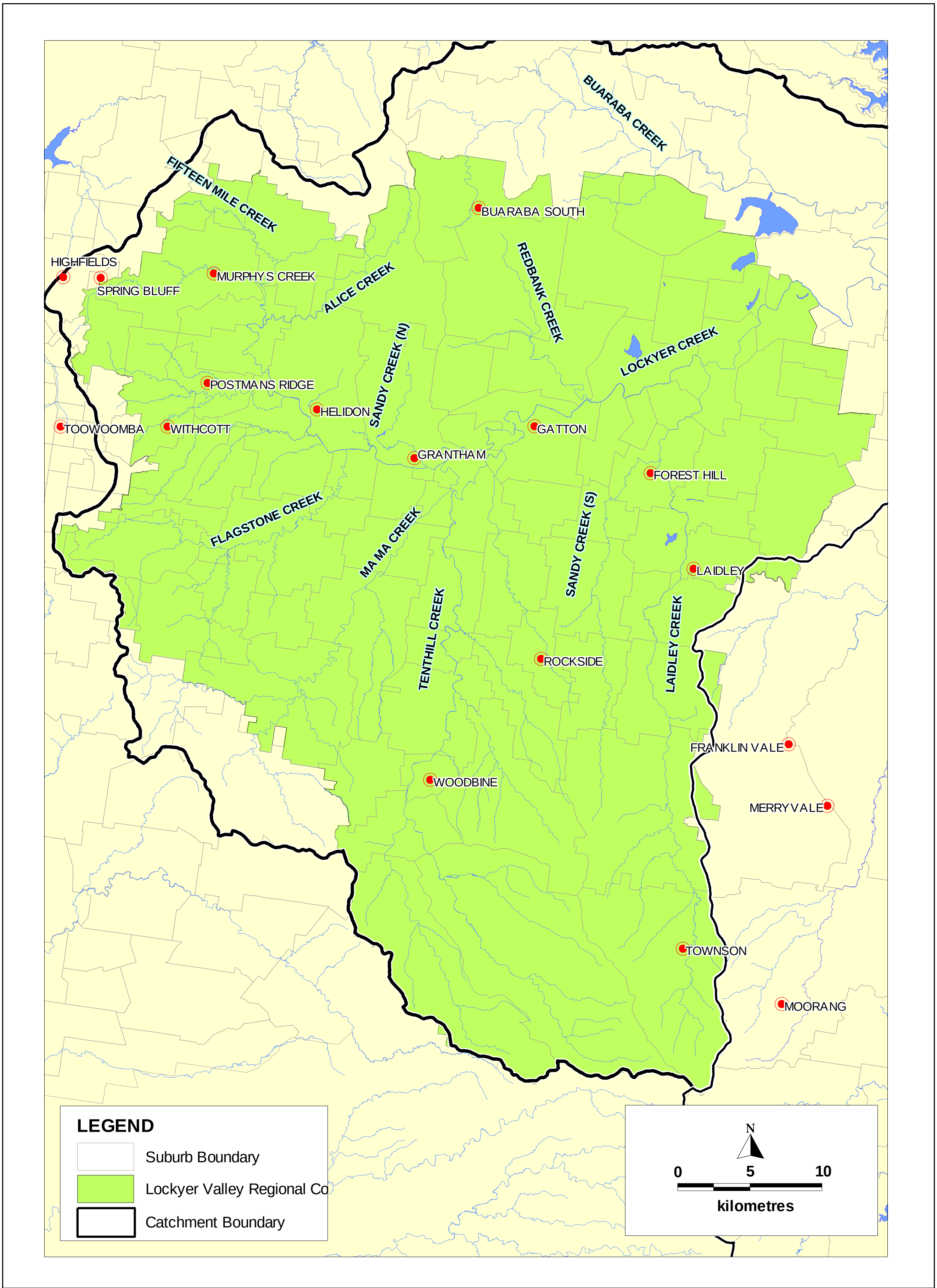

Figure 5.1 Lockyer Creek Catchment

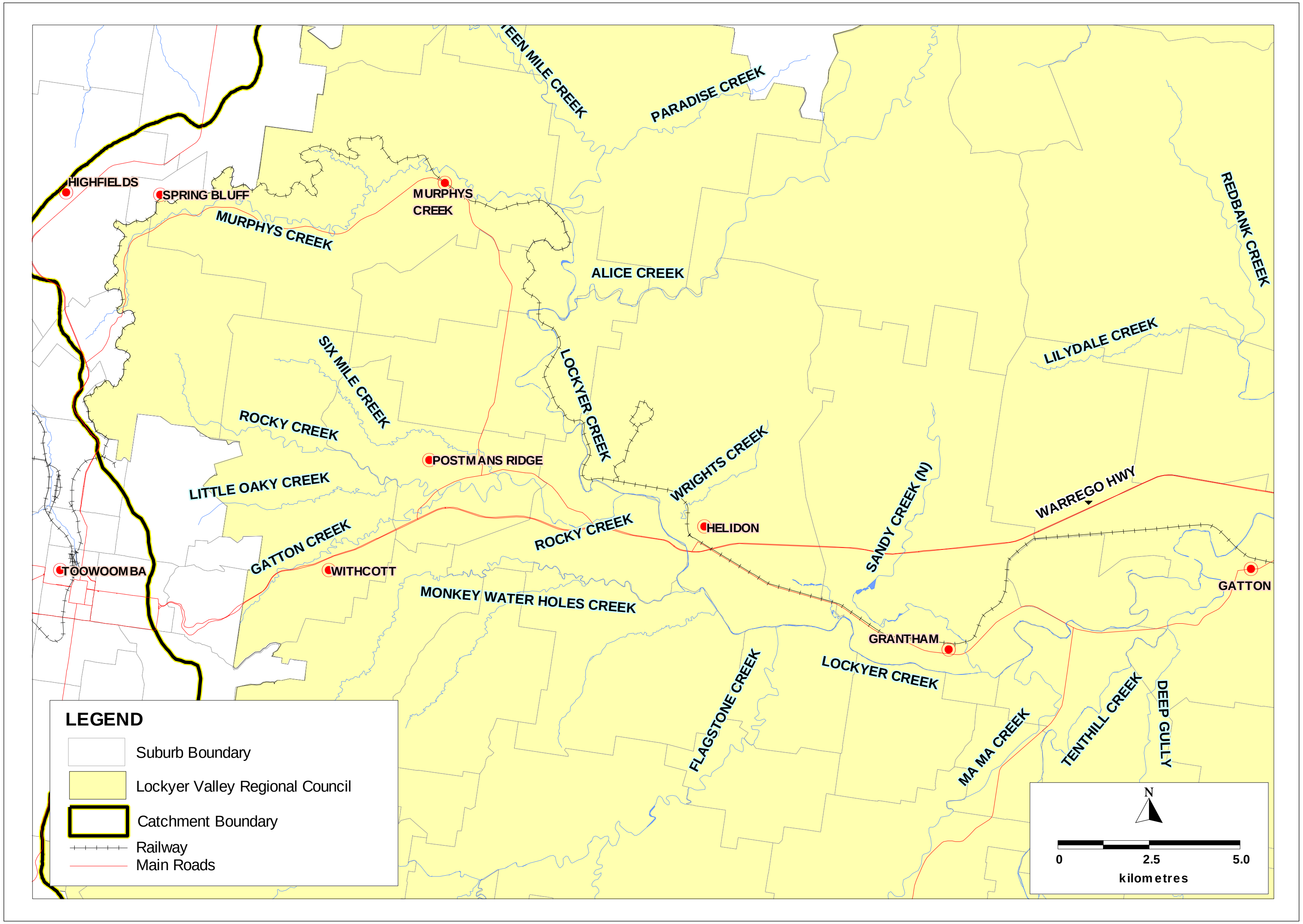

Figure 5.2 Upper Lockyer Creek Catchment

6 METEOROLOGY OF 9-12 JANUARY 2011 STORM EVENT

6.1 SYNOPTIC SITUATION

The rainfall events that caused flooding across the Lockyer Valley RC LGA over the period Sunday to Thursday 9-13 January 2011 culminated from the interaction of a low-pressure system (1000-1005 hPa) off the mid and southern 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).

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. Warm moist air delivered into this trough by the high off New Zealand led to heavy rainfalls across the southeast corner of Queensland from Sunday 9 January until Wednesday 12 January. Over the Lockyer Valley LGA, rains fell from Sunday evening 9 January until Tuesday evening 11 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 (128 km range) from the Mount Stapylton weather radar operated by BoM. These images show the inferred rate of rainfall over the period 2112 hours on Saturday 8 January to 0000 hours on Wednesday 12 January. Over this period, the radar images indicate a series of storms travelling in a southwesterly or westerly direction from the Sunshine Coast across the Brisbane Valley and Lockyer Creek catchment towards Toowoomba.

6.3.1 Sunday 9 January

Two rainfall events are indicated over the Lockyer Creek catchment on Sunday 9 January:

- Light to moderate rain fell over most areas of the catchment from around 1100 to 1200 hours (see Figure A3).
- Scattered falls of light to moderate rain fell over the central and northern area of the catchment from around 1500 to 2100 hours (see Figures A3 and A4).

6.3.2 Monday 10 January

Again, two rainfall events are indicated over the Lockyer catchment on Monday 10 January:

- Light to moderate rain fell over most areas of the catchment from around 0500 to 0900 hours on Monday morning (see Figures A6 and A7).
- Moderate to heavy rains fell over the upper areas of Lockyer Creek from 1200 to 1300 hours (see Figure A7). This is the storm that caused flash flooding and the loss of 20 lives along Lockyer Creek and its upper tributaries. (Although indicated as 'moderate to heavy' on BoM's radar, the actual intensity of rainfall over these upper catchment areas was very high – see Section 7). The approaching band of rainfall is readily apparent in the radar image at 1100 hours (Figure A7), situated to the north-northeast of the Lockyer catchment.

6.3.3 Tuesday 11 January

From around 0500 hours until 1600 hours on Tuesday, 11 January, most areas of the catchment experienced light to moderate rainfall:

- Between about 0500 to 0700 hours, moderate falls occurred progressively over the north-western area, the central area and the southern area of the catchment (see Figure A9).
- Light to moderate rain occurred over the eastern portion of the catchment from around 1100 to 1600 hours (see Figures A10 and A11). (From 0500 to 1700 hours, moderate to heavy rains were occurring over Lake Wivenhoe and it immediate catchment and the Bremer River catchment – see Figures A9, A10 and A11). From 1700 hours onwards, falls over the eastern area of the Lockyer catchment were generally light.)
- By 1900 hours, rains across the catchment had effectively ceased.

7 RAINFALL BEHAVIOUR IN LOCKYER VALLEY RC LGA OVER 9-13 JANUARY 2011

7.1 AVAILABLE DATA

There is a modest network of daily and short duration (pluviograph) rainfall recording stations across and adjacent to the Lockyer Creek catchment operated by the Bureau of Meteorology (BoM), the Department of Environment and Resource Management (DERM), and Toowoomba Regional Council. Rainfall data used in this investigation were obtained from all three of these agencies.

7.1.1 Daily Rainfall Stations

Figure 7.1 shows the locations of daily rainfall stations with available data for the January 2011 flood events. Data from all these stations were used in the preparation of the daily isohyets presented in this report. Table 7.1 shows details of these stations.

7.1.2 Short Duration Rainfall Stations

BoM collects daily and short duration rainfalls to complement data collected by other agencies and assist in the forecasting of floods along the Brisbane River and its major tributaries, including Lockyer Creek.

Figure 7.2 shows the locations of pluviograph stations where recorded data were available for the January 2011 flood events. Table 7.1 shows details of these pluviograph stations.

7.2 RECORDED RAINFALLS

7.2.1 Daily Rainfalls

Table 7.2 shows daily rainfalls to 0900 hours over the period Sunday 9 January to Thursday 13 January at a number of stations in and close to the Lockyer Creek catchment. Missing data have been highlighted, as have daily falls over 100 mm. The results of Table 7.2**Error! Reference source not found.** indicate the following:

- There was little rainfall across the catchment in the 24-hour period ending at 0900 hours on Sunday 9 January.
- There were falls of 50–130 mm across the catchment in the 24-hour period ending at 0900 hours on Monday 10 January. The heavier falls were around the lower reaches of Lockyer Creek and to the north into the Brisbane River catchment draining to Wivenhoe Dam.

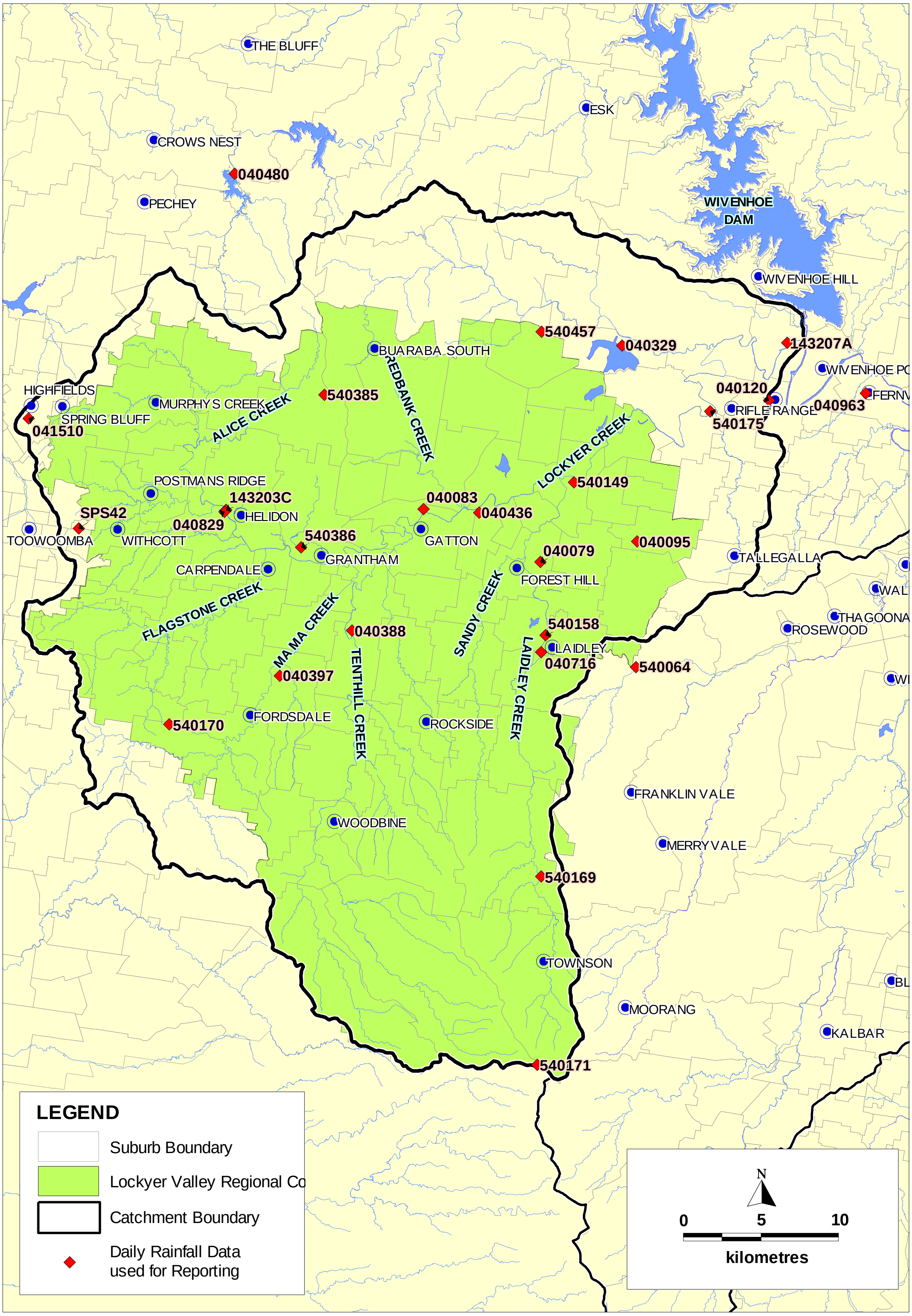

Figure 7.1 Daily Rainfall Stations with Available Data, Lockyer Creek Catchment

Table 7.1 Rainfall Stations with Available Data, Lockyer Creek Catchment and Adjacent Areas

Station Name	Station No.	Location	Daily Data	Pluvio Data
Atkinsons Dam, Coominya	40 329	Buaraba Creek	✓	
Buaraba Alert	540 457	Buaraba Creek		✓
Burns St, Fernvale	40 963	Brisbane River, Fernvale	✓	
Forest Hill, Gatton	40 079	Lockyer Creek, Gatton	✓	
Gatton Allan St	40 083	Lockyer Creek, Gatton	✓	
Gatton QDPI Res. Station	40 436	Lockyer Creek, Gatton	✓	
Gatton Alert	540 156	Lockyer Creek, Gatton		✓
Glenore Grove Alert	540 149	Lockyer Crk, Glenore Grove	✓	✓
Grandchester Alert	540 064	Western Creek, Bremer River	✓	
Hattonvale Store, Laidley	40 095	Laidley Creek, Laidley	✓	
Helidon Number 3	143 203C	Lockyer Creek, Helidon	✓	
Helidon TM	40 829	Lockyer Creek, Helidon	✓	
Laidley	40 716	Laidley Creek, Laidley	✓	
Little Egypt Alert	540 170	Upper Ma Ma & Tenthill Crks	✓	✓
Lowood, Don St	40 120	Brisbane River, Lowood	✓	
Lyons Bridge Alert-B	540 183	Lockyer Creek, Lyons Bridge	✓	
Mt Castle Alert	540 171	Upper Laidley Creek	✓	✓
Mt Whitestone, Helidon	40 397	Lockyer Creek, Helidon	✓	
O'Reillys Weir	143 207A	Lockyer Creek, O'Reillys Weir	✓	
Perseverance Dam	40 480	Upper Brisbane Catchment	✓	
Prince Henry Drive	SPS 42	Escarpment, Upper Rocky Creek		✓
Sandy Creek (N) Road Alert	540 386	Sandy Creek (N), Grantham	✓	✓
Showground Weir Alert	540 158	Lower Laidley Creek	✓	✓
Tamba, Toowoomba	41 510	Toowoomba	✓	
Thornton Alert	540 169	Mid-Laidley Creek	✓	✓
Toowoomba Alert	540 162	Escarpment, Upper Murphys Creek		✓
Upper Sandy Creek Alert	540 385	Upper Sandy Crk (Grantham)	✓	✓
Upper Tenthill, Gatton	40 388	Upper Tenthill Creek	✓	

•

- The 24 hours to 0900 hours on Tuesday 11 January encompass the rains that produced the flash flood down Lockyer Creek on Monday afternoon 10 January. From Table 7.2, it is seen that the daily totals are substantial, amounting to 160-180 mm, and that the highest falls occurred in the eastern and southern areas of the catchment. Thus, the daily rainfall results of Table 7.2*mask the flash flooding that occurred in Lockyer Creek* on the afternoon of Monday 10 January.
- Substantial falls occurred in the 24-hours to 0900 hours on Wednesday 12 January. Again, the heaviest falls were limited to eastern areas of the catchment.
- No falls of consequence occurred in the 24-hours to 0900 hours on Thursday 13 January.

7.2.2 Daily Isohyets

Figures 7.3 to 7.7 shows isohyets of daily rainfall (to 0900 hours) across the Brisbane River catchment (including Lockyer Creek catchment) from Sunday 9 January to Thursday 13 January. Figure 7.8 shows isohyets of total rainfall for this period (see the Overview Report for details of the stations used to construct these isohyets – ICA, 2011b). These figures indicate the following in relation to Lockyer Creek catchment:

- In the 24-hours to 0900 hours on Sunday 9 January, rainfall across the catchment was everywhere less than 25 mm.

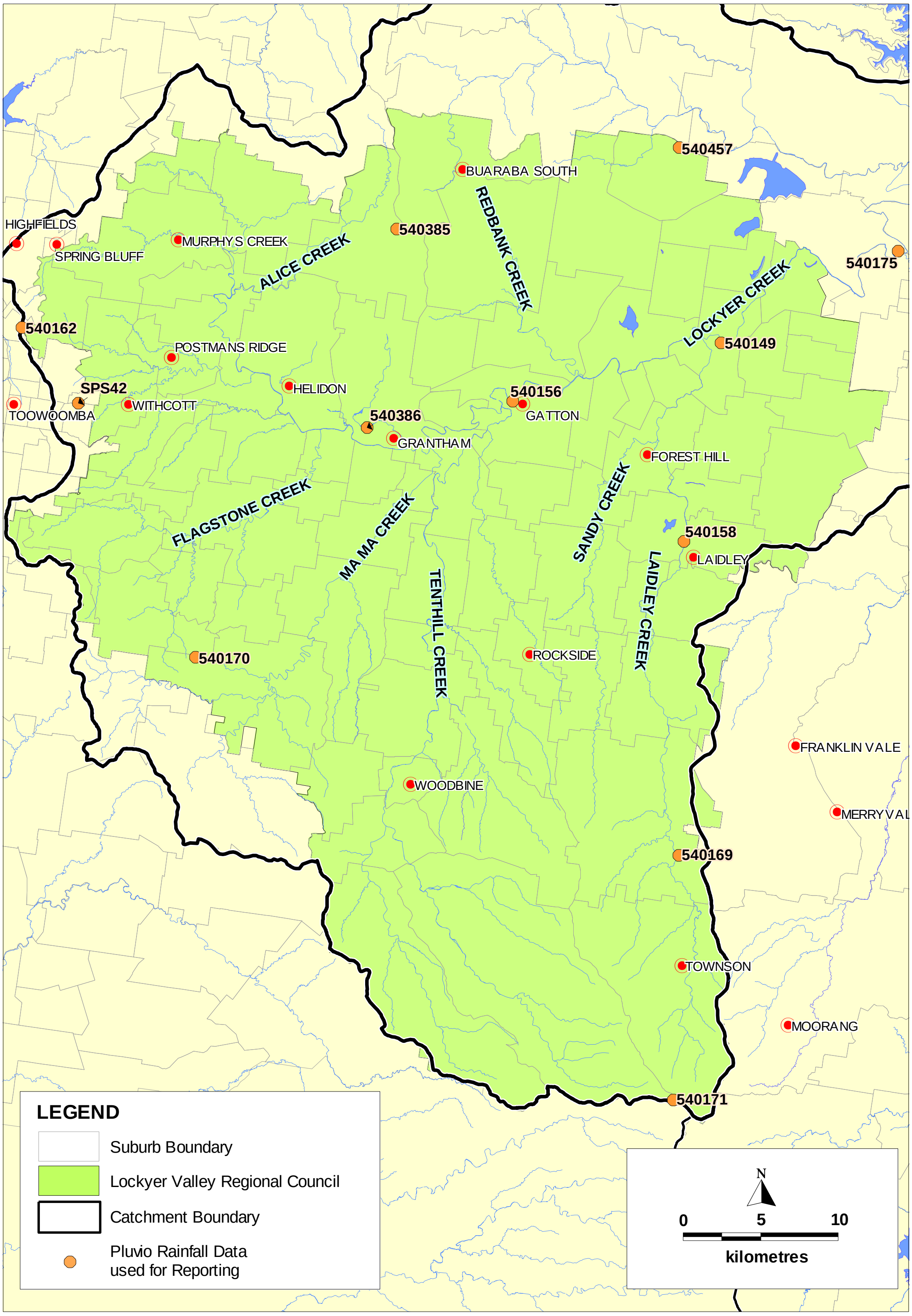

Figure 7.2 Pluviograph Stations with Available Data, Lockyer Creek Catchment

- In the 24 hours to 0900 hours on Monday 10 January, there were heavier falls across the northern area of the catchment (100-125 mm) falling away in a generally southerly direction to 50 mm or less.
- The heaviest falls in the 24-hour period to 0900 hours on Tuesday 11 January were in the southern area of the catchment around Mount castle (194 mm). Rainfalls to 125-150 mm occurred across the northwestern area of the catchment, the heaviest falls (to 125-150 mm) occurring around Toowoomba and over the upper tributaries of Rocky, Flagstone and Ma Ma Creeks. Again, the devastating flash flood behaviour of Lockyer Creek on the afternoon of Monday 10 January is not readily apparent from the daily isohyets.
- In the 24-hours to 0900 hours on Wednesday 12 January, heavy rains (generally to around 100-125 mm) fell over the extreme eastern region of Lockyer Valley LGA in a relatively narrow north-south band. This band included Lake Wivenhoe, the northwestern region of the Bremer River catchment, and the southern area of Somerset Regional Council LGA. Falls over most of the remainder of Lockyer Creek catchment were 75 mm or less.
- No rain fell over the Lockyer LGA catchment in the 24-hours to 0900 hours on Thursday 13 January.

Table 7.2 Daily Rainfalls to 0900 Hours, Lockyer Creek Catchment

Station Name	Station No.	Location	Date				
			9	10	11	12	13
Atkinsons Dam, Coominya	40 329	Buaraba Creek	9.2	107.2	108.0	1.4	0.0
Buaraba Alert	540 457	Buaraba Creek	9.4	114.0	48.0	96.0	0.6
Burns St, Fernvale	40 963	Lockyer Creek, Fernvale	7.4	125.8	NA	NA	NA
Forest Hill, Gatton	40 079	Lockyer Creek, Gatton	3.3	63.6	84.1	75.9	0.6
Gatton Allan St	40 083	Lockyer Creek, Gatton	9.4	67.2	77.6	108.2	NA
Gatton QDPI Res. Station	40 436	Lockyer Creek, Gatton	5.6	88.0	79.4	126.0	0.0
Glenore Grove Alert	540 149	Lockyer Crk, Glenore Grove	86.0	77.0	129.0	0.0	0.0
Grandchester Alert	540 064	Western Creek, Bremer River	3.0	81.0	165.0	169.0	0.0
Hattonvale Store, Laidley	40 095	Laidley Creek, Laidley	7.0	66.0	NA	277.2[a]	0.0
Helidon Number 3	143 203C	Lockyer Creek, Helidon	4.0	58.0	29.0	0.0	0.0
Helidon TM	40 829	Lockyer Creek, Helidon	3.0	57.0	29.0	NA	NA
Laidley	40 716	Laidley Creek, Laidley	2.0	58.0	55.0	100.0	NA
Little Egypt Alert	540 170	Upper Ma Ma & Tenthill Crks	1.0	30.0	94.0	29.0	2.0
Lowood Don St	40 120	Brisbane River, Lowood	6.0	102.0	180.6	203.2	0.0
Lyons Bridge Alert-B	540 183	Lockyer Creek, Lyons Bridge	7.0	84.0	128.0	241.0	0.0
Mt Castle Alert	540 171	Upper Laidley Creek	6.0	87.0	194.0	122.0	22.0
Mt Whitestone, Helidon	40 397	Lockyer Creek, Helidon	2.2	49.6	67.0	85.6	0.0
O'Reillys Weir	143 207A	Lockyer Creek, O'Reillys Weir	3.0	110.0	162.0	198.0	0.0
Perseverance Dam	40 480	Upper Brisbane Catchment	11.8	136.6	150.2	25.0	0.8
Prince Henry Drive	SPS 42	Escarpment	NA	138.0	NA	NA	NA
Sandy Creek Road Alert	540 386	Sandy Creek (N), Grantham	4.0	73.0	86.0	54.0	0.0
Showground Weir Alert	540 158	Lower Laidley Creek	1.0	67.0	105.0	119.0	0.0
Tamba, Toowoomba	41 510	Toowoomba	14.4	104.6	NA	NA	NA
Thornton Alert	540 169	Mid-Laidley Creek	7.0	46.0	116.0	77.0	1.0
Upper Sandy Creek Alert	540 385	Upper Sandy Crk (Grantham)	8.0	130.0	104.0	33.0	1.0
Upper Tenthill, Gatton	40 388	Upper Tenthill Creek	1.6	60.6	73.0	63.4	1.0

NA: Not Available; [a] 2-Day Total.

