

# East Coast Lows and the Pasha Bulker storm—lessons learned nine years on

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East Coast Lows (ECLs) are intense low pressure systems that form several times a year off the east coast of Australia. When these systems occur close to land they can cause major damage to infrastructure and communities due to gale force winds, intense rainfall, storm surge and coastal erosion. In June 2007, Newcastle and Central Coast regions of New South Wales (NSW) experienced severe weather and subsequent flash flooding. The ‘Pasha Bulker’ storm, as it has become known, was one of the most significant meteorological events in Australia’s history, with large economic losses and social disruption due to the loss of critical infrastructure. This paper provides background information on the meteorology of the event, the impact of the Pasha Bulker storm and a discussion of the lessons learned from the event and subsequent adaptation strategies employed. The paper also provides important reflections, at both regional and national level, on the Pasha Bulker storm and other similar storm events. Lessons for all levels of government and community groups are discussed, including preparedness before the event, actions during the event, and recovery processes post-event. From this, recommendations and conclusions are made on actions and strategies to increase adaptive capacity and resilience to extreme weather events like ECLs.

## 1. Introduction

A series of East Coast Lows (ECLs) impacted coastal regions between Illawarra and the Hunter during June 2007 (see Figure 1). The succession of storms from 7–10 June 2007 resulted in widespread flooding and wind damage, coastal erosion, the grounding of the Pasha Bulker (a 40 000 tonne bulk carrier ship) and the loss of nine lives (along with nearly 20 000 calls for emergency assistance). The Pasha Bulker storm, as it has become known, was one of the most significant meteorological events in Australia’s history. At the time it was the eighth largest general insurance loss (adjusted for both inflation and current levels of development) since systematic insurance records were started in 1968 (Crompton and McAneney 2008). The storm consisted of three distinct impacts:

- flash flooding on the night of 8 June in the urban area of Newcastle and as far south as the Central Coast (about 1 in 100 year return period, impacting 800 000 people);
- more general flooding on the Hunter River three days later (about 1 in 40 return period, impacting about 100 000 people); and

- high winds and wave heights on the night of 8 June (the worst in the Newcastle–Sydney region since the ‘Sygna Storm’ in 1974, also an ECL).

