Hunter, Central and Lower North Coast

Regional Climate Change Project

2010

CASE STUDY 4: Potential Impacts of Climate Change on Extreme Events in the Coastal Zone of the Hunter, Lower North Coast and Central Coast Region

An Initiative of the Hunter & Central Coast Regional Environmental Management Strategy

(Hunter & Central Coast Regional Environmental Management Strategy – a program of the Environment Division of Hunter Councils)

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Table of Contents

List of Figures

List of Tables

ABBREVIATIONS

ARI	AVERAGE RETURN INTERVAL
BOM	BUREAU OF METEOROLOGY
ECL	EAST COAST LOW
EHE	EXTREME HEAT EVENT
ENSO	EL NINO SOUTHERN OSCILLATION
CSIRO	COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION
FFDI	FOREST FIRE DANGER INDEX
GCM	GLOBAL CLIMATE MODEL
HCCREMS	HUNTER AND CENTRAL COAST REGIONAL ENVIRONMENTAL MANAGEMENT STRATEGY
IDF	INTENSITY-DURATION-FREQUENCY
IPO	INTERDECADAL PACIFIC OSCILLATION
MA	MOVING AVERAGE
MSLR	MEAN SEA LEVEL RISE
SAM	SOUTHERN ANNULAR MODE
SD	STATISTICAL DOWNSCALING
SLP	SEA LEVEL PRESSURE
SOM	SELF-ORGANISING MAP
ST	SYNOPTIC TYPE

EXECUTIVE SUMMARY

This case study provides an analysis of both historic and projected changes for a range of key climate variables that are considered to represent `extreme events' in the coastal climatic zone of the Hunter, Central and Lower North Coast region of NSW. An analysis of historical climate records has identified that:

- Extreme rainfall events occur more frequently during January, February and March. In Newcastle this period extends through April & May, and peaks in June. No changes in the frequency or intensity of extreme rainfall events has been identified from the historic record
- A slight decreasing trend in the frequency of Extreme Heat Days (ie. greater than or equal to 37^{o}C) is evident at Newcastle, while an increasing linear trend is evident at Taree
- All seasons show an increase in average recorded wind gusts from 1957-2007. This increase is most pronounced during summer
- No historic trends in East Coast Low (ECL) formation have been found (Speer, et al. 2009)

Projected changes in extreme events (for the 2020-80 period based on the A2 global emissions scenario) include:

- Increased frequency of extreme rainfall events during summer and a slight increase during spring. A slight increase in frequency is also projected for Newcastle during winter
- Increased frequency of extreme heat events (ie greater than or equal to 37^{o}C) during summer and autumn
- Increased intensity of northwesterly wind gusts during spring and increased frequency of on shore wind gusts during summer and autumn
- Increased frequency of East Coast Lows during autumn and winter
- Increased incidence of extreme sea levels during autumn and winter

This historic and projected climate data has formed the basis of a sub-regional scale risk assessment and adaptation planning process that has identified and ranked the potential risks arising from projected changes in the occurrence of *individual* extreme weather variables across the coastal zone. The risk assessment has not considered the potential for coincident events of extreme climate variables due to an absence of data in this area. The key risks (i.e. rated Extreme or High) that have been identified include:

- Public health issues arising from extreme heat events
- Increases in wind gust during spring and summer increasing fire risk during these seasons
- Increased demand on power supplies and possible loss of power during extreme weather events
- Exacerbation and more widespread flooding of property and environment due to extreme rainfall events
- Increased coastal erosion in vulnerable areas associated with extreme storm events
- Increase in public injury during extreme storm events
- Potential change in marine and estuarine habitat distribution in the littoral zone arising from sea level rise and extreme sea level events

As can be seen, many of these risks are already present in the region. Rather than creating a whole new set of risks, changes in extreme events arising from climate change will exacerbate a number of existing risks for which, in many cases, effective control strategies are already in place. However, climate change may increase the frequency and extent of these current problems, which will require further refinement of existing controls.

In light of this, it is generally considered that the refinement and further development of existing controls represents the most effective strategy for managing many of the Extreme and High rated risks that have been identified. While in some areas new or improved planning is identified as an adaptation priority, many of the adaptation strategies identified in this case study actually focus on research, decision making frameworks and community education programs that aim to improve the effectiveness of the existing control mechanisms.

INTRODUCTION

This case study examines the potential impacts of climate change on extreme events in the coastal zone. It has been completed as part of a regional research program to identify the regional and sub regional scale impacts of climate change in the Hunter, Central and Lower North Coast region of New South Wales.

In addition to an overall analysis of historic and projected climate change for the region (Blackmore & Goodwin 2008; Blackmore & Goodwin 2009), four (4) case studies have been developed to more specifically analyse and understand the potential impacts of climate change on the Hunter Valley Wine Industry, Human Health (Extreme Heat), Bushfires and Extreme Events in the Coastal Zone.

OVERVIEW OF KEY CLIMATE CHANGE CONCERNS

Extreme weather events are a key concern for the community, government and industry. Their occurrence can cause significant economic loss, social stress (e.g. injury, sickness & loss of life), dislocation (e.g. loss of homes) and considerable environmental damage.

Although often considered through economic indicators of loss or damage (Easterling et al., 2000), this case study aims to provide an objective assessment of historical trends and projected changes in the frequency of extreme events in the *coastal climatic zone* of the Hunter, Central and Lower North Coast region of NSW (see Figure 1). This is conducted through an analysis of key climate variables considered to be representative of, or contributing to, the severity of extreme events.

The variables included in the analysis include:

- extreme long duration rainfall events as measured by:
    - the number of daily and three day rainfall events per annum greater than intensity-duration-frequency (IDF) thresholds
    - the number of daily and three day rainfall events in the 99th and 95th percentiles that occur per annum
    - the yearly highest daily and three day rainfall event
- wind gusts
- extreme heat events
- storm frequency
- wave climate
- sea level rise and extreme sea levels

It is important to note that this climate analysis has focused on each of the climate parameters on an individual basis. It has not analysed the potential for the coincident occurrence of more than one climate variable. This reflects the fact that no climate projections are available in relation to coincident events of this nature, however it is recognised that extreme climate events are often characterised by this feature (eg. extreme sea level combined with intense rainfall).

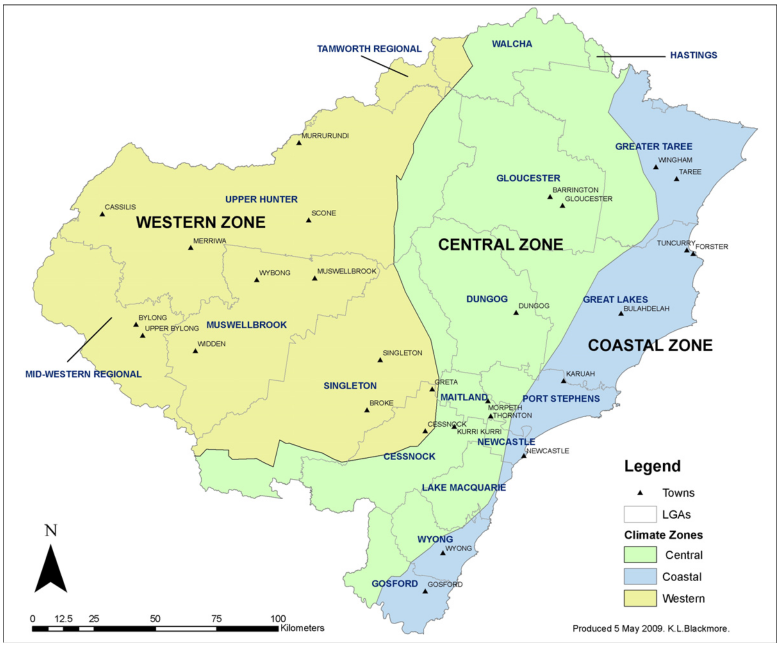


Figure 1 - Map of the study region showing climate zone boundaries and the location of the 11 Bureau of Meteorology (BOM) recording stations in the coastal zone used for analysis.

In providing an assessment of extreme events it also important to realise that such events may be very localised in their nature. To address this issue, readings from a number of individual Bureau of Meteorology (BOM) recording stations throughout the coastal zone of the Central, Hunter and Lower North Coasts of NSW have been analysed to identify key patterns and trends (Figure 1).

The coastal zone itself is one of three climate zones that were identified for the Hunter, Central and Lower North Coast as part of the broader climate change study for the region. These were identified through a process known as climate zonation. This is a statistical process which divides a region into distinct sub-regions or zones where climatic similarity is maximised within zones and minimised between zones.

The coastal zone is the area of interest for this case study. As such, it is used as the basis for selecting BOM recording stations to analyse historic records for key climate variables. It is also acknowedged that extreme events in the coastal zone may arise as a result or consequence of events occurring in the western and central zone. For example, extreme rainfall events occurring in the central and/or western areas of the region may produce flooding in the coastal zone. While these potential impacts are recognised, the focus of the case study remains on the coastal zone and the direct key climate variable measurements recorded therein.

BUREAU OF METEOROLOGY STATIONS

Details of the precipitation recording Bureau of Meteorology (BOM) stations that are used in the analysis are provided in Table 1.

STATION NUMBER	NAME	SITE OPENED	LATITUDE	LONGITUDE	STATE	ELEVATION (m)
61087	Gosford (Narara Research Station) AWS	01/1916	-33.3949	151.3290	NSW	20
61083	Wyong (Wyong Golf Club)	01/1885	-33.2720	151.4320	NSW	37
61074	The Entrance (Eloora Street)	01/1943	-33.3531	151.4960	NSW	22
61055	Newcastle Nobbys Signal AWS	01/1862	-32.9185	151.7980	NSW	33
61072	Tahlee (Carrington House)	01/1887	-32.6678	152.0140	NSW	3
60002	Bulahdelah Post Office	01/1905	-32.4129	152.2080	NSW	10
60036	Wingham (Lanark Close)	01/1888	-31.8620	152.3440	NSW	66
60013	Forster – Tuncurry R.V.C.P.	01/1896	-32.1755	152.5090	NSW	4
60028	Seal Rocks Camping Reserve	01/1897	-32.4324	152.5230	NSW	4
60017	Hannam Vale (Hannam Vale Road)	01/1926	-31.6994	152.5830	NSW	33
60023	Harrington (Oxley Anchorage Caravan Park	01/1887	-31.8714	152.6830	NSW	6

Table 1 – BOM stations used for analysis of extreme rainfall events

Details of the minimum/maximum temperature stations that are used in the analysis of extreme heat events are provided in Table 2.

BOM ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61055	Newcastle Nobbys Signal Station AWS	01/1862	-32.919	151.798	33
60030	Taree (Radio Station 2RE)	01/1881	-31.899	152.483	5

Table 2 - BOM stations used for analysis of extreme heat events

Wind gust records covering an extended period in the region are only available from Williamtown.

Although some stations opened as early as January 1862, the earliest records considered in the analysis presented in this case study commence 1 January 1948. This is because, to ensure accuracy and reliabilility, it is important that the data sets used in the analysis are of sufficient length, cover a common time span, and are reasonably complete. Thus a data interrogation process has been used to determine the completeness of each of the rainfall records (Verdon & Goodwin 2008). This process identified that the optimum time period that provides BOM records that are 90% complete across recording locations is 1948 – 2007.

When analysing extreme events, it is also necessary to consider the time-varying and cyclical impacts of the El Nino-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) periods. The time-varying circulation is due to the interaction of the major climate modes of oscillating atmospheric pressure and sea surface temperature in the Southern Hemisphere which are the El Nino-Southern Oscillation (ENSO) and the Southern Annular Mode (SAM). These are the dominant climate modes for the tropical and extratropical Southern Hemisphere, respectively. These patterns control the growth and decay of synoptic weather systems over Australia.

Interdecadal variability within the Australasian and South West Pacific regions is associated with the Interdecadal Pacific Oscillation (IPO). During the time period from 1948 to 2007 there have been two phases of this oscillation: IPO –ve phase (La Nina-like) from 1948 to 1976; and, IPO +ve phase (El Nino-like) from 1977 to 2007. Regionally, the IPO –ve phase is associated with generally wetter and more variable levels of precipitation (and other climate variables). The impacts and variability of extreme events in the region are influenced by each of these cycles.

CASE STUDY METHODOLOGY

A two-step methodological process has been adopted for the analysis of climate parameters completed for this case study. Firstly, key climate variables associated with extreme weather events have been identified and changes in these variables assessed using historic records obtained from the Bureau of Meteorology. Secondly, climate projections for the region obtained from Global Climate Model (GCM) output and a process called Statistical Downscaling (SD) have been utilised to assess likely impacts on the relevant key climate variables for the period from 2020-2080 A.D.

Global Climate Models generate future climate scenarios and provide outputs for a range of key climate variables. The CSIRO Mk3.5 GCM and the A2 scenario have been determined as the most appropriate to identify projected changes in climate for the Hunter, Central and Lower North Coast region. This is because the A2 scenario most accurately reflected global emission trajectories at the time of the the research. Because of the coarse scale outputs generated by Global Climate Models however, the additional process of Statistical Downscaling has also been used to generate climate projections more relevant and applicable for regional scale analysis and management purposes. Statistical Downscaling is a term given to techniques used to derive values for climate variables at a regional or sub-regional level from the coarse scale output of Global Climate Models. Specifically, a weather typing approach to Statistical Downscaling has been adopted for the research presented in this case study. In summary, this process has included:

1. Identifying the key synoptic types that drive climate variability in the region

2. Identifying the relationships between these synoptic types (ST's) and Bureau of Meteorology historic records for key climate variables

3. Using the Global Climate Model to identify projected changes in the frequency of occurrence of these key synoptic types based on sea level pressure (SLP) output data generated by the model

4. Combining our understanding of how the region's weather is impacted by these key synoptic types, with projected changes in their frequency, to predict likely changes in key climate variables across the region

A more detailed overview of the methodology is included in the report *Climatic Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW* (Blackmore & Goodwin 2009). The key benefit of this approach is that it provides a richer understanding of the drivers of weather patterns within the region and how these "drivers" are likely to change in the future.

However, an assumption regarding the relationship between synoptic types and the historic record is made that excludes the inclusion of new drivers. That is, it is assumed that the weather patterns occurring under each synoptic pattern evident in the historic record will continue in the projection. The emergence of new synoptic patterns is not considered, nor is the possibility that the weather pattern produced by a given synoptic pattern will change in the future.

HISTORICAL CLIMATE VARIABILITY AND TRENDS

EXTREME RAINFALL EVENTS

For the purpose of this case study, extreme rainfall events are considered in terms of:

1. the number of daily and three-day rainfall events per annum greater than intensity-duration-frequency (IDF) thresholds
2. the number of daily and three-day rainfall events in the 99th and 95th percentiles per annum
3. the yearly highest daily and three-day rainfall events

Generally, historical analysis of rainfall events (Blackmore & Goodwin 2008) has identified that across the coastal zone:

- Extreme rain events occur more frequently during January, February and March. In Newcastle, this period extends through April and May, and peaks in June
- Extreme rain events are less likely to occur during late winter to early spring
- Extreme daily rainfall events occur most frequently closest to the coast, with the centres of Gosford and Buladelah, and the area north of Taree, receiving the highest rainfall

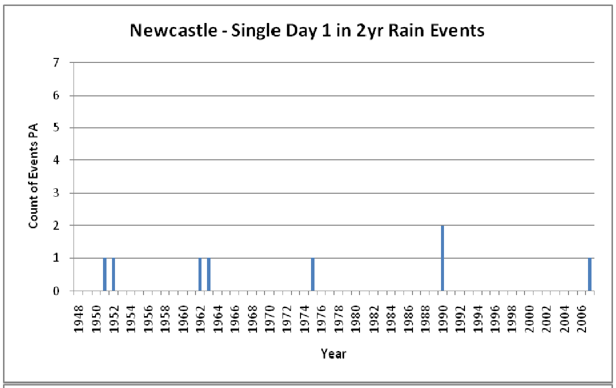
RAINFALL EVENTS EXCEEDING INTENSITY-DURATION-FREQUENCY THRESHOLDS

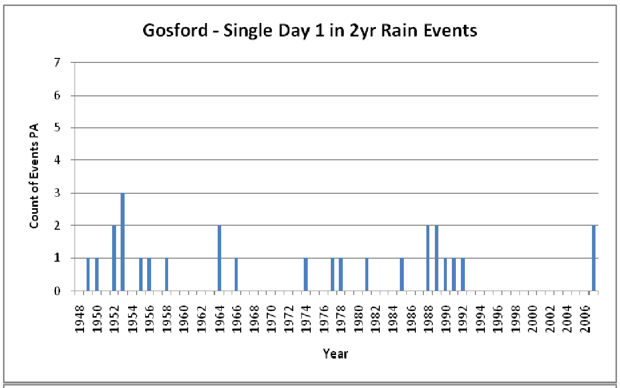
Intensity Duration Frequency (IDF) curves show the relationship between rainfall intensity and duration for different levels of frequency. Each curve represents the rainfall intensity-duration which will be equaled or exceeded once in a certain number of years, indicated as the frequency of that curve. Consistent IDF design rainfall data has been derived for the whole of Australia at a resolution of about 2.5 km. This work has been completed by the Bureau of Meteorology as part of the revision of *Australian Rainfall and Runoff* (Inst. Engineers Aust., 1987). IDF design rainfall curves range from 5 minutes to 72 hours in duration for average return intervals (ARIs) of 1 year, 2 years, 5 years, 10 years, 20 years, 50 years and 100 years. One day (24 hours) and 3 day (72 hours) IDF thresholds for the selected stations in the coastal zone for 2, 5 and 10 year ARIs are provided in Table 3.