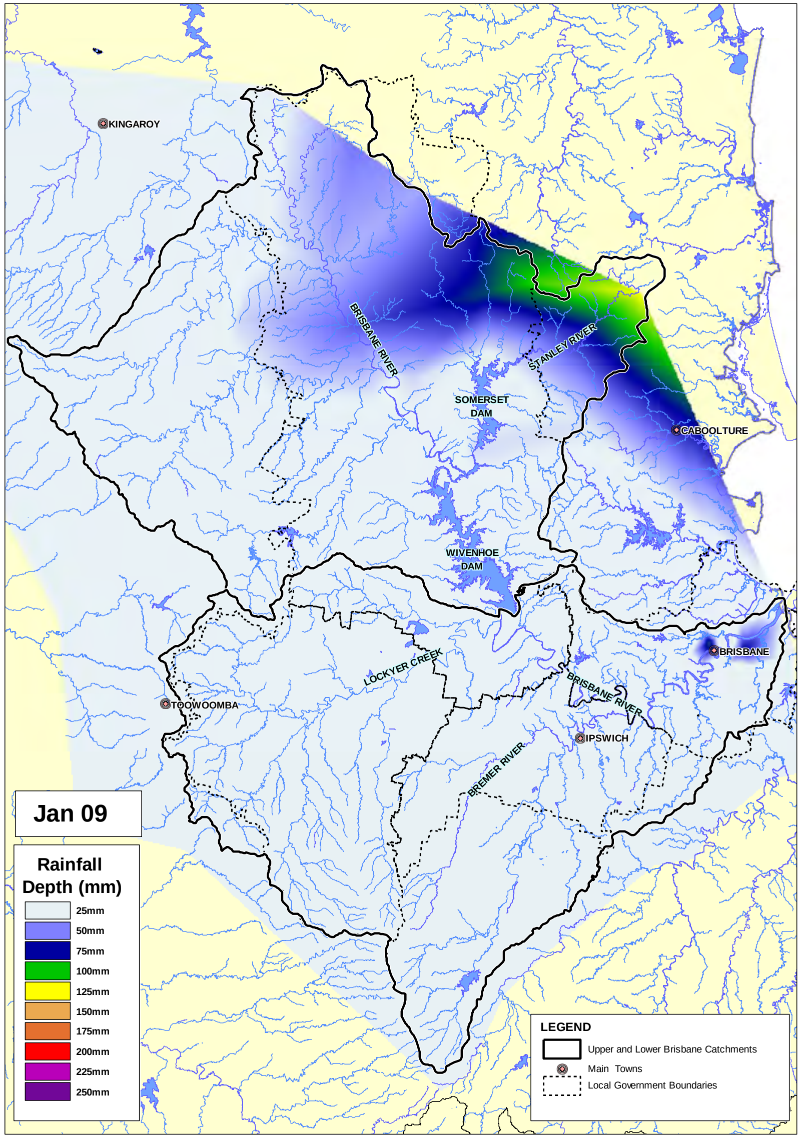

Figure 7.3 Daily Rainfall Isohyets to 0900 Hours on Sunday 9 January 2011, Lockyer Creek Catchment

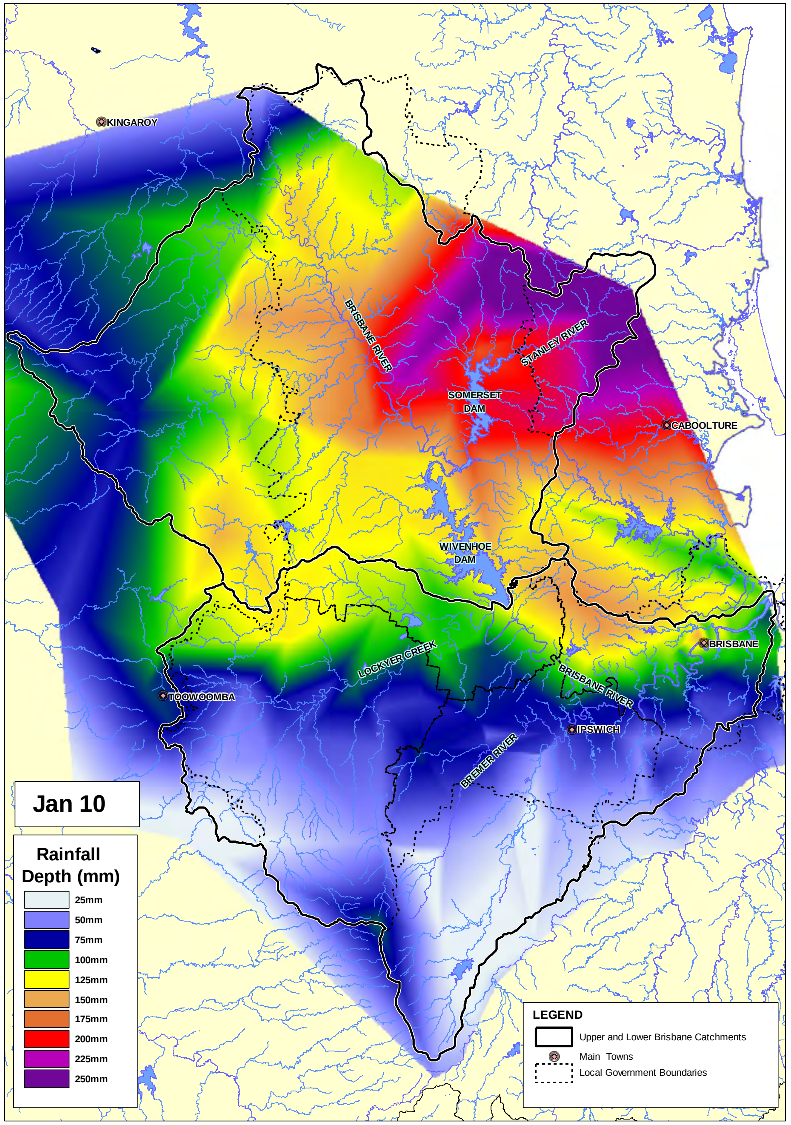

Figure 7.4 Daily Rainfall Isohyets to 0900 Hours on Monday 10 January 2011, Lockyer Catchment

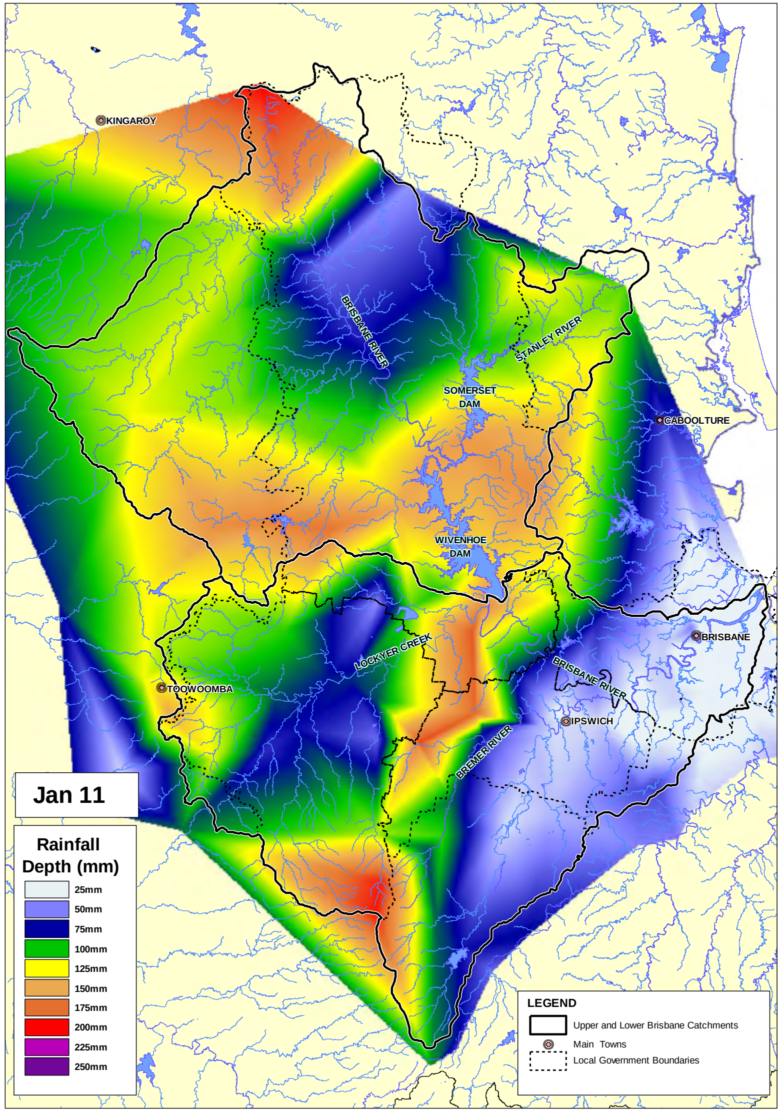

Figure 7.5 Daily Rainfall isohyets to 0900 Hours on Tuesday 11 January 2011, Lockyer Creek Catchment

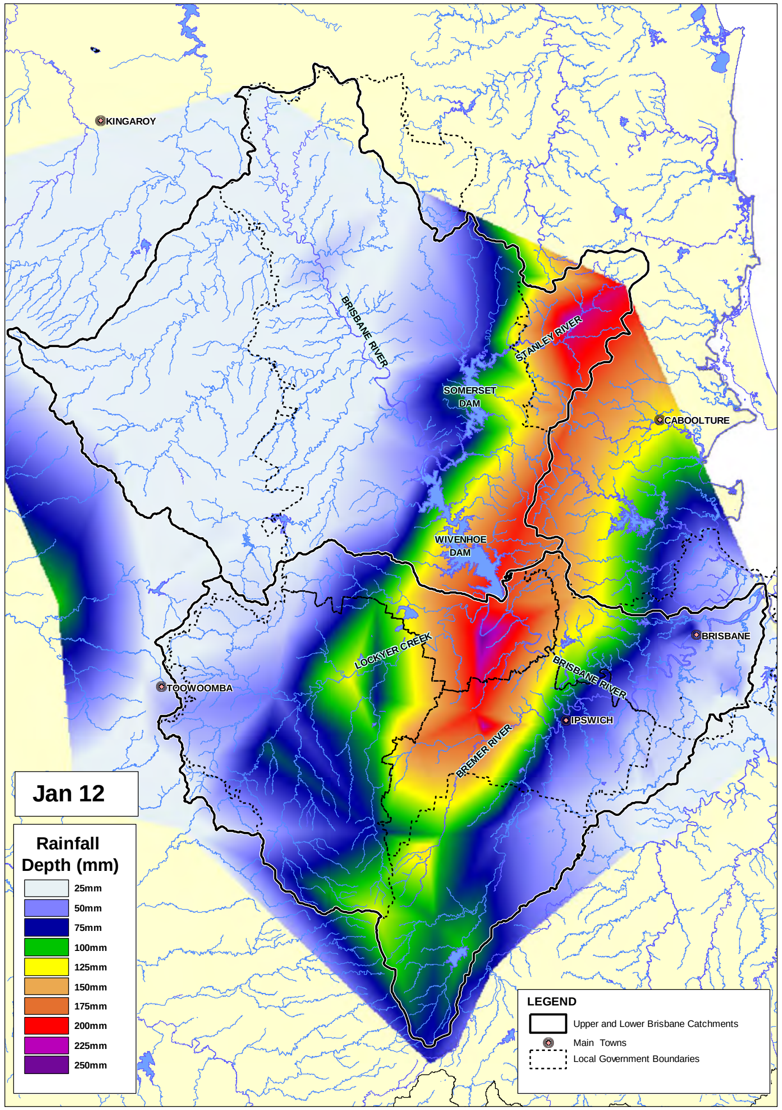

Figure 7.6 Daily Rainfall isohyets to 0900 Hours on Wednesday 12 January 2011, Lockyer Creek Catchment

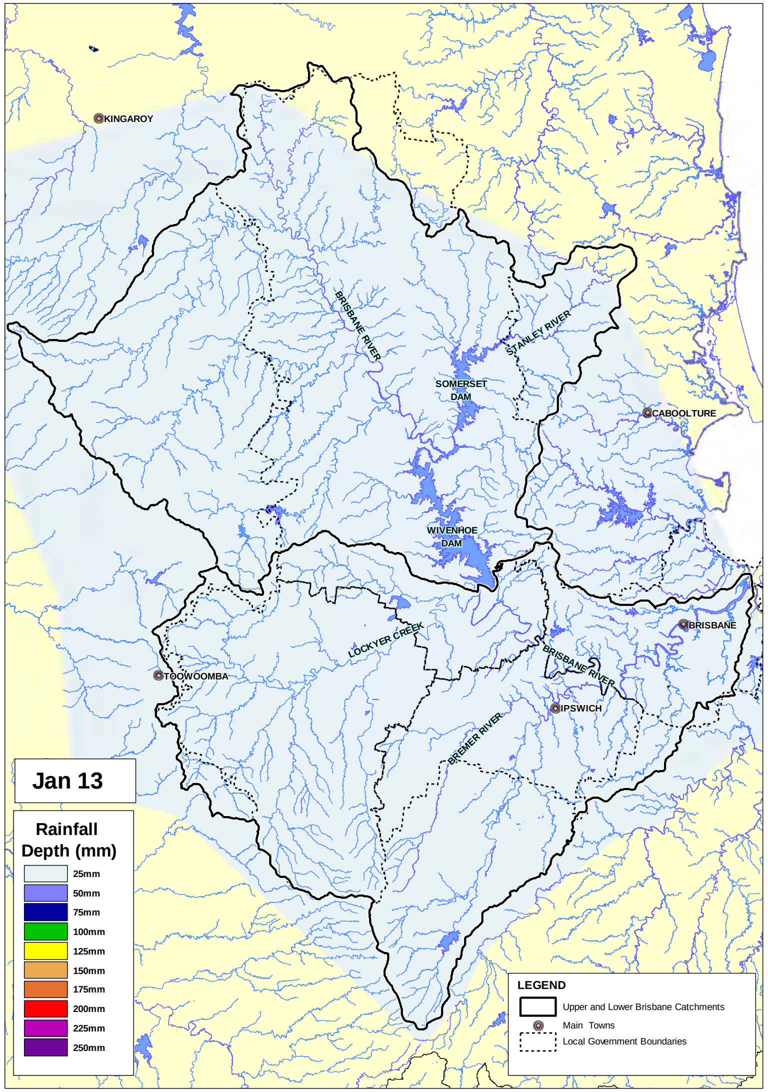

Figure 7.7 Daily Rainfall isohyets to 0900 Hours on Thursday 13 January 2011, Lockyer Creek Catchment

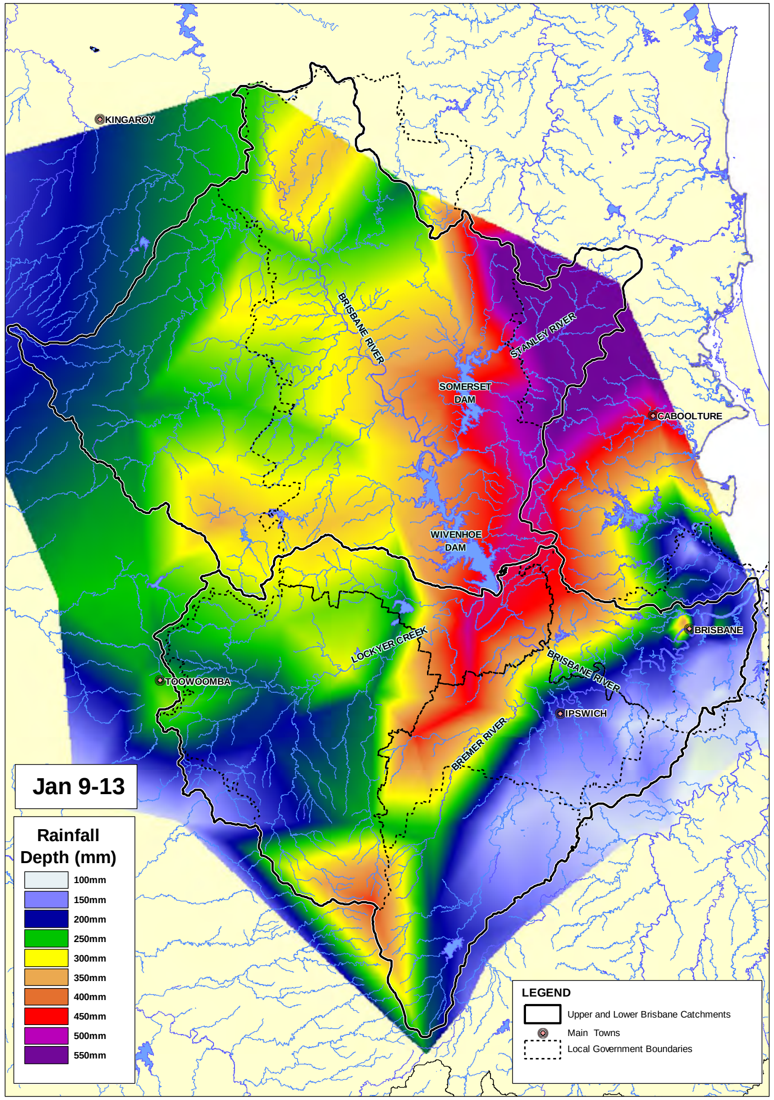

Figure 7.8 Cumulative Rainfall Isohyets from 0900 Hours on Sunday 9 January to 0900 Hours on Thursday 13 January 2011, Lockyer Creek Catchment

7.2.3 Rainfall Intensities

General

Figure 7.9 shows the cumulative rainfall recorded at 11 pluviographs in and around Lockyer Creek catchment over the period 9-13 January 2011. Stations shown in the legend of Figure 7.9 are listed in order of total cumulative rainfall over this period, from highest to lowest.

It is noted that many pluviographs in the upper Lockyer catchment failed during the storm event on the afternoon of Monday 10 January. So we are left to infer rainfall intensities and severities on the basis of records at nearby stations. Of special interest are the two pluviographs on the Escarpment, namely the Prince Henry Drive station (SPS 42, operated by Toowoomba City Council) and the Toowoomba Alert Station (540 162, operated by BoM). Unfortunately a complete record of rainfalls at the Prince Henry Drive pluviograph station over the period of interest is not available. From Figure 7.2, it is seen that the Prince Henry Drive pluviograph lies in close proximity to the upper reaches of Rocky Creek and Monkey Waterholes Creek, and that the Toowoomba Alert station lies in close proximity to the upper reaches of Murphys Creek and Rocky Creek.

The results of Figure 7.9 indicate the following rainfall behaviour:

- The major rainfall event over the period 9-13 January generally occurred over the period from around 0300 hours to around 1800 hours on Tuesday 11 January. Heavy rains were concentrated over the eastern and southern parts of the catchment: over this period some 350 mm of rain fell at Lyons Bridge (lower Lockyer Creek) and 150 mm at Mount Castle (upper Laidley Creek). Typically, 100 mm or less fell across other areas of the catchment.

Upper Lockyer Creek

Figure 7.10 shows cumulative rainfalls over the 24-Hour period ending at midnight Monday 10 January. Again, stations in the legend of Figure 7.10 are listed in order of cumulative rainfall to 2400 hours on Tuesday night, from highest to lowest.

The following rainfall behaviour is apparent from the results of Figure 7.10:

- The greatest total fall (151 mm) was at Mount Castle Alert (540 171), which is located in the remote southeast of the catchment.
- The rainfalls that caused flash flooding in Lockyer Creek are readily apparent at Prince Henry Drive (SPS 4211), which recorded a total fall of 138 mm over this period, at Toowoomba Alert (540 162), which received 96 mm, and to a lesser extent at Upper Sandy Creek (N) Alert (540 386), which received some 80 mm of rain.
- Rainfall intensities and depths were greatest at Prince Henry Drive. The intensity of the rainfall is measured by the steepness of the cumulative curve. It is seen that intense falls occurred at Prince Henry Drive and Toowoomba Alert over the period 1300-1400 hours on Monday 10 January. The intense falls over upper Sandy Creek (N) Alert occurred earlier between 1200-1300 hours, when the storm was still travelling south-westerly towards Toowoomba, and were noticeably less intense (less steep) and lighter.

[11] The pluviograph at Prince Henry Drive (SPS 42) is operated by Toowoomba City Council and not by DERM or BoM. Toowoomba City Council made available rainfall data recorded here (and at other gauges in the area – see ICA, 2011a). The pluviograph at Prince Henry Drive provides the only solid indication of the intensity and severity of rainfalls causing the Monday afternoon flash flood down Lockyer Creek.

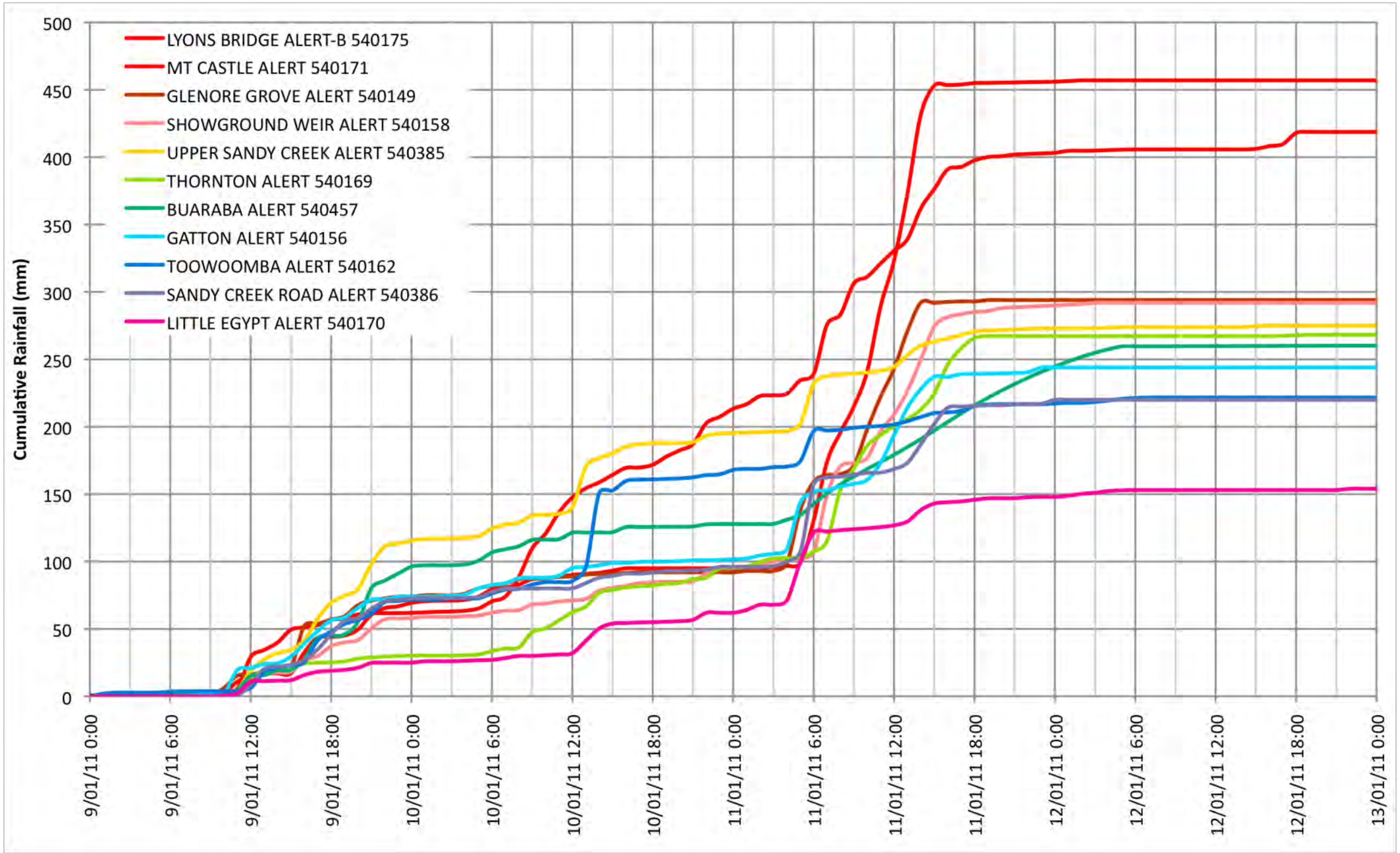

Figure 7.9 Cumulative Rainfalls, Lockyer Creek Catchment, Sunday to Thursday 9-13 January 2011

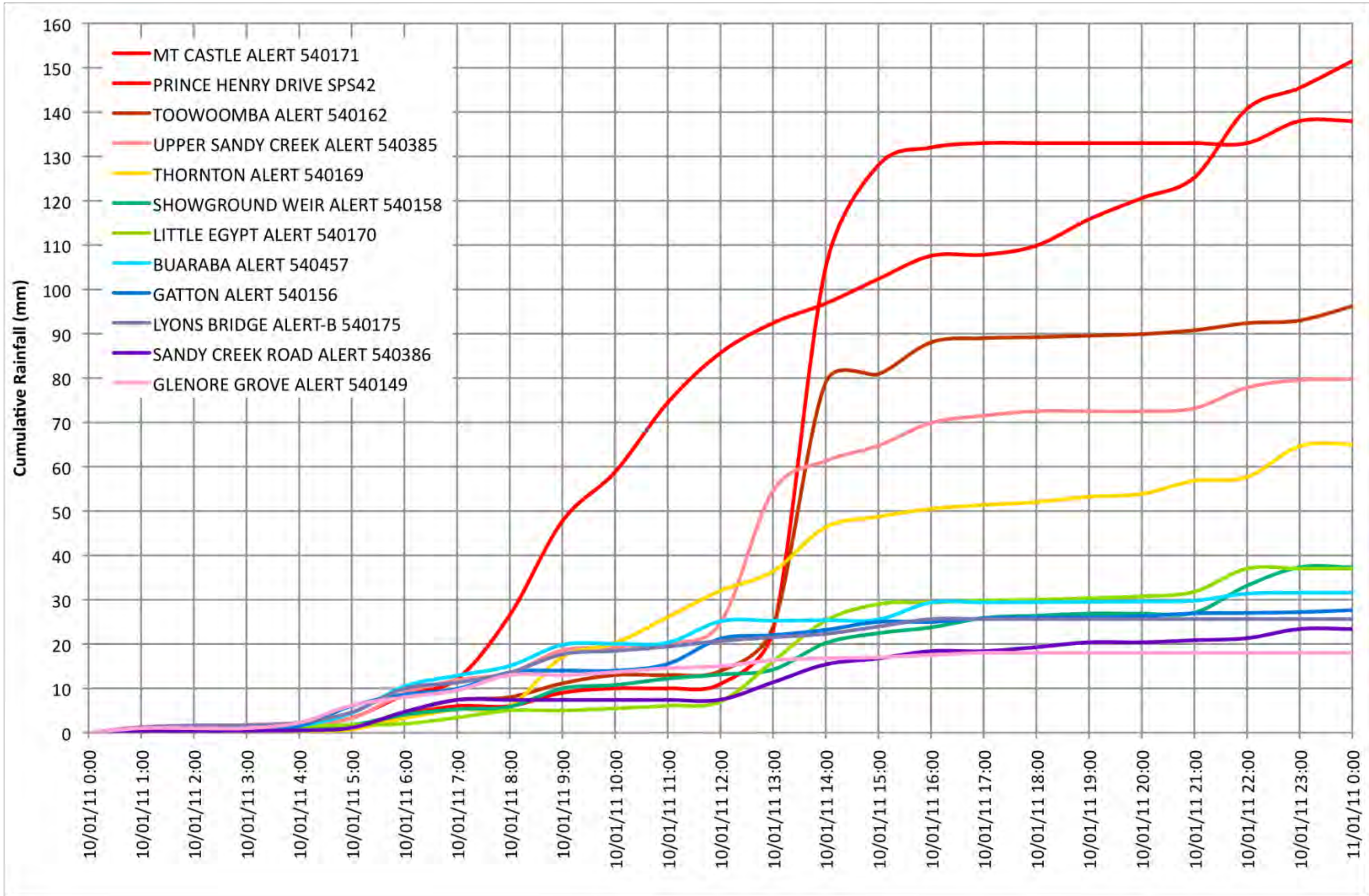

Figure 7.10 Cumulative Rainfall, Prince Henry Drive, Gatton and Upper Sandy Creek, Monday 10 January 2011

- The Prince Henry Drive and Toowoomba Alert pluviographs are both located to the immediate west of The Escarpment (see Figure 5.2). Based on available rainfall data, rainfalls recorded here are taken to be more-or-less representative of falls over the upper reaches of Lockyer Creek and its tributaries that drain the northwestern area of The Escarpment. Given that the storm band delivering the flash flood rainfalls was moving in a south-south-westerly direction, it is expected that the heaviest and most intense falls occurred to the west of Upper Sandy Creek (see radar images at 1100, 1212 and 1300 hours on Figure A7).

It is possible that rainfall intensities at other locations within the upper catchment of Lockyer Creek were higher than those recorded at the official rainfall recording stations.

Rainfall Severities

Table 7.3 shows the maximum rainfall intensities recorded over the period Sunday to Thursday 9-13 January 2011[12] at the 12 pluviograph stations described above. Table 7.3 also shows rainfall severity, as measured in terms of Average Recurrence Interval (ARI). Design rainfall ARIs were determined from data given in Australian Rainfall and Runoff (I.E.Aust, 1998). In Table 7.3, rainfall durations with severities greater than 100-Years ARI are shaded dark-grey; severities greater than 50-Years ARI are shaded light-grey. Appendix B shows plots of rainfall intensity-severity-duration at the various stations and also indicates how severity varied over the course of the rainfall events. The results of Table 7.3 and Appendix B indicate the following:

- Only five stations had rainfall severities greater than 50-Years ARI: Prince Henry Drive Alert (SPS 42); Glenore Grove Alert (540 149); Lyons bridge Alert (540 175); Showground Weir Alert (540 158) and Mt Castle Alert (540 171). The highest severity at all five stations was greater than 100-Years ARI, being so for short duration events at Prince Henry Drive (3 hours or less) and for longer duration events at the other three stations (3-hours or longer at Lyons Bridge and 12-hours or longer at the other three stations). At all other stations in Table 7.3, the severity was generally less than 40-Years ARI for all durations.
- From Figure B1 of Appendix B, it is seen that at the Prince Henry Drive pluviograph, intense rainfalls occurred over the period 1200-1500 hours on Monday 10 January (117 mm in total), with the highest hourly fall (74 mm) occurring over the period 1300-1400 hours. The severity of rainfalls at this station is seen to be greater than 100-Years ARI for all durations between 0.5-hours and about 4-hours, being greatest for a duration of around 1-hour. As discussed above, the intensity and severity of rainfall at this gauge are taken to be representative of rainfall over the upper reaches of Rocky Creek and Monkey Waterholes Creek.
- From Figure B1 of Appendix B, it is also seen that at the Toowoomba Alert pluviograph, intense rainfalls occurred over the period 1200-1400 hours on Monday 10 January (64 mm in total), with the highest hourly fall (52 mm) occurring over the period 1300-1400 hours. These values are considerably less than what was recorded at Prince Henry Drive. The highest rainfall severity at the Toowoomba Alert station was 28-Years ARI for the 1-hour duration fall. Again, this is considerably less than severities recorded at Prince Henry Drive, and presumably reflects the vagaries of the spatial and temporal patterns of the flood-producing storm event. It is thought that the intensities and severities recorded at prince Henry Drive may be more representative of rainfalls over the northern tributaries of Lockyer Creek, especially Murphys Creek, where a pronounced flash flood spike was recorded at the Spring Bluff streamgauging station (see Section 8.2.1)
- Thus, it is inferred that the rainfall intensities and severities recorded at Prince Henry Drive were representative of rainfall behaviour over the upper catchments of Murphys, Rocky and Monkey Waterholes Creeks. Rainfall intensities and severities declined in an easterly direction across these catchments, as evidenced by the results in the Sandy Creek (N) catchment at upper Sandy Creek (N) Alert and at Sandy Creek (N) Road Alert (see below and Figure B2).

[12] The analyses for the Prince Henry Drive pluviograph (SPS 42) are limited to the 24-hour period ending at midnight on Monday 10 January.

- It is noted that rainfall over Sandy Creek (N) catchment was quite benign, especially for the short duration events that caused the flash flood down Lockyer Creek. For durations of 0.5 to 3 hours, the ARI at upper Sandy Creek (N) Alert (540 385) was only 1-Year or less. At Sandy Creek Road Alert (540 386), the maximum severity for durations of 15-minutes to 3-hours was 7-Years ARI.
- Severe rainfalls at Lyons Bridge Alert (540 175) occurred on the Tuesday between about 0530 hours and 1500 hours. The severity of all rainfall events with durations from 3 to 72-hours was greater than 100-Years ARI. The severity of the 12-hour duration event was markedly greater than 100-Years ARI. (These are the intense rainfalls that occurred over Lake Wivenhoe – see ICA, 2011b).
- Rainfall severities greater than 100-Years ARI at the other three stations in the east of the LGA are associated with longer duration events: 12 hours at Glenore Grove and Showground Weir Alert, and 48 hours at Mount Castle Alert. The high severities at the first two stations are also associated with the heavy rains that occurred over Lake Wivenhoe and its immediate surrounds during the period 0300-1500 hours on Tuesday 11 January (see ICA, 2011b and *Figure 7.6*). The high severity at Mount castle Alert is associated with heavy rains over the period 0800 hours on Monday 10 January until 1500 hours on Tuesday 11 January.
- Thus, across the Lockyer LGA catchment, rainfall severity was high (greater than 100 years) for longer duration events at stations falling in a north-south band across the eastern boundary of the catchment, and it is inferred, in the northwest corner of the catchment over the upper tributaries of Lockyer Creek, as evidenced by results at the Prince Henry Drive gauge. Across the remainder of the catchment, especially the southwestern area, severities were low (less than 10-Years ARI), especially for short duration events (less than 3–hours), with severity rising to 20 to 40-Years ARI for longer durations (48 hours or longer).