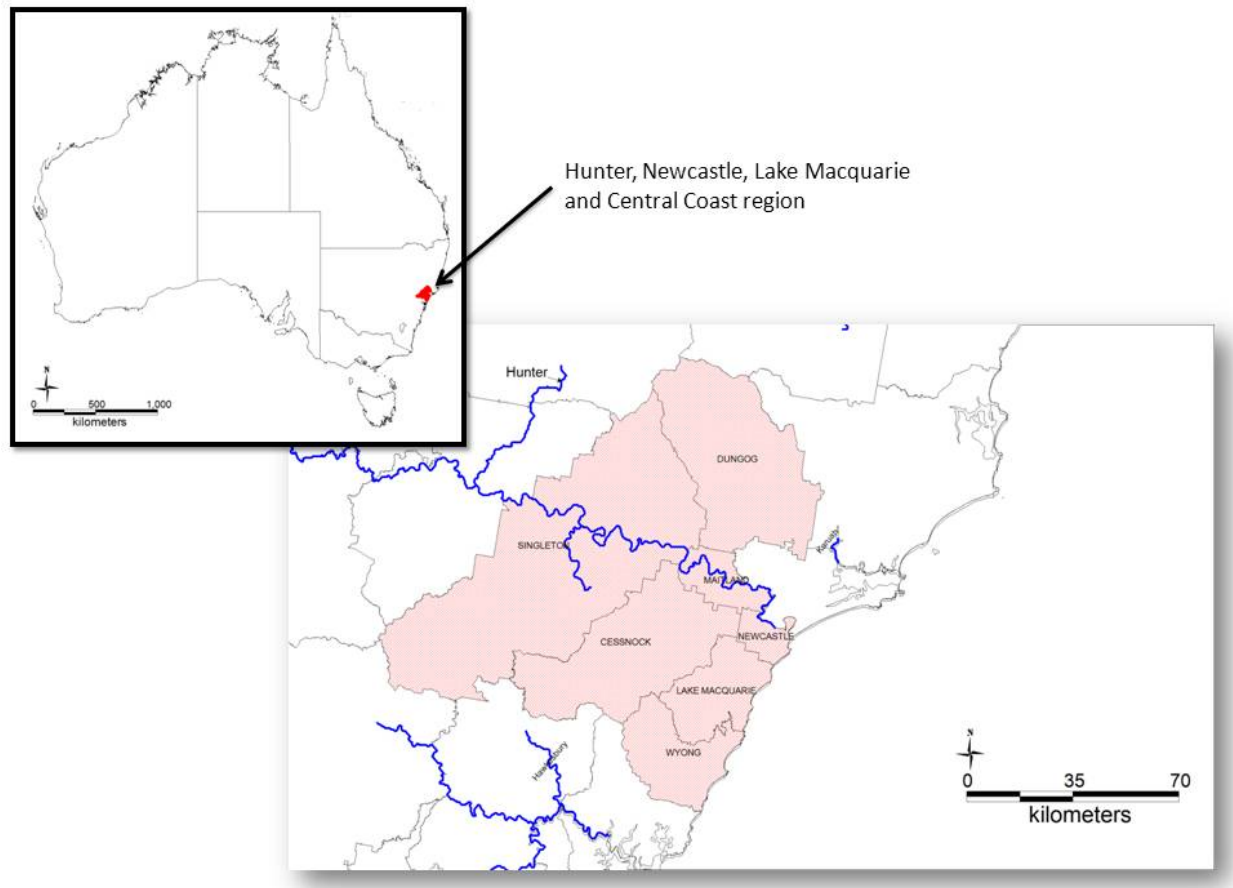


Figure 1 Location map and areas affected by the Pasha Bulker storm (highlighted in red).

While the media focus was on the grounded Pasha Bulker and the Hunter River floods, most insurance losses resulted from the 8 June flash flooding in the Newcastle, Lake Macquarie and Central Coast region. The Hunter River floods were successfully managed by the extensive flood mitigation measures installed along the Hunter River as a result of previous floods in this area (e.g. Franks and Kuczera 2002, Kiem et al. 2003, Kiem and Verdon-Kidd 2013) and will not be discussed in this paper.

In this paper we focus on the urban flash flooding and other immediate storm impacts within the greater Newcastle and Lake Macquarie area. The paper builds on the earlier National Climate Change Adaptation Facility (NCCARF) funded project ([www.nccarf.edu.au/content/case-study-east-coast-lows-and-newcastle-central-coast-pasha-bulker-storm](http://www.nccarf.edu.au/content/case-study-east-coast-lows-and-newcastle-central-coast-pasha-bulker-storm)) which provided a whole-of-government (federal, state and local), business and community perspective on the:

- context and impact of the Pasha Bulker storm;
- adaptation measures being put in place as a result of the knowledge gained from the experience from within and immediately after the storm;
- adaptation measures being put in place following subsequent reflection on ways of better preparing for such storms.

This paper highlights the regional and national implications of extreme events like ECLs, and emphasises the need for further research into the historical variability, potential future changes in the timing, frequency and/or magnitude and suitable adaptation responses to ECLs for coastal cities in Australia.

## 2. Geographic, climatological and historical context of the storm

ECLs typically form between 20°S and 40°S, often with some motion parallel to the eastern coastline. ECLs can occur at any time of the year, but tend to be more common in Austral autumn and winter (Speer et al. 2009). The environmental conditions associated with the development of ECLs are described by Holland et al. (1987) who showed that formation generally occurs (1) at night, (2) near the coast in a region of strong oceanic temperature gradients, (3) in the divergent exit region just poleward of a subtropical jet streak and (4) just downstream of a midlevel cold pool. Leslie et al. (1987) also confirmed that higher absolute sea surface temperatures (SSTs) are important for ECL intensification. These large-scale storms can result in destructive winds along the coast and adjacent waters, intense rainfall, storm surges and prolonged heavy swells causing damage to the coast line. However, they are also a critical source of rainfall for catchments east of the Great Dividing Range. For example Sydney's Warragamba catchment tends to replenish in bursts linked to extreme rainfall events associated with ECLs (Pepler and Rakich 2010). ECLs have high interannual variability, with some years experiencing several ECLs while during other years only a few will develop. They also exhibit intra-annual clustering. ECLs are responsible for approximately 16% of all heavy rainfall events and 7% of major Australian disasters (Hopkins and Holland 1997).

