

Article

The 2011 Brisbane Floods: Causes, Impacts and Implications

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Abstract: On 13th January 2011 major flooding occurred throughout most of the Brisbane River catchment, most severely in Toowoomba and the Lockyer Creek catchment (where 23 people drowned), the Bremer River catchment and in Brisbane, the state capital of Queensland. Some 56,200 claims have been received by insurers with payouts totalling \$2.55 billion. This paper backgrounds weather and climatic factors implicated in the flooding and the historical flood experience of Brisbane. We examine the time history of water releases from the Wivenhoe dam, which have been accused of aggravating damage downstream. The dam was built in response to even worse flooding in 1974 and now serves as Brisbane's main water supply. In our analysis, the dam operators made sub-optimal decisions by neglecting forecasts of further rainfall and assuming a 'no rainfall' scenario. Questions have also been raised about the availability of insurance cover for riverine flood, and the Queensland government's decision not to insure its infrastructure. These and other questions have led to Federal and State government inquiries. We argue that insurance is a form of risk transfer for the residual risk following risk management efforts and cannot in itself be a solution for poor land-use planning. With this in mind, we discuss the need for risk-related insurance premiums to encourage flood risk mitigating behaviours by all actors, and for transparency in the availability of flood maps. Examples of good flood risk management to arise from this flood are described.

Keywords: flood; Brisbane River; January 2011; water release strategy; flood risk management; insurance; land use planning

1. Introduction

On Thursday 13th January 2011 Brisbane, the state capital of Queensland, Australia (27°30' S, 153°1' E) (Figure 1), experienced its second highest flood since the beginning of the 20th Century. Major flooding occurred throughout most of the Brisbane River catchment, most severely in the catchments of the Lockyer Creek and Bremer River (major tributaries of the Brisbane River) where numerous record flood heights were experienced. The flooding caused the loss of 23 lives in the Lockyer Valley and one in Brisbane, and an estimated 18,000 properties were inundated in metropolitan Brisbane, Ipswich and elsewhere in the Brisbane River Valley. This paper collates information on the flood from a number of public sources, notably the Bureau of Meteorology (BoM) and submissions to the Queensland Floods Commission of Inquiry [1], and offers some commentary on the operational management of the Wivenhoe Dam, and insurance and land use planning issues.

Figure 1. Location of Brisbane.



The paper is organised as follows. Section 2 provides a description of the Brisbane River system and catchment, while Section 3 reports on the history of flooding in Brisbane. Section 4 details the rainfall recorded in eastern Australia over the period December 2010 to January 2011. Section 5 describes and comments on operational strategies for water releases from Brisbane's flood mitigation and storage dams, while Section 6 examines the impacts of the flooding on the urban environment, and includes an aerial photographic comparison of the extent of flooding with the largest previous flood in Brisbane in January 1974. Subsequent sections report on the Interim Report of the Queensland Floods Commission of Inquiry, and consider insurance and land-use planning issues and their implications for reducing future flooding risks, concerns that, at the time of writing, have yet to be fully examined by the Commission.

2. The Brisbane River Catchment

2.1. The Brisbane River

The Brisbane River is the longest river (309 km) in south east Queensland. Its source is located in the Brisbane Range some 120 km north west of the city of Brisbane. From there it makes its way south before meeting the Stanley River, just downstream of Somerset Dam, to run into Lake Wivenhoe, the main water supply for Brisbane. Lake Wivenhoe was created by the Wivenhoe Dam completed in 1984 in response to severe flooding in 1974 and with the principal aim of protecting Brisbane from future floods. Since its construction many considered that this dam would eliminate the flood risk to Brisbane, notwithstanding warnings against this way of thinking [2]. Downstream from the Wivenhoe dam the river flows eastwards, meeting the Bremer River near Ipswich before making its way through Brisbane's western suburbs towards the Pacific Ocean.

2.2. The Brisbane River Catchment

The Brisbane River's catchment is some 13,570 km² in area, bounded to the west by the Great Dividing Range and to the southeast and north by a number of smaller coastal ranges. Most of the catchment is rural—forestry and grazing land—but also includes the major metropolitan areas of Brisbane and Ipswich, as well as a number of smaller townships (Figure 2).

Figure 2. A topographical map of the Brisbane River catchment.



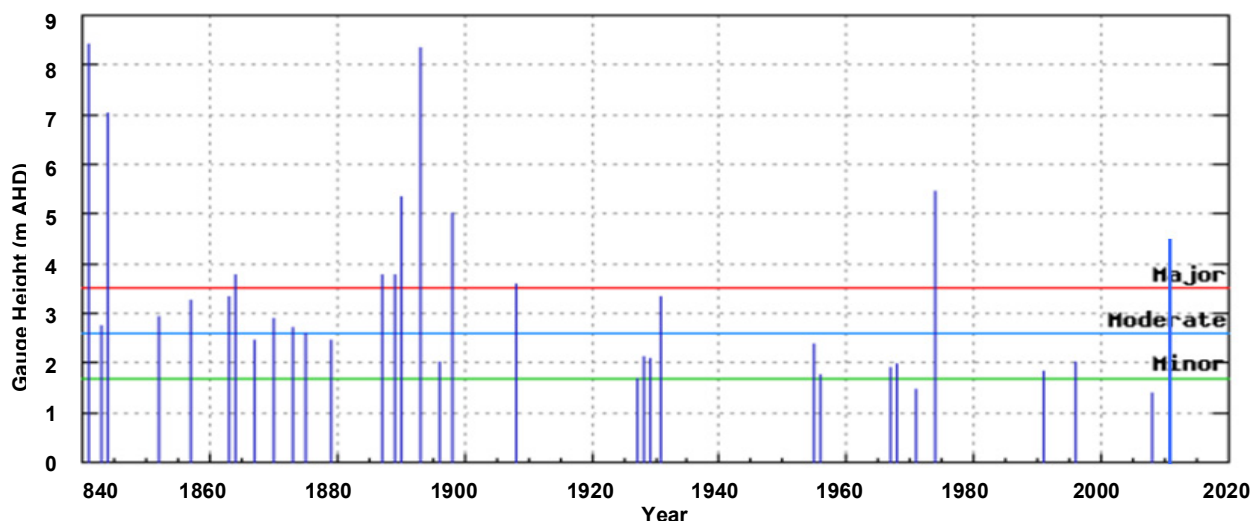
The physical characteristics of the catchment have changed over the last 100 years due to progressive settlement and development along the banks of the river [3]. This development has included the construction of the Wivenhoe and Somerset Dams. At full supply level (FSL) Wivenhoe and Somerset Dams have water supply capacities of 1.15 million mL and 0.37 million mL respectively. Total available storage capacities for flood mitigation are 1.45 million mL and 0.52 million mL respectively [3].

Just *where* and *how much* rain falls within the catchment will critically determine the dams' effectiveness as flood mitigation measures. Situated upstream from where the Lockyer Creek and the Bremer River join the Brisbane River, the dams can only have a limited influence on the Bremer River by reducing the downstream level of the Bremer River as it enters the Brisbane River. In extreme scenarios in small reservoirs, incoming waters will have to be released at at least the same rate in order to avoid destruction of the dam itself; larger reservoirs (like Wivenhoe and Somerset Dams) can provide significant flood attenuation until the flood compartments are filled. In such scenarios, the dam will have no moderating influence on downstream flooding. We will return to the role of the dam in moderating or aggravating the recent flooding in later discussion.

3. Historical Flood Events on the Brisbane River

The city of Brisbane is built on a flood plain [4]. Flood records extend back as far as the 1840's, only a few years after European settlement of the area in 1824 (Figure 3).

Figure 3. Maximum recorded gauge height on the Brisbane River at the Brisbane City gauge for significant flood events (Adapted from [2]) (Brisbane River at Brisbane City Gauge Highest Annual Flood Peaks).



The largest recorded gauge heights were in 1841 and 1893 (over 8.35 m AHD (Australian Height Datum)), which represents a depth of approximately 6.5 m above the highest tide level. The largest flood of the 20th Century was in January 1974, when a gauge height of 5.45 m was recorded at the Brisbane City gauge. As the Brisbane River flooded, it backed up the Bremer River, resulting in 4 to 5 days of record water heights in Ipswich [2].

The floods of 1893 (actually a series of three flood peaks over a period of three weeks) and 1974 were both caused by rainfall from decaying tropical cyclones.

In January 1974 Tropical Cyclone *Wanda* crossed the coast about 150 km north of Brisbane, and then followed a southwesterly track. In addition to providing rain that saturated the catchment, it forced a monsoonal trough southwards to Brisbane, which persisted for four days and resulted in several periods of very intense rainfall. January 1974, with a monthly total of 872 mm, was the wettest January on record and the second wettest month ever, surpassed only by February 1893 in which 1,026 mm was recorded. Brisbane's mean January rainfall is 166 mm [5].