Table 7.3 Recorded Maximum Rainfall Intensities and Severities, Lockyer Creek Catchment, 9-13 January 2011

Storm Duration	Toowoomba Alert 540 162		Prince Henry Drive Alert SPS 42		Upper Sandy Crk (N) Alert 540385		Sandy Creek (N) Road Alert 540 386		Gatton Alert 540 156		Glenore Grove Alert 540 149	
	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)
5min	109.4	2	144.0	4	99.8	1	113.3	2	92.4	<1	119.9	1
10min	88.5	2	144.0	18	82.4	1	90.1	2	91.7	2	100.5	2
15min	85.5	3	140.0	38	68.5	1	91.5	3	82.9	2	103.6	4
20min	81.7	5	135.0	89	60.9	1	80.4	4	70.6	2	100.4	6
30min	73.0	9	128.0	>100	48.4	1	67.9	4	55.7	2	76.1	4
1hr	58.1	28	94.0	>100	31	1	51.3	7	35.3	2	54.6	6
2hr	32.7	15	57.5	>100	19.4	1	29.1	4	21.6	1	31.6	4
3hr	22.6	9	40.0	>100	13.8	<1	21.7	4	19.1	2	26	8
6hr	12.7	5	20.5	59	11.7	2	11.4	2	13.3	4	21.2	49
12hr	7.3	4	11.0	23	9	5	9.6	11	11	23	16.6	>100
24hr	5.6	9	5.8	8	6.1	8	5.2	5	6	12	8.4	76
48hr	4.1	16	-	-	4.9	24	3.9	16	4.4	28	5.7	94
72hr	3.0	15	-	-	3.8	30	3.1	21	3.4	38	4.1	87

Table 7.3 Recorded Maximum Rainfall Intensities and Severities, Lockyer Creek Catchment, 9-13 January 2011 (Cont.)

Storm Duration	Lyons Bridge Alert 540 175		Buaraba Alert 540 457		Showground Weir Alert 540 158		Little Egypt Alert 540 170		Thornton Alert 540 169		Mt Castle Alert 540 171	
	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)	Intensity (mm/hr)	ARI (Years)
5min	112.9	1	45.3	<1	111.5	1	84.8	<1	110.3	1	109.8	1
10min	111.2	2	37.4	<1	81.9	1	83.7	2	96.9	2	93.6	2
15min	103.8	3	31.6	<1	83.8	2	72.1	1	84.1	2	86.2	2
20min	95.4	4	28.9	<1	76.4	2	71.8	3	70.2	2	74.5	2
30min	83.0	5	28	<1	66.9	3	63.5	4	57.2	2	58.8	2
1hr	73.6	20	24.9	<1	45.1	3	48.3	8	38.4	2	38.9	2
2hr	57.7	76	18.7	<1	33.2	6	25.7	3	27.2	3	24.9	2
3hr	49.6	>100	14	<1	23.1	4	17.8	2	23.6	5	22.4	4
6hr	41.5	>100	10.6	2	17.4	17	9.9	2	15.7	9	15.3	8
12hr	29.8	>100	7.3	3	15.1	>100	6.3	2	13.2	46	13.9	55
24hr	15.1	>100	5.3	5	8.5	79	4	2	7.7	24	9.4	66
48hr	9.1	>100	3.7	8	5.4	69	2.7	5	5	22	7.1	>100
72hr	6.3	>100	3.6	28	4.1	80	2.1	7	3.7	20	5.6	>100

8 WATER LEVEL BEHAVIOUR IN LOCKYER VALLEY RC LGA ON 9-13 JANUARY 2011

8.1 AVAILABLE DATA

8.1.1 Streamgauging Data

There is a modest network of stream gauging stations located along the Lockyer Creek and its tributaries. BoM and DERM collect water level data at these stations. DERM also provides estimates of discharges (via the use of rating curves) at many of their stream gauging stations. All stream gauging data collected by BoM and DERM were available for this investigation.

Figure 8.1 shows the locations of stream gauging stations at which water level data were available for the January 2011 Flood events. It is noted that a number of gauges along Lockyer Creek and its tributaries failed under the onslaught the flood event of Monday afternoon 10 January. Table 8.1 shows details of these stations. It is unfortunate that both stations at Helidon and both stations at Gatton malfunctioned on Monday afternoon 10 January, as continuous, valid records at these stations would have shed unambiguous light on flood behaviour along the upper and middle reaches of Lockyer Creek during this flood event.

Table 8.1 Streamgauging Stations that Malfunctioned During the Flood Events of 9-13 January 2011

Waterway	Station Details	
	Name	No.
Lockyer Creek	Helidon Alert	540 143
Lockyer Creek	Helidon No. 3	143 203C
Lockyer Creek	Gatton Alert	540 156
Lockyer Creek	Gatton	540 363
Laidley Creek	Mulgowie Alert	143 209B
Laidley Creek	Warrego Highway	143 229A

Table 8.2 shows details of streamgauging stations in Lockyer Creek catchment with available data, including the recorded peak water level and time of peak water level over the period Friday–Thursday 9-13 January 2011.

8.1.2 Extent of Flooding Data

Lockyer Valley RC made available flood data in the form of GPS locations and measured depth of flooding at these locations. Unfortunately, this information was found to be unsuitable for generating the extent and depth of inundation maps, as has been done in other studies (ICA, 2011a; ICA, 2011c; and ICA, 2011d). Accordingly, this report contains no information regarding the extent and depth of inundation in the various flooded townships in Lockyer Valley RC LGA.

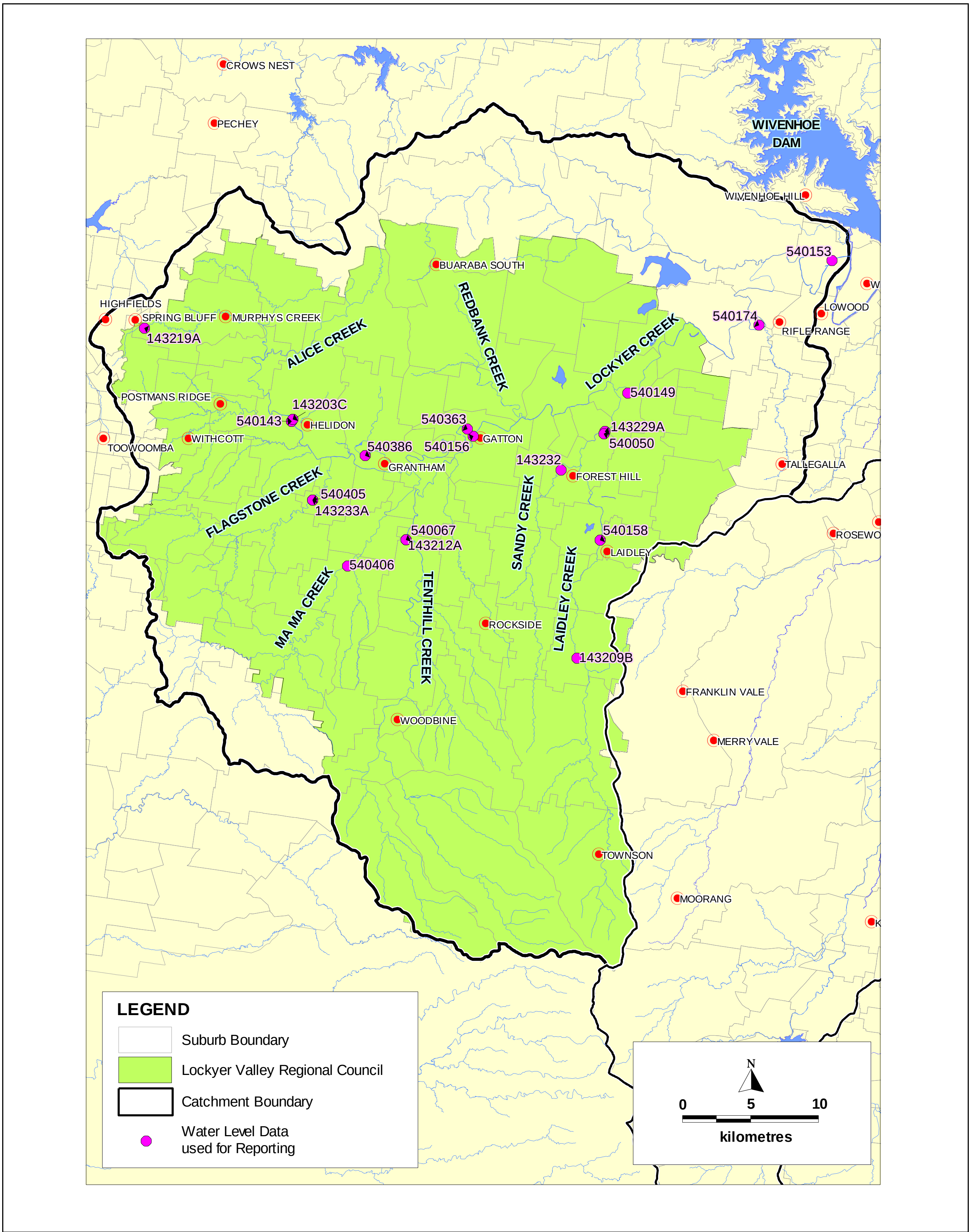

Figure 8.1 Streamgauging Stations with Available Data, Lockyer Creek Catchment

Table 8.2 Details of Streamgauging Stations and Peak Flood Levels, Lockyer Creek Catchment, 9-13 January 2011

Gauge Details		Waterway	Catchment Area (km²)	AMTD (km)	Start of Record	Gauge Zero	Peak Water Level 9-13 January		
Name	No.						(m GH)	Time	Day and Date
Flagstone Creek Brown-Zirbels Road	540 405 143 233A	Flagstone Creek	157	6.8	1-Jun-93	140.350 AHD	8.84[13]	0745 hrs	Tuesday 11 Jan.
Mulgowie Alert	143 209B	Laidley Creek	167	31	6-Mar-67	132.62 AHD	7.88[14]	1600 hrs	Monday 10 Jan.
Showgrounds Weir Alert	540 158	Laidley Creek	241	17.6	20-Sep-84	97.000 AHD	9.36	1600-1730 hrs	Tuesday 11 Jan.
Warrego Highway Warrego Highway	540 050 143 229A	Laidley Creek	445	5.0	11-Aug-90	76.339 AHD	9.38	220-2400 hrs	Tuesday 11 Jan.
Helidon Alert	540 143	Lockyer Creek	350	99.0	19-Nov-97	128.651 AHD	12.74[15]	1453 hrs	Monday 10 Jan.
Helidon No. 3	143 203C	Lockyer Creek	357	99.3	19-Nov-87	128.625 AHD	Failed	Failed	-
Gatton Alert	540 156	Lockyer Creek	1,550	72.0	1-Sep-29	87.539 AHD	15.64[16]	0422 hrs	Monday 10 Jan.
Gatton	540 363	Lockyer Creek	1,550	72.0	4-Feb-00	29.270 ASD	13.87[17]	1840 hrs	Tuesday 11 Jan.
Glenore Grove Alert	540 149	Lockyer Creek	2,230	51.8	1-Jan-55	48.525 AHD	17.34	1715 hrs	Tuesday 11 Jan.
Lyons Bridge Alert-P	540 174	Lockyer Creek	2,530	29.1	1-Oct-94	47.528 AHD	17.25	1757 hrs	Tuesday 11 Jan.
O'Reillys Weir Alert	540 153	Lockyer Creek	2,980	1.4	1-Dec-48	23.620 AHD	23.68	1940 hrs	Tuesday 11 Jan.
Harms	143 213C	Ma Ma Creek	227	13.6	25-Aug-95	146.713 AHD	6.12[18]	0810 hrs	Tuesday 11 Jan.
Spring Bluff	143 219A	Murphys Creek	18	129.9	1-Oct-79	380.829 AHD	4.96	1340 hrs	Monday 10 Jan.
Sandy Creek (N) Rd Alert	540 386	Sandy Creek (N)	-	NR	25-May-06	-	4.45[19]	0033 hrs	Monday 10 Jan.
Forest Hill	143 232A	Sandy Creek (S)	94	2.5	5-Sep-95	90.588 AHD	3.20[20]	1650 hrs	Monday 10 Jan.
Tenthill Tenthill	540 067 143 212A	Tenthill Creek	450	14.6	18-Mar-68	123.845 AHD	4.97	1600 hrs	Monday 10 Jan.

13 A separate peak of 6.68 m GH occurred at 1650 hours on Monday 10 January.
14 Gauge failed at 0700 hours on Tuesday 11 January.
15 Water level when gauge ceased functioning. The peak water level was higher (amount unknown).
16 Gauge failed around 1700 hours on Tuesday 11 January. Peak water level recorded Monday night was 10.57 m GH at 0420 Tuesday 11 January.
17 Gauge failed around 1840 hours on Tuesday 11 January.
18 A separate peak of 3.79 m GH occurred at 1740 hours on Monday 10 January.
19 A separate following peak of 3.85 m GH was recorded at 1721 hours on Monday 10 January.
20 A separate peak of 3.10 m GH was recorded over the period 1500-1600 hours on Monday 10 January.

8.2 WATER LEVEL HYDROGRAPHS

8.2.1 Upper Tributaries of Lockyer Creek

Figure 8.2 shows water level hydrographs recorded in Murphys Creek at Spring Bluff (143 219A), Lockyer Creek at Helidon (540 143) and Flagstone Creek at Brown-Zirbels Road (143 233A). Details of these stations are shown in Table 8.2. The following flood behaviour is apparent in Figure 8.2:

- There were four separate and distinct flood events down the upper Lockyer Creek system over the period 9-13 January, as is apparent in the continuous record for Murphys Creek at Spring Bluff and Flagstone Creek at Brown-Zirbels Road.
- A double-peaked flood event is apparent at all three stations from around 1500 hours on Sunday 9 January to around 0600 hours on Monday 10 January.
- The flood that caused the devastation and loss of life along Lockyer Creek and its upper tributaries is apparent in the steep rise in water levels at Spring Bluff on Murphys Creek and at Helidon Alert on Lockyer Creek around 1330 hours on Monday 10 January. It is noted that both gauges at Helidon failed[21]. The indicated peak water level on Figure 8.2 is not the actual peak water level (unknown), but the recorded level immediately before the gauge failed.
- The second of flood event in Flagstone Creek, which peaked at 6.49 m GH around1640 hours on Monday 10 January, corresponds to the flash flood down Lockyer Creek. The third event down Flagstone Creek was notably higher (at 8.78 m GH) than the second.

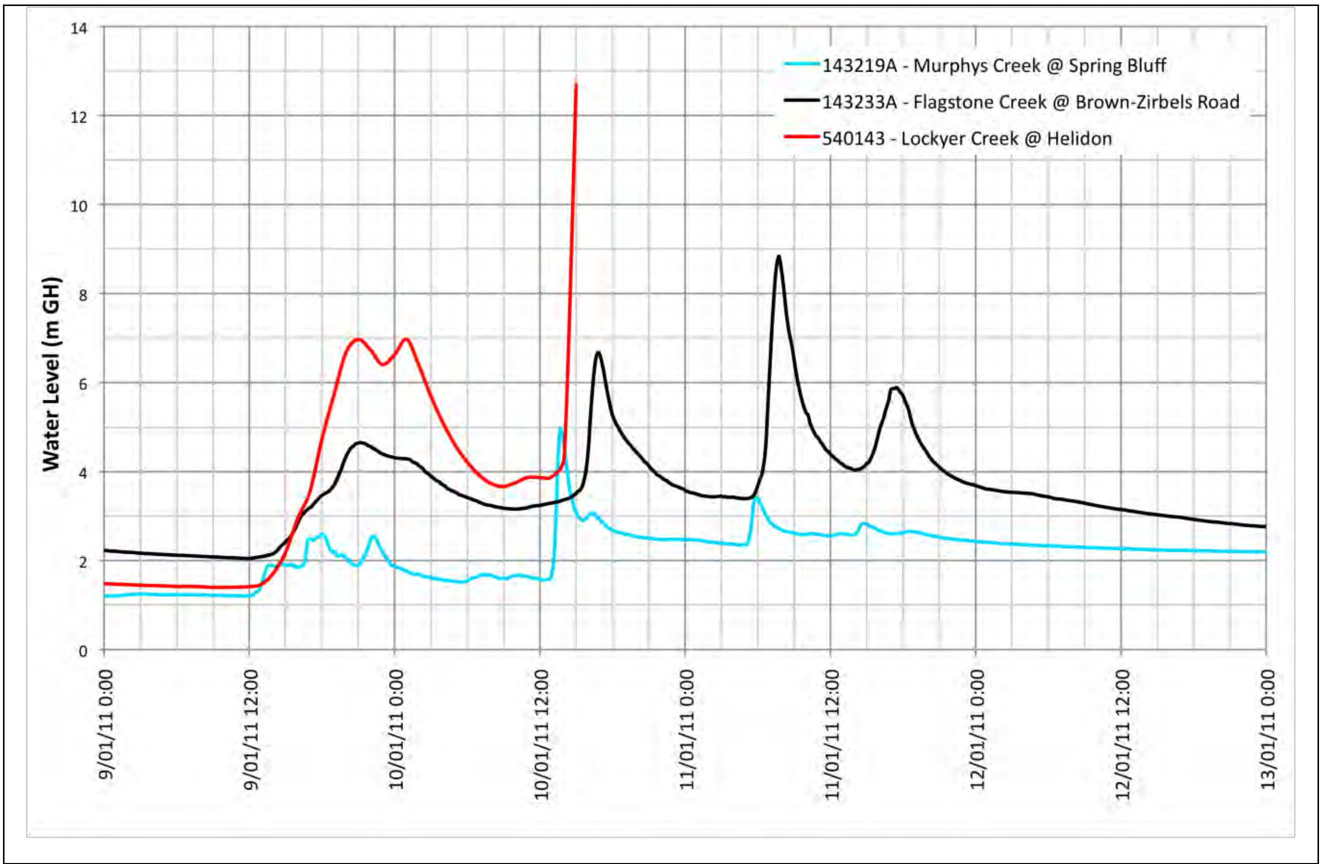

Figure 8.2 Water level Hydrographs, Upper Tributaries of Lockyer Creek

[21] Gauge 143 203C failed before it started recording the rising limb of the Monday afternoon flood event.

Figure 8.3 shows discharge hydrographs recorded in Murphys Creek at Spring Bluff (143 219A), in Lockyer Creek at Helidon Alert (540 143) and in Flagstone Creek at Brown-Zirbels Road (143 233A). Details of these stations are shown in Table 8.2. The following flood behaviour is apparent in Figure 8.3:

- The pronounced 'flood spike' on Monday afternoon is readily apparent at Spring Bluff on Murphys Creek and demonstrates typical flash flood behaviour: a rapid rise and fall in discharges. The estimated peak discharge at this station was some 360 m^3/s, a very substantial output from a catchment area of only 18 km^2.
- At Helidon, the twin-peaked flood event from 1500 hours on 9 January to 0600 hours on 10 January was substantial, with estimated peak discharges[22] of around 850 m^3/s. As noted above, the gauge at Helidon malfunctioned on the rising limb of the Monday afternoon flood at a water level of 12.74 m GH. According to the DERM rating tables, the estimated discharge associated with this water level is some 3,000 m^3/s. The peak discharge at Helidon will have been higher.
- The estimated peak discharge down Flagstone Creek for the Monday afternoon event was some 190 m^3/s. Thus, this flood event will not have substantially added to the peak flow in Lockyer Creek. The estimated peak discharge for the following flood event in Flagstone Creek (Event No. 3) was some 520 m^3/s.

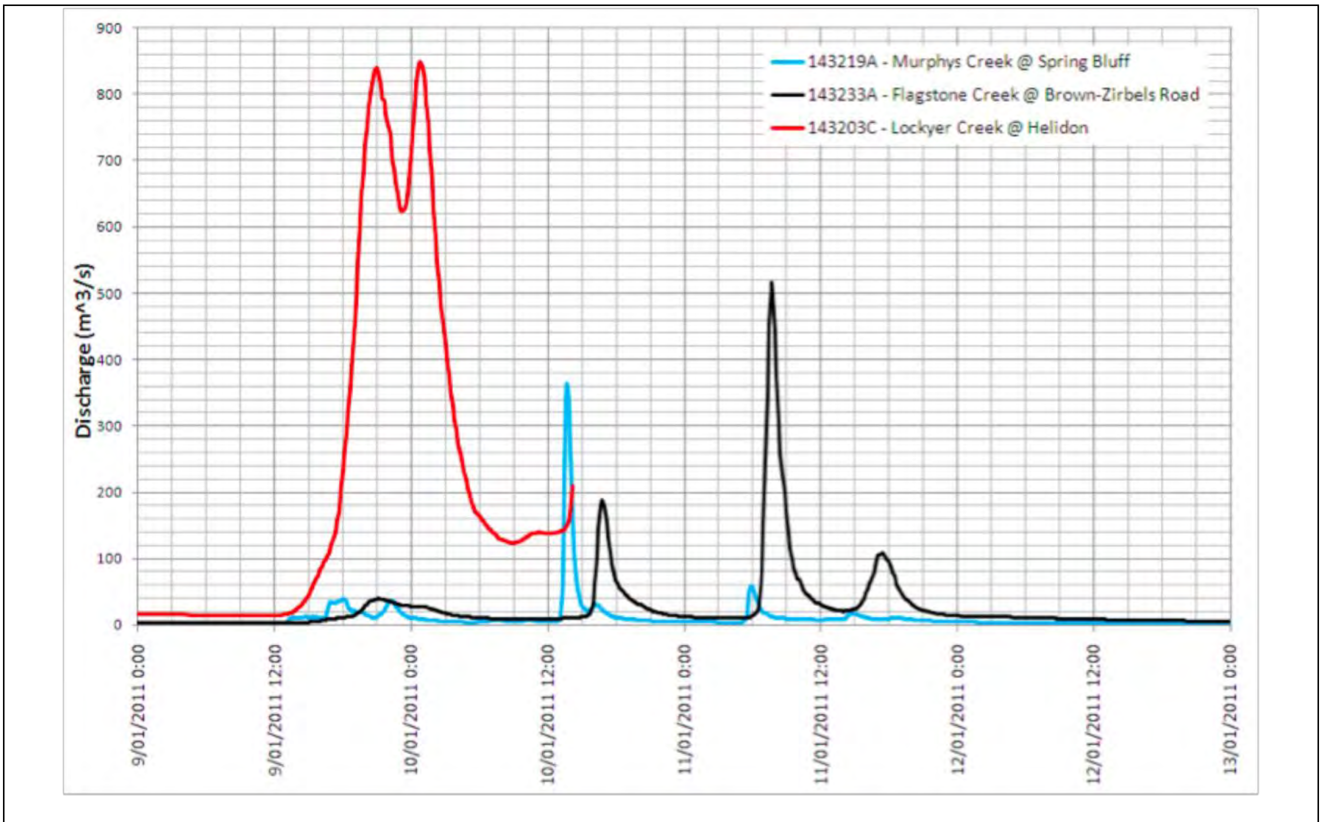

Figure 8.3 Discharge Hydrographs, Upper Tributaries of Lockyer Creek

8.2.2 Middle Reaches of Lockyer Creek

Figure 8.4 shows water level hydrographs recorded in Locker Creek at Helidon Alert (540 143), at Gatton at Gatton Alert (540 156) and Gatton (540 363), and at Glenore Grove Alert (540

[22] DERM has established rating curves at its various gauging stations on the basis of gauged (measured) discharges and open channel flow hydraulic formulae. Most of the stations referred to in this report have only been gauged to several m^3/s. Thus, estimated discharges, especially peak discharges, are based solely on hydraulic formulae. The appropriateness of these rating curves has not been checked.

149). Details of these stations are shown in Table 8.2. It is noted that Gatton is some 27 km downstream from Helidon and Glenore Grove is 20 km downstream from Gatton.

The following flood behaviour is apparent in Figure 8.4:

- The flood event of Sunday night 9 January is readily apparent at all four stations, although the twin peaks at Helidon have disappeared by the time the floodwave reaches Gatton.
- The flash flood event of Monday afternoon and the failure of the gauges at Helidon and Gatton are apparent, as is the remnant of the flash flood event at Glenore Grove. These aspects are discussed in greater detail in Section 8.3.

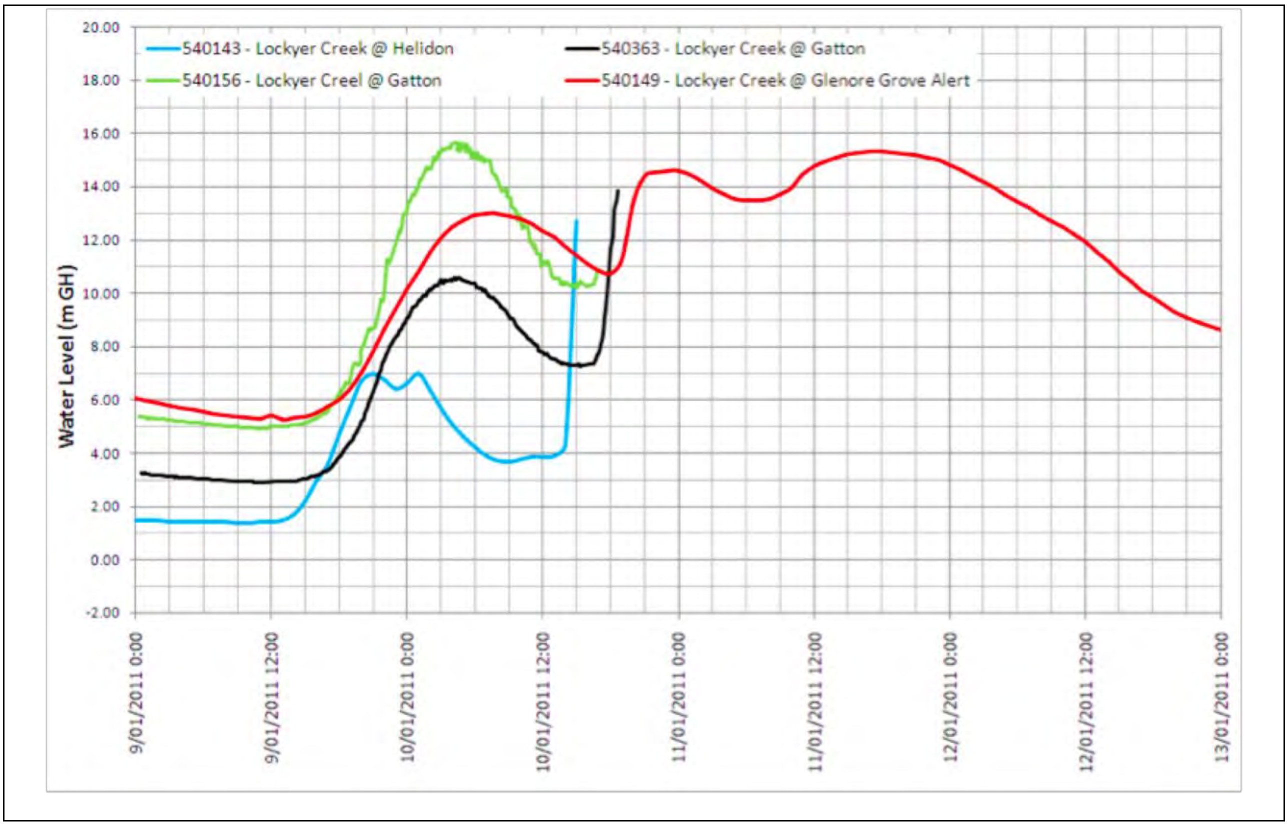

Figure 8.4 Water Level Hydrographs, Middle Reaches of Lockyer Creek

8.2.3 Middle Tributaries of Lockyer Creek

Figure 8.5 shows water level hydrographs recorded in Ma Ma Creek at Harms (143 213C), in Tenthill Creek at Tenthill (143 212A) and in Sandy Creek (N) at Sandy Creek Road (540 386), tributaries draining to the middle reaches of Lockyer Creek. Details of these stations are shown in Table 8.2.

The following flood behaviour is apparent in Figure 8.5:

- The four flood events of the upper reaches of Lockyer Creek are also apparent in tributaries draining to the middle reaches. These four events are especially apparent at the Sandy Creek Road gauge on Sandy Creek (N), which drains through Grantham.
- In Ma Ma Creek, water level behaviour has become a little more complex because of the vagaries of rainfall over this catchment. The flood event of Monday afternoon is apparent (Event No. 2), but is preceded immediately by a minor flood sub-peak. The sharp rise in water levels associated with the main Monday afternoon event is readily apparent. The third peak is preceded by a minor flood sub-peak and followed by another

minor flood sub-peak. As in Flagstone Creek, the third flood event is substantially larger than the second (Monday afternoon) flood event.

- In Tenthill Creek, the Monday afternoon event is readily apparent, but has a more ‘normal’ flood appearance, with gentler rising and falling limbs. The third flood event in Tenthill Creek has ‘absorbed’ the preceding and following sub-peaks apparent in Ma Ma Creek, and is seen to be substantially larger than the second Monday afternoon peak.

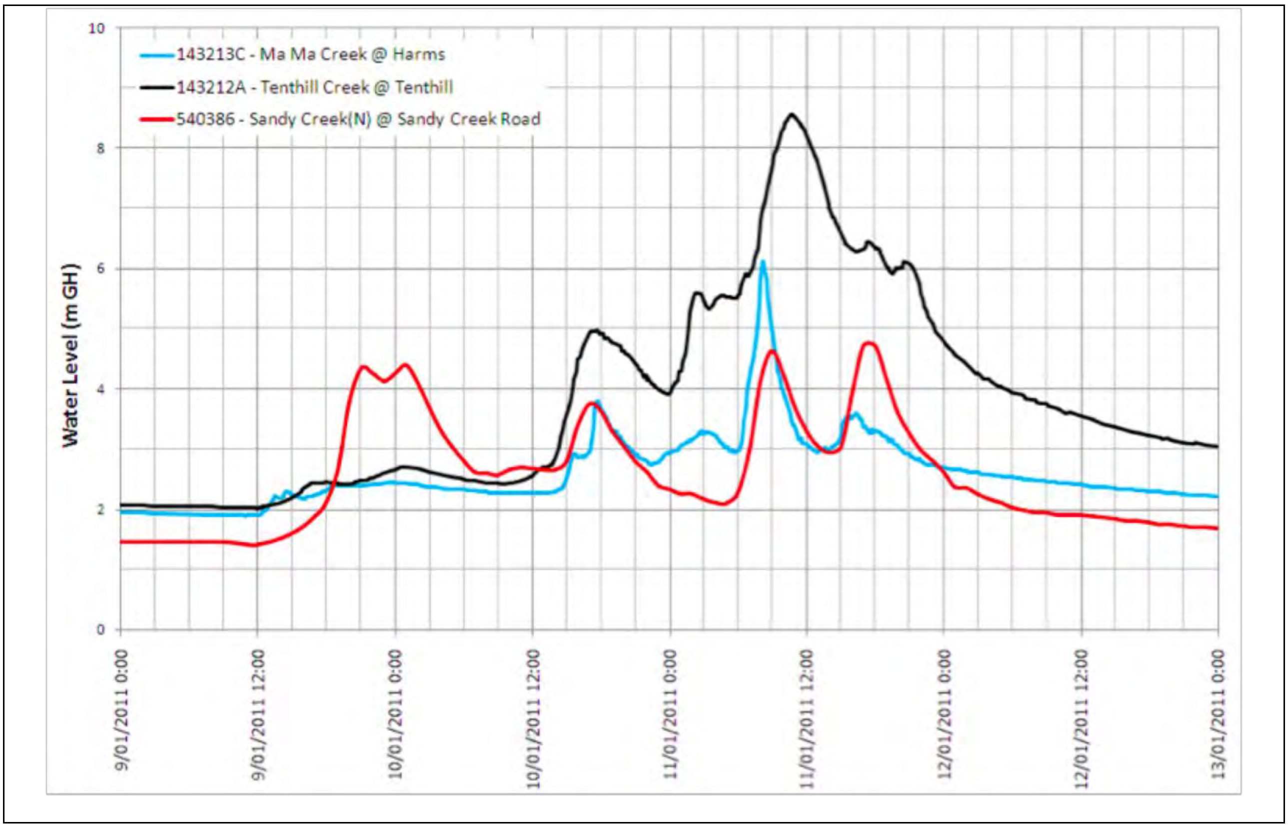

Figure 8.5 Water Level Hydrographs, Lower Tributaries of Lockyer Creek (1)

8.2.4 Lower Tributaries of Lockyer Creek

Figure 8.6 shows water level hydrographs recorded in Sandy Creek (S) at Forest Hill (143 232A), and in Laidley Creek at Mulgowie (143 209B) and at the Warrego Highway (143 229A), tributaries draining to the lower reaches of Lockyer Creek. Details of these stations are shown in Table 8.2.