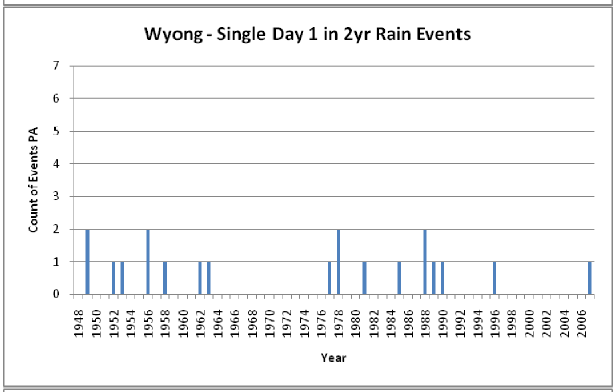
		Newcastle	Gosford	Wyong	The Entrance	Tahlee	Bulahdelah	Wingham	Forster	Seal Rocks	Hannam Vale	Harrington
1day	2yr	109.68	139.68	132.96	122.4	111.84	86.88	125.04	129.84	117.12	165.6	137.28
	5yr	142.8	184.32	176.4	160.8	147.84	115.2	165.84	164.4	144.96	215.52	176.64
	10yr	162.48	210.96	202.32	183.6	169.68	132.96	190.32	184.08	160.32	244.8	199.68
3day	2yr	161.28	210.24	189.36	177.84	113.76	125.28	175.68	189.36	156.96	254.88	200.88
	5yr	215.28	278.64	254.16	238.32	144.72	167.04	242.64	240.48	204.48	336.96	259.2
	10yr	248.4	319.68	293.04	276.48	163.44	192.96	285.12	269.28	232.56	387.36	293.76

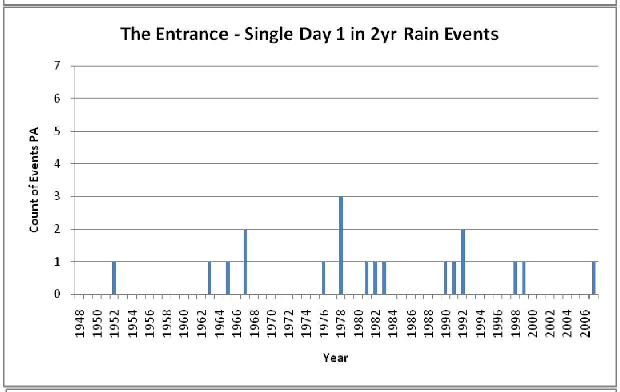
Table 3 - 1 Day and 3 Day IDF Thresholds for 2, 5 and 10 Year ARIs (in Millimeters)

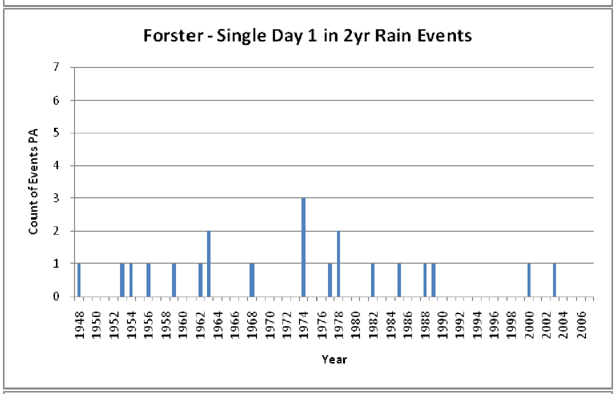
The 2 year average return interval (ARI) was used to analyse rainfall events exceeding IDF thresholds (Figure 2 on pages 8 & 9). Using the derived IDF thresholds, selected stations within the coastal zone have recorded between 8 and 113 two year ARI events over the period from 1948 to 2007. Due to the small sample size, statistical analysis of trends is not possible however it is noted that no discernable patterns are evident in the graphs. It is also noted that the derived threshold for Bulahdelah results in a high number of events equal to or exceeding the threshold.

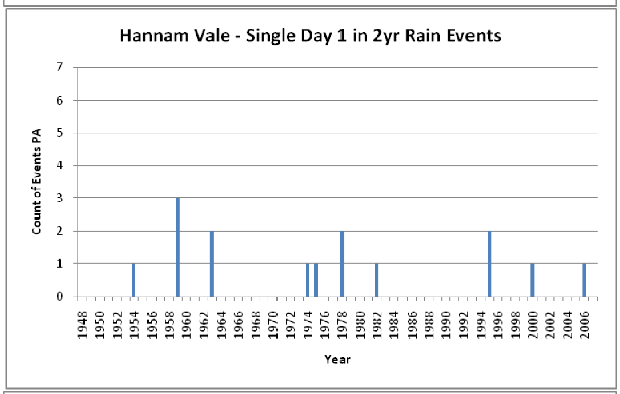

Newcastle - Single Day 1 in 2yr Rain Events
Count of Events PA
Year

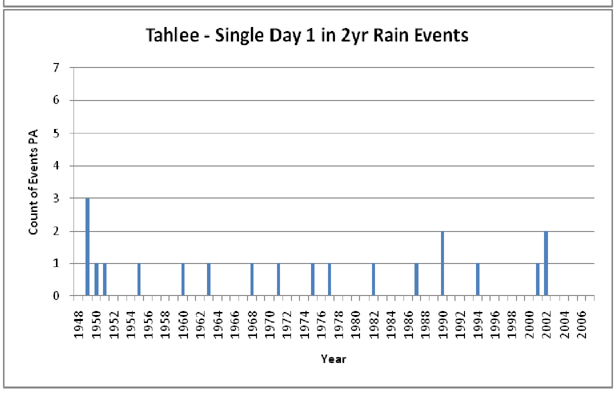

Gosford - Single Day 1 in 2yr Rain Events
Count of Events PA
Year

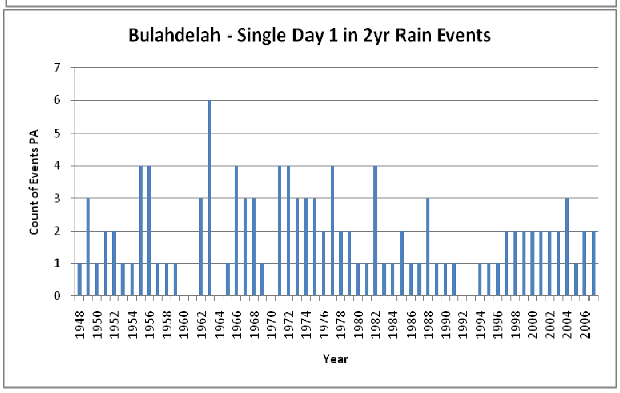

Wyong - Single Day 1 in 2yr Rain Events
Count of Events PA
Year


The Entrance - Single Day 1 in 2yr Rain Events
Count of Events PA
Year


Forster - Single Day 1 in 2yr Rain Events
Count of Events PA
Year


Hannam Vale - Single Day 1 in 2yr Rain Events
Count of Events PA
Year


Tahlee - Single Day 1 in 2yr Rain Events
Count of Events PA
Year


Bulahdelah - Single Day 1 in 2yr Rain Events
Count of Events PA
Year

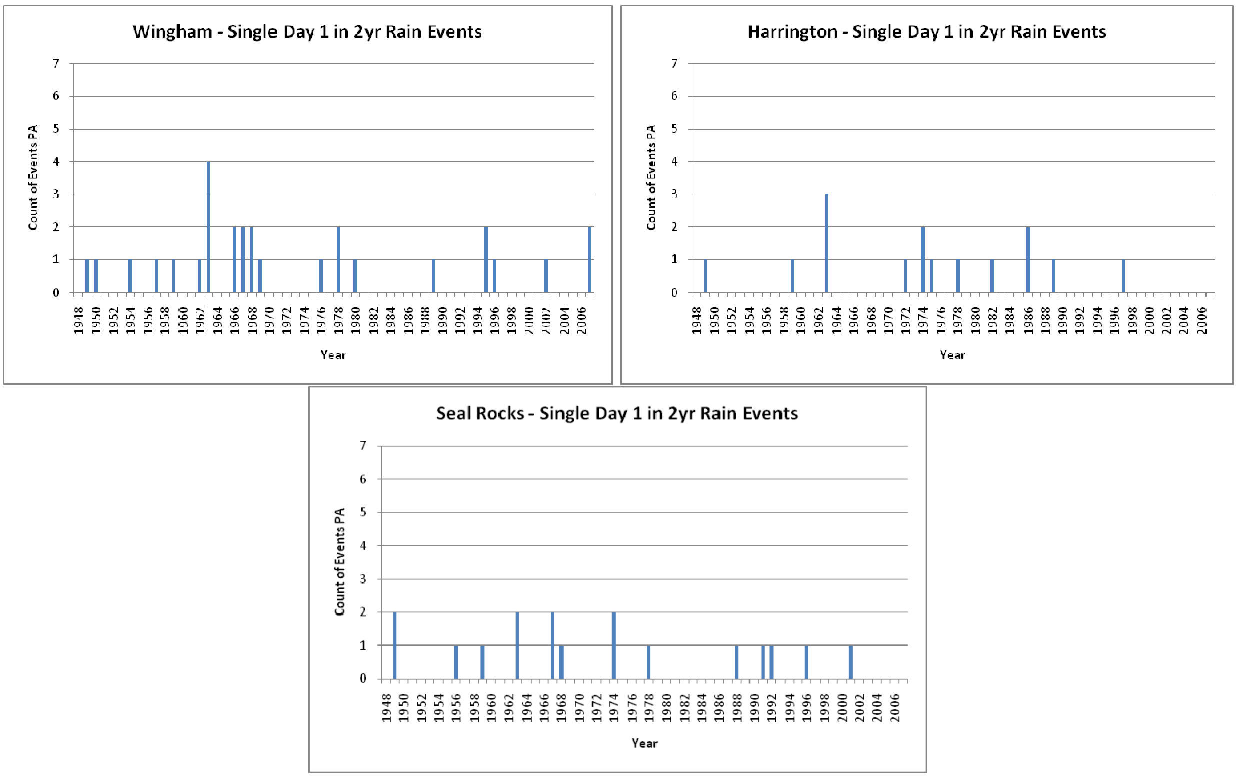
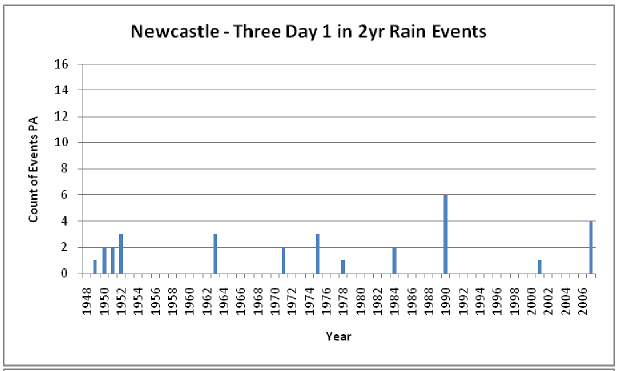
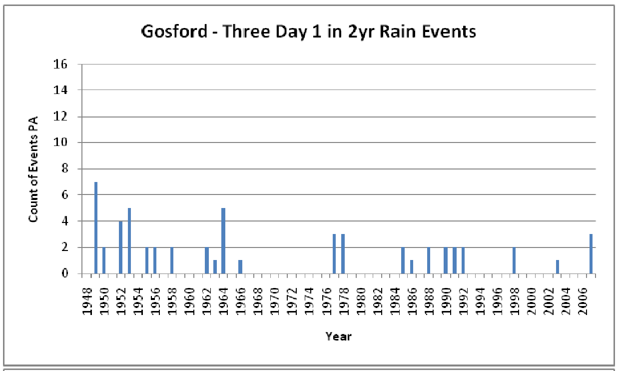
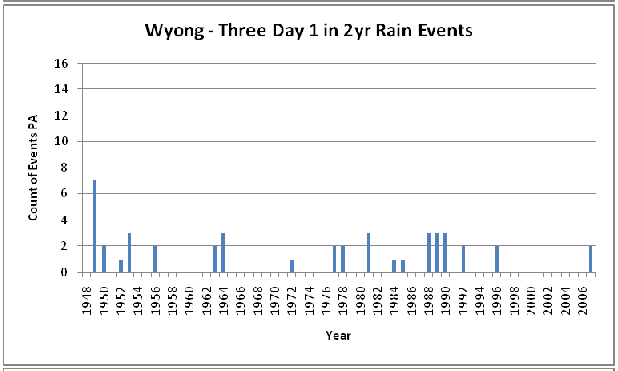


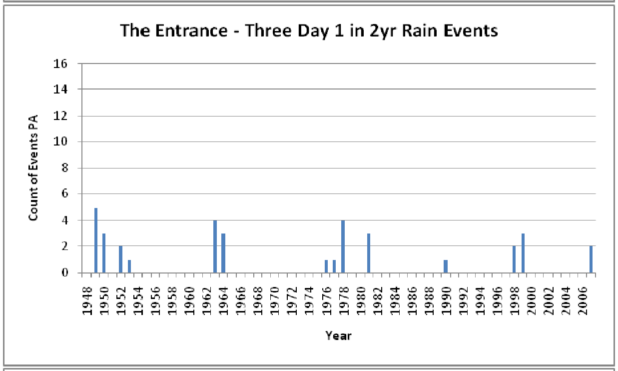
Figure 2 – Count of single day 1 in 2 year rain events per annum for selected stations (1948-2007).

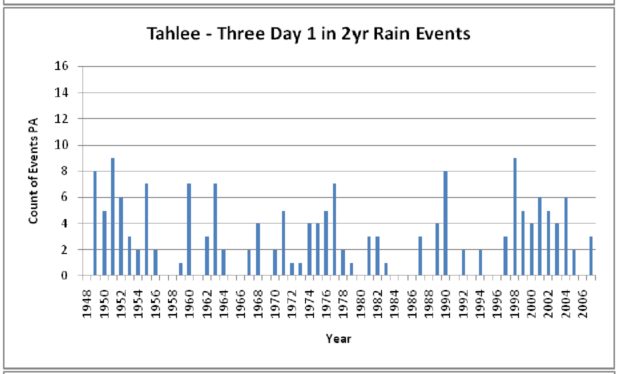
Extreme rain events often cause considerable damage when heavy rain persists over a number of consecutive days. In particular, longer duration events of this nature can cause considerable flooding and damage of riverine catchments. Using the derived IDF thresholds for a 3 day period (72 hours), selected stations within the coastal zone have recorded between 30 and 196 two year ARI events over the period from 1948 to 2007 (in Figure 3 on pages 10 & 11). As with single day events, statistical analysis of trends is not possible due to small sample sizes however it is noted that no discernable patterns are evident in the graphs.

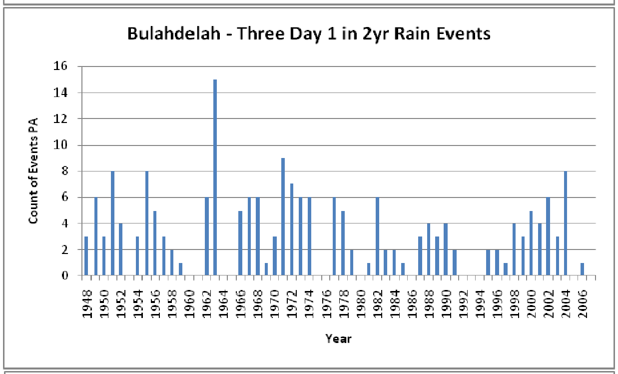

Newcastle - Three Day 1 in 2yr Rain Events
Count of Events PA
Year

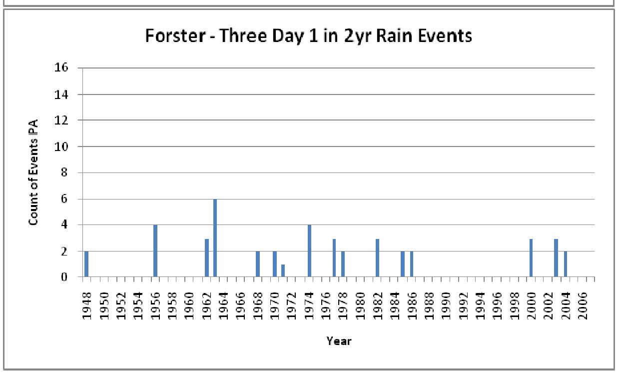

Gosford - Three Day 1 in 2yr Rain Events
Count of Events PA
Year

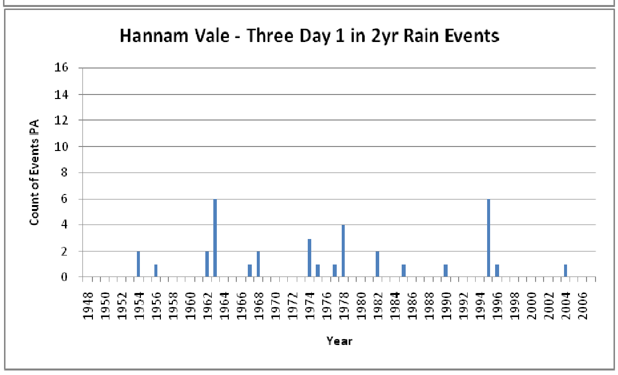

Wyong - Three Day 1 in 2yr Rain Events
Count of Events PA
Year


The Entrance - Three Day 1 in 2yr Rain Events
Count of Events PA
Year


Tahlee - Three Day 1 in 2yr Rain Events
Count of Events PA
Year


Bulahdelah - Three Day 1 in 2yr Rain Events
Count of Events PA
Year


Forster - Three Day 1 in 2yr Rain Events
Count of Events PA
Year


Hannam Vale - Three Day 1 in 2yr Rain Events
Count of Events PA
Year

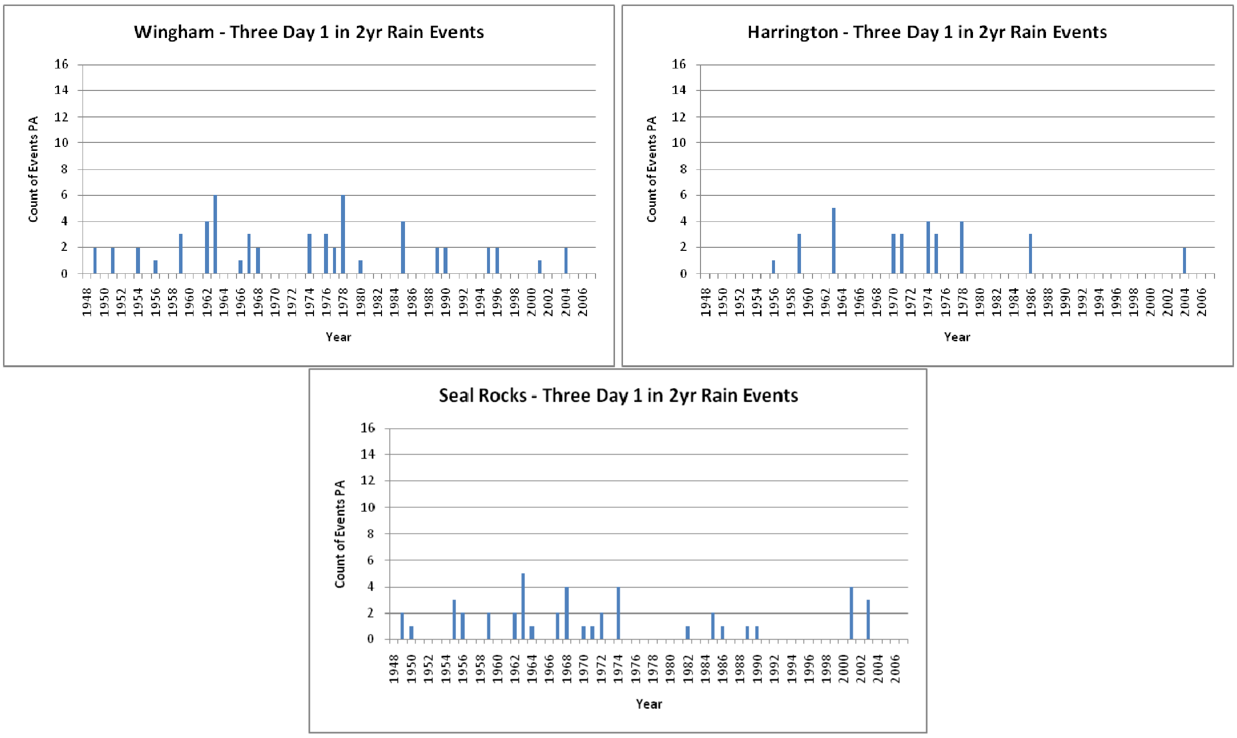


Figure 3 - Count of three day 1 in 2 year rain events per annum for selected stations (1948-2007).