Although smaller in magnitude than the 1893 floods, the impact of the 1974 flood remains the most severe example of urban flooding in Australia. Damage in the 1974 flood was greater than in 1893 because Brisbane's population had grown from around 175,000 in 1893 to around 1 million and the greater exposure afforded by new buildings and infrastructure. Table 1 shows some comparative damage statistics from the 1893 and 1974 floods. Insured losses from the 1974 event ran to almost \$2.29 billion (normalised to 2006 exposure, societal conditions, inflation and wealth) [6]. Given 2011 exposure, the normalized insured losses are of the order of \$3.3 billion [7].

Table 1. Comparative damage statistics—February 1893 and January 1974 Brisbane River floods (Source: [8]).

Station	February 1893	January 1974
Deaths	35	16
Injuries	300	300
Persons left homeless	5,000	9,000
Persons evacuated		9,000
Buildings damaged	5,000	7,000
Cars damaged or destroyed		1,000

4. Causes (1): Rainfall in Eastern Australia: December 2010 to January 2011

4.1. Rainfall During December 2010 and January 2011

The second half of 2010 and early 2011 was characterized by one of the four strongest La Niña events since 1900 (Figure 4). Strong La Niña events are often associated with extreme rainfall and widespread flooding in eastern Australia [9].

An extremely wet spring (September to November) meant that catchments were already saturated before the December 2010 and January 2011 rains. Figure 5 shows total rainfall across Australia for November 2010 to January 2011. During this period, rainfall in the 600 to 1,200 mm range was widespread along most of the Queensland coast. Some stations north and west of Brisbane exceeded 1,200 mm during this same period.

Figure 4. Average summer (October to March) Southern Oscillation Index (SOI), 1900/01 to 2010/11. (Source of data: [10]).

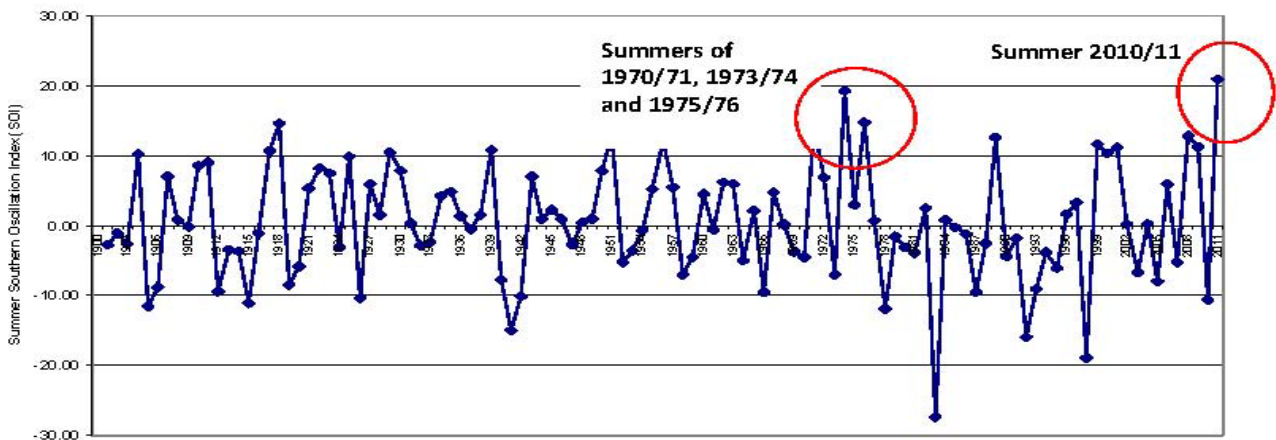
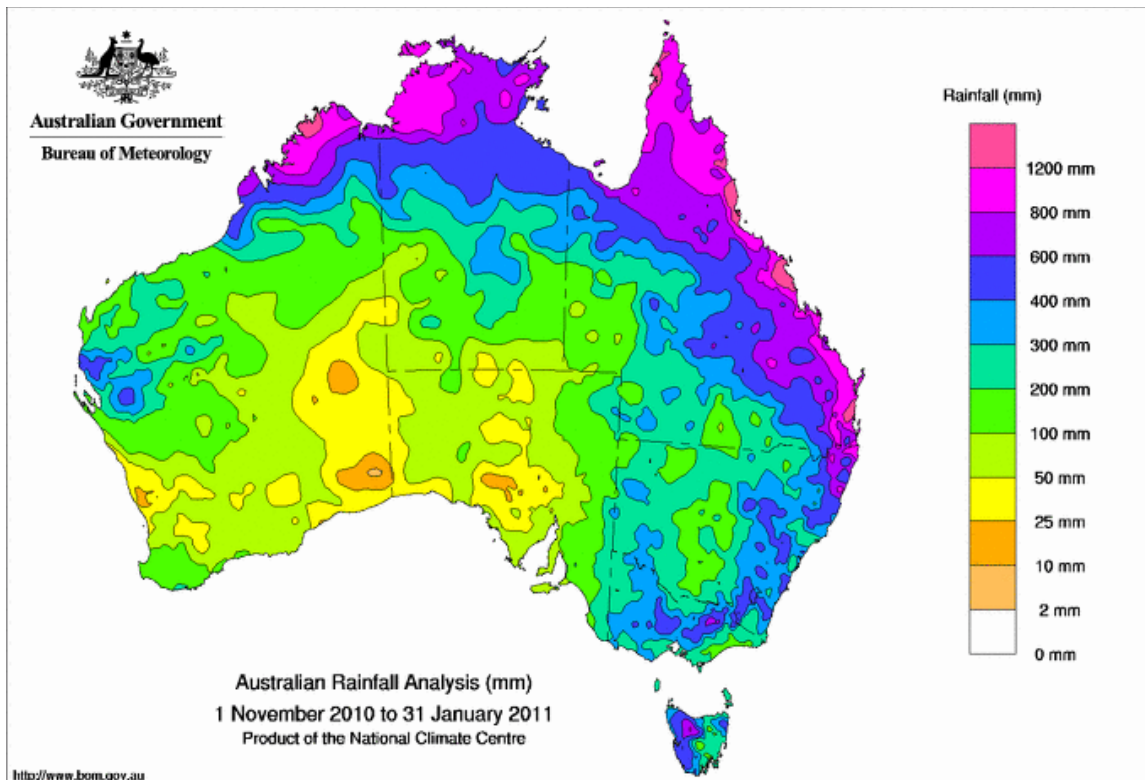


Figure 5. Total rainfall for the period November 2010–January 2011 (Source: [11]).



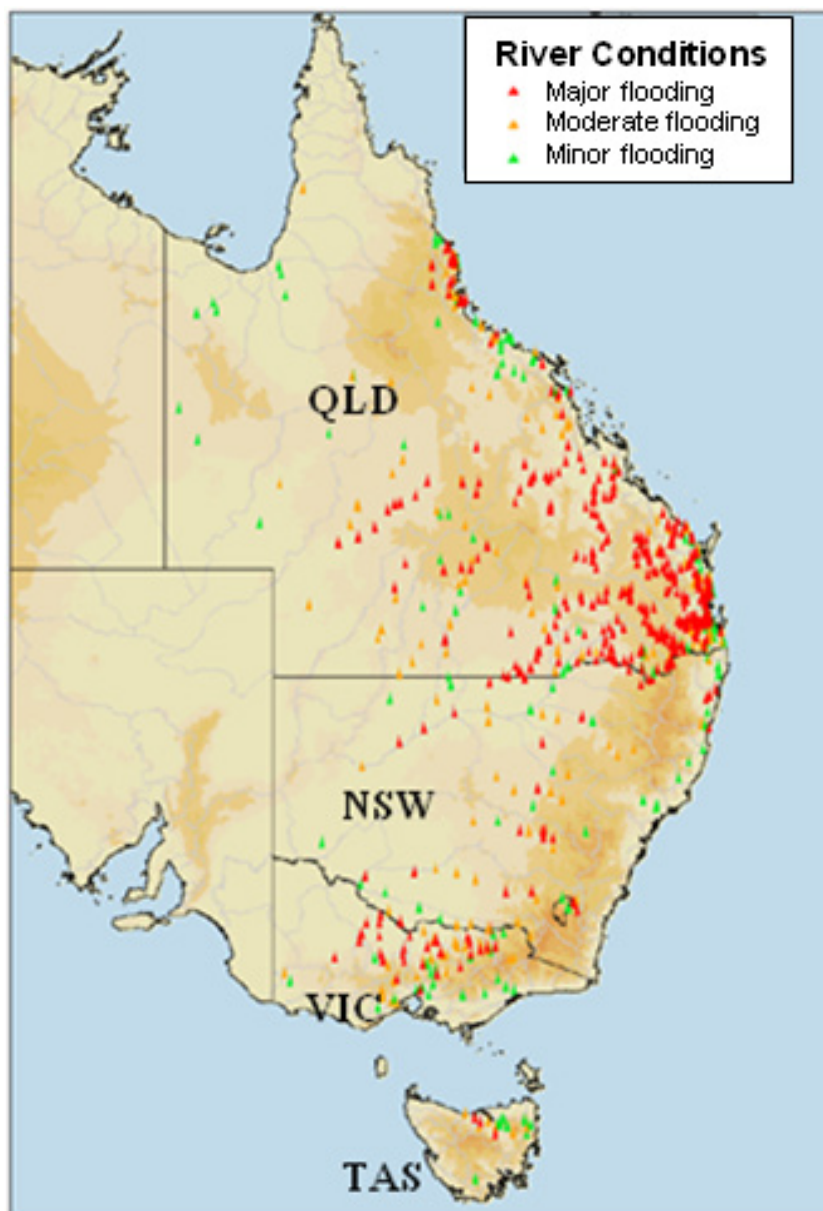
The Bureau of Meteorology warned the public and government about the likely strength of the La Niña event [12]. This did not, however, invoke any action on the part of the dam operators to draw down water levels from Full Water Supply to accommodate likely increased rainfall. We will address the question of dam operation during the flooding event in a later section.

