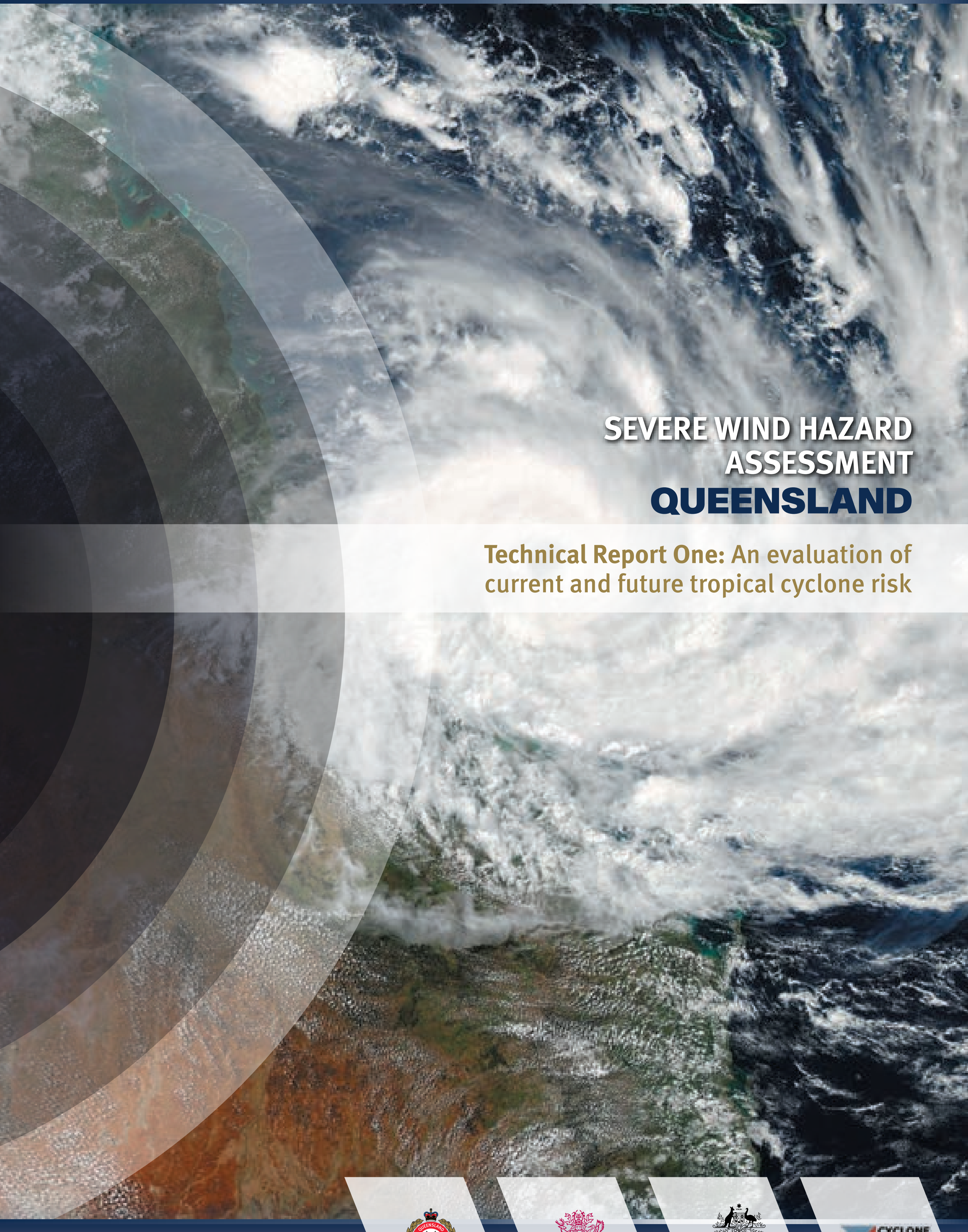

SEVERE WIND HAZARD ASSESSMENT
QUEENSLAND

Technical Report One: An evaluation of current and future tropical cyclone risk

Queensland Government
Australian Government
Geoscience Australia
CYCLONE TESTING STATION

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Additional contributions acknowledged throughout.

Acknowledgements

This project would not have been possible without:

The tireless efforts of Geoscience Australia and the Hazard and Risk Unit, Queensland Fire and Emergency Services (QFES), with the support of the Department of Environment and Science's Environmental Policy and Planning Division, to pursue the best available information to improve the understanding of current and future tropical cyclone risk in Queensland, and more broadly across Australia.

The Queensland Government's Natural Disaster Resilience Program supported by the Queensland Reconstruction Authority and the Commonwealth Government for providing funding to the project.

James Cook University's Cyclone Testing Station for contributions to the risk mitigation sections of this document as well as the provision of general advice to the project.

The Queensland Department of Environment and Science's Science Delivery and Knowledge Division for determined efforts and collaboration on the climate change analysis and development of all associated resources.

The Department of Fire and Emergency Services, Western Australia for general advice and lessons learnt from the development and implementation of the Severe Wind Hazard Assessment for Western Australia.

Dr Dave Callaghan (University of Queensland) and Marji Puotinen (Australian Institute of Marine Science) for their contributions to the evaluation of cyclone impacts to the Great Barrier Reef.

The National Computational Infrastructure Facility for providing the computing resources to develop and analyse the scenarios. The resources provided enabled the project to complete the development of the catalogue in minimal time, and also permitted interactive analysis and scenario selection.

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Bibliographic reference: Queensland Fire and Emergency Services and Geoscience Australia, 2022. *Severe Wind Hazard Assessment for Queensland. Technical Report One: An evaluation of current and future tropical cyclone risk.* Queensland Fire and Emergency Services, Brisbane. Geoscience Australia, Canberra. https://www.disaster.qld.gov.au/qermf/Pages/Assessment-and-plans.aspx

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Foreword from the Minister for Police and Corrective Services and Minister for Fire and Emergency Services

It is beyond doubt that climate and disaster risks are increasing and becoming more severe. That's why it is becoming more important than ever to explore a range of scenarios so we can better understand and prepare for a range of disaster events.

Lessons from Black Summer bushfires of 2019-20 and the ongoing COVID-19 global pandemic show us the need to prioritise our understanding of disaster risk and to work collaboratively across sectors to address the cascading and systemic impacts of these events.

This report offers us all a reminder that no part of Queensland's coastline is immune to the impacts of tropical cyclones.

It provides a comprehensive assessment of the potential impacts of severe tropical cyclones on key population centres across the State and can be used by all disaster management stakeholders to inform tailored risk reduction strategies relevant to their communities. The broader project also includes the development of a range of supporting products and resources to further safeguard our communities.

This work demonstrates that Queensland, as Australia's most disaster affected State, is proactively working to address these disaster risks and highlights Queensland's continuing commitment to safeguard people, property and the environment from disaster impacts.

The Honourable Mark Ryan MP
Minister for Police and Corrective Services and Minister for Fire and Emergency Services

The Tropical Cyclone Preparedness Guide developed as part of this project provides targeted guidance for households to understand and manage their tropical cyclone risks, prepare for events and become more resilient.

The Tropical Cyclone Impact Model, developed collaboratively between Queensland Fire and Emergency Services (QFES), the Western Australian Department of Fire and Emergency Services (DFES) and Geoscience Australia (GA) provides a significant enhancement to our ability to prepare for, respond to and recover from the impacts of tropical cyclones and contributes in part to the Queensland Government's implementation of recommendations outlined by the Royal Commission into National Natural Disaster Arrangements.

I commend the work of QFES, the Western Australia DFES, GA, the James Cook University Cyclone Testing Station and the participating local governments for their contributions to this important body of work.

I encourage all stakeholders to consider how the information within this report can be used to help prevent new risks, reduce existing risks and manage the residual risks associated with severe tropical cyclones.

Foreword from the Commissioner of Queensland Fire and Emergency Services

Disasters affect the lives of all Queenslanders. We are exposed to a range of hazards which can have a significant impact on our economy, our environment and our communities. These hazards are becoming increasingly extreme and complex, exacerbated by our globally interlinked economies, and the systemic impacts of climate change.

Mr Greg Leach
Commissioner, Queensland Fire and Emergency Services

Within the last decade, we have experienced disasters of a scale and intensity that escapes recent memory. From the Queensland floods and Tropical Cyclone Yasi in 2011, to the nationwide bushfires of 2019/20, and now the ongoing response to the COVID-19 pandemic. These events are a clear indication that we face new challenges understanding and responding to these disasters, and the effect climate change has on those hazards.

This includes the changing nature of Queensland's tropical cyclone risk. In 2017, the impacts of Tropical Cyclone Debbie were a catalyst for a renewed look at the type of information needed to effectively manage tropical cyclone risk in Queensland.

The 2017 State Natural Hazard Risk Assessment, and consultation with stakeholders across all levels of Queensland's disaster management arrangements has further highlighted a need for access to detailed and consistent risk information.

We should all recognise that the communication of consistent risk information between each tier of Queensland's disaster management arrangements — starting at the local level and flowing through to district and State — can support communities and government, emergency services and all emergency management partners to make more informed decisions.

Risk-based planning is key to better prevent, prepare for, respond to and recover from the impact of natural disasters in Queensland. Including detailed climate change projections for communities represents a maturing capability for informing the development of current and future risk-based plans, across Queensland's disaster management arrangements and the emergency management sector.

I thank all stakeholders for their contribution to this assessment and for their continued commitment to creating safer and more resilient communities.
I would also like to thank the Department of Environment and Science and Geoscience Australia for partnering with Queensland Fire and Emergency Services (QFES) on this initiative, and the participating local governments for their ongoing support and cooperation.

Finally, QFES acknowledges the funding contribution of the Commonwealth Government of Australia and Queensland Government through the National Disaster Resilience Program in helping to deliver this project.

I encourage all stakeholders to consider the information and strategies within this valuable assessment and use it to inform the management of risks applicable to their interests and responsibilities.

Foreword from Department of Environment and Science

Queenslanders are more familiar than most with the devastating impacts that severe tropical cyclones can have on our economy, communities, and environment. The increasing effects of climate change, already being felt by our ecosystems including our iconic Great Barrier Reef, mean it is more important than ever that we are as prepared as we can be for natural disasters.

The Queensland Government is taking significant action to mitigate climate change, but we know there is also a significant amount of work to be done in how we adapt and manage increased risks from climate change.

Meaghan Scanlon MP

Minister for the Environment and the Great Barrier Reef and Minister for Science and Youth Affairs

To support climate risk management in Queensland, we are continuing to play our part in progressing our understanding of how climate change is likely to affect the risk posed by natural hazards. This includes the risk of tropical cyclones to Queensland's communities, infrastructure, and the environment into the future.

I am proud of the work that our Department of Environment and Science (DES) has done to partner with Queensland Fire and Emergency Services (QFES), Geoscience Australia, and other stakeholders, to provide the best science to inform their work in managing future risk.

The Queensland Future Climate Dashboard allows Queenslanders to visualise climate projections for Queensland, right across the state. To enhance this understanding the QFC webpages now feature a Tropical Cyclone Dashboard to display the future projections in terms of the frequency and intensity of tropical cyclones for current and future risk analyses.

I look forward to the ongoing collaboration between DES and QFES, and other partners, to continue to advance our state's preparation for the future.

Foreword from Geoscience Australia

The Australian Government is working to reduce the risks posed by disaster and meet the 2030 goals set out in the National Disaster Risk Reduction Framework.

In order to achieve this aim, Geoscience Australia provides nationally consistent data, information and advice on the potential impacts of natural hazards such as floods, tropical cyclones, bushfires, earthquakes and tsunami. This enables decision makers in government, industry and the community to make evidence-based decisions so that they can better prepare for, respond to and reduce the impact of these potentially devastating events.

Dr James Johnson
CEO, Geoscience Australia

For Geoscience Australia, an important part of this work is collaborating with state emergency services agencies. Together, we investigate the likelihood and potential impacts of a range of natural hazards on communities around Australia.

Geoscience Australia welcomed the opportunity to collaborate with QFES and the DES in this important work that applies our national-scale data and information at the local level and, in partnership, delivers tangible, actionable information.

This collaborative effort now provides the Queensland Government with the best evidence to work confidently with councils and communities to reduce the impact of tropical cyclones and, importantly, quantify how future climate will affect these events. For Geoscience Australia, this collaboration advances our understanding of Australia's vulnerability to tropical cyclones and, for the first time in Australia, integrates climate projections into a hazard assessment.

While learning from the impact of past tropical cyclones is valuable, our aim is that all local communities have access to the most recent data, science and modelling to prepare for likely future events. We do this by combining our understanding of tropical cyclone hazard – the intensity and frequency of these events – with our knowledge of people and buildings exposed, and how they are likely to respond.

Bringing these three components together means emergency managers, infrastructure owners, town planners and engineers can plan for and reduce the threat of tropical cyclone hazard before the next event. While modelling future hazard scenarios is never going to be perfect, it is an important guide to improve resilience and prepare for probable worst-case scenarios. It gives local communities the best chance to plan ahead, in order to minimise the potential effects of major weather events.

1 INTRODUCTION AND BACKGROUND

1 Introduction and background

The Severe Wind Hazard Assessment for Queensland arose as a project to better understand the potential impacts of tropical cyclones (TCs) on population centres and elements of critical infrastructure in Queensland. The rationale for this project was reinforced by lessons from TC Debbie, the direct and indirect impacts of which affected a significant area of Queensland, stretching from Bowen to the City of Gold Coast and Northern New South Wales between 28 March and 7 April 2017, resulting in 14 mostly flood associated deaths and more than A$3.5 billion in direct losses (see Figure 1).

This project addresses Recommendation 7.b of the Queensland Inspector General Emergency Management (IGEM) Cyclone Debbie Review[1], that *"Significant effort should be invested to provide disaster decision-makers at every level with a shared understanding of risks, the situation, and capability, so that they can agree the best decisions for the communities they serve"*. This project has sought to meet that recommendation through the objectives outlined later within this section.

Importantly, this project also aligns with the Queensland Climate Adaptation Strategy (Q-CAS)[2], which is part of the broader Queensland Government's Climate Change Response. The Q-CAS recognises links between climate change and shifting, often worsening, impacts from natural disasters and extreme events, and therefore the need for continued collaboration in Queensland across climate adaptation and disaster resilience agendas. This project contributes to addressing that need in relation to severe wind hazard in Queensland.

The intent of this project is not to re-examine historical events but to explore and assess a range of scenarios that extend beyond the contemporary recollection of severe events in order to inform decision making for rarer but more high-consequence events. Research suggests that although TCs may become less frequent under a changing climate, they are likely to become more intense and start reaching further south (CSIRO and Bureau of Meteorology, 2018; Kossin et al., 2014). Importantly, this project also provides information on the changing nature of severe winds in Queensland that are projected under a changing climate.