The following flood behaviour is apparent in Figure 8.6

- Sandy Creek is a tributary of Laidley Creek. Three runoff events are apparent in Sandy Creek at Forest Hill. The second of these events corresponds to the Monday afternoon flood down Lockyer Creek. The third event is of considerably longer duration than the second event, lasting from around 0400 hours to 2400 hours on Tuesday 11 January. The flat nature of water levels during flood events is indicative of flow over a weir of substantial width (a small rise in water level produces a large increase in discharge). In this case, Sandy Creek at Forest Hill has limited channel capacity and, as a consequence, the creek broke its banks upstream of the town. These breakout flows travelled across a wide flat floodplain (including the township of Forest Hill). The Monday afternoon flood event is seen to have muted rising and falling limbs and is typical of a ‘normal’ flood.

- The Monday afternoon flood event is readily apparent at Mulgowie on Laidley Creek. Again, this is a 'normal' flood event, rather than a flash flood of the ilk that battered its way down the upper and middle reaches of Lockyer Creek. It is noted that runoff at Mulgowie commenced considerably earlier (around 0900 hours) than runoff at Spring Bluff (around 1300 hours) or Helidon (around 1330 hours). This reflects earlier rainfalls over the Laidley Creek catchment (which did not receive the intense rainfalls of the upper northwestern Lockyer Creek tributaries). It is noted that the gauge at Mulgowie malfunctioned during the third flood peak (Tuesday) and it is not clear whether the third peak was higher than the peak of Monday afternoon.
- Water level behaviour in Laidley Creek at the Warrego Highway reflects the three upstream flood peaks in Sandy Creek and Laidley Creek at Mulgowie. The flood peak of Monday afternoon arrives in the early hours of Tuesday morning, before being swamped the following third flood peak. Again, flood behaviour in Laidley Creek at the Warrego Highway is characteristic of 'normal' floods. It is noted that the gauge in Laidley Creek at Warrego Highway also malfunctioned around over the peak of the third flood event. The flat nature of water levels during the third flood peak is indicative of significant breakout flows over a wide flat floodplain upstream of the streamgauging station.

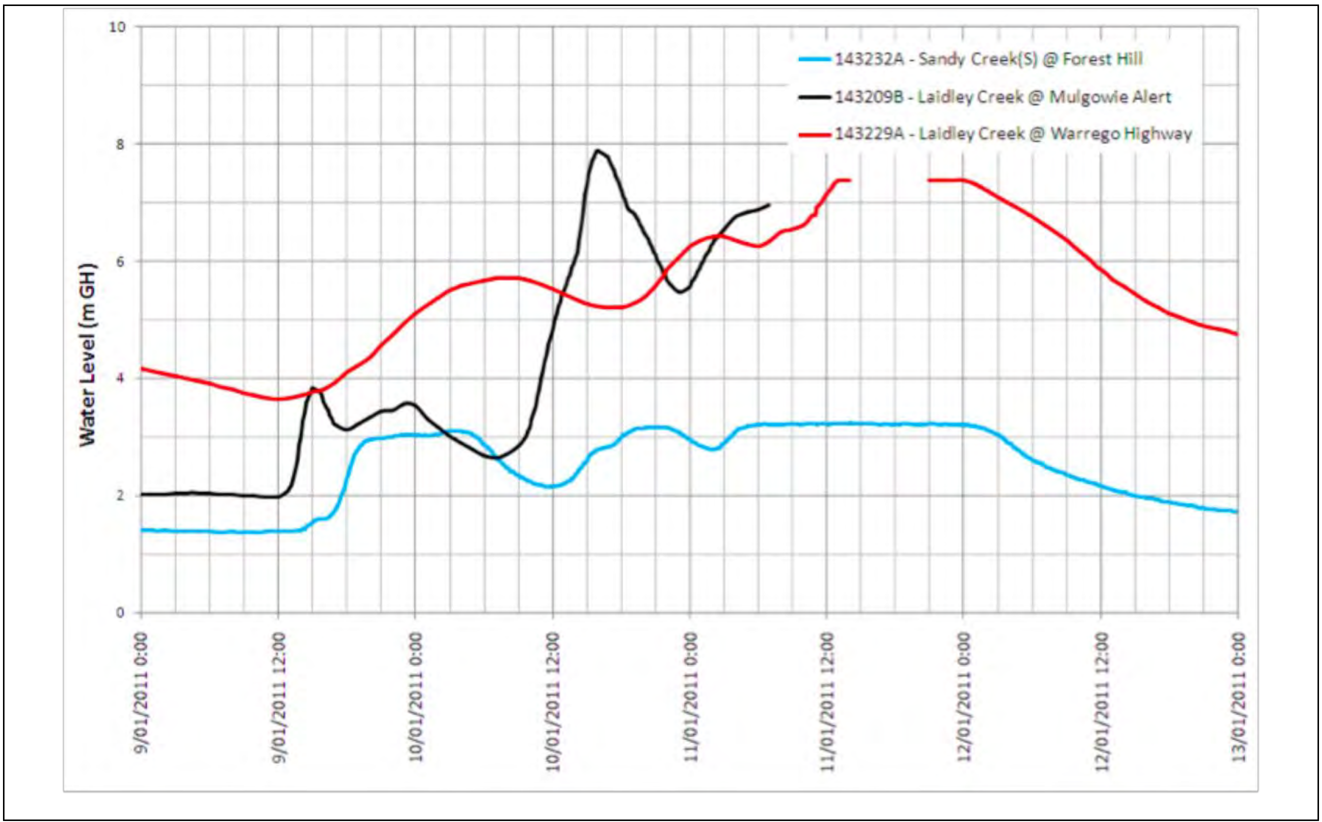

Figure 8.6 Water Level Hydrographs, Lower Tributaries of Lockyer Creek (2)

Figure 8.7 shows discharge hydrographs recorded in Ma Ma Creek at Harms (143 213C), in Tenthill Creek at Tenthill (143 212A), and in Laidley Creek at Mulgowie (540 143). Details of these stations are shown in Table 8.2.

The following flooding behaviour is apparent in Figure 8.7:

- The Monday afternoon flood event is apparent at all three stations, but has modest peak discharges: 130 m^3/s in Ma Ma Creek at Harms, 220 m^3/s in Laidley Creek at Mulgowie, and 240 m^3/s in Tenthill Creek at Tenthill.

- The third flood event in Ma Ma Creek and Tenthill Creek had considerably higher discharges (510 m³/s and 1,100 m³/s respectively). The gauge at Mulgowie on Laidley Creek malfunctioned before the peak of the third flood event. Tenthill Creek at Tenthill and Laidley Creek at the Warrego highway have similar catchment areas (450 km² and 445 km² respectively). From Figures A9 to A11 of Appendix A, it is expected that both catchment received similar rainfalls over the period 0500-1600 hours on Tuesday 11 January. Thus, the runoff and peak discharge of both catchments at these locations are also expected to be similar, and it is concluded that Laidley Creek was delivering a substantial flood to Lockyer Creek in the late hours on Tuesday night or the early hours of Wednesday morning.

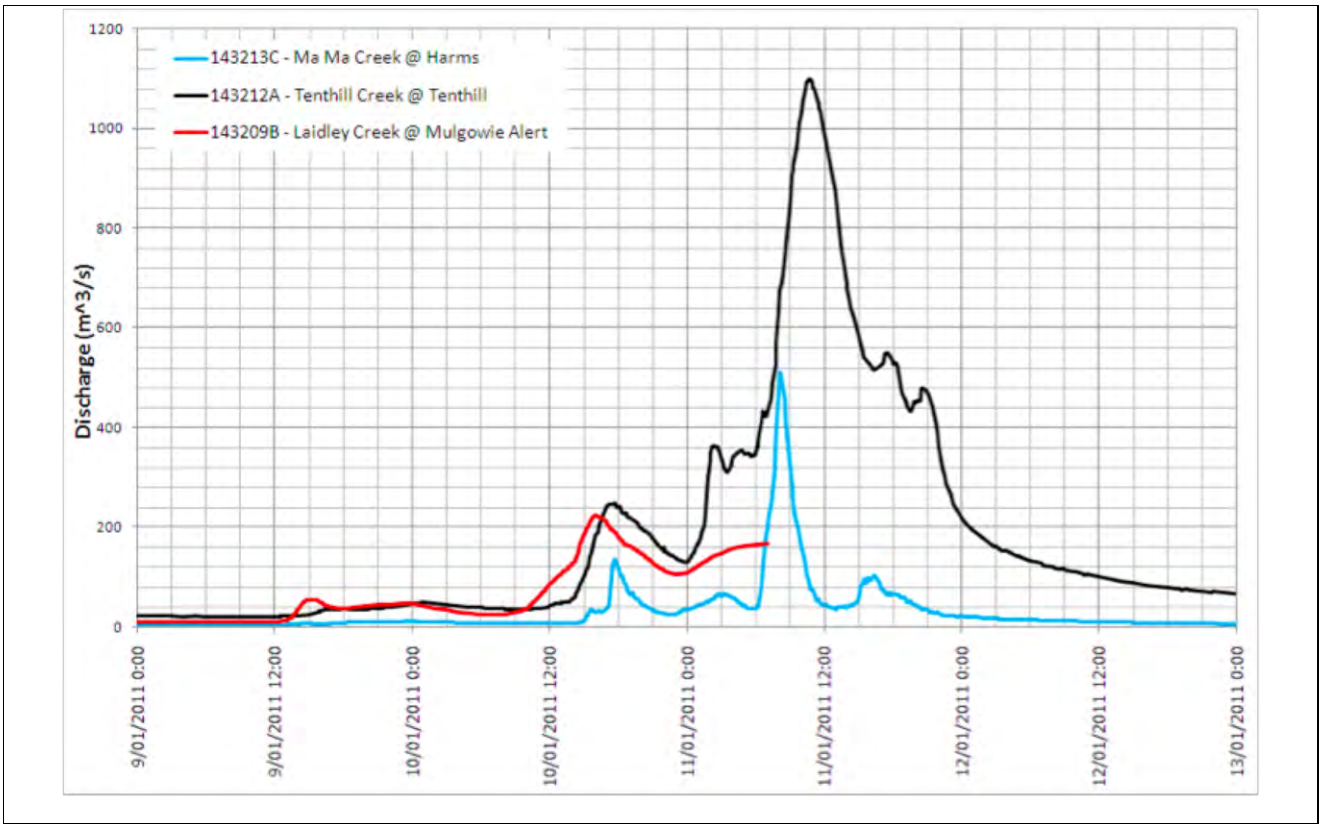

Figure 8.7 Discharge Hydrographs, Lower Tributaries of Lockyer Creek

8.2.5 Lower Reaches of Lockyer Creek

Figure 8.8 shows water level hydrographs recorded in Lockyer Creek at Glenore Grove (540 149), Lyons Bridge (540 174) and O'Reillys Weir (540 153), and in the Brisbane River at Lowood (540 183). Details of these stations are shown in Table 8.2. It is noted that the Glenore Grove and Lyons Bridge stations on Lockyer Creek encompass all of the tributaries discussed above, and that between Lyons Bridge and O'Reillys Weir, the substantial tributary, the easterly flowing Buaraba Creek, enters the Lockyer. The following flood behaviour is apparent in Figure 8.8:

- Three distinct flood events are apparent at Glenore Grove. The second of these events represents the remnants of the Monday afternoon flash flood travelling down Lockyer Creek. The rate of rise of this event is much steeper than the rates of rise of the other two events, thereby confirming its 'flash flood' heritage. It is noted that the peak water level of the Monday afternoon event (14.6 m GH) is a little higher than that of the first event (12.8 m GH) and only a little less than that of the third event (15.3 m GH). Further, the Monday afternoon event has an extended peak. Thus, evidence of the upstream flash flood spike has all but disappeared by the time the flood wave reaches Glenore Grove.

- The third flood event at Glenore Grove reflects the widespread, moderate rainfalls that occurred over the period 0300-1800 hours on Tuesday 11 January (see Figures B4 to B6 of Appendix B). These rains caused a peak flow in Flagstone Creek at Brown-Zirbels Road of 520 m³/s (at 0745 hours on Tuesday morning), in Ma Ma Creek at Harms of 510 m³/s (at 0810 hours on Tuesday morning), and in Tenthill Creek at Tenthill of 1,100 m³/s (at 1030 hours on Tuesday morning). The gauge in Laidley Creek at Mulgowie malfunctioned and did not record the third flood event.
- By the time the three upstream flood waves reach Lyons Bridge, which is some 32 km downstream from Glenore Grove and 29 km upstream from the confluence of Lockyer Creek and the Brisbane River, the three events have coalesced into a single flood wave that peaks around 1800 hours on Tuesday 11 January. The rise associated with the remnants of the flash flood wave is perhaps still discernible over the period 0000 to around 1200 hours on Tuesday 11 January.
- At O'Reillys Weir, which is located 1.4 km upstream from the confluence with the Brisbane River, the most noticeable aspect of flooding behaviour is the increase in water levels associated with the releases from Wivenhoe Dam over the period from around 0600 hours on Tuesday 11 January to around 0300 hours on Wednesday 12 January (see ICA, 2011b for details). The rise in water levels at O'Reillys Weir induced by releases from Wivenhoe Dam occurs several hours after the water level increase at Lowood.
- Backwater effects from dam releases into the Brisbane River may have penetrated as far upstream along Lockyer Creek as Lyons Bridge, where a slight increase in water levels is discernible over the period 1200-1800 hours on Tuesday 11 January.

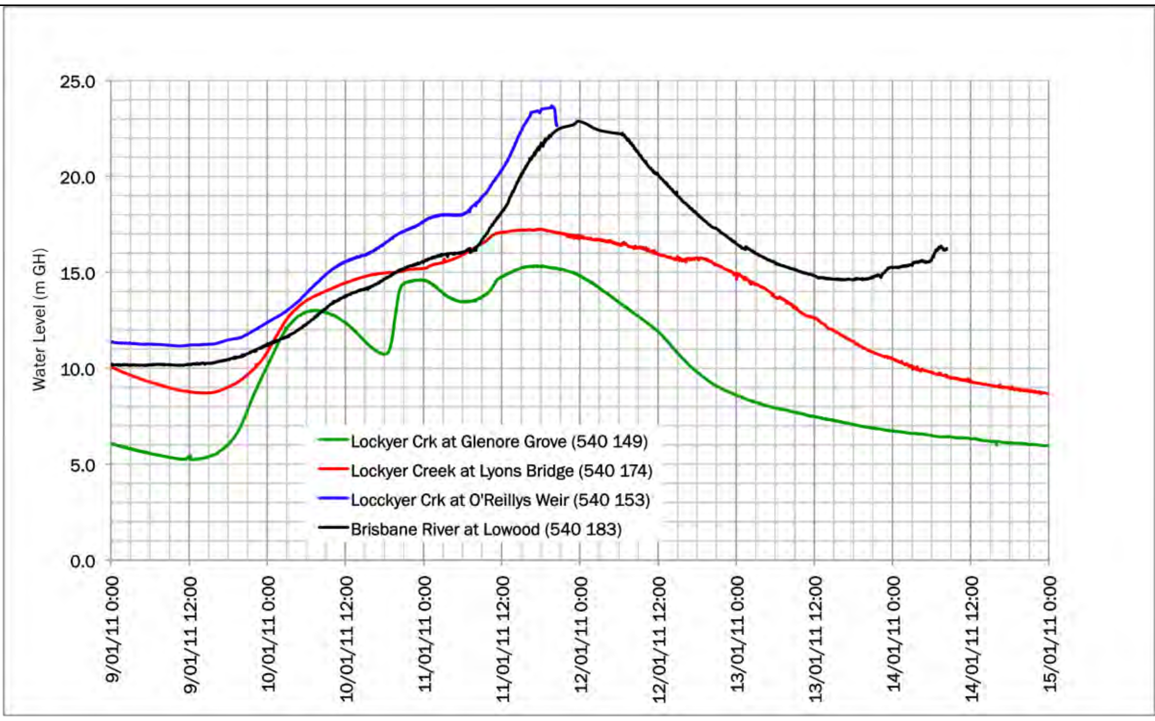

Figure 8.8 Water level Hydrographs, Lower Reaches of Lockyer Creek

8.3 FLOODING BEHAVIOUR

8.3.1 Flash Flood Along the Upper and Middle Reaches of Lockyer Creek

Onset of Flooding and Floodwave Velocity

On the basis of rainfall intensities and severities recorded at the Prince Henry Drive pluviograph operated by Toowoomba Council (SPS 42), It is inferred that he intense rainfalls of short duration (1-2 hours) with severities of greater than 100-Years ARI that fell over the upper western and northwestern tributaries of Lockyer Creek, generating 'flash floods' that pummelled their way down the tributaries to coalesce into the flash flood that travelled down Lockyer Creek on the afternoon of Monday 10 January.

The period of most intense rainfall at the Prince Henry Drive and Toowoomba Alert pluviographs (SPS 42 and 540 162) occurred between 1300 and 1400 hours on Monday afternoon 10 January. Thus, the flash flood producing rainfalls probably commenced between 1300 and 1400 hours on the Monday afternoon. Table 8.3 shows the time of arrival (onset of flooding) at locations down Lockyer Creek between Spring Bluff and Glenore Grove. Also shown are estimated discharges and the velocity of the flood wave.

The following aspects of Table 8.3 are noted:

- As far downstream as Gatton, the onset of flooding occurred within 6 hours of the commencement of the flood-producing rains. Downstream as far as Grantham, it can be inferred that flood levels peaked within 6-hours of commencement of the flood-producing rains, so formally qualifying the Monday afternoon flood down Lockyer Creek as a 'flash flood' according to the terminology of this Report (see Section 3.2.3).
- Between Spring Bluff and Helidon, the velocity of the flood wave was 16 km/hr (4.4 m/s), between Helidon and Gatton, the velocity was 12 km/hr (3.3 m/s), and from Gatton to Glenore Grove, the velocity was also some 12 km/hr (3.3 m/s). Note that this velocity refers to the speed of the floodwave; actual water velocities will have been higher, especially in and immediately adjacent to deeper flows, perhaps by a factor of 1.5 or more.

Table 8.3 Details of Flash Flood, Lockyer Creek and Tributaries, Monday afternoon 10 January 2011.

Location	Gauge No.	AMTD (km)	Onset of Flooding	Estimated Peak Discharge (m^3/s)	Velocity of Flood Wave (km/hour)
Spring Bluff	143 219A	130	1220 hours	350	-
Helidon	540 143	99	1420 hours	3,000 (3,500-4,000)[a]	16 (S. Bluff-Helidon)
Downstream of Confluence of Monkey Waterholes Creek	-	96	1430[a] hrs	4,000-4,500[a]	10[b]
Grantham	-	87	1500-1530[a] hrs	3,500-4,000[a]	14[a] (Helidon-Grantham)
Gatton	540 156	72	1630 hours	2,500-3,000[a]	12 (Helidon-Gatton)
Glenore Grove	540 149	52	1800 hours	2,500-3,000[a]	12 (Gatton-G.Grove)

[a] Inferred/estimated

Peak Discharge Estimates

Estimates of peak discharges along Lockyer Creek can be inferred from the available data and from site inspection. First, as already noted, the Prince Henry Drive pluviograph (SPS 42) is located close to the headwaters of both Rocky Creek and Monkey Waterholes Creek, and it is inferred that significant flash flood flows occurred down both creeks on the Monday afternoon. Rocky Creek enters Lockyer Creek immediately upstream of Helidon, and the gauge at Helidon will have recorded the contribution of Rocky Creek flows to Lockyer Creek flows. Monkey Waterholes Creek enters Lockyer Creek immediately to the south of Helidon and the Warrego Highway and immediately upstream of 'Murphys Bridge' on the Back Flagstone Road.

Inspection of Lockyer Creek at this site indicated that Monkey Waterholes Creek had delivered a large volume of water to Lockyer Creek, reinforcing and amplifying the Lockyer Creek flash flood as it passed downstream.

The following estimates of peak flood discharge can be made (see Table 8.3):

- The estimated discharges at Spring Bluff and Helidon shown in Table 8.3 are taken from DERM's rating curves for these stations. It is noted that the gauge at Helidon failed before the peak as reached. Using DERM's estimate of 3,000 m^3/s at a water level of 12.74 m GH as a foundation, it can be inferred that the actual peak discharge at Helidon was in the range 3,500-4,000 m^3/s.
- An approximate estimate of the discharge at the railway bridge at Murphys Creek township indicates a value of perhaps 1,000-1,500 m^3/s.
- Immediately downstream of Helidon, Monkey Water Holes Creek joins Lockyer Creek. The combined peak discharge in Lockyer Creek immediately downstream of the confluence was estimated to be approximately 4,000-4,500 m^3/s.
- On Monday afternoon, the peak discharge in Flagstone Creek at Brown-Zirbels Road (catchment area 157 km^2) was a modest 190 m^3/s and occurred around 1700 hours (see Figure 8.3). Thus, inflows from Flagstone Creek provided little reinforcement to the flash flood as it travelled downstream along Lockyer Creek.
- Immediately downstream of Grantham, Ma Ma Creek joins Lockyer Creek, and further downstream Tenthill Creek also flows into the Lockyer (upstream of Gatton). On the Monday afternoon, only modest flows were recorded in Ma Ma Creek at Harms (catchment area 227 km^2) and in Tenthill Creek at Tenthill (catchment area 450km^2). The peak discharges were respectively 130 m^3/s and 240 m^3/s. Thus, it is further concluded that inflows from Ma Ma Creek and Tenthill Creek at best provided some compensation for the attenuation of the flash flood as it travelled downstream.
- Based on the above figures, it is inferred[23] that the peak discharge in Lockyer Creek at Grantham was perhaps some 3,500-4,000 m^3/s and at Gatton, was perhaps some 2,500-3,000 m^3/s. It is noted that the Lockyer Creek floodplain broadens out downstream of Quarry Bend, ie some 3 km upstream from Grantham. It is expected that the flash floodwave underwent significant attenuation as it passed down this reach of creek and spilled out onto the northern flats where Grantham is located. The flood wave underwent further considerable attenuation between Grantham and Gatton. (The growth and attenuation of the flash floodwave is discussed later in this Section).
- Finally, what of the peak discharge at Glenore Grove? Between Gatton and Glenore Grove, Laidley Creek enters the Lockyer. The only discharge estimate available for Laidley Creek at the time of writing this Report was a peak discharge of 220 m^3/s at Mulgowie Alert (catchment area 167 km^2), which occurred at 1600 hours on Monday afternoon. The catchment area of Laidley Creek to the Warrego Highway is some 445 km^2. In the 24-hours to 0900 hours on Tuesday 11 January, the heaviest rains over Laidley Creek were upstream of Mulgowie Alert station (see *Figure 7.5*). So perhaps Laidley Creek delivered some 300-350 m^3/s to Lockyer Creek on the evening of Monday 10 January. This would have offset some of the attenuation that occurred between Gatton and Glenore Grove and suggests that the peak discharge at Glenore Grove may have been maintained in the range 2,500-3,000 m^3/s.

In passing, it is noted that the estimated peak discharges at Helidon, and Grantham are high, and amount to about 50-percent of the peak release of some 7,500 m^3/s from Wivenhoe Dam over the critical period 0600 hours on Tuesday 11 January to 0300 hours on Wednesday 12 January. Thus, the Monday afternoon flood at Helidon, Grantham and at locations further upstream was a very significant event.

[23] Hydrological modelling of the complete catchment of Lockyer Creek down to Glenore Grove is required to provide more accurate assessments of peak flood flows.

Rate of Water Level Rise

Table 8.4 shows details of the recorded rise in water levels at Spring Bluff, Helidon, Gatton and Glenore Grove. Details are given of the total rise in water levels over the rising limb of the stage hydrograph and the maximum rate of rise, which is determined over the steepest period of the rising limb. It is noted that the estimates at Helidon and Gatton are based on incomplete records of the rising limb of the stage hydrograph at these locations. The followings aspects of flooding behaviour can be inferred from Table 8.4:

- The greatest maximum rates of rise were recorded at Spring Bluff and Helidon. The total rise and maximum rate of rise were greatest at Helidon. It is noted that the gauging stations at Helidon are upstream of the Warrego Highway embankment and bridge. The constriction in creek width at this location and these structures impede flows in Lockyer Creek, especially high flood flows, and will accentuate the rate of rise recorded at these gauging stations. The high rates of rise at Spring Bluff and Helidon reflect the intensity and severity of upstream rainfalls, the generally steep and narrow nature of upstream creek cross-sections, and the impeding effects of the Warrego highway embankment and Bridge at Helidon.
- The rate of rise at Gatton is considerably less than at Helidon and indicates that the flash flood wave had attenuated substantially by the time it reached Gatton. In passing, it is noted that locals referred to the flood in Gatton as a ‘normal’ flood characterized by ‘normal’ flood behaviour (normal rates of rise and fall). As noted above, only modest inflows entered Lockyer Creek on the Monday afternoon from Flagstone and Ma Ma Creeks and provided little if any reinforcement to the flood wave in Lockyer Creek as it passed downstream. It well may be that the flash flood wave underwent significant attenuation by moving upstream along the lower reaches of these creeks as it passed their confluences[24]. Whatever the reason, it is concluded that the flash flood wave had undergone significant attenuation and had lost most of its sting by the time it reached Gatton.
- The maximum rate of rise at Glenore Grove was the least of the four stations and reflects additional attenuation as the flood wave travels downstream.

Table 8.4 Rates of Water level Rise, Monday Afternoon 10 January Flash Flood, Lockyer Creek

Location	Gauge No.	Catchment Area (km^2)	Total Rise (m)	Max. Rate of Rise (m/hour)
Spring Bluff	143 219A	18	3.4 m in 50 mins	6.7 (over 20-mins)
Helidon	540 143	350	8.3 m in 48 mins[a]	21.1 (over 12-mins)
Gatton	540 163	1,550	7.7 m over 17.3 hrs[a]	4.8 (over 50-mins)
Glenore Grove	540 149	2,230	4.0 m over 3.6 hrs	2.3 (over 60-mins)

[a] Based on an incomplete record of the rising stage. The total rise will be greater than the indicated value. The maximum rate of rise should be representative of the true value.

Figure 8.9 shows a series of photos taken across Lockyer Creek from a farm that is thought to be on the northern side of Lockyer Creek between the confluences of Monkey Water Holes and Flagstone Creeks. Based on these photos, the rate of rise of floodwaters can be estimated to be approximately 10-14 m/hour at this location, which is consistent with the estimate at Helidon (which will be greater because of the constricting effect of the Warrego highway embankment and bridge).

[24] It is noted that the town of Carpendale lies on the eastern bank of the lower reaches of Lockyer Creek. Properties in Carpendale were flooded, but this township was not inspected. If the flooding occurred on the Monday afternoon, it would have been caused by backflows from the Lockyer Creek flash flood moving upstream along the lower reaches of Flagstone Creek. If the flooding occurred on the Tuesday, it would have been associated with the ‘normal’ flood event moving down the creek (Event No. 3 of Figure 8.3, which peaked at Brown-Zirbels Road at 0930 hours on the Tuesday).

Figure 8.9 Time Sequence of Photos Showing Flooding in Lockyer Creek, Monday Afternoon 10 January (Source: Unknown)

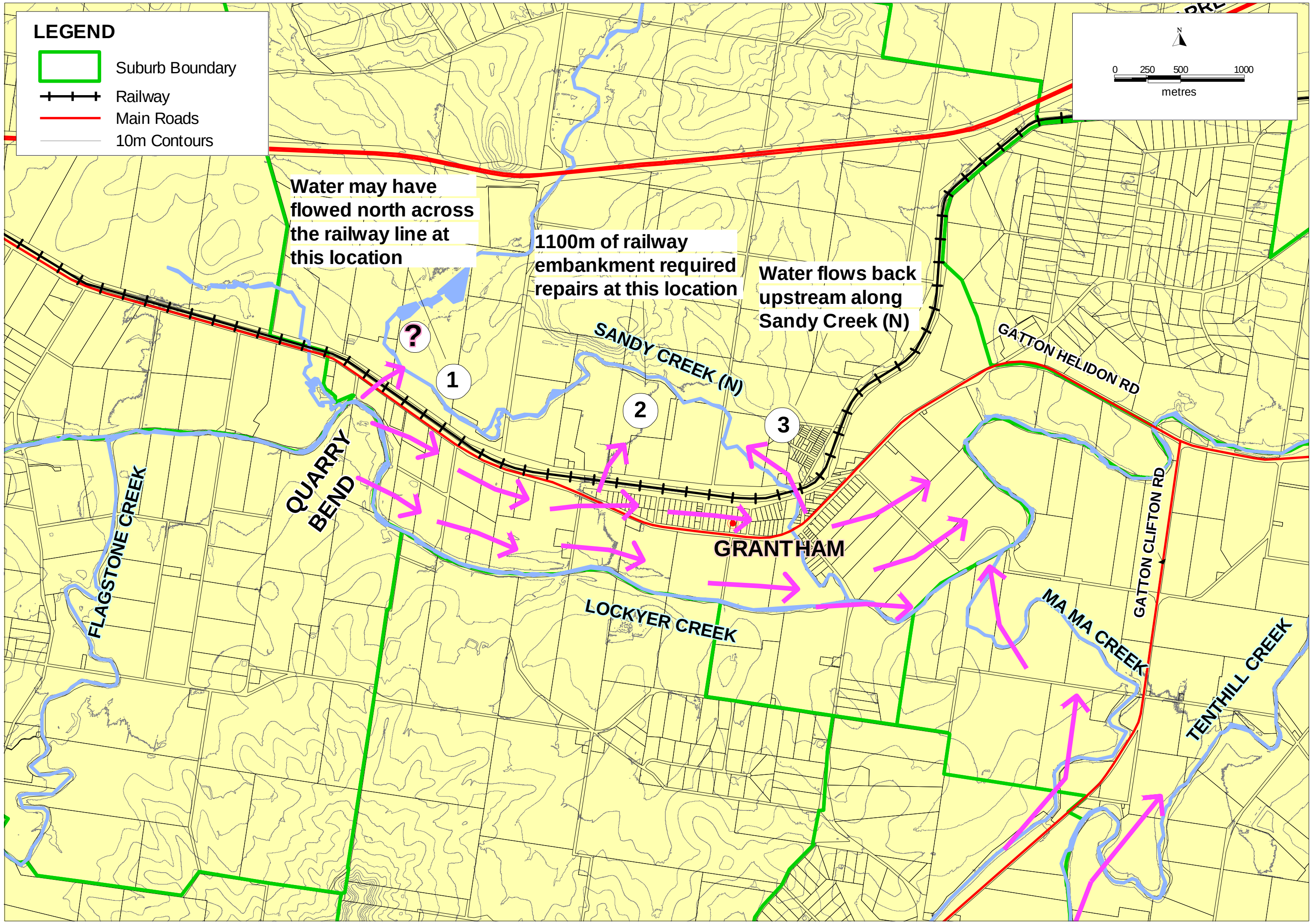

Figure 8.10 Locality and Flooding Behaviour Map, Grantham, Monday afternoon 10 January Flash Flood Event

Reports in the Press indicated that a number of people in Grantham likened flooding behaviour on Monday afternoon to that of an 'inland tsunami'. Whilst the rate of water level rise along the upper and middle reaches of Lockyer Creek was extreme for a rainfall flood event, it is sobering to realize that the recent Japanese tsunami inflicted water level rises of 10 m in 15-seconds on all in its path.