4.2. Flooding in Eastern Australia

The excessive rainfall over December and the first half of January resulted in almost every river in Queensland south of the Tropic of Capricorn and east of Charleville and Longreach recording major

flood levels at some stage during this period [9]. Severe flooding also affected other parts of Queensland, northern and western Victoria, inland New South Wales and northern Tasmania (Figure 6).

Figure 6. Flood peaks in eastern Australia over the period 26th November 2010–20th January 2011 (Source: [9]).



4.3. Rainfall Meteorology in South East Queensland During 8th to 12th January 2011

The flooding in southeast Queensland during the second week of January was caused by the interaction of a low-pressure system situated off the mid and south Queensland coasts, and upper level and monsoonal troughs [13]. Between Friday 7th January and Sunday 9th January the low-pressure system moved in a southerly direction from east of Mackay (800 km north west of Brisbane) to an area north east of Fraser Island, before moving closer to the coast on Monday 10th January. Early on Sunday 9th January the low-pressure system combined with an upper level trough to deliver heavy rains to southeast Queensland. This rainfall continued for much of the day.

The upper level trough dissipated early on Monday 10th January, but the low-pressure system intensified and moved north to combine with a southward moving monsoonal trough. Warm moist air delivered into this trough system by a high pressure system located off New Zealand led to very heavy rainfalls across the southeast corner of Queensland from the evening of Monday 10th until the late afternoon of Tuesday 11th January, with rainfall tailing off on Wednesday 12th [13]. Direct rainfall for the period 9th–13th January into Wivenhoe and Somerset Dams was very heavy, with totals of 480 mm and 370 mm respectively.

The 10th–11th January rainfall led to very high water levels in the two dams. Levels in Somerset Dam peaked at 104.96 m AHD around 05:30 on Wednesday 12th January 2011. Water levels in Wivenhoe Dam peaked at 74.97 m AHD around 19:00 on Tuesday 11th January and remained above 74.9 m AHD for six hours from 18:00 on Tuesday 11th January [13].

Downstream of the dams, areas in the lower Brisbane River catchment also experienced significant rainfall, decreasing towards the south and east. In the Lockyer Creek catchment total rainfalls of around 450 mm were recorded close to its downstream end, with intensities having an Average Return Interval (ARI) greater than 100-years for durations greater than 3 hours. In the Bremer River catchment, 420 mm was recorded near the northwestern limit. The lowest rainfalls across the lower reaches of the catchment were recorded in the southern and eastern suburbs of Brisbane (110–160 mm) [13].

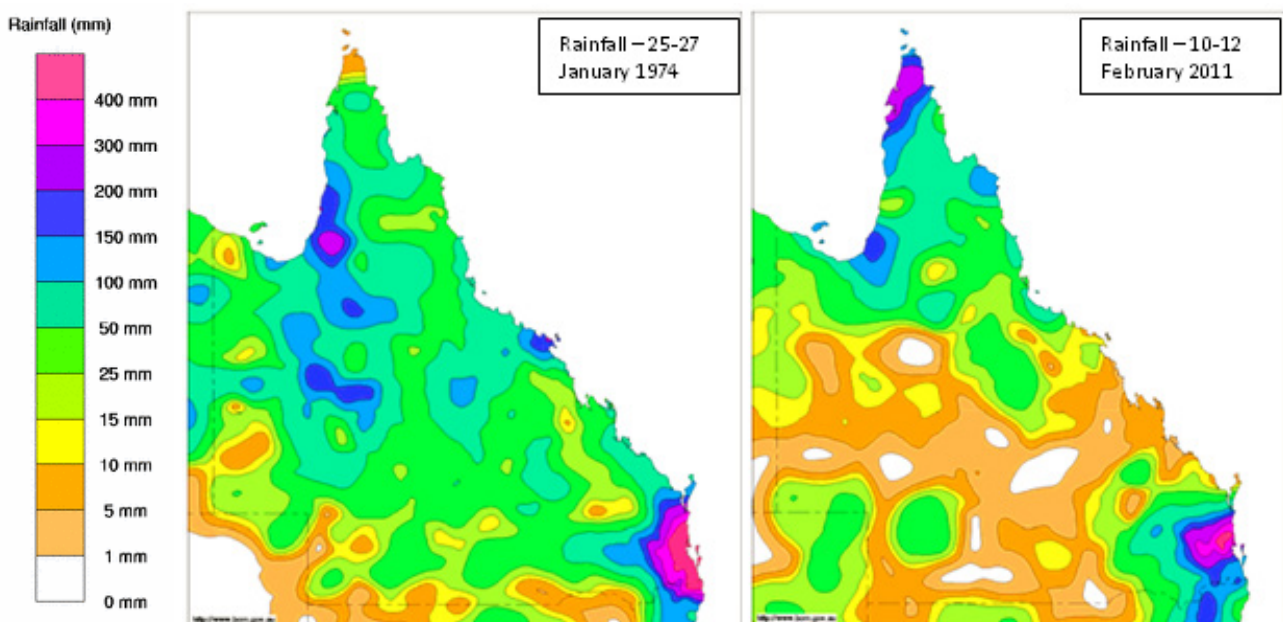
4.4. Comparing the Three-Day Rainfall Totals from the January 2011 Flood Event with Those of the January 1974

Figure 7 displays three-day rainfall totals from the period 10th–12th January 2011 and for the 25th–27th January 1974. Key points to emerge are:

- (1) Peak rainfalls in 1974 were substantially heavier than those in 2011. A number of rainfall stations in southeast Queensland had three-day rainfall totals in excess of 1,000 mm in 1974 compared with a maximum of 648 mm recorded during the 2011 event. Over the Brisbane River catchment as a whole, the average three-day rainfall in 1974 was 349 mm, compared with 286 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 (442 mm *vs.* 417 mm) and Lockyer (331 mm *vs.* 292 mm) sub-catchments [9].
- (2) The above observation also extends to metropolitan Brisbane where three-day and one-day totals of 600 mm and 314 mm in 1974 were significantly greater than the 166 mm and 111 mm recorded in 2011 [9].
- (3) In 1974 the heaviest rains in south east Queensland occurred close to the coast, whereas in 2011 the heaviest rainfalls spread further inland, particularly on the western fringe of the Brisbane River catchment and on the Great Dividing Range.

Insufficient data exists for a full assessment of the 1893 event. However, available station data indicate that peak rainfalls in the region during the 1893 event were heavier than those during either the 1974 or 2011 events [9].

Figure 7. Three-day rainfalls for the periods from 25th–27th January 1974 (**left**) and 10th–12th January 2011 (**right**) (Source: [9], © Commonwealth of Australia, 2011).



5. Causes (2): Water Releases from Wivenhoe Dam

Hydrologists appointed by the Insurance Council of Australia to investigate events leading to flood damage claims in Brisbane, Ipswich, Toowoomba and the Lockyer Valley consider the Brisbane flood event to be a “dam release flood.” In other words, in their view release of water from the Wivenhoe Dam was a key contributor to the flooding downstream over the period 11th–12th January 2011 [13]. This does not imply fault, but merely acknowledges that the water that caused much of the damage came from dam releases. In what follows we briefly discuss this issue.

Seqwater operates the Wivenhoe and Somerset Dams in accordance with procedures contained in its operations manual [14]. The manual provides objectives and strategies to guide operational decision-making during a flood event, and lists its operational objectives, in descending order of importance, as:

- (1) ensuring the structural safety of the dams;
- (2) providing optimum protection of urbanised areas from inundation;
- (3) minimising disruption to rural life in the valleys of the Brisbane and Stanley Rivers;
- (4) retaining the storage at Full Supply Level (for water supply purposes) at the conclusion of the Flood Event;
- (5) minimising impacts to riparian flora and fauna during the drain down phase of the flood.

Apart from the obvious most important objective of ensuring the structural integrity of the dam itself, it can be seen that the dam is expected to serve two contradictory functions. On the one hand it serves as a buffer against drought, meaning that it is desirable to keep the dam as full as possible in case future rainfall is low (objective 4); on the other hand, the dam was specifically built to provide a buffer against floods, meaning it is desirable to keep it as empty as possible to maximize retention of

flood waters (objectives 2, 3 and 5). Since keeping the dam full and empty are not simultaneously possible, Seqwater's engineers have to balance these conflicting objectives.

