# The Estimated Cost of Tropical Cyclone Impacts in Western Australia

**A Technical Report for**

**The Indian Ocean Climate Initiative (IOCI) Stage 3**

**Project 2.2: Tropical Cyclones in the North West**

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GOVERNMENT OF
WESTERN AUSTRALIA

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# 1 Executive Summary

An analysis is presented of the economic impact of tropical cyclones (TCs) on Western Australia. The analysis is based on a search of relevant literature, information on government websites, and discussions with forecasters and mining company representatives. It also derives from the author's long-term experience as a researcher in the field of tropical cyclones.

From analysis of insurance industry disaster payouts, it is found that tropical cyclones cause economic losses to Western Australia due to *direct damage* of the order of $40 million to $100 million per year. The range of this estimate depends on the data source, and on the method of extrapolating from insurance payout to total cost. This cost is not large in comparison with other Australian disasters such as flooding, bushfire and hailstorms in major cities.

The economy of Western Australia is dominated by the extraction and export of minerals and energy. This economic sector is highly affected by cyclone events, through flooding of mines, evacuation of off-shore oil platforms when a cyclone is forecast, cutting of road transport, closure of ports and cessation of construction activities. *Given the large scale of the mining sector in Western Australia, it is proposed that impact on that industry is the major economic impact of tropical cyclones in the State.* This is as compared with the impact through damage to private property and public infrastructure.

Drawing on discussions with industry representatives, details are given of tropical cyclone-related costs to the oil and gas industry. In addition, several examples are given of tropical cyclone-related disruptions to mining in Western Australia having an impact on the national economy and on the trade balance. Despite these examples, it is difficult to fully substantiate the contention that the largest economic impact of tropical cyclones to the State is cost to mining, without obtaining documentation of costs from within the industry.

The concept is presented of "extreme disasters" such as Tropical Cyclone Tracy, the 2011 Queensland floods, and the Black Saturday Victorian fires. It is contended the cost of these extreme disaster events is several multiples of a “normal” tropical cyclone (or other disaster) event. For example the time series of (inflation-adjusted) tropical cyclone losses for Australia is dominated by one very large event, Tropical Cyclone Tracy. Any figures on mean annual losses are changed totally according to whether or not this one event is included. This sensitivity to individual major events also applies when comparing tropical cyclone losses to losses caused by other natural hazards.

A framework is proposed for understanding tangible costs due to tropical cyclone events. It is proposed that economic losses can be grouped in three categories: (i) damage costs; (ii) ongoing operating costs to industry; (iii) extreme disaster costs. The first two costs could be considered as part of the cost of carrying out industry in a state where the climatology has five cyclones per year off shore, two coastal crossings per year and a high interannual variability. The analogy is given of farming in a region where droughts occur three years out of seven, or of a concrete laying business where it rains 50 days per year. Thus the costs of normal cyclone events can be considered a climatological factor or an annual outgoing expenditure in the business ledger.

The damage costs and mitigation costs associated with these “regular” cyclone events have risen in recent decades due to increasing coastal settlement and infrastructure and due to increasing construction and replacement costs. These trends will continue in coming decades. *Any changes in cyclone activity due to global warming will affect these trends, but given the uncertainties in cyclone projections, and the size of population and infrastructure trends, such an impact is likely to be undetectable*.

*A detectable impact from climate change would be if the frequency of extreme events (such as Tropical Cyclone Tracy in Australia, Hurricane Katrina in the US) were to increase.* This remains a possibility, but there is no hard evidence at present that climate change will cause an increase in frequency of such events. There is however a body of theory stipulating that the extreme intensity (tail of the distribution) of tropical cyclones will increase in a warmer planet. The possibility of an increase in extreme tropical cyclone events under climate change should be further studied. *A second major impact of climate change would be the possibility of an acceleration in the time-series of costs due to the tropical cyclone storm surge occurring against a background of higher sea levels.*

It is also noted that tropical cyclones have a positive economic impact in Western Australia through their contribution to rainfall, particularly in the context of water supply for cities and rainfall for agriculture. A recent study (funded by IOCI) has shown that along the northern coastline tropical cyclones contribute between 20 to 40 percent of mean wet season rainfall within 150 km of the coast and approximately 20 percent further inland. This has an impact on water supplies, with storage dams falling to low levels during some years, while filling to capacity during tropical cyclone-related flood events in other years.

A caveat is given that economic cost is only one component of cyclone damage. It is understood that a cyclone event can destroy all infrastructure in an island nation or severely damage the economy of a developing country. However, the same cyclone would appear as a minor event, when measured in dollars, compared to such an event in a major western economy.

Returning to the Western Australia context, the lack of publicly available documentation of the cost to industry is a concern. If we are to understand our nation and its vulnerability to tropical cyclones, it is important that steps be taken to develop such documentation. Lastly, this report is the perspective of an experienced meteorologist who has worked with cyclone forecasters and disaster experts around the world. It is hoped that Australian economists will address these same issues.

# 2 Introduction

This report stems from Project 2.2 of the third stage (2008-2012) of the Indian Ocean Climate Initiative (IOCI), a joint climate change research project between the Western Australian Government and two research organisations: the Bureau of Meteorology (BoM) and the Commonwealth Scientific and Industrial Research Organization (CSIRO). Project 2.2, titled "Tropical Cyclones of the North West" had as its primary focus advancing the science of tropical cyclones in the Western Australian region by making contributions to: * their climatology and interannual variability; * improved forecasting methods; and * expert assessments of the impact of climate change on tropical cyclone activity. The project resulted in a large number of operational products and publications as listed in the Appendix (Section 11).

This current report addresses the economic impact of tropical cyclones in the state of Western Australia. The author is a research meteorologist who has specialised in the physical science of weather and climate and in research in support of Bureau of Meteorology operational forecasting and climate services. Thus the report draws on that experience rather than on any economic background or experience.

Section 3 of this report documents the climatology of tropical cyclones as they affect Western Australia. It also describes the physical means by which cyclones cause damage: strong winds, flooding rains, storm surge, wave action at sea and tornadoes. Section 3 also gives a brief resume of the importance of the mining sector to the economy of Western Australia and of the importance of export through the major WA mining ports. Here it is proposed that the major economic impact of tropical cyclones to Western Australia may not be direct damage, but rather the cost of an industry (the mining sector) conducting business in a cyclone-prone area.

Section 4 describes the sources of data for information on economic cost of tropical cyclone events. Section 5 introduces the concept of "extreme disasters", making the point that time series of disasters are dominated by a small number of major events whose average cost is four or five times the average cost in normal or non-extreme disaster years. Section 6 describes an infrastructure for studying the economic cost of tropical cyclones in Western Australia. Section 7 uses that framework to document the economic cost of tropical cyclones to Western Australia. A key point is that for an economy dominated by the mining sector the major costs are adaptation, mitigation and disruption of activities for industry. This is illustrated through a case study of costs to the oil and gas industry. Section 8 addresses the potential impact of climate change. Section 9 summarises the major findings.

This is an exploratory work, written from the perspective of a meteorologist who has worked with tropical forecasters from around the globe. The questions addressed are important to those studying tropical cyclones and attempting to place them into a societal context. Thus the author would encourage others with better economic credentials to follow up with alternate analyses of the socioeconomic impact of tropical cyclones.

# 3 Climatology and Setting

## a) Cyclone climatology

Tropical cyclones are synoptic low-pressure weather systems occurring over tropical or subtropical oceans with organised convection and cyclonic wind circulation at the surface. Tropical cyclones are monitored and forecast by Tropical Cyclone Warning Centres (TCWCs) and by Regional Specialised Meteorological Centres (RSMCs) around the globe. These are run by the National Hydrometeorological Services of different countries and coordinated by the World Meteorological Organization (WMO). These centres also have responsibility for issuing cyclone warnings and for coordinating with emergency agencies. Consistent with this infrastructure, a tropical cyclone has a precise definition.

In the Australian region, a synoptic scale tropical weather system is defined as a tropical cyclone when the low pressure system has sustained gale force winds (63 km/h) or greater and gusts in excess of 90 km/h extending more than halfway around the centre and lasting for more than six hours. This is usually around the time that the system forms a characteristic structure with a central cyclone eye. Warnings issued by the Bureau of Meteorology classify tropical cyclones as category 1 to category 5 according to the magnitude of wind speed and gusts, with categories 3-5 being referred to as severe tropical cyclones.

Tropical cyclones are a seasonal phenomenon occurring over the summer months, referred to in Northern Australia as the "wet season", with approximately 60 percent of occurrences between January and March. Figure 1 taken from an interactive plotting facility on the Bureau of Meteorology website shows the tracks of tropical cyclones over five recent wet seasons. Climatologies of tropical cyclones in the Australian region have been published by McBride and Keenan (1982) and Dare and Davidson (2004). A large amount of climatological information as well as summaries of individual cyclones is available through the website of the Bureau of Meteorology (www.bom.gov.au). As described there, "the northwest Australian coastline between Broome and Exmouth is the most cyclone-prone region of the entire Australian coastline, having the highest frequency of coastal crossings. On average about five tropical cyclones occur during each tropical cyclone season over the warm ocean waters off the northwest coast between 105 and 125°E. On average about two cyclones cross the coast, one of which is severe. Indeed about 75 percent of severe cyclone crossings in Australia between 1970-71 and 2007-08 were in Western Australia."