RAINFALL EVENTS ABOVE THE 99TH AND 95TH PERCENTILES

A percentile is the value below which a certain percent of data values lie. Thus 99 percent of values lie below the 99th percentile (99%ile) and 95 percent of values lie below the 95th percentile (95%ile). The percentiles for Newcastle, Gosford and Wingham have been calculated to identify daily rainfall thresholds (Table 4) and these are used to analyse the top one and five percent of rainfall events respectively.

Location	95%ile Threshold (mm)	99th%ile Threshold (mm)
Newcastle	33.8	66.4
Gosford	48.0	104.1
Wingham	40.6	87.0

Table 4 – One day 99th and 95th percentile thresholds (mm)

The count of the number of daily rainfall events per annum exceeding the 95th and 99th percentile threshold values in Newcastle, Gosford and Wingham are shown in Figure 4 over page. Decreases in the frequency of these events are evident in Gosford and Wingham. The decrease in 95%ile rainfall events occurring in Gosford is statistically significant at the 5% level.

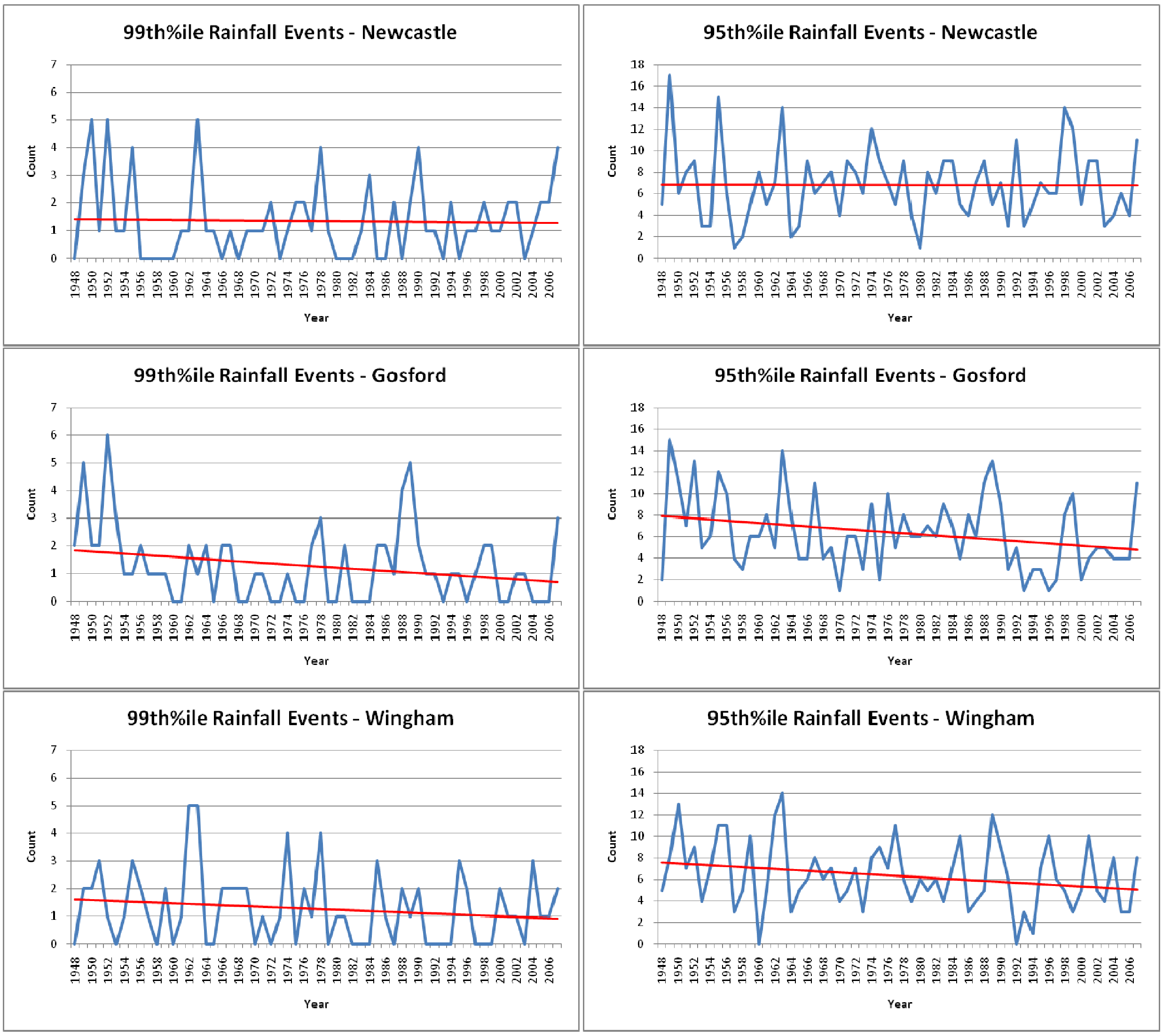


Figure 4 - Number of daily rainfall events per annum exceeding 99th and 95th percentile thresholds (1948-2007)

The number of three-day rainfall events per annum exceeding the 95th and 99th percentile threshold values (Table 5) in Newcastle, Gosford and Wingham are shown in Figure 5. Decreases in the frequency of these events are evident in Newcastle, Gosford and Wingham. The decreases in the 99th%ile and 95th%ile rainfall events occurring in Wingham are statistically significant at the 5% level.

Location	95%ile Threshold (mm)	99th%ile Threshold (mm)
Newcastle	56.4	108.7
Gosford	76.8	164.2
Wingham	65.4	136.4

Table 5 - Three day 99th and 95th percentile thresholds (mm)

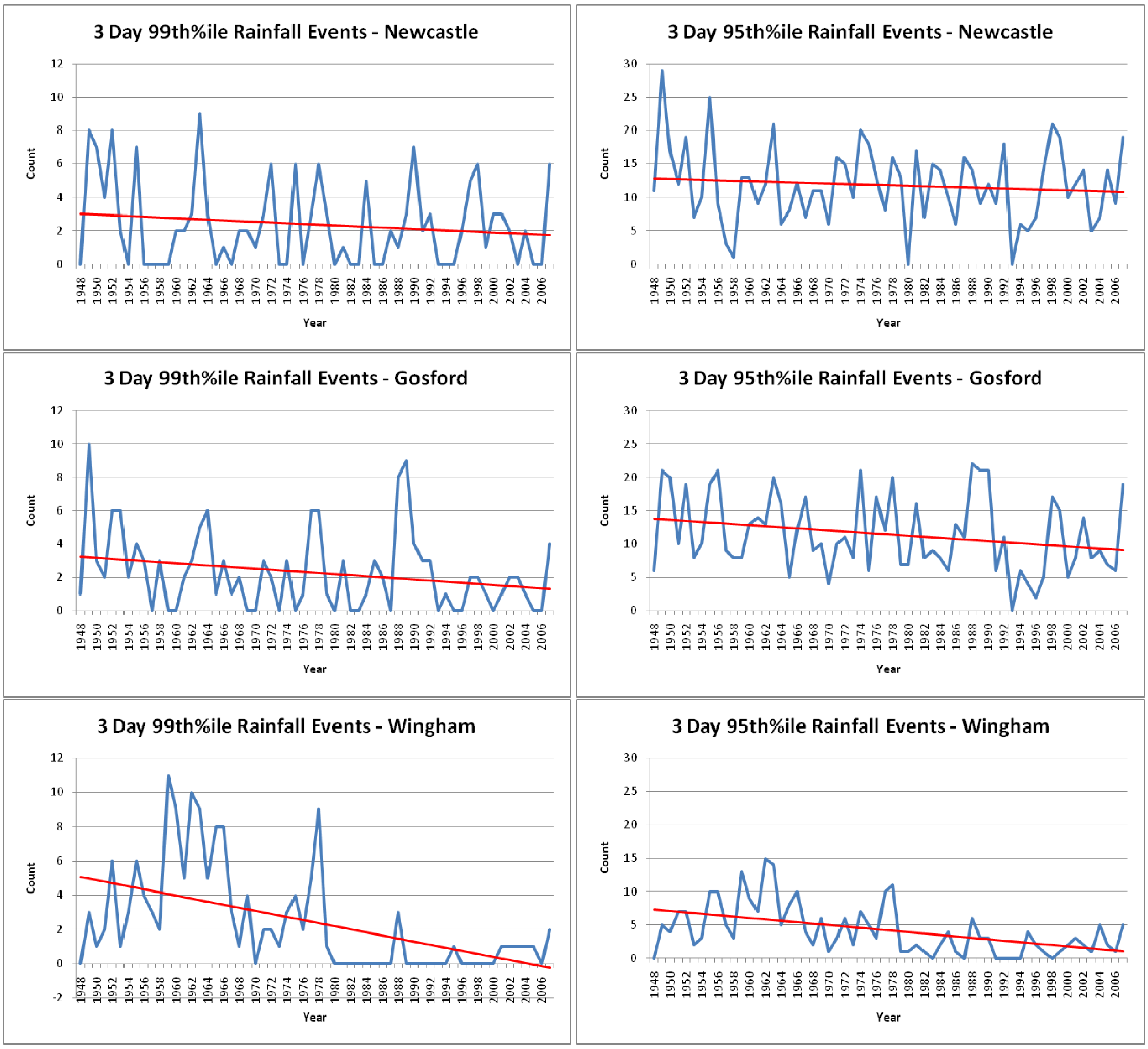
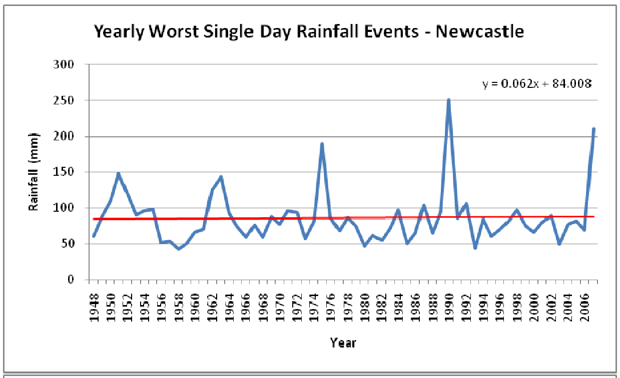
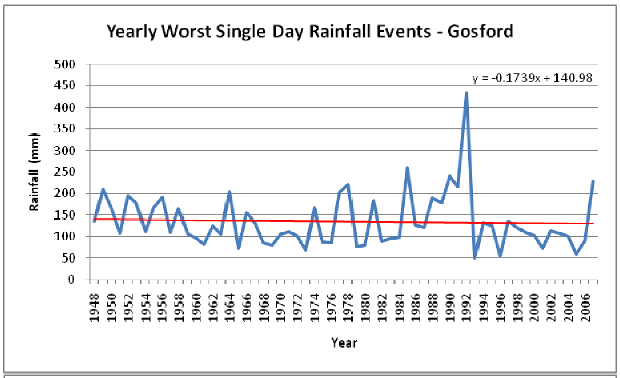


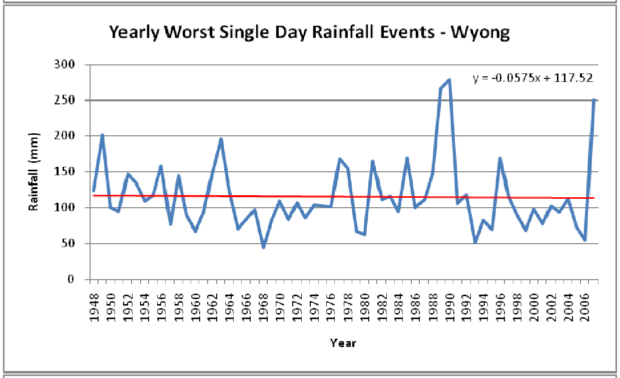
Figure 5 - Number of three day rainfall events per annum exceeding 99th and 95th percentile thresholds (1948-2007)

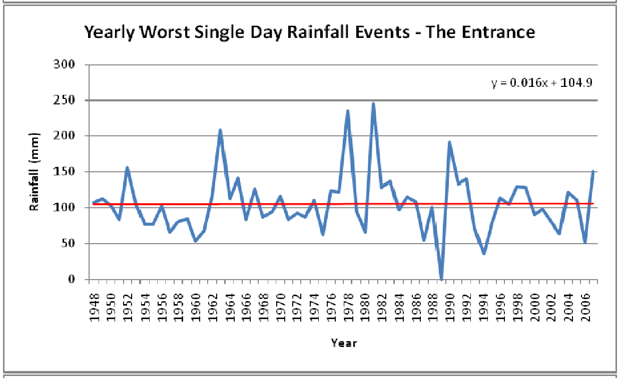
YEARLY HIGHEST SINGLE AND THREE DAY RAIN EVENTS

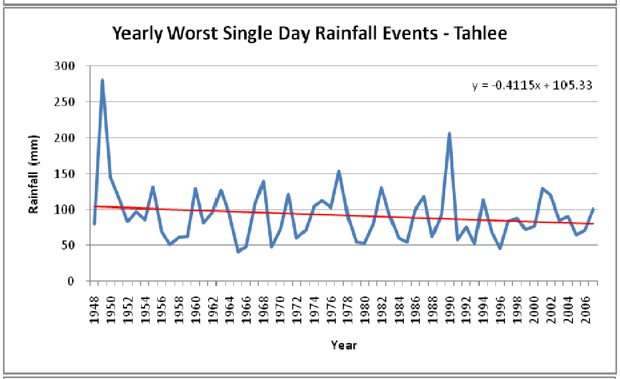
The highest recorded single day (24 hour) and three day (72 hour) rainfall events are plotted for the period from 1948 to 2007 (Figure 6 and Figure 7 on pages 14-17). Analysis of these events provides an indication of trends in the intensity or severity of rainfall events occurring the in the region's coastal zone.

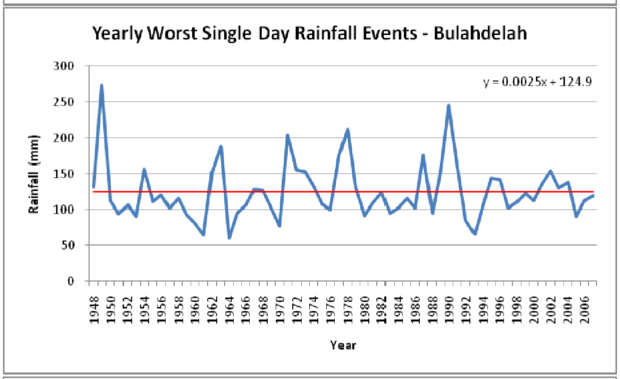

Yearly Worst Single Day Rainfall Events - Newcastle
y = 0.062x + 84.008
Rainfall (mm)
Year

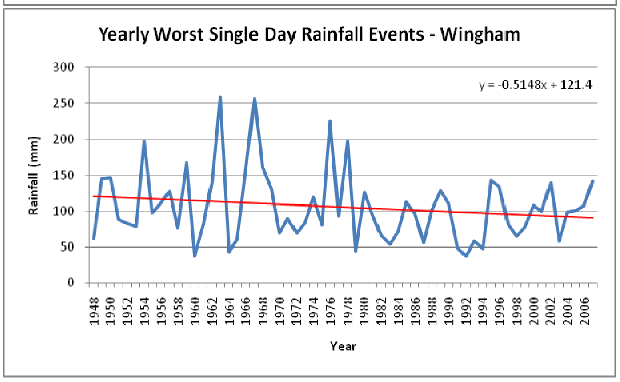

Yearly Worst Single Day Rainfall Events - Gosford
y = -0.1739x + 140.98
Rainfall (mm)
Year

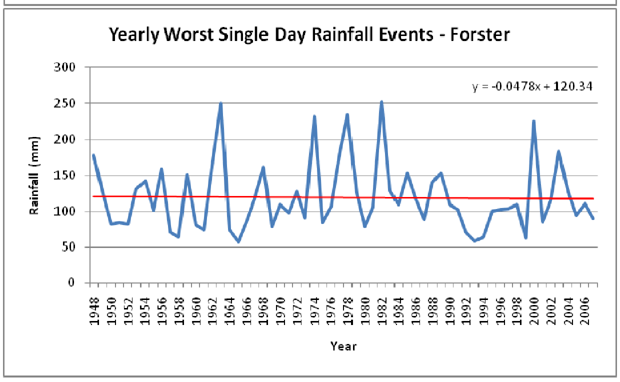

Yearly Worst Single Day Rainfall Events - Wyong
y = -0.0575x + 117.52
Rainfall (mm)
Year


Yearly Worst Single Day Rainfall Events - The Entrance
y = 0.016x + 104.9
Rainfall (mm)
Year


Yearly Worst Single Day Rainfall Events - Tahlee
y = -0.4115x + 105.33
Rainfall (mm)
Year


Yearly Worst Single Day Rainfall Events - Bulahdelah
y = 0.0025x + 124.9
Rainfall (mm)
Year


Yearly Worst Single Day Rainfall Events - Wingham
y = -0.5148x + 121.4
Rainfall (mm)
Year


Yearly Worst Single Day Rainfall Events - Forster
y = -0.0478x + 120.34
Rainfall (mm)
Year