In January 2011, Wivenhoe Dam was called upon to accommodate massive inflows made up of surface runoff from the upstream catchment area, releases from Somerset Dam and direct rainfall into the lake. The greater the volumes and rate of inflow, the less effective are dams in mitigating flood flows, and the more constrained are management options for dam operators. According to a Seqwater report into the January 2011 flood event ([15,16]) operational decisions were made in accordance with the manual. Dam outflows were delayed until it was clear that no other option was available without risking the safety of the dams. Seqwater reported that:

Two distinct flood peaks entered Wivenhoe Dam during the flood event. The first flood into Wivenhoe Dam was similar in nature and magnitude to the comparable flood flows of the January 1974 event. The combined mitigation effect of Somerset and Wivenhoe Dams ensured that this first flood did not result in urban damage below Moggill (some 20 km upstream from Brisbane CBD), however achieving this result did cause significant filling of the dams' flood storage compartments. The second flood was also similar in nature and magnitude to the comparable flood flows of the January 1974 event. The flood compartments of the dams were filled to a high level by the first flood and there was not sufficient time to release this water prior to the second flood arriving. Accordingly, the second flood could not be completely contained without risking the safety of the dams. The resulting inflow of water into the Brisbane River, combined with floodwaters from Lockyer Creek, the Bremer River and the Lower Brisbane River resulted in significant urban damage. However, the extent of this damage was greatly reduced by the operation of the dams. [15]

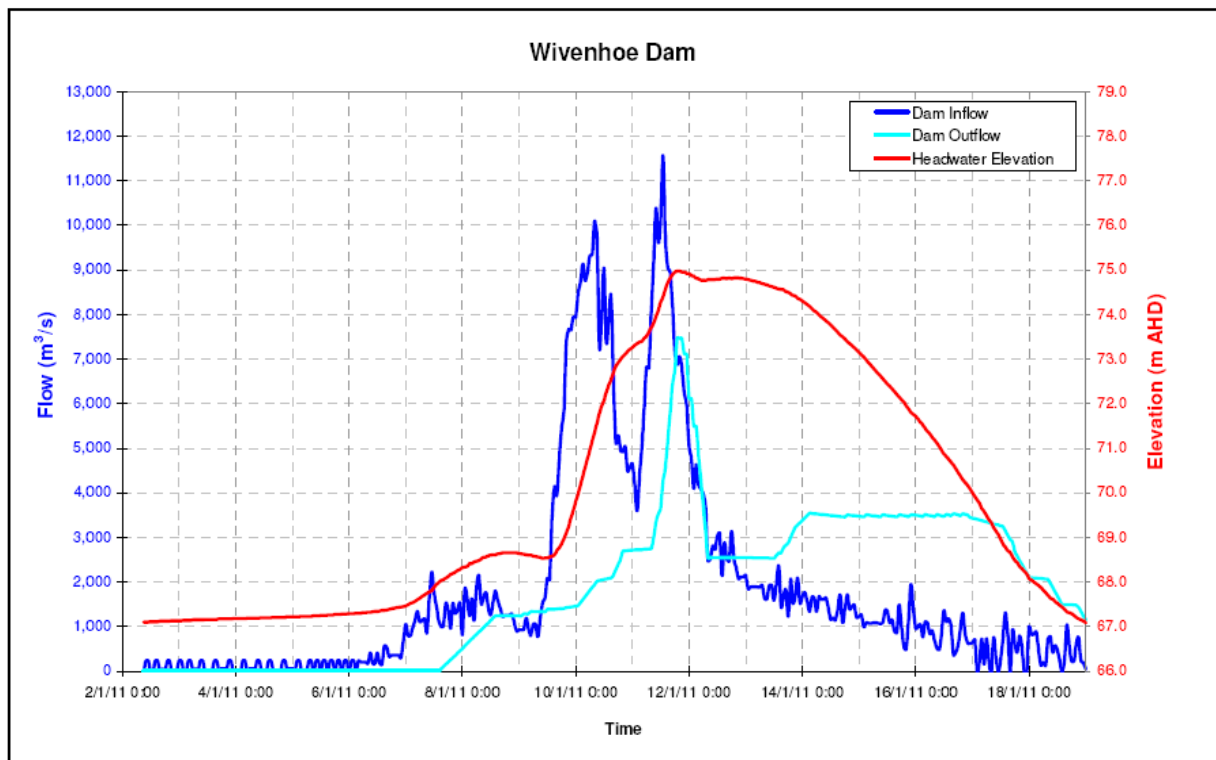
The inflow of water into the Wivenhoe Dam, the outflows and the headwater elevation of the dam around the time of the 2011 flood are shown in Figure 8. The peak of the outflow from the dam (around 23:30 on 11th January) was approximately 40% lower than the peak of the inflows (at about 13:00 on the same day). Indeed, model estimates provided to Seqwater by Brisbane City Council indicate that without the mitigating effects of Wivenhoe the peak flood height measured at the City gauge near the Brisbane CBD would have been approximately 2.0 m higher than was actually experienced, and a further 14,000 properties impacted [15].

Figure 8 shows that water releases commenced only at 15:00 Friday 7th January when Wivenhoe Dam was at 109.6% and Somerset at 110.9% of FSL, with a total of 153,000 mL already in flood storage. In the week from 06:30 Tuesday 4th January, when Wivenhoe Dam was at 102.1% and Somerset at 102.9% of FSL and Seqwater were required under the manual to declare a Flood Event, there were only 14 hours during which the release rates from Wivenhoe Dam exceeded inflows.

The balancing act between retaining as much water as possible and releasing water to make space for further significant inflows has been automated to some extent with the operations manual directing that the water release strategy chosen at any point in time will depend on the *actual* water level in the dam, as well as modeling predictions about future water levels. The latter are to be made using the best available *forecast* rainfall and stream flow information [14]. In the aftermath of the January 2011 flood, a senior Wivenhoe engineer has stated before the Commission of Inquiry [17] that uncertainty in BoM rainfall forecasts and the paucity of rain gauges in the catchment immediately above the

Wivenhoe Dam led them to conclude that the precipitation forecasts were not sufficiently reliable to form the basis for operational decision making [18]. Seqwater claim there were gaps in the information on which operational decisions needed to be made, despite them having available the best rain gauge of all-the dam itself!

Figure 8. Inflow and release of water for the January 2011 flood event—Wivenhoe Dam (Source: [15]).



With this in mind, and rather than employing data from forecasting models, Seqwater’s modeling considered “no further rainfall” as the most appropriate scenario for predicting the future dam level. Thus less-than-perfect information contained in the BoM’s forecast rainfall was given zero weight in decision-making. In other words, the dam operators chose a scenario guaranteed to be wrong over a forecast that was likely uncertain. From this outcome it is difficult not to conclude that the fact that Queensland had been in drought for most of the previous decade [19] anchored their decision making towards conserving FSL.

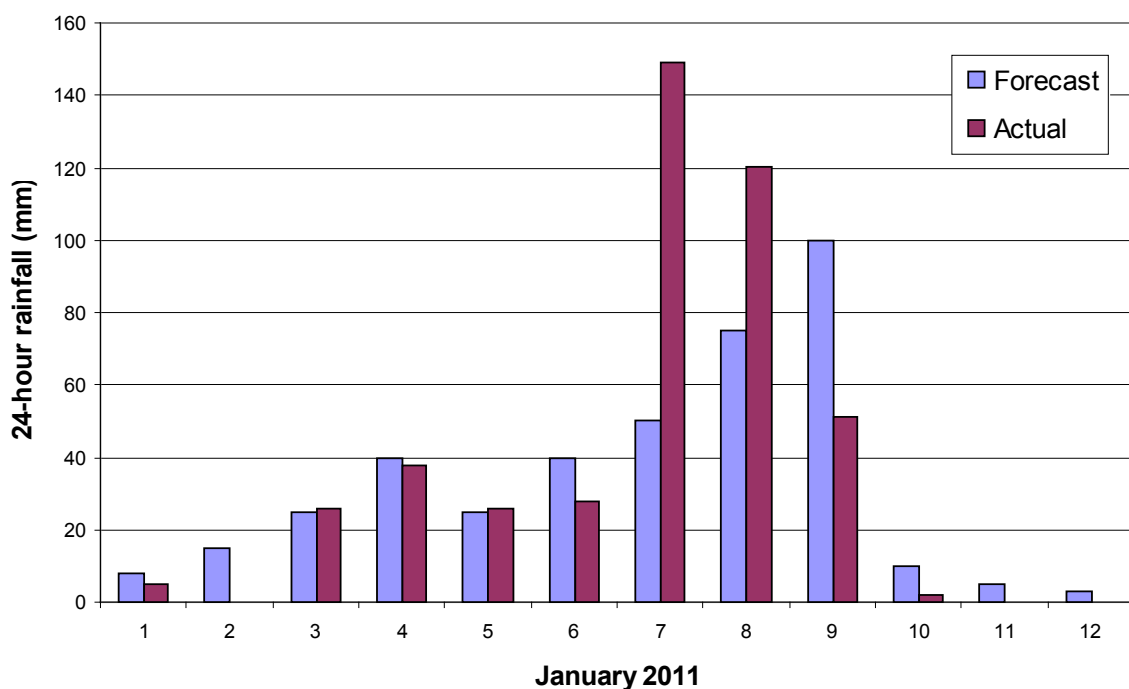
Many tools exist to facilitate decision making under uncertainty, e.g., [20]. None of these guarantee favourable outcomes, but we must learn to differentiate between bad outcomes and bad decisions. One example of a tool that may have proved useful to decision makers at Wivenhoe is the geostatistical technique of kriging [21,22]. This method is widely used to interpolate the value of a random variable, in this case rainfall, at an unobserved location from observations at nearby locations, a process that would seem very appropriate in the Wivenhoe rainfall problem.