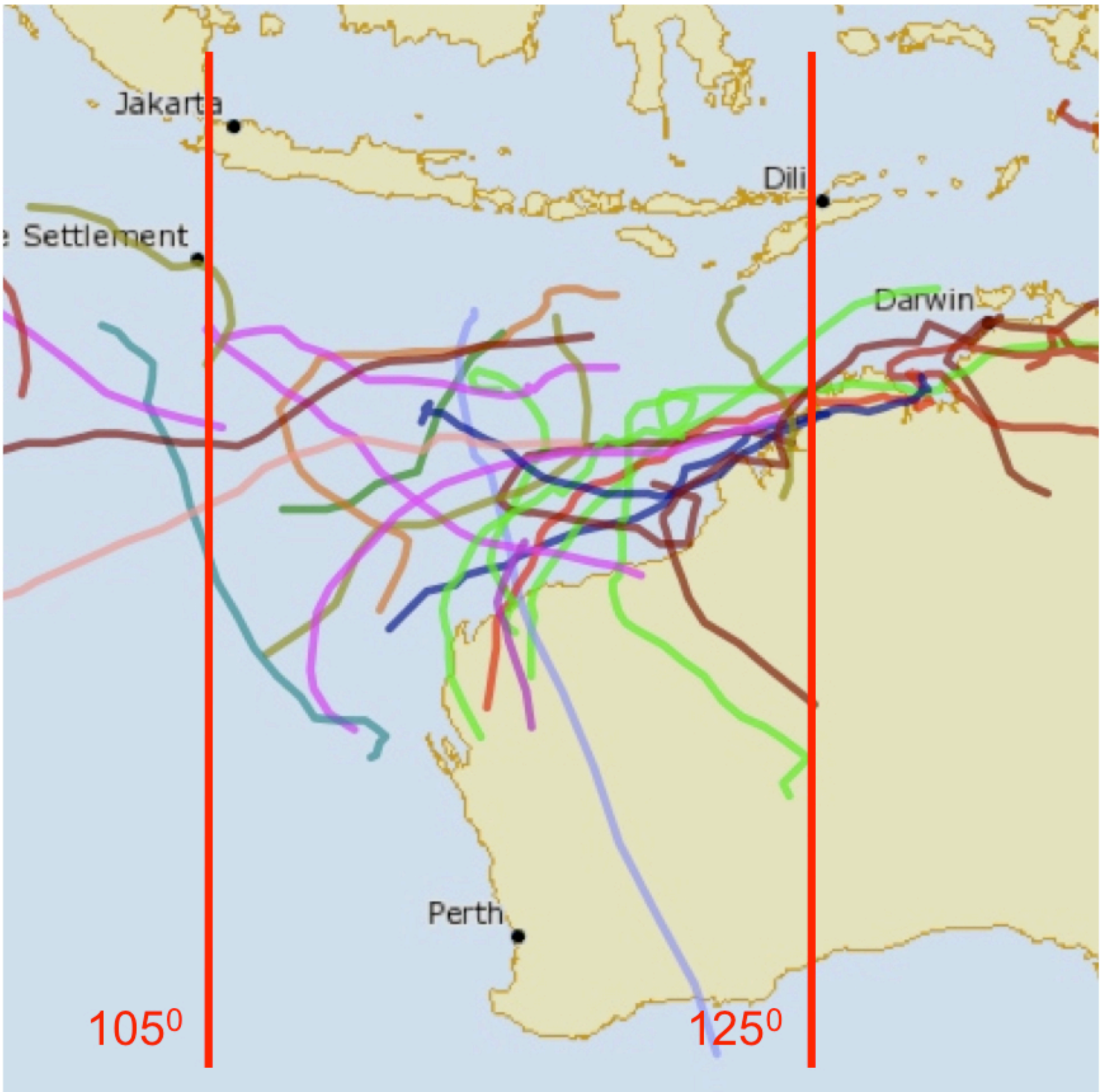


**Figure 1 Official tracks of tropical cyclones between the 2005-06 season and the 2009-10 season. Tracks plotted from the Interactive Cyclone Tracker are available at www.bom.gov.au.**

### b) Tropical cyclone damage

Tropical cyclones cause damage to property and loss of life in a number of ways. These are:

- *wind damage*. The destruction of the city of Darwin in 1974 due to Tropical Cyclone Tracy was primarily due to wind damage.

- *Fresh water flooding associated with the heavy rainfall*. In Western Australia this is the major cause of damage inland from the coast. Tropical cyclones lose their wind energy relatively quickly (within a day) after making landfall. However, the heavy rainfall can continue for several days as the former cyclone crosses the inland portions of the continent.
- *Salt water flooding associated with storm surge*. A tropical cyclone approaching a coastline causes elevated sea levels due to storm surge and high waves. On an international level, storm surge is the cause of major disasters associated with tropical cyclones. In recent times these included 1,300 deaths in the U.S. state of Louisiana in 2005 (Knabb et al., 2005), and 138,000 deaths in Myanmar in 2008 (EM-DAT, International Disaster Database). Going back to 1970, more than 300,00 lives were lost in a storm surge in Bangladesh. In Australia, when Tropical Cyclone Vance crossed the WA coast in March 1999, the storm surge at Exmouth was measured at 3.5 metres which resulted in a storm tide of 4.9 metres at 10:20 a.m. Had the peak surge occurred at high tide a few hours later the storm tide could have reached 6.1 metres (Bureau of Meteorology, Report on Tropical Cyclone Vance, unpublished 1999). In the State of Queensland, Tropical Cyclone Larry (2006) had a measured storm surge of 2.3 metres and Tropical Cyclone Yasi (2011) had a measured surge described as being 2.3 metres above Highest Astronomical Tide (Bureau of Meteorology Reports on Tropical Cyclone Larry and on Tropical Cyclone Yasi).
- *Wave action associated with the high wind speeds over open water*. For the state of Western Australia, wave action and high seas can cause considerable damage to offshore oil and gas platforms. Wave heights over 20 metres were recorded at North Rankin platform off the WA coast in 1989 during Tropical Cyclone Orson (www.bom.gov.au/cyclone/history/pdf/orson_full.pdf). Building to withstand cyclone-generated waves is a major design criterion and so a major factor in the cost of such platforms. These offshore facilities are routinely evacuated when a cyclone warning is present, causing loss of

production. High seas also cause the closure of the major ports for export of iron ore and other mining products, thus affecting company products as well as trade exports for the country.

- *The landfall of tropical cyclones also gives rise to tornados.* Internationally these are reported as an additional major source of damage caused by tropical cyclones. In Australia there are reports of tornados caused by the outer rainbands of land-falling cyclones. For example, a tornado caused extensive damage in the central business district of Karratha in February 2011 while Tropical Cyclone Carlos was offshore. However, to the author's knowledge there are no reports of widespread tornado outbreaks associated with cyclone landfall in Australia.

### c) Economy of Western Australia

The economy of the state of Western Australia is dominated by the mining Industry, the State's largest single industry accounting for approximately one fifth of the Gross State Product (GSP; Department of Treasury and Finance, 2005). Mining-related processing accounts for more than half the State's manufacturing output; and the State is a world leader in the production and export of a number of commodities.

At the time of writing, the Australian economy is undergoing a resources boom or a mining boom. Western Australia is a major source of this resource boom, that State contributing 58 percent of Australia's total mineral and energy exports in the 2010-2011 financial year (Department of Mines and Petroleum [DMP], 2012). The mining sector extracts oil and gas, iron ore and other major minerals, the majority of production being exported through the State's major ports. An indicative figure showing the locations of the energy sources (left panel) and mines and mineral resources (right panel) is given in Figure 2. Recent newspaper accounts state that during the 2009-2010 fiscal year the two busiest tonnage WA ports (Port Hedland, Dampier) reported a combined trade of almost 350 million tonnes, up 16 percent on the previous year and an increase of 70 percent since 2005. (The Australian Newspaper: http://www.theaustralian.com.au/business/record-exports-stretch-pilbara-iron-ore-ports/story-e6frg8zx-1225889568597).

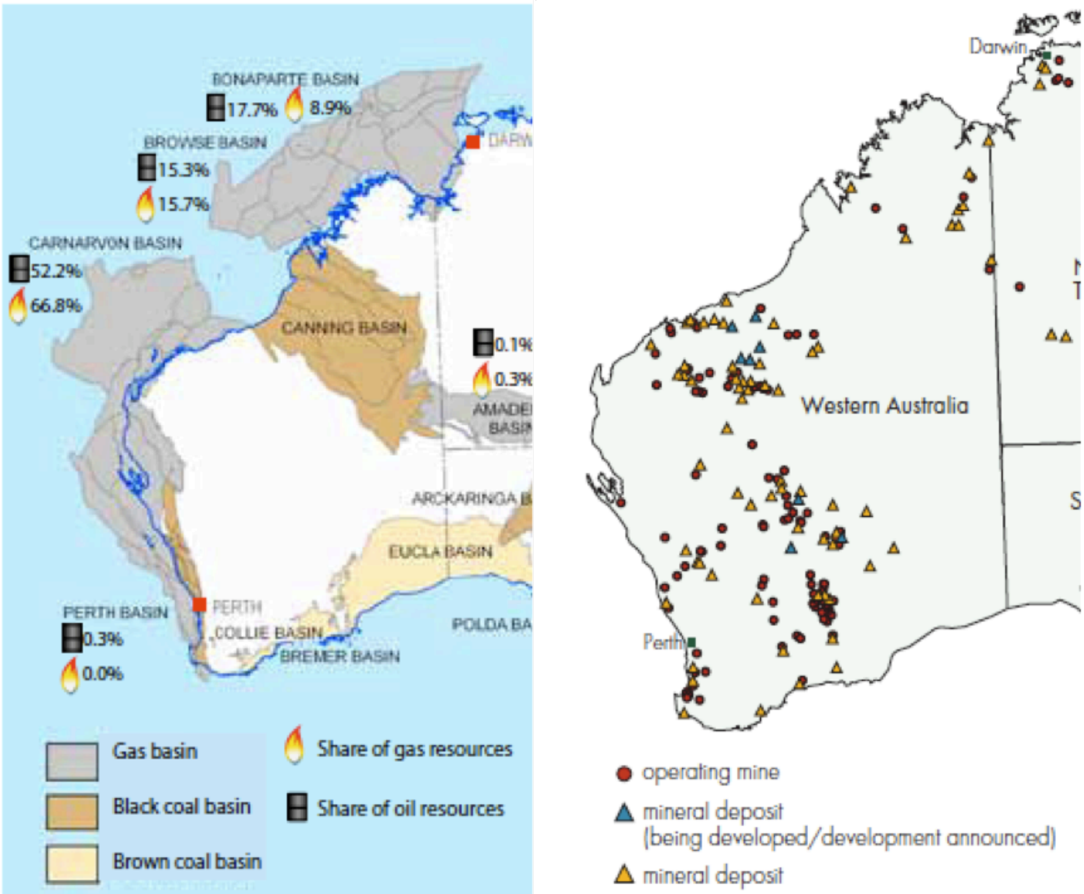


**Figure 2 Left panel is the distribution of the State of Western Australia's oil, gas and coal resources as of 2011. Source: Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2011. Right Panel shows the distribution of mines and mineral resources in Western Australia as of 2007. Source: Australian Bureau of Agricultural and Resource Economics (ABARE) 2007.**

The relevance of this is that much of the economic impact of tropical cyclones is not so much associated with the cost of damage repair when major cyclone-related disasters occur. Rather it will be related to the cost of an industry conducting business in a cyclone-prone area. This will involve carrying out export subject to port closures during cyclone events, flooding of mines, closing down of road transports due to flooding and road damage, as well as ongoing adaptation and preventive measures underpinning activities of the mining sector.

To the author's knowledge there is no systematic documentation of this ongoing impact of tropical cyclones on the business sector. However, there are occasional interpretive reports on the impact on trade. For example, during the 2011-2012 wet season Tropical Cyclone Heidi brought about port closures and widespread mining industry shutdowns for several days. In that month (January 2012), Australia recorded its first seasonally adjusted trade deficit for 11 months. A press release by the Australian Minister for Trade and Competiveness issued in March 2012 reported this deficit "was in part caused by Cyclone Heidi, which prevented companies like Rio Tinto and Fortescue Metals loading ships in Port Hedland in Western Australia."