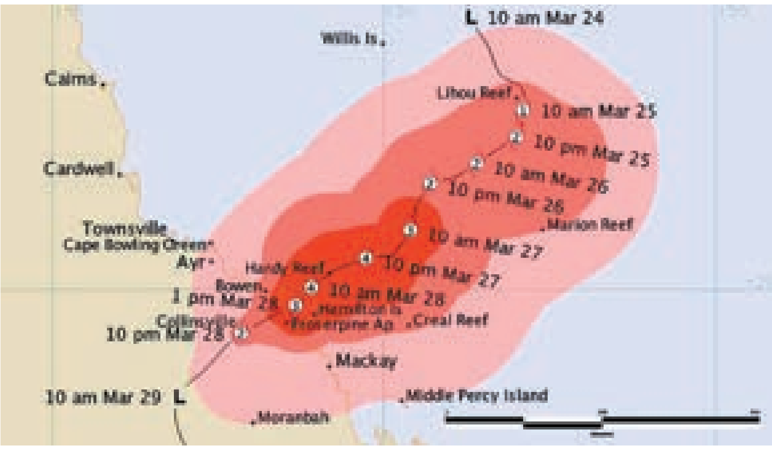


Figure 1: Track map for Tropical Cyclone Debbie issued at 7.49pm on 26 March. Source: Bureau of Meteorology

Figure 2: Damage to Shute Harbour. Source: ABC News (Dan Peled)

Figure 3: A badly-damaged plumbing business in Proserpine, 101km north west of Mackay. Source: ABC News

Figure 4: Coastal inundation at Seaforth Beach, Mackay. Source: ABC News (Lisa Hunter)

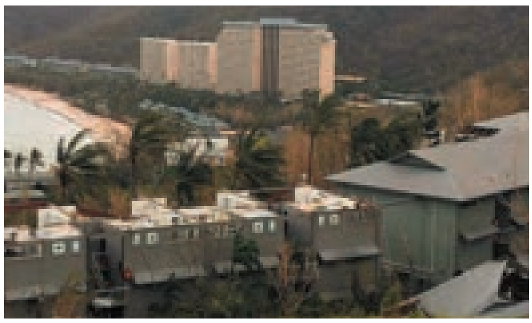


Figure 5: Roof damage sustained to holiday accommodation on Hamilton Island. Source: ABC News (Dennis Garrett)

Timeline of TC Debbie

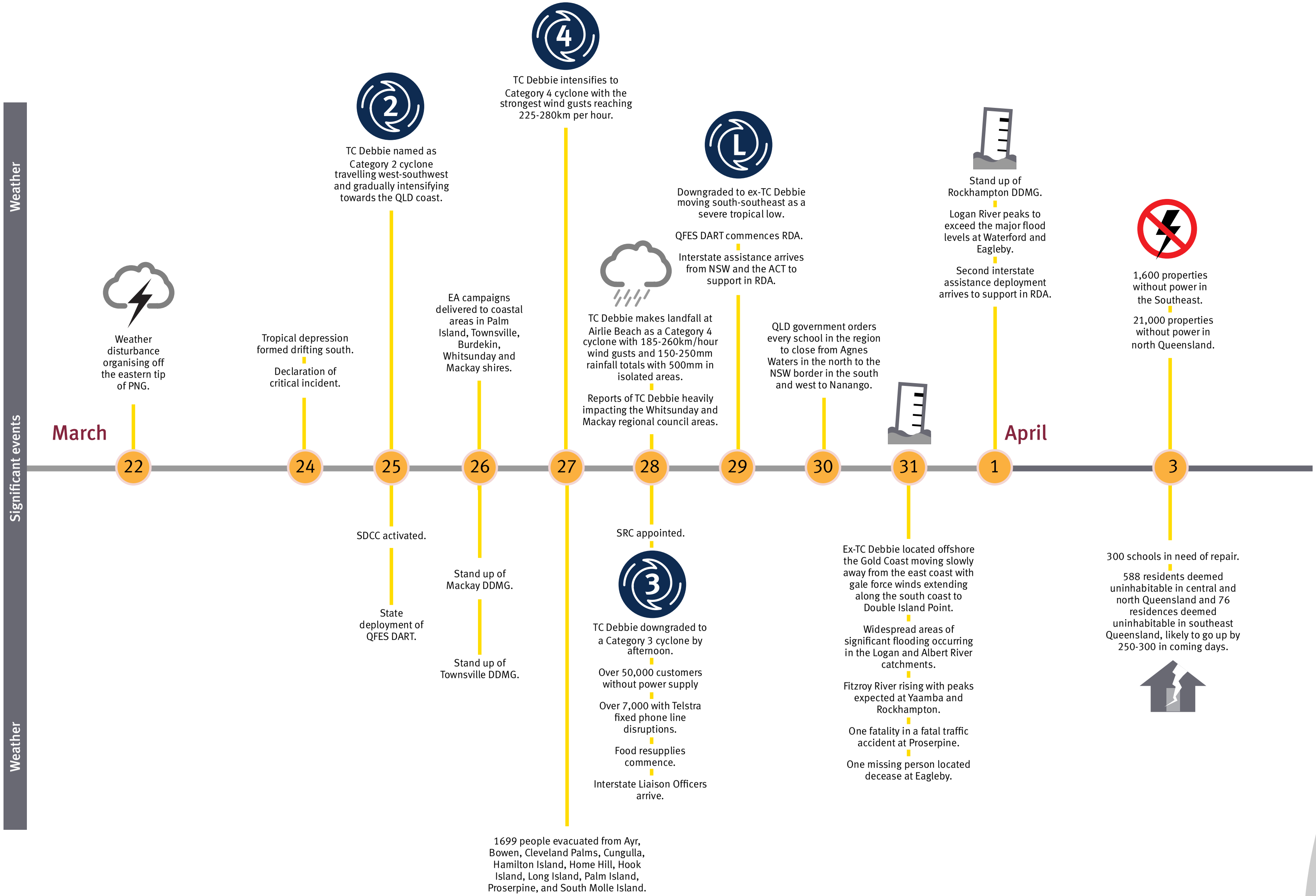


Figure 6: Timeline of TC Debbie and its impacts – 22 March to 4 April 2017.

1.1 Strategic background

The Queensland Government's disaster management objectives and strategies[3] recognise that communities are at the forefront of disaster impacts and, accordingly, prioritise supporting communities to prevent, prepare for, respond to, recover from and become more resilient to disasters. These objectives seek to:

- safeguard people, property and the environment from disaster impacts
- empower and support local communities to manage disaster risks, respond to events and be more resilient.

The strategies developed to achieve these objectives, that are relevant to this study, include:

- build capacity, skills and knowledge to enable adaptation to changing environments
- effectively collaborate and share responsibilities for disaster management across all levels of government, industry and communities
- incorporate risk-based planning into disaster management decision making
- continuously improve disaster management through implementation of innovation, research and lessons learnt.

According to the Queensland State Natural Hazard Risk Assessment (2017), tropical cyclones, alongside riverine flooding, remain the hazards whose impacts pose the greatest risk to Queensland. A strong need, therefore, exists to understand the disaster risk posed by severe wind and tropical cyclones in sufficient detail to meet the community's needs and communicate appropriate risk information across the three tiers of Queensland's disaster management arrangements: local, district and state.

Relatedly, the Queensland Emergency Risk Management Framework (QERMF), as the framework endorsed by the Queensland Disaster Management Committee (QDMC), was developed to build on and enhance the risk assessments and risk-based plans developed by local governments and disaster districts. The QERMF is a holistic disaster risk management paradigm to be applied across all levels of the Queensland's disaster management arrangements. The QERMF risk-based planning methodology directly contributes to the implementation of the Queensland Strategy for Disaster Resilience (QSDR) and aligns with its four guiding principles: shared responsibility, an integrated risk- based approach, evidence-based decision-making and continual learning.

As highlighted in the introduction, the Queensland Climate Adaptation Strategy (Q-CAS) recognises links between climate change and shifting, often worsening, impacts from natural disasters and extreme events. Further, with its strong focus on the need for collaboration, the Q-CAS supports stronger collaboration in Queensland across climate adaptation and disaster resilience agendas. Indeed, in alignment with the Q-CAS and the QSDR, strong collaboration and a sense of shared responsibility has guided the development of this project and its related science communication work. This project was supported, whether formally or informally, by representatives from across Federal, state and local governments, academia and industry.

In a similar vein, under the Q-CAS, the Emergency Management Sector Adaptation Plan (EM-SAP) recognises that the climate is already changing and that the need to incorporate climate change into a comprehensive approach to risk management across prevention, preparedness, response and recovery is paramount.

In support of its objectives, the Q-CAS also calls for the advancement of climate science and, based on that science, the education of Queenslanders. Under a partnership between QFES and DES, this project has both advanced and been informed by climate science in relation to the modelled projection of future severe wind hazard, under climate change, for Queensland. This partnership has also supported the inclusion throughout the project's development and in this report, of climate adaptation considerations, as well as some analysis of the exposure of the natural environment to modelled severe wind hazard (to complement the project's focus on the built environment).

The project has also seen relevant science communication and education resources about severe wind hazard collaboratively developed, in support of many of the findings and objectives highlighted in the abovementioned disaster risk and/or climate adaptation documents. Indeed, in alignment with the Q-CAS and the QSDR, this project seeks to:

- collaboratively support Queenslanders to improve their recognition of the natural hazard of severe wind, including under projected future climate
- better equip Queenslanders to make well-informed decisions about severe wind hazard and
- support Queenslanders to continue to integrate disaster resilience and climate adaptation considerations in relation to severe wind hazard, into policies and processes.

1.2 Project objectives

The core objectives of this project are to:

1. Provide information for decision makers to better understand the hazard and potential physical impacts to Queensland communities of tropical cyclones.
2. Inform decision makers and the community of our evolving understanding of how climate change might affect tropical cyclone risk in Queensland, and thereby facilitate the development of risk management strategies that account for this understanding and the related uncertainty. To achieve this, there is a need to identify:
   a. information gaps regarding the impacts on Queensland of a tropical cyclone under the current climate
   b. how climate change might affect Queensland's tropical cyclone risk into the future.
3. Identify opportunities for increasing resilience of residential houses across Queensland's cyclonic regions.

The project focuses on population centres and elements of critical infrastructure, while also considering impacts to our natural ecosystems, including the Great Barrier Reef, one of Australia's most treasured natural wonders.

It is important to note, for this project, a quantitative assessment of the damage arising from associated water ingress and storm surge was out of scope due to project constraints. However, and where possible, the analyses of the scenarios within this report will offer a limited qualitative assessment of the additional potential impacts from storm surge, wind driven debris and riverine flooding. This seeks to aid stakeholders with the consideration of associated cyclonic hazards and risks.

To communicate the potential impacts of tropical cyclones across the diverse region of Queensland, the assessment has selected seven communities or regions of Queensland that are representative of the differences in:

- **climatology**
- **demographics** (as defined by the Queensland Government Statistician's Office, 2019)
- **social vulnerability** – using the Australian Bureau of Statistics' Socio-Economic Indexes for Areas (SEIFA) as a baseline (Australian Bureau of Statistics, 2018)
- **regional economic profiles** (as defined by the Queensland Government Statistician's Office, 2019).

These are:

- **Complex Urban Environment** (SEQ): City of Gold Coast
- **Complex Urban Environment** (NQ): Townsville and surrounding region
- **Regional Economic Centre:** Gladstone and Mackay
- **Tourism Centre:** Cairns and the surrounding region
- **Remote Indigenous Communities:** Kowanyama and Pormpuraaw.

The project includes the co-development and implementation of the:

- **Tropical Cyclone Risk Model** (TCRM), which provides the ability to undertake scenario based and probabilistic assessments of severe wind.[4]
- **Tropical Cyclone Impact Model** (TCIM), which provides forecast operational information on the estimated severe wind impacts based on Bureau of Meteorology published cyclone track forecasts.[5]
- **Tropical Cyclone Dashboard**, a visualisation tool for modelled current and future cyclone hazard that allows users to understand the change in likelihood of severe wind across all local government areas, disaster districts and 200 individual locations across Queensland.[6]

In addition to this report, the above resources provide information to support decision making by the community and across all levels of Queensland's disaster management arrangements.[7]

The evaluation of cyclone risk to the Great Barrier Reef and other environmental values in this report adds to the ability of asset managers and their research partners to better understand and manage future impacts.

1.3 The hazard

1.3.1 What is a tropical cyclone?

Tropical cyclones (cyclones or TCs) are low-pressure systems that develop over the warm oceans off the northern coasts of Australia. They can vary significantly in terms of size and direction of travel (Figure 7 to 10 below), and can produce very strong winds, storm surge, heavy rainfall and flooding. The severity of a TC is described using a five-category system, shown in Table 1, that is based on the strongest wind speeds generated near the centre of the cyclone.

Category	Maximum Mean Wind (km/h)	Typical Strongest Gusts (km/h)	Typical Effects
1	63 - 88	< 125	Damaging winds. Negligible house damage. Damage to some crops, trees and caravans. Boats may drag moorings.
2	89 - 117	125 - 164	Destructive winds. Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small craft may break moorings.
3	118 - 159	165 - 224	Very destructive winds. Some roof and structural damage. Some caravans destroyed. Power failures likely.
4	160 - 199	225 - 279	Significant roofing loss and structural damage. Many caravans destoyed and blown away. Dangerous airborne debris. Widespread power failures.
5	> 200	> 279	Extremely dangerous with widespread destruction.

Table 1: The five-category system used to describe the severity of a tropical cyclone. Source: Adapted from the Bureau of Meteorology

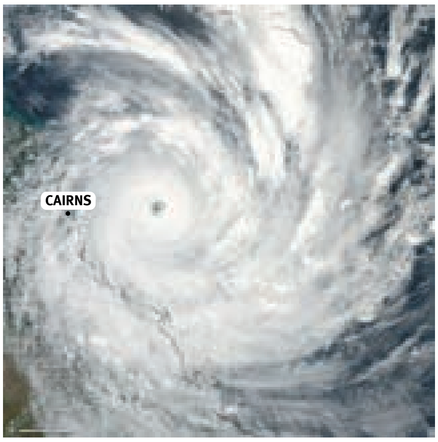


Figure 7: Tropical Cyclone Yasi.

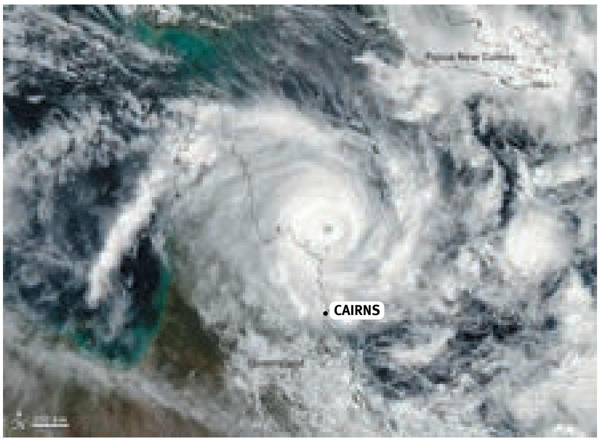


Figure 8: Tropical Cyclone Ita.

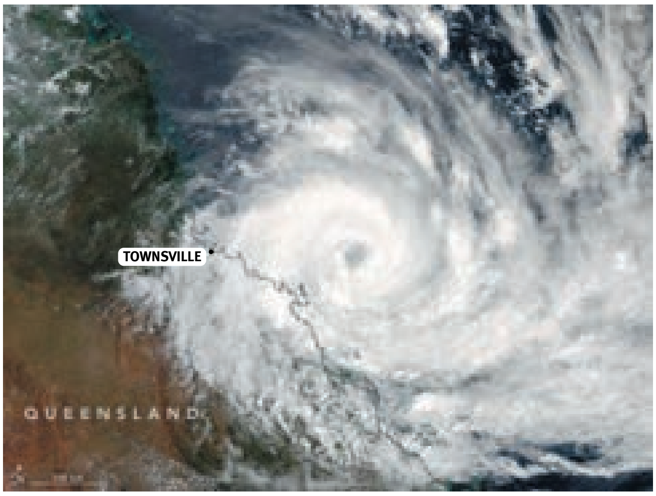


Figure 9: Tropical Cyclone Debbie.

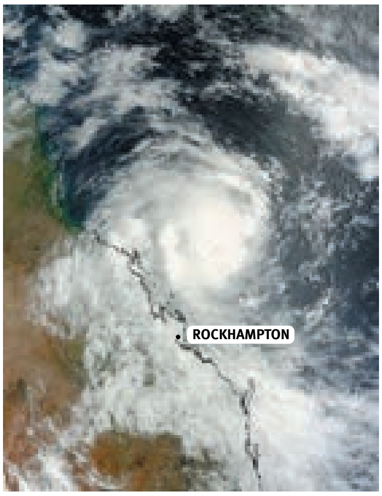


Figure 10: Tropical Cyclone Marcia.

1.3.2 How do tropical cyclones form?

A cluster of thunderstorms can develop over warm tropical oceans. If that cluster persists in an area of low pressure, it can start rotating. If the conditions are just right, the cluster of thunderstorms can grow in size and sustain itself and then develop into a TC.

Once developed, a TC is like a giant, atmospheric heat engine. The moisture from the warm ocean acts as its fuel, generating huge amounts of energy as clouds form.

The rotating thunderstorms form spiral rainbands around the centre (eye) of the cyclone where the strongest winds and heaviest rain are found (eye wall), transporting heat 15km or higher into the atmosphere. The drier, cooler air at the top of the atmosphere becomes the exhaust gas of the heat engine.