Grantham

The flash flood passing down Lockyer Creek on Monday afternoon devastated the township of Grantham and took 13 lives. Some care has been taken to interpret as fully as possible the flooding behaviour that devastated Grantham. To investigate this fully requires the use of a hydraulic flood simulation model, which is beyond the scope of this investigation.

Figure 8.10 is a locality map of Grantham. Sandy Creek (N), a tributary of Lockyer Creek, drains a relatively small catchment area to the north of Grantham. The township has been built along the northern floodplain of Lockyer Creek. Most of the houses in Grantham, along with most of the commercial establishments, have been built on the floodplain flats between the railway and Lockyer Creek in an area that is referred to as the 'southern development' in this report. The developed area of Grantham to the north of the railway line and to the east of Sandy Creek (N) is on high ground and was not flooded on Monday afternoon.

A flood event occurred down Sandy Creek (N) on Sunday night 9 January (see Figure 8.5), during which Sandy Creek (N) reportedly 'backed up' because of high water levels in Lockyer Creek (presumably caused by the Sunday evening flood passing downstream: see Event No. 1 at Helidon and Gatton in Figure 8.4). This 'backing up' was in accord with 'normal' flooding experience of Sandy Creek (N) in Grantham. The Sunday night flood was followed by a smaller flood event from Sandy Creek (N) on Monday afternoon, when the gauge at Sandy Creek Road (540 386) peaked at 3.7 m GH around 1700 hours. It is recalled that the onset of flooding in Grantham occurred around 1500-1530 hours. So as the Lockyer Flash flood was peaking or on the wain, additional floodwaters will have come down Sandy Creek (N) into the township.

Figure 8.10 also shows the inferred flood behaviour on Monday afternoon. This flooding behaviour has been determined on the basis of a site inspection of the area and likely flows in Lockyer Creek and its immediate tributaries.

The following factors influenced flooding in Grantham on Monday afternoon 10 January:

- It is recalled that flows down Flagstone Creek were modest on the Monday afternoon. The discharge at Brown-Zirbels Road peaked at 190 m^3/s at 1700 hours. This discharge will have taken a further 2-3 hours to travel down the remainder of Flagstone Creek and enter Lockyer Creek. Thus, 'natural' discharges from Flagstone Creek[25] are not expected to have played any substantial role in flooding behaviour at Grantham, but may have prolonged higher water levels into the night.
- As the flash flood passed down Lockyer Creek, the creek broke its northern banks at 'Quarry Bend' with overbank flows surging northwards and eastwards. Initially the railway embankment corralled these flows and directed them eastwards towards Grantham. Substantial and deep easterly flows occurred across the northern floodplain. These flows crossed the Gatton-Helidon Road and swept through the southern development of Grantham.
- Some of these floodplain flows surged back upstream along Sandy Creek (N), passing under the railway bridge. The remainder continued to flow eastwards.
- As flood levels across the floodplain rose, the railway embankment was overtopped, probably at a number of locations. When Grantham was visited on 22 February, railway crews were repairing an 1,100 m length of track opposite the western end of the southern development. These floodwaters ponded upstream of the railway embankment and bridge, joining the northerly flowing floodwaters moving upstream under the railway

[25] It is expected that flash flood flows from Lockyer Creek surged upstream along the lower reaches of Flagstone Creek on the Monday afternoon, possibly flooding Carpendale. As water levels in Lockyer Creek subsided, these floodwaters will have re-entered Lockyer Creek as part of the flash flood recession rather than as 'normal' flood flows.

bridge. Overtopping may also have occurred to the immediate north of Quarry bend, as indicated in Figure Figure 8.10.

- There were only modest flows in Ma Ma and Tenthill Creeks on the Monday afternoon. Ma Ma Creek at Harms peaked at 130 m^3/s at 1740 hours; Tenthill Creek at Tenthill peaked at 240 m^3/s at 1700 hours. It will have taken a couple of hours for these peak discharges to find their way into Lockyer Creek. At the time of the onset of flash flooding in Grantham (1500-1530 hours), the flows entering Lockyer Creek from Ma Ma and Tenthill Creeks are expected to have been less than 20 m^3/s and less than 100 m^3/s respectively. Thus, it is concluded that inflows from Ma Ma and Tenthill Creeks would not have materially influenced peak flooding behaviour in Grantham, but may have prolonged higher water levels into the night.
- The depth and velocity of flood flows across the floodplain at Grantham were estimated. Depth of flooding data provided by Lockyer Valley RC indicated a depth of flow of some 2.0-2.5 m across the floodplain and a water surface gradient of 0.0026 m/m along the floodplain parallel to the railway line. This corresponds to an average velocity of flow of 1.6-1.9 m/s and a discharge across the floodplain of some 2,500-3,500 m^3/s, a number in rough keeping with the inferred total discharge of 3,500-4,000 m^3/s at Grantham. (The balance of the total discharge comprises flows in Lockyer Creek itself and across the southern floodplain). In passing, it is thought that the peak velocities across the floodplain will have been in the order of 2-3 m/s, and will have occurred as water levels were rising. It is also thought that local peak velocities through parts of the town will have been greater than the above estimates.
- The extreme hazard and destructiveness of the floodwaters passing through Grantham was caused by the combination of depth and velocity of flow across the floodplain, the rate of rise of floodwaters and the number of properties (and people) at risk. The maximum rate of rise of floodwaters at Grantham can be estimated at around 12 m/hour on the basis of Table 8.4 and Figure 8.9. Thus, a water level rise of 2-3 m over the floodplain area may have occurred in as little as 10-15 minutes. These depths, velocities and rates of water level rise, together with the relatively high population at risk, made for an exceptionally hazardous flooding situation, leading to the loss of 13 lives.

Figure 8.11 shows a photograph of the railway bridge in Grantham after the flood had subsided (looking upstream). Much of the debris deposited on and at the bridge was collected by the floodwaters as they surged eastwards through the area of southern development, and was deposited on the southern side of the bridge as the floodwaters then surged upstream along Sandy Creek (N). As the flood subsided – and it is thought that water levels may have initially subsided quite quickly - floodwaters ponding to the north of the railway embankment will have drained southwards into Lockyer Creek via Sandy Creek (N). These recession flows down Sandy Creek (N) may have been quite fast and will have deposited additional debris on the northern side of the bridge.

Growth and Dissipation of the Lockyer Creek Flash Flood

As the flood spike at Helidon travelled downstream along Lockyer Creek, it will have 'flattened' (ie the peak discharge will have fallen and the time-base of the flood have will lengthened) due to storage routing effects. This attenuation will have been offset by any incoming floodwaters from tributaries, but as discussed above, whilst inflows from Monkey Waterholes Creek are inferred to have been large and to have significantly reinforced and amplified the flood wave as it passed by, inflows from Flagstone, Ma Ma, Tenthill and Laidley Creeks were low on the Monday afternoon and will have played no significant part in subsequent flood behaviour along Lockyer Creek.

The flood spike at Spring Bluff grew in size as it travelled downstream along Murphys Creek and upper Lockyer Creek, as ever-increasing catchment areas contributed runoff. Immediately upstream of Helidon, the spike will have been substantially amplified by large 'flash flood' inflows from Rocky Creek. Immediately downstream of Helidon, the spike will have been further reinforced and amplified by substantial 'flash flood' inflows from Monkey Waterholes Creek. After this, there were no further tributary inflows of significance along the remainder of Lockyer

Creek to its confluence with the Brisbane River. Thus, the Monday afternoon flash flood was generated solely in the tributaries of Lockyer Creek upstream and immediately downstream of Helidon.

Figure 8.11 Aftermath of the Lockyer Creek Flash Flood, Grantham. Railway Bridge across Sandy Creek (Looking Upstream). Source: Courier Mail, 8 March 2011.

This abrupt flash flood spike, which is expected to have reached its maximum size immediately downstream of Helidon, then bore down on Grantham where it wreaked enormous damage and took 13 lives. The spike will have attenuated somewhat on this journey, between Monkey Waterholes Creek and Grantham, perhaps substantially, especially over the broad, flat northern floodplain downstream of Quarry bend, where Grantham is located. The backflow of Lockyer Creek floodwaters upstream along the lower reaches of Flagstone Creek will have contributed to this attenuation. However, any attenuation was obviously inconsequential, as reflected in the damage and loss of life in Grantham. (Grantham is 9 km downstream from the confluence of Monkey Waterholes and Lockyer Creeks).

The attenuation of the flood spike by the time it reached Gatton was not recorded because of the malfunction of the Gatton streamgauge. However, the maximum rate of rise has fallen to 1.0 m/hour at Gatton[26], substantially less than that at Helidon and the inferred rate of rise at Grantham (see Table Table 8.4). Gatton is some 15 km downstream of Grantham and the Lockyer Valley is progressively widening and flattening as one travels downstream from Helidon, especially downstream of Quarry bend, so increasing the storage routing capacity of the waterway and its floodplains to attenuate floodwaves. Significant attenuation must have occurred over this reach of Lockyer Creek, as the flood in Gatton was judged to be 'normal' by the locals.

The remnants of the flash flood spike can be seen in the stage hydrograph at Glenore Grove stream gauging station, which is located 20 km downstream of Gatton. The flood spike remnant is the water level peak at Glenore Grove (recorded around midnight on Monday 10 January) that immediately follows the rising limb of the spike at Gatton (see Figure 8.4). This

[26] This maximum rate of rise was determined from the partial record of the rising limb at Gatton.

flood peak at Glenore Grove is 'well rounded' and indicates that the flood spike has lost its abrupt nature due to storage-routing effects and mixing with tributary inflows on its way downstream. Further downstream at Lyons Bridge, the upstream peaks have all but disappeared into the mass of water making up the general 'flood hydrograph', although the increase in water levels associated with backwater effects from the Brisbane River is apparent around 0600 hours on Tuesday 11 January.

Thus, it would seem that by the time the flood spike reached Gatton, and certainly by the time it reached Glenore Grove, it had lost much of its abrupt nature and had been transformed into a more 'normal' floodwave.

8.3.2 Backwater Flooding Along the Lower Reaches of Lockyer Creek

Releases from Wivenhoe Dam over the period 0600 hours on Tuesday 11 January to 0300 hours on Wednesday 12 January generated a dam release floodwave in the Brisbane River (see ICA, 2011b for details). As this floodwave travelled downstream along the Brisbane River, it caused backwater flooding along the lower reaches of Lockyer Creek and backwater effects from the Brisbane River impeded the floodwave trying to exit Lockyer Creek and increased upstream flood levels. This 'Tuesday' floodwave is apparent in the various tributaries draining to Lockyer Creek (Flagstone, Ma Ma, Tenthill and Laidley Creeks) and at Glenore Grove on Tuesday afternoon (see Figure 8.8).

Figure 8.8 shows water level behaviour at three stations along the lower reaches of Lockyer Creek and at the Lowood streamgauge in the Brisbane River. As discussed in Section 8.2.5, backwater effects from dam releases affect water levels at O'Reillys Weir and possibly at Lyons Bridge, but not at Glenore Grove. Hence it is concluded that backwater effects from the Brisbane River did not influence flooding behaviour along Lockyer Creek or its tributaries in the Lockyer Valley RC LGA upstream of Glenore Grove, but may have had some minor effect on flood levels along the reach of Lockyer Creek downstream of Glenore Grove and within Lockyer Valley RC LGA.

8.3.3 Normal Floods

Flash floods in the tributaries or upper and middle reaches of Lockyer Creek caused the Monday afternoon flooding experienced at Spring Bluff, Murphys Creek township, Postmans Ridge, Withcott, Helidon, possibly at Carpendale (if flooding occurred on the Monday afternoon), and at Grantham. By the time the flash flood arrived at Gatton, it was pretty well spent and flooding here, although characterized by a modest rate of water level rise, was more 'normal' in nature.

A modest flood was moving down Flagstone Creek on the morning of Tuesday 11 January (see Figure 8.7 and Section 8.2.3). It is not known whether the flooding at Carpendale was caused by this event (a 'normal' flood) of by backwater effects from the flash flood in Lockyer Creek on Monday afternoon.

The flood event occurred in Tenthill Creek on the afternoon and evening of Tuesday 11 January (see Figure 8.7 and Section 8.2.3). Council officers reported that Tenthill Creek did not break its banks. Thus, any flooding along Tenthill Creek was 'normal' and minor in nature.

A significant 'normal' flood event also occurred in Sandy Creek (S) on the morning, afternoon and evening of Tuesday 11 January (see Figure 8.6 and Section 8.2.3). Council officers reported significant flooding in the Forest Hill area of Sandy Creek from breakout flows upstream (south) of Glen Cain Road. It was reported that more than 50 percent of the flow bypassed the streamgauging station and travelled across the floodplain inundating most of the properties in Forest Hill and washing out about 1 km of the railway. It was also reported that the whole town had to be evacuated by helicopter.

A significant 'normal' flood event also occurred in Laidley Creek on the morning, afternoon and evening of Tuesday 11 January (see Figure 8.6 and Section 8.2.3). According to Council officers, floodwaters breaking out of Laidley Creek to the south-east of Laidley inundated a large area of the town including the commercial centre.

8.4 COMPARISON OF WATER LEVEL HYDROGRAPHS AND RAINFALL HYETOGRAPHS

Figure 8.12 to Figure 8.18 compare stage hydrographs (water level variations) in Lockyer Creek and its tributaries with hourly rainfall depths recorded at the nearest pluviograph station. These figures indicate when rainfall and waterflow flooding was occurring at a particular locality. The following behaviour is apparent from these Figures:

- Any rainfall of consequence had ceased across all sites by 1800 hours on Tuesday 11 January. Any inundation after this time will have been caused by waterflows.
- The rainfall events causing the flood events of Sunday night-Monday (9-10 January) morning are readily apparent at all stations with the exception of Prince Henry Drive. These rainfalls occurred over the period from around 1200 to 2400 hours on Sunday 9 January. (Only rainfall data for the period 0000-2400 hours on Monday 10 January were available at the Prince Henry Drive pluviograph).
- Comparing the water level rise on Monday afternoon at Helidon to rainfalls recorded at Prince Henry Drive and Toowoomba Alert (Figure 8.12 and Figure 8.13), it is seen that the water level rise followed quickly after the onset of heavy rainfalls and that it was still raining during the rising limb of the hydrograph, as defined before the streamgauge malfunctioned. The severity of short duration rainfall events, as recorded at the Prince Henry Drive pluviograph, was extreme (greater than 50-Years ARI for durations between 15-minutes and 6-hours). Thus, in townships of the upper tributaries of Lockyer Creek (Murphys Creek township, Withcott township and Helidon township), inundation by overland flow may have occurred before or during the flash flood event caused by overloaded stormwater drainage systems. Even in areas without stormwater drainage, overland flow could have caused inundation before or during the flash flood event.
- At Sandy Creek (N) (Figure 8.14), which drains through Grantham to Lockyer Creek, little rain occurred over Monday afternoon and evening (1200-2400 hours) (10 January) when the flash flood was passing through Grantham. Further, rainfall events up to 3-hours duration all had an ARI of 1-Year or less (see Figure B2 of Appendix B). Thus, it is not expected that overland flow inundation occurred in Grantham before flash flood flow inundation by floodwaters from Lockyer Creek.
- In Laidley Creek at Showgrounds Weir (Figure 8.15), the main rainfall event was from around 0600-1600 hours on Tuesday 11 January. It is seen that rainfall was still occurring during the resulting ‘normal’ flood event down Laidley Creek. The severity of short-duration events was 2-3 Years ARI for durations of 15 minutes to 1 hour, increasing to 6-Years ARI for the 2-hour duration event (see Figure B5 of Appendix B). Thus, overland flow inundation caused by overloaded stormwater drainage systems could have occurred in this area before or during waterflow inundation along Laidley Creek.
- In Sandy Creek (S) at Forest Hill (Figure 8.16), the main rainfall event was from around 0600-1600 hours on Tuesday 11 January (based on Showground Weir Alert rainfalls). It is seen that rainfall was still occurring during the resulting ‘normal’ flood event down Sandy Creek (S). The severity of short-duration events was 2-3 Years ARI for durations of 15 minutes to 1 hour, increasing to 6-Years ARI for the 2-hour duration event (see Figure B5 of Appendix B). Thus, overland flow inundation could have occurred in this area before or during waterflow inundation along Sandy Creek (S).
- In Lockyer Creek at Glenore Grove (see Figure 8.17), the major rainfall event is seen to be that of Tuesday 11 January (over the period 0400-1500 hours). It is seen that rain was occurring during the associated flood event. From Figure B5 of Appendix B, it is seen that at the Showground Weir Alert pluviograph, the severity of rainfall events of duration 15-minutes to 1 hour was about 5-Years ARI. Thus, overland flow inundation caused by overloaded stormwater drainage systems may have occurred. No rainfall of consequence occurred whilst the remnants of the flash flood were passing through on the Monday evening.

- Lockyer Creek at Lyons Bridge is outside the Lockyer valley RC LGA. In Lockyer Creek at Lyons Bridge Alert (see Figure 8.18), the major event was again that of Tuesday 11 January (over the period 0600-1500 hours). From Figure B4 it is seen that rainfall severities at Lyons Bridge Alert pluviograph were greater than 5-Years ARI for durations of 30-minutes and upwards. Thus, overland flow inundation caused by overloaded stormwater drainage systems could have occurred around the Lyons Bridge area before and during the normal flood event of Tuesday morning-afternoon, and by projection, over the reaches of Lockyer Creek downstream of Glenore Grove.

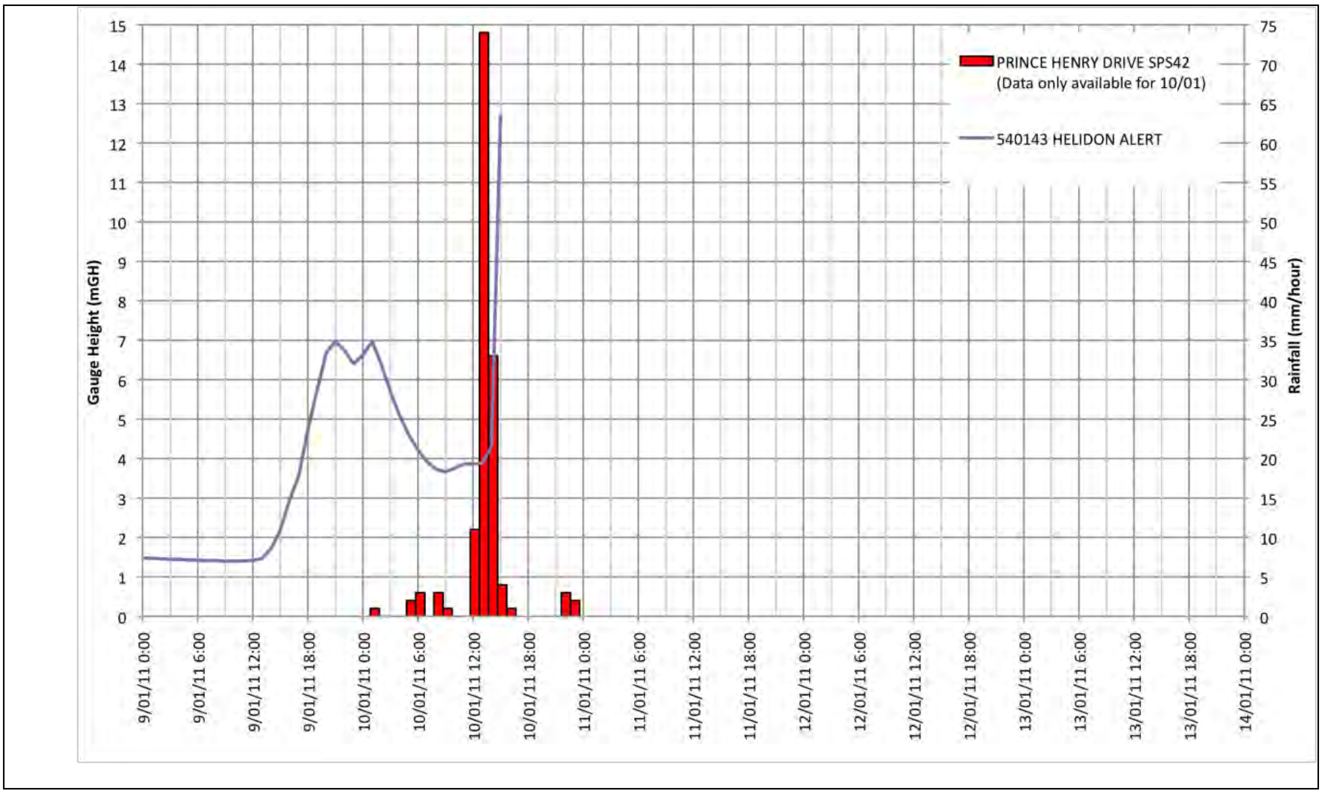

Figure 8.12 Comparison of Water Levels in Lockyer Creek at Helidon Alert (540 143) and Rainfalls at Prince Henry Drive Pluviograph (SPS 42), 9-13 January 2011

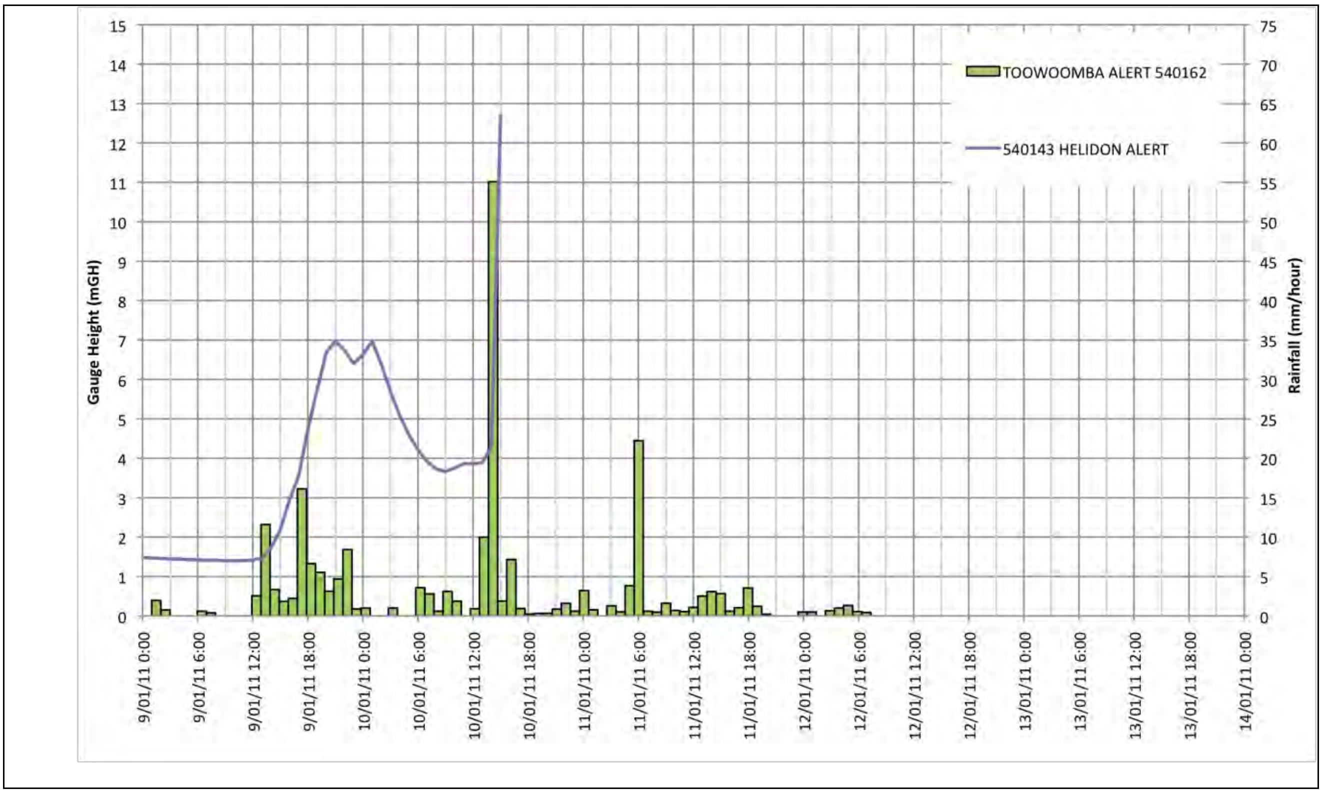

Figure 8.13 Comparison of Water Levels in Lockyer Creek at Helidon Alert (540 143) and Rainfalls at Toowoomba Alert Pluviograph (540 162), 9-13 January 2011

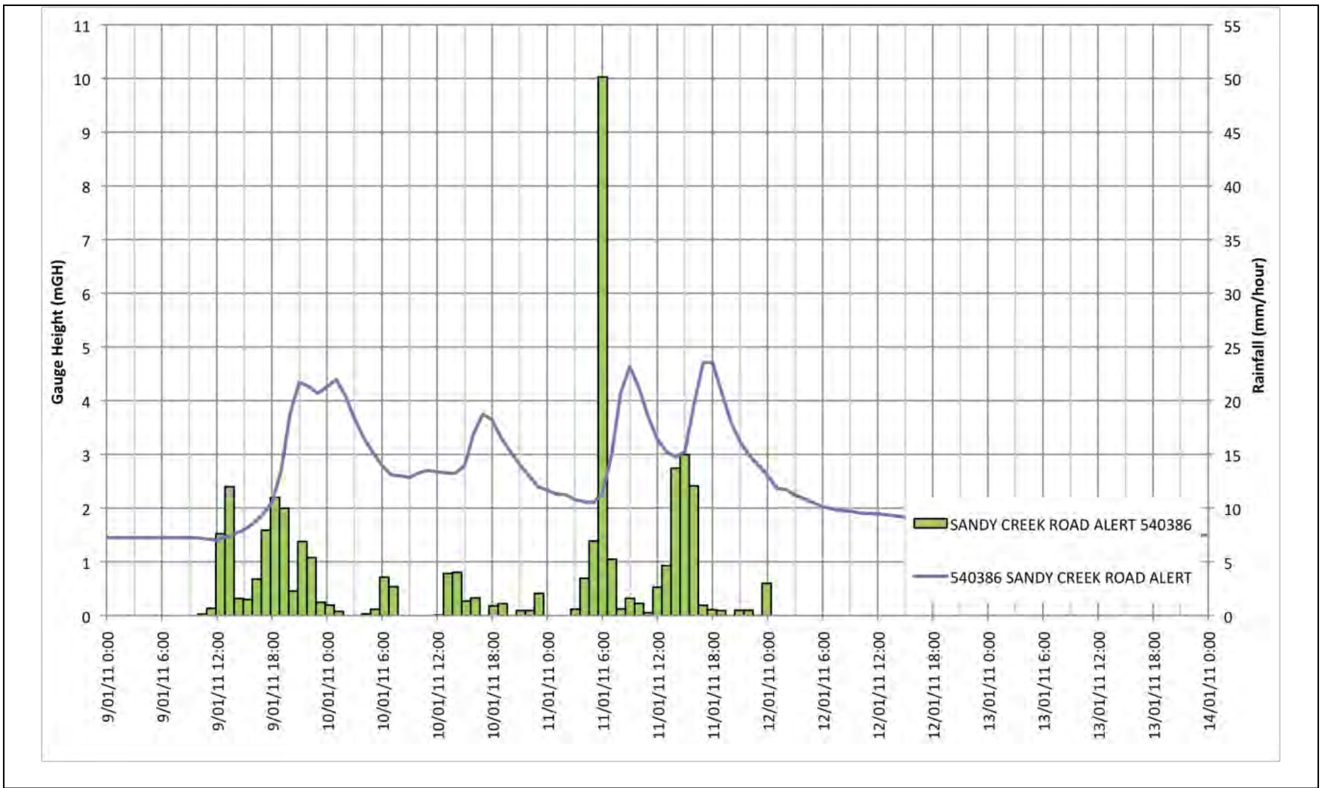

Figure 8.14 Comparison of Water Levels in Sandy Creek (N) at Sandy Creek Road Alert (540 386) and Rainfalls at Sandy Creek Road Alert Pluviograph (540 386), 9-13 January 2011

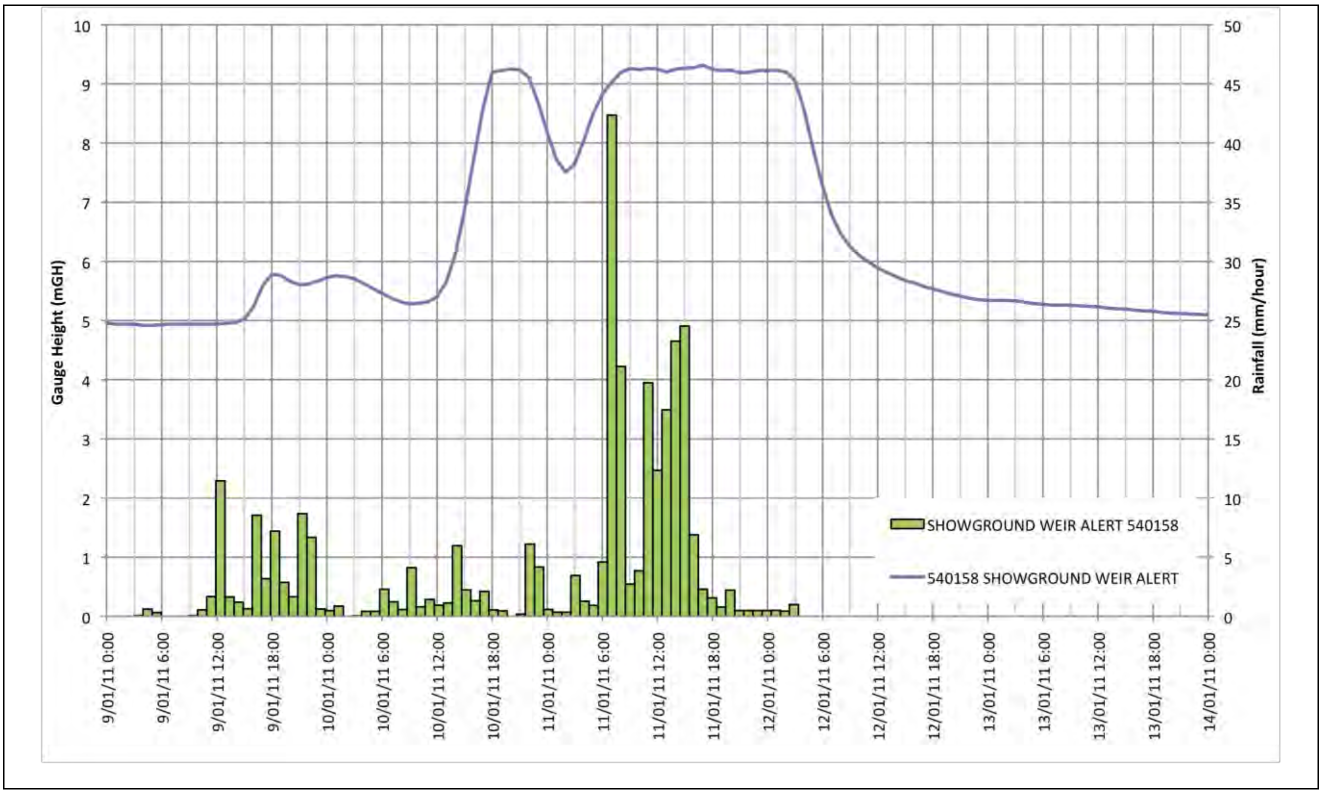

Figure 8.15 Comparison of Water Levels in Laidley Creek at Showgrounds Weir Alert (540 158) and Rainfalls at Showgrounds Weir Alert Pluviograph (540 158), 9-13 January 2011