A total of five ECLs occurred during June 2007, which is a rare but not unprecedented number of ECLs to occur within a month or within June (similar years include 1950 and 1974). The five ECLs were the result of favourable conditions in the upper atmosphere (i.e. major upper-tropospheric cut-off low, Mills et al. 2010) as shown in Figure 2a and a strong SST gradient (Chambers et al. 2014). Three out of the five ECLs formed out of an easterly trough that developed off the NSW coast (the other two developed as secondary systems in the wake of an earlier low pressure system). Of the five ECLs, the first event (8–9 June, Figure 2b) was the most serious (in terms of impact) but the third event (19–20 June) was in fact the most intense (in terms of central low pressure). However the full impact of the third event (19–20 June) was not felt over land as the low did not venture as close to the coast as the first event. The Pasha Bulker storm was the 8–9 June event and is the focus of this paper. A full description of the meteorology of the Pasha Bulker storm is given in Mills et al. (2010) and summarised by Dowdy et al. (2011) who explain how the evolving structure of the upper-tropospheric cut-off low over southeastern Australia lead to explosive surface development.

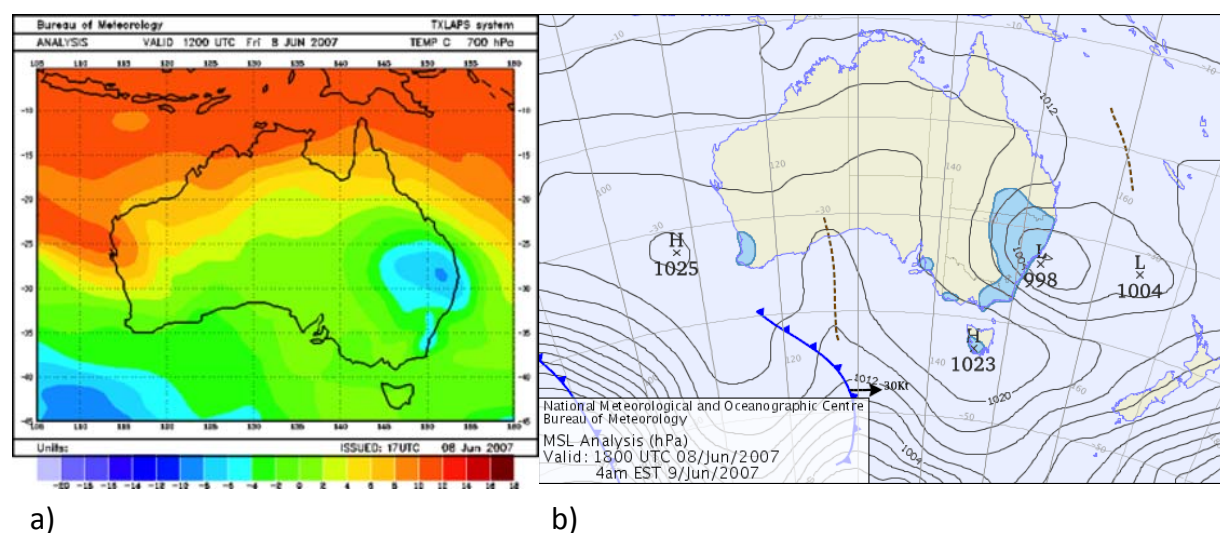


Figure 2 (a) Mid-atmospheric temperature pattern at 700hpa at 10.00 pm on 8 June 2007; (b) MSLP contours at 4.00 am on 9 June 2007 (source: www.bom.gov.au).

Heavy rainfalls were received from 7–10 June across Newcastle, Central Coast and the Hunter, with over 400 mm of rainfall received at some locations (more than twice the average monthly totals for June). The peak in rainfall occurred for most regions on 8–9 of June when Newcastle (Nobbys Signal Station) recorded 164.8 mm in 6 hours (Figure 3a). Haines and Thyer (2008) analysed data from a network of 30 pluviographs throughout the Hunter region to assess the statistical significance of the event. There was a high degree of variability among the pluviographs, however at some locations the measured rainfall for 3, 6, 12 and 24 hour durations had a recurrence interval in excess of 100 years. It is important to note however that these recurrence intervals are estimated using short data sets, which may not capture the true rainfall distribution (see Verdon-Kidd and Kiem 2015).