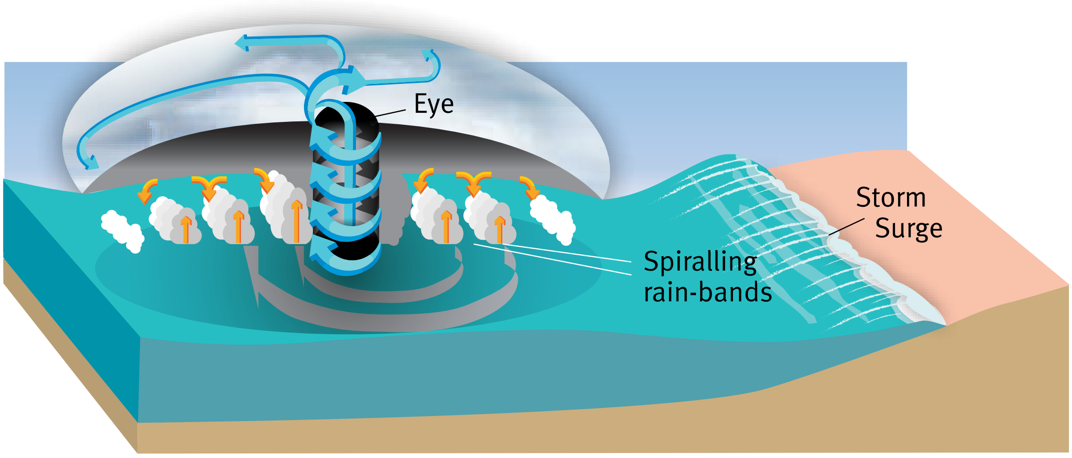


Figure 11: Diagram of a tropical cyclone system.

Some of the cool air sinks into the low-pressure region at the centre of the cyclone, hence causing the relatively calm eye. The eye is usually about 40km wide but can range from 10km to over 100km, with light winds and often clear skies. The rest of the cool air spirals outward, away from the cyclone centre, sinking in the regions between the rainbands.

As long as the environmental conditions support this atmospheric heat engine, the TC can maintain its structure and even intensify over several days.

1.3.3 Characteristics of a tropical cyclone

1.3.3.1 Strong winds and rain

Strong winds generated during severe cyclones can cause extensive property damage and create wind-borne debris that can result in injury to people and damage to buildings. Cyclones can also produce very heavy rainfall, which can cause both flash flooding and widespread flooding. Flooding can damage properties but will also cut roads and other infrastructure. The combination of damage from wind and rain can affect a community for many months.

1.3.3.2 Storm surge and storm tide

Storm surge is a rapid rise in sea level above the normal tide levels caused by strong onshore winds generated by an approaching cyclone. Storm surge has been responsible for more deaths during cyclones than strong winds.

Storm surge is potentially most damaging when a cyclone's surge of water coincides with high tide – "storm tide". A three-metre storm surge on top of a high tide that is two-metres above the mean sea level will produce a storm tide that is five-metres above mean sea level.

A severe storm surge can damage or destroy buildings and wash away roads. The extent of sea water flooding from a storm tide can last for several hours, extend up to 100km along the coastline and up to several kilometres inland in low-lying areas.

1.3.3.3 Expected damage from cyclones

Previous tropical cyclones, including TC Larry in 2006, TC Yasi in 2011, TC Marcia in 2015 and TC Debbie in 2017, caused significant damage to properties in several towns in North and Far North Queensland with consequential flood impacts in Central and Southern Queensland.

The most common types of damage included:

- roofs blown away due to failure of rusted fasteners, connector plates, roof battens and other roof components; in some cases, houses that had been re-roofed were damaged because either over-battens were removed and not replaced, or the new tie-downs had inadequate strength
- damage to verandahs and roofs caused by failure of rot or termite-affected timber
- failure of inadequately secured gutters, flashings, fascia and eaves
- wind-driven rain entering buildings through vents, under flashings or through weep holes in windows and glass sliding doors, causing damage to floors, ceilings, walls and building contents
- broken doors and windows caused by wind-borne debris, which let in more rain and wind
- doors and windows blown open due to inadequate fixing to walls or inadequate locks and door sets
- garage doors being blown in or out
- collapse of unreinforced masonry walls
- damage to buildings, fences, pools, patios, carports and other structures caused by falling trees or wind-borne debris
- property inundation and damage caused by storm tide.

Importantly, buildings that are older (pre-1980s), poorly maintained and/or located in exposed positions such as near the top of hills, on the beach or next to open land are significantly more likely to experience damage than those buildings of modern construction or those that are well sited topographically.

Wind and debris damage to buildings

Severe winds generated by cyclones can cause structural damage to homes and other buildings. This damage may cause injury to occupants and place other members of the community at risk because the debris picked up by the wind can damage other buildings.

Figure 12: Damage to buildings in Yeppoon in the aftermath of Tropical Cyclone Marcia, 2015. Source: Queensland Fire and Emergency Services

Damage from wind-driven rain

Even if there is no structural or debris damage to roof or external walls, wind-driven rainwater can cause significant damage to ceilings, internal walls, carpets, furniture and belongings. Strong winds can drive large volumes of water into property during a cyclone through:

- weep holes (drainage slots at the bottom of frames) or seals in windows and glass sliding doors
- roof vents
- holes, cracks, gaps or wherever a pipe or cable pierces the wall or roof
- flashings.

Rainwater bubbling through weep holes in windows.

Water on timber floor.

Damage to plasterboard ceiling from water ingress through the roof.

Mould on ceiling.

Figure 13: Examples of internal damage to houses caused by Tropical Cyclone Debbie, 2017.
Source: James Cook University (Cyclone Testing Station's post-impact damage assessment, Tropical Cyclone Debbie, 2017)

Damage from storm tides and storm surge

Storm tides are abnormally high sea levels that result from the combination of normal (astronomical) tide levels and the storm surge height. If the water level rises high enough that it floods infrastructure and buildings, it can cause significant damage and risk to life. Buildings close to the sea front can be damaged by waves and debris such as rocks, damaged building material, trees, furniture and even cars that can be swept along by the storm tide. Storm tides can also erode soil and expose building foundations. Inundation by saltwater can also cause buildings and infrastructure to corrode more quickly than they otherwise would have, which can have longer-term social and economic consequences.

Figure 14: *The effects of storm surge at Tully Heads from Tropical Cyclone Yasi in February 2011. Source: ABC News (Kerrin Binnie)*

1.4 Historical tropical cyclone activity in Queensland

The eastern Australian coastline from Cape York Peninsula to Coolangatta has experienced many TCs over the past 100 years, with many severe TCs causing major destruction to communities, such as TC Althea at Townsville in 1972 and TCs Larry and Yasi at Innisfail in 2006 and 2011 respectively (Figure 15).

There are extensive historical records of other TCs, including TC Mahina, one of the most intense TCs to ever occur in the Southern Hemisphere which made landfall in Far North Queensland in 1899 (Nott et al., 2014; Townsend, 2020) see also Appendix D). There are also records of TCs making landfall in South East Queensland in the 1950s (The Great Gold Coast Cyclone, 1954), and numerous cases of TCs passing close to South East Queensland but remaining offshore (e.g. TC Dinah, 1967 and TC Oma, 2019), causing significant impacts from wind, rain and waves.

This level of TC activity is reflected in construction standards, with much of the Queensland coastline defined in Australian Standards/New Zealand Standards 1170.2 Structural design actions, Part 2: Wind actions (hereafter AS/NZS 1170.2; 2011; Figure 17 and Table 2) as a cyclonic region. South East Queensland is defined in AS/NZS 1170.2 as an intermediate region, recognising that TC winds are possible but rare.

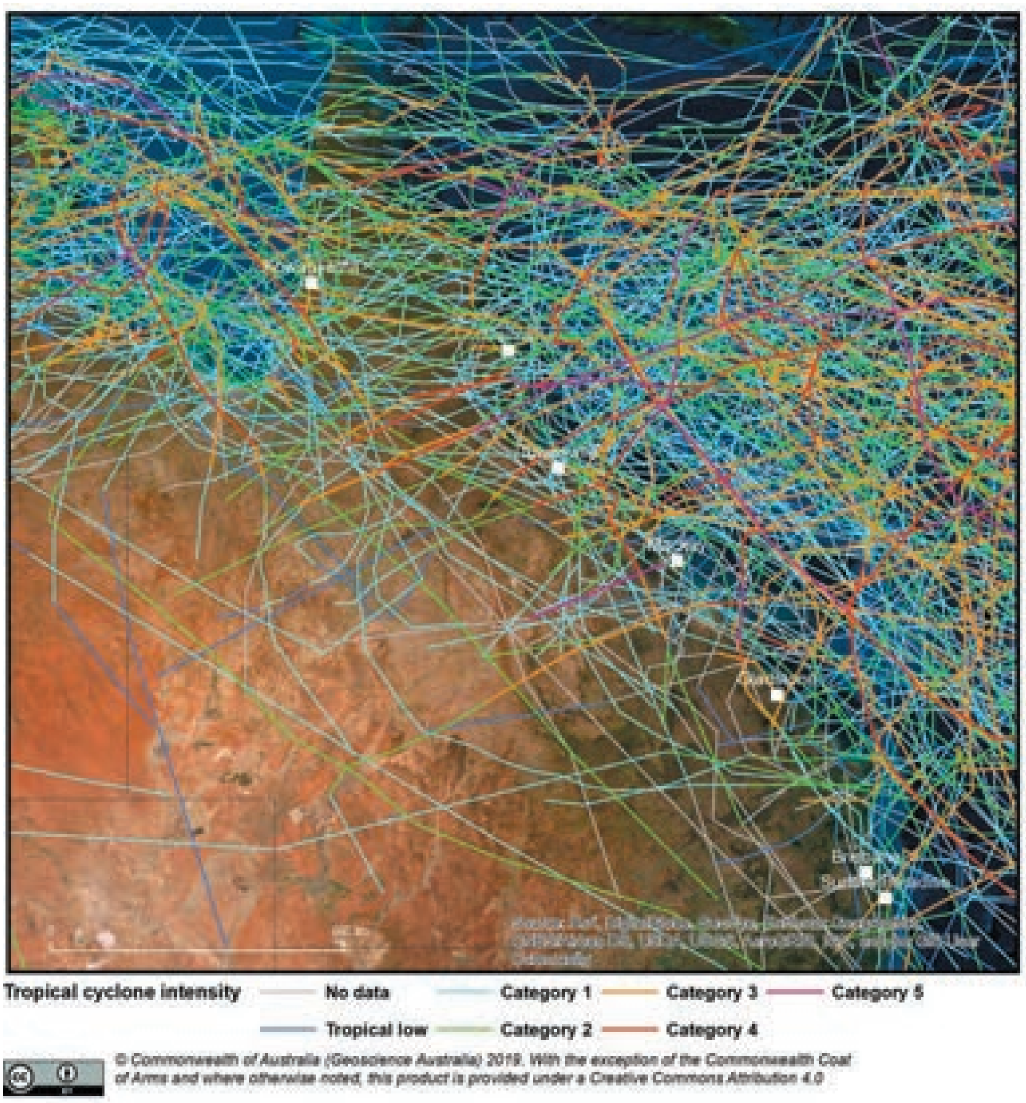


Figure 15: Historical TCs in the Queensland region 1907 - 2018. Tracks are coloured by the estimated intensity category, based on minimum central pressure. Source: Bureau of Meteorology / IBTrACS (Knapp et al., 2018)

1.4.1 Wind loading regions

Within the AS/NZS 1170.2 framework and definitions, there are three wind loading regions in Queensland: Cyclonic, Intermediate and Low. Property owners in cyclone specific areas should inspect and maintain their properties to help reduce potential damage to both their home and the homes of their neighbours.

Wind Region C (Cyclonic)

Includes Cairns, Townsville, Mackay, and Gladstone.

Buildings in this region should be designed to resist a Category 4 cyclone with expected gust winds speeds of approximately 250km/h.

Wind Region B (Intermediate)

Includes City of Gold Coast, Brisbane, Sunshine Coast and the Fraser Coast. Generally borders Wind Region C.

Properties in Wind Region B must therefore be designed to resist weakened tropical cyclones.

Property owners in this area should also inspect and maintain their properties.

Wind Region A (Non-cyclonic)

Areas inland and south of the cyclone wind regions can also experience high winds and large amounts of rain as a cyclone decays and moves inland or further south.

Figure 16: AS/NZS 1170.2 2011 Wind Regions for Queensland, with key locations marked (after AS/NZS 1170.2, 2011).

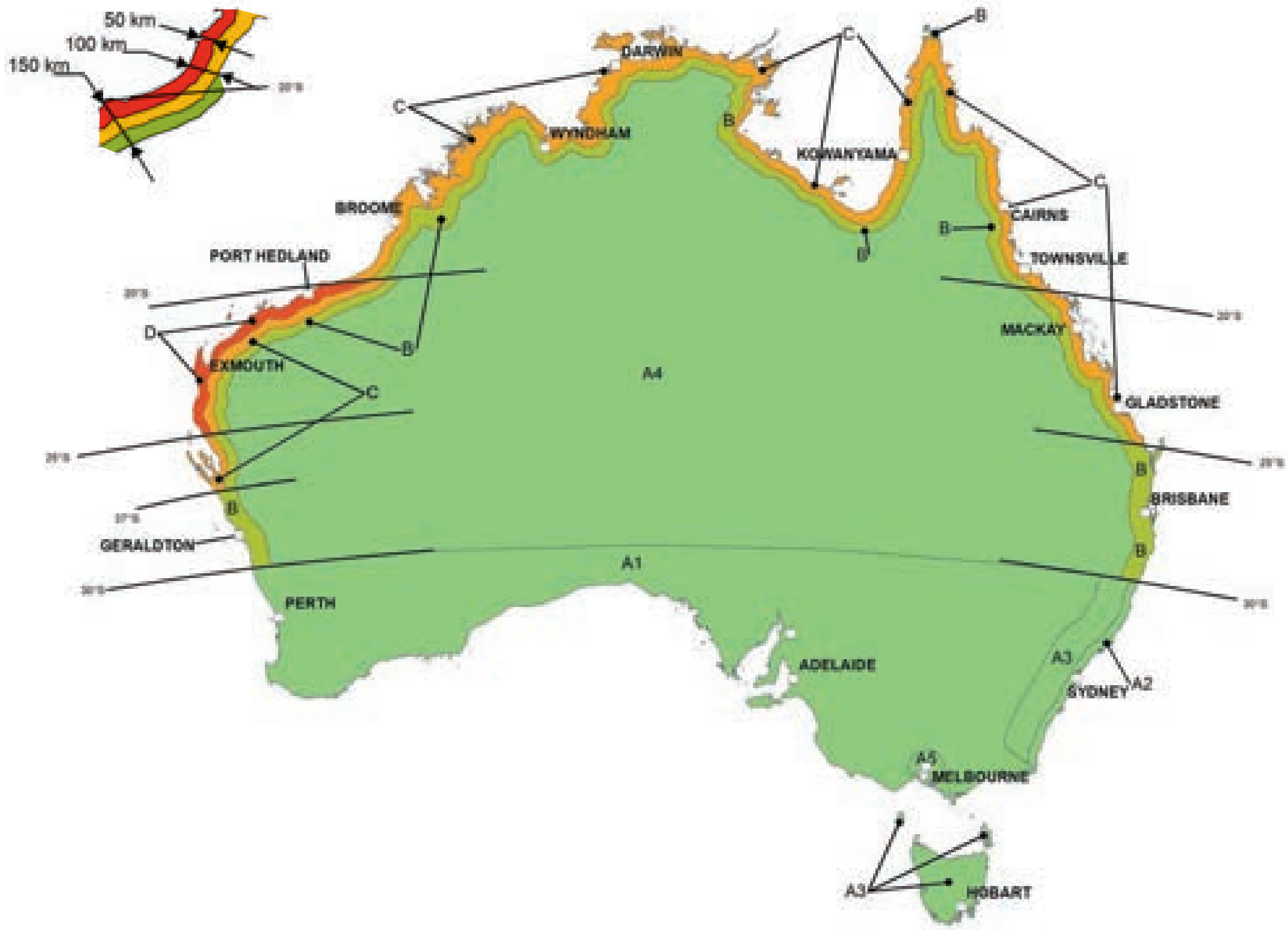


Figure 17: *AS/NZS 1170.2 2011 Australian Wind Regions, with key locations marked (after AS/NZS 1170.2, 2011).*

Wind Region	Design gust wind speed		TC Category
	metres/second	km/h	
A1-A4	45	162	2
B	51	184	3
C	69	248	4
D	88	317	5

Table 2: *AS/NZS 1170.2 minimum design wind speeds for residential houses and TC category.*

Direct impacts of a TC on communities are comparatively rare, especially for severe TCs (Category 3-5). For example, Townsville has recorded 24 TCs passing within 50km of the airport since 1907 (Figure 18). A number of those were severe TCs, including TC Althea in 1972. However, that does not immediately translate into the corresponding wind speeds being experienced in the city, as the strongest winds are often experienced in only a small region near the path of the cyclone. There have been only seven instances of wind gusts exceeding 100km/h in Townsville between 1940 and the present day, the strongest being TC Althea in 1972, where gusts of 196km/h (Category 3) were recorded (Australian Bureau of Meteorology, 2020).