A "staff working paper" of the Australian Government Productivity Commission (Topp et al., 2008) reported that cyclonic activity around the Pilbara region in north western Australia was exceptionally bad in early 2006, leading to flooding of many iron ore open cut mines and the Telfer gold mine pit. Oil and gas extraction in the North-West Shelf was also adversely affected by the severe weather, with 13 percent of annual production lost in 2005-06 (ABARE, 2006). The severe rain caused by tropical cyclones, many of which crossed the coast and proceeded through the Pilbara region, had a significant impact on mining activities, and probably impacted on productivity in the 2005-06 financial year (Topp et al., 2008). Consistent with this, the Australian Bureau of Statistics (2006) reported that exports of petroleum detracted from growth during the fiscal year to June 2006, as crude petroleum oils for Western Australia declined by $297 million[1] (20.3 percent) and refined petroleum oils declined by $7 million (6.8 percent) - the result of the prolonged impact of Tropical Cyclones Clare and Glenda on oil production.

Despite these examples, the mention of either cyclones or weather in annual reports is only occasional; and to the author's knowledge there is no systematic documentation of the impact of cyclones on either the minerals or oil and petroleum sectors.

Besides the mining sector, effectively all other sectors of the economy are subject to losses associated with flooding and destruction of building and infrastructure brought about by tropical cyclones. In the context of water supply for cities and for agriculture, tropical cyclones may well have an important positive benefit. In a recent study (funded by the IOCI Project 2.2), Dare et al. (2012) documented the direct

[1] Dollar amounts are in Australian dollars unless otherwise indicated.

contribution of tropical cyclones to seasonal (six-month) wet season rainfall along the northern coastline of Western Australia. They show that tropical cyclones contribute between 20 and 40 percent of mean six-month rainfall within 150 km of the coastline and approximately 20 percent further inland. In most locations the contribution of tropical cyclones is not consistent, varying interanually from 0 to 85 percent. This has an impact on water supplies, with storage dams falling to low levels during some years, while filling to capacity during TC-related flood events in other years.

# 4 Data Sources

As will be discussed below, the economic impact of tropical cyclones consists of a number of factors other than the direct cost of replacement, repair and cleanup to damaged property and infrastructure. There are also large costs associated with shutdown of ports, evacuation of staff from offshore drilling platforms, closure of mines, disruption of transport, etc. One of the conclusions of this report is that the cost to industry is not well documented and a recommendation is that systematic industry wide procedures be initiated to carry out such documentation.

There is, however, a reasonable level of documentation of insured costs associated with cyclone damage. The major sources are as follows:

**a) Insurance Council of Australia**

This is a database of disasters statistics compiled by the Insurance Council of Australia (ICA). The data are derived from the submissions of general insurance companies following large events incurring cost to the community and insurers. The figures for an event do not represent the entire cost of the event, but are an approximation of the insured loss based upon reported data. Events are only recorded where there is a potential for the insured loss to exceed $10 million. These data can be downloaded from the Insurance Council website at:

www.insurancecouncil.com.au/industry-statistics-data/disaster-statistics

A number of academic studies and analyses of disasters in Australia and their economic cost have been carried out with the Insurance Council data, notably by the Risk Frontiers Natural Hazards Research Centre located at Macquarie University. Examples are McAneney et al. (2007) Crompton and McAneney (2008). Tables 1 and 2 and Figure 3 of the current report were complied by the author using this data source.

**b) The Emergency Management Australia (EMA) Disasters Database**

This database, extending back to the 1800s, contains total estimated cost of each disaster as well as insurance cost. The database has been compiled using estimates from the ICA, published disaster reports and reports in newspapers and other media. The database relies heavily on media reports. The data are available online at:

www.disasters.ema.gov.au/

The total estimated costs for disasters in the database are in most cases based on insurance costs multiplied by a factor representing the ratio of total cost to insured costs, according to the disaster type. These ratios are taken from Joy (1991) and are as follows:

**bushfire:** **multiplication factor of 3**

**severe storm:** **multiplication factor of 3**

**earthquake:** **multiplication factor of 4**

**tropical cyclone:** **multiplication factor of 5**

**flood:** **multiplication factor of 10**

For tropical cyclones, the multiplication factor of 5 effectively means that insurance payouts are estimated as being 20 percent of the total cost to the economy. The accuracy of these multiplication factors and their appropriateness for Western Australia is difficult to judge. The factor is as high as 10 for floods basically because many insurance policies do not cover flood damage. For Western Australia, much of the damage reported as being caused by cyclones is actually due to cyclone-caused flooding. Thus the factor of 5 may be too low. In addition, as discussed earlier, a large proportion of cyclone damage in WA is to private industry which carries it own internal self-insurance, and so is not represented in insurance industry statistics.

Possibly the most important study carried out on economic cost of disasters affecting Australia is the study Economic Cost of Natural Disasters in Australia (Bureau of Transport Economics, 2001, henceforth BTE 2001). This report was put together by a multi-agency Disaster Mitigation Research Working Group, and had as its aim "a first step in better understanding the costs of natural disasters in Australia". It also brings together information allowing a consistent approach to the estimation of future disaster costs.

**c) EM-DAT, the International Disasters database available at: http://www.emdat.be/**

Since 1988 the World Health Organization (WHO) Collaborating Centre for Research on the Epidemiology of Disasters (CRED) has been maintaining an Emergency Events Database. EM-DAT was created with the initial support of the WHO and the Belgian Government. The main objective of the database is to serve the purposes of humanitarian action at national and international levels. It is an initiative aimed to rationalise decision making for disaster preparedness, as well as providing an objective base for vulnerability assessment and priority setting. EM-DAT contains essential core data on the occurrence and effects of over 18,000 mass disasters in the world from 1900 to the present. The database is compiled from various sources, including UN agencies, non-governmental organisations, insurance companies, research institutes and press agencies.

**d) PerilAUS Australian disaster database.**

This is a CD-ROM database of natural perils in Australia, compiled from Insurance Industry Statistics and information from Government departments, primarily the Bureau of Meteorology and Geosciences Australia. It is distributed by Risk Frontiers, and described on their website as having been funded by the Insurance Council of Australia.

**e) Munich Reinsurance Company NatCat**

This is a private international level database of insurance costs for natural disasters worldwide. It is described on the Munich Re website as being the most comprehensive natural catastrophe loss database in the world. It comprises 28,000 data records. Approximately 1,000 events are recorded and analysed each year. The source is:

www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice

# 5 The Concept of Extreme Disasters and Climatological Disasters

Figure 3 shows a time series of total national insurance cost due to natural disasters for Australia, taken directly from the figures in the Insurance Council of Australia database. There are a number of features of interest in this diagram. The first is that over the past several decades insurance costs in Western Australia have been only a very small fraction of disaster-related costs across the country. This is consistent with the hypothesis made in Section 3c that the major economic impact of cyclones in Western Australia is the ongoing cost to industry (predominantly mining) conducting business in a region where losses and mitigation costs are ongoing.

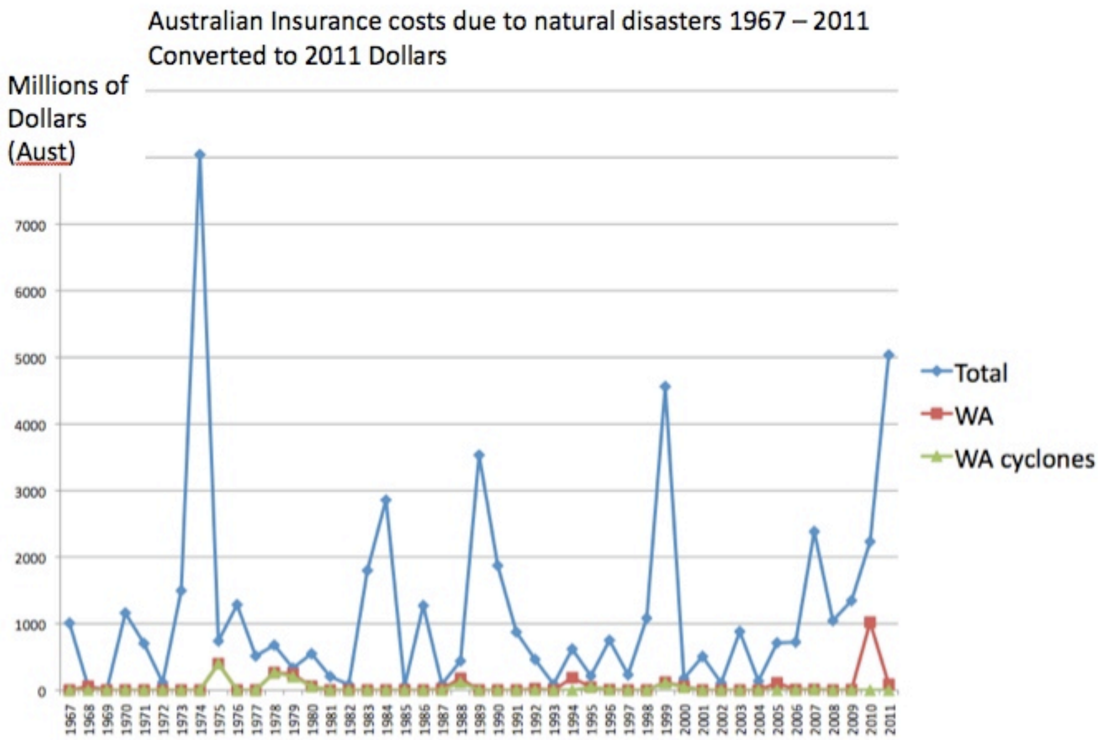


**Figure 3 Total Australian insurance costs associated with natural disasters complied from Insurance Council Australia disasters database. Also shown are the contributions from disasters and tropical cyclones located in Western Australia.**

The second major feature of Figure 3 is that the time series is dominated by a relatively small number of years with very high insurance payouts. Inspecting the series, there are major events in seven years: 1974 (Tropical Cyclone Tracy, Tropical Cyclone Wanda and follow-on floods); 1984 (Brisbane hail event); 1989 (Newcastle earthquake); 1999 (Sydney hail event); 2007 (Newcastle east coast low); 2010 (Perth storm, Melbourne storm); 2011 (Queensland flooding, Tropical Cyclone Yasi). The average annual insurance cost of natural disasters over the 45 years was $1.178 billion. If the 10 events that occurred in the above years are removed from the series, the annual cost declines to $645 million per year. The 10 (extreme disasters) had an average insurance cost of $2.4 billion, which becomes an average of $12 billion total economic cost per disaster when the multiplication factors of Section 3b above are applied.