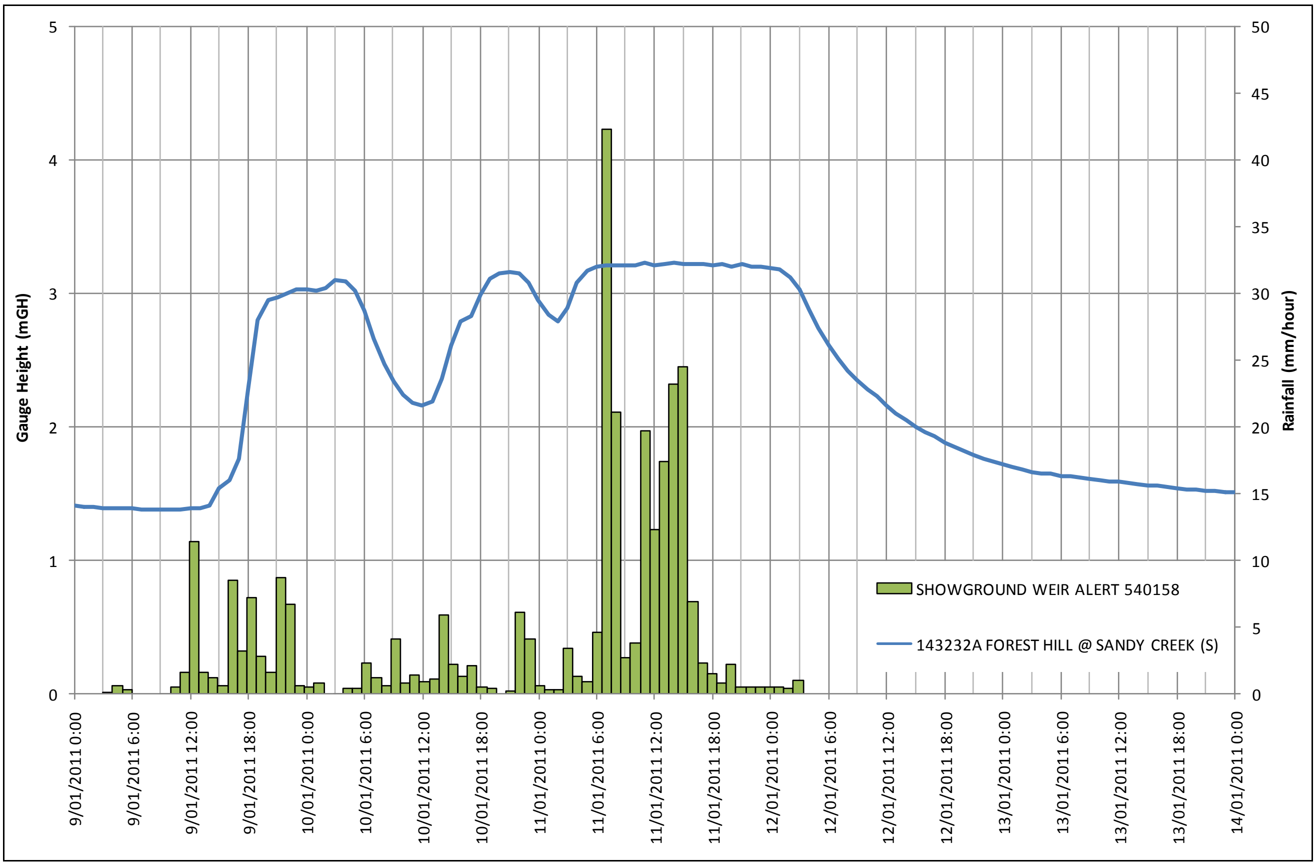

Figure 8.16 Comparison of Water Levels in Sandy Creek (S) at Forest Hill (143 232 A) and Rainfalls at Showgrounds Weir Alert Pluviograph (540 158), 9-13 January 2011

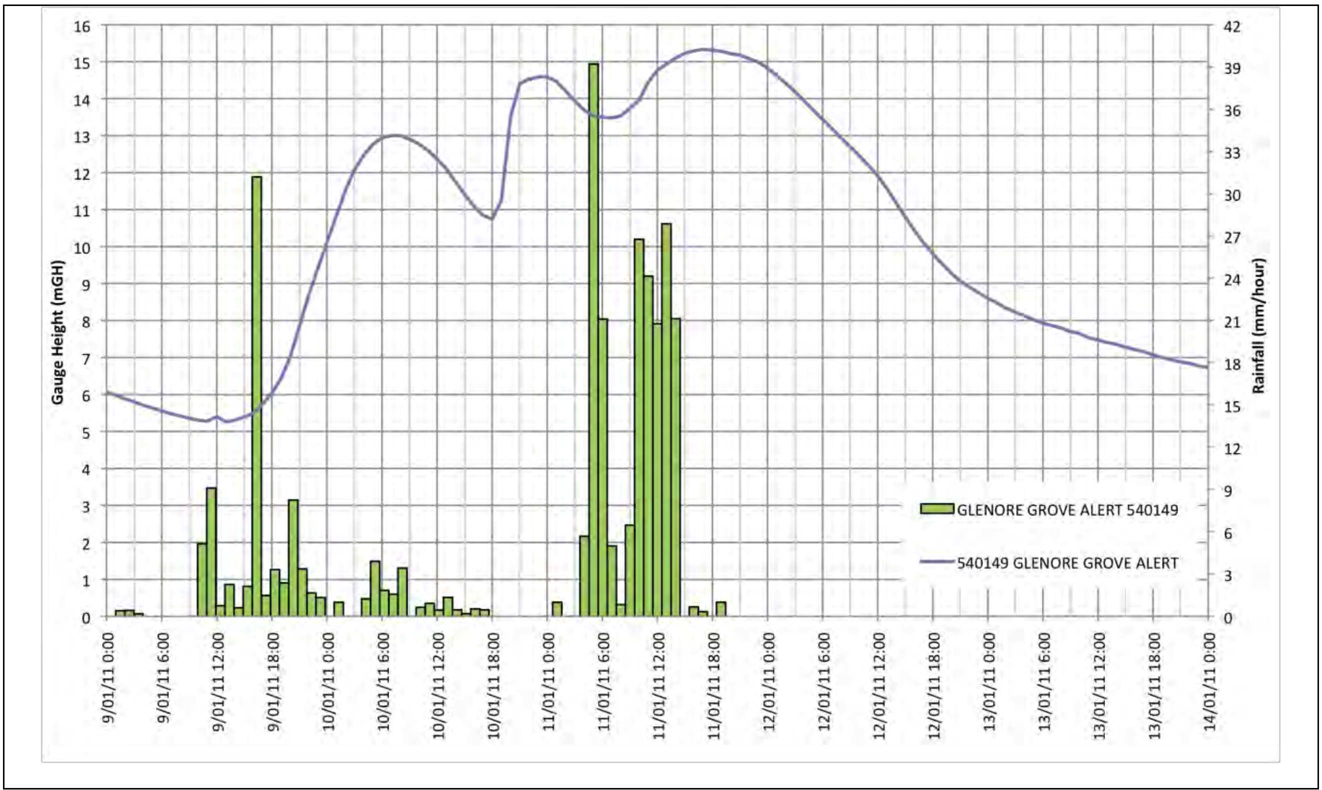

Figure 8.17 Comparison of Water Levels in Lockyer Creek at Glenore Grove Alert (540 149) and Rainfalls at Glenore Grove Alert Pluviograph (540 149), 9-13 January 2011

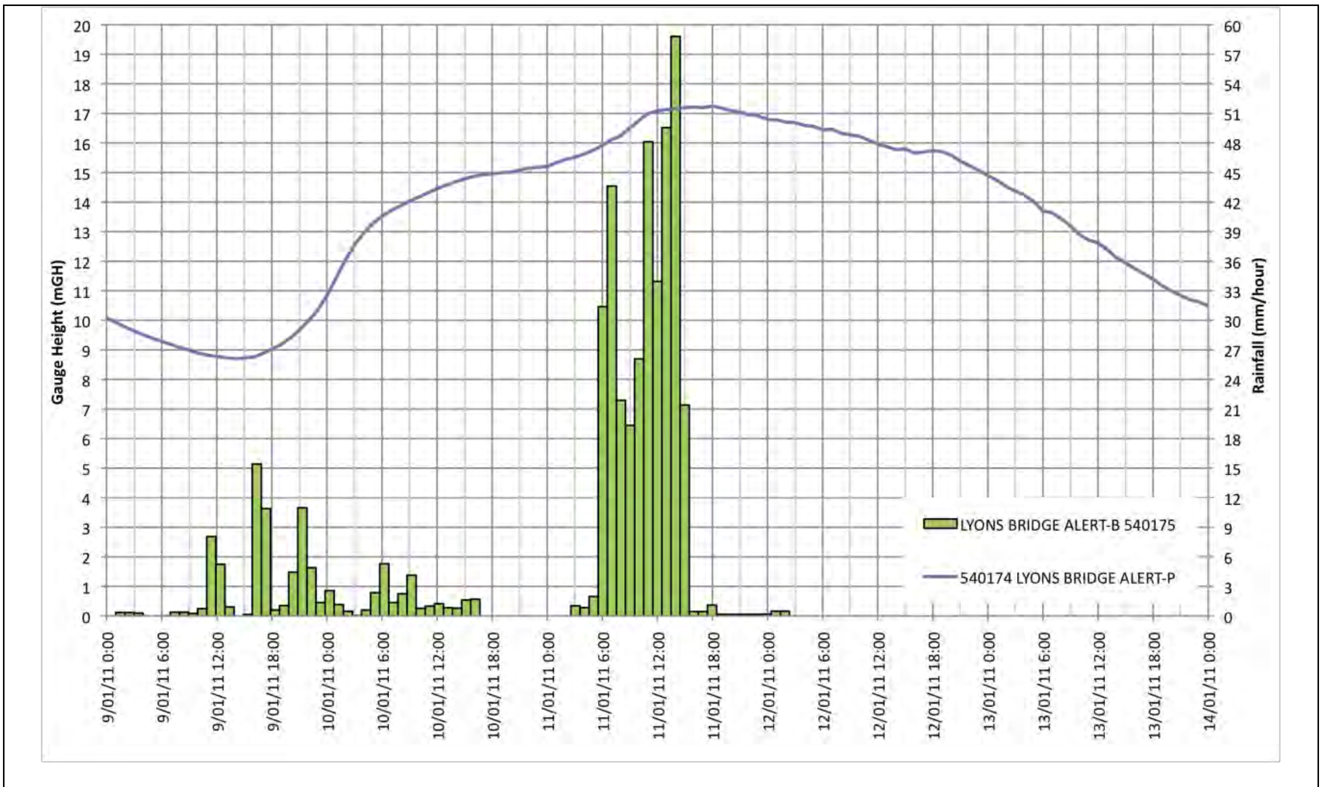

Figure 8.18 Comparison of Water Levels in Lockyer Creek at Lyons Bridge Alert (540 174) and Rainfalls at Lyons Bridge Alert Pluviograph (540 175), 9-13 January 2011

8.5 EXTENT OF INUNDATION

As discussed in Section 8.1.2, no maps showing the extent and depth of inundation were prepared for Lockyer Valley LGA.

9 CAUSE AND NATURE OF FLOODING IN LOCKYER VALLEY RC LGA ON 9-13 JANUARY 2011

9.1 RAINFALL AND WATERFLOW TIMING

Rain was falling during the flash flood events of Monday afternoon 10 January at Helidon and, it is inferred, at most if not all other locations inundated by flash flood flows (including the townships of Murphys Creek, Withcott and Postmans Ridge) with the exception of Grantham and possibly Carpendale (if flooding in Carpendale was caused by backflows up Flagstone Creek associated with the passage of the flash flood down Lockyer Creek on Monday afternoon). Accordingly, overland flow inundation could have occurred before or during flash flood flow inundation in all the above areas, with the exception of Grantham and Carpendale (if the flood at Carpendale was on the Monday).

Rain was also occurring at the Showgrounds Weir area of Laidley Creek, and in the Glenore Grove Lyons Bridge areas of Lockyer Creek, during the ‘normal’ flood events of the morning, afternoon and evening of Tuesday 11 January. Accordingly, overland flow inundation could have occurred in these areas before or during the associated ‘normal’ flood event.

9.2 OVERLAND FLOW INUNDATION

As noted above, overland flow inundation could have occurred on the Monday afternoon in Murphys Creek township, Withcott, Postmans Ridge and Helidon. Overland flow inundation is not expected to have occurred at Grantham or Carpendale (if flooding at Carpendale occurred on the Monday afternoon).

As also noted above, overland flow inundation could have occurred in the Laidley area of Lockyer Creek and in the Glenore Grove and Lyons Bridge areas of Lockyer Creek. It is inferred that it was raining at most other locations along tributary creeks during the flood event of Tuesday 11 January. Whether or not overland flow inundation occurred will depend on the severity of the resulting rainfalls and local topography.

9.3 WATERFLOW INUNDATION

Waterflow inundation caused by flash flood flows (as defined in this report) in upper Lockyer Creek and its tributaries occurred at Spring Bluff, Murphys Creek township, Withcott, Postmans Ridge, Helidon, possibly at Carpendale, and at Grantham. (If Carpendale was flooded on Tuesday 11 January rather than the afternoon of Monday 10 January, inundation will have been caused by waterflows from a ‘normal’ flood).

Any inundation that occurred on the morning, afternoon and evening of Tuesday 11 January, will have been caused by ‘normal’ flood flows in Lockyer Creek and its tributaries. Normal flood flows were generated in Flagstone, Ma Ma, Tenthill, Sandy (S) and Laidley Creeks over this period.

Backwater effects associated with releases from Wivenhoe Dam did not affect flooding behaviour anywhere along Lockyer Creek and its tributaries in Lockyer Valley RC LGA upstream of Glenore Grove stream gauging station on Lockyer Creek. Backwater effects are possibly discernible at Lyons Bridge streamgauging station on Lockyer Creek. Thus, backwater effects from the Brisbane River may have influenced flooding behaviour along the reach of Lockyer Creek between Glenore Grove stream gauging station and the downstream LGA boundary, but these effects will have been small.

Flash flood flows in Lockyer Creek area caused backwater flooding at one or possibly two locations. First, flash flood flows forcing their way under the railway bridge at Grantham and upstream along Sandy Creek (N) will have caused (or contributed to) any flooding along Sandy Creek upstream of the railway embankment. Second, if Carpendale was flooded on Monday afternoon, inundation was caused by flash flood flows in Lockyer Creek moving upstream along Flagstone Creek.

9.4 UNCERTAIN

At a number of locations, rain was falling whilst waterway inundation was occurring. Thus, uncertainties exist as to whether properties flooded by waterflows on the afternoon-evening of Monday 10 January and on the morning-afternoon-evening of Tuesday 11 January 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 systems, which is beyond the scope of this report.

10 FACTORS AFFECTING FLOODING IN LOCKYER VALLEY RC LGA ON 9-13 JANUARY 2011

The following factors affected and exacerbated the nature of flooding in Lockyer Valley RC LGA over the period Monday-Thursday 9-13 January 2011:

- The intense and severe rainfalls that are inferred to have occurred over the upper tributaries of Lockyer Creek, especially Murphys Creek, Rocky Creek and Monkey Waterholes Creek. Rainfall severities at the Prince Henry Drive pluviograph (SPS 42), which is situated atop The Escarpment, were equal to or greater than 100-Years ARI for rainfall durations of 30-minutes to 3-hours, and were greatest for the 1-hour duration event. These severities are taken to be representative of rainfall behaviour over the upper tributaries of Lockyer Creek. Rainfall severity declined in easterly and southeasterly directions away from The Escarpment.
- The soil of these catchments was saturated from previous rainfall, especially over Sunday night 9 January. Given the saturated antecedent catchment conditions, the extreme rainfall intensities and the relatively steep nature of the catchments of upper Lockyer Creek tributaries, flash flood events were generated in Murphys Creek, Rocky Creek and Monkey Waterholes Creek. The response times of these small catchments will be of the order of 1-2 hours, corresponding to the maximum rainfall severity.
- As these flash floods pummelled their way downstream as abrupt, rapidly moving flood ‘spikes’, they grew along the way as increasing upstream catchment areas contributed their runoff. The drainage configuration of these upper tributaries resulted in significant growth of the flash flood wave at Helidon. Immediately upstream of Helidon, Rocky Creek delivered its flash flood flows to Lockyer Creek, amplifying water levels and discharges as the Lockyer Creek flash flood passed through. Immediately downstream of Helidon, Monkey Waterholes Creek also delivered its flash flows to Lockyer Creek, again reinforcing and amplifying flash flood flows in Lockyer Creek. It is inferred that the flash flood in Lockyer Creek achieved its maximum size immediately downstream of the Monkey Waterholes Creek confluence. This flood wave then surged downstream to devastate Grantham, some 9 km downstream.
- As the flash flood wave travelled downstream along Lockyer Creek from the Monkey Waterholes Creek confluence, it will have begun to attenuate due to storage routing effects along the way. It is thought that significant attenuation will have occurred downstream of Quarry bend, where the floodwave spilled over the broad, northern floodplain on which Grantham is located (this floodplain is some 750 m wide between the creek and the railway embankment). Nevertheless, any attenuation was inconsequential by the time the floodwave reached Grantham (9 km downstream from Monkey Waterholes confluence), as evidenced by the destruction of property and infrastructure and the loss of 13 lives there. However, significant attenuation had occurred by the time the floodwave reached Gatton, a further 15 km downstream, where its nature was more ‘normal’ with regard to peak water levels and the rates of water level rise and fall on the rising and recession limbs. It is anticipated that little further attenuation will have occurred between Gatton and Glenore Grove, a further 20 km

downstream, as the abrupt peak of the flash flood had been lost to attenuation and the floodwave itself had been flattened into a broader wave more characteristic of a 'normal' flood.

- During the Monday afternoon flash flood event, there was little inflow from the northerly draining tributaries of Lockyer Creek (Flagstone, Ma Ma, Tenthill and Laidley Creeks). Any inflows from these creeks will have played no significant role in flood behaviour as the flash flood wave travelled downstream, but inflows may have prolonged the subsequent recession.
- Releases from Wivenhoe Dam over the period 0600 hours on Tuesday 11 January to 0300 hours on Wednesday 12 January had no little or effect on flood behaviour in Lockyer Creek and its tributaries downstream of Glenore Grove streamgauging station on Lockyer *Creek*. No evidence of backwater effects was apparent in water level behaviour at Glenore Grove (52 km upstream from the confluence of Lockyer Creek and the Brisbane River), but backwater effects are perhaps discernible in water level behaviour at Lyons Bridge streamgauging station on Lockyer Creek (29 km from the mouth of Lockyer Creek). Along the reach of Lockyer Creek between Glenore Grove and the eastern boundary of Lockyer Valley RC LGA, backwater effects from the Brisbane River may have played a minor part in flood behaviour.
- 'Normal' floods occurred in most tributaries of Lockyer Creek and in Lockyer Creek itself over the morning, afternoon and evening of Tuesday 11 January.
- Flooding in Grantham was especially hazardous because of the combined depth and velocity of floodwaters across the floodplain, the rate of rise and the population at risk. Floodwaters were some 2.0-2.5 m deep across the northern floodplain with a maximum velocity of perhaps 2-3 m/s, and probably higher at some locations through the town. The rate of rise was inferred to be some 12 m/hour, indicating that it would have taken only 10-15 minutes to rise to full depth.
- Flooding was especially hazardous adjacent to waterways experiencing flash flooding because of high water depths and velocities (perhaps to 3-4 m/s). Houses built adjacent to waterways were washed away in Murphys Creek township, Postmans Ridge and possibly elsewhere. Nearly every house in the 'southern development' area of Grantham sustained structural damage caused by the velocity of the floodwaters. Some were washed off their stumps and completely destroyed. Others were rendered uninhabitable.