Similar circumstances apply in other towns along the Queensland coast, so it is important for the emergency management sector to understand the scale of impacts that could occur if a severe TC was to make a direct impact on any of these communities. Relying on past experiences alone may result in underestimating the likely impacts from TCs, especially in the case of severe TCs in areas not frequently impacted by TCs more generally, such as South East Queensland (i.e. south of Bundaberg and the demarcation of the Wind Region C & B border, as shown in Figure 16).

Further to this, the highest recorded wind speed anywhere in mainland Australia is 267km/h at Learmonth Airport during TC Vance in 1999 (Australian Bureau of Meteorology, 2000), emphasising the point that no community in Australia has experienced the impact of Category 5 TC winds in modern times (post-1967). Callaghan and Power (2011) reported there is a high level of decadal to interdecadal variability in TC landfalls along the Queensland coast, so the lack of Category 5 landfalls in recent decades does not exclude the possibility of a return to more frequent landfalls in the future.

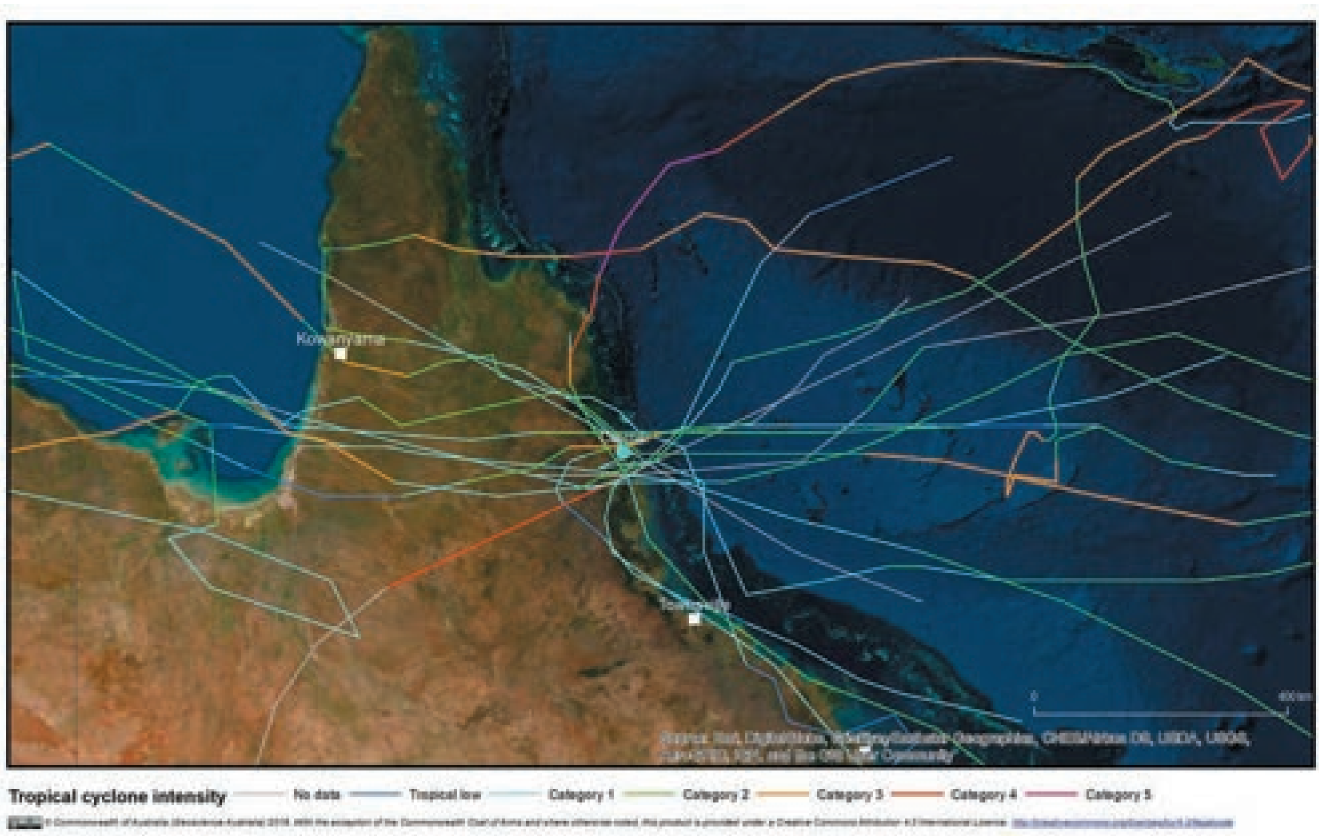


Figure 18: Historical tropical cyclones passing within 50km of Townsville, Qld (1907-2017). Source: Bureau of Meteorology / IBTrACS (Knapp et al., 2018)

2 SCENARIO DEVELOPMENT

2 Scenario development

An absence of historical examples of severe wind impacts on many townships along the Queensland coastline provides the rationale for this project. A lack of severe cyclonic winds impacting communities with large and dense populations since the 1970s means that emergency management (EM) agencies within Queensland and across Australia have not retained many of the direct lived experiences associated with those events. To overcome this challenge, scenarios were selected from the catalogue of synthetic events generated for the 2018 Tropical Cyclone Hazard Assessment (TCHA; Arthur, 2018), in consultation with Queensland Fire and Emergency Services (QFES) and those local governments involved within the project. The TCHA provides a catalogue of 10,000 years of plausible tropical cyclone (TC) events across Australia. Whilst this project has modified the tropical cyclone hazard analysis from the TCHA to more accurately model the physical characteristics of tropical cyclones and therefore the underpinning catalogue, the nature of the scenarios is fundamentally similar with the key difference being the likelihood associated with each scenario. The modifications specifically included updates to the radius to maximum winds regression model and landfall decay model, and correcting the translation speed implementation. These modifications result in the reduction of the occurrence of large storms, hazard levels inland and far field winds. For this project, the selection of scenarios was based on the Category of the event rather than its likelihood.

The events in the TCHA were generated using the Tropical Cyclone Risk Model (TCRM; Arthur, 2021). The hazard analysis undertaken for this project using github version v3.0 of the TCRM (https://github.com/GeoscienceAustralia/tcrm/tree/v3.0 commit hash bf466800). All models are estimations and future updates to these models will reflect the continuous improvement to the estimation of wind hazard. A statistical-parametric model based on historical TC activity. TCRM generates a collection of tracks, and the associated wind fields around the track, which can in turn be used in impact assessment applications. TCRM can also be used with TC track information derived from climate models to provide guidance on possible TC activity under projections of climate change (Siqueira et al., 2014). This coupling of TCRM and climate models has informed the development of the companion to this report, *Technical Report Two: Hazard Assessment for Future Climate Scenarios in Queensland.*

The local influence of topography and land cover is incorporated via the use of site exposure multipliers (Krause and Arthur, 2018; Yang et al., 2014). Land-use data from the Queensland Land-Use Mapping Program[8] was used in conjunction with the SRTM-derived 1 Second Digital Elevation Models to develop site exposure multipliers across the communities studied in this project. Local effects can lead to reductions and increases in wind speed relative to standard observing conditions, for example, at airports.

For maps of the local wind field produced in this project, the wind speeds represent the maximum 0.2-second duration wind gust, at 10m above ground level. The gust duration refers to the response time of the Dines anemograph instruments widely used in calculating wind loads from AS/NZS 1170.2 (Holmes and Ginger, 2012). The height above ground level corresponds to the standard measurement height of gust wind speeds at BoM weather stations and other national meteorological services around the world. This gust duration also represents the intensity measure for the wind vulnerability curves used in the impact modelling software.

In some cases, application of the site exposure multipliers means the maximum winds in the communities are less than the category of the cyclone. For example, in scenario 011-01326 for Townsville (refer 4.5.2), which outlines a Category 5 TC that passes to the north of the city, the simulated TC generates maximum wind gusts in the urban area that only reach 160km/h (Category 3), while at the airport, the maximum wind gusts are in the range of 240km/h (Category 4). Other scenarios would produce different wind footprints, depending on the simulated track and intensity. This highlights the importance of incorporating local effects into the impact analysis workflow.

Additionally, it highlights that, in a severe wind event, the wind speeds experienced in urban areas and impacting on buildings may be significantly different than what is reported from correctly-sited weather stations. This further highlights the importance of leveraging programs like SWIRLnet (Surface Weather Instrumentation Relay network) led by James Cook University (see Boughton et al, 2017) which records wind field characteristics locally within the complex terrains and topographies of communities (as opposed to weather stations sited at airports, for example) during severe weather events. Local topographic effects may lead to higher or lower wind speeds. These local effects are accounted for in residential building design standards (AS/NZS 1170.2, 2011).

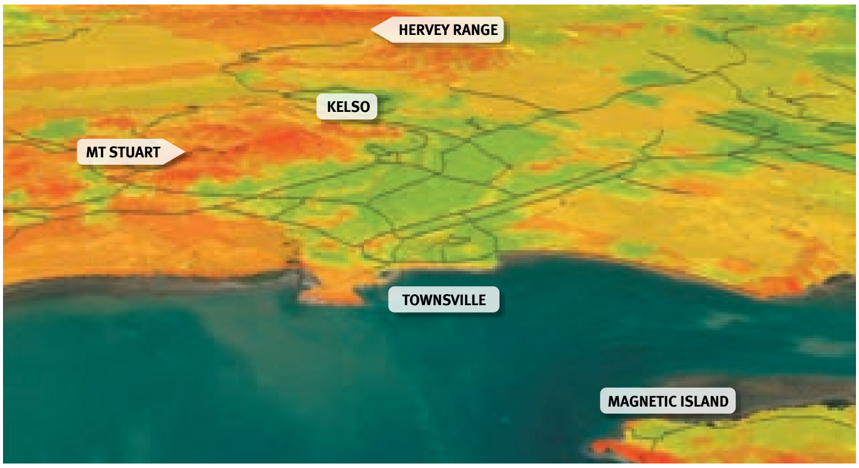


Figure 19: This is a view of Townsville, where local effects on wind speeds are incorporated. The topographic effects act to enhance winds, especially on the top of ridge lines. Mt Stuart to the left and the Hervey Range in the background show this effect due to the steep slopes in those regions (orange to red areas). In the urban area, wind speeds are reduced (green to yellow) because of the shielding afforded from neighbouring buildings.

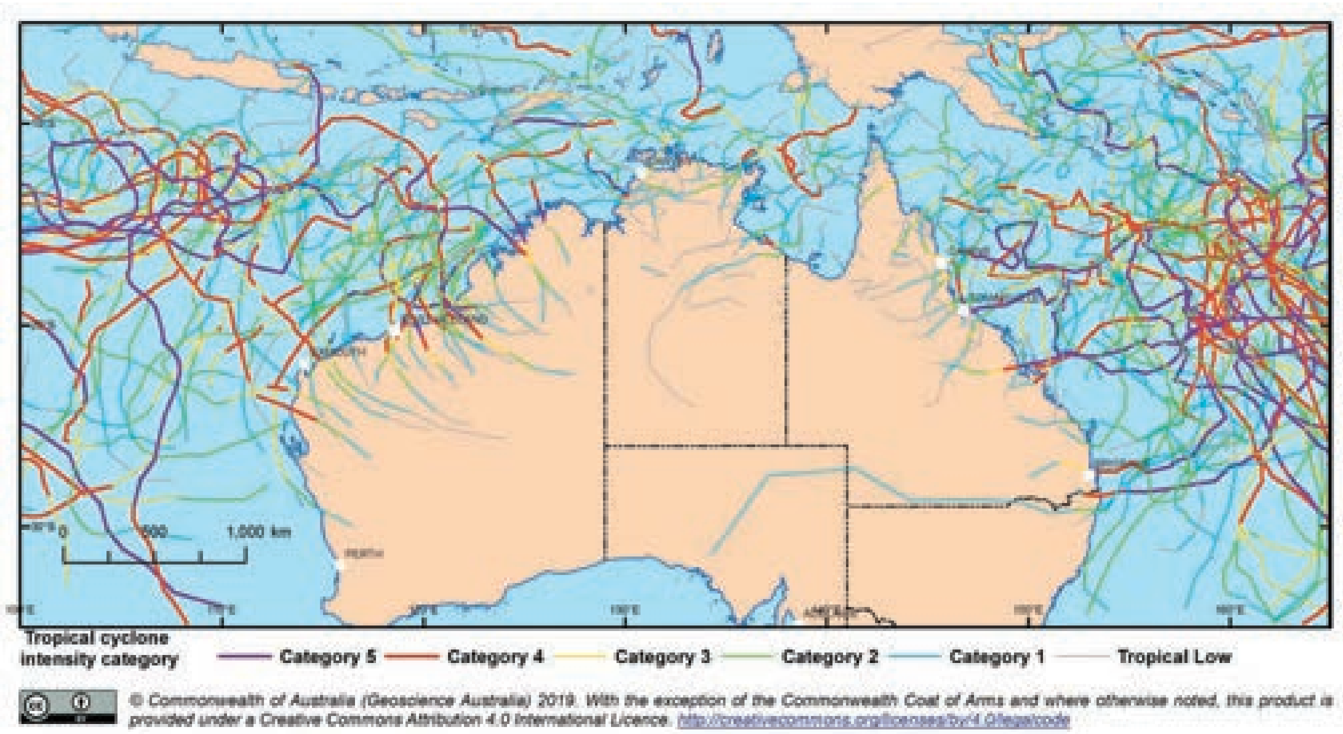


Figure 20: Sample of 35 years of synthetic tropical cyclones for Australia, generated by TCRM.

2.1 Scenario selection

Event selection was undertaken in consultation with QFES using an interactive interface to interrogate the simulation database.[9] This method allows users to select a location, extract any TC events passing within a defined distance of the location and then explore the tracks of those events to identify a candidate TC event for more detailed modelling. The interactive approach allowed project members to discuss the merits of selecting any given event over another for the selected location. In all scenarios, consideration was given to regional historical analogues for the track (as shown in Table 3), potential for significant storm surge and multiple impacts along the coastline.

Two TC events were modelled for each location for this project – a Category 3 and a Category 5 – with "favourable" tracks for impact analysis as well as the aforementioned historical analogues (see Figures 21 through 25 and the 1918 Mackay Cyclone case study). These categories were chosen as they represent events with a moderate and very low likelihood with respect to intensity, based on historical observations. This also takes into account the suggested future climate of less TCs but more intense occurrences, highlighting the different impacts arising from different events. It is important to emphasise and understand that each individual TC event will be different and lead to different impacts.

The analyses in this report represent only one outcome and should not be relied upon in the event of an actual imminent TC. However, they provide guidance on the scale of impacts that may arise.

These events may not represent the worst-case scenario for each community either. A probabilistic impact assessment would be required to evaluate the worst-case scenarios, where impacts are evaluated for all events affecting a community.

2.2 Selected scenarios

Seven scenarios were selected from the synthetic event catalogue for detailed analysis (refer Table 3). Each synthetic event is given a unique identifying code, based on the simulated year and the number of events in each simulated year. For example, scenario 013-03564 is the fourteenth storm in simulated year 3564 (the code uses zero indexing). This allows us to identify the individual event in the simulation database and easily retrieve the corresponding wind field.