Other tools such as decision trees [23] could have proved useful. Here uncertainties in random variables are expressed through probability density functions that describe the range of possible values and the relative likelihood of values in between. Rather than choosing a single scenario, the dam operators could have considered a spectrum of possible futures with various downstream flooding

outcomes weighted by their likelihood of occurrence and contingent upon various rainfall scenarios. A decision tree would have allowed the operators to incorporate what was known or expected about future rainfall explicitly into the decision process. In the event, the dam operators chose not to do this and thus rather than making a decision under *uncertainty*, they chose to make a decision under *ignorance*.

How bad were the rainfall forecasts? Figure 9 compares the 24-hour Quantitative Precipitation Forecasts (QPFs) for the Wivenhoe Dam catchment, and the actual rainfall intensities observed for the first half of January 2011.

Figure 9. Forecast and actual rainfall intensities in the Wivenhoe catchment, January 2011 (Source of data: [15]).

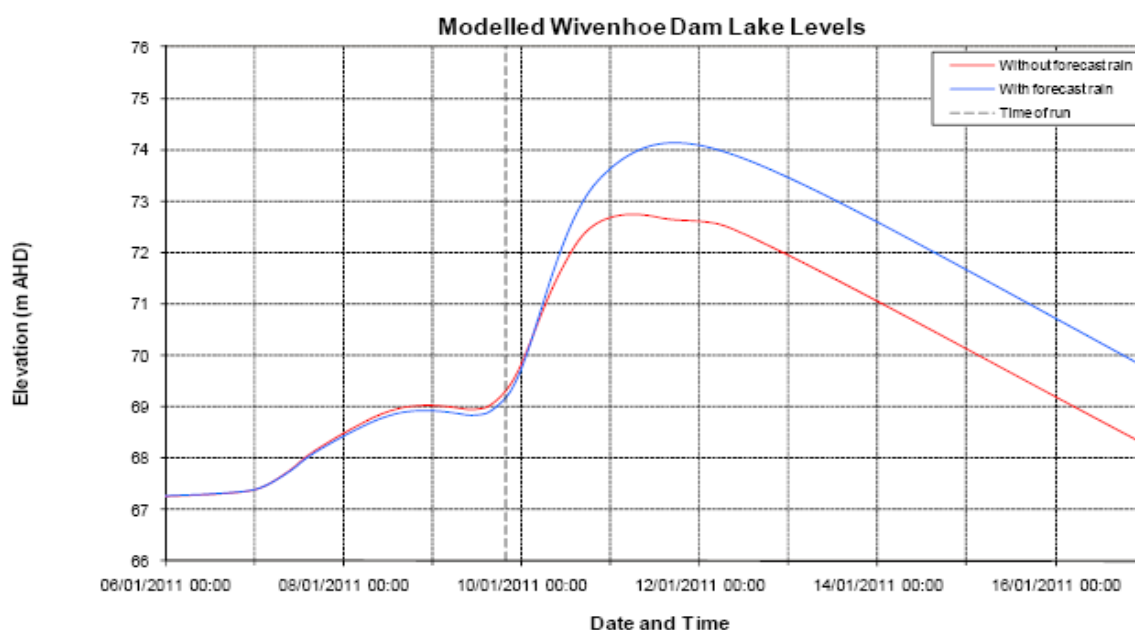


Rainfall forecasts correspond reasonably well with actual average rainfall recorded up until 8th January 2011. Over the next two days the 24-hour forecasts significantly underestimated the average rainfall subsequently recorded. On 11th January the situation was reversed: the forecast was almost double that actually recorded. Thus extremely heavy rainfall was correctly predicted around the time of the flood, but the intensity of the main peak was underestimated, and its timing off by around 48 hours. Using this forecast as an input would allow the decision to be based on a probabilistic approach, which could be tested and implemented using Monte Carlo simulation or stochastic modeling. It would also be advisable to take account of the variability in spatial and temporal (as in Figure 9) patterns of rainfall forecasts. The accuracy of forecasts could be incrementally improved (that is, the variability of the forecast reduced) as more information became available. This is known as iterative “Bayesian updating”.

The operators use a computer-based modeling tool, the so-called “real time flood model”, to predict the reservoir water level. Two predictions are generated: a *with forecast* prediction that incorporates the BoM’s rainfall forecasts and a *without forecast* that assumes zero rainfall. The former is tracked in

blue in Figure 10 while the latter is shown in red. The *with forecast* prediction suggests that the level of the lake would exceed 74.0 m, the tipping point for the purposes of moving to a water release strategy where the primary consideration is the structural safety of the dam. This strategy, according to the manual, has no upper limit on the maximum release rate of water from the dam. The red line, however, the *without forecast* prediction, remains well below the 74.0 m threshold. In short, by failing to use all the information available to them (however incomplete), the dam operators made a sub-optimal decision, even if the dam was operated according to the operations manual.

Figure 10. Modeled Wivenhoe dam lake levels—8:00 pm on 9 January 2011 (Source: [12]).



6. Impacts and Flooding

During the January 2011 event there were two major floods. The first of these was a severe flash flood that occurred on the afternoon of Monday 10th January in the inland city of Toowoomba and downstream in the Lockyer Valley (Figure 2). The Toowoomba/Lockyer Valley flash flooding was exacerbated by way a series of intense storms, with falls of 40–50 mm in 30 min, which moved over the already saturated catchment. Runoff was concentrated to maximum effect down gullies and streets in Toowoomba. Unable to cope with the volume of water, the creeks burst their banks, pushing a wall of water up to 11 m high through the city centre [24].

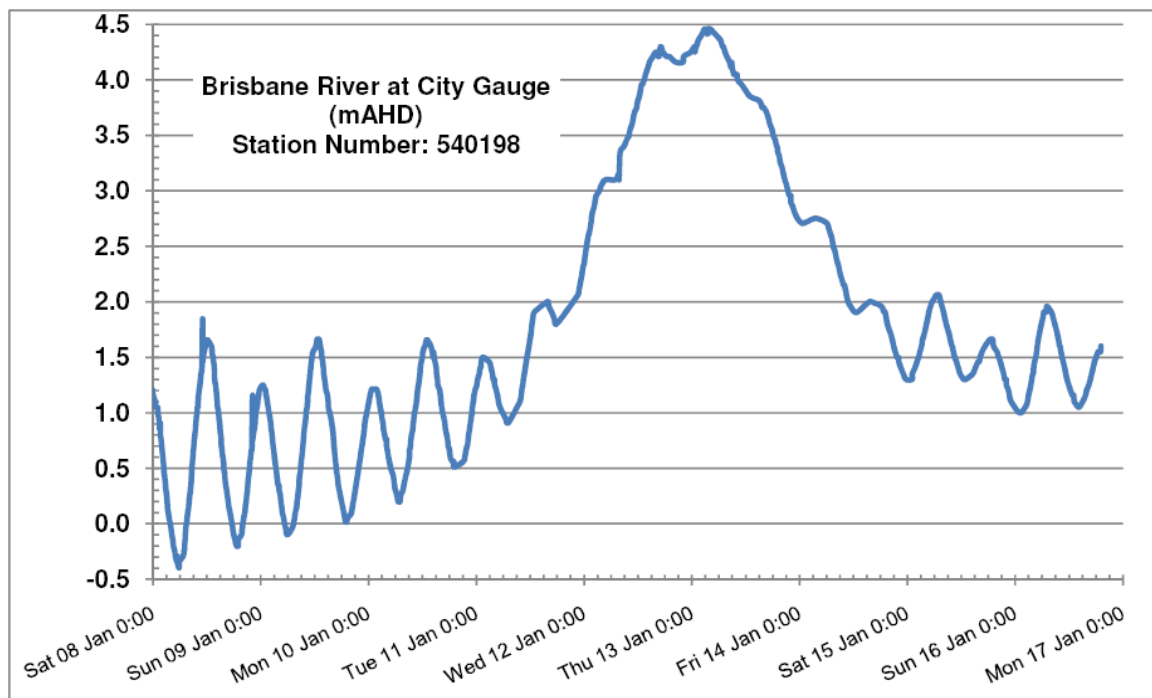
The speed of the flash flooding gave little time for warning. Flash flooding occurred at about 2:30 pm on 10th January; at 1:00 pm the Bureau of Meteorology issued a warning of localized flash flooding in the area and also alerted the State Disaster Coordination Centre. Informal warnings were blogged by the community at 1:40 pm, reporting that a wall of water was threatening Lockyer Creek.