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APPENDIX A

RADAR IMAGES OF JANUARY 2011 STORMS

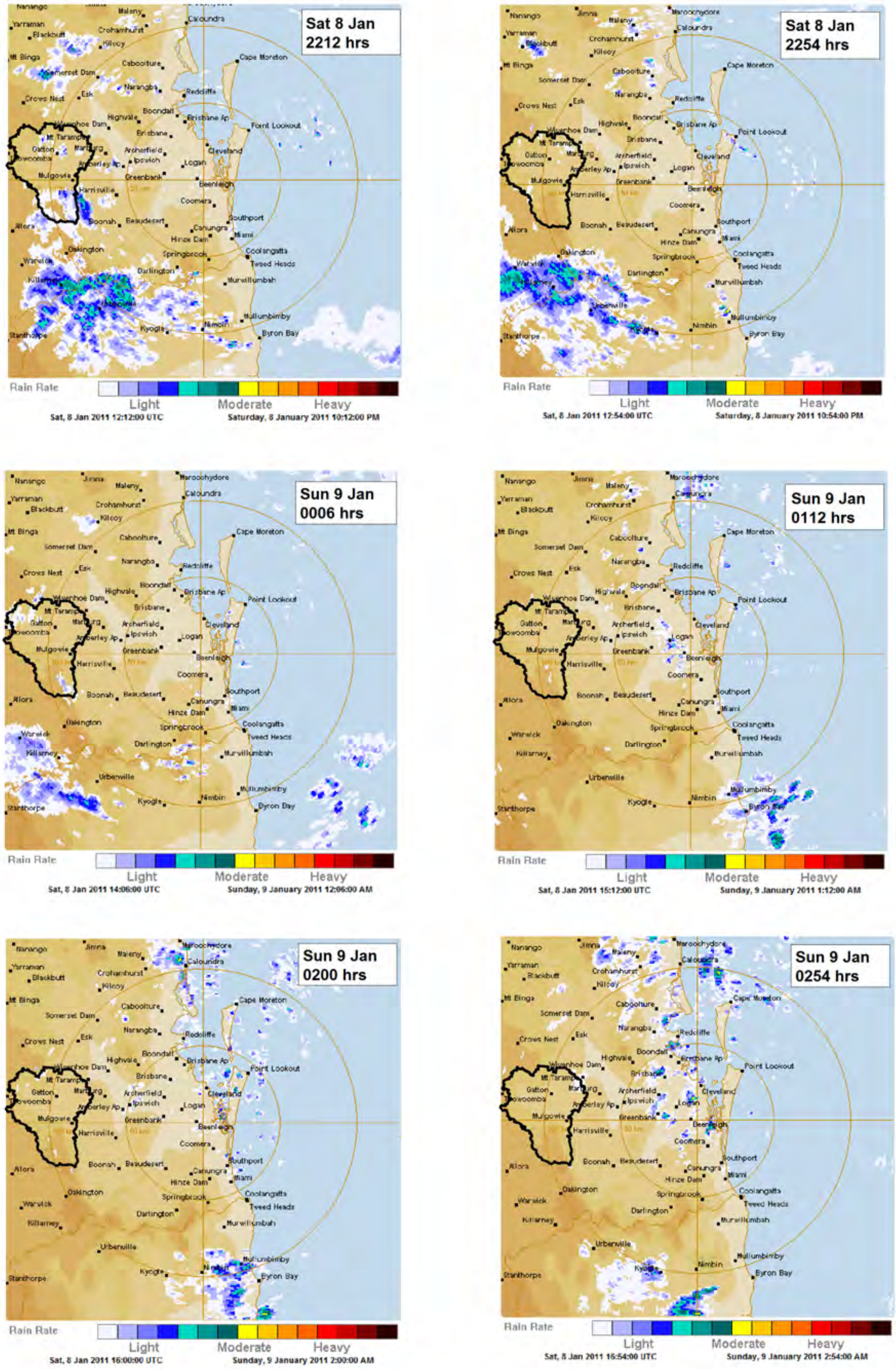

Figure A1 Radar Images Saturday 8 January 2212 hrs to Sunday 9 January 0254 hrs

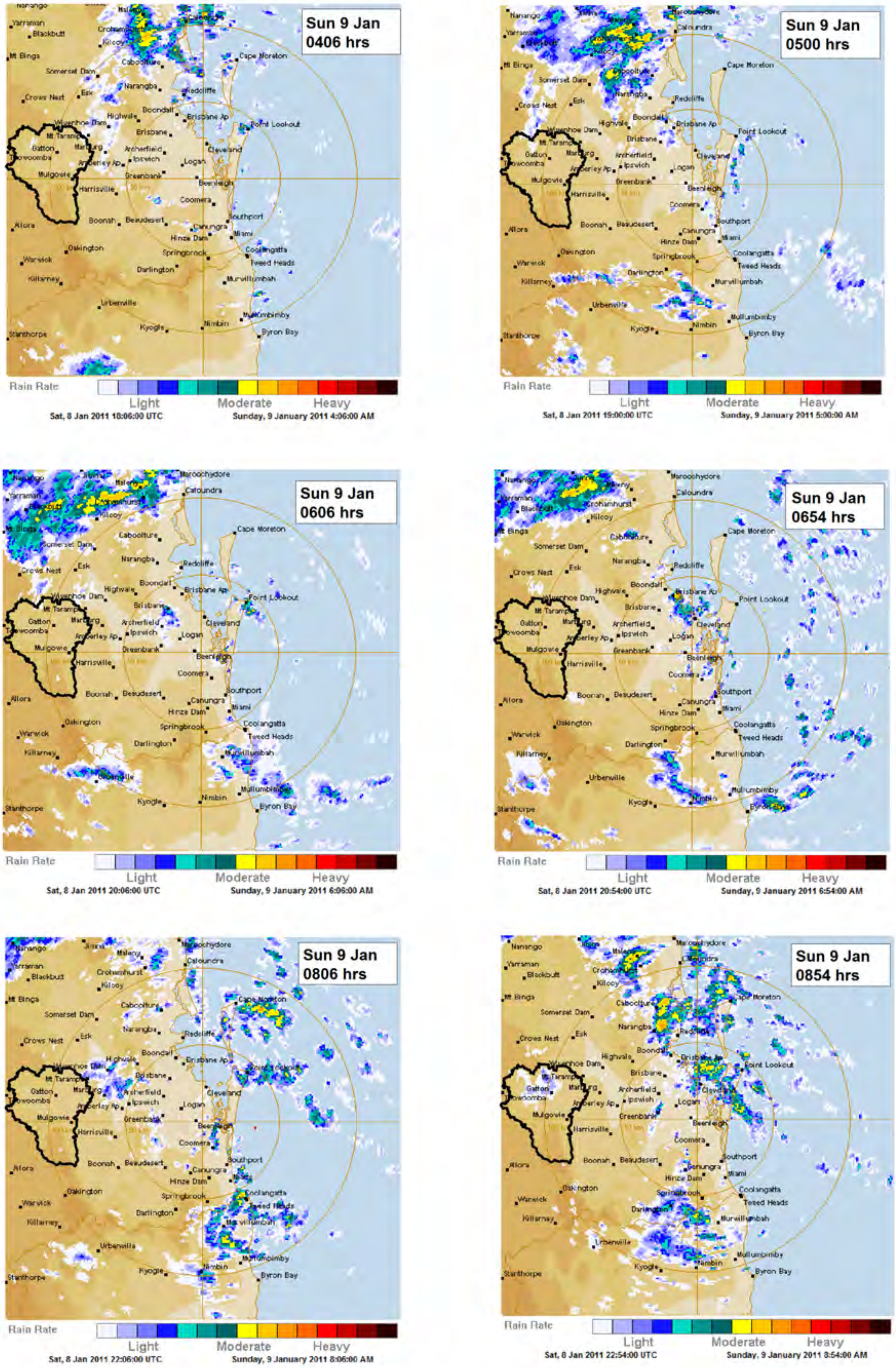

Figure A2 Radar Images, Sunday 9 January 0406 hrs to Sunday 9 January 0854 hrs

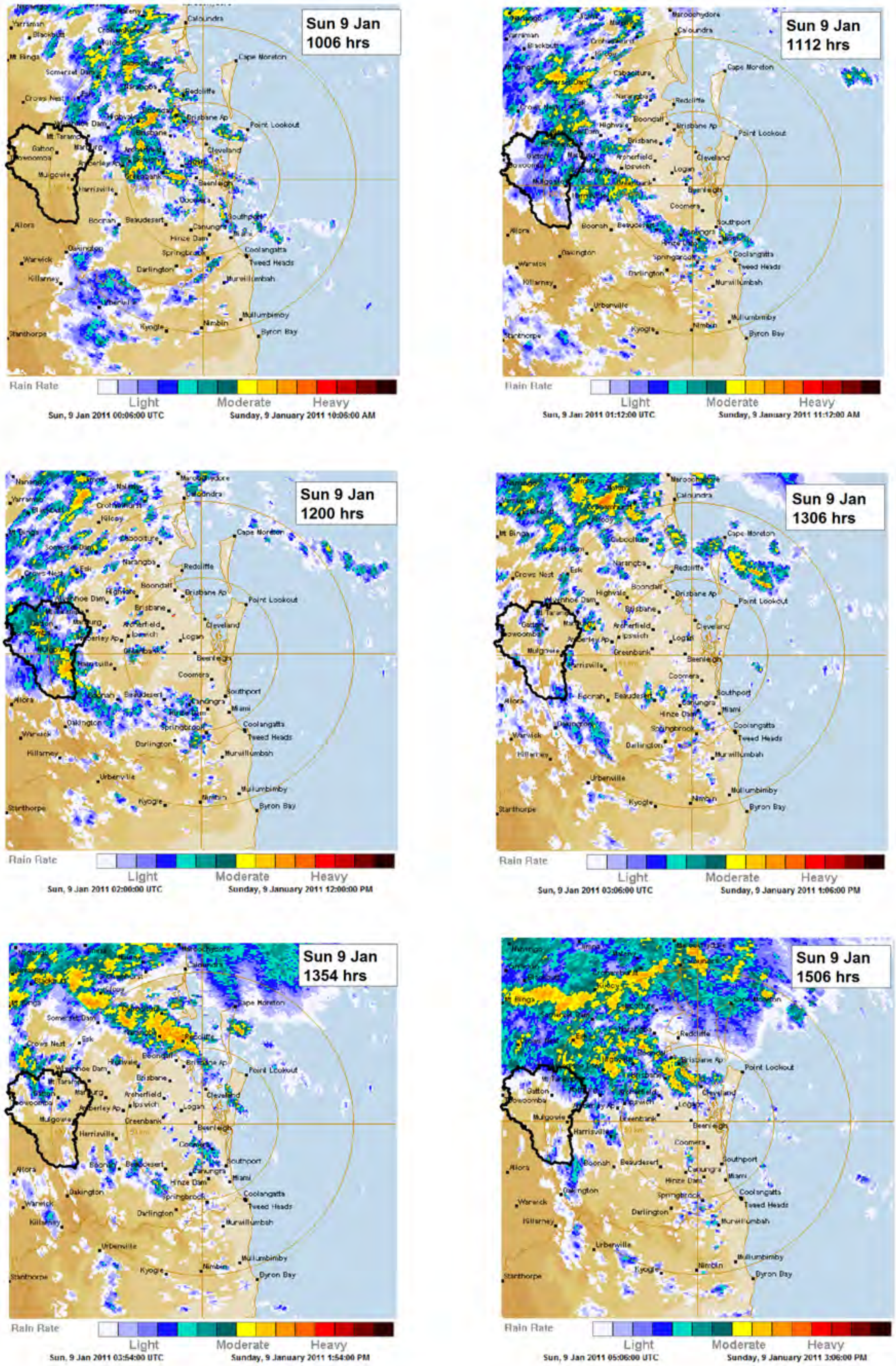

Figure A3 Radar Images, Sunday 9 January 1006 hrs to Sunday 9 January 1506 hrs

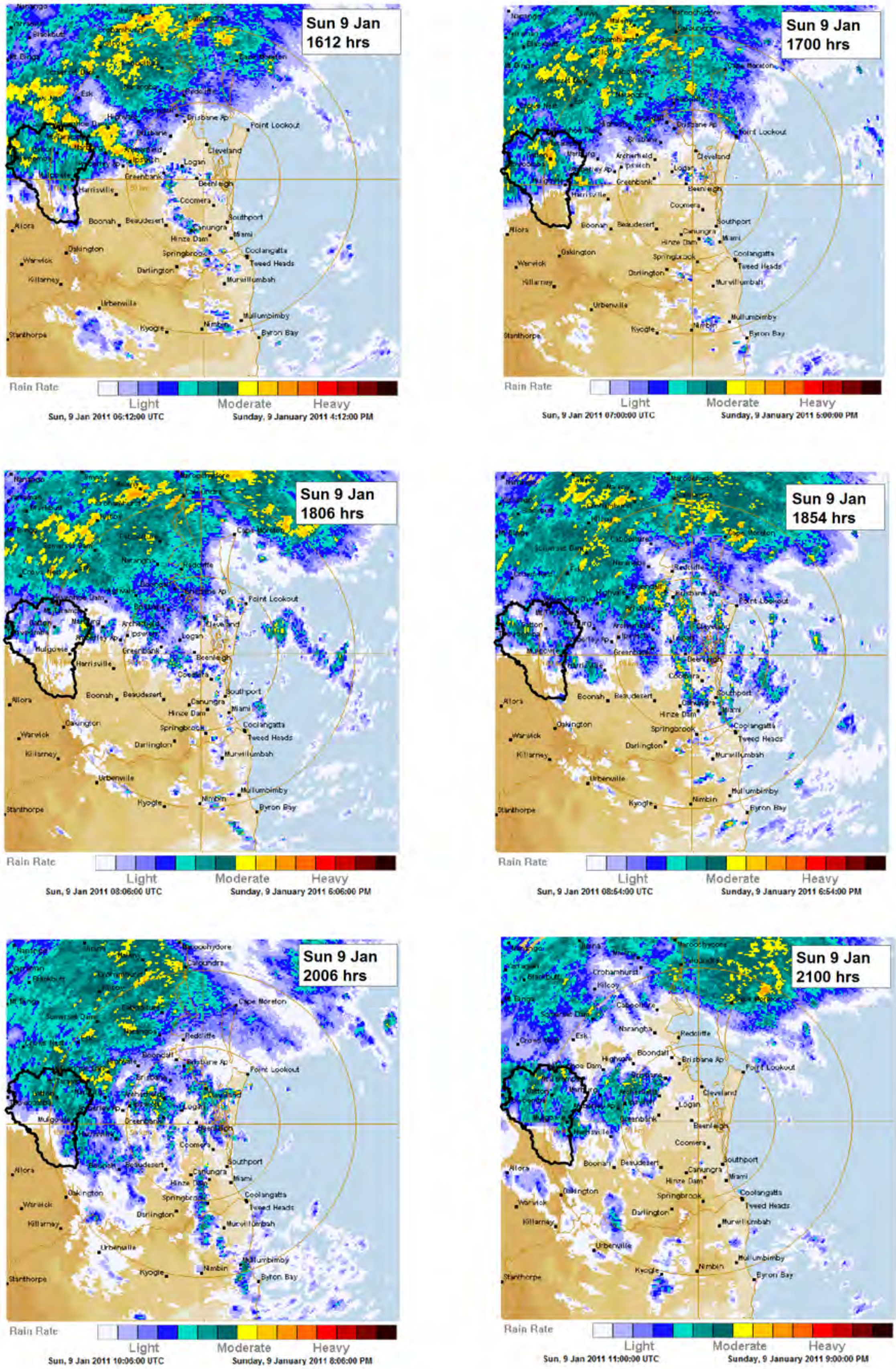

Figure A4 Radar Images Sunday 9 January 1612 hrs to Sunday 9 January 2100 hrs

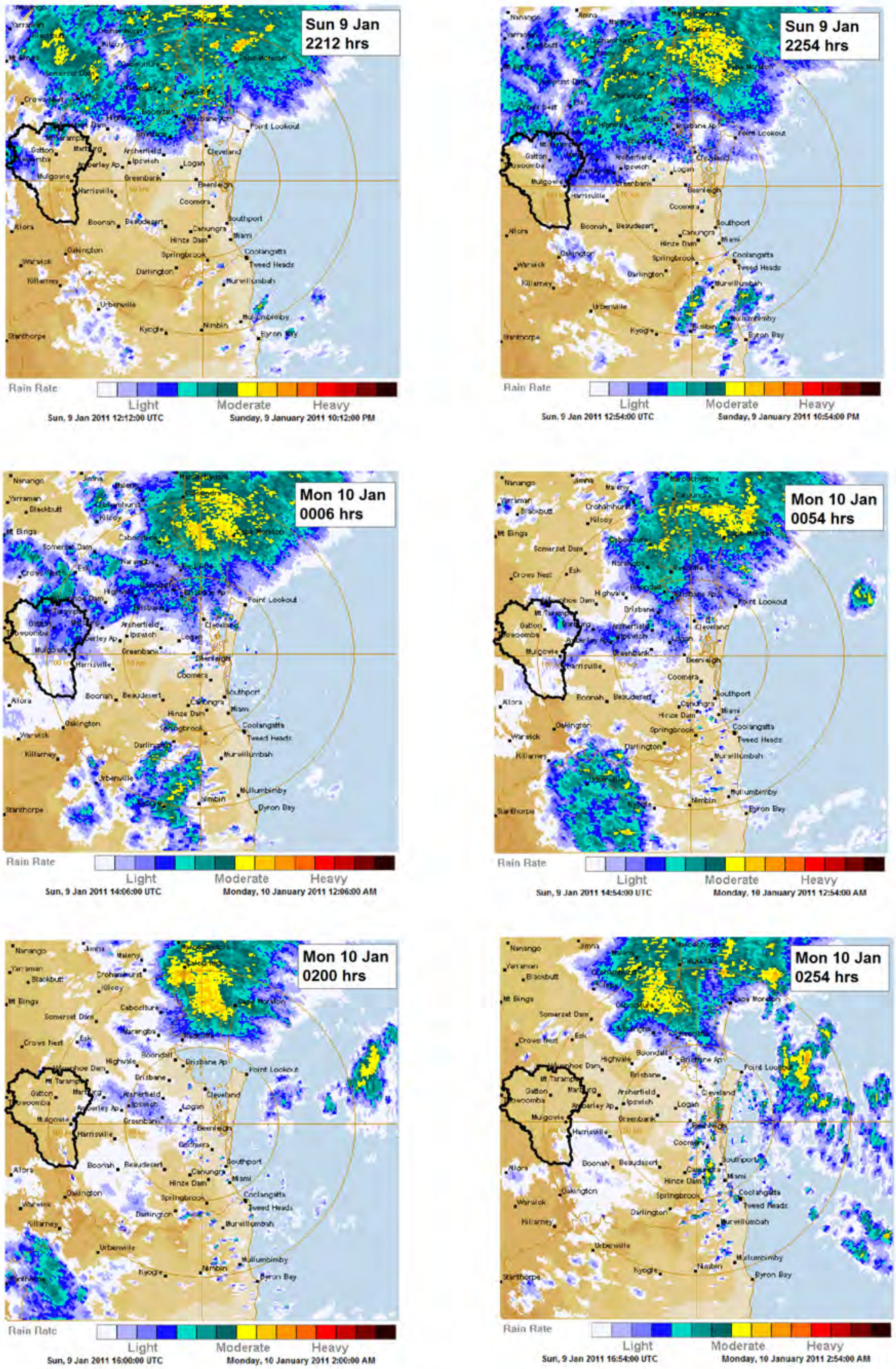

Figure A5 Radar Images Sunday 9 January 2212 hrs to Monday 10 January 0254 hrs

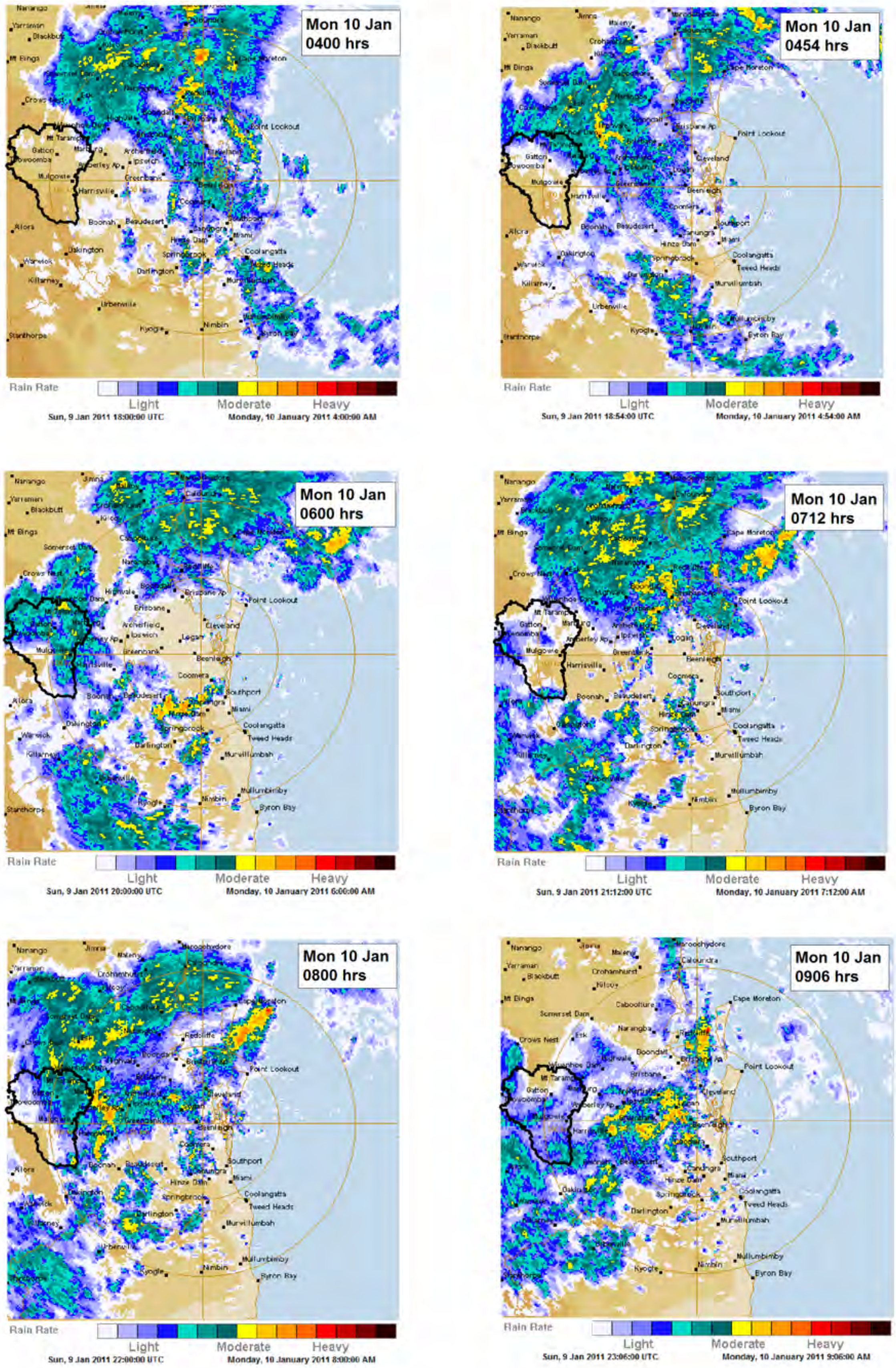

Figure A6 Radar Images Monday 10 January 0400 hrs to Monday 10 January 0906 hrs

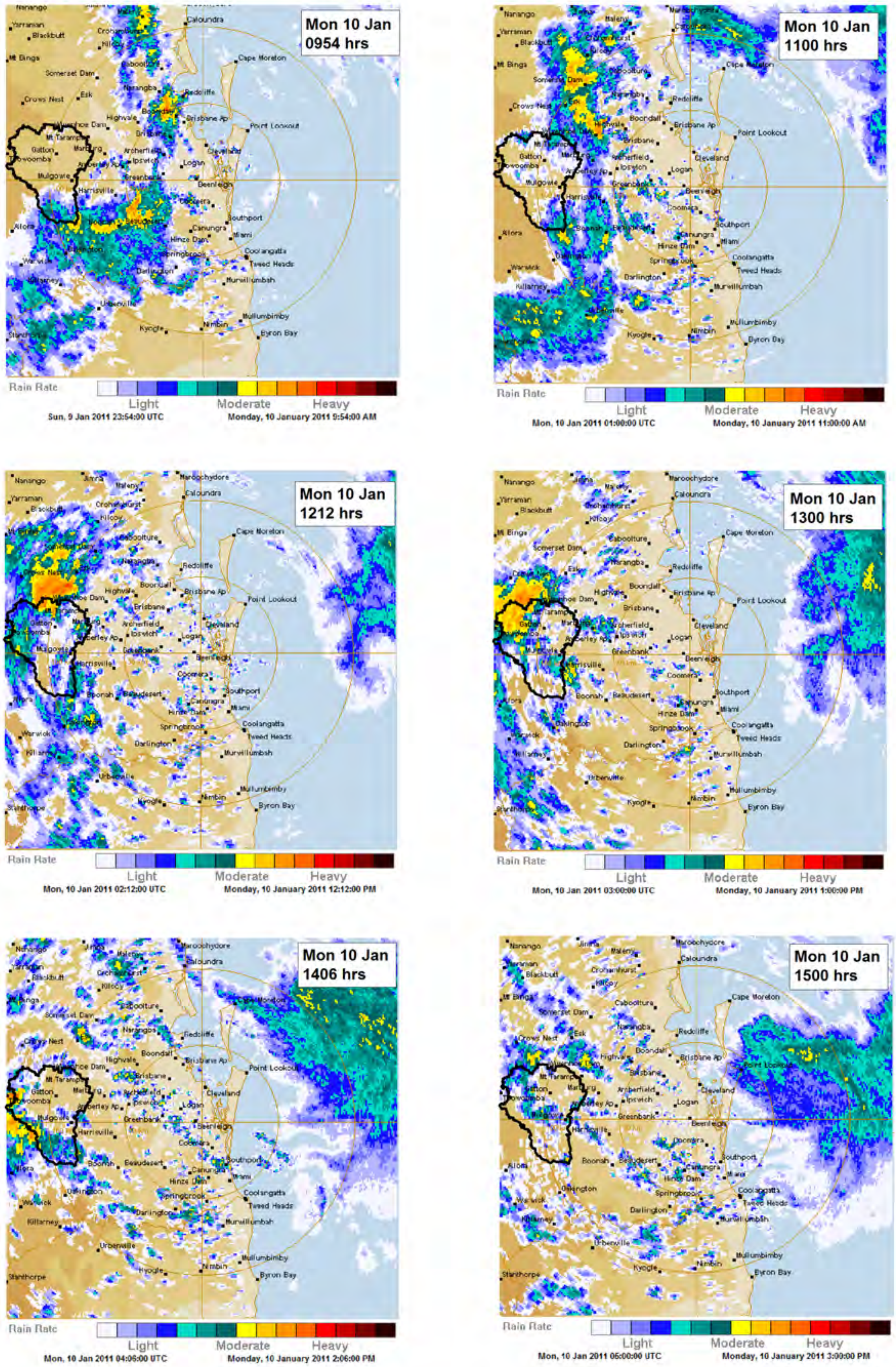

Figure A7 Radar Images Monday 10 January 0954 hrs to Monday 10 January 1500 hrs

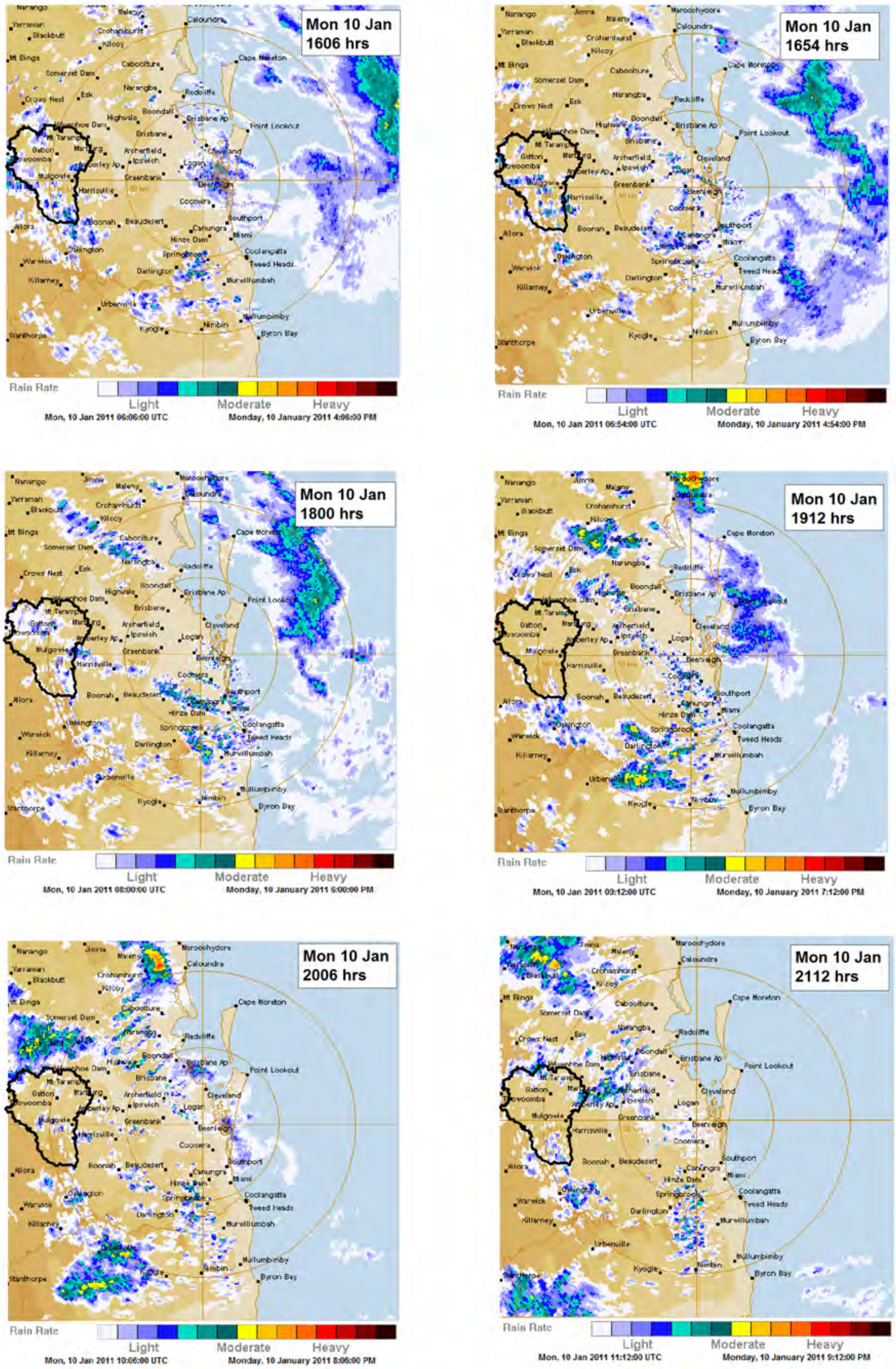

Figure A8 Radar Images Monday 10 January 1606 hrs to Monday 10 January 2112 hrs

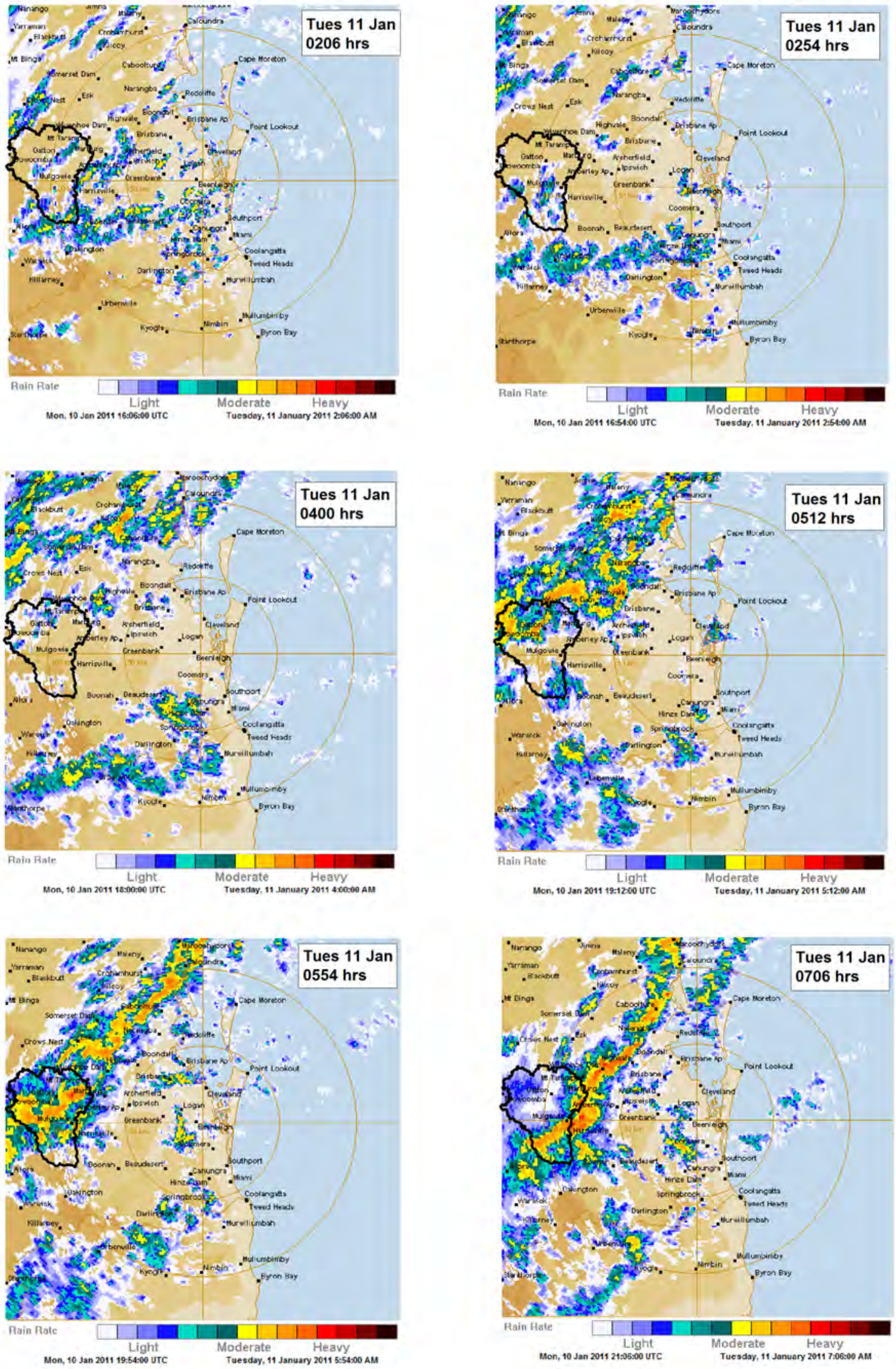

Figure A9 Radar Images Tuesday 11 January 0206 hrs to Tuesday 11 January 0706 hrs

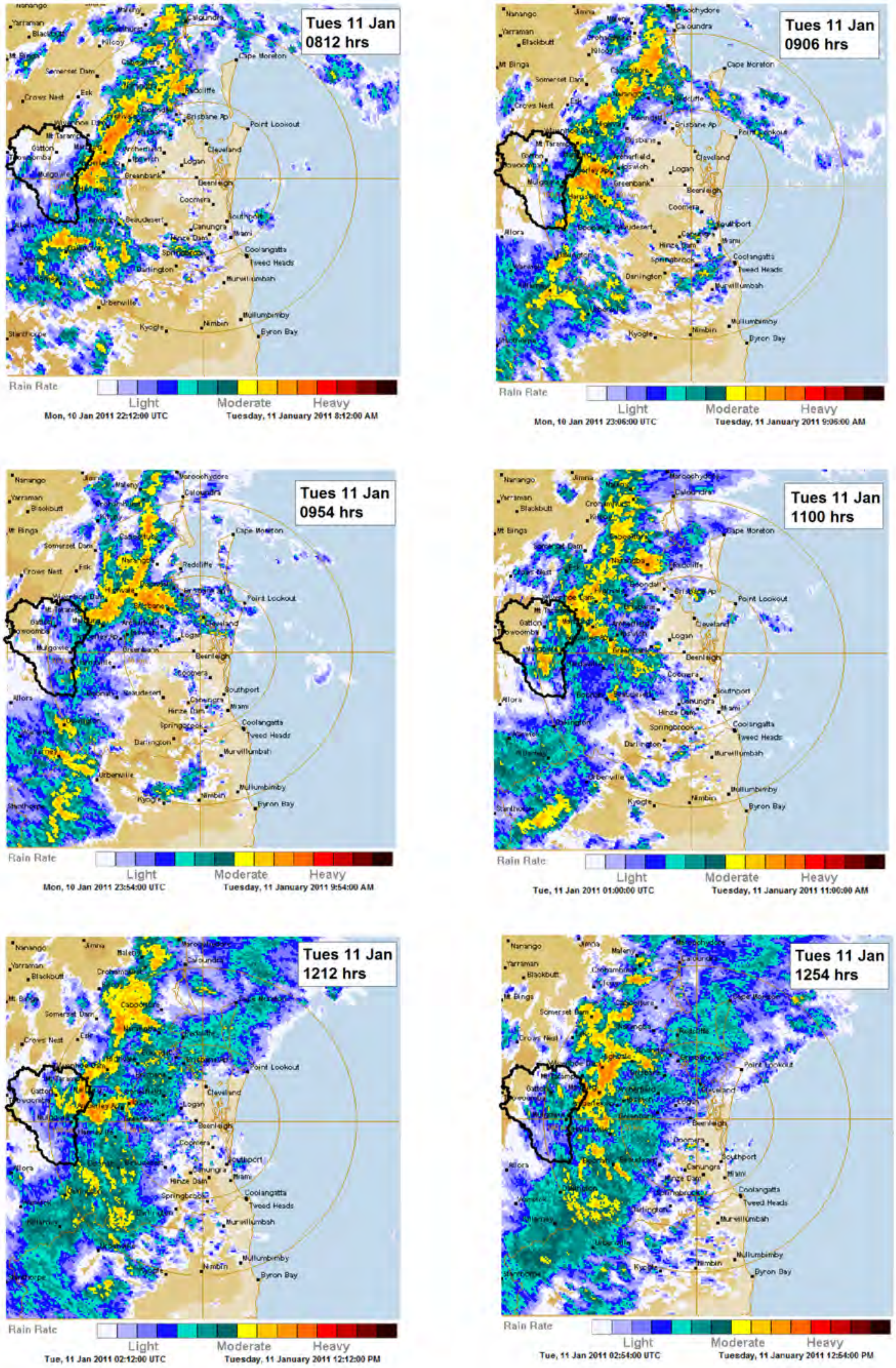

Figure A10 Radar Images Tuesday 11 January 0812 hrs to Tuesday 11 January 1254 hrs

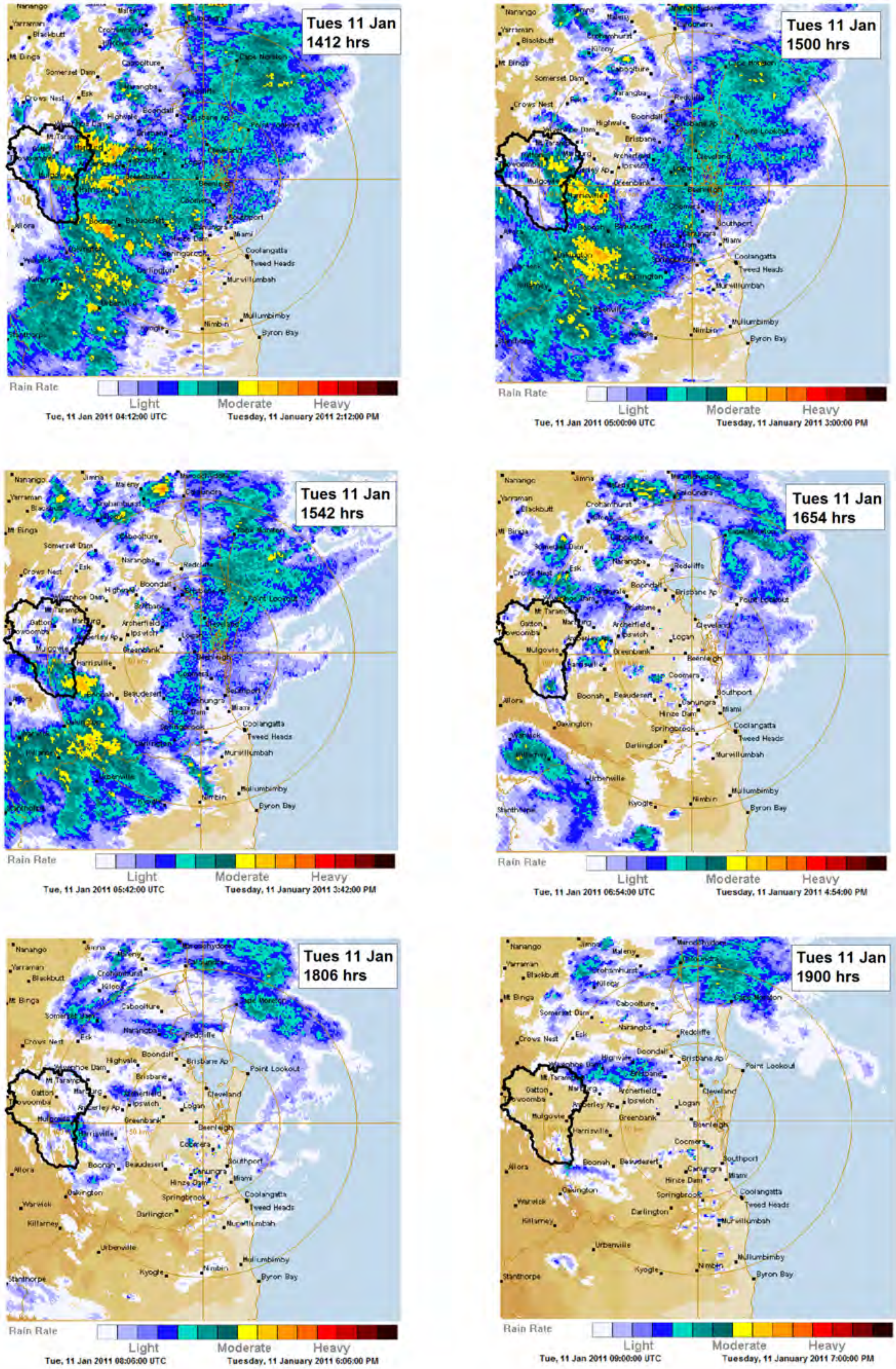

Figure A11 Radar Images Tuesday 11 January 1412 hrs to Tuesday 11 January 1900 hrs