It is proposed here that for natural disasters, a number of storms, tropical cyclones, flood events and major fire events can be considered part of the climatology of the country. Thus, the annual cost of $645 million in insurance payout can be considered part of the working expenses of living in this climate. An analogy to this would be a concrete business than cannot pour concrete when it rains. If a location has an average of 60 rain days per years with a standard deviation of 20 days (for example), the disruption of business when it rains is not an economic loss but part of the costing of doing business in that environment.

Another analogy would be the occurrence of drought for farming. If a drought is defined as the lowest quintile in the distribution of growing season rainfalls, then by definition a drought occurs on average every five years. Thus for sustainable farming, the losses during a drought would not be considered to be a disaster. Rather they are part of the climatological rainfall distribution to be taken into account in farming that region.

A similar consideration can be applied to the economic cost of tropical cyclones. Figure 4 (from BTE, 2001) shows the total economic cost per year of tropical cyclone disasters. As can be seen, for the period 1967-1999 the series is dominated by a single event, Tropical Cyclone Tracy, which effectively destroyed the city of Darwin. Thus, as pointed out by BTE (2001), this phenomenon of dominance by the rare extreme event makes consideration of annual cost due to cyclone damage highly misleading, if not meaningless.

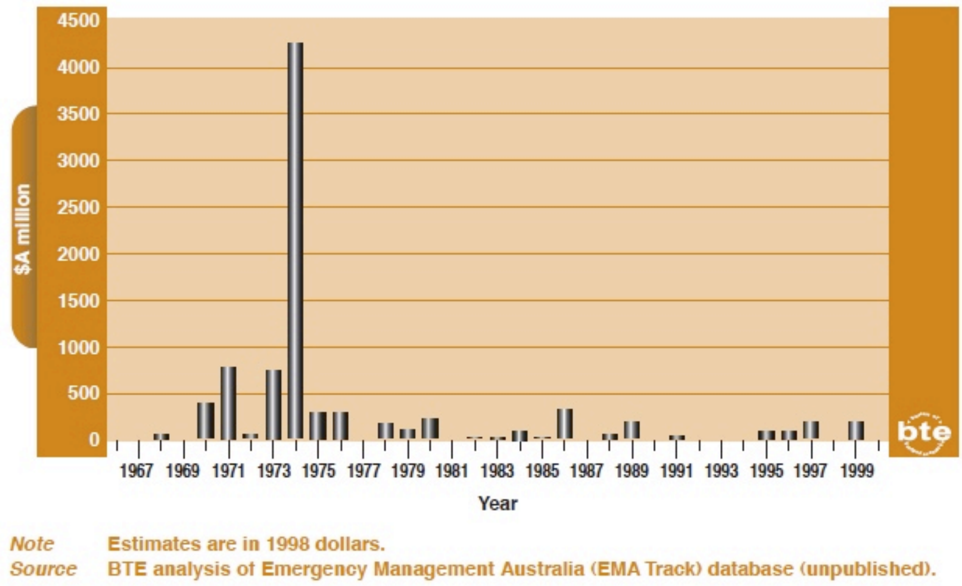


**Figure 4 Time series of total economic cost for Australia of tropical cyclones over the period 1967 to 1999 expressed in 1998 dollar value, from Bureau of Transport Economics (2001).**

This concept of economic-extreme disasters will be used and expanded on through the remainder of this report. A similar concept was discussed by Miller et al. (2008) in their analysis of trends in global natural catastrophe losses. They carried out a sensitivity analysis on their trend of normalized losses, and demonstrated that a small number of "super events" such as Hurricane Katrina and the 1990 China floods exerted a large influence on magnitude of the global trend.

The international insurance industry makes extensive use of catastrophe modeling to determine and manage risk of natural disasters (Grossi et al., 2008). The recent catastrophe modeling literature has defined the term "super cat" to describe major catastrophes (in an economic loss sense) whereby secondary consequences become significant factors in loss generation. This results in an amplification of the loss due to containment failures (e.g. failure of flood defenses, failure of systems designed to contain fire), evacuation, and systematic economic impacts (e.g. delayed re-opening of business due to lack of customers, delays in rebuilding due to lack of labourers; Muir-wood and Grossi, 2008).

For major insurance-related disasters, the insurance literature has developed the concept of “demand surge”. This refers to an increase in costs following a disaster due to lack of locally available rebuilding resources and labour. The concept has been reviewed by Olsen and Porter (2011) who gave examples of price increases of 30 percent for oriented strand board following Hurricane Katrina to a 2,000 percent increase for securing a tarpaulin to a damaged roof after the 1999 Sydney hailstorm.

A report by the Australian Securities and Investments Commission (ASIC 2007) documented the fact that in Australia "mass disasters" can cause huge and unpredictable increases in rebuilding costs. It documented that after Tropical Cyclone Tracy in Darwin in 1974, building costs increased by 75 percent. After the Newcastle earthquake in 1989, costs increased by 35 percent. After the ACT bushfires in 2003, building costs increased by 50 percent between November 2002 and January 2003. Following Tropical Cyclone Larry (Queensland, 2006) insurers estimated that building costs increased by at least 50 percent immediately after the disaster.

The Australian Securities and Investments Commission Report attributed the increases in local building costs after the Tropical Cyclone Larry disaster as resulting from the following factors:

• the remote nature of the location and the breadth of the damage path,

• limited availability of builders and initial difficulties in accessing sites, particularly due to ongoing rains, and

• the fact that many of the homes were older structures and were not compliant with new cyclone building codes.

# 6 Framework for Determining Economic Impact

There is a small pre-existing literature on frameworks for determining the economic impact of a natural disaster. Concise summaries of key concepts can be found in Chapter 2 of Middelman (2007) and in the introduction of BTE (2001). As described in BTE (2001) losses from a natural disaster are normally categorised into tangible and intangible losses, which are further sub-divided into direct and indirect losses. Direct tangible costs are losses resulting from the physical destruction or damage to buildings, infrastructure, vehicles and crops. Indirect costs, which are more difficult to estimate, are costs incurred as a consequence of the event occurring, but not due to the direct impact. These may include financial elements, such as accommodation costs and lost revenue, and the loss of opportunity through disruption of public services. Business continuity is also a significant component of indirect tangible costs (Middelman, 2007, p.17). The intangible cost category attempts to capture all losses not considered as a direct or indirect tangible cost. Intangible costs are typically those for which no market exists. They include the loss of lives, the social disruption, health effects, household disruption, loss of memorabilia, emotional trauma and environmental impacts.

The current study, directed specifically at tropical cyclone impacts in Western Australia, will address tangible costs only. Rather than classify these as direct and indirect, we find it convenient to classify under the following three categories: (i) *damage costs*; (ii) *ongoing operating costs to industry*; and (iii) *Extreme Disaster costs*.

*Damage costs:* These are the costs caused by the regular tropical cyclones that skirt the Australian coastline or make landfall. Such costs include the cost of replacement, cleanup, and repair to private insured property associated with a cyclone event, as documented in insurance company records and databases. They also include uninsured costs associated with replacement and repair to private property (currently undocumented) and the cost of replacement and repair to public infrastructure. These last costs should be documented in public records. However, to the author’s knowledge, the cost of cleanup, replacement and repair for tropical cyclone events have not been collated and synthesised.

The damage costs category includes the cost of replacement and repair to the business sector including large international companies. A proportion of these costs would be covered by (external) insurance. Based on the considerations in the final paragraph of Section 7b below, it seems the majority of these costs are covered by company "self-insurance". Thus the losses are incorporated into the annual profit and loss of the companies involved. (Records of these costs are usually not publicly available.)

Damage costs also include lost production due to destruction of farmlands, engineering infrastructure, and buildings that are an essential part of company production. These costs usually are incurred for a period of days to months after the cyclone event. Some of these costs may be included in insurance records. Some will not be documented.

The damage costs as defined here also include costs associated with lost production during a cyclone event due to mitigation of damage and avoidance of loss of life. These costs include loss of export earnings due to closure of ports, loss of production due to evacuation of mines, closure of offshore rigging platforms, and closure of roads.

There are costs associated with lost production due to forecasts of cyclone events even when the events do not occur. These do not necessarily relate to inaccurate or incorrect forecasts, but rather may occur in response to probabilistic forecasts. For example the Bureau of Meteorology or a private company may issue a 50 percent probability of cyclone occurrence at a location in the coming seven days. One of the pieces of research funded by the current IOCI Tropical Cyclone Project 2.2 is the development of a statistical forecast model for cyclone activity over the coming one through three weeks (see Table 1 of the Appendix).

*Ongoing operating costs to industry:* The second category of costs is described here as ongoing operating costs to industry, that is, the ongoing continuous annual costs associated with disaster mitigation. These include issuing of warnings, community preparedness, building and construction to cyclone-proof standards for both private property and business and industry. (Disaster mitigation can be defined as measures taken in advance of a disaster aimed at reducing or eliminating its impact on society and the environment; EMA 1998, p. 85.) For example, parts of coastal Northern

Australia are designated as cyclone regions with different high wind return periods according to cyclone climatology. Building designs in the various cyclone-prone subregions are regulated to withstand certain wind loadings (Standards Australia / Standards New Zealand, 2002). This represents an additional cost to both private and public infrastructure.

For the oil and gas industry, consideration of tropical cyclones impacts controls the design of all offshore production facilities. The environmental conditions are severe off north-west Australia, among the worst in the world. Accordingly fixed oil and gas production platforms and associated submarine pipelines must be designed to withstand the large forces associated with these storms.

*Extreme disasters:* The third category of costs are those associated with an extreme disaster as defined in Section 4.

It is noted that BTE (2001) make a strong statement that the cost of loss of business should not be included when examining the impact of the disaster from a national perspective. Appendix IV of BTE (2001) develops a simple economic model to illustrate this. The basic reason is that business disruption usually involves a transfer between producers, without a significant loss in national economic efficiency. Quoting from BTE (2001), “The loss of supply from disaster-affected businesses will result in an increase in demand for the output from other businesses. The increase in demand may be felt in industries other than the disaster-affected industries. For example, it is usual for the necessary rebuilding activity following a disaster to stimulate the construction industry.” The economic model analysis in BTE (2001) finishes with the conclusion:

“The major economic impact of business disruption is a transfer of producer surplus from disaster-affected producers to producers unaffected by the disaster. Transfers of surplus do not represent an economic loss, although they do represent distributional effects of a disaster. There may be a net change in economic welfare, but it is likely to be small relative to the other impacts of the disaster. If the lost supply must be replaced by imports or if the lost production is for export, then there is no offsetting gain in producer surplus by other domestic producers. The loss in producer surplus by the disaster-affected businesses is a loss to the economy.”

Rephrasing the above conclusion, it means the losses associated with disruption of business can be taken into account when the business output is primarily for export, as it is then that the national economy is affected. (As pointed out to the author by Ryan Crompton of Risk Frontiers, the same holds when the lost supply has to be replaced by imports.)