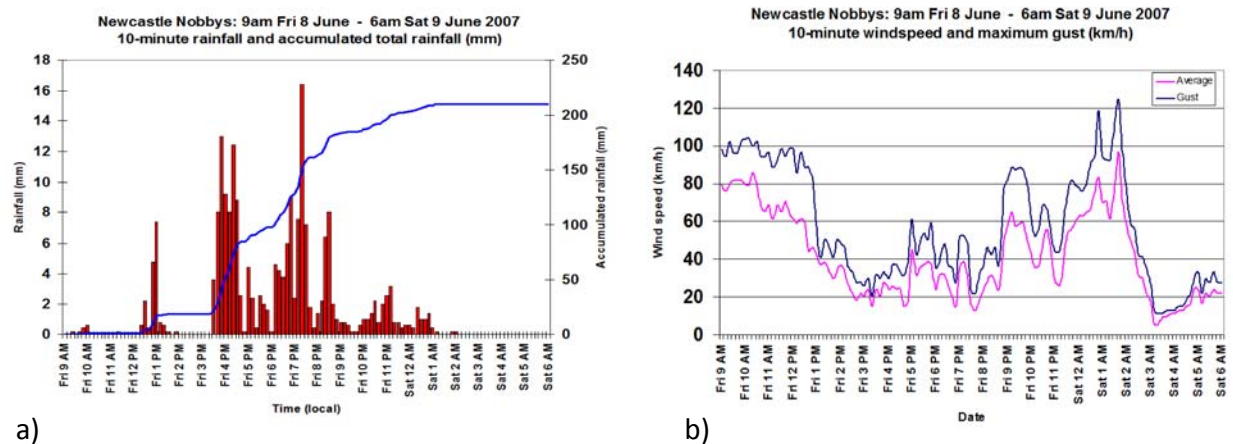


Figure 3 Climate data at Nobbys Lighthouse for 8–9 June (a) rainfall, (b) wind.

Gale force winds were sustained for approximately 20 hours from 6.00 am 8 June through to 2.00 am 9 June. The maximum wind gust speed recorded was 135 km/h at Norah Head, followed by 125 km/h at Nobbys Head at 1.30 am 9 June (Figure 3b). While a significant event, wind speed records were not broken during this ECL (Carpenter 2007).

The June 2007 ECL was not a particularly strong or deep low pressure system (compared to past ECLs) with ECLs of similar strength (in terms of central pressure) tending to occur annually on average. However, the June 2007 storm developed close to shore, with the area of maximum rainfall centred on a highly developed part of the coast (Carpenter 2007). The near-surface structure of the Pasha Bulker storm, with a strong (easterly) wind band on its southern side associated with the major rainband, and a weaker pressure gradient near the centre of the storm meant that the strongest winds and rainfall were directed onshore. The orientation of the coastal orography acted to further enhance the rainfall effects (Mills et al. 2010). The ECL was also slow moving as it crossed the coast (Mills et al. 2010), allowing convective rain bands to affect the coast close to the centre of the low and produce intense, short duration flash flood producing rain.

To date studies have found inconclusive evidence of any long term linear trend in the frequency of ECLs along the east coast based on the Australian Bureau of Meteorology (BOM) database of historical ECLs beginning in 1972 (Speer et al. 2009). However, there is some evidence of enhanced frequency and intensity during La Niña periods (Harper and Granger 2000, Browning and Goodwin 2013). Periods of transition between El Niño and La Niña have also been linked to increased frequency of ECLs due to an enhanced sea surface temperature gradient offshore (Hopkins and Holland 1997). Speer (2008) also identified a possible link between ECLs and the Interdecadal Pacific Oscillation (IPO), whereby a reduction in ECLs was observed when the IPO shifted from a negative phase (with anomalous negative sea level pressure off the east coast and onshore flow) to a positive phase (positive sea level pressure and fewer rain producing coastal systems) during the mid-1970s. A strong correlation between the Southern Annular Mode (SAM; leading mode of variability in the Southern Ocean) and the frequency of ECLs has also been identified (Speer et al. 2009, Browning and Goodwin 2013), highlighting the need for further investigation into the relationship between ocean-atmospheric climate drivers and the variability of ECLs. Work to address this need is underway at BoM (e.g. the MATCHES ECL computer database) and also as part of ESCCI (see for example Kiem et al. 2016).