The flood had reached up to 7 m by the time it struck with destructive velocity the town of Grantham, further downstream. Buildings adjacent to waterways were swept away in Murphy's Creek, Postmans Ridge and other locations. Conditions were especially hazardous at Grantham because of the number of dwellings constructed on the floodplain close to the river. Water depths of 2.0–2.5 m over the floodplain were realized in 10–15 min with velocities estimated to have been between 2 and

3 m/s. Nearly every house on the floodplain area of Grantham suffered major damage; a number were washed off their foundations and some totally destroyed. In total 23 people drowned in the Toowoomba and the Lockyer Valley flash floods, with nine others still missing, presumed dead.

The second major flood event occurred on 13th January when dam releases from Wivenhoe Dam flooded the city of Brisbane and surrounding areas. Figure 11 shows a hydrograph of the Brisbane River at the Brisbane City gauge between 8th January and 16th January.

Figure 11. Height of the Brisbane River at the City Gauge between Saturday 8th January and Sunday 16th January (Source: [25], based on data from [26]).



Evident in Figure 11 are two peaks—a minor peak at 5:00 pm on Wednesday 12th January (4.30 m) and then later at 3:00 am on Thursday 13th January, when the river reached 4.46 m. Given a “major flood” at the Brisbane City gauge is defined as a gauge height of 3.50 m or greater, Brisbane City experienced a major flood from 10:00 am on Wednesday 12th January until 6:00 pm on Thursday 13th January, a period of 32 hours.

This 32-hour period at the City gauge spanned three high tides [25]:

- 14:15 Wednesday 12th January
- 02:34 Thursday 13th January
- 14:54 Thursday 13th January

The major peak of 4.46 mAH at the City gauge corresponded almost exactly with the high tide at 2:34 am on 13th January. The minor peak of 4.30 mAH at 17:03 Wednesday 12th January (Figure 11) probably represents the highest river flows. Brisbane felt the full force of these. More than 15,000 properties were inundated in metropolitan Brisbane [8] and some 3,600 homes evacuated.

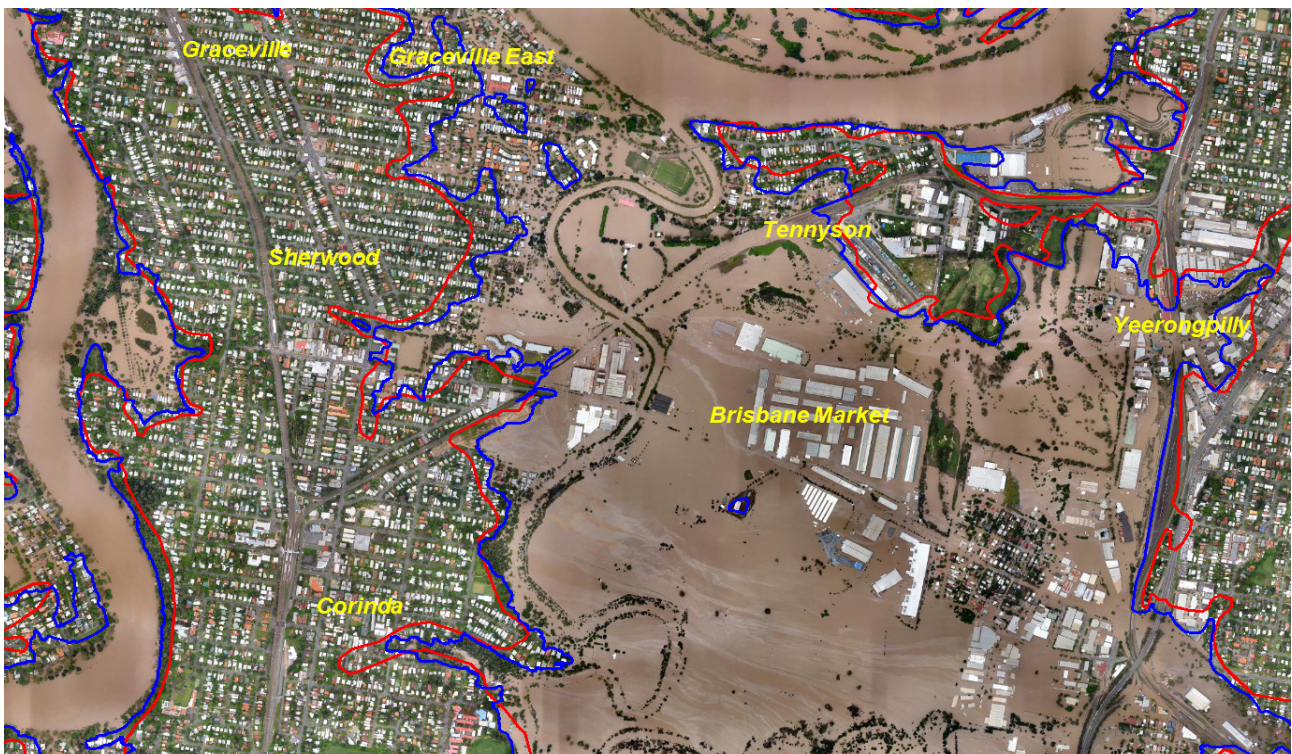
Across Queensland approximately 12,000 people were accommodated in 34 evacuation centers managed by the Red Cross, with a number of other official and informal evacuation centers also

operating. Altogether over 200,000 people were affected. Approximately 3,570 business premises were inundated, and commercial losses of approximately \$4 billion were reported across the mining, agriculture and tourism sectors. Over 19,000 kilometres of roads were damaged, around 28 percent of the Queensland rail network damaged and three major ports significantly impacted. An estimated 28,000 homes would need to be rebuilt, while vast numbers of dwellings require extensive repairs [8]. According to the Insurance Council of Australia, almost 56,200 claims were received by insurers, with an insured cost of \$2.55 billion [27].

The community response to assist with the aftermath of the floods was tremendous: over 55,000 volunteers registered to help clean up Brisbane's streets and homes, with thousands more unregistered volunteers. This overwhelming community involvement was a feature of the disaster response. Community Recovery Centres were set up in several locations, Red Cross and Lifeline provided a full range of services on the ground and eight specialised counselling teams from the Department of Communities were deployed across the Lockyer Valley and Toowoomba [28].

Inspection of the 2011 event shows that the extent of flooding in most areas of Brisbane City was very similar to that observed during the 1974 flood. The aerial photographs in Figures 12 and 13 display the extent of flooding during the 2011 (blue line) event while the red line represents the flood extent in 1974. The four images depict different parts of Brisbane City. The point here is that while there may have been uncertainty in the Annual Return Interval of this flooding, where it flooded was largely predictable.

Figure 12. Flood extent comparison between (a) the 2011 flooding (blue polygon) and (b) the 1974 Brisbane flood inundation extent (red polygon). (Source: [29]).



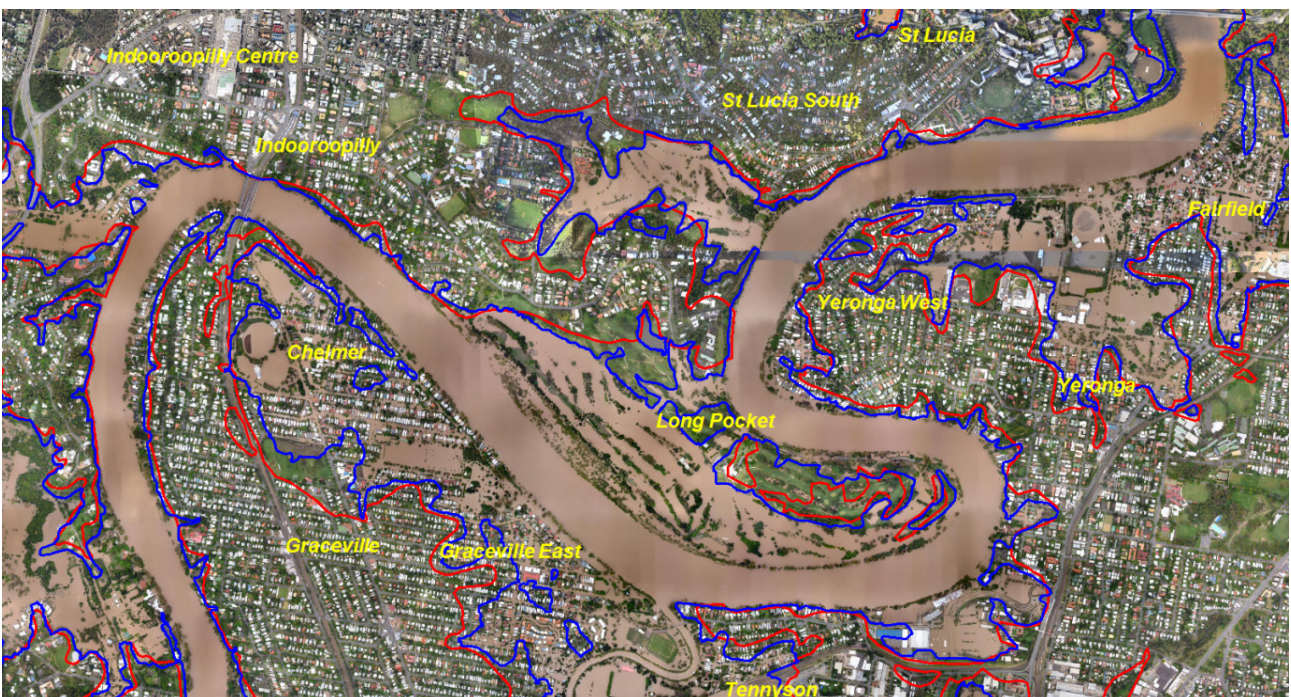
(a)

Figure 12. Cont.