If we are to accept this viewpoint, it affects the first categorization of economic costs, the damage costs. In the case of Western Australia, the loss or disruption of industry can still be included due to the facts that (i) the major industry affected is the mining sector, and (ii) that the majority of mineral and energy resources produced in Australia are exported (McInnes et al. 2007).

# 7 Economic Impact of Tropical Cyclones on Western Australia

### a) Damage losses based primarily on Insurance industry records

Using the above framework, the damage costs associated with tropical cyclones can be estimated from the insurance statistics kept by the Insurance Council of Australia and from the "total economic cost" figures in the EMA database. Table 1 lists the highest 15 insurance losses in Australia due to natural disasters (adjusted for inflation to Australian dollars) in the ICA database. Tropical cyclones feature prominently among these extreme disasters, contributing five of the 15. It is noteworthy, however, that only one disaster wholly in Western Australia appears in the list, that being a thunderstorm and hailstorm in the city of Perth in 2010.

Table 2 shows the results of the same data compilation, this time for disasters in Western Australia. As discussed above in Section 4, the results are skewed by one extreme event, the 2010 thunderstorm event. For Western Australia, tropical cyclones feature as being the major cause of natural disasters, appearing as half of the entries in the table. Analysing the ICA data base for Western Australian cyclones, it is found that over the period 1967-2011, insurance payouts in WA equalled $1,256 million dollars (adjusted to 2011 dollars), which averages $28 million per year. If the multiplier factor of Joy (1991) for ratio of insured loss to total damage is applied, this comes to total damage of $140 million per year.

These findings are consistent with those McAneney et al. (2007) who analysed one hundred years of records in the ICA data base. According to those authors, meteorological hazards dominate building losses in Australia's short recorded history. In terms of the total number of buildings destroyed (insured and uninsured) between 1900 and 2003, tropical cyclones have been most destructive, accounting for almost one third of losses with floods and bushfires each contributing another 20 percent, as do thunderstorms if hail, gust and tornado are combined.

| **Losses in 2011 Australian dollars from Insurance Council Data** | | **Year** | **Loss($ Aust million)** |
|---|---|---|---|
| Hail Sydney | NSW | 1999 | 4296 |
| **Tropical Cyclone Tracy** | NT | 1974 | 4090 |
| Earthquake Newcastle | NSW | 1989 | 3240 |
| **Tropical Cyclone Wanda and subsequent flood** | Qld | 1974 | 2645 |
| Flooding | Qld | 2011 | 2377 |
| Hail Brisbane | Qld | 1984 | 2063 |
| Severe storm east coast low | NSW | 2007 | 1742 |
| **Tropical Cyclone Madge** | Qld, NT WA | 1973 | 1492 |
| Fire Ash Wednesday | Vic | 1983 | 1489 |
| **Tropical Cyclone Yasi** | Qld | 2011 | 1405 |
| Hail Sydney | NSW | 1990 | 1297 |
| Fires | Vic | 2009 | 1266 |
| Melbourne Storm | Vic | 2010 | 1160 |
| Perth Storm | WA | 2010 | 1019 |
| **Tropical Cyclone Ada** | Qld | 1970 | 1001 |

**Table 1 The highest 15 insurance losses due to natural disasters (losses are inflation-adjusted to 2011 Australian Dollars). Compiled from the Insurance Council of Australia Disaster Statistics, as of 29 March 2012. (Note the damage associated with TC Madge is labelled TC Leah in the ICA database).**

| Natural disaster | Location | Date | Loss Million Dollars |
|---|---|---|---|
| storm | Perth | 22-Mar-2010 | 1019 |
| **Tropical Cyclone Joan** | Port Hedland | 7-Dec-75 | 398 |
| **Tropical Cyclone Alby** | Perth | 4-Apr-78 | 265 |
| **Tropical Cyclone Hazel** | Kimberley and Pilbara Coast | 13-Mar-79 | 202 |
| storm | Perth | 23-May-94 | 187 |
| **Tropical Cyclone Vance** | Exmouth, Onslow | 22-Mar-99 | 108 |
| storm | South West | 22-Aug-88 | 60 |
| earthquake | Meckering | 14-Oct-68 | 57 |
| fire | Margaret River | 24-Nov-11 | 53 |
| **Tropical Cyclone Bobby** | Kalgoorlie | 25-Feb-95 | 48 |
| earthquake | Cadoux | 2-Jun-79 | 38 |
| fires | Perth | 7-Feb-2011 | 35 |
| **Tropical Cyclone Amy** | Port Hedland | 10-Jan-80 | 31 |
| **Tropical Cyclone Rosita** | North | 20-Apr-2000 | 28 |
| **Tropical Cyclone Dean** | Pilbara | 1-Feb-80 | 27 |

**Table 2. The highest 15 insurance losses due to natural disasters in Western Australia (losses are inflation-adjusted to 2011 Australian Dollars). Compiled from the Insurance Council of Australia Disaster Statistics, as of 29 March 2012. (Note: in the ICA database, certain of these tropical cyclones are named incorrectly, for example the damage at Port Hedland in 1975 is attributed in the database to TC Thelma. The damage associated with TC Rosita is labelled in the database as caused by TC Paul.)**

A similar perspective to that in Tables 1 and 2 is found in the analysis of the total economic cost of disasters (both insured and uninsured) in BTE (2001). The major findings of BTE (2001) were synthesised into a short article by Gentle et al. (2001). Figure 5 from Gentle et al. (2001) shows the proportion of insurance costs to total economic cost for different disaster types across Australia. Nationwide tropical cyclones are responsible for 24 percent of the national cost of natural disasters (behind floods at 29 percent and severe storms at 26 percent). For the State of Western Australia, the period analysed by BTE (2001) showed that tropical cyclones contributed 66 percent of total cost, and according to the BTE analysis cost the state $41.6 million per year (in 1998 dollars, which adjusting for inflation would equal $61.3 million per year in 2011 dollars). As discussed in BTE (2001) and discussed above in Section 4, these average annual costs depend very much on the time period chosen. In the words of BTE (2001), "an extreme event in the future could radically change the proportions". This has happened already for Western Australia due to the severe thunderstorm and hail storm event in Perth in 2010 (Tables 1 and 2).

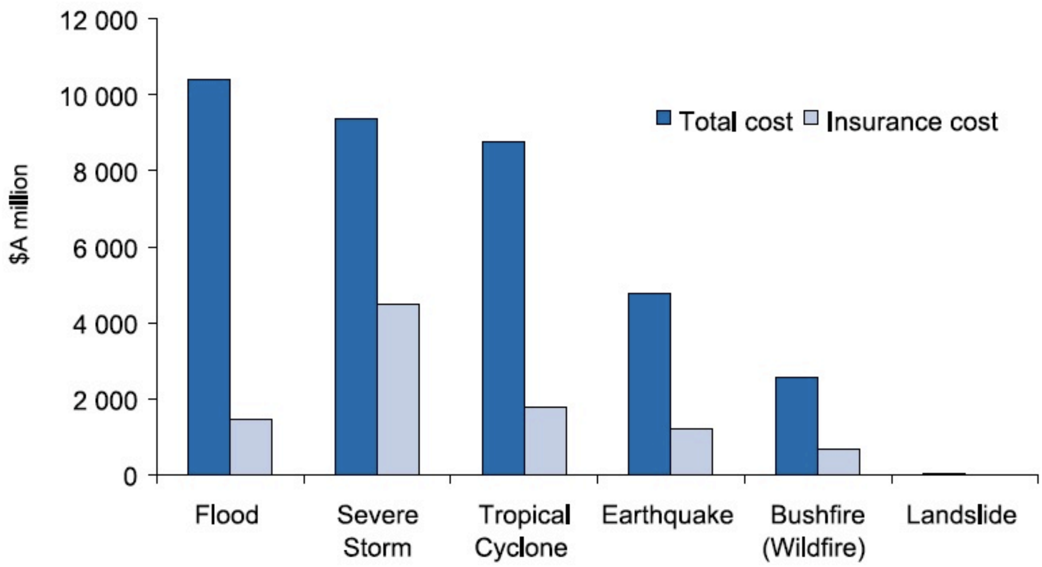


**Figure 5 Total and Insurance costs across Australia for different disaster types, 1967 – 1999. Source: BTE analysis of Emergency Management Australia (EMATrack) database (unpublished). Costs indexed to 1998 Dollars. From Gentle et al. (2001).**

As seen in Figure 5, the total economic cost in the EMA database and in the BTE (2001) analysis is several multiples of the insurance cost. Tables 2 and 3 of Gentle et al. list the various methods of cost estimation. It is worth listing the cost categories considered. For direct costs, these include depreciated economic value of residential buildings (structure and contents), depreciated economic value of commercial and industrial buildings, depreciated economic value of public buildings, cost of restoration of infrastructure, market value of crops (less input avoided), cost of restoration of pastures, cost of repairs of fences, market value of livestock. The indirect costs calculated include loss of value added due to business disruption, cost of provision for lost public services, cost of materials plus opportunity cost of labour used for cleanup (both residential and non-residential), additional cost of accommodation and transport costs associated with household alternative accommodation, costs to agriculture such as fodder, agistment and lack of productivity, increased vehicle operating costs and value of time for delayed vehicle and freight when transport networks are disrupted, marginal costs incurred by disaster relief and response agencies, plus opportunity costs of volunteer labour.

**b) Ongoing losses to the mining sector**

The estimation of these costs on a national scale by BTE (2001) was an important exercise in documenting and understanding economic impacts of disasters in Australia. For the situation in Western Australia, however, these estimates of *damage costs* do not represent the true cost to the state. As documented in Section 3c, the economy of the state is dominated by the mining sector operating through private companies, the major ones of which are international or multinational companies. The proposition is that the major economic impact of tropical cyclones is the ongoing cost of industry conducting business in a cyclone-prone area. These costs will appear in company income and expenditure balances, but are not publicly documented. In particular there is no industry-wide survey or estimation of these costs.

Drawing on discussions with representatives of the oil and gas industry, some of these costs are described in the following paragraphs.

*Design:* Tropical cyclones considerations control the design of all offshore production facilities. Fixed oil and gas production platforms and associated submarine pipelines must be designed to withstand the large forces associated with tropical cyclones.

*Exploration drilling*: Exploration drilling is undertaken from floating drill ships, which are usually anchored or dynamically positioned. Tropical cyclones and tropical low-pressure systems interrupt exploration operations. These operations run at about $800,000 per day, and a tropical cyclone would usually cause one to four days of lost time per storm (say an average of four storms affecting these per season).

*Production operations - fixed structure:* These are production platforms such as North Rankin A, Goodwyn A, Angel A, Pluto A, and operations by other companies.