Location	Category 3	Historical Analogue	Category 5	Historical Analogue
Gold Coast	001-00406	TC Dinah, 1967	006-05866	'The Great Gold Coast Cyclone', 1954
Gladstone	001-04162	TC Marcia, 2015	003-08775	TC Emily, 1972
Mackay	007-06740	TC Ivor, 1990	007-03074	The 1918 Mackay Cyclone
Townsville	005-03821	TC Charlie, 1988	011-01326	TC Althea, 1971
Cairns	013-01524	TC Ita, 2014	013-03564	TC Yasi, 2011
Kowanyama	002-00483	TC Nora, 2018	006-07657	TC Dominic, 1982
Pompuraaw	015-09711	TC Nora, 2018	004-03396	TC Owen, 2018

Table 3: Scenarios selected for detailed modelling for each location and their historical analogues.

Figure 21: Track map for and images from 'The Great Gold Coast Cyclone, 1954'.

Figure 22: Tuesley's Jetty Bait Shop

Figure 23: Storm Surge at Tuesleys Jetty, Southport

Figure 24: Beach erosion at Palm Beach SLS Club

Figure 25: Roof Loss in Norman Street

Case study: The 1918 Mackay Cyclone as an analogy to Scenario 007-03074 (see section 4.4.2)

On 21 January 1918, a Category 5 tropical cyclone (TC) crossed the coast just north of Mackay. The cyclone was very large, thought to be greater in size than Cyclone Yasi, with destructive winds extending down to Rockhampton, with the worst damage occurring after the winds shifted from SE to NE.

The barograph situated at the Mackay Post Office fell to 944.8 hPa (Category 4) at 4am on the 21st but was prevented from falling below 944.8 hPa by a failure in the internal mechanism. The wind changed from the south east to the north around 8am with no abatement and increased markedly in intensity. The lowest pressure of 932.6 hPa (equivalent to a Category 4) was recorded at 7.30am on the 21st by a barograph situated about 5km north of the Pioneer River in Mackay. However, this was the lowest reading achievable by the barograph and the pressure was almost certainly much lower thereby allowing the categorisation of the cyclone as a Category 5 system.

Very few buildings in Mackay escaped any damage, with 1000 completely destroyed. Three steamers were sunk and three were grounded. The Harbour Master's report to Parliament stated that the cyclone's approach was accompanied by a rise in sea level which slowly rose for about an hour reaching a height of 2.36 metres above the highest spring tide. The cyclone then brought a 3.6 metre storm surge into Mackay with waves 2.4 to 2.7 metres high breaking in the centre of Mackay. Severe storm surge damage was also experienced at Slade Point, Blacks Beach and Eimeo Beach north of Mackay.

Several houses were destroyed and large trees were uprooted in North Rockhampton. Many other houses had verandas blown off and lost portions of their roofs. Two men were drowned at Rockhampton. At Yeppoon, a man drowned, trees were uprooted, three buildings were badly damaged or unroofed and several houses were lifted off their blocks. At Emu Park many houses were badly damaged, and the fishing severely suffered. At Mt Morgan and Clermont, roofing iron was lifted off buildings and thousands of trees were uprooted along all the surrounding roads.

Widespread flooding occurred across Central Queensland including a record flood of 10.11 metres for the Fitzroy River at Rockhampton with widespread property damage. In Mackay the death toll was at least 20 by 31 January 1918 and it is now thought that 30 people lost their lives in the cyclone and the subsequent floods in Central Queensland.

Cyclone damage along the Pioneer River, Mackay, 1918.

Less than two months later, on 10 March, Innisfail was subsequently hit by an unnamed Category 5 cyclone. Prior to impact, Innisfail was a town of 3,500 people. After the cyclone, only 12 houses remained. It is thought 37 people died in the town and possibly another 60 (mostly First Nations peoples) in the surrounding region. A storm surge in the Bingil Bay / Mission Beach area swept hundreds of metres inland leaving debris 7 metres up in some trees, with widespread damage reported in Cairns and on the Atherton Tablelands.

In this study, the Category 5 scenario for Mackay (007-03074) seeks to mirror the track and intensity of the 1918 Mackay Cyclone. Education, where there is no or limited prior disaster experience, is an essential factor in determining disaster preparedness behaviour. Demonstrating how this same event, while rare, would impact Mackay and the surrounding region today is important for disaster preparedness. The 'Learn from the Past, Prepare for the Future' approach helps our local, district and state disaster management stakeholders to relate to these previous events, of which there is limited to no living or institutional memory, and explore how they would manage these events across all phases of prevention, preparedness, response and recovery.

Adapted for use from Jeff Callaghan's "History of tropical cyclone impacts along the Australian east coast from November to April 1858 to 2000".
Pictures contributed by QldPics.

George Hamilton's Bakery damaged post impact.

Looking south down Sydney Street post the impact of the 1918 cyclone.

3 IMPACT ASSESSMENT DEVELOPMENT

3 Impact assessment development

In line with the principles of the Queensland Emergency Risk Management Framework (QERMF)[10] and those used by Geoscience Australia, disaster impact is quantified as a product of *Hazard, Exposure* and *Vulnerability*, as shown in Figure 26.

In this project:

- *Hazard* refers to the maximum gust wind speed generated by tropical cyclone (TC) scenarios.
- *Exposure* refers to the elements that are exposed to the hazard event, specifically detached residential dwellings.
- *Vulnerability* is the measure of the level of damage caused by a given magnitude of the hazard and is a characteristic of each type of exposed element. Vulnerability can be quantified for physical assets (i.e. houses, buildings and high-voltage transmission lines) or can be a qualitative measure (e.g. for social or economic vulnerability).

The quantification of disaster impact is an estimation based on models for Hazard, Exposure and Vulnerability. Each model is verified, where possible, against observations. Disaster impact is estimated at the Statistical Area Level 1 geography, that it, disaster impact is not estimated for an individual residential building. This disaster impact information is intended to guide decision making only. Geoscience Australia has previously used this approach for analysing the impacts of past TCs – such as TC Tracy (Arthur et al., 2008) and TC Debbie (Krause and Arthur, 2018) – and for other hazards, such as earthquakes.

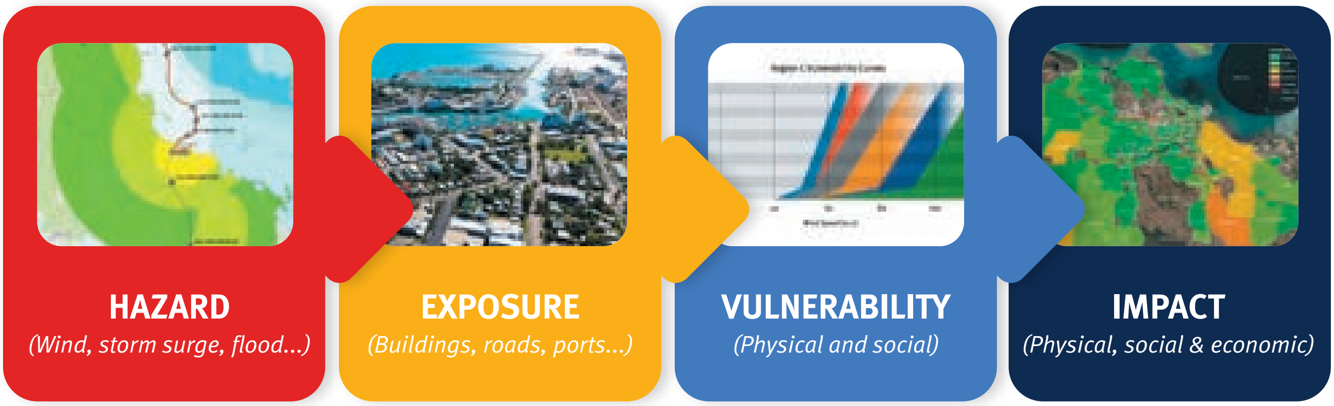


Figure 26: The function of hazard, exposure and vulnerability information that is used to determine impact.

3.1 Disaster risk

Disaster risk expands on the understanding of impact by introducing the concepts of probability and capacity. Probability refers to the likelihood of an event or scenario occurring over a specified period of time. For example, the influence of climate change means that the same hazard scenario today may have a different likelihood of occurrence 50 or 100 years from now. Capacity – also referred to as capability in the context of disaster risk management – refers to the collective abilities and capacities available to effectively manage disaster risk (Australian Government, Department of Home Affairs, 2018; United Nations General Assembly, 2016).

The definition of disaster risk is *"The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity"* (United Nations General Assembly, 2016), as shown in Figure 27.

In Queensland, capacity to manage disasters is primarily afforded through the main objectives of the *Disaster Management Act 2003* (Qld), which are:

- To help communities:
  - mitigate the potential adverse effects of an event
  - prepare for managing the effects of an event
  - effectively respond to, and recover from, a disaster or an emergency situation.
- To provide for effective disaster management for the state.

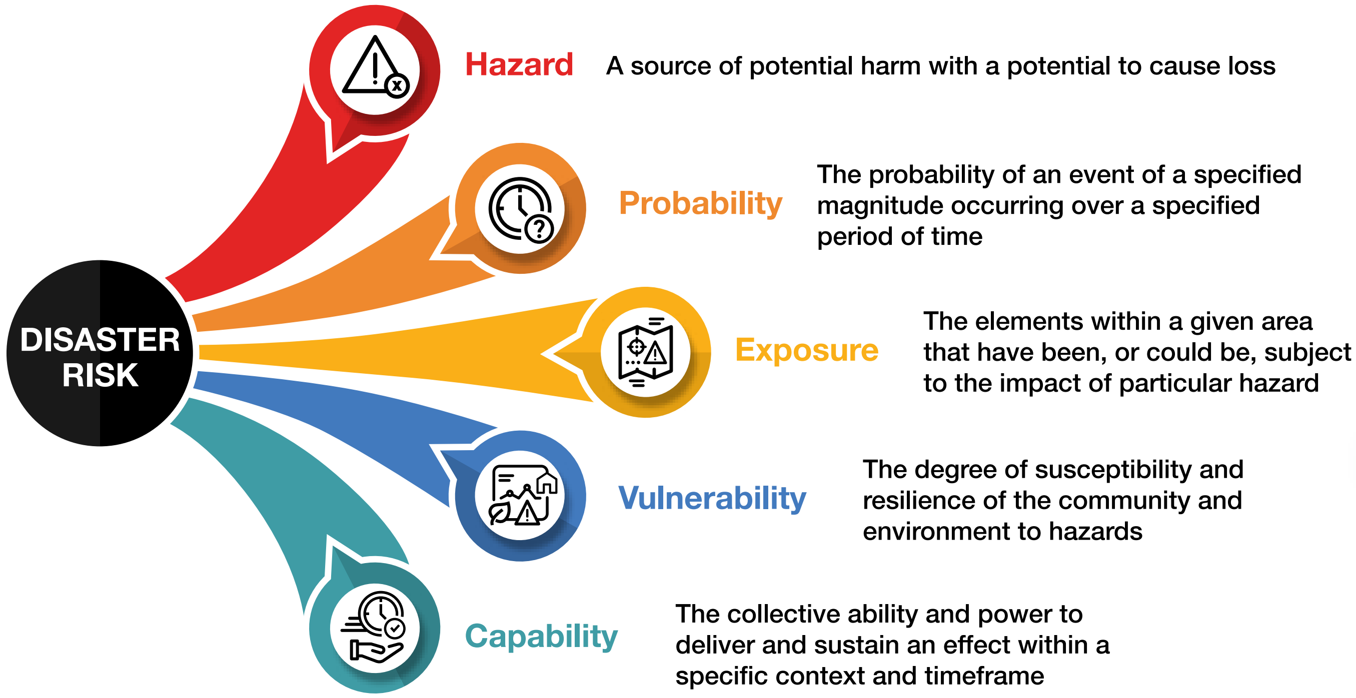


Figure 27: Components of disaster risk. The components of disaster hazard, exposure and vulnerability determine impacts. Risk can be comprehensively evaluated when probabilistic information is available (e.g. when impacts from a large number of scenarios are evaluated) and disaster management capabilities are assessed. (adapted from Australian Government, Department of Home Affairs, 2018 and United Nations General Assembly, 2016)

3.2 Exposure information

Exposure refers to the elements at risk to adverse outcomes or exposed to any hazard event. Exposure elements include buildings (residential, commercial or industrial buildings), institutions (e.g. schools, hospitals, government facilities), infrastructure (e.g. utility/energy and transport), business, agricultural and environmental exposure. Each of these elements will experience different impacts from extreme winds, depending on their characteristics.

For this project, the focus was on understanding impacts to residential housing utilising existing approximated vulnerability functions for generic residential construction which were extrapolated across Queensland. This focus aligns to the core objective of Queensland Fire and Emergency Services which is *'to protect persons, property and the environment…for a safer Queensland'*.

Prior to this project, the primary source of exposure data was the National Exposure Information System (NEXIS). Across the local government areas (LGAs) relating to this project, NEXIS had limited information about actual building level attributes required for the impact assessment. Many of these attributes were derived, by various methods depending on the type of attribute, to populate a best estimate of the types of building and their associated attributes in the absence of actual data.

However, the project coordinated with the LGAs included in this project to obtain best available building data, which was integrated into NEXIS and used for impact analysis. The type of data obtained from these LGAs is identified in Appendix F and the method for its incorporation into NEXIS is outlined in Figure 28.

For remote Indigenous communities, the project engaged the Centre for Appropriate Technology (CfAT) to conduct building surveys in the three communities (Kowanyama, Pompuraaw and Yarrabah) within our identified scenarios. The CfAT project provided validated building attributes for these communities which is further discussed at Appendix F.

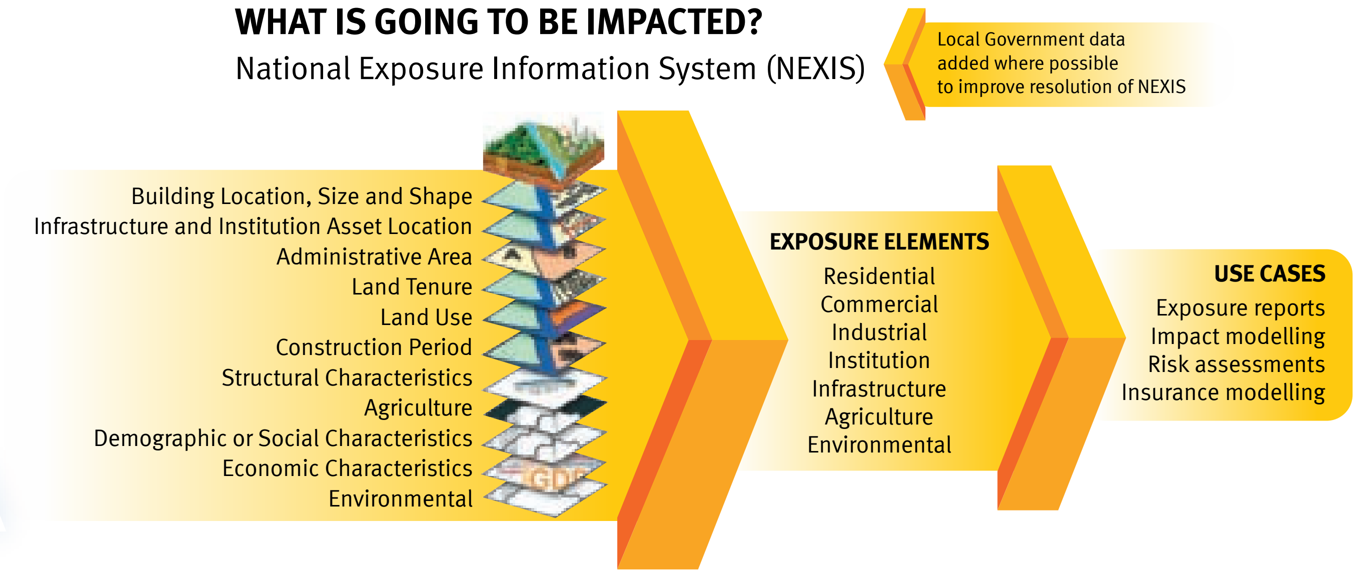


Figure 28: Diagrammatic representation of NEXIS illustrating the process for incorporating local government data to improve the resolution for this study.