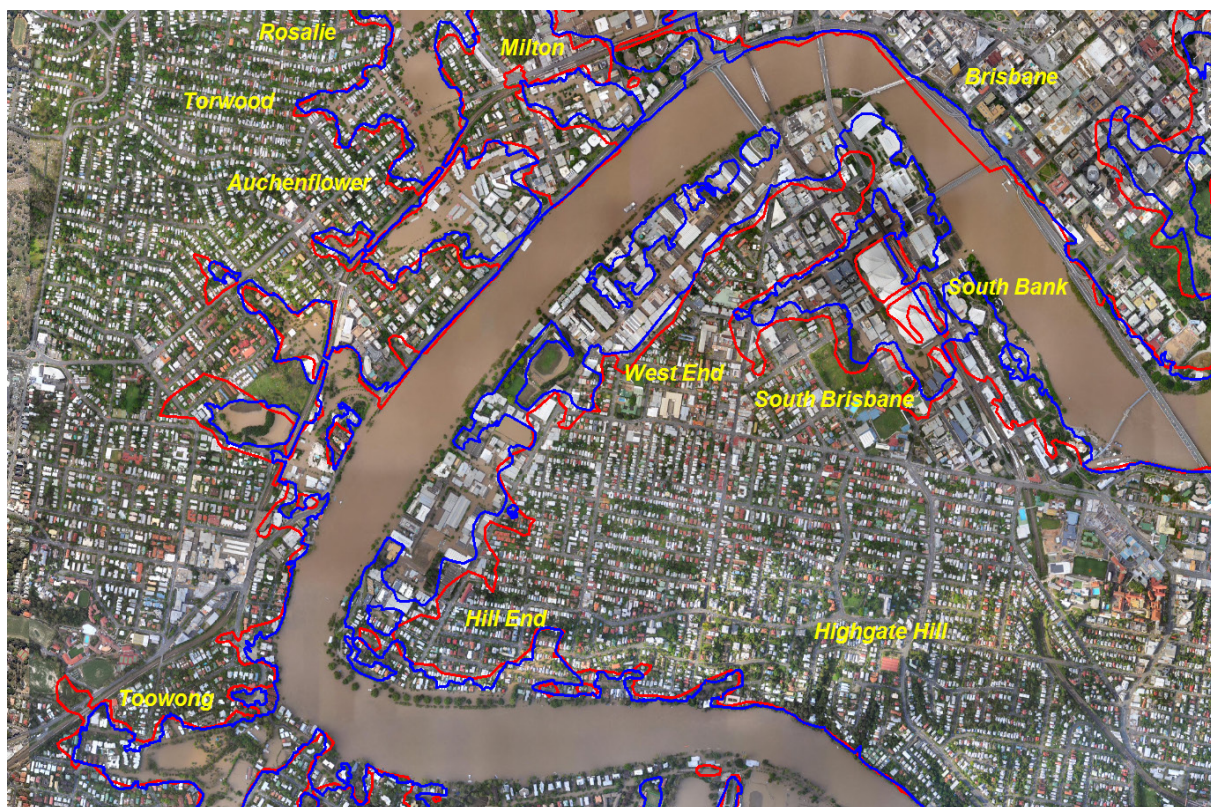
(b)

Figure 13. Flood extent comparison between (a) the 2011 flooding (blue polygon) and (b) the 1974 Brisbane flood inundation extent (red polygon). (Source: [29]).



(a)

Figure 13. Cont.



(b)

7. Implications

7.1. Queensland Floods Commission of Inquiry

On Monday 17th January 2011 the Premier of Queensland, Anna Bligh, announced an independent Commission of Inquiry to examine the flood disaster. The terms of reference provide for an independent and thorough examination of the chain of events leading to the floods, and all aspects of the response and the subsequent aftermath. The Commission was tasked to deliver an Interim Report in August 2011, covering matters associated with flood preparedness to enable early recommendations to be implemented before the next summer's wet season. The Final Report is to be handed down by January 2012. The Interim Report [12] summarised submissions and testimony on the:

- preparation and planning for the flooding by governments at all levels, emergency services and the community;
- supply of essential services during the floods;
- adequacy of forecasts and early warning systems, with particular reference to Toowoomba and the Lockyer Valley;
- compliance with, and the suitability of, dam operational procedures for safety and flood mitigation.

A total of 175 recommendations were proposed, which were subsequently fully supported by the Queensland Government [30].

Most relevant to our study here is the Commission of Inquiry's view that Wivenhoe Dam had been operated according to the operations manual. Nonetheless, the Commission has recommended that the manual be reviewed including a re-evaluation of the design hydrology using a probabilistic approach, consideration of temporal and spatial variability in rainfall, and of the relative timings of inflows from the dams and downstream tributaries. It was also recommended that the reliability of rainfall forecasts and the use of weather radar be assessed and considered for decision-making. Furthermore the recommendations called for modeling of the consequences (in terms of risk to life and safety, and economic, social and environmental damage) of the water release strategies for a spectrum of historical, design and synthetic flood events. This is very much in line with the authors' view expressed earlier about the utility of decision trees and probabilistic methods in general to improve decision making in relation to dam releases of water during flooding situations.

The Commission also recommended that every local government with a flood risk should ensure that, before the onset of the next wet season (*i.e.*, before November 2011), it updates its local disaster management plan in accordance with Queensland's State-wide Natural Hazard Risk Assessment [31] and the *Disaster Management Act 2003*. Each local disaster management plan should address local circumstances and risks, be simple to use, and be published on the relevant local government's website. Training for disaster management personnel and volunteers should be provided, and community education programs regarding *inter alia* flood preparations, warnings, evacuation and emergency assistance instigated.

Matters relating to land use planning and insurance will be dealt with in the Commission of Inquiry's Final Report, and hearings will not be held until late in 2011. However information contained in public submissions provides the opportunity for some *a priori* discussion about issues and implications of these topics as they relate to flood risk management. We discuss these next.

7.2. Insurance Issues and Implications for Land-Use Planning

Following a natural disaster, the insurance industry plays a vital role in funding the rebuilding, repair or replacement of damaged homes, infrastructure and assets. In recent years, the Australian insurance industry has responded effectively to a range of natural disasters such as the Hunter Valley storms (2007), the 'Black Saturday' bushfires in Victoria (2009), the Perth and Melbourne hailstorms (2010), and Cyclone Yasi (2011) [32]. Some 88% of Australian homeowners have home and contents policies [32] that cover damage arising from most natural perils with the exception of riverine flood. Flash flooding, as a direct consequence of rainstorm runoff, following high intensity rainfall [33] is covered.

For the purposes of insurance in Australia, riverine flooding is defined as *the overflow from rivers and creeks following long duration rainfall over large catchment areas, or water rising up from flooding rivers, in contrast to water coming down from rain and storm* [33]. While some insurers offer cover for riverine flood, many currently do not, something that many policy holders discovered only after the January 2011 floods [34,35]. Thus whilst claims by insured victims of flash flooding in Toowoomba and the Lockyer Valley were generally settled by insurers, many residents along the Brisbane River had claims denied. Whilst the Insurance Council of Australia has put the proportion of denied claims at 15% [33,36], the perceived lack of performance of private insurers in assisting the

recovery from the flood has led to a community backlash. Many people were unaware that they were at risk of flood (something that can and should not be blamed on insurers); others rejected flood insurance where offered because it was viewed as being prohibitively expensive [35].

To address the issue of availability and affordability of insurance for flood offered by the private insurance market to homeowners, the Natural Disaster Insurance Review (NDIR) was announced by the Assistant Treasurer in the Australian Commonwealth Government on 4th March 2011. Key discussion points include the issue of a single unified and consistent definition of “flood” for insurance purposes, and, in the context of availability and affordability of flood insurance, non-insurance and under-insurance, consumer understanding and dispute resolution, flood risk measurement and mitigation, and some aspects of government funding of natural disaster relief and recovery.