Usually these structures are de-manned in the event of severe storms, and this may cause interruption to production. In this case oil and gas production is delayed, but results in less production in that financial year. These interruptions occur only once each two to three years, and the loss of production may be of the order of $20 to $30 million

*Production operations - floating disconnectable structures*: These are ships that are moored on a rotating turret mooring (RTM). Oil is produced from subsea well, and flows up the RTM to the ship. The moorings on the RTM are sufficiently strong to allow for the normal operation of the ship in all conditions except in tropical cyclones. When threatened by a tropical cyclone, the ships disconnect from the RTM. Companies such as Woodside, Santos and BHPP have facilities such as these off north-west Australia, probably about six or seven presently in operation. Each of these facilities would be affected by about two tropical cyclones each season, leading to probably about five days loss of production per ship. These vessels produce about 25,000 bbl[2] per day each.

*Gas processing, liquefaction and port operations*: Woodside is presently the only liquefied natural gas (LNG) producer in WA. Conoco-Phillips operate a LNG plant in Darwin. Ship loading of LNG at the Woodside Dampier facility is stopped when the port is threatened by a tropical cyclone or a tropical low or due to swell generated by a distant tropical cyclone. Normally through these periods (lasting one to three days), LNG production continues until the LNG tanks become full. At that point LNG production may be curtailed.

*Construction activities (onshore and offshore):* All construction activities are weather sensitive and are severely affected when threatened by tropical cyclones. In this case offshore construction activities are stopped, facilities are de-manned, and the construction barges are taken to a safe haven, such as behind the islands of the Dampier Archipelago. Such stoppages would generally delay construction activities by four to seven days per storm. Typical spread costs are about $1 million per day. Cost impact is dependent on the amount of construction activities in progress.

*Port operations iron ore industry*: The major iron ore ports at Dampier, Cape Lambert and Port Hedland are shut down when threatened by tropical cyclones or

[2] bbl: standard barrels of crude oil or other petroleum product.

tropical lows. Normally shut downs would be of the order of two to three days per storm, affecting many ships (perhaps six to 12), and incurring demurrage costs. Putting a monetary figure on the loss to industry from port closures is beyond the scope of the current report. However, as reported in Section 3c, cyclone-caused port closures contributed to a national trade deficit in the March 2012 quarter. The newspaper article referenced in Section 3c reported that the two ports (Hedland and Dampier) handled $40 billion worth of commodities in the 2009-2010 fiscal year. Simply dividing this figure by 365 gives a trade loss of $100 million for each day that both ports are closed. This should be considered a "ball-park" figure only as clearly there are other considerations, including increased production in subsequent months to make up for delayed shipments.

Some details of the impact of tropical cyclones on the mining industry are contained in the 2012 Quarterly Report of the Fortescue Metals Group Ltd (www.fmgl.com.au), a Western Australia based iron producer. Quoting from that report: "Shipped tonnes in the March quarter were below original guidance due to the impact of two cyclones that both resulted in the closure of Port Hedland port and collectively delayed ship loading for around eight days." The report also notes performance of mining operations during the quarter was impacted by excessive rain experienced in January 2012 from Tropical Cyclone Heidi. Over 470 mm of rain was recorded at Cloudbreak within a two-day period, which impaired operations at the company's principal mine for around two weeks. The report also noted that the "Cash costs per tonne" increased in that quarter as a result of lower shipped volumes caused by port closures and tropical cyclone flooding.

Besides possibly being the major economic impact of tropical cyclones in the state, it is clear that the ongoing losses to the mining sector (both minerals and energy) are not documented on any industry-wide basis. The documentation would exist within company balance sheets and internal records, but not publicly.

Some evidence for this lack of documentation can be found by returning to the examples given Section 3 of the impact of Tropical Cyclones Clare and Glenda (2006) which were reported as contributing to a loss of 13 percent of annual production in the mining industry (ABARE, 2006) and decline of oil production (Australian Bureau of Statistics, 2006). Despite these significant losses that had a visible impact on national exports, these cyclone are not recorded in Tables 1 and 2, and do not appear the Insurance Council of Australia database of disaster statistics. In addition, as reported on the ICA website, Munich Reinsurance Group (Australasia) compiled a report titled “Summary of Australian & New Zealand Major Property Losses by Industry Type 2005 – 2009”. That report, which lists the property losses for each year for each state and territory, does not mention either Tropical Cyclone Clare or Glenda. Our point here is not to criticise the industry statistics. On the contrary they are an extremely valuable resource and are the basis of much important research. The purpose of this example is to illustrate that the cost of cyclones to the minerals sector is most likely much larger than the recorded private and public damage, and is not currently documented.

**c) Positive economic benefits of cyclones**

As discussed in Section 3, for water supply for cities and for agriculture, tropical cyclones may well have an important positive benefit through their contribution to rainfall (Dare et al., 2012).

# 8 Impact of Climate Change

The research literature and reviews by the Intergovernmental Panel on Climate Change project that the Earth's climate will continue to warm through the remainder of the 21st century (Xu et al., 2005; Meehl et al., 2006; Yukimoto et al., 2006, IPCC, 2007). The implications of this warming for tropical cyclone behaviour are not well understood. An assessment of the state of the science of climate change impact on tropical cyclones was carried out by Knutson et al. (2011), a study partially funded by the current IOCI Project 2.2 (see Appendix).

Knutson et al. concluded that it remains uncertain whether any of the observed changes in tropical cyclone activity over recent decades can be attributed to global warming. One of the reasons for the uncertainty is the existence of large amplitude fluctuations in the frequency and intensity of tropical cyclones. The presence of these fluctuations, some of which can be attributed to natural oscillations, greatly complicate both the detection of long-term trends and their attribution to rising levels of atmospheric greenhouse gases. The second major reason is that trend detection is impeded by substantial limitations in the availability and quality of global historical records of tropical cyclones. Several important contributions on the quality of the tropical cyclone database and on the difficulties with trend detection in the Australian region have been made by Trewin (2008), Harper et al. (2008), Kuleshov et al. (2010) and Callaghan and Power (2010). One of the major issues in data quality is that cyclone intensity and wind speeds at sea are based on remote sensing techniques from meteorological satellites. Such techniques were implemented routinely in the Australian region in the early 1980's and are still developing. A consequence of this is that a stable time series of cyclone intensity records exists for less than 30 years. Given the high interannual variability of intense cyclones (with a standard deviation of intense cyclone numbers comparable to the average), this is not a long enough series for trend detection.

Confidence in climate modelling projections of cyclone numbers and cyclone intensity in a warmer climate is limited by the fact that climate models have difficulty in duplicating distributions of cyclone number, intensity and interannual variability in the current climate. It is also limited by the above-mentioned lack of clear detection of any anthropogenic or global warming induced trends in the historical data. Despite these limitations, the high importance of understanding and projections of disasters has resulted in a large number of ongoing international studies on the problem. These are described and reviewed in the Knutson et al. paper.

From these studies there is an emerging consistent result that the intensity of tropical cyclones will increase (by the order of two to 11 percent by 2100). For cyclone numbers the opposite is true - the global models consistently predict a decrease in cyclone frequency on the same time scale by the order of six to 34 percent, depending on the modelling study (Knutson et al., 2010). These projections have been confirmed recently for the Western Australian region in a model downscaling study, carried out for IOCI by Abbs (2010).

The key question concerning climate change in the context of this report is: *What effect will a warmer climate have on the economic costs reported on here*? Going to a national scale and including all disasters (not only cyclones), it is clear the annual economic losses have been steadily increasing over the past decade. This can be seen in the figures in Table 1, where six of the 15 highest insurance-loss disasters have occurred since 2007. The increasing trend can also be seen in the blue line in Figure 3, which represents the total annual insurance loss due to natural disasters. On a global scale, the picture is even more dramatic. Figure 6 shows overall losses and insured losses from weather- and climate-related disasters worldwide (in 2010 US$) and has been derived by IPCC (2011) from the Munich Reinsurance Company NatCat database (see Section 4).

There have been many studies of these trends in disaster-related costs in various countries of the world. The current author has led two separate assessment exercises of climate change impacts on tropical cyclones on behalf of the World Meteorological Organization. The first of these (McBride et al. 2006) was developed in a workshop environment with approximately 100 scientists from universities, government and private research organisations and representatives of National Hydrometeorological Services from around the globe (McBride et al. 2006). In that statement we reported: "Recent decades have seen a continuous increase in economic damage and disruption by tropical cyclones. This has been caused, to a large extent, by increasing coastal populations, by increasing insured values in coastal areas (e.g., Pielke 2005) and, perhaps, a rising sensitivity of modern societies to disruptions of infrastructure.

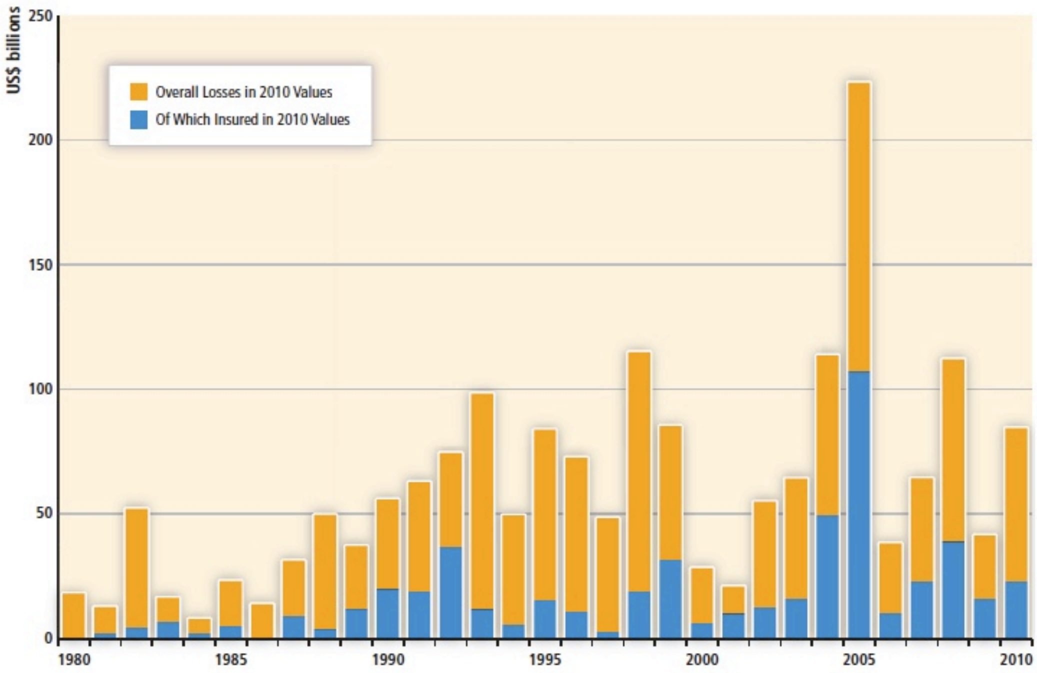


**Figure 6 The overall losses and insured losses from weather- and climate-related disasters worldwide (in 2010 US$). These data for weather- and climate-related 'great' and 'devastating' natural catastrophes are plotted without inclusion of losses from geophysical events. A catastrophe in this data set is considered 'great' if the number of fatalities exceeds 2,000, the number of homeless exceeds 200,000, the country's gross domestic product is severely hit, and/or the country is dependent on international aid. A catastrophe is considered 'devastating' if the number of fatalities exceeds 500 and/or the overall loss exceeds US$ 650 million (in 2010 values). Data from Munich Re (2011). Figure from IPCC (2011).**

For developing countries large loss of human life will continue, as the increasing coastal populations are a result of population growth and social factors that are not easily countered (Zapata-Marti, 2006)." In a second statement (Knutson et al., 2010), this time by a WMO Expert Team on Climate Change Impacts on tropical Cyclones, we made a very similar assessment. In this later statement we added the opinion that "climate change is hence one of several factors likely to affect the future evolution of damage from tropical cyclones".