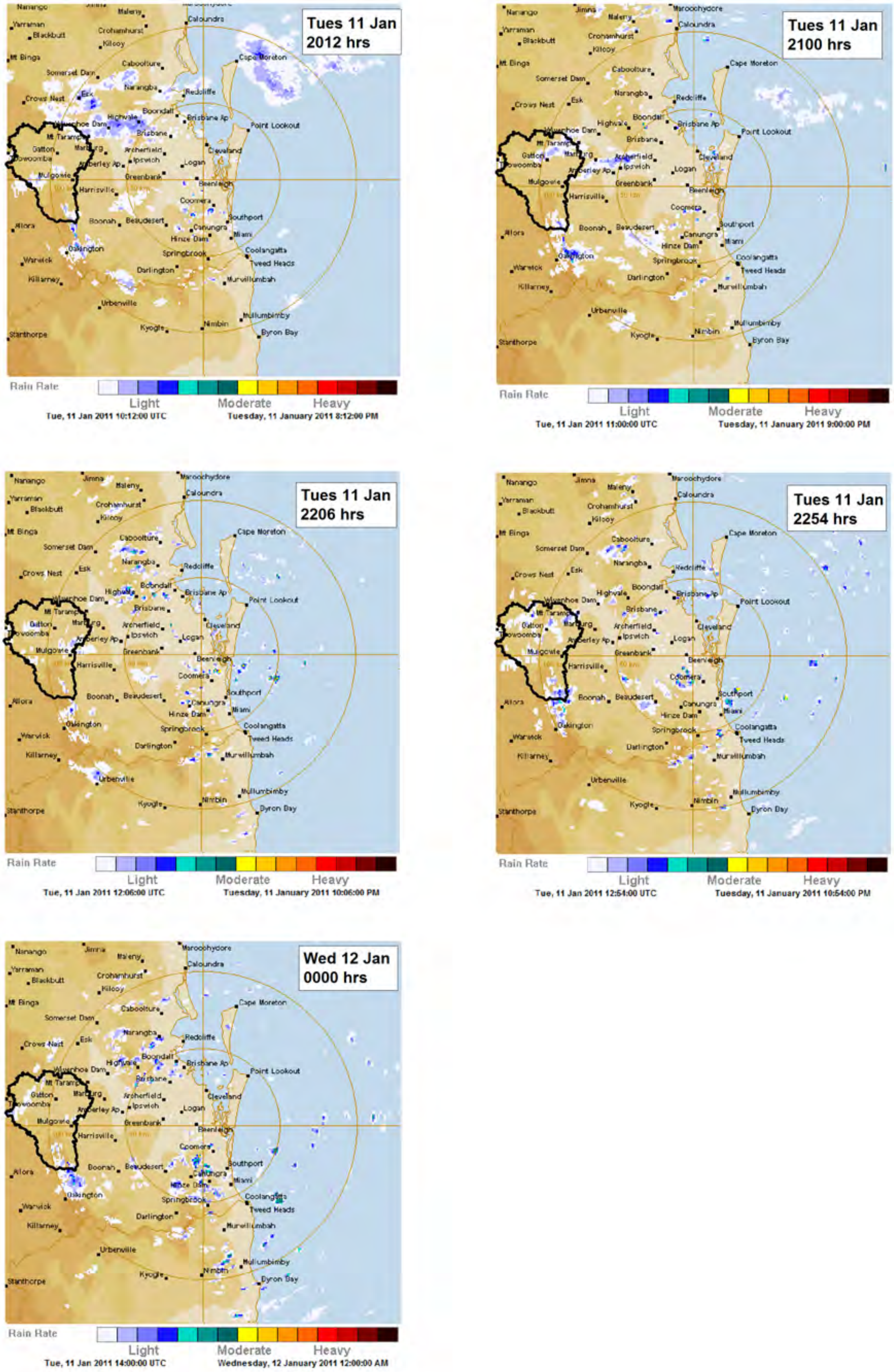

Figure A12 Radar Images Tuesday 11 January 2012 hrs to Wednesday 12 January 0000 hrs

APPENDIX B

RAINFALL HYETOGRAPHS AND INTENSITIES

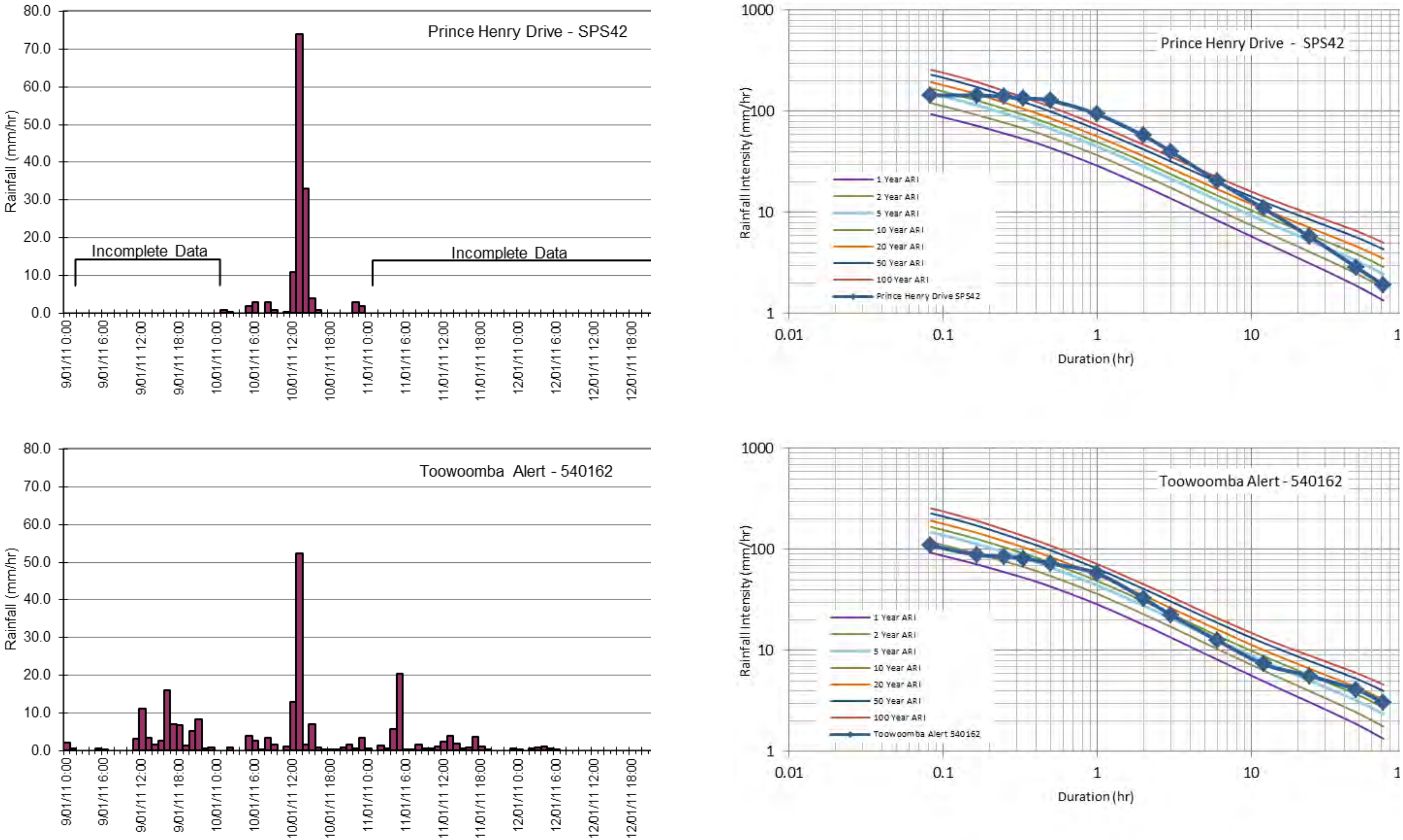

Figure B1 Rainfall Intensities and Severities, Prince Henry Drive Alert (SPS 42) and Toowoomba Alert (540 162)

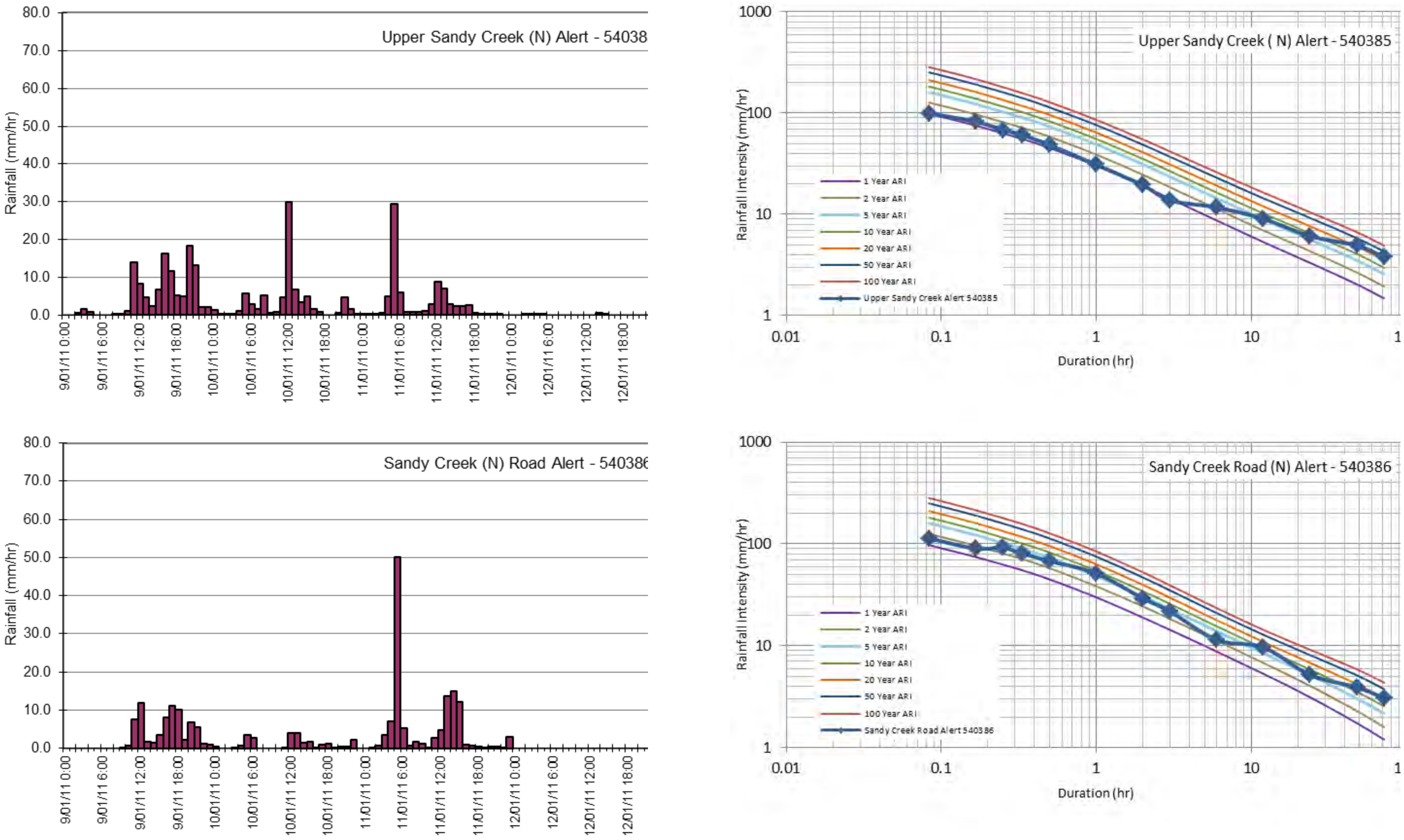

Figure B2 Rainfall Intensities and Severities, Upper Sandy Creek (N) Alert (540 385) and Sandy Creek (N) Road Alert (540 386)

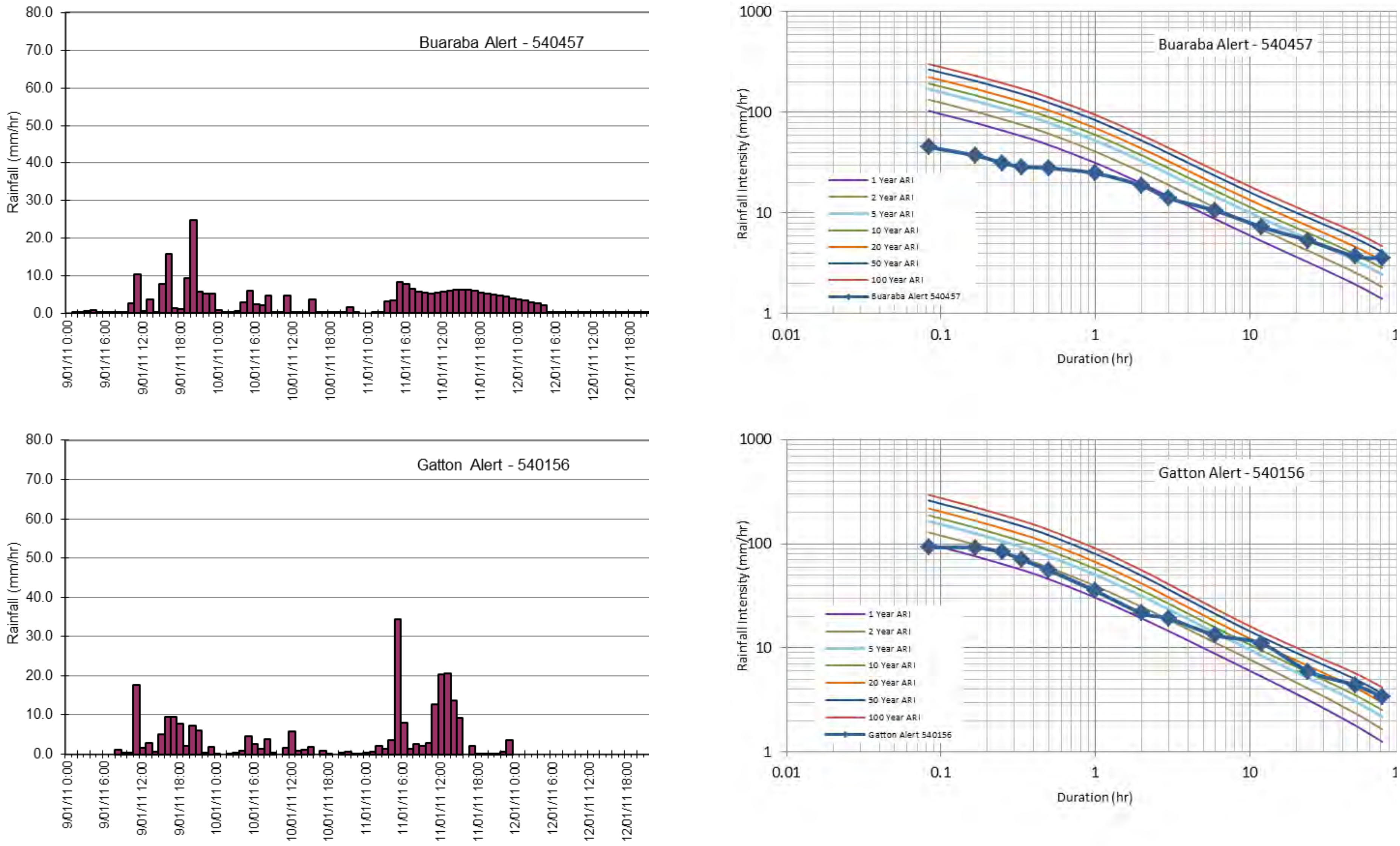

Figure B3 Rainfall Intensities and Severities, Buaraba Alert (540 457) and Gatton Alert (540 156)

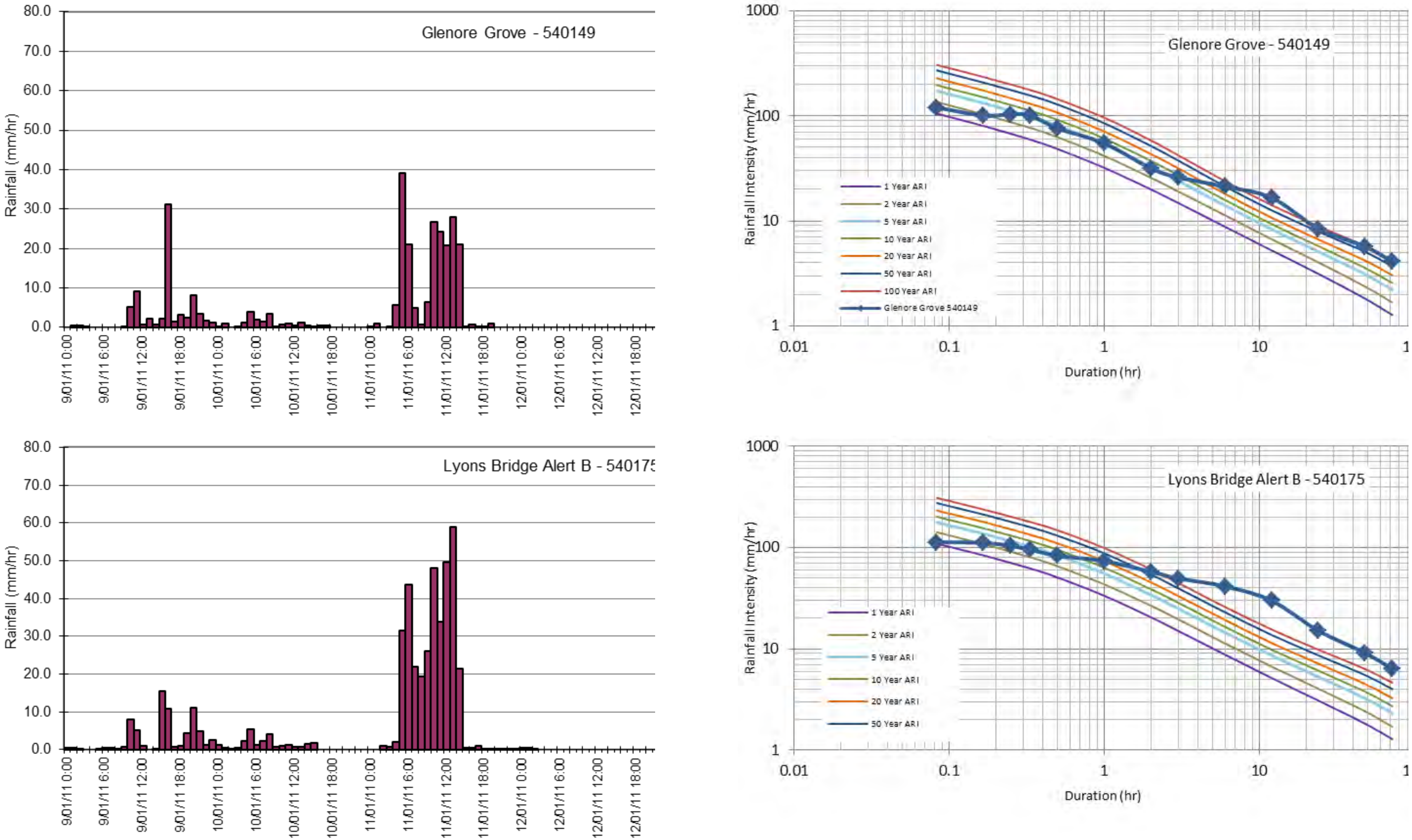

Figure B4 Rainfall Intensities and Severities, Glenore Grove (540 149) and Lyons Bridge Alert B (540 175)

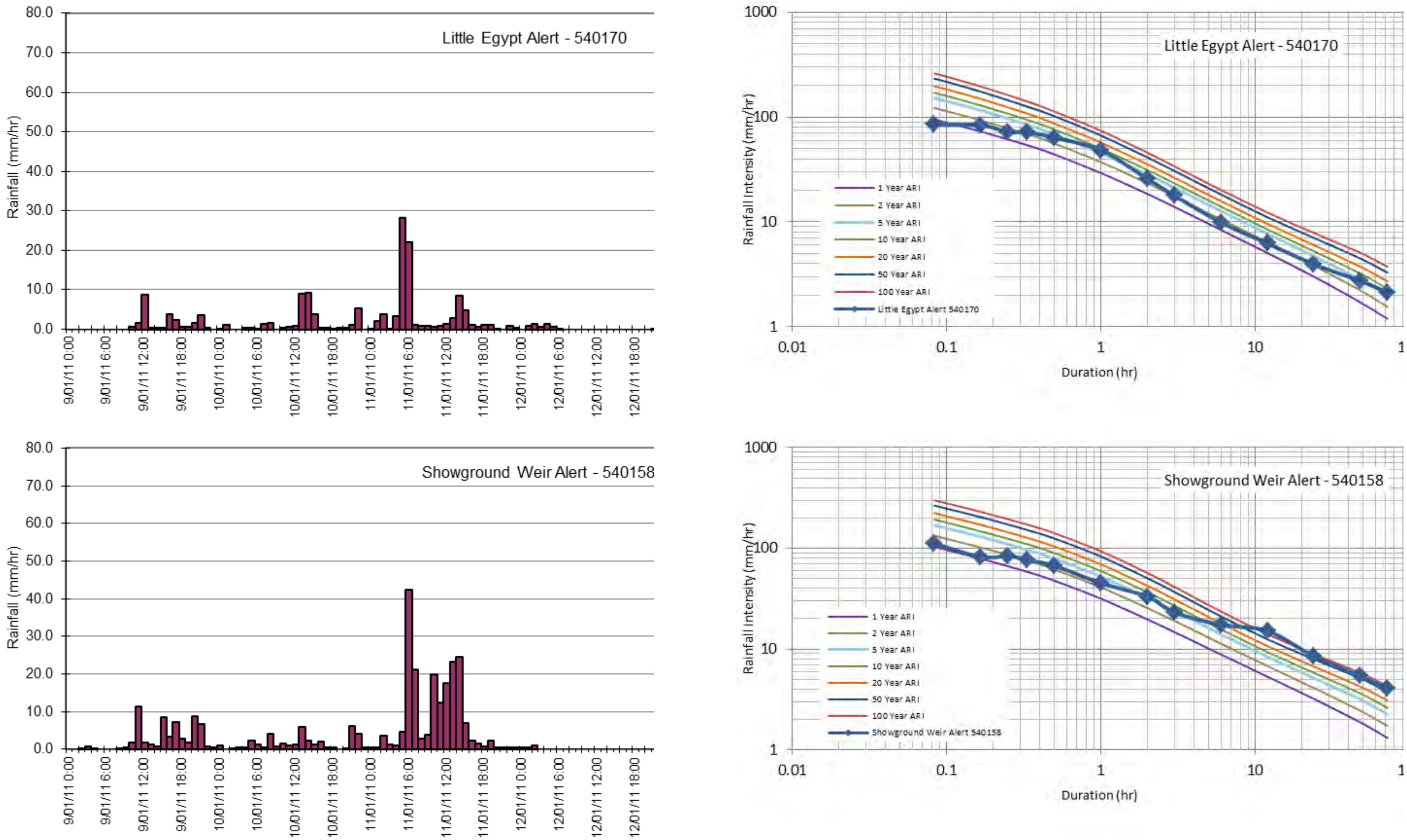

Figure B5 Rainfall Intensities and Severities, Little Egypt Alert (540 170) and Showground Weir Alert (540 158)

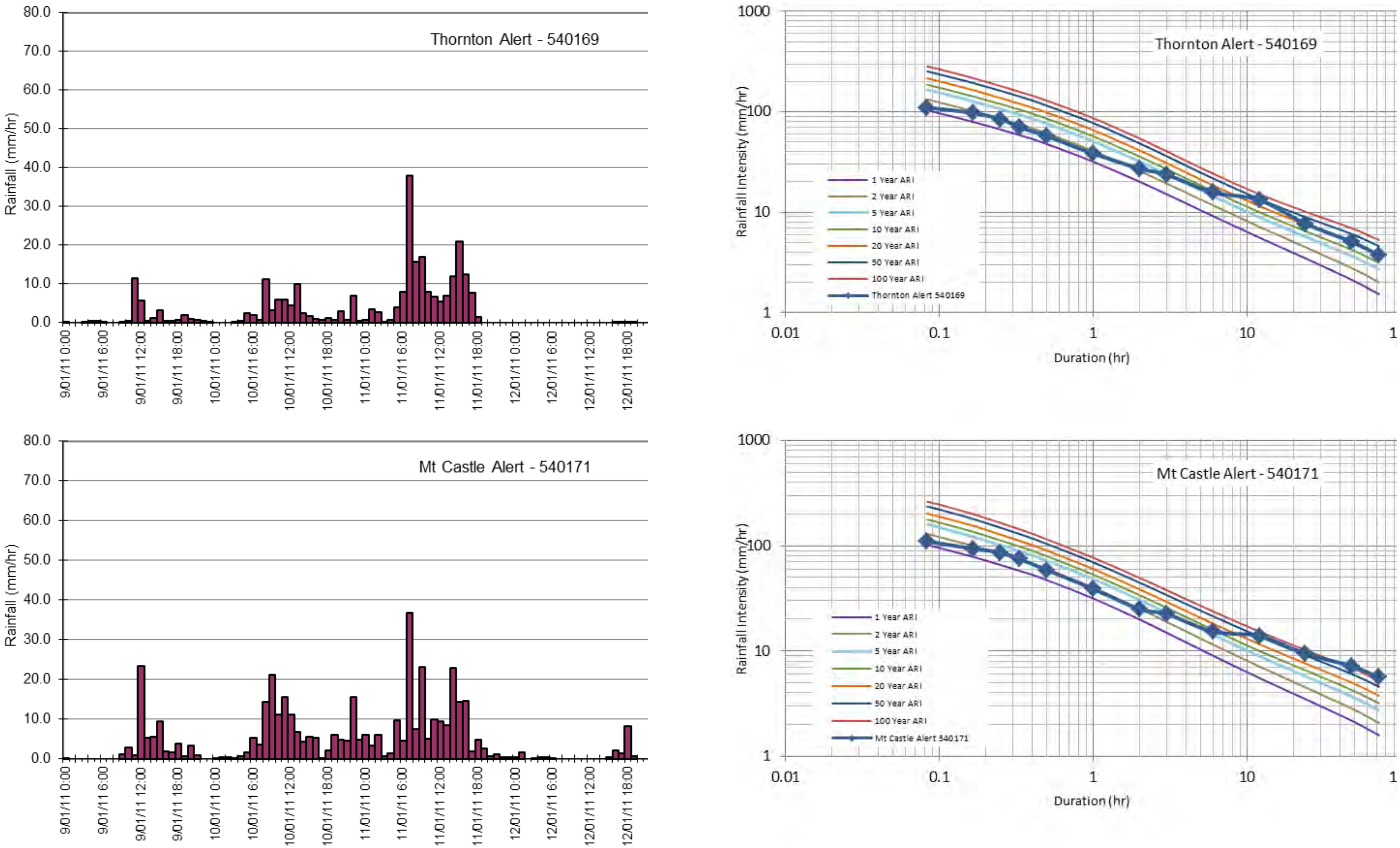

Figure B6 Rainfall Intensities and Severities, Thornton Alert (540 169) and Mt Castle Alert (540 171)

APPENDIX C

PHOTOGRAPHS

Photograph No. 1 Murphys Creek Railway Bridge, Murphys Creek Township

Floodwaters overtopped the bridge. The peak flow in Murphys Creek at this location was estimated to be some 1,000-1,500 m^3/s.

Photograph No. 2 Flood debris caught on Chain-wire Fence to the South of the Railway Line, Railway Street, Murphys Creek Township

The flood debris was swept onto the fence by easterly flowing waterflows from Murphys Creek and/or by northerly flowing overland flows attempting to enter Murphys Creek.

Photograph No. 3   Lockyer Creek at the Willows, MacDonald Road (to the north of Helidon)

Scour and debris indicating fast flowing floodwaters.

Photograph No. 4   Murphys Creek Road, Postmans Ridge

Vehicles swept into trees by floodwaters from Six Mile Creek.

Photograph No. 5 Confluence of Six-Mile and Rocky Creeks, Postmans Ridge Road, Postmans Ridge

Looking downstream along Six-Mile Creek to confluence; Rocky Creek flows from right to left. Note flood debris on trees.

Photograph No. 6 Rocky Creek, Postmans Ridge

Floor slab is all that remains of a building swept away by flood flows down Rocky Creek.

Photograph No. 7 Lockyer Creek at Warrego Highway Bridge, Helidon

Looking upstream. Floodwaters overtopped bridge. Constriction in Creek width at this location will have amplified rate of water level rise upstream of bridge. Peak discharge at this location estimated to be 3,500-4,000 m³/s.

Photograph No. 8 Lockyer Creek at Murphys Bridge, Flagstone Road (1)

Looking north across creek section and adjacent flats. Monkey Waterholes Creek joins Lockyer Creek to immediate left of photo. Flood debris to right of photo indicate flood depths.

Photograph No. 9   Lockyer Creek at Murphys Bridge, Flagstone Road (2)

Looking south. Monkey Waterholes Creek enters to right of photo. Note flood depths indicated by debris in tree.

Photograph No. 10   Lockyer Creek at Murphys Bridge, Flagstone Road (3)

Looking upstream. Monkey Waterholes Creek enters on left of photo. The peak discharge at this location was estimated to be 4,000-4,500 m^3/s.

Photograph No. 11 Lockyer Creek at Quarry Bend, Upstream of Grantham (1)

Note depth of flooding from debris in tree.

Photograph No. 12 Lockyer Creek at Quarry Bend, Upstream of Grantham (2)

Note scour and debris in trees. Peak discharge at this location was perhaps 3,500-4,000 m^3/s.

Photograph No. 13 Sandy Creek (N) Railway Bridge, Grantham

Looking northeast. High area of Grantham that did not flood is located to immediate right of photo. Northerly flowing floodwaters overtopped the railway embankment at various locations and surged up Sandy Creek (N). Many residents were forced to use the railway embankment and bridge as an evacuation route to high ground.