3.3 Vulnerability models

The development of detailed structural vulnerability models was not part of the project, instead simplified piece-wise linear vulnerability models for pre-1980s and post-1980s construction were provided by James Cook University's Cyclone Testing Station (CTS). Residential buildings were grouped into three categories: Type 1: pre-1980s, Type 2: pre-1980s and Type 3: post-1980s. It is important to note that these curves are highly generalised approximations of building performance that have not been calibrated against other loss data (e.g. insurance claims and QFES RDA data). As state-of-the-art vulnerability modelling is further progressed for the public domain, these curves should be revisited and updated. Smith et al. (2020), provides an assessment of the state of vulnerability models for Australian housing, including assumptions and limitations.

Considering the simplified nature of the vulnerability models used herein, scenario outcomes (refer Chapter 4) showing damage states for different construction eras should be considered as indicating trends not as providing hard numbers. Knowledge of the underlying assumptions associated with the curves, exposure and the hazard wind model must be carefully considered when using scenario outputs for guidance or decision-making.

The scenario modelling outputs provide damage numbers for several construction eras based on the granularity of house ages in NEXIS. However, at this stage, all construction eras prior to 1981 have the same underlying pre-80s vulnerability curve and likewise for post-80s construction eras. For example, the differences in proportions of damage for different decades for the pre-80s are based on the derived numbers of houses in each decade and not on any modelled difference in vulnerability.

3.4 Impact processing

The impact of the chosen TC events on residential houses was modelled using the Hazard Impact (HazImp) Assessment Application.[11] HazImp simulates the loss of value to structures from natural hazards using modelled relationships between hazard severity and structure damage. HazImp uses information on the location, use and construction attributes from NEXIS (Power et al., 2017) to assign vulnerability models, and then determines the magnitude of structural damage to those buildings based on the location-specific wind speed. Results are aggregated to the Australian Bureau of Statistics Australian Statistical Geography Standard mesh block level (approximately 30-60 dwellings) for reporting purposes.

Impacts on residential buildings are presented in terms of damage state (Appendix H), and damage index, evaluated for each individual building. The damage state provides no indication of the habitability of the building (i.e. whether it can be occupied after the event has passed) but can be inferred from the damage state based on anecdotal experiences of emergency services. It is assumed that structures with Moderate, Extensive and Complete damage states may be uninhabitable post-impact (refer to Appendix H for damage state definitions).

The numbers of residential buildings reported for each damage state should be taken as a guide only. These values can be taken to understand the indicative scale of an event and the distribution of damage across a local government area. This information is intended to support planning for future events and the values are not precise.

As previously stated, the focus in this assessment is on impacts of severe wind for residential separate housing only. Because of the diversity of construction styles, materials and building sizes, there is little information available on the vulnerability of multi-dwelling structures (e.g. apartments) and non-residential buildings. In general, these classes of buildings would require unique vulnerability functions for each building. For this reason, these are not included in the damage assessment and can only be discussed in general within section 6.1 Risk assessment.

The maps and analyses are restricted to structural damage arising from severe winds to residential buildings only. It is likely that other hazards would cause significant additional damage. For example, overland flooding (flash flooding), storm surge inundation and water ingress are all significant causes of damage to buildings. These are not presently considered but the framework for damage analysis could be applied using appropriate hazard and vulnerability information. Examples of severe damage from wind-driven rainwater ingress and associated factors can be found in damage investigation reports by the CTS (Boughton et al., 2017, Henderson et al., 2018). Further research into these damage types would be beneficial for future scenario modeling.Note, for the impact maps produced in this project, areas with no shading contain no residential buildings, therefore no damage is reported in those areas. There are likely other elements at risk including institutions, infrastructure, business, agricultural and environmental exposure in these areas that may suffer damage in the scenarios presented.

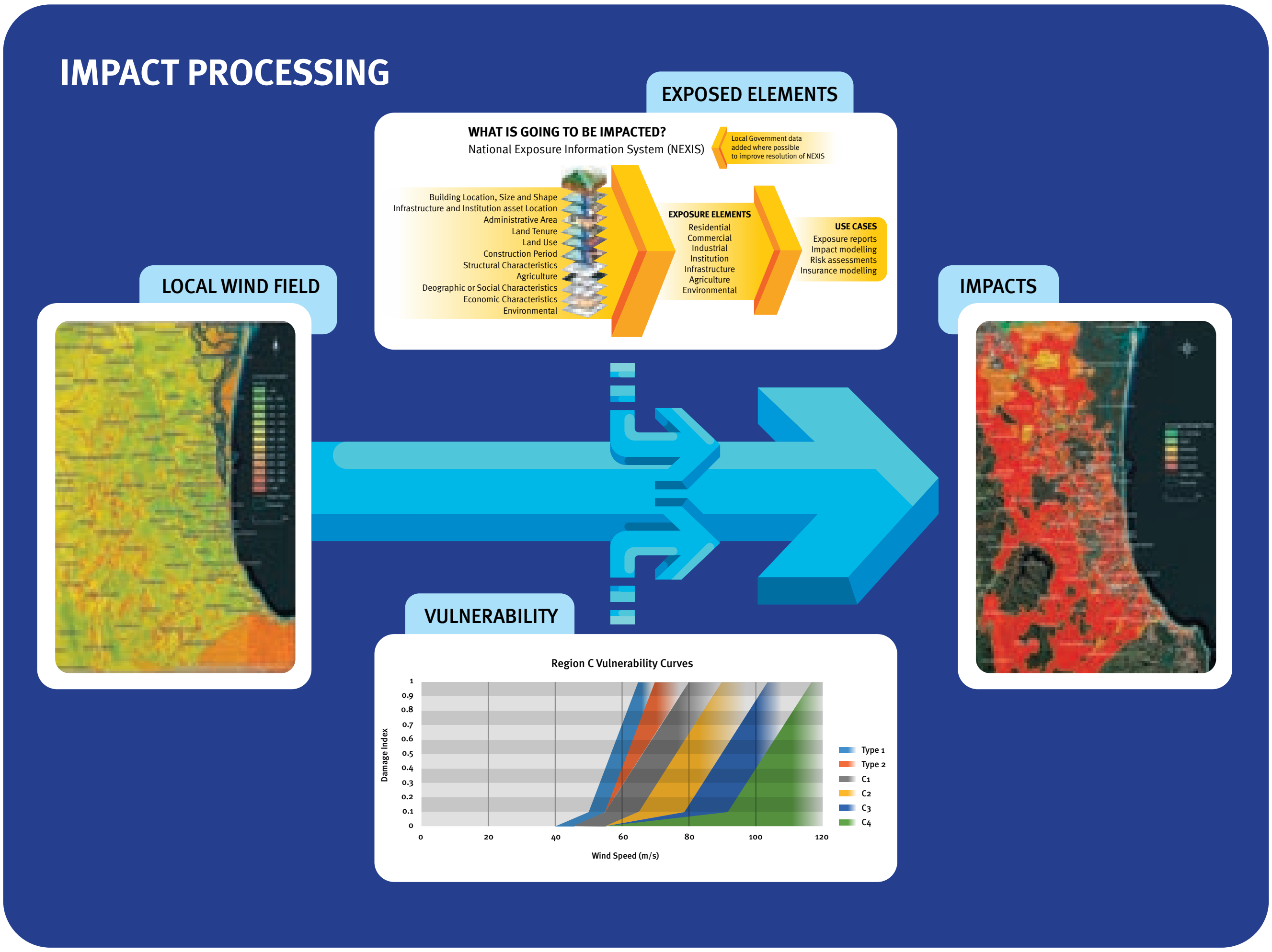


Figure 29: *Local winds are used to determine impacts, as the level of damage is non-linearly related to the wind speed. Vulnerability curves describe the level of damage for a given incident wind speed. There are different curves for different groups of buildings, such as pre-1980s versus modern construction, and also whether the buildings are designed for cyclonic regions or non-cyclonic regions. Information on the building characteristics are drawn from the National Exposure Information System (NEXIS).*

When we combine the information on the local wind speeds, the buildings affected and their corresponding vulnerability characteristics, we can determine, and spatially map, damage across the community.

Each individual scenario will have a different outcome because the local wind speeds for each event depend on the track of the cyclone and the orientation of the winds to the local topography and terrain. That in turn impacts the buildings in different ways, leading to different overall outcomes.

4 SCENARIO ASSESSMENT AND OUTCOMES

4 Scenario assessment and outcomes

The scenarios described in this section can be used to help plan for tropical cyclone (TC) events. This includes developing a better understanding of how the capabilities of emergency services and supporting elements may be impacted in actual events.

Transforming information on hazards (wind speeds), exposures (detached residential buildings) and vulnerability (residential building vulnerability models) into quantitative impact information provides guidance on the range of consequences that can be expected with severe TCs in these communities. However, the assumptions used in all components of the modelling process (wind footprint model, NEXIS database and house vulnerability models) must always be kept in mind when reviewing the scenario outputs. The scenarios add a valuable layer of information to the emergency management (EM) sector to help support decision making on the scale of response and recovery actions, including:

- **Triggers for evacuation** – What is the vulnerability profile of my community? What are the thresholds for community safety? What level of forecast impact would initiate evacuation? Have I communicated my needs and intentions with the district and state groups?
- **Scale of evacuation, temporary accommodation and return** – How many people will be affected, where can they go and for how long?
- **Relief supplies** – How much is required? How will it arrive and how will it be distributed?
- **Effecting repairs** – Who will do it? How will material be brought in?

While these scenarios do not represent actual TCs, this scenario information has previously been used to guide preparations ahead of TC events in other jurisdictions (Arthur et al., 2021). A more robust solution is to deliver similar information to emergency services based on forecast tracks of TCs, which is being implemented in partnership with QFES, Western Australia's Department of Fire and Emergency Services and Geoscience Australia. Additionally, enabling access to a broader suite of scenarios will support EM services to exercise events across more communities, using consistent information on the consequences across the state.

The modelled impacts arising from these scenarios are specific to the details of the selected cyclone event (e.g. track, cyclone size and intensity). The priority for track selection was the major regional centres, with the potential impacts on smaller satellite communities' subsequent considerations. For example, in the Cairns Category 5 cyclone scenario, the selected track results in minimal damage to Port Douglas and Mareeba as it passes sufficiently far from those communities. Conversely, Atherton and the wider Tablelands experiences significant impact from this scenario due to the track's south west trajectory. Were this track to pass slightly further north west after landfall, Port Douglas and Mareeba would suffer much greater damage. The scenarios should be considered a guide on the magnitude of impacts likely to occur in a cyclone of the corresponding intensity.

4.1 Use of scenarios for risk assessments

The impacts of (Category 3 to 5) tropical cyclones are likely to affect all sectors of Queensland's communities, including public and government organisations and industries, health, utilities, commerce, agriculture, and infrastructure as shown in Figure 30.

Chapter 5: Hazard assessment for current and future climate scenarios and Chapter 6: Implications for emergency management in Queensland, explore impacts of (Category 3 to 5) tropical cyclones – both those that are expected currently, and those that are projected for the future, as trends in the frequency, intensity and duration of tropical cyclones continue to shift.

While cyclones of all intensities have direct impacts on life and property, they also cause a range of indirect and systemic impacts to communities. Some examples, expanded upon in section 6.1, include:

- disruption of electricity supply and telecommunications, reducing the ability of the community to access timely information and make informed decisions
- interruption to the normal service delivery of emergency services, hospitals and health services and
- disruption to businesses, the economy and recovery efforts because of damage of transport infrastructure and transport delays.

Assessing hazard exposure and associated vulnerability provides a clear understanding of the potential impacts. It should be noted that throughout this document 'impacts' refers specifically to structural damage of detached residential buildings arising from wind loads. Even with little structural damage from winds, it is likely houses in these scenarios would also sustain substantial damage from water ingress. This ranges from water across the floor through to collapsed ceilings as shown in Figure 31 (Henderson et al., 2018).

Damage investigations by James Cook University's Cyclone Testing Station (CTS), following recent tropical cyclone impacts details the high occurrence of wind-driven rain ingress with approximately 75% of residences having some form of water ingress on the property.

Impacts of tropical cyclones on communities

Figure 30: Diagrammatic representation of the direct and indirect impacts from tropical cyclones and their associated hazards. There are wide-ranging impacts that will occur within any given scenario in addition to the impacts to housing, including, but not limited to, infrastructure damage, business interruptions, downturn in tourism and agricultural losses. A more holistic assessment of these impacts would demonstrate even more severe and catastrophic consequences for not only the community but for Queensland as a whole – both socially and economically. Section 6.1, explores this further in a qualitative assessment of potential impact.
Source: Queensland Fire and Emergency Services

For the purposes of this project, potential impact has been assessed against the occurrence of tropical cyclones. This is because people, infrastructure and the environment typically have a greater capacity to cope during more common, low intensity cyclones. This is not to suggest that these cyclones cannot deliver significant impact from sustained winds and associated flood waters – as was experienced in 2013 across Queensland with ex-TC Oswald, for example. This assessment is applicable Queensland-wide but should be applied and tailored at the local and district level by considering the information below, as well as the future of TC occurrence under climate change as outlined in Chapter 5 and the associated digital resources.

Note: As outlined at Appendix H, the damage state definitions utilised throughout this project provides no guidance on habitability of residential buildings post impact. As a guide, all buildings in a Moderate to Complete damage state should be considered as being potentially uninhabitable post impact.

Figure 31: Collapse of ceiling from rain ingress via gable end during TC Larry. Source: CTS

4.2 Gold Coast

The Gold Coast is one of the three main population areas in South East Queensland and has undergone rapid, unabated growth since the 1970s with further and significant development planned for the future (see Table 4 below). The region is comprised of a landscape that is conducive to cyclonic and non-cyclonic severe winds and associated hazards (i.e. flash and riverine flooding, and storm tide). This includes coastal dune landscapes, canal estates and peri-urban areas across the undulating hinterland terrain forming part of the Great Dividing Range.

The region has experienced tropical cyclones in the past – most notably the 1954 'Great Gold Coast Cyclone', and the 1967 cyclone season which included the indirect impacts (including significant coastal erosion and riverine flooding) from five tropical cyclones, including TC Dinah, and three east coast lows. There is significant likelihood of direct and indirect impacts from future TC events. However, the region is designated Wind Region B in AS/NZS 1170.2 2011 (as shown in Figure 16), the consequences of which will be discussed extensively within this assessment.

It is for these reasons that the City of Gold Coast was chosen as the South East Queensland location for this assessment.

Population Change in City of Gold Coast				
Year	1954	1967	2020	2041
Population	36,000	72,000	699,000	1,076,000

Table 4: Population change in the City of Gold Coast, Qld highlighting the population during periods of historically significant cyclone impact versus the modern day and projected increases. Source: Queensland Government Statistician's Office, 2020

In both Category 3 and Category 5 scenarios, the older suburbs along the coastline suffer significant damage – the majority of older houses are classified as Moderate or higher damage states even in the Category 3 scenario. In the Category 5 scenario, all pre-1980s houses are classified as either Extensive or Complete damage state (refer Appendix H for damage state definitions). This is likely to have profound implications for emergency management – large numbers of people requiring evacuation and temporary accommodation in a remote location with a significant and costly return and reconstruction effort following an event.

The exposure of houses along the foreshore and in the hinterland is the driving issue behind this outcome. There are developments sited on and around dunes systems up to 15 metres high, which is sufficient to locally enhance winds by around 10%. In combination with the non-linear nature of damage (damage increases exponentially with wind speed), this leads to locally extreme impacts in an already extreme event. Further inland, the complex topography leads to greater local accelerations and, consequently, major damage to houses throughout the region.

4.2.1 Category 3 cyclone: scenario 001-00406

The storm initially develops in the Coral Sea, remaining in the area for several days and intensifying to a maximum intensity of Category 5. The storm takes a south-south-westerly track towards the coast, making landfall over the southern portion of Stradbroke Island. This track was selected as it is similar in its progression over time to TC Dinah (1967) but, in this scenario, the cyclone makes landfall. Therefore, it provides an opportunity to understand the onshore impacts of an already locally significant event, a detailed evaluation of which was also undertaken, at a similar scale, by Dr Matthew Mason of the Bushfire & Natural Hazards Cooperative Research Centre (BNHCRC) (Mason, 2016).