Several authors have carried out normalization studies on time series of total economic costs from natural disasters.  Prominent among these are the studies by Roger Pielke Jnr and colleagues (Pielke 2005; Pielke et al., 2005, 2008) and by the Australian group at Risk Frontiers  (McAneney et al., 2007, 2009; Crompton and McAneney, 2008).  A comprehensive summary of loss normalisation studies was made by Bouwer (2011).

An example is the study of Crompton et al. (2008) who developed a normalisation methodology to adjust for changes in population, wealth and inflation since the time of the original event. Their approach uses the increase in the number of dwellings and the average nominal (in other words, in the dollars of the day) dwelling values as surrogates for population, wealth and inflation variables. An additional factor for Australian conditions is the influence of building regulations introduced in 1981 that stipulate more wind-resistant construction in tropical cyclone–prone areas. Application of these normalization methods, in most studies, removes any trend in the value of losses due to natural disasters.  This is shown in Figure 7, taken from their study.

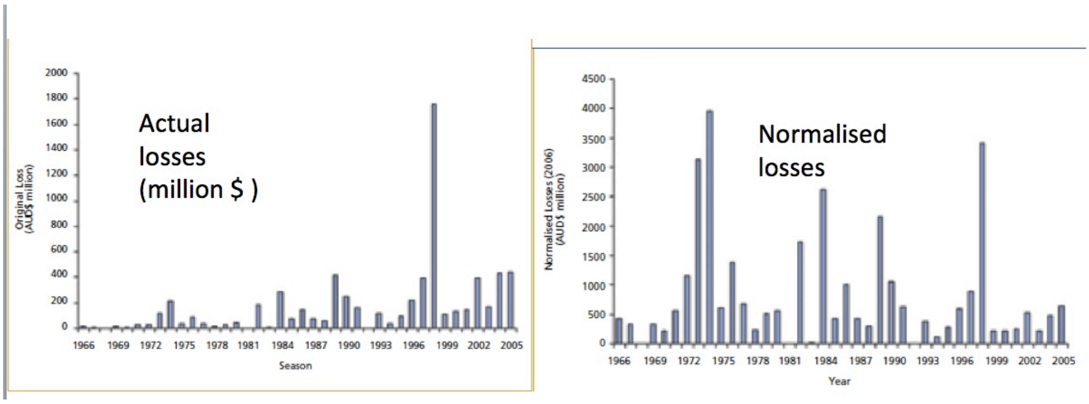


**Figure 7  Left panel: Original annual aggregate insured losses (AUD$M) for weather-related events in the Insurance Council of Australia Disaster List for twelve-month periods beginning 1 July. Right Panel, the same series (expressed in 2006 dollars) but adjusted backwards to take into account changes in population, wealth and inflation.  Figure from Crompton and McAneney (2008).**

As discussed by several authors, the degree to which normalisation removes the trend depends vey much on the quantitative assumptions and parameters in the normalisation model. The report on Climate Extremes by the Intergovernmental Panel on Climate Change (IPCC, 2011) reviewed the results of all global studies on economic losses. They concluded the following:

"Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters. Long-term trends in economic disaster losses adjusted for wealth and population increases have not been attributed to climate change, but a role for climate change has not been excluded" (IPCC, 2011).

Turning this finding around, it means that due to the same factors (increasing exposure, and increasing economic assets), the costs of disasters to Australia, and the cost of tropical cyclones to private property and to the minerals sector in Western Australia will continue to increase. Thus, if there is a small percentage change in the frequency of cyclones or the number of intense cyclones due to global warming, it will be difficult (perhaps impossible) to detect in insurance and private industry disaster statistics. This thesis has been addressed quantitatively for United States hurricane damage by Pielke (2009) and Crompton et al. (2011).

In reviewing a draft of this report, Dr Diana Greenslade of the Australian Centre for Australian Weather and Climate Research challenged the above conclusion that the impacts of climate change are likely to be non-detectable in future time series of cyclone-disaster related cost of damages. Her challenge is related to the statements of Knutson et al. (2011):

"Even assuming no future changes in tropical cyclone behaviour, storm-surge incidence from tropical cyclones, the most damaging aspect of tropical cyclone impacts in coastal regions, would be expected to increase because of highly confident predictions that at least some future increase in sea level will occur" (Knutson et al., 2011).

Current projections for sea level rise for the end of the 21$^{st}$ century have an upper limit of approximately 0.8 cm (Church et al., 2001; IPCC, 2007; Pfeffer et al., 2008). As postulated by Greenslade, if increases in background sea level are near this upper range, then a major amplification in damage costs is likely to occur associated with storm surge and inundation. This hypothesized non-linear amplification should be detectable in the damage costs time series even in the presence of increased costs associated with increasing coastal settlement and infrastructure. Several authors have studied the potential for increased storm surge inundation due to the projected rise in sea level (for example: McInnes et al., 2007; Walsh et al., 2012). However, to the current author's knowledge no one has modeled the potential impact on projected time series of damage costs.

We return now to the concept used throughout this report of climatological cyclone disasters or events and extreme events (Tropical Cyclone Tracy, Hurricane Katrina). Climate change or global warming could have a major impact if it were to bring about an increase in frequency or probability of extreme disasters. Risk is not simply a function of the frequency of a hazard occurring, but also of the vulnerability to that hazard. Tropical Cyclone Tracy was an example of an extreme disaster as the cyclone eye wall went directly over the centre of a major city. If the same cyclone had made landfall 100 km further long the coast, it still would have caused damage but would not have been an extreme event in terms of economic impact.

By this consideration, a spreading of population and infrastructure along the coastline gives rise to greater potential for extreme disasters, even with no change on the meteorological hazard. However, if climate change brings about an increased frequency of the most intense cyclones, this will increase the probability of extreme disasters.

The major index of a cyclone's potential for damage is its intensity, measured either by maximum sustained wind speed or by the minimum central pressure. A body of scientific literature has developed a theory for the maximum intensity that a cyclone can attain in a given environment. The main idea is illustrated in Figure 8. This shows a schematic probability density distribution of the maximum wind speed obtained by each tropical cyclone in a region over a period of, say, 30 years. The most intense cyclones are those at the right-hand end or the "tail of the distribution". The Maximum Potential Intensity (MPI) theories specify the magnitude of the maximum wind speed that a cyclone can attain. This maximum wind speed is specified depending on the value of sea surface temperature, tropopause height and other parameters that can be determined from climate model runs of current or future climates. For discussion of Maximum Potential Intensity theory and its application to climate change projections of cyclones see Emanuel (1987) and Holland (1997). The predictions of maximum potential intensity theory are one of the major reasons that climate scientists predict more intense cyclones in a warmer climate (Knutson et al., 2010).

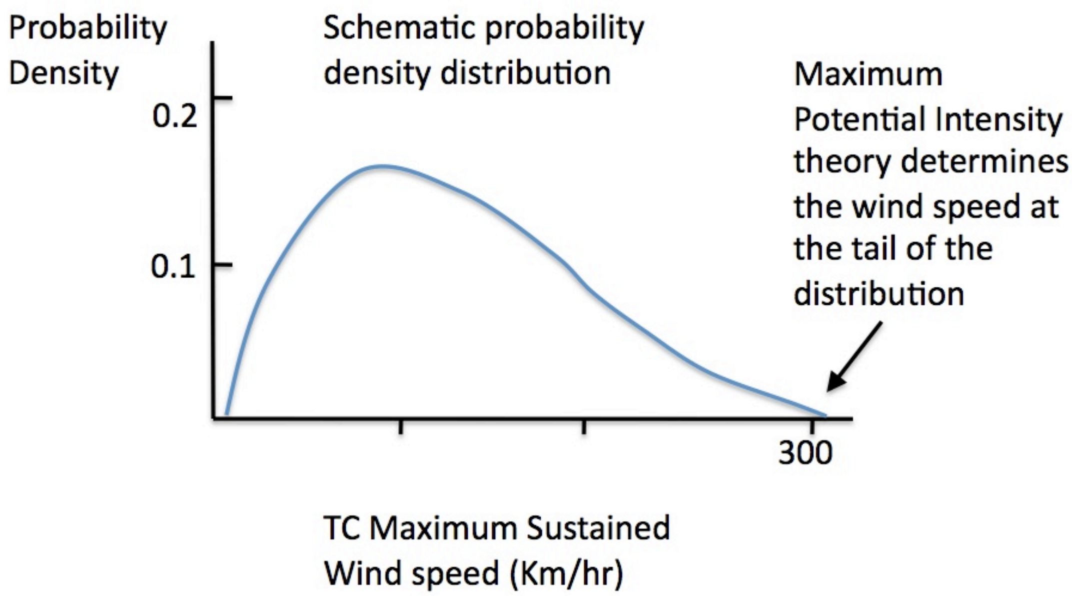


**Figure 8 A schematic illustration of the purpose of Maximum Potential Intensity theory for tropical cyclones. The curve represents the distribution of maximum wind speeds of all tropical cyclones in a region over a number of years. The arrow points to the maximum wind speed obtained, or the upper limit of cyclone intensity. MPI theory specifies what this speed can be under various climate conditions, according to sea surface temperature value, tropopause temperature and other parameters that can be predicted by climate models.**

As stated above, there is potential for tropical cyclone-related extreme disasters to occur in the future in Western Australia, independent of whether this is affected by climate change. The very large insurance payouts associated with the severe thunderstorm and hail storm in Perth in 2010 (Table 2) give an indication of the vulnerability of Perth to tropical cyclone passage. During the 95 year period from 1910 to 2004 there were a total of 14 tropical cyclones that either caused gales or caused wind-related property damage in the Perth region, equating to an annual frequency of occurrence of 0.15, equivalent to about one every six to seven years (Bureau of Meteorology www.bom.gov.au/cyclone/history/wa/perth.shtml). The vulnerability of industry can be seen from the example of the explosion at a processing plant on Varanus Island off the Western Australia coastline in June 2008. This caused a loss of approximately 35 percent to the State's gas supply. A survey by the Western Australia Chamber of Commerce and Industry estimated the disruption cost business and industry $2.4 billion in lost turnover during June and July 2008. As discussed earlier in this report, exports of mining products through the major WA ports are major contributors to Australia's balance of trade. Any tropical cyclone event that caused disruption for a period of several weeks or a month to one of these ports would have a major impact on the economy. Thus, it seems the major threat to Western Australia from climate change impact of tropical cyclones would be if it were to increase the probability of such events.