The June 2007 ECL storms have often been compared to the May 1974 ECL storms, which displayed a similar central low pressure (~980 hPa; Callaghan and Helman 2008) also resulted in widespread devastation along the coast of NSW. The ECL of 24–27 May 1974 ECL was concentrated between Illawarra and the Hunter and also claimed a bulk carrier ship (the *Syigna*), which ran aground on Stockton Bight just north of Nobbys beach where the *Pasha Bulker* was grounded. The ‘*Syigna* storm’, as it became known, produced much stronger wind gusts (170 km/h) than the June 2007 event (Callaghan and Helman 2008). However, the storm had a much shorter duration and the amount of rainfall recorded was much less (maximum 24-hour rainfall was 194 mm at Pambula; Carpenter 2007). The storm event was determined to have a corresponding wave height recurrence interval in the order of 20–70 years and Newcastle port reported a swell of over 17 m at the entrance (Lord and Kulmar 2000). The water level encountered during the May 1974 storm was 53 cm higher than the June 2007 storm (2.37 m) in Sydney Harbour—the highest level since records commenced over 100 years ago. The *Syigna* storm also had a greater impact on coastal erosion than the *Pasha Bulker* storm due to larger off shore wave heights.

## 4. Impacts of the storm

The *Pasha Bulker* storm generated significant rainfall across the central and mid-north coast regions of NSW. The maximum 24 hour rainfall exceeded 300 mm at a number of stations in the local area. Rainfall intensities exceeded 1 in 100 year probability at a number of sites across the region, some by up to 63% (Haines and Thyer 2008). Rainfall intensities typically reduced with distance inland, which correlates with the westward tracking of the storm from offshore.

### 4.1 Flooding

The intensity of the rain combined with the steep topography of the local catchments resulted in flash flooding throughout many areas of Newcastle and Lake Macquarie, with the most severe flooding occurring downstream of the areas that received the greatest rainfall. Comparison of actual flood information with existing probabilistic flood models suggests that in some areas, such as Throsby/Styx and Cottage Creeks, the resulting flood had an indicative recurrence probability of 1 in 100 years, while for Ironbark Creek at Wallsend, the flooding was about 1 in 40 years (BMT WBM 2009).

Cardiff Central Business District (CBD) in the Lake Macquarie Local Government Area (LGA) was greatly affected by the flooding, with an estimated \$2 million damage losses to business (Jones 2007). Commercial areas of Wallsend and Newcastle West (both Newcastle LGA) were also particularly hard hit (Figure 4) with premises inundated by up to 1.6 m of floodwater (BMT WBM, 2009). Evacuations of many properties, including Wallsend Plaza, were required at the peak of the event, increasing the level of personal risk. Flooding in Newcastle West was significantly worsened through blockage of culverts by shipping containers, which had been dislodged from nearby building sites (Carpenter 2007). For most areas, flooding came quickly and lasted less than an hour. Flood depths and velocities across overland flowpaths were high, and caused considerable traffic chaos as the event coincided with a Friday afternoon peak hour. Flood velocities were reported to be particularly high within the concrete-lined open channels—even the smaller drains in the upper catchments (BMT WBM 2009). In comparison, velocities were generally slower across overland flow paths. Floodwaters had sufficient force to dislodge a number of large concrete panels from within stormwater channels. Where floodwaters departed or re-entered a formal channel, the velocities mobilised footpath slabs and damage footings of some houses.



Figure 4 Flood damage (a) supermarket car park, (b) footbridge abutment, (c) car yard debris.