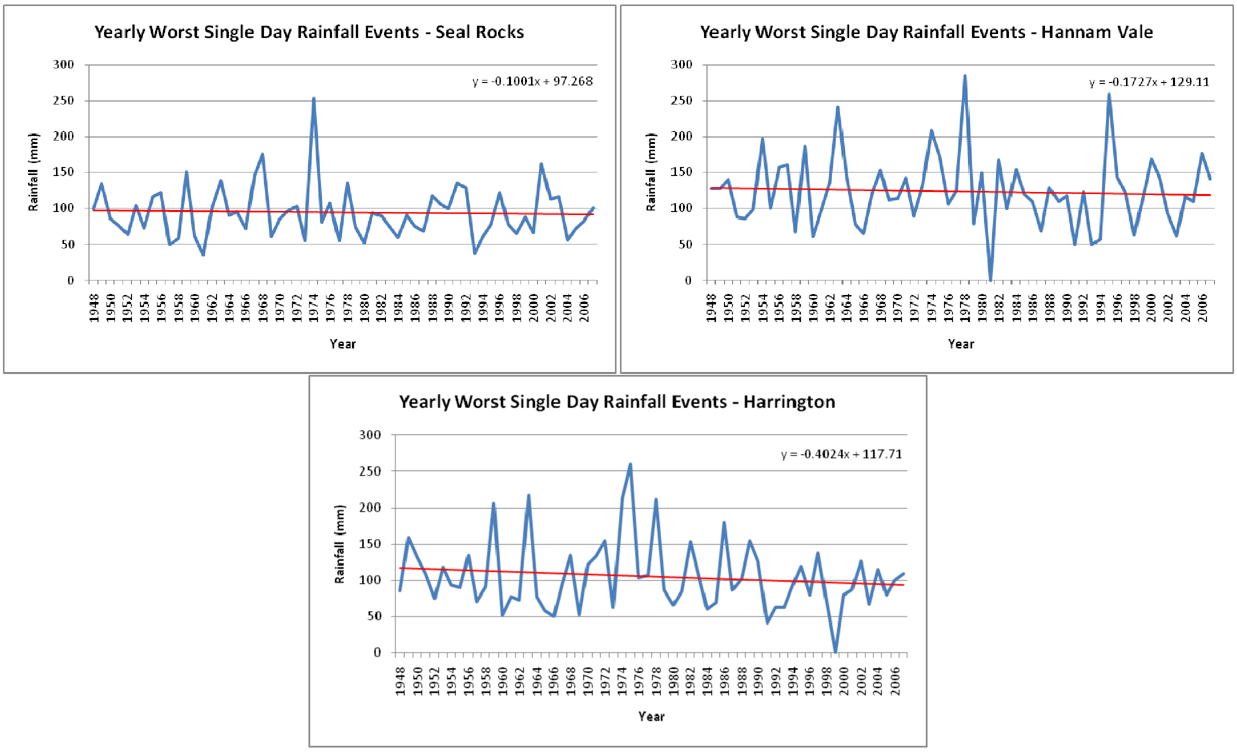
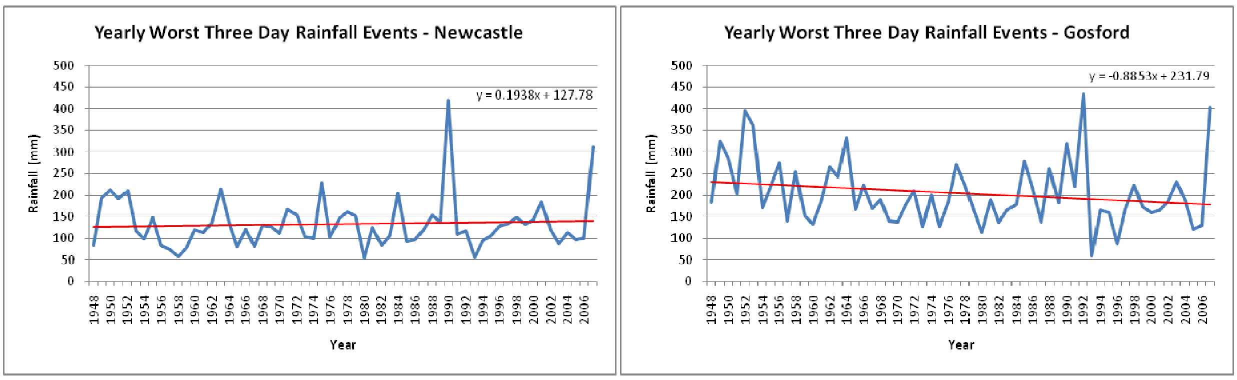
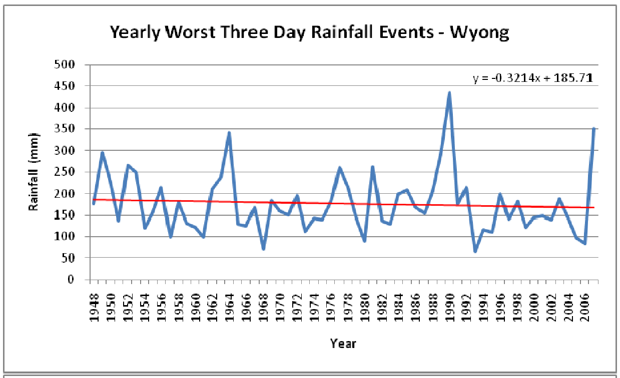
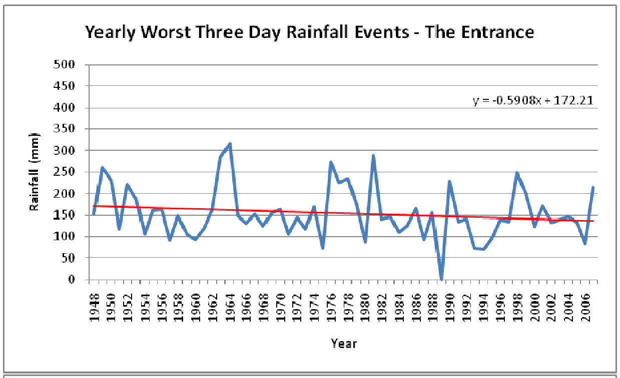


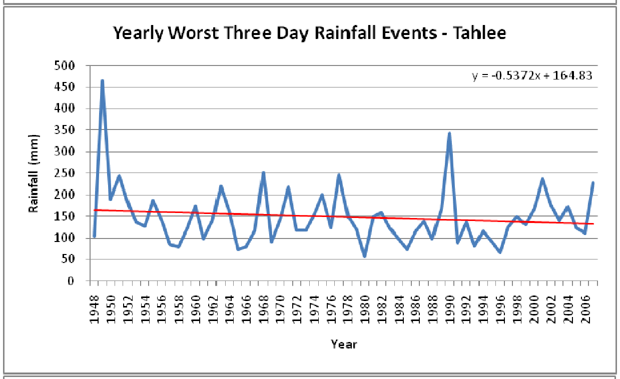
Figure 6 – Annual trends in yearly highest single day rainfall events

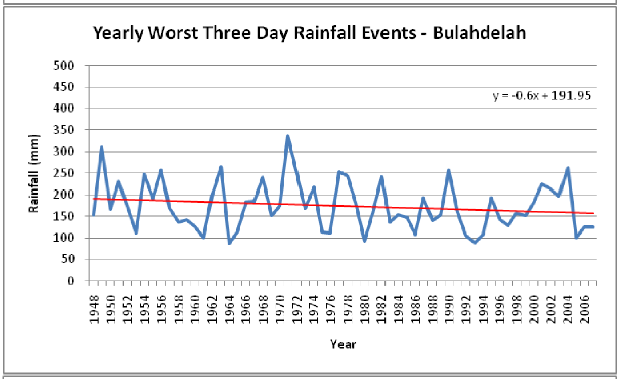
Centres within the coastal zone show either no changes or slight decreases in recorded rainfall occurring during yearly highest events. Decreases in the severity of single day events are most notable at Gosford, Wingham, Tahlee and Harrington. Decreases in the severity of three-day events are most notable at Gosford, Bulahdelah, Seal Rocks and Harrington. Despite notable decreases, none of these trends were found to be statistically significant.

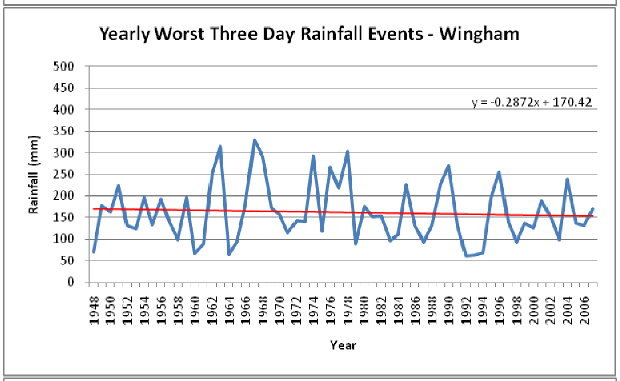


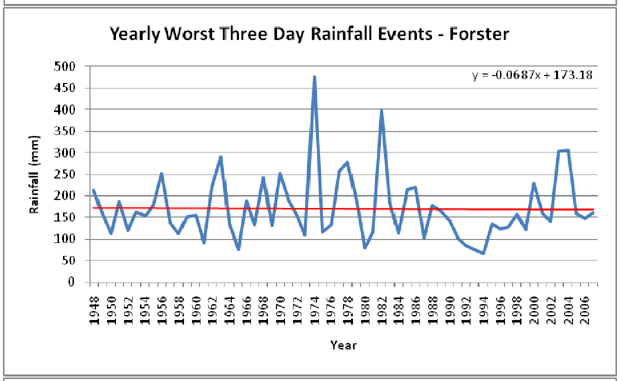

Yearly Worst Three Day Rainfall Events - Wyong
y = -0.3214x + 185.71
Rainfall (mm)
Year

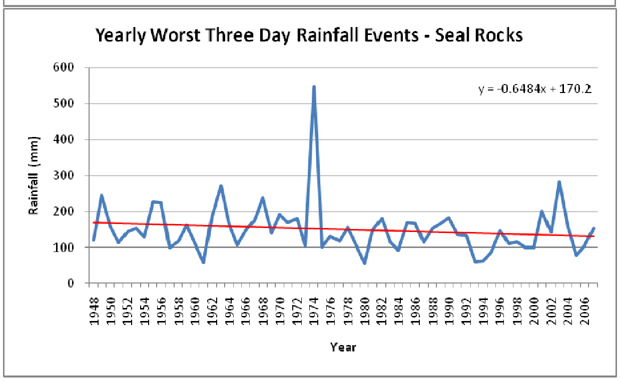

Yearly Worst Three Day Rainfall Events - The Entrance
y = -0.5908x + 172.21
Rainfall (mm)
Year

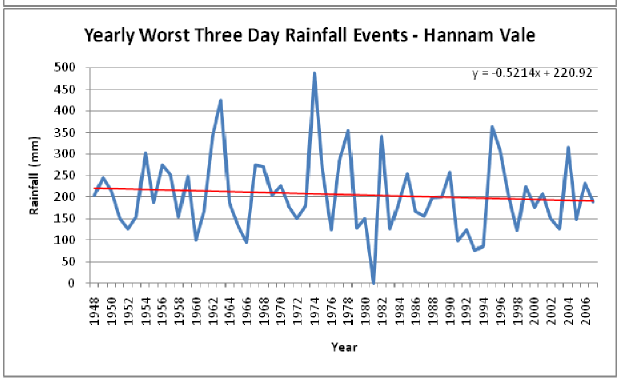

Yearly Worst Three Day Rainfall Events - Tahlee
y = -0.5372x + 164.83
Rainfall (mm)
Year


Yearly Worst Three Day Rainfall Events - Bulahdelah
y = -0.6x + 191.95
Rainfall (mm)
Year


Yearly Worst Three Day Rainfall Events - Wingham
y = -0.2872x + 170.42
Rainfall (mm)
Year


Yearly Worst Three Day Rainfall Events - Forster
y = -0.0687x + 173.18
Rainfall (mm)
Year


Yearly Worst Three Day Rainfall Events - Seal Rocks
y = -0.6484x + 170.2
Rainfall (mm)
Year


Yearly Worst Three Day Rainfall Events - Hannam Vale
y = -0.5214x + 220.92
Rainfall (mm)
Year

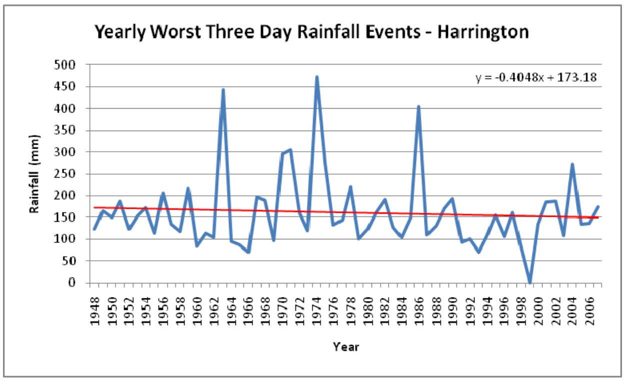


Figure 7 - Annual trends in yearly highest three day rainfall events

EXTREME HEAT EVENTS

Two stations in the coastal zone that provide temperature data of sufficient duration and completeness are selected to provide an effective analysis of extreme heat events. These stations are Newcastle (Nobby's Head) and Taree (Figure 8). A slight decreasing trend (non significant) in days per year with maximum temperature greater than or equal to 37^{o}C over the period from 1970-2007 is evident at Newcastle. An increasing linear trend is evident at Taree. This increase is statistically significant. On average, Taree records between 3 and 4 days per annum with temperatures greater than or equal to 37^{o}C. Over the period from 1970 to 2007, an increase of approximately 3.3 days in total is evident.

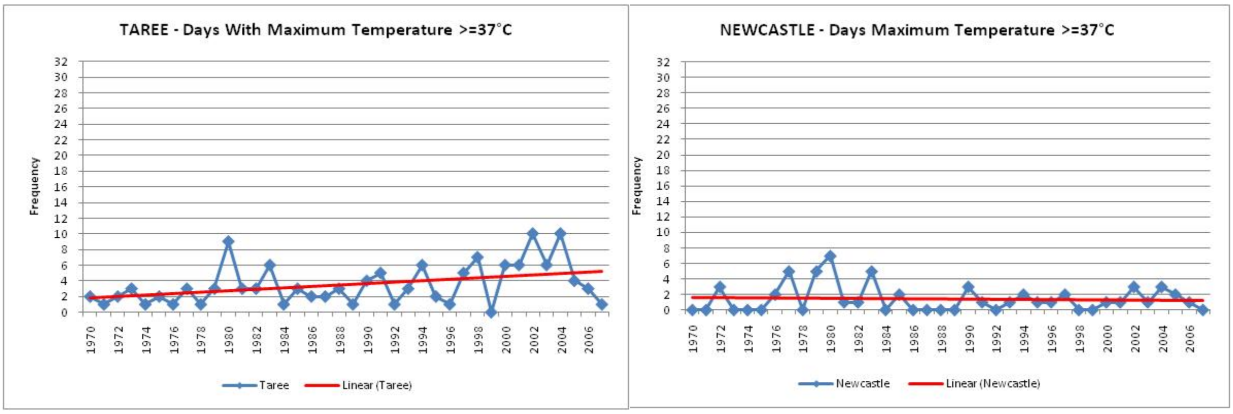


Figure 8 - Annual trend in extreme heat days at Taree and Newcastle

WIND GUSTS

Suitable (i.e. of a sufficient duration) maximum wind gust data is available from only one station in the coastal zone (Williamtown). Although wind gust station data records from Williamtown RAAF began on 1/10/1942, consistent recording of data does not commence until 1/10/1956. Historic wind gust patterns include:

- Maximum wind gusts average 44km/hr during summer from a south easterly direction
- Autumn and spring wind gusts tend southerly (average of 37.5km/hr and 45.7km/hr respectively)
- Winter winds tend south westerly with average gusts at 42km/hr

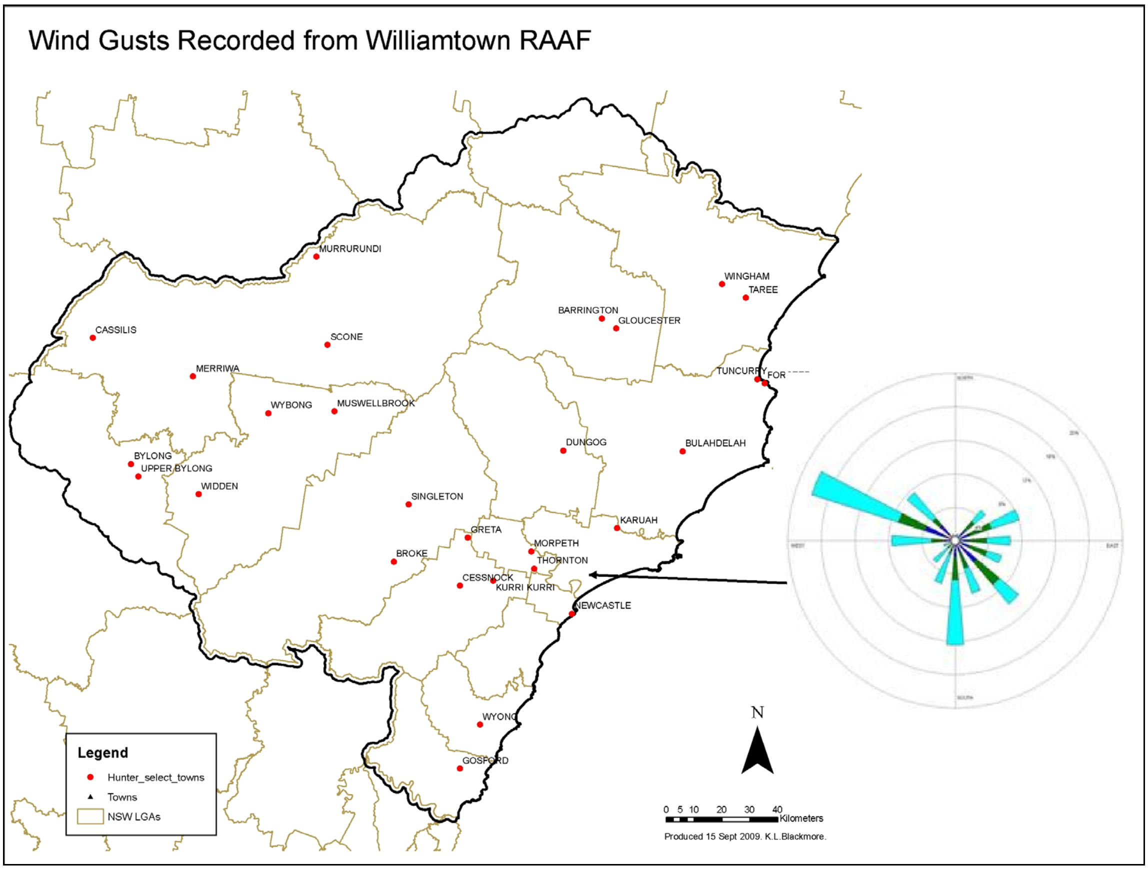


Figure 9 - Wind rose diagram of wind gusts recorded from Williamtown RAAF

The wind rose diagram in Figure 9 clearly shows the dominance of the westerly wind gusts in the coastal zone. Seasonal trends in wind gusts are shown in Figure 10 over page. All seasons show an increase in average recorded wind gusts over the period from 1957 to 2007. This increase is most pronounced during summer and only the increase in summer was found to be statistically significant ($P<0.05$).