Despite this warning, it is important to note there is no strong evidence of any increased likelihood of these events occurring. Clearly however, this aspect of climate change and tropical cyclone modelling should be the subject of further research.

For completeness, we should note that in 2008, the Australian Government commissioned a major report on the economic impact of climate change to Australia. (Garnaut, 2008). This extensive work commissioned a number of studies on the economic impact of climate and weather on various sectors of the economy. The studies on the mining industry, on government infrastructure and on buildings in coastal cities all included the effect of tropical cyclones. The study commissioned extensive economic modelling of Australia's economy under various climate change scenarios.

The impact of tropical cyclones is synthesised in Table 11.2 of Garnaut (2008), labelled " Assessing the market impacts of climate change" available at: www.garnautreview.org.au/chp11.htm

The Garnaut commission incorporated the effect of the projected increased intensity of tropical cyclones on damage to residential and commercial buildings and infrastructure, including the possible risk of southward movement of climatological tropical cyclone tracks. The modelling considered the risk of these events to be "high", but the last column of their Table 11.2 listed the "likely economic consequence by the year 2100". For the entries incorporating the effect of tropical cyclones, the listed economic consequence is always listed as "low", meaning less than 0.1 percent loss of GDP (Garnaut, 2008, Table 11.2).

This is consistent with the analysis above which concludes the impact of increased intensity and decreased frequency of tropical cyclones in likely to be undetectable on a background of increased disaster costs due to inflation, increased population and increased coastal infrastructure. The major risk is probably if climate change brings about an increased likelihood of the extreme tropical cyclone disasters such as Tropical Cyclone Tracy in Australia and Hurricane Katrina in the US.

# 9 Conclusions

This report has documented and analysed the economic impact of tropical cyclones on the State of Western Australia. The major findings are as follows:

- The damage due to cyclone losses is not well documented. The only consistent records are those kept by the insurance industry. This extremely important resource has been the basis of almost all national and international studies on the cost of disasters.
- Non-insured losses, including losses to public infrastructure and to private companies are hardly recorded at all. Various estimation techniques have been developed giving widely varying results.
- Insured losses to Western Australia due to direct damage by tropical cyclones is averaged at $28 million per year. This is small compared to the cost of a number of individual natural disasters across the nation, for example $4296 million (2011 dollars) for the 1999 Sydney hailstorm, $4090 million for Tropical Cyclone Tracy (Darwin 1974), and $1019 million for the thunderstorm and hail event in Perth in March 2010. The Bureau of Transport Economics 2010 report on Australian disasters finds that disasters located in Western Australia contribute only 6 percent of the average annual cost of disasters in Australia
- Several examples are given of tropical cyclone related disruptions to mining in Western Australia having an impact on the economy and on the trade balance. The national trade deficit of January 2012 was attributed in part to the impact of mine closures and port closures due to cyclone Heidi. A loss of 13 percent of annual production of petroleum in 2005-2006 was attributed to the impact of Tropical Cyclones Clare and Glenda.
- It is proposed that the major economic impact of tropical cyclones to WA *is not the cost of damage repair* when cyclone-related disasters occur. Rather *it is the cost to an industry conducting business in a cyclone-prone area.* This will involve carrying out export subject to port closures during cyclone events, flooding of mines, closing down of road transports due to flooding and road damage, as well as ongoing adaptation and preventive measures underpinning activities of the mining sector.

- This ongoing cost to industry, particularly the mining the sector, is currently undocumented. Clearly, for national planning and for understanding the impact of cyclones on the economy of the country, steps should be taken to begin this documentation.
- The concept is presented of *extreme disasters* such as Tropical Cyclone Tracy, the 2011 Queensland floods, and the Black Saturday Victorian fires. It is contended the cost of these major events is several multiples of a normal tropical cyclone (or other disaster) event. For example the time series of (inflation-adjusted) tropical cyclone losses for Australia is dominated by one very large event, Tropical Cyclone Tracy. Any figures on mean annual losses or comparisons of cyclones with other hazards are changed totally according to whether or not this one event is included.
- A framework is proposed for understanding tangible costs due to tropical cyclone events. It is proposed that economic losses can be grouped in three categories: (i) damage costs; (ii) ongoing operating costs to industry; (iii) Extreme Disaster costs. The first two costs could be considered as part of the cost of carrying out industry in a state where the climatology has five cyclones per year off shore and two coastal crossings.
- Projections for changes in cyclone behaviour in a warmer climate are that the intensity will increase and the number or frequency will decrease. Increasing insurance payouts over recent decades for disasters are believed to be dominated by increasing vulnerability due to development of population and infrastructure in coastal regions. There is no clear evidence of any climate change signal in disaster costs.
- Consistent with this, the annual cost to private property, government infrastructure and the mining sector in Western Australia should rise in coming decades for the same reasons: higher infrastructure costs and increasing vulnerability due to greater population and coastal infrastructure. If tropical cyclone activity changes consistent with climate scientists' projections, the signal will be difficult to detect in the regular tropical cyclone insurance loss statistics.

- A potential major impact of climate change would be if the frequency of extreme disasters (such as cyclone Tracy in Australia, Hurricane Anita in USA) increased. There is no scientific evidence that this is likely to happen. However, it remains a major potential impact of climate change and should be further studied.
- Another potential impact of climate change may be the effect of inundation associated with storm surge. Even assuming no future changes in tropical cyclone behaviour, inundation from storm-surge would be expected to increase because of highly confident predictions that at least some future increase in sea level will occur. To our knowledge no studies have been carried out on incorporating this effect into projections of future economic impacts.
- Tropical cyclones also have a positive impact in Western Australia in that they are major contributors to annual coastal rainfall. They also play an important role in filling dams that then last several years before the next major rain event.
- The author is aware that economic impact, measured in dollars, is only one aspect of tropical cyclone damage. I have worked with meteorologists from South Pacific countries where a cyclone event can have an impact on economy and infrastructure including roads and hospitals that can last many years. I have worked with meteorologists from the Philippines, Myanmar and Bangladesh where large death rates are common with cyclone events. In these circles, presentations of global damage where the major disasters are to economic infrastructure in the United States are received with derision and distaste.
- Despite that reservation, it is important that work on the economic impact of tropical cyclones be carried further in both advanced and developing economies. The work presented here is by a meteorologist. It is hoped that economists will further the work and help address some of the questions raised.

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# 11 Appendix: Scientific Results of IOCI Project 2.2 Tropical Cyclones of the North West

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| **Scientific Papers in the international refereed literature.**<br><br>In the case of multi-authored publications, the contributions of J. McBride, H. Ramsay and R. Dare were funded by the IOCI project. | **1. Tropical cyclones and climate change**. Knutson, Thomas R., J McBride, J Chan, K A Emanuel, G Holland, C Landsea, Isaac Held, J Kossin, A K Srivastava, and M Sugi, March 2010: *Nature Geoscience*, 3, doi:doi:10.1038/ngeo779.<br><br>**2. Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean**. Y. Kuleshov, R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride and H. Ramsay: 2010*: J. Geophys. Res*. 115, D1, D01101, 0148-0227<br><br>**3. On Developing a Tropical Cyclone Archive and Climatology for the South Indian and South Pacific Oceans** Y. Kuleshov, L. Qi, D. Jones, R. Fawcett, F. Chane-Ming, J. McBride and H. Ramsay, 2010:. In, *Indian Ocean Tropical Cyclones and Climate Change*, 4, 189-197, DOI: 10.1007/978-90-481-3109-9_23 Springer, Netherlands.<br><br>4. **Sea Surface Temperature response to tropical cyclones**. Dare, R.A. and J.L. McBride. *Monthly Weather Review*. 2011. 139, 3798–3808..<br><br>**5. The threshold Sea Surface Temperature Condition for Tropical Cyclogenesis**. Dare, R.A. and J.L. McBride. *Journal of Climate*, 2011, 24, 4570-4576.<br><br>**6. Tropical Cyclone Contribution to Rainfall over Australia.** Dare, R.A., N.E. Davidson and J.L. McBride *Monthly Weather Review*, 2012. In Press. |
| **Presentations at International Scientific Conferences.**<br><br>In the case of multi-authored publications, the contributions of J.McBride, H. Ramsay, R. Dare and A.LeRoy were funded by the IOCI project. | 1. **Southern Hemisphere Sea Surface Temperatures and Tropical Cyclone Activity**. J.L. McBride and H. Ramsay: *Greenhouse 2009*, Climate Change and resources, Perth. 2009.<br><br>**2. Relationships between Tropical Cyclone Activity and Sea Surface Temperature in the Southern Hemisphere**: J.L. McBride and H. Ramsay. *2nd International Summit on Hurricanes and Climate Change,* Aegean Conferences, Corfu Greece, 31 May – 4 June. 2009.<br><br>**3. Global relationship between sea surface temperature and tropical cyclone activity**. John L. McBride , Richard A. Dare and Hamish A Ramsay *Third International Summit on Hurricanes and Climate Change,* Corfu, Greece: Invited/Keynote Presentation:. June 2011:<br><br>4. **Intraseasonal TC prediction in the southern hemisphere**. M. Wheeler, J.L. McBride, A. LeRoy and F.Vitart. Invited Paper for the *Symposium on Monsoons, Tropical Cyclones, and Tropical Dynamics, IUGG General Assembly,* Melbourne, Australia. June 2011. |
| **Operational Forecast Product**. | **Statistical predictions of tropical cyclogenesis and of tropical cyclone activity for the Southern Hemisphere**.<br><br>http://www.meteo.nc/espro/previcycl/cyclA.php<br><br>This product appears on the French Meteorological Weather Service (MeteoFrance) website from the Forecast Office in New Caledonia. The forecasts are in the form of maps of tropical cyclone activity 1-week, 2-weeks and 3-weeks ahead. The original published method by LeRoy and Wheeler (2008) produced single numbers for four regions across the Southern hemisphere. The revised method to produce spatial maps was funded by Project 2.2 of IOCI-3. |

**Appendix Table 1 Publications and operational products on tropical cyclones funded by IOCI stage 3 Project 2.2 Tropical Cyclones of the North West.**

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