Almost 20 000 calls for help were made to the State Emergency Service (SES), with more than 2500 requesting assistance from flooding (Cretikos et al. 2007). More than 5000 cars were written off and more than 90 000 claims were filed with insurance companies (Carpenter 2007). An estimated 10 000 properties were inundated across the Newcastle LGA, which typically included yards, garages, and outside buildings. Of these, some 1000 to 2000 properties experienced over-floor flooding (BMT WBM 2009). The commercial district of Wallsend had flooding of up to 1.5 m over the floors, while many residential areas (e.g. Hamilton North) had over-floor flooding of greater than 800 mm (Haines and Thyer 2008). Many thousands of properties reported flood waters reaching just below their floors. Localised low points in the topography experienced substantial flood inundation. In some cases, flooding in these areas was exacerbated by flow impediments such as rail embankments (Haines and Thyer 2008). Flood impacts were also reported to be compounded by a range of other flow impediments including high median strips on major roads, high camber levels on local roads (above gutter level), and solid colourbond fencing built across overland flowpaths (Haines and Thyer 2008). In addition to the constructed flow impediments, flooding associated with the Pasha Bulker storm was made more severe by debris blockages within the stormwater drainage system. Gale force winds and rain generated considerable debris, while overland flows mobilised this storm debris and many other floatable items, such as garbage/recycling wheelie bins, colourbond and other fence panels, shopping trolleys and cars (Haines and Thyer 2008). To complicate matters, sudden failure of colourbond fences was reported to cause local surges in floodwater, contributing to the speed and ingress of flooding into some areas. Many cars became lodged within open drains across Newcastle, most notably in Hamilton and Wallsend (Haines and Thyer 2008).

A notable aspect of the interaction between the debris and the stormwater system in the Cottage Creek catchment was that (1) proceeding downstream there are numerous switches between open channel and narrow (narrower than the open channel) pipe entrances providing numerous points at which debris could block the stormwater system (2) numerous bridges with in-channel piers that reduce the channel opening significantly and these openings are of the size that a colourbond or cyclone-mesh panel can become entangled, and (3) numerous crossings of the open channel with pipes and other infrastructure at levels just above the 1 in 100 year flood level but below the surrounding ground level (Figure 5). All three characteristics provide ample opportunity for debris to block the storm water system. It is notable that current design recommendations (e.g. Australian Rainfall and Runoff (Pilgram 1987)) do not mention the potential role of urban debris in reducing flow cross-sections in stormwater systems (as compared with their recommendations for rural flooding). The most substantial blockage occurred at the downstream end of Cottage Creek, where shipping containers from nearby construction sites became lodged within culverts (Carpenter 2007). These particular blockages resulted in elevated water levels on the upstream side. The extent of exacerbation of flooding impacts resulting from the blocked drains was investigated using computer flood models (BMT WBM 2008). The Cottage Creek blockage was found to generate flood levels of up to a metre higher than normal through the Newcastle West business area, and up to 500 mm higher through Marketown Shopping Centre. Further, the damming effect caused by the containers meant that inundation persisted for many hours after the peak event, with water unable to drain out of the catchment.



Figure 5 Stormwater system features that capture debris (a) low pipes below ground elevation, (b) pipes, telecommunications, and in-stream piers, and (c) open channel to culvert transitions.

## 4.2 Wind impact

The storm caused unprecedented and widespread damage to Energy Australia's network. Wind gusts of up to 135 km/h (Carpenter 2007) uprooted trees, damaging power lines and washing some power lines away in the resulting flood waters. Tree throw was higher than expected because of significant rainfall preceding the event so that soils were saturated at the beginning of the event reducing tree root stability. Over 200 000 homes and businesses were affected by storm related electricity interruptions (Cretikos et al. 2007) for periods ranging from few hours to several days. In the Hunter, one in three of Energy Australia's customers were without power in the region. At times Energy Australia's call centre was taking up to 1000 calls every half an hour and a total of more than 93 000 calls were received, which at the time, was the highest number of calls ever received by the call centre (Energy Australia, pers. comm. 2009). The power restoration process was the biggest undertaken in the organisation's history (Energy Australia, pers. comm. 2009).

## 4.3 Water and wastewater impacts

There were 6000 to 7000 Hunter Water customers without water for periods ranging from a few hours to several days (Hunter Water, pers. comm. 2009). Approximately 60 to 70 sewerage pumps failed from (1) power failure, and/or (2) flooding of pumps and switchboards at dry well wastewater pump stations (Hunter Water, pers. comm. 2009). These resulted in sewage main overflows and subsequent contamination of flood water across Newcastle and Lake Macquarie. Power outages at Bensville, near Gosford, also caused sewerage infrastructure failures (Calvert et al. 2007). Where network electrical power could not be reconnected immediately the electricity utility worked with the water utilities to provide connections to temporary portable electrical generators to reinstate supply and sewage services (Main et al. 2008). Some difficulties were encountered in obtaining a sufficient number of generators and some had to be sourced from interstate (Queensland and Victoria). In addition 14 wastewater tankers were operating around the clock for a number of days to minimise sewer overflows (Hunter Water, pers. comm. 2009).