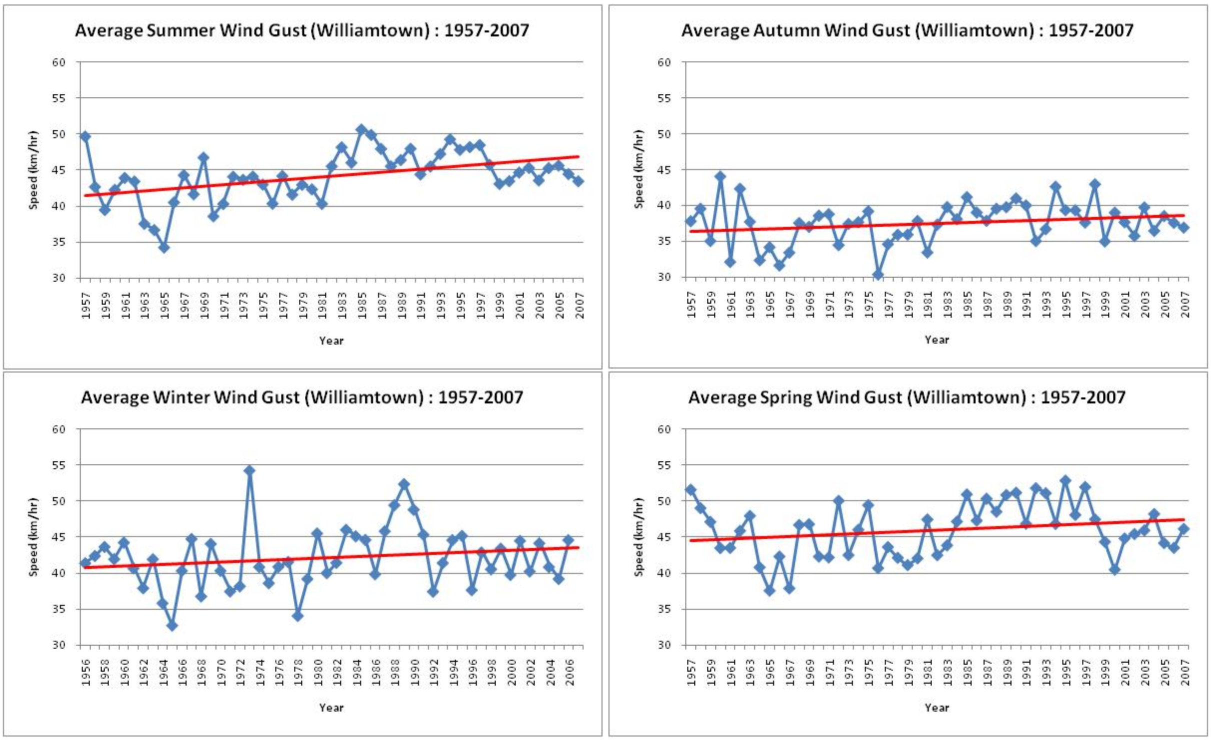


Figure 10 - Seasonal trends in average wind gusts (Williamtown) : 1957-2007

Maximum daily wind gusts of 65km/hr or greater are considered potentially damaging (Martin & Konrad 2006). These wind events occur most frequently during winter and spring from predominantly west and south westerly directions. Despite no significant annual trend in the frequency of high wind gust events (Figure 11), a statistically significant decrease in autumn is evident (Figure 12 over page).

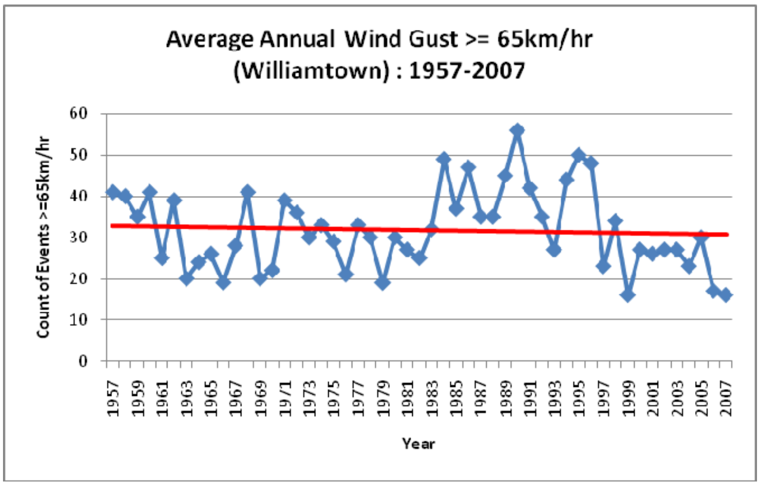


Figure 11 - Average annual wind gusts >= 65km/hr

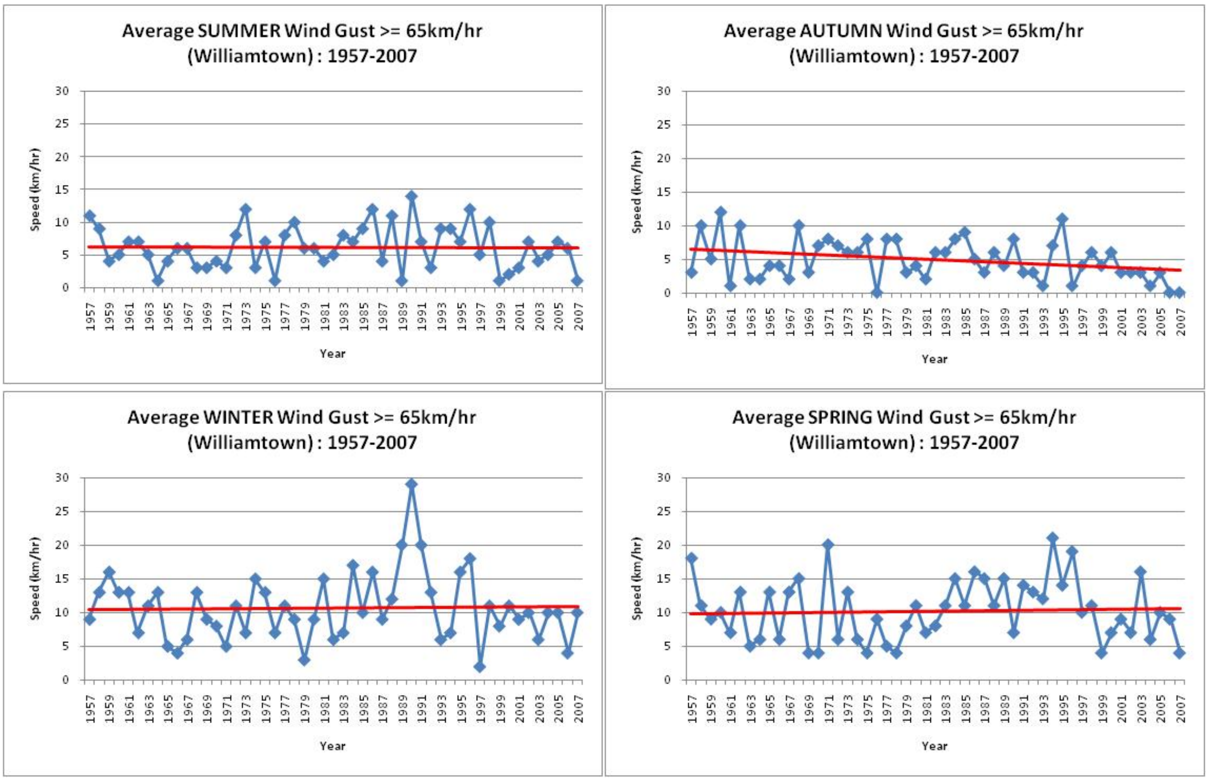


Figure 12 - Seasonal graphs of average wind gusts >=65km/hr

STORM FREQUENCY AND WAVE CLIMATE

The Central, Hunter and Lower North Coasts of NSW receive storm wave energy from both tropical cyclones and from intense low pressure systems (known as East Coast Lows) over the southern Coral Sea and northern Tasman Sea. Significant wave heights at Sydney that are associated with East Coast Lows or Southern Secondary Lows can be in excess of 7 metres. These significant wave heights and the ensuing storm wave erosion are more frequent during the La Niña phases of the El Nino Southern Oscillation and Interdecadal Pacific Oscillation. The greatest number of significant storm events over the past century occurred during the Interdecadal Pacific Oscillation La Niña-like phase between 1950 and 1976.

Storm surge during Newcastle June 2007 storm event.

No significant trends in the frequency of maritime East Coast Lows have been found since 1970. However, a statistically significant increase in inland trough lows since 1980 has been identified (Speer, et al. 2009).

SEA LEVEL RISE AND EXTREME SEA LEVELS

Relative sea level has risen by 0.1 to 0.15 m along the east coast of Australia over the past 150 years (Church et al., 2004). The trend in sea level rise is also impacted on by the observed interannual fluctuations of between ± 0.05 to ±0.075m due to both the El Nino-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) phenomena (Goodwin, in prep). High sea level anomalies occur during La Niña whereas low sea level anomalies occur during El Niño climate phases. Hence, mean annual sea level along the Hunter, Central and Lower North Coast of NSW can vary by as much as 0.150 m between years, even if long term changes in sea level are not taken into account. The annual mean sea level time series from Newcastle Harbour is shown below for the period from 1966 to 2006 (Figure 13), and shows a sea level rise of 1.15 mm/year.

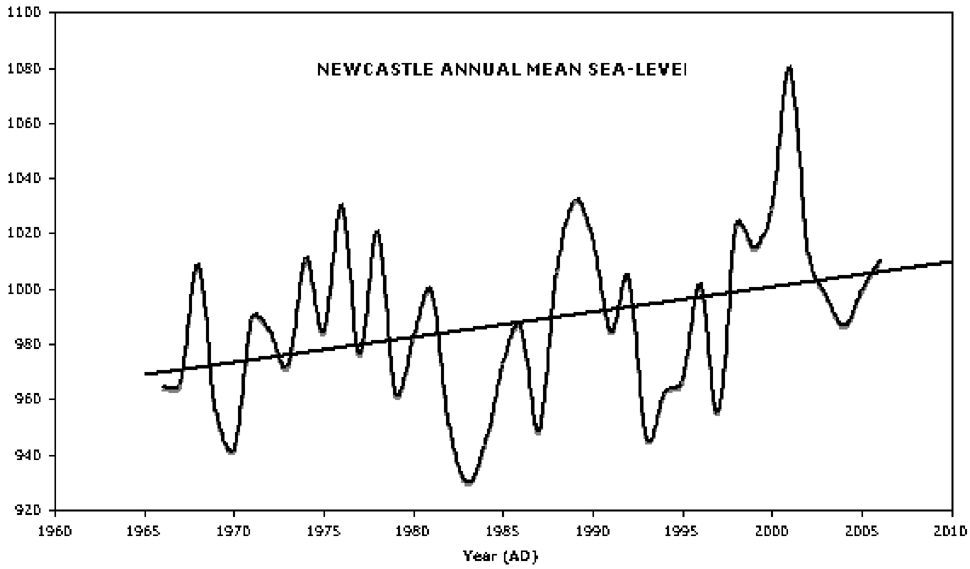


Figure 13 - Annual mean sea level recorded at Newcastle.

PROJECTED CHANGES IN CLIMATE

EXTREME RAINFALL EVENT PROJECTIONS

An analysis of projected changes in the occurrence of synoptic types associated with extreme rainfall events has identified a likely increase in the frequency of these events in the coastal zone. All of the twelve synoptic types (ST's) identified as driving climate variability in the region are associated with differing proportions of one day and 3 day two-year average return interval (ARI) rainfall events (Figure 14). Of the twelve synoptic types, STs 1, 3 and 12 have the highest association with high rainfall events. Of these, the high correspondence between high rainfall events in Newcastle and ST1 and events in The Entrance and ST3 are particularly notable. Thus within the coastal zone, significant differences between individual locations and the relationship between synoptic types and extreme rainfall events is evident.

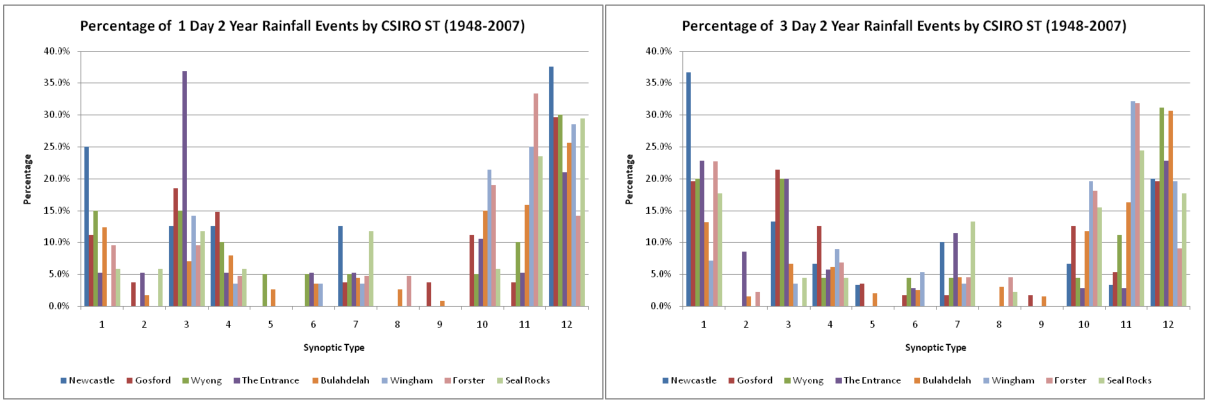


Figure 14 - Percentage of 1 day and 3 day 2 year rainfall events by CSIRO ST from 1948 to 2007.

Seasonal differences in the frequency of synoptic types for projected time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080) relative to 1968-1996 are shown in Figure 15 over page. The 1968-1996 time period is used as a standard Global Climate Model calibration period as it covers two known Interdecadal Pacific Oscillation cycles. Projected changes in regard to extreme rainfall events include:

- An increase in the frequency of occurrence of high rainfall events in summer due to projected increases in STs 10 and 12
- A decrease in events during autumn due to a strong decrease (~20%) in ST10 during this season
- Little change during winter due to projected increases in ST1 being offset by decreases in STs 2 and 3 However in Newcastle, the strong relationship between ST1 and high rainfall events is likely to result in an increased frequency of these events during winter
- A slight increase during spring due to overall increases in STs 1 and 3 during this season

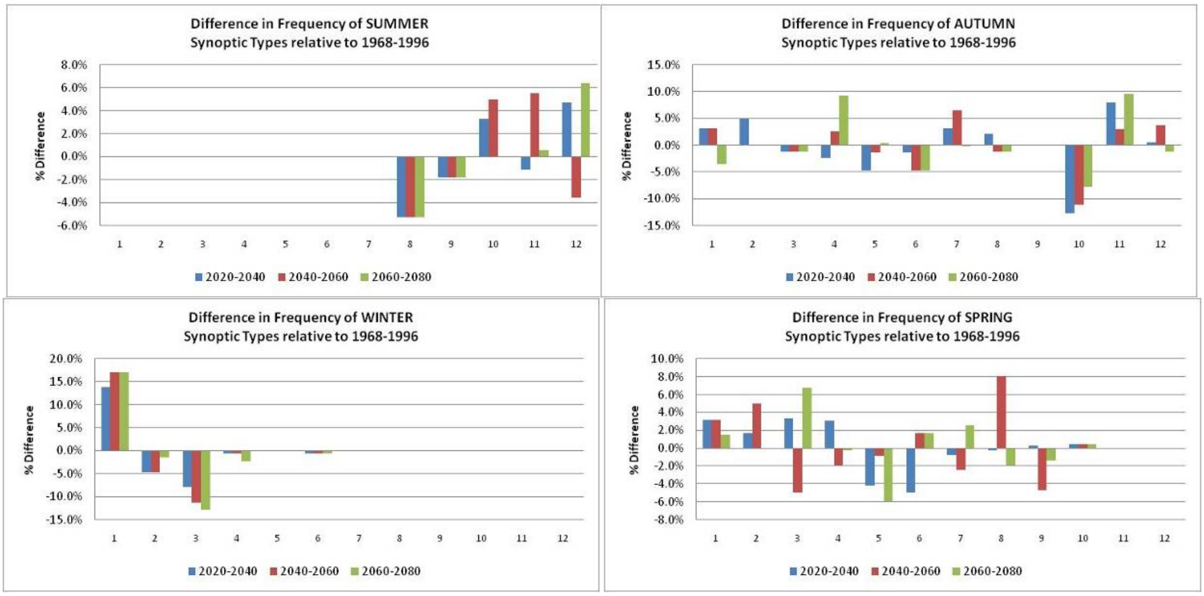


Figure 15 - Seasonal differences in the frequency of STs for projected time horizons (2020-2040, 2040-2060 and 2060-2080) relative to the frequency which ocurred during 1968-1996

MAXIMUM TEMPERATURE (EXTREME HEAT DAYS)

A clear relationship between ST12 and extreme heat days (EHDs) exists for both stations (Figure 16). This relationship is strongest in the far north of the region (Taree) where ~58% of all extreme heat days (daily temperature greater than or equal to 37^{o}C) occur when ST12 is the dominant monthly type. Projected increases in this ST during summer and autumn are likely to result in increased frequency of extreme heat days in the region during the period from 2020-2080.

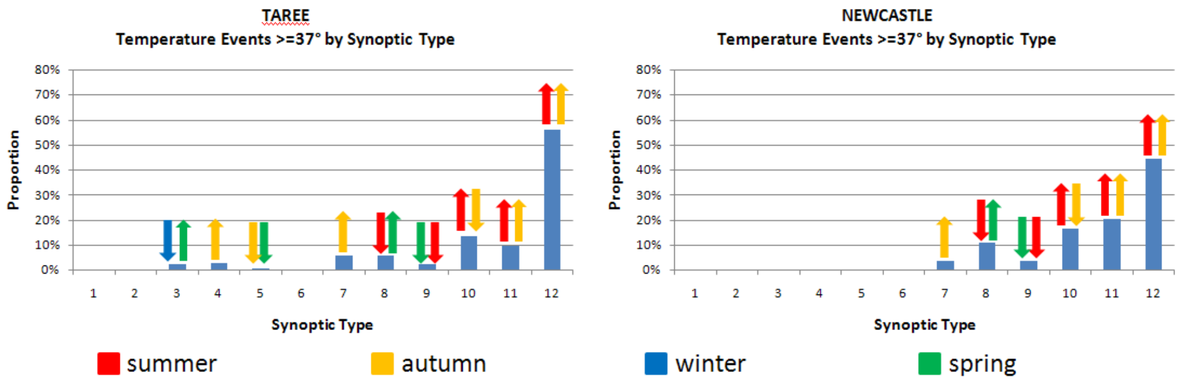


Figure 16 - Frequency of temperature events >=37^{o}C by ST (2020-2080) for selected stations with arrows indicating seasonal shifts

WIND GUST PROJECTIONS

Wind gust rose diagrams for Williamtown associated with each of the CSIRO STs are shown in Figure 17. Projected changes in wind gusts have been derived from analysing the change in frequency of each of the identified twelve (12) synoptic types (STs) that drive climate variability in the region.