Measuring flood risk by way of flood maps has been raised with the Review Panel by:

- insurers, as a necessary input to enable them to assess and price flood risk;
- homeowners seeking to assess their personal flood risk; and
- councils as part of their planning and risk management.

The Review Panel has produced an Issues Paper [33] for public discussion in which it identified two alternative models of flood insurance for the future, assuming that the status quo is no longer acceptable. Under the first model, cover for riverine flood would be automatically provided as part of home insurance policies. This would eliminate disputes about what constitutes a flood, but would significantly increase premiums for homes at risk of flooding. The second model allows a homeowner to ‘opt out’ of the flood portion of a home insurance policy. Both of these demand that high flood risk homes be identified, and the Review Panel has proposed that a discount be provided to owners of these high flood risk homes. How funding premiums for these homeowners would be achieved is an ongoing issue for discussion.

In the authors view, the fundamental question that needs addressing is not the insurability of flood risk, but how best to deal with the legacy of poor land-use planning decisions that has left some homeowners in locations now designated as high risk. Development in the low-lying areas along the lower Brisbane River, for example, has occurred despite the city’s history of severe flooding and has resulted in large concentrations of properties exposed (Figure 3). How to reduce this exposure to flooding should be the key policy objective. Flood risk management should aim to reduce a community’s flood risk to acceptable levels, either by reducing exposure to flooding by prudent land-use planning, or by reducing the vulnerability of people and property to flooding [3]. The legacy issues are an issue that governments and the insurance sector are now grappling with. The authors believe that nothing will change until local councils are held accountable for bad land-use planning decisions [37]. Resolving the problem is not simple, but risk-adjusted insurance premiums must form part of the solution [38]. These provide a market signal and will act to incentivise risk-reducing behaviour by all parties. One very positive initiative of the local council in Grantham, involves a land swap for flooded residents. We return to this example in later discussion.

Insurance is not an alternative to risk management; it is a means of transferring the residual risk once risk management measures have been put in place. To actively contribute to flood risk management, insurance must act to reduce the number of homes at risk. The only mechanism available is to ensure that premiums reflect the real risk and thereby encourage homeowners, local councils and governments

to undertake appropriate mitigation efforts and enact risk-informed land-use planning practices. Government may offer premium discounts to homeowners who have already been permitted to build in flood prone locations, but further development has to either be prevented or allowed only in a flood-resilient manner by choice of building materials and with raised floor heights. Any such construction must be undertaken with full disclosure of the flood risk. In discounting market premiums, it is critical that the government not interfere with actual pricing and so distort the price signal that can act to incentivise all parties to act to minimize risk.

Development in high-risk areas is certainly not unique to Brisbane [39] or just with respect to flood. Moreover, the practice of post-event handouts by government often encourages victims to rebuild in the same way and in the same location. This was the case immediately after the February 2009 “Black Saturday” bushfires in Victoria when the State Premier announced payments of up to \$50,000 to homeowners whose principal residence was destroyed in the conflagration [40]. This was despite the knowledge that in the most severely affected communities of Marysville and Kinglake some 10% of destroyed structures were physically located within bushland, and some 60% within 10 m of the bushland boundary [41], and it having been well demonstrated that the likelihood of home survival in such extreme fires increases with increasing separation from the bush [42]. This is an example of government generosity not encouraging risk-reducing behaviour.

The situation is not all negative. A very positive example of sensible land-use planning to arise out of the 2011 flooding has occurred in the township of Grantham, devastated by flash flooding as discussed earlier. In March 2011, Grantham township was formally declared a “reconstruction area”, which enabled the Lockyer Valley Regional Council to fast-track a master planning process, which was completed within four months. Part of the master plan includes relocation of residential homes from the floodplain to higher ground outside the flood-zone for flood-impacted residents from the townships of Grantham, Murphys Creek, Postmans Ridge, Withcott and Helidon. It is expected that 70 to 80 percent of residents formerly living on the floodplain will move into new homes from December 2011. Nowhere else in Australia are we aware of a Local Government authority assisting a disaster-struck community in this way [43].

Another positive signal to come out of the 2011 flooding has been a decision by the Brisbane City Council to raise the Defined Flood Level (DFL) for rebuilding purposes using the January 2011 peak flood level in most areas. Prior to this the flood control levels were based on the notional (modeled) 1-in-100 year flood. The new minimum habitable floor level for residential development was changed to 500 mm above the DFL except where the existing level was higher. These specifications are now imposed upon all new residential, industrial and commercial developments [44], and will serve to reduce the city’s vulnerability to future flooding. Needless to say the larger floods are still possible (Figure 3).

It seems axiomatic that if risk-reducing behaviours are to be encouraged, then homeowners must understand their flood risk. Similarly, it is difficult to see why insurers should offer flood cover if information that would allow them to assess and price risk is denied them. Unfortunately, such information is often not publically available even when flood studies by hydrologists and hydraulic engineers have been carried out and funded by public money. A recent study of publically available flood risk information on local government websites [45] identified that less than 50% of local

councils provide flood risk information. Of those with a recognised flood risk, only 67% provided flood maps online.

Ideally insurers (and land-use planners) need modeled flood surfaces that can be interpreted to see how flood depths vary as a function of the Annual Return Interval (ARI) at given locations. When available, flood maps vary greatly in terms of information content with many only recording the extent of inundation in a modeled 1-in-100 year flood. This is not a measure of risk and says nothing about how flood damage may vary in larger floods. In the case of the Hawkesbury-Nepean River catchment, for example, many tens of thousands of homes have been built with planning approval just beyond the 1-in-100 year flood, and the difference in the height of inundation between the 1-in-100 year flood and the maximum possible flood is 9 m! [46]. This is a very different circumstance to some inland catchments where the difference may only be a meter or so. Again having a uniform ARI threshold for building approvals ignores the reality of risk, which is a function of the hazard, exposure and vulnerability.

The primary source of flood information currently available to the insurance industry in Australia is the National Flood Information Database (NFID), which is developed from publically-available flood information and digital terrain maps, and which currently covers around 5.6 million individual addresses across the country [47]. The total number of addresses in Australia is around 12 million but many of these are not flood prone. Even so, NFID does not include every property at risk in Australia because not all catchments have been studied, and even where this has been done not all councils will make this information available, a situation that is most common in Queensland. In a submission to NDIR the Insurance Council of Australia (ICA) claim that this lack of completeness is one of the key factors limiting some insurers' ability to provide flood insurance in certain geographic areas [36].

The January 2011 floods have exposed the non-insurance or under-insurance of not just individual homeowners, they have also focused attention on the Queensland government's lack of insurance cover for its own infrastructure. State governments in Australia have a longstanding arrangement with the Commonwealth Government under the Natural Disaster Relief and Recovery Arrangements (NDRRA), whereby the Federal Government fund 75% of all infrastructure reconstruction costs in the event of a natural disaster. There is no compulsion at present for State Governments to take out insurance cover although Queensland is the only one to opt not to purchase reinsurance for its infrastructure assets, claiming that it was "not a value-for-money proposition" [48]. Thus 'self-insurance' by the State applies only to 25% of the reconstruction costs, with the Commonwealth covering the other 75%. To offset the NDRRA costs of the January 2011 flood event, the Federal Government will raise \$1.8 billion by imposing a one-off flood levy on all Australian taxpayers with a taxable income greater than \$50,000 and who were not in receipt of a government Disaster Recovery Payment for a flood event [49]. The impact of the flood will thus be felt by all Australians, not only those living in southeast Queensland.

8. Conclusions

This paper has examined the causes, impacts and some implications of the January 2011 Brisbane flood. The period December 2010 to January 2011 coincided with a strong La Niña event, often associated with extreme rainfall and widespread flooding in eastern Australia.

The flood has been termed a “dam release flood” by hydrologists appointed by the Insurance Council of Australia. This suggests that a release of water from the Wivenhoe Dam was a principal cause of flooding along the mainstream and tributaries of the Brisbane River downstream of the dam over the period 11th–12th January 2011. Whilst the dam operators were acting in accordance with the operations manual for the dam, their modeling did not take account of forecast rainfall in determining the predicted dam water level, and this resulted in a sub-optimal water release strategy. Employing tools for decision making under uncertainty would have resulted in a different water release strategy.

Many insurers do not provide riverine flood insurance due to a lack of information on which to determine and price the risk. An official Review of natural disaster insurance has proposed models to ensure more homeowners are covered by flood insurance. We argue that the real issue is how to deal with the legacy of past poor land use planning, which has left some home owners in locations now designated as high risk. Insurance premiums should reflect the real flood risk of a property, and insurers should have access to the best flood studies available on which to determine the cost of this risk.

Nevertheless, a positive example of sensible land-use planning to arise out of the 2011 flooding occurred in the township of Grantham. The plan drawn up after the floods includes relocation of residential homes from the floodplain to higher ground outside the flood-zone.

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