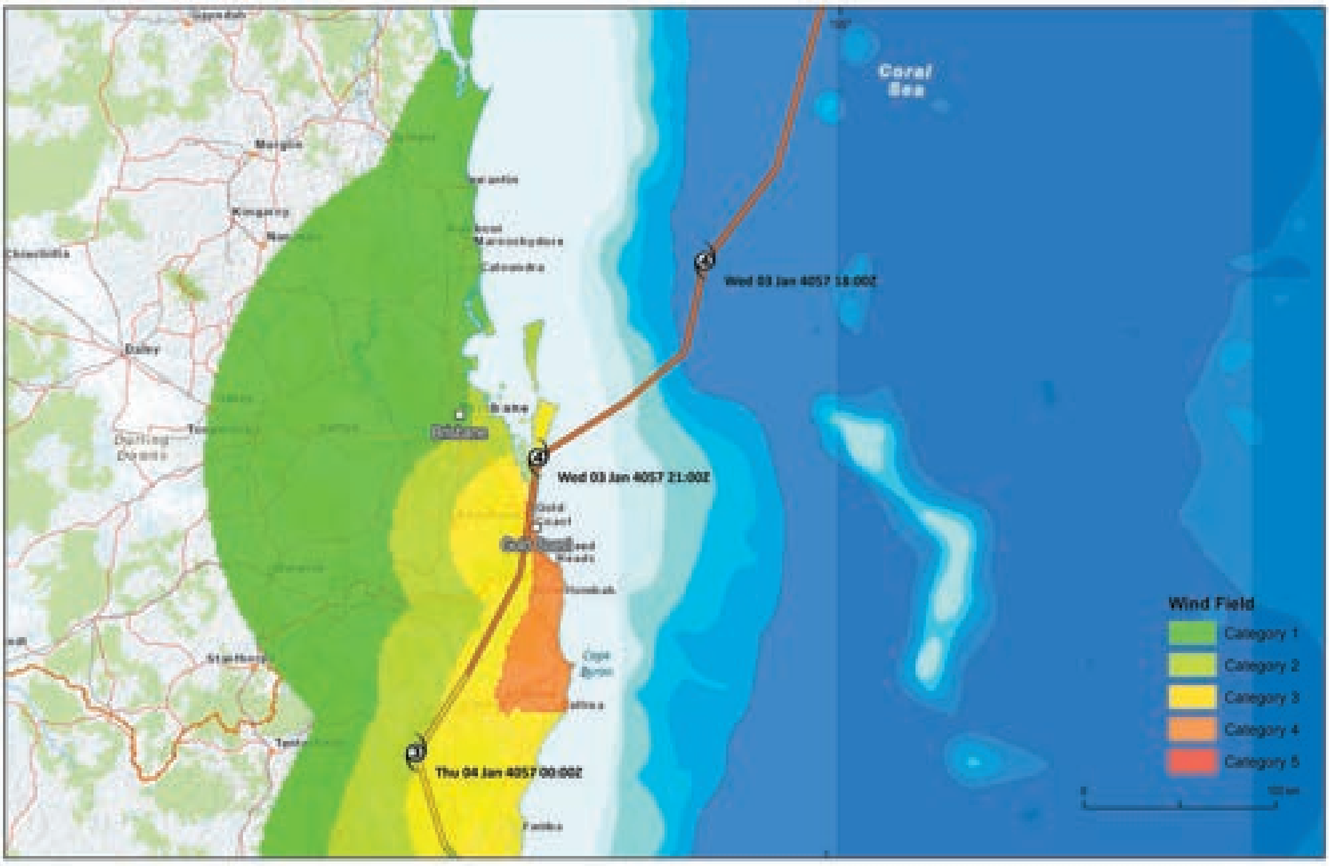


Figure 32: Regional wind field for scenario 001-00406, a Category 3 cyclone impacting Gold Coast, Qld.

The local winds associated with this scenario are presented in Figure 33. Highest winds of around 220km/h are experienced along the coastal strip, where there are minimal obstructions. In comparison, estimated maximum wind gusts in the 1954 Gold Coast cyclone were around 170km/h. There are also areas of high winds well inland, due to local topographic enhancement over the steep topography of the Gold Coast hinterland. In some areas, the maximum local wind speed may exceed 250km/h.

These wind speeds are still sufficient to exceed local design levels in some areas, so a significant amount of damage is sustained (refer Figure 34, Figure 35 and Table 5). There is a narrow band along the coastal strip that sustains major (Moderate, Extensive or Complete) damage. Behind the coastal strip, damage levels are lower due to the reduced local wind speeds that arise from the change in terrain (from open water to urban areas). Further inland again, around the Gold Coast hinterland, there are pockets of Extensive and Complete damage. These occur because of the local enhancement of wind speeds through the steep topography of the area, leading to areas where winds again exceed the design levels for the site conditions.

For the residential housing analysed here, the construction standards for modern houses only partly acknowledge the threat of cyclones. A severe TC (mid-range Category 3 or higher) would generate wind gusts that exceed the current regional design standards for residential housing (205km/h), leading to major structural damage, even in well-constructed and maintained houses. Past experience with thunderstorm events (e.g. The Gap Storm, 2008[12]) indicates that wind gusts of 170km/h are sufficient to destroy modern houses in the region as it is a combination of the wind speed and pressure distribution. A potentially important driver of the damage is that modern homes in Wind Regions A and B are most likely not designed to accommodate a dominant opening. That is, large positive pressure resulting from a broken window or door can double the load on the roof structure. If this magnitude of cyclone impacted elsewhere in South East Queensland, similar impacts are likely in any of the large metropolitan areas, as the cyclonic Wind Region, and the higher design wind speeds, starts at (approximately) Bundaberg (AS/NZS 1170.2, 2011).

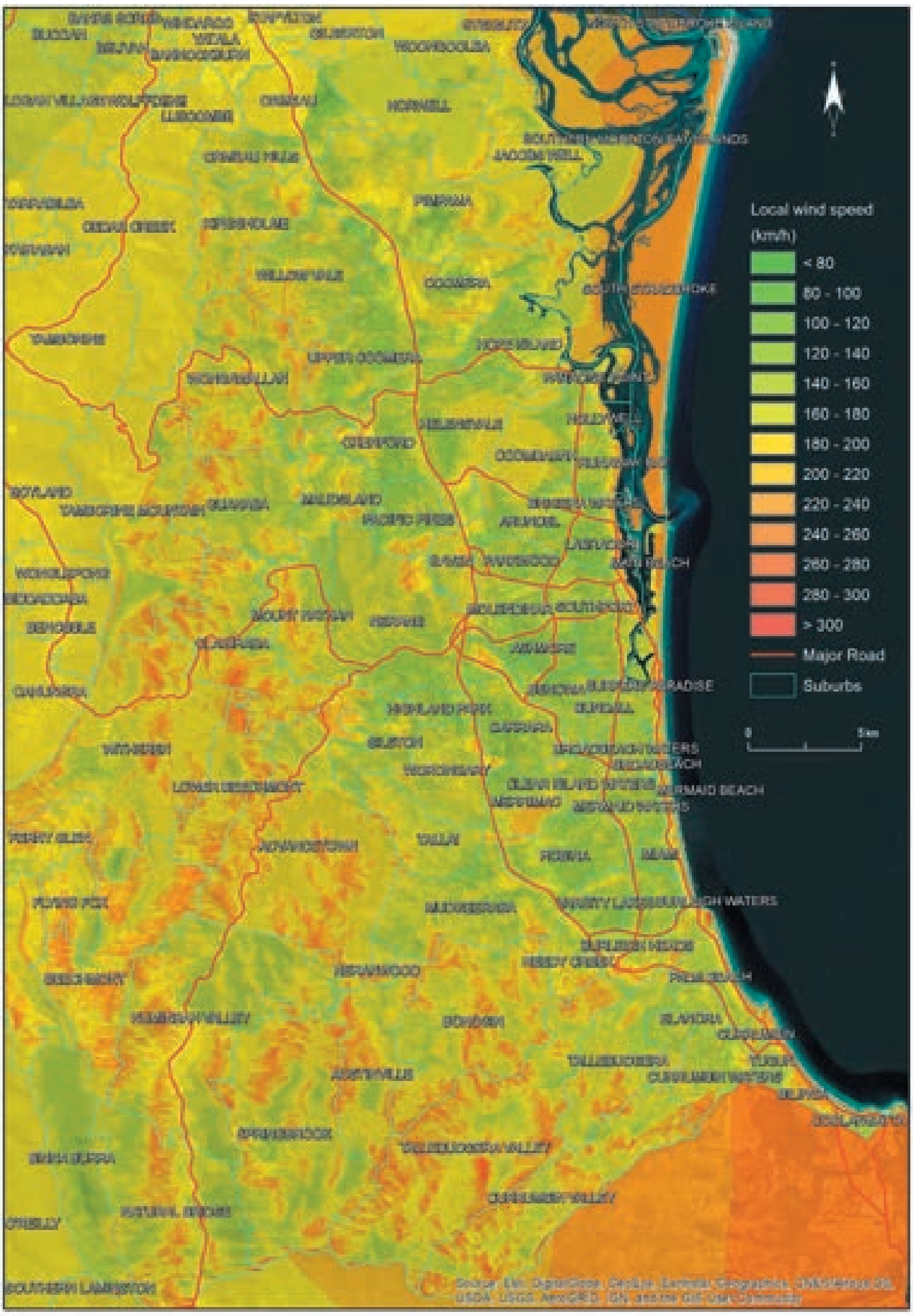


Figure 33: Local wind field for scenario 001-00406, a Category 3 cyclone impacting Gold Coast, Qld. See Appendix B for TC intensity categories and the corresponding wind speeds. Areas outside the Gold Coast Local Government Area do not have local wind multipliers applied in this scenario.

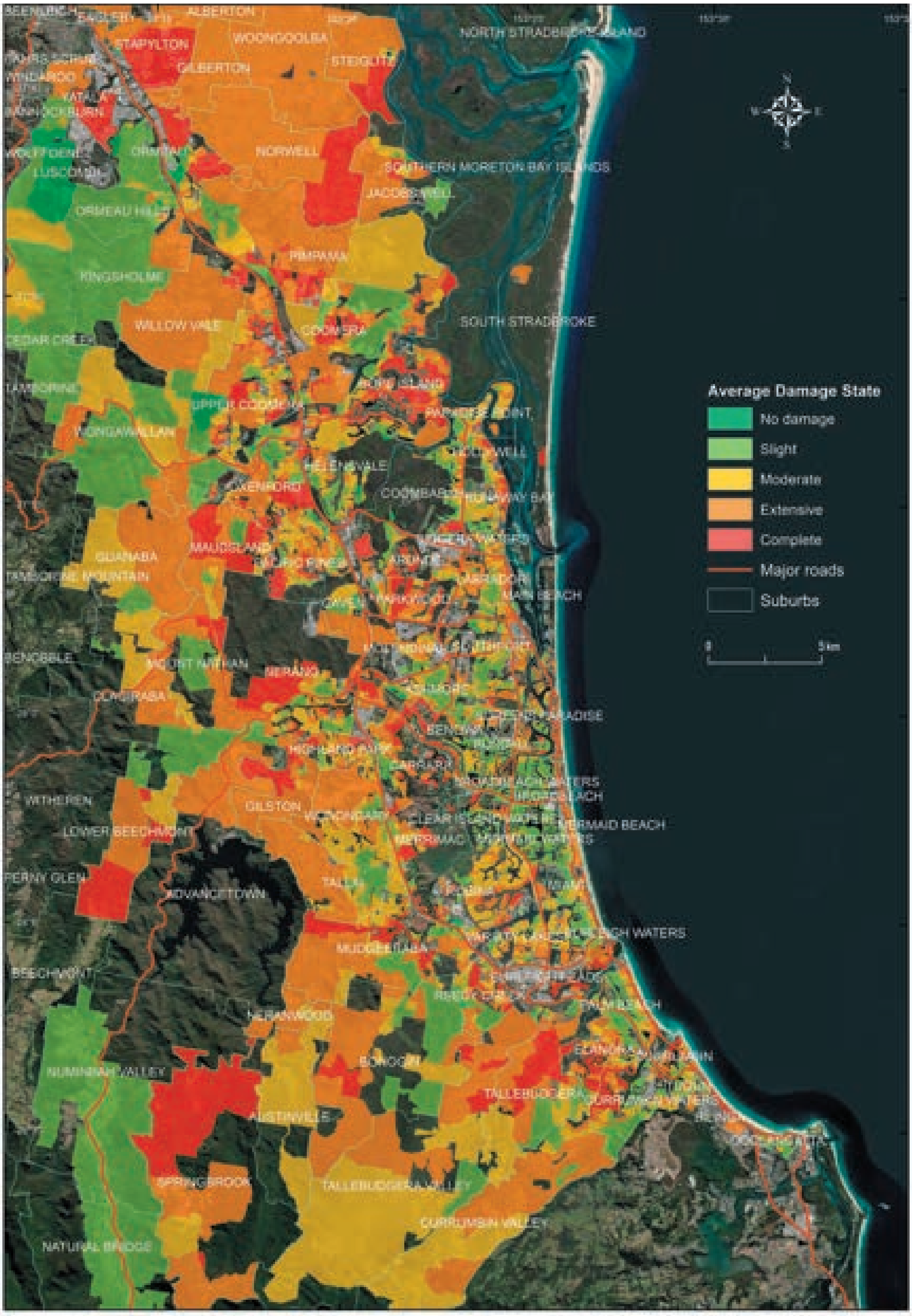


Figure 34: Aggregated residential building damage states for mesh block areas, for scenario 001-00406, a Category 3 cyclone impacting Gold Coast, Qld.

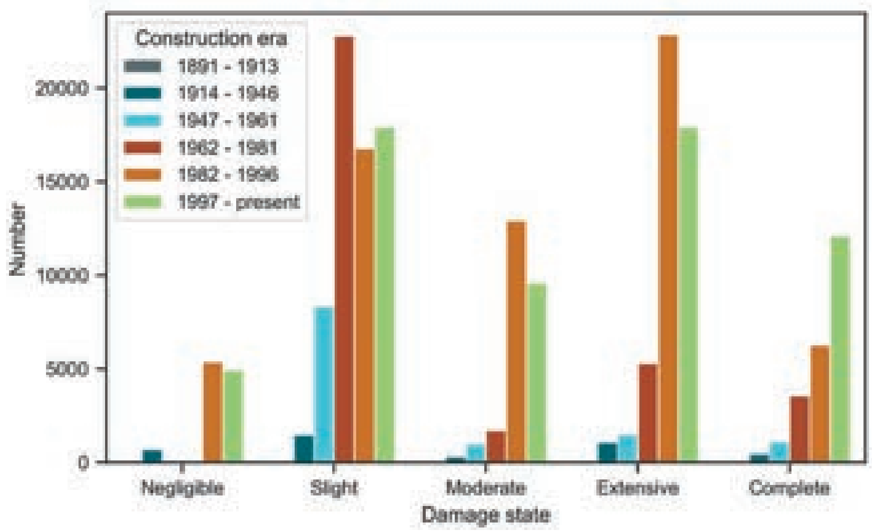


Figure 35: Count of buildings in each damage state, grouped by construction era, for scenario 001-00406, a Category 3 cyclone impacting Gold Coast, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	362	305	19	58	34
1891 - 1913	84	48	3	9	4
1914 - 1946	693	1,481	316	1,079	460
1947 - 1961	4	8,359	989	1,515	1,118
1962 - 1981	19	22,786	1,722	5,296	3,588
1982 - 1996	5,363	16,787	12,929	22,858	6,277
1997 - present	4,936	17,904	9,590	17,901	12,097
Total	11,461	67,670	25,568	48,716	23,578

Table 5: Count of residential buildings in each damage state, classified by construction era, for scenario 001-00406, a Category 3 cyclone impacting Gold Coast, Qld. See Appendix H for definitions of the damage states.

4.2.2 Category 5 cyclone: scenario 006-05866

For the Category 5 scenario, the cyclone again forms well out in the Coral Sea, slowly intensifying to Category 5 around 1,000km east of Mackay. It drifts slowly east for a period then turns south, through to southwest and accelerates towards the coast. Just prior to landfall, the cyclone track shifts southwards, taking the eye over the southern end of North Stradbroke Island. This brings the southern eyewall over South Stradbroke Island and the northern end of Main Beach. It should also be noted that this track is similar to the initial forecasts for TC Oma, 2019.