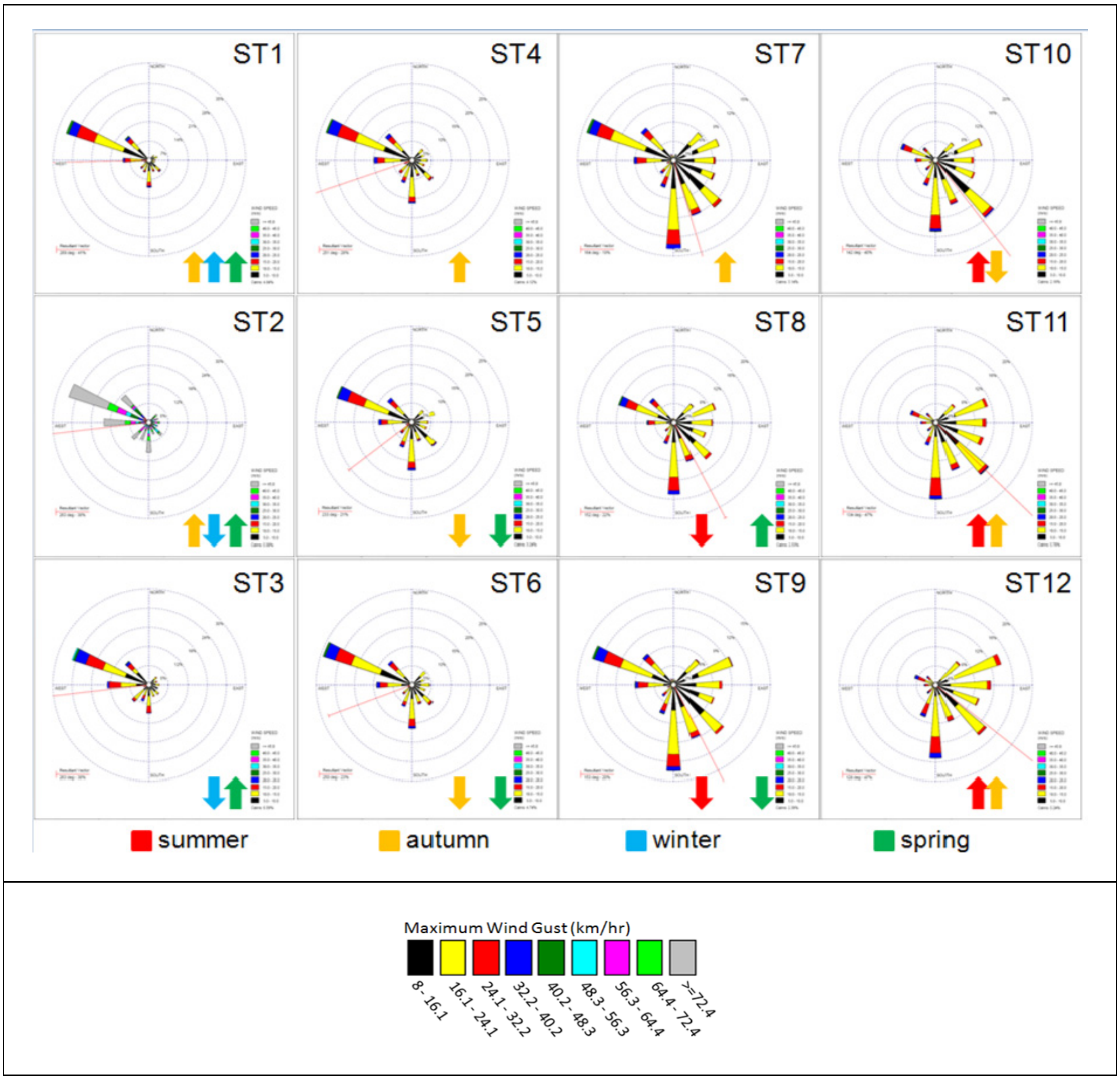


Figure 17 - Regional maximum wind gust patterns for CSIRO STs and projected seasonal shifts for the period from 2020-2080 relative to historic period from 1968-1996.

Projected changes include:

- Decreased intensity of wind gusts during winter due to projected decreases in the frequency of STs 2 and 3 during this season
- Increases in the frequency of on shore wind gusts during summer and autumn due to projected increases in STs 11 and 12 during these seasons. There is no indication from the synoptic type patterns that the intensity of summer wind gusts will change

- Increases in the intensity and frequency of north-westerly wind gusts during spring due to projected inxreases in STs 1, 2 and 3 during this season

Further details on projected changes in wind gust relative to each synoptic type are summarised in Table 6.

ST	Dominant Wind Direction	Change Projected
1	North-Westerly	Increase in autumn, winter and spring
2	North-Westerly	Increase in autumn and spring, decrease in winter
3	North-Westerly	Decrease in winter, increase in spring
4	North-Westerly, Southerly	Increase in autumn
5	North-Westerly, Southerly	Decrease in autumn and spring
6	North-Westerly, Southerly	Decrease in autumn and spring
7	Southerly, North-Westerly	Increase in autumn
8	Southerly, North-Westerly	Decrease in summer, increase in spring
9	Southerly, North-Westerly	Decrease in summer and spring
10	Southerly, South-Easterly	Increase in summer, decrease in autumn
11	Southerly, South-Easterly, Easterly	Increase in summer and autumn
12	Southerly, North-Easterly, South-Easterly	Increase in summer and autumn

Table 6 - Summary of projected wind gust changes for each synoptic type

STORM FREQUENCY AND WAVE CLIMATE PROJECTIONS

The frequency of extreme sea level events due to storm surges, and high waves during storm events, is an important consideration for coastal management. The storm systems that produce these elevated sea levels include East Coast Lows (ECL's), cut-off lows and southward moving tropical cyclones. Extreme East Coast Lows are particularly relevent to the region due to their influence on extreme storm events. Extreme East Coast Lows preferentially develop within ST1.

Analysis of the projected changes in the frequency of Synoptic Types (ST's) from the CSIRO Mk3.5 Global Climate Model indicates a 4% increase (relative to 1968 to 1996) in ST1 during autumn and winter. Extreme East Coast Lows preferentially develop within ST1. Accordingly there is a higher probability of East Coast Low formation over the future decades. Unfortunately the current generation of Global Climate Models are not sophisticated enough to provide information on the probability of changes in the magnitude nor frequency of these extreme maritime storms (CSIRO, 2007). Hence, it can only be concluded that the increase in the monthly frequency of ST1 will be accompanied by an increase in the frequency of extreme maritime storm events along the NSW coast.

The latitudinal difference in extreme water levels also has an important effect on the spatial variability of coastal response on decadal timescales, and is coupled to wave direction changes (e.g. storm waves with an east mean wave direction are coupled to frequent extreme high water levels). Greater discussion on latitudinal differences in sea level is included in the following section.

An overall summary of wave climate projections (trends) derived from the downscaling process, relative to the 1948-2007 period, are outlined in the following table (Table 7). These identified trends are not statistically significant.

Season	***Projected change in wave climate***
Summer	Wave climate is projected to experience a slight increase in significant wave height to 2030-2040, followed by a decrease, coupled with no trend in mean wave direction
Autumn	Wave climate is projected to experience a slight decrease in wave height, coupled with no trend in mean wave direction
Winter	Wave climate is projected to experience a decrease in significant wave height, coupled with no trend in mean wave direction
Spring	Wave climate is projected to experience no clear trend

Table 7 - Summary of projected changes in wave climate

SEA LEVEL RISE AND EXTREME SEA LEVEL PROJECTIONS

Sea level rise is a global process and the Hunter, Central and Lower North coast regions of NSW can expect to typically experience rates of sea level rise as identified by the IPCC (2007a). The adopted sea level rise estimates by the NSW Government (Draft Sea Level Rise Policy, 2008) are +0.4 m and +0.9 m above the 1990 sea level by 2050 and 2100 AD respectively. Hence, we adopt these values in this study and have ***not calculated sea level rise estimates from the Global Climate Model output***.

Extreme sea levels can cause direct inundation of foreshore areas and considerably exacerbate local flooding – Belmont foreshore, Lake Maqcuarie, June 2007.

However, it is important to recognise that the regional impacts of sea level rise depend upon the relative movement of the land to the ocean, caused by sedimentation, land subsidence, tectonism and millennial scale geodynamics (Goodwin, 2003). The latter has and will cause a small, ongoing, relative sea level lowering along the NSW coast of ~0.5 mm/yr which reduces the relative sea level rise along the region's coastline, by this amount. In addition, spatial variability in mean sea level rise (MSLR) exists across the latitudinal extent of the south-east Australian coast. In this regard, Church et al. (2004) indicate that maximum rates of sea level rise in Australia in excess of 2 mm per year are observed between Sydney and Brisbane, and rates of between 1 and 1.5 mm per year along the southern NSW coast.

McInnes et al. (2007) also examined projections of the relative mean sea level rise along the NSW coast due to thermal expansion in two CSIRO global climate models. In both models the mean sea level rise along the NSW coast due to thermal expansion (and uncorrected for land motion) was greater than the global average values, and indicated considerable spatial variability due to the warming of sea surface temperatures in this region and the strengthening of the East Australian Current. The projected sea level rise estimate of IPCC (2007) differed by up to 4 cm from present to 2030 (approx 1 mm per year) between Batemans Bay and Wooli Wooli on the NSW coast. With respect to coastal behaviour however, this differential in mean sea level rise rates is probably insignificant on multi-decadal time scales.

Based on all of this work it can be concluded that mean sea level rise will be greater in the Hunter, Central and Lower North Coast region than global Intergovernmental Panel on Climate Change (IPCC) forecasts but slightly less than NSW state government policy levels that are based on IPCC projections and CSIRO analysis. However given interdecadal time scales this variation is not considered significant from a planning perspective.

Lastly, extreme sea levels are produced by storm systems such as East Coast Lows. Thus changes in the frequency of occurrence of these storm systems in the region will impact on extreme sea levels. A projected 4% increase in the synoptic type under which East Coast Lows form is likely to see more of these systems forming in the region over future decades and as such, the incidence of extreme sea levels is projected to increase.

SUMMARY OF PROJECTED CHANGES IN EXTREME CLIMATE EVENTS IN THE REGION

Changes in key climate variables associated with extreme weather events are projected for the period from 2020-2080 AD (Table 8). As can be seen from the table, the most significant changes in these variables overall are projected to occur during autumn and spring, with some possible localised impacts during winter in the Newcastle area. Extreme rainfall events are also projected to increase during summer. Storm frequency (i.e. East Coast Lows) are projected to increase during autumn and winter with an associated increase in extreme sea levels. Adjusted sea level rise figures for 2050 and 2100 AD are also provided that reflect regional characteristics.

Climate Variable	Change
Extreme Rainfall Events	• Increased frequency during summer • Decreased frequency during autumn • No change for winter (except for a slight increase in frequency in Newcastle) • Slight increase in frequency during spring
Extreme Heat Events	Increases projected during summer and autumn
Wind gusts	• Decreased intensity of wind gusts during winter • Increase in the intensity of north westerly wind gusts during spring • Increased frequency of onshore wind gusts during summer and autumn. No indication that the intensity of summer wind gust will change.
Storm Frequency and Wave Climate	• Increased frequency of East Coast Lows (~4%) during autumn and winter (relative to 1968-1996) • Slight increase in wave height for summer to 2030 followed by a decrease • Slight decrease in wave height during autumn • Decrease in significant wave height during winter • No projected changes in mean wave direction
Sea Level rise and Extreme Sea Level	• Sea level rise increase of 0.4m by 2050 and 0.9m by 2100 (Draft Sea Level Rise Policy, 2008) adjusted to +0.37m and +0.845m due to regional impacts. • Increased incidence of extreme sea levels (as a result of ~4% increase in East Coast Low formation) during autumn and winter.

Table 8 - Summary of projected climate changes

RISK ASSESSMENT PROCESS AND OUTCOMES

In addition to providing an analysis of historic and projected climate change as it relates to extreme climate events in the coastal zone of the Hunter, Central and Lower North Coast region of NSW, this Case Study applies this analysis to a risk assessment and adaptation planning process. This involved a broad scale sub regional risk assessment process being completed collaboratively by a working group comprising representatives of the NSW Department of Environment, Climate Change & Water, local government and HCCREMS staff.

The Risk Assessment Framework used as the basis for this process is shown in Figure 18. This has been sourced from `Australian Greenhouse Office, in the Department of the Environment and Heritage. *Climate Change Impacts and Risk Management: A Guide for Business & Government. Commonwealth of Australia 2006'*. A summary of the Extreme and High rated risks identified through this process and the potential adaptation strategies identified for these risks is shown in Table 9 over page. The complete risk analysis matrix identifying the specific climate data that informed the risk assessment process, the total range of potential risks identified and their ratings are also included in Appendix 1. The identified risk ratings have been determined directly from the likelihood and consequence scales agreed to for each risk by the working group. Guidelines for the determination of likelihood and consequence scales are included in Appendix 2.

	Consequences				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	Medium
Rare	Low	Low	Low	Low	Medium

The interpretation of the risk priority levels included in Figure 20 is usually as follows:

- **Extreme** risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations without executive sanction.
- **High** risks are the most severe that can be accepted as a part of routine operations without executive sanction, but they will be the responsibility of the most senior operational management levels, and be reported upon at the executive level.
- **Medium** risks can be expected to form part of routine operations but they will be explicitly assigned to relevant managers for action, maintained under review, and reported upon at senior management level.
- **Low** risks will be maintained under review but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe.

Figure 18 - Risk Assessment Matrix (source: Australian Greenhouse Office. *Climate Change Impacts and Risk Management: A Guide for Business & Government.* Commonwealth of Australia 2006).

In regard to the complete list of risks identified and ranked for the purposes of the Case Study, it is important to note that, given the sub regional scale of the risk assessment, a number of these risks have rated only medium or below. This reflects the fact that while many of these risks may be of considerable concern to local communities, when viewed at a sub regional rather than local scale, and given the fact that many extreme weather events are very localised in their nature, the relative consequences of these risks are less at the broader scale.

For example, while at a local level, extreme storm and rainfall events and associated flash flooding may cause significant damage and stress, their local impacts are not felt widely throughout the region. In contrast, extreme heat events tend to be much more widespread, substantially increasing the potential impacts and level of risk because of their greater spatial extent and associated community exposure.

The relative rankings also reflect the fact that many of the risks are already known to be occurring within the coastal zone. As a result, it is anticipated that rather than changes in extreme climate events creating whole new sets of risks, they will exacerbate existing ones. Because many of these risks already have management controls in place, further refining these controls will effectively address projected change.

It is also important to note that the risk assessment process has been based on the analysis of historic and projected trends for individual climate parameters. It does not specifically explore the potential for the coincident occurrence of more than one climate variable. This reflects the fact that no climate projections are available in relation to coincident events of this nature. However, it is recognised that extreme climate events are often characterised by this feature (eg. extreme sea level combined with intense rainfall) and that where this occurs the consequences of an extreme event can be significantly worsened.

Table 9 - Summary of projected climate changes
EXTREME HEAT EVENTS
Risk 1 Public health issues (heat related morbidity and mortality) [1] Risk rating – Extreme
Key Stakeholders: Councils, NSW Department of Health, Hunter New England Health Service, Northern Sydney – Central Coast Health Service, State Emergency Service (SES)
Potential Adaptation Responses *Research & Information* • Develop improved regional economic and social indicators and datasets, disaggregated to at least the municipal level and compile datasets on regional housing stock, age and quality • Undertake research to identify community risk perceptions and behaviour during extreme heat events. This information will inform strategies for increasing community preparedness, particulary of vulnerable groups • Complete a spatially-explicit risk assessment of the vulnerability of human health to climate change that accounts for spatial variability in climate conditions at the local scale, regional projections of future climate, the distribution of sensitive subpopulations and housing/building stock and its thermal efficiency

Planning

- Development and implementation of Heat Management Plans. Plans of this nature are appropriate at a number of scales including state, regional, and local government levels as well as individual event (eg. concerts or festivals) and personal health care levels. Heat Management Plans should incorporate:
  - Agreement on lead agency and participating organisations
  - A consistent, standardised warning system
  - Public education, communication and involvement (particularly during Spring and immediately prior / during extreme heat events (Mella et al, 2008))
  - Targeting high risk assets, regions, communities and individuals
  - Evaluation and revision of program
  - Monitoring of climate & health trends and making adaptations
- Improved interventions to increase coverage and support for socially isolated older people in the community. This could include changes to social services delivery or implementing neighbourhood programs that promote a culture of `looking out' for your neighbour, older friend or family member during a heatwave (Mella et al, 2008)
- Develop building design guidelines / retrofit strategies for at-risk locations and community facilities to reduce impacts of extreme heat events on public health
- Improved greening of the built environment – trees, plants and green spaces act as natural air conditioners & provide shade (Mella et al, 2008)

Emergency Management & Response

- Integration of Extreme Heat Events into agency and organisational Disaster Management Plans. A heatwave meets the first part of the definition of an emergency by Emergency Management Australia – ie *an emergency is an event, actual or imminent, which endangers or threatens to endanger life, property or the environment, and which requires a significant coordinated response as appropriate* (Mella et al, 2008)
- Increase emergency preparedness and resourcing during heat wave conditions (eg police and ambulance services and hospital emergency departments)

Community Education

- Deliver coordinated campaigns across the region to improve community awareness of appropriate strategies for reducing exposure to extreme heat, particularly in vulnerable groups and locations

Risk 2

Increased demand on power supplies and possible loss of power

Risk rating – Extreme

Key Stakeholders

Energy Australia, Country Energy, Transgrid, Councils, Department of Planning, State Emergency Service (SES)

Emergency Response & Recovery

- Electricity providers to increase emergency preparedness during heat wave conditions to ensure continuity of power supplies. This should include:
  - Electricity providers should develop and implement a business continuity plan consistent with Australian Standards and best practice on business continuity management. The plan would aim to

provide procedures to ensure continuity of electricity supply during extreme heat events.

  - participation in emergency preparation / modeling exercises for extreme heat events conducted across multiple agencies & zones. This will improve the preparedness and capacity of these organisations to maintain supply of services during extreme heat events.