Not all impacts of the storm were negative. The storm significantly increased water levels in Hunter Water's reservoirs (mostly in the Grahamstown off-stream storage). Hunter Water reservoirs escaped the worst of the drought experienced across most of eastern Australia in the period 2000–2007 due to fortuitous local climate conditions. Two clusters of ECLs (in March–June 2005 and September 2006), produced rainfall that fell in a very narrow band over the Hunter Water catchments. Without these two events the capacity of the Hunter Water system at the time of the Pasha Bulker storm would have been about 35% capacity instead of the 82% that actually occurred (Berghout 2009). The Pasha Bulker storm increased the water stored by a further 15% to 97% (Hunter Water, pers. comm. 2009). The relatively small impact of the storm was because it was not focussed over the reservoir catchments.

## 4.4 Emergency services

By 10 June (3 days after the first ECL) New South Wales (NSW) State Emergency Service (SES) had logged 19951 calls for assistance, triggering the second largest response operation in NSW history (SES, pers. comm. 2009). Around 60% of the calls reported fallen trees, 24% roof damage and 15% flood (Carpenter 2007). The SES undertook a total of 7434 jobs in the Hunter and 5372 in the Central Coast, including repairs to buildings, roofs, erection of tarpaulins and help with subsidence problems, among others (Calvert et al. 2007). Extra SES support (70 teams) was provided from the Australian Capital Territory (ACT), Victoria and Queensland (SES, pers. comm. 2009). A problem faced by the SES in the Newcastle region was a level of unpreparedness for urban flash flooding on such a scale. During the flood events the SES had plans that relied on the Army providing high ground clearance vehicles from their Adamstown base. However these vehicles had been relocated to Singleton due to residential development of the Adamstown Army base. Without access to the Army vehicles SES has to borrow personal four wheel drives, which in some cases proved to be inadequate (SES, pers. comm. 2009).

It was vital that people affected by flood/sewage damage be able to clean their homes as quickly as possible to avoid risk of disease. To help with the clean-up fact sheets on how to clean were distributed through the disaster recovery centres, media and Health Services. All sports events that involved contact with potentially contaminated sports grounds were postponed (Cretikos et al. 2007). A public emergency operations centre was set up by the Hunter New England Area Health Service to coordinate activities, respond to acute public health issues and prevent disease outbreaks (Cretikos et al. 2007). The emergency operations centre coordinated daily briefings with water utilities for four weeks after the storm focusing on water quality and quantity, along with results of microbiological monitoring, sewerage overflows and public

complaints. The emergency operations centre also reviewed progress on mitigation of health risks to food premises, private swimming pools, mosquito breeding sites and schools (Cretikos et al. 2007).

## 5. Adaptation response

First-hand experience in emergency flood management in Newcastle and Lake Macquarie gained during the 2007 storms has highlighted areas of specific concern that need to be addressed as part of future flood planning. Some of these are ongoing problems faced during such events and therefore are important to highlight for emergency managers. These include:

- Rescue and management efforts are quickly hampered when roads become inundated, leading to stranded vehicles and heavy traffic.
- Vehicles (mostly four-wheel drives) travelling through floodwaters created sizable bow waves, up to 0.5 m high. These waves can propagate into private properties and exacerbated flood damage (in some instances, resulting in above floor inundation that otherwise would not have occurred).
- The lack of knowledge and appreciation of flood behaviour meant that many people placed themselves at unnecessary risk by driving or wading through fast flowing floodwaters. Gissing et al (2007) found that 67% of survey respondents in Newcastle walked or drove through floodwater at some stage—nearly 40% did it to get to safety, 20% to get home, 15% to assist others, and 10% to protect property.
- Many residents reported that the flooding of their property was the result of blocked drains, irrespective of the size of the drain or its likely capacity to carry the extreme volumes of rainfall received. The broader community therefore believed that Council and Hunter Water were to blame for the flooding.
- A number of people experienced depression and anxiety over the flood, particularly over the tenuous nature of whether or not insurance would cover personal damage.
- Some new developments (and even some still under construction), built in accordance with Council's flood requirements, experienced over-floor flooding of, in some cases, up to 300 mm.