- Encourage independent power supplies in households to reduce reliance on centralised power supplies

BUSHFIRE

Risk 1

Increase in northwesterly wind gusts during spring and on-shore wind gusts during summer increasing fire risk during these seasons[2]

Risk rating – Extreme

Key Stakeholders:

Councils, Rural Fire Service, NSW Fire Brigades, Department of Environment, Climate Change & Water (DECCW), Land & Property Management Authority (LPMA)

Potential Adaptation Responses

Research & Information

- Undertake scenario planning to identify exposed assets

Planning

- Enhance focus on strategic provision / location / rationalization of fire trails / containment lines to enhance capacity / ability for fire control in exposed areas
- Increase level of resources allocated to monitoring of fuel levels in exposed areas
- Review bushfire planning regulations and policy for construction standards for new buildings (at bushland interface and beyond) in exposed fire prone areas to ensure adequate fire preparedness, particularly protection from ember attack. This should include a an evaluation of the existing and potential range of planning tools, building codes and approaches (nationally & internationally) for managing current and future development in bushfire affected areas
- Examine possibilities for retrofitting existing building stock in exposed areas to improve fire resistance, particularly from ember attack
- Explore the opportunity for developing individual property planning programs in exposed areas. Such programs would aim to engage property owners and provide them with information to assist in preparing their properties for fire

Emergency Response & Recovery

- Conduct emergency preparation / modeling exercises targeting exposed areas. Cross organisational exercises of this nature will evaluate and refine the effectiveness of fire planning and response procedures in these areas
- Identify key traffic routes likely to be affected by bushfire events in exposed areas, identify alternative emergency evacuation routes and update local and regional traffic plans to encompass alternatives
- Critically analyse (across organisations, agencies and zones) the effectiveness of emergency response and recovery operations following extreme fire events. This will foster continual improvement of emergency response procedures
- Encourage independent power and water supplies in exposed bushfire prone areas to improve fire

fighting capacity and reduce reliance on centralised power and water supplies

FLOODING

Risk 1

More widespread / extensive catchment[3] and flash flooding[4] of property and environment caused by extreme rainfall events, sea level rise and extreme sea levels

Risk rating – High

Key Stakeholders

Councils, Department of Environment, Climate Change & Water (DECCW), NSW Department of Planning (DoP), State Emergency Service (SES), Hunter-Central Rivers Catchment Management Authority (HCRCMA)

Potential Adaptation Responses

Research & Information

- Undertake modelling of changes to extreme rainfall intensities and durations to inform sensitivity analysis processes for identifying regionally significant `at risk' areas. Modelling should aim to include rainfall events of less than 1 day duration to better inform risk assessment and planning in relation to flash flooding events
- Fill gaps in high resolution integrated elevation/bathymetry data sets for use in hydrological and coastal flood modelling
- Use the results of the above modelling exercise to update and integrate site-specific hydrological/flood modelling of regional priority areas, or, where there is limited knowledge and the perceived risk is high
- Undertake modelling of the risks to coastal areas from concurrent storm surge and extreme rainfall events in regional priority areas, as the joint effects of such events are likely greater than suggested by assessments that treat each in isolation
- Integrate revised AR&R (Australian Rainfall & Runoff) forecasts (currently in preparation) into flood / stormwater management planning and management processes
- Evaluate the existing and potential range of planning tools, building codes and approaches (nationally & internationally) for managing current and future development in vulnerable flood affected areas
- Complete legal review of liability to local government arising from climate change in relation to coastal planning and flooding processes, and of the implications of pursuing the potential adaptation options identified above
- Research & develop consistent criteria / process for identifying condition and vulnerability of flood and stormwater management assets / measures to climate change impacts (eg SLR & intense rainfall)
- Research and provide recommendations for the development of new design standards to account for changed climate / sea level rise parameters when constructing or upgrading flood and stormwater management infrastructure
- Ensure that the above research & information relating to flood plain risk management is consistent with the requirements of the NSW Government Floodplain Development Manual (2005)

Planning

- Develop guidelines for integrating climate change projections into new and existing flood management models, flood maps and management plans, consistent with the Manual and other related NSW Government guidelines / requirements. This will facilitate a consistent approach by councils to the preparation and publication of these resources

- Develop protocols and a decision making framework to provide a consistent & transparent approach to land use planning in flood affected areas (based on the outputs of research and the legal review identified above). This would provide councils, agencies and the community with greater certainty when making difficult decisions regarding whether to permit development in potentially affected areas, both through long term strategic processes (eg Local Environment Plans and / or Development Control Plans) or through every day development application processes
- Develop planning tools in the form of guidelines, model planning provisions, practice notes & development consent conditions for consistent application by councils. This will provide increased certainty for councils when dealing with development and flooding issues in coastal areas

Infrastructure & Services

- Develop decision making frameworks / guidelines (including case studies) to assist asset managers incorporate adaptation requirements when designing and constructing new, or when upgrading or maintaining flood and stormwater management infrastructure. These would include elements such as calculating impacts of climate change on asset lifespan and options for adapting assets gradually over time versus total replacement
- Develop regionally consistent Condition Assessment Tools for natural and built flood and stormwater management infrastructure. This will ensure a consistent approach by all councils to the ongoing assessment of condition and performance of such infrastructure in the context of their ability to meet changing climate conditions
- Develop and integrate Integrated Water Cycle Management (IWCM) / Waster Sensitive Urban Design (WSUD) technical standards and planning tools into council urban planning and infrastructure design mechanisms as a means of improving the management of flash flood events. This will particularly assist with reducing runoff levels during intense rainfall events

Emergency Response & Recovery

- Conduct emergency preparation / modeling exercises for multiple scenarios / events across multiple agencies & across zones to test effectiveness of emergency response plans and procedures. This will improve preparedness and efficiency of councils, agencies and emergency management authorities when responding to extreme flooding events
- Identify key traffic routes likely to be affected by extreme flooding events, identify alternative emergency routes and update local and regional traffic plans to encompass alternatives
- Critically analyse (across organisations, agencies and zones) the effectiveness of emergency response and recovery operations following each extreme flooding event. This will foster continual improvement of emergency response procedures

Education and Capacity Building

- Deliver a professional capacity building program for council senior management and planning staff and elected Councillors on implications of coastal flooding & planning issues associated with climate change, including recommended approaches for managing these
- Establish a regional professional forum to facilitate networking and the ongoing exchange and evaluation of information and strategies for improving flood planning and management, particularly in the context of climate change
- Prepare a range of community focused information resources that build community awareness and resilience to the hazards and risks associated with flood events, and to build their capacity to effectively plan and manage such events at community and individual levels

- Implement a region wide professional capacity building program on IWCM and WSUD approaches for managing stormwater and flash flooding. Its focus would include the contribution of these approaches to better managing projected changes in rainfall intensity and duration and how to design / upgrade new & existing stormwater systems, networks & catchments to encompass IWCM / WSUD principles in the context of climate change

FORESHORE EROSION AND HABITAT

Risk 1

Increased coastal erosion in vulnerable areas arising from extreme storm events, sea level rise and extreme sea levels

Risk rating – High

Key Stakeholders:

Councils, Department of Environment, Climate Change & Water (DECCW), Land & Property Management Authority (LPMA), Hunter- Central Rivers Catchment Management Authority (HCRCMA)

Potential Adaptation Responses

Research & Information

- Prepare Smartline Mapping for all estuarine foreshores in the region to improve understanding of the vulnerability of estuarine foreshores to erosion
- Model changes to extreme rainfall intensities and durations to inform sensitivity analysis processes for identifying `at risk' areas
- Complete site-specific modelling of coastal and estuarine erosion (for highly vulnerable areas) based upon coastal geomorphology, sea level rise and storm events
- Evaluate existing and potential range of planning tools and other approaches (nationally & internationally) for managing current and future development in vulnerable foreshore locations
- Complete legal review of liability to local government arising from climate change in relation to coastal erosion processes, and of the implications of pursuing the potential planning tools and measures identified above
- Identify potential sources of sand supply to support beach nourishment activities in the region aimed at combating anticipated increases in beach erosion

Planning

- Develop guidelines for integrating climate change projections into new and existing coastal hazard models, flood maps and management plans. This will facilitate a consistent approach by councils to the preparation and publication of these resources
- Develop protocols and a decision making framework for councils to provide a consistent & transparent approach to land use planning in areas vulnerable to coastal erosion. This would provide councils, agencies and the community with greater certainty when making difficult decisions regarding whether to permit development in potentially affected areas, both through long term strategic processes (eg LEP’s) or through every day development application processes
- Develop planning tools in the form of guidelines, model planning provisions, practice notes & development consent conditions for consistent application by councils. This will provide increased certainty for councils when planning & assessing development in vulnerable coastal areas

Infrastructure & Services

- Develop decision making frameworks / guidelines (including case studies) to assist asset managers incorporate adaptation requirements when designing and constructing new, or when upgrading or maintaining coastal infrastructure and assets. These would include elements such as calculating impacts of climate change on asset lifespan and options for adapting assets gradually over time versus total replacement
- Develop regionally consistent Condition Assessment Tools for coastal infrastructure and assets. This will ensure a consistent approach to the ongoing assessment of the condition and performance of such infrastructure in the context of their ability to meet changing climate conditions

Community Education

- Prepare and deliver a range of community focused information resources that build community awareness of basic coastal erosion processes and factors contributing to these

Risk 2

Potential change in marine and estuarine habitat distribution in the littoral zone arising from sea level rise and extreme storm events

Risk rating – High

Key Stakeholders:

Councils, Department of Environment, Climate Change & Water (DECCW), Land & Property Management Authority (LPMA), Hunter Central Rivers Catchment Management Authority (HCRCMA), NSW Industry & Investment (I&I)

Potential Adaptation Responses

Research & Information

- Research and prepare high resolution maps of littoral habitat types across the coastal zone
- Develop landscape elevation and ecosystem models to identify habitat responses (eg wetlands, sea grasses, mangroves & rock platforms) to sea level rise to identify vulnerable habitat areas, to predict habitat shifts and to identify potential opportunities for retreat
- Complete modelling of estuarine hydrology and sediment movement to identify levels and patterns of sediment build up and distribution within estuaries
- Prepare Smartline Mapping for all estuarine foreshores in the region to improve understanding of the vulnerability of littoral habitat to erosion

Planning & Implementation

- Identify and implement management strategies for identified vulnerable habitats to facilitate their long term conservation. Responses may include:
    - updating council land use planning mechanisms (eg LEP's / DCP's) to ensure opportunities for retreat of littoral habitat
    - establishment and active management of marine protected areas and conservation reserves
    - targeted on ground rehabilitation works to improve ecosystem quality and resilience

PUBLIC SAFETY
Risk 1 Increase in public injury / safety (eg drowning - small boaters) during extreme storm events Risk Rating – High
Key Stakeholders: NSW Industry & Investment (I&I), NSW Maritime, Councils, Land & Property Management Authority (LPMA), Recreational boating and fishing associations
Potential Adaptation Responses *Research & Information* • Undertake research to improve the quality and accuracy of extreme storm event forecasting, including lengthening the available warning period • Undertake research and document ocean processes to enhance the effectiveness of emergency response and recovery operations (eg improved understanding of tidal processes to prioritise locations for search and rescue operations) *Capacity Building and Education* • Enhance the level and focus of extreme storm warnings for at-risk audiences (eg rock fishers and boaters) at appropriate locations (eg popular rock fishing areas and marinas, wharves and jetties) • Deliver targeted education and training programs tailored to the needs and demographics of at risk audiences. These programs should aim to raise awareness of the risks associated with extreme storm events to reduce the likelihood of exposure, as well as improve the capacity of participants to survive emergencies should they occur (eg through having appropriate emergency and communication equipment) *Emergency Response & Recovery* • Conduct emergency preparation / modeling / response exercises targeting public injury and loss during extreme storm event scenarios

[1] A Case Study exploring the impacts of extreme heat events on human health in the Hunter, Central & Lower Coast region has also been prepared and should be referenced for more detailed information on the potential nature and level of risks associated with these events in the region (Blackmore K.L, Goodwin I.D & Wilson S. (2010). *CASE STUDY 2: Potential Impacts of Climate Change on Extreme Heat Events Affecting Public Health in the Hunter, Lower North Coast and Central Coast Region*. A report prepared for the Hunter and Central Coast Regional Environmental Management Strategy, NSW).

[2] A Case Study exploring the impacts of projected climate change on bushfire risk in the Hunter, Central & Lower Coast region has been prepared and should be referenced for more detailed information (Blackmore K.L, Goodwin I.D & Wilson S. (2010). *CASE STUDY 3: Potential Impacts of Climate Change on Bushfire Risk in the Hunter, Central and Lower North Coast region*. A report prepared for the Hunter and Central Coast Regional Environmental Management Strategy, NSW).

[3] The risks identified and assessed in relation to catchment flooding are based on the assumption that an increase in frequency of storm events during summer (ie multiple events) will contribute to a more saturated catchment and higher likelihood of flooding. While the risk assessment has been specifically completed for the coastal zone, it recognises that rainfall events in the central and western climate zones also have an impact on catchment flooding in the coastal zone. Additionally, the risk assessment for catchment flooding does not consider the likelihood of extreme dry periods. It is recognised that the impacts of extreme rainfall and catchment flooding events are generally more severe following extended periods of dry weather.

[4] Identification of the increased risk posed by flash flooding is linked to projected increases in Synoptic Types that have the highest statistical association with one and three day two year ARI events. It is recognised however, that flash flooding is generally associated with rainfall events of much shorter duration. In the absence of shorter duration data however, a precautionary approach has been taken to the risk assessment that assumes projected increases in extreme rainfall events of 1 and 3 day durations may also translate to shorter duration extreme rainfall events. Of additional note is the fact that the risk assessment for flash flooding was based on projected increases in extreme rainfall events projected to occur during the summer months across the entire coastal zone. The climate analysis also identifies that key storm and flood events associated with East Coast Lows are projected to increase locally in the Newcastle area during winter, however the risk assessment did not address this local variation.

CONCLUSION

An analysis of both historic and projected changes for a range of key climate variables considered to represent `extreme events' in the coastal climatic zone of the Hunter, Central and Lower North Coast region of NSW is provided in this case study. Historic trends identified include:

- Extreme rainfall events occur more frequently during January, February and March. In Newcastle this period extends through April & May, and peaks in June. No changes in the frequency or intensity of extreme rainfall events has been identified from the historic record
- A slight decreasing trend in the frequency of Extreme Heat Days (ie greater than or equal to 37^{o}C) is evident at Newcastle, while an increasing linear trend is evident at Taree
- All seasons show an increase in average recorded wind gusts from 1957-2007. This increase is most pronounced during summer
- No historic trends in East Coast Low (ECL) formation have been found (Speer, et al. 2009)

Projected changes in extreme events in the coastal zone (for the 2020-80 period based on the A2 global emissions scenario) include:

- Increased frequency of extreme rainfall events during summer and a slight increase during spring. A slight increase in frequency is also projected for Newcastle during winter
- Increased frequency of extreme heat events (ie greater than or equal to 37^{o}C) during summer and autumn
- Increased intensity of northwesterly wind gusts during spring, and increased frequency of on-shore wind gusts during summer and autumn
- Increased frequency of East Coast Lows during autumn and winter
- Increased incidence of extreme sea levels during autumn and winter

This historic and projected climate data has formed the basis of a sub regional scale risk assessment that has identified and ranked the potential risks arising from projected changes in the occurrence of *individual* extreme weather variables across the coastal zone. The risk assessment has not considered the potential for coincident events of extreme climate variables due to an absence of data in this area.

The key risks (i.e. rated Extreme or High) that have been identified include:

- Public health issues arising from extreme heat events
- Increases in north-west wind gusts during spring and on-shore wind gusts during summer increasing fire risk during these seasons
- Increased demand on power supplies, and possible loss of power during extreme weather events
- Exacerbation and more widespread / extensive flooding of property and environment due to extreme rainfall events and extreme storms
- Increased coastal erosion in vulnerable areas associated with extreme storm events
- Increase in public injury (eg drowning of small boaters, fishers) during extreme storm events

- Potential change in marine and estuarine habitat distribution in the littoral zone arising from sea level rise and extreme sea level events

Many of these risks are, to an extent, are already present in the region. As such, rather than creating a whole new sets of risks, it is considered that future changes in extreme events arising from climate change will exacerbate a number of existing risks for which in many cases, effective control strategies are already in place. It is recognised however, that climate change may increase the frequency and extent of these current problems.

In light of this, the refinement and further development of existing controls represents the most effective strategy for managing many of the Extreme and High rated risks that have been identified. This is reflected in many of the potential adaptation strategies included in the report. While in some areas new or improved planning is identified as an adaptation priority, many of the adaptation strategies focus on research, decision-making frameworks and community education programs to improve the effectiveness of existing control mechanisms.

Two other key principles that underpin the adaptation strategies that have been identified include:

1. The importance of future planning in avoiding the impacts of extreme climate events in the region. Given the already significant vulnerability of the coastal zone to extreme climate events, planning to avoid locating both present and future communities in susceptible areas represents a primary and cost effective strategy for reducing future risk to life and property.

2. The importance of making decisions that do not close off future adaptation options. For example the Case Study identifies the need to identify future retreat options for coastal ecosystems, however this needs to be supported by complimentary land-use and infrastructure planning processes. For example, permitting the construction of housing or infrastructure in potential retreat areas effectively closes off this retreat option and therfore should be avoided.

The potential adaptation strategies identified within the Case Study are summarised and grouped below. The complete list of adaptation responses can be found in Table 10 (page 25) of the report.

Extreme Heat Events
- More specifically identifying the nature and location of vulnerable communities
- Developing and implementing heat management plans at state, regional, local and event scales
- Community based education and intervention programs to assist vulnerable groups and individuals
- Integrating extreme heat events into agency and organisational Disaster Management Plans

Bushfires
- Undertaking scenario planning to identify vulnerable areas
- Enhancing the focus on strategic provision / location / rationalisation of fire trails / containment lines to enhance capacity / ability for fire control
- Reviewing construction standards for new buildings and examining possibilities for retrofitting existing buildings in fire prone areas
- Encouraging independent power and water supplies in bushfire prone areas to improve fire fighting capacity and reduce reliance on centralised power and water supplies

Flooding
- Improving modelling and research to understand likely future changes in flood behaviour

- Developing consistent criteria / processes for identifying the condition and vulnerability of flood and stormwater management assets / measures to climate change impacts and developing new design standards to account for changes in climate / sea level rise parameters when constructing or upgrading flood and stormwater management infrastructure
- Developing guidelines for integrating climate change projections into new and existing flood management models, flood maps and management plans
- Developing protocols, decision making frameworks and tools to provide a consistent and transparent approach to land use planning in flood affected areas in the context of climate change, and to inform the design and maintenance of flood management / stormwater infrastructure
- Developing and integrating Integrated Water Cycle Management (IWCM) / Water Sensitive Urban Design (WSUD) principles and standards into planning and infrastructure design processes as a means of improving the management of flood events

Foreshore erosion and habitat

- Preparing Smartline Mapping for all estuarine foreshores in the coastal zone to improve understanding of the vulnerability of foreshores to erosion
- Modelling changes to extreme rainfall intensities and durations to inform sensitivity analysis processes for identifying at risk areas, and completing site specific modelling of coastal and estuarine erosion (for highly vulnerable areas) based upon coastal geomorphology, sea level rise and storm events
- Developing guidelines for integrating climate change projections into new and existing coastal hazard models, flood maps and management plans
- Developing protocols, a decision making framework, and supporting tools to provide a consistent & transparent approach to land use planning in areas vulnerable to coastal erosion

Public safety during extreme storm events

- Undertaking research to improve the quality and accuracy of extreme storm event forecasting, including lengthening the available warning period
- Enhancing the level and focus of extreme storm warnings for at risk audiences (eg rock fishers and boaters) at appropriate locations (eg popular rock fishing areas and marinas, wharves and jetties)
- Delivering targeted education and training programs tailored to the needs and demographics of at risk audiences
- Conducting emergency preparation / modeling / response exercises targeting public injury and loss during extreme storm event scenarios

REFERENCES

Blackmore, K.L. & Goodwin, I.D. (2008) *Climate Variability of the Hunter, Lower North Coast and Central Coast Region of NSW*. Consultancy report by Newcastle Innovation for the Hunter and Central Coast Regional Environment Management Strategy (HCCREMs). HCCREMS. p.91.

Blackmore, K.L. & Goodwin, I.D. (2009) *Climatic Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW*. Consultancy report by Newcastle Innovation for the Hunter and Central Coast Regional Environment Management Strategy (HCCREMs). HCCREMS.

Blackmore K.L, Goodwin I.D & Wilson S. (2010). *CASE STUDY 2: Potential Impacts of Climate Change on Extreme Heat Events Affecting Public Health in the Hunter, Lower North Coast and Central Coast Region*. A report prepared for the Hunter and Central Coast Regional Environmental Management Strategy, NSW

Blackmore K.L, Goodwin I.D & Wilson S. (2010). *CASE STUDY 3: Potential Impacts of Climate Change on Bushfire Risk in the Hunter, Central and Lower North Coast region*. A report prepared for the Hunter and Central Coast Regional Environmental Management Strategy, NSW.

Church, J.A., N.J. White, R. Coleman, K. Lambeck and J.X. Mitrovica (2004), Estimates of the Regional Distribution of Sea Level Rise over the 1950 to 2000 Period. JOURNAL OF CLIMATE, 17, pp.2609-2625.

Church, J. A., and White, N.J. (2006). A 20th century acceleration in global sea level rise. *Geophysical Research Letters*, 33, L01602, doi:10.1029/2005GL024826.

CSIRO (2007). *Climate change in Australia*. Technical Report 2007. Australian Government, 148 pp.

Easterling, D.R., Evans, J.L., Groisman, P.Ya., Karl, T.R., Kunkel, K.E. & Ambenje, P. (2000). Observed variability and trends in extreme climate events: a brief review, *BAMS*, *81(3),* pp.417-425.

Goodwin, in prep.

Goodwin, I. D. (2003). Unravelling climate influences on late Holocene sea-level and coastal evolution. In Mackay, A., Battarbee, R., Birks, J. and Oldfield, F. *Global Change in the Holocene*. Edward Arnold, London., pp.406-421.

Institution of Engineers, Australia (1987). *Australian Rainfall & Runoff - A Guide to Flood Estimation*, Pilgrim, DH, (ed)., Barton, ACT.

IPCC (2007a). Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007b). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, p.976.

Martin, J. and C.E. Konrad, (2006). Directional characteristics of potentially damaging wind gusts in the Southeast United States. *Physical Geography*, 27, pp.155-169.

McInnes, K.L. , Abbs, D., O'Farrell, S., Macadam, I., O'Grady, J., Ranasinghe, R. (2007). Projected changes in climatological forcing for coastal erosion in NSW. CSIRO Marine and Atmospheric Research Report to the NSW Dept. Environment and Climate Change, 38pp.

Mella S., Madill P., Broome R. & Lewis P. (2008). Central Coast Heatwave Pilot Project. Public Health Unit, Northern Sydney Central Coast Area Health Service.

NSW Government (2009). *Draft sea-level rise policy for NSW*. NSW Department of Environment and Climate Change.

Speer, M, Wiles, P. and Pepler, A. (2009). Low pressure systems off the New South Wales coast and associated hazardous weather: establishment of a database. *Aust. Met. Oceanog. J.*, 58, pp.29-39.

Verdon, D & Goodwin, I.D. (2007). *Progress Report 1 to HCCREMS on Stage 1 of the Regional Climate Change Study*. Consultancy report by Newcastle Innovation for the Hunter and Central Coast Regional Environment Management Strategy (HCCREMs). HCCREMS. p.29.

APPENDIX 1 – RISK ASSESSMENT MATRIX

CLIMATE CHANGE RISK ASSESSMENT MATRIX – EXTREME EVENTS IN THE COASTAL ZONE					
Climate Variable	**Historic & Projected Climate Change**	**Potential Impacts**	**Risk Assessment**		
			Likelihood	**Consequences**	**Risk Priority**
Extreme Rainfall Events	<u>Historic</u> • No discernible change in 2 or 3 day average return interval (ARI) exceeding Intensity Duration Frequency (IDF) thresholds • Decreased frequency of daily rainfall events per annum exceeding the 95th & 99th percentile threshold. • Decreased frequency of 3 day rainfall events per annum exceeding the 95th & 99th percentile threshold. • No change or slight decrease in recorded rainfall during yearly worst single and 3 day rainfall events • Extreme rain events occur most frequently during January, February and March. In Newcastle this extends through April & May and peaks in June. • Extreme rain events are less likely to occur during late winter to early spring • Extreme daily rainfall events occur most frequently closest to the coast, with the centres of Gosford and Buladelah, and the area north of Taree receiving the highest rainfall	**SUMMER CATCHMENT FLOODING[1]**			
		• More widespread / extensive flooding of property and environment *NB. The risk and adaptation strategies identified for catchment and flash flooding arising from extreme rainfall events are consistent with those identified as arising from sea level rise and extreme sea levels below. This reflects the close interrelationship between these climate parameters in their contribution to flooding issues.*	Likely	Moderate	High
		• Changes to landscape (bank and bed erosion, sediment change in estuaries)	Possible	Moderate	Medium
		• Significant economic impacts (eg. need for harbour dredging, agricultural loss, reduced tourism, debris impacts on port related activity)	Likely	Minor	Medium
		• Flood levels increase due to sedimentation	Unlikely	Minor	Low
		• More frequent inundation changes wetland hydrology, possibly expanding extent of wetland areas	Possible	Moderate	Medium
		• Inundation of floodplain pasture causing death of vegetation and subsequent black water events & fish kills	Possible	Moderate	Medium
		• Increase in mosquito breeding and associated health impacts	Almost Certain	Minor	Medium
		• Increased frequency of opening events for Intermittently Opened Coastal Lakes (ICOL’s)	Possible	Minor	Medium
		• Damage to public infrastructure (bridges, roads, railways & drains)	Possible	Minor	Medium
		• Water pollution caused by sewer and stormwater overflows	Almost Certain	Minor	Medium

CLIMATE CHANGE RISK ASSESSMENT MATRIX – EXTREME EVENTS IN THE COASTAL ZONE					
Climate Variable	**Historic & Projected Climate Change**	**Potential Impacts**	**Risk Assessment**		
			Likelihood	**Consequences**	**Risk Priority**
	Projected changes • Increased frequency during summer • Decreased frequency during autumn • No change for winter (except for a slight increase in frequency in Newcastle) • Slight increase in frequency during spring	• Social dislocation caused by greater frequency of inundation	Possible	Minor	Medium
		• Community health impacts (physical injury, stress & illness/ disease)	Possible	Minor	Medium
		• Increased insurance premiums / increased building costs	Almost Certain	Minor	Medium
		SUMMER FLASH FLOODING[2]			
		• Social dislocation caused by greater frequency of inundation	Possible	Moderate	Medium
		• Community health impacts (physical injury, stress & illness/ disease)	Possible	Moderate	Medium
		• Impacts on public infrastructure (bridges, roads, railways & drains)	Possible	Moderate	Medium
		• Water pollution caused by sewer and stormwater overflows	Almost Certain	Minor	Medium
		• More frequent flooding of property	Possible	Minor	Medium
		• Economic losses for business due to need for business recovery	Possible	Minor	Medium
		• Increased insurance premiums / increased building costs	Almost Certain	Minor	Medium

CLIMATE CHANGE RISK ASSESSMENT MATRIX – EXTREME EVENTS IN THE COASTAL ZONE					
Climate Variable	**Historic & Projected Climate Change**	**Potential Impacts**	**Risk Assessment**		
			Likelihood	**Consequences**	**Risk Priority**
Extreme Heat Days	Historic • Slight decreasing trend (non significant) in days per year with maximum temperature greater than or equal to 37^{0}C at Newcastle • Increasing (statistically significant) trend evident in Taree. An increase of approximately 3.3 extreme heat days in total has occurred between 1970-2007 Projected Change • Increases projected during autumn and summer	• Increased demand on power supplies and possible loss of power	Almost Certain	Major	Extreme
		• Public facilities can't cope with increased demand (eg increased visitation and usage of air conditioned public buildings, pools etc)	Likely	Minor	Medium
		• Possible impacts on physical infrastructure (eg rail, roads)	Possible	Minor	Medium
		• Ability of water supply infrastructure to meet potential increase in demand	Almost Certain	Minor	Medium
		• Impact on horticulture / agriculture through heat stress	Likely	Minor	Medium
		• Public health issues[3]	Almost Certain	Major	Extreme
		• Injury and death of domestic animals from heat stress.	Likely	Minor	Medium

CLIMATE CHANGE RISK ASSESSMENT MATRIX – EXTREME EVENTS IN THE COASTAL ZONE					
Climate Variable	**Historic & Projected Climate Change**	**Potential Impacts**	**Risk Assessment**		
			Likelihood	**Consequences**	**Risk Priority**
Wind Gust	Historic • Increase in average recorded wind gust during all seasons from 1957-2007. Most pronounced (& statistically significant) increase has occurred during summer • Statistically significant decrease in the frequency of wind gusts above 65km/hr during Autumn (1957-2007) • No significant change in annual frequency of wind gusts above 65km/hr Projected Change • Decreased intensity of wind gusts during winter • Increase in the intensity of north westerly wind gusts during spring • Increased frequency of onshore wind gusts during summer and autumn. No indication that the intensity of summer wind gust will change	• Increase in north west wind gusts during spring and on shore wind gusts during summer increasing fire risk during these seasons[4]	Almost Certain	Major	Extreme
		• Direct damage to physical structures & infrastructure (eg power lines, houses, boats)	Possible	Moderate	Medium
		• Increase in falling trees causing damage to homes and infrastructure	Possible	Moderate	Medium
		• Increased wind wave erosion of foreshore from onshore wave action (both open coast and estuaries) – particularly in high fetch areas	Possible	Minor	Medium
		• Social dislocation caused by damage to houses etc	Unlikely	Minor	Low
		• Community health impacts (physical injury, stress)	Possible	Minor	Medium
		• Damage to horticulture	Possible	Minor	Medium
		• Increased insurance premiums/ increased building costs	Almost certain	Minor	Medium

CLIMATE CHANGE RISK ASSESSMENT MATRIX – EXTREME EVENTS IN THE COASTAL ZONE					
Climate Variable	**Historic & Projected Climate Change**	**Potential Impacts**	**Risk Assessment**		
			Likelihood	**Consequences**	**Risk Priority**
Storm Frequency & Wave Climate	Historic Change • Significant wave heights associated with East Coast Lows or Southern Secondary Lows can be in excess of 7 metres • Significant wave heights and the ensuing storm wave erosion more frequent during the La Niña phases of the ENSO and IPO. The greatest number of significant storm events over the past century occurred during the IPO La Niña-like phase between 1950 and 1976 • No significant trends in frequency of maritime east coast lows (ECLs) evident since 1970 Projected Change • Increased frequency of East Coast Lows (~4%) during autumn and winter (relative to 1968-1996) • Slight increase in wave height for summer to 2030 followed by a decrease • Slight decrease in wave height during autumn • Decrease in significant wave height during winter • No projected changes in mean wave direction	• Increased coastal erosion in vulnerable areas	Almost Certain	Moderate	High
		• Increase in catchment and flash flooding	Refer to more detailed identification and assessment of risks included for flash flooding above.		
		• Increase in wind gust leading to physical damage of structures, trees and people; foreshore erosion; community health impacts & social dislocation; and increased insurance premiums	Refer to more detailed identification and assessment of risks for wind gust included above.		
		• Risk to marine and port related infrastructure and vessels	Possible	Minor	Medium
		• Loss of public access to and amenity of foreshore areas	Possible	Minor	Medium
		• Loss / damage of foreshore infrastructure, facilities and houses	Possible	Minor	Medium
		• Increase in public injury / safety (eg drowning, small boaters, fishers)	Likely	Major	High
		• Potential change in marine habitat distribution in the littoral zone.	Unlikely	Minor	Low

CLIMATE CHANGE RISK ASSESSMENT MATRIX – EXTREME EVENTS IN THE COASTAL ZONE					
Climate Variable	**Historic & Projected Climate Change**	**Potential Impacts**	**Risk Assessment**		
			Likelihood	**Consequences**	**Risk Priority**
Sea Level Rise and Extreme Sea Levels	<u>Historic</u> • Increase in sea level rise of 1.15mm per annum from 1966-2006 (Newcastle Harbour) <u>Projected Change</u> • SLR of 0.4m by 2050 and 0.9m by 2100 • Increased incidence of extreme sea levels (as a result of ~4% increase in East Coast Low formation) during autumn and winter	• Increased coastal erosion in vulnerable areas	Almost Certain	Moderate	High
		• Increase in flash flooding – risks consistent with those identified for flash flooding above *NB. The risks identified for flash flooding are consistent with those for extreme rain events above. This reflects the close interrelationship between these climate parameters in their contribution to flooding*	Refer to more detailed identification and assessment of risks included in flash flooding above.		
		• Risk to marine and port related infrastructure and vessels	Possible	Minor	Medium
		• Loss of public access and amenity of foreshore areas	Possible	Minor	Medium
		• Loss / damage of foreshore infrastructure, facilities and houses	Possible	Minor	Medium
		• Potential change in marine and estuarine habitat distribution in the littoral zone	Almost Certain	Moderate	High
		• Permanent inundation of property and infrastructure	Almost Certain	Minor	Medium
		• Exacerbation of other natural hazards (eg flooding)	Almost Certain	Moderate	High
		• Change in salinity regimes / limits in estuaries	Almost Certain	Minor	Medium
		• Impacts on groundwater supplies and groundwater dependent ecosystems	Almost Certain	Minor	Medium

APPENDIX 2 – GUIDELINES FOR ASSESSING LIKELIHOOD AND CONSEQUENCE SCALES

(source: Australian Greenhouse Office. *Climate Change Impacts and Risk Management: A Guide for Business & Government. Commonwealth of Australia 2006*)

Likelihood Scales

It is necessary to describe the likelihood of a risk arising if a particular climate change scenario comes about. This is a conditional likelihood, to be assessed as if the climate change scenario was going to happen.

A five point scale can be effectively applied for likelihood ratings. The extreme ends of this scale are those risks that are almost certain to happen and those that are almost, but not quite, certain not to happen.

There is one potential source of confusion to be addressed concerning how often the same risk might occur. Some risks are most realistically thought of as events that could happen once, such as the loss of an endangered plant or animal species at the centre of a tourism business or a permanent move of population from increasingly arid land to regional centres and major cities.

Other risks make more sense when considered as recurring events such as structural damage to domestic buildings from severe storms or episodes of heat related deaths. A scale that can be used to rate the likelihood of both single and recurrent events is shown in Table 11 below.

Table 11: Likelihood (given that the climate scenario arises)

Rating	Recurrent risks	Single events
Almost certain	Could occur several times per year	More likely than not – Probability greater than 50%.
Likely	May arise about once per year	As likely as not – 50/50 chance.
Possible	May arise once in ten years	Less likely than not but still appreciable – Probability less than 50% but still quite hig
Unlikely	May arise once in ten years to 25 years	Unlikely but not negligible – Probability low but noticeably greater than
Rare	Unlikely during the next 25 years	Negligible – Probability very small, close to zero.

source: Australian Greenhouse Office. *Climate Change Impacts and Risk Management: A Guide for Business & Government. Commonwealth of Australia 2006*

Consequence Ratings

To complete the risk assessment process it is also necessary to describe the level of consequence arising from the identified risks. This is usually achieved by defining a five point scale that describes levels of consequences ranging from:

- **catastrophic**, the level that would constitute a complete failure; to
- **insignificant**, a level that would attract no attention or resources

Scales like those in Table 8 and 9 on the following pages are proven mechanisms for describing the consequences of risks. Note that they contain no firm numbers but use simple descriptions that are understood by the participants in the process. There may be occasions where numbers are appropriate, such as in describing levels of financial loss, but even here descriptions of how the organisation would react may be adequate: for example, Catastrophic may equate to closure of operations or replacement of the senior management team, Major to having to carry a financial burden over into future years, Moderate to having to curtail planned expenditure in the short to medium term and so on.

Table 8: Example – consequence scales for a local authority

Rating	SUCCESS CRITERIA Public safety	Local economy & growth	Community & lifestyle	Environment & sustainability	Public administration
Catastrophic	Large numbers of serious injuries or loss of lives	Regional decline leading to widespread business failure, loss of employment and hardship	The region would be seen as very unattractive, moribund and unable to support its community	Major widespread loss of environmental amenity and progressive irrecoverable environmental damage	Public administration would fall into decay and cease to be effective
Major	Isolated instances of serious injuries or loss of lives	Regional stagnation such that businesses are unable to thrive and employment does not keep pace with population growth	Severe and widespread decline in services and quality of life within the community	Severe loss of environmental amenity and a danger of continuing environmental damage	Public administration would struggle to remain effective and would be seen to be in danger of failing completely
Moderate	Small numbers of injuries	Significant general reduction in economic performance relative to current forecasts	General appreciable decline in services	Isolated but significant instances of environmental damage that might be reversed with intensive efforts	Public administration would be under severe pressure on several fronts
Minor	Serious near misses or minor injuries	Individually significant but isolated areas of reduction in economic performance relative to current forecasts	Isolated but noticeable examples of decline in services	Minor instances of environmental damage that could be reversed	Isolated instances of public administration being under severe pressure
Insignificant	Appearance of a threat but no actual harm	Minor shortfall relative to current forecasts	There would be minor areas in which the region was unable to maintain its current services	No environmental damage	There would be minor instances of public administration being under more than usual stress but it could be managed

source: Australian Greenhouse Office. *Climate Change Impacts and Risk Management: A Guide for Business & Government. Commonwealth of Australia 2006*

Table 9: Example - consequence scales for a public utility

Rating	SUCCESS CRITERIA				
	Service quality	Service delivery	Interaction with other providers	Administration	Community confidence
Catastrophic	Services would fall well below acceptable standards and this would be clear to all	Services would be incorrectly targeted, delivered late or not at all in a large number of cases	The organisation would be in conflict with other providers and this would directly affect services	Administration of the organisation would be seen to have failed and in need of external intervention	There would be widespread concern about our capacity to serve the community
Major	The general public would regard the organisation's services as unsatisfactory	There would be isolated instances of services being incorrectly targeted, delivered late or not delivered at all	The effort of managing relations with other providers would drain resources and badly degrade service delivery	Administration of the organisation would be seen to be deficient and in need of external review	There would be serious expressions of concern about our capacity to serve the community
Moderate	Services would be regarded as barely satisfactory by the general public and the organisation's personnel	There would be isolated but important instances of services being poorly targeted or delivered late	Unnecessary overheads arising from relations with other providers would be a drain on resources but the public would be unaware of this	Administrative failings might not be widely seen but they would cause concern if they came to light	There would be isolated expressions of concern about our capacity to serve the community
Minor	Services would be regarded as satisfactory by the general public but personnel would be aware of deficiencies	There would be isolated instances of service delivery failing to meet acceptable standards to a limited extent	Unnecessary overheads in dealing with other providers would absorb some effort but the public would be unaware of this and would not be affected	There would be some administrative shortcomings demanding attention but they would not be regarded as serious failures	There would be some concern about our capacity to serve the community but it would not be considered serious
Insignificant	Minor deficiencies in principle that would pass without comment	Minor technical shortcomings in service delivery would attract no attention	Minor unnecessary overheads arising from relations with other providers but no material effect	There would be minor areas of concern but they would not demand special attention	There would be minor concerns but they would attract no attention

source: Australian Greenhouse Office. *Climate Change Impacts and Risk Management: A Guide for Business & Government. Commonwealth of Australia 2006*

HCCREMS Member Councils