Lack of appropriate funding from all levels of government may be a 'road block' to achieving the above objectives. Council relies on supplementary annual grant funding from State and Commonwealth Governments to undertake flood study/plan projects and if these grants aren't forthcoming, then strategic prioritisation catchment projects may be compromised (Lake Macquarie City Council, pers. comm. 2009).

The availability of contingency plans that Hunter Water had prepared (across some assets) prior to the June 2007 event aided greatly in the crisis management and reinforced the need to finish the suite of documents across all critical assets. One of the longer term issues arising out of the storm event was the loss of operations of a number of dry well wastewater pump stations which were flooded (Hunter Water, pers. comm. 2009). Hunter Water has approximately 50 dry well pump stations across the network and there is a clear need to give some longer term consideration to identifying those which are at most risk of flooding and consider a program of converting such stations to the more modern submersible variety so that the equipment is not susceptible to flooding scenarios. Hunter Water have provided dedicated plug in facilities for generators at a large number of assets over recent years, however this was not yet widespread across the whole network (Hunter Water, pers. comm. 2009). The need to wire in generators in an emergency required both additional resources and extended times, therefore there is a need to take steps to ensure the use of generators can be facilitated in the most expeditious way. Hunter Water lost both a water main and sewer main at a creek crossing. A review of major creek crossings was consequently undertaken to determine the vulnerability of such assets to extremely high stream flows (Hunter Water, pers. comm. 2009).

## 6. Conclusion

This review of the Pasha Bulker storm and subsequent flooding leads to the following conclusions and policy recommendations:

- Greater community awareness of insurance cover inclusions (and exclusions) is needed along with a framework to cover aspects of storm damage not included under general home/business insurance (e.g. landslip, fallen trees, blocked drains).



- A consistent policy for coastal developments (agreement at Federal, State and local level of governments) is needed to deal with existing coastal infrastructure/housing and planning guidelines around new infrastructure/housing.
- Ongoing communication and education of communities susceptible to flooding (both flash flooding and river flooding) is required to ensure people respond appropriately to flood warnings in the future. Appropriate programs should be established.
- Further work needs to be carried out to evaluate the benefits of flash flood warning systems in fast response catchments in order to build a strong case for the installation of such systems.
- Clarification is required with respect to the lines of responsibility and regulatory powers for the establishment, maintenance, and enhancement, and planning controls on developments adjacent to and over, the open channel component of the stormwater system. For instance, in the Newcastle CBD it appears that responsibility is divided between a number of parties with no single entity having oversight of, or responsibility for, strategies to reduce flood damage risk.

A number of research questions and knowledge gaps were also identified, including:

- What causes periods of enhanced ECL activity and how likely is it to experience clustering of ECLs (e.g. the five in a month such as occurred in June 2007)?
- What are the climatological/oceanographic conditions that result in ECLs occurring close to the coast (as was the case with this event)? Has the amount of time an ECL once formed spent near the coast changed over time (noting the slow moving nature of the June 2007 ECL)?
- What is the likelihood of similar events (in terms of duration, intensity and proximity to the coast) occurring elsewhere along the eastern seaboard?
- How do large-scale drivers of interannual to multidecadal climate variability influence the behaviour of ECLs (e.g. frequency, intensity, duration, location, path)? Initial findings have shown that ENSO, IPO and SAM play a role in modulating the behaviour of ECLs (Browning and Goodwin 2013, Speer 2008, Speer et al. 2009), however there are still questions that are unresolved such as how these climate modes interact to enhance or suppress.
- How might ECL behaviour be altered under anthropogenic climate change? Note that to answer these questions it is first necessary to demonstrate that general circulation models (GCMs) and regional climate models (RCMs), and their associated downscaling of their outputs, satisfactorily simulates (a) existing ECL behaviour and (b) existing patterns and drivers of large-scale interannual to multidecadal climate variability (e.g. ENSO).
- Is the current instrumentation network (particularly pluviograph) sufficient to satisfactorily monitor flash flooding? Are there more strategic locations such as high topography where the observation network should be extended? Current flash flood monitoring catchments are inaccessible to the public and therefore not available to local councils and state utilities.

Some of these questions are being addressed under a major program established in 2010 by the Bureau of Meteorology and NSW Office of Environment and Heritage called the Eastern Seaboard Climate Change Initiative (ESCCI) as detailed in the accompanying papers in this special issue.

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