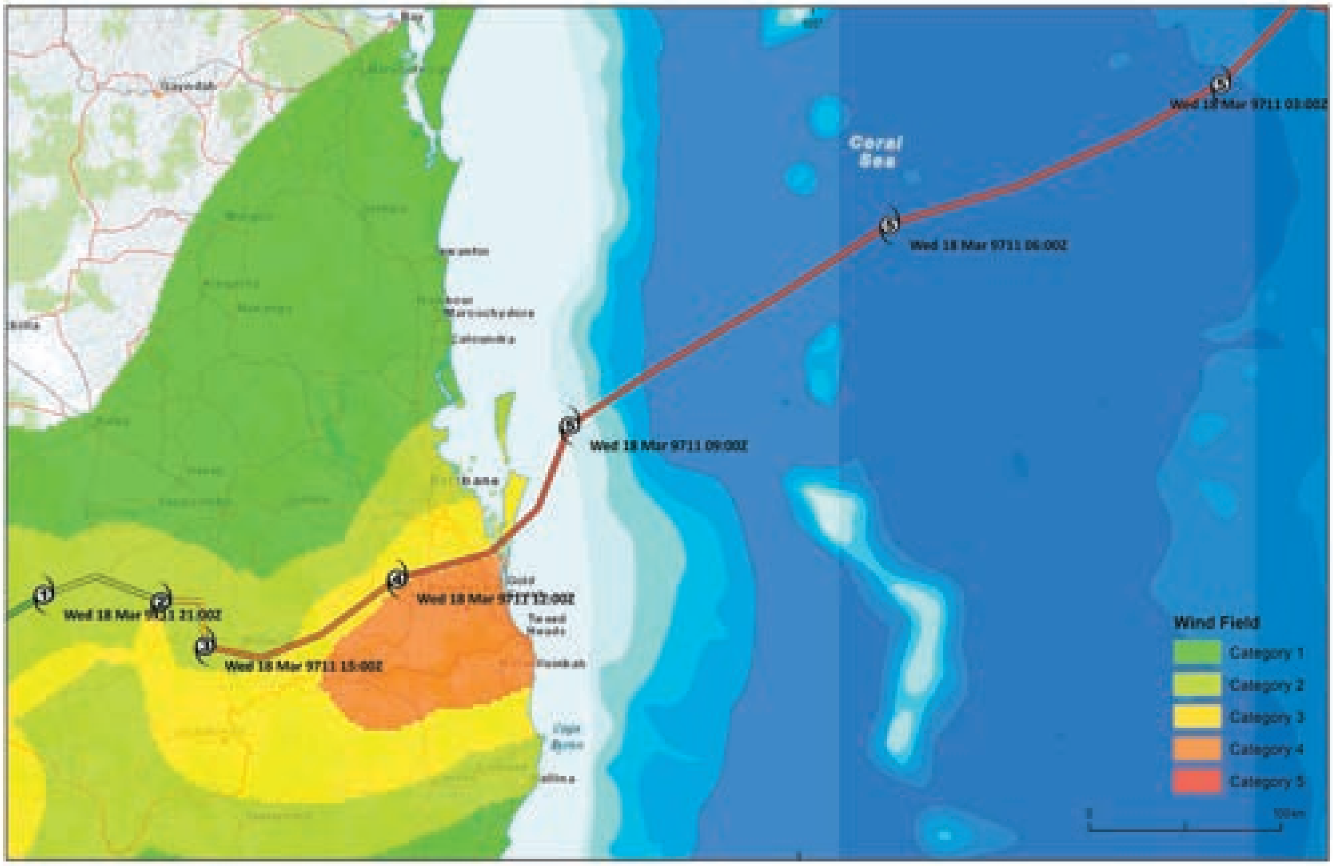


Figure 36: Regional wind field for scenario 006-05866, a Category 5 cyclone impacting Gold Coast, Qld.

In this case, local winds exceed 260km/h along the Main Beach area down to Surfers Paradise. Behind the foreshore, most of the suburban areas experience winds in excess of 200km/h. There are isolated points along the coastline where wind gusts may exceed 250km/h, such as around Burleigh Heads. Further inland, maximum wind speeds over the Hinterland exceed 300km/h due to the local topographic enhancement as far inland as Springbrook.

Due to the intensity of the cyclone, its westward track, speed of movement and the presence of the undulating terrain associated with the Great Dividing Range, Category 5 wind speeds may be present as far inland as Beaudesert and the areas surrounding the Mount Barney National Park. Category 4 wind speeds would have the potential to affect areas as far inland as Stanthorpe and Goondiwindi (over 300km inland). Impact over such a wide area, encompassing major urban and regional centres, would be catastrophic for the region, the state and Commonwealth. It is worth noting that this assessment does not consider the impact to the Northern New South Wales communities identified in Figure 36. The Category 5 scenarios for both Cairns and Townsville highlight the impacts that may be experienced by inland regional centres.

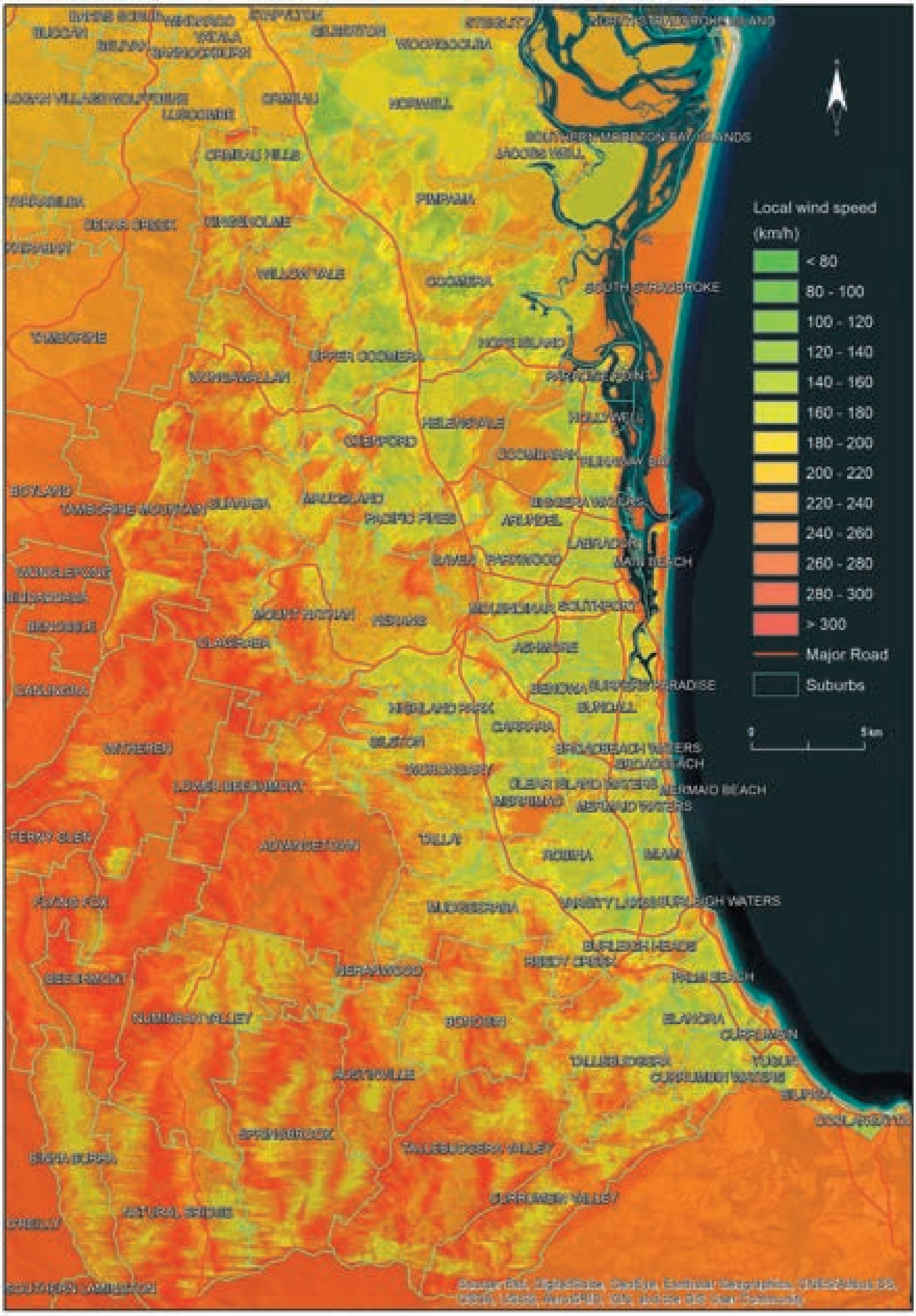


Figure 37: Local wind field for scenario 006-05866, a Category 5 cyclone impacting Gold Coast, Qld.

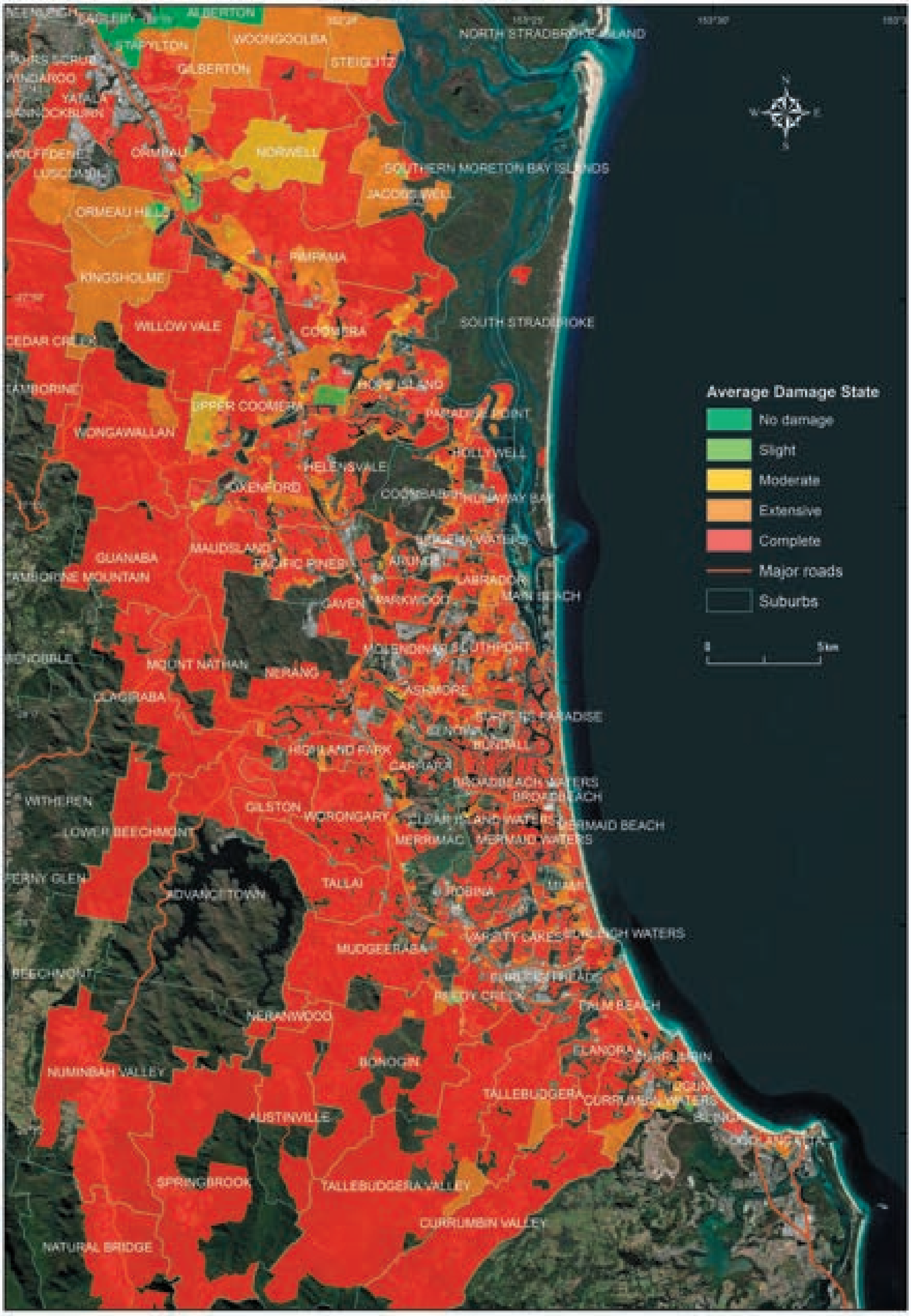


Figure 38: Aggregated residential building damage states for mesh block areas, for scenario 006-05866, a Category 5 cyclone impacting in Gold Coast, Qld.

This scenario results in widespread Moderate to Complete damage across the Gold Coast region. The local wind speeds exceed design wind speeds by a significant margin, including for modern construction (which dominates the population in the Gold Coast), so over 135,000 houses (90% of residential buildings within the impacted study area) are classified as either an Extensive or Complete damage state. The northern fringes of the Gold Coast suffer less damage, as the local winds are lower as one moves further north in this scenario (the Greater Brisbane area would be unlikely to see winds greater than 120 km/h in this scenario).

While the probability of a Category 5 impact on the Gold Coast (or anywhere in South East Queensland) is low, the consequences would be catastrophic – comparable to the impact of Hurricane Andrew (1992) on Miami, Florida where 63,000 houses were completely destroyed. This scale of impact would be the outcome regardless of the exact details of the track of the cyclone, as the housing on the Gold Coast is not constructed to the same standards as the cyclonic regions further north in Queensland. A direct strike from a Category 3 cyclone is likely to bring major damage to South East Queensland communities, however in those situations, damage would be greatest among older and more exposed houses.

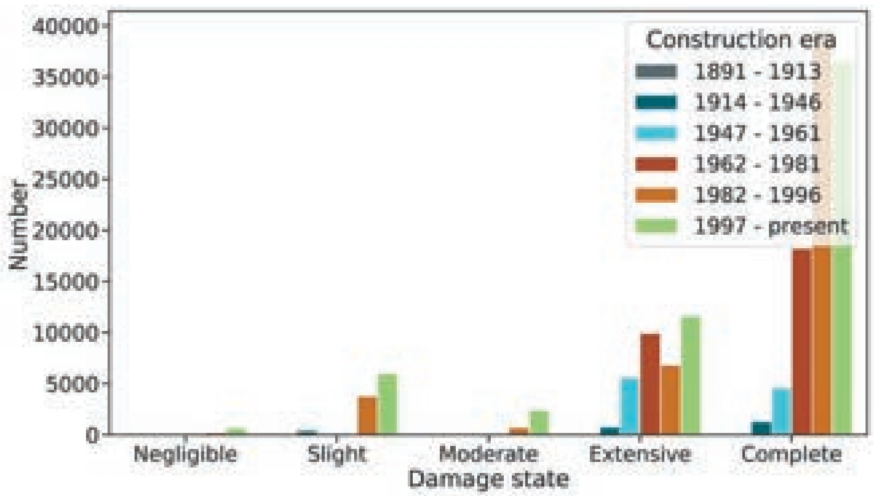


Figure 39: Count of buildings in each damage state, grouped by construction era, for scenario 006-05866, a Category 5 cyclone impacting Gold Coast, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	90	296	23	143	171
1891 - 1913	5	59	4	35	33
1914 - 1946	11	417	55	776	1,294
1947 - 1961	34	11	72	5,628	4,622
1962 - 1981	88	38	118	9,944	18,248
1982 – 1996	238	3,792	717	6,829	39,473
1997 - present	666	5,987	2,418	11,622	36,614
Total	1,132	10,600	3,407	34,977	100,455

Table 6: Count of residential buildings in each damage state, classified by construction era, for scenario 006-05866, a Category 5 cyclone impacting Gold Coast, Qld.

Case study: Severe Tropical Cyclone Seroja and implications for South East Queensland (2021)

Extract from Boughton, G., et.al. (2021), Tropical Cyclone Seroja Damage to buildings in the Mid-West Coastal Region of Western Australia

Severe Tropical Cyclone Seroja (TC Seroja) crossed the coast near Port Gregory, a small town between Kalbarri and Geraldton, around 8:15 pm on Sunday 11 April 2021, as shown in Figure 40. Port Gregory is at around the same latitude as the Queensland – New South Wales border. The Bureau of Meteorology (BOM) classified the system as a Category 3 at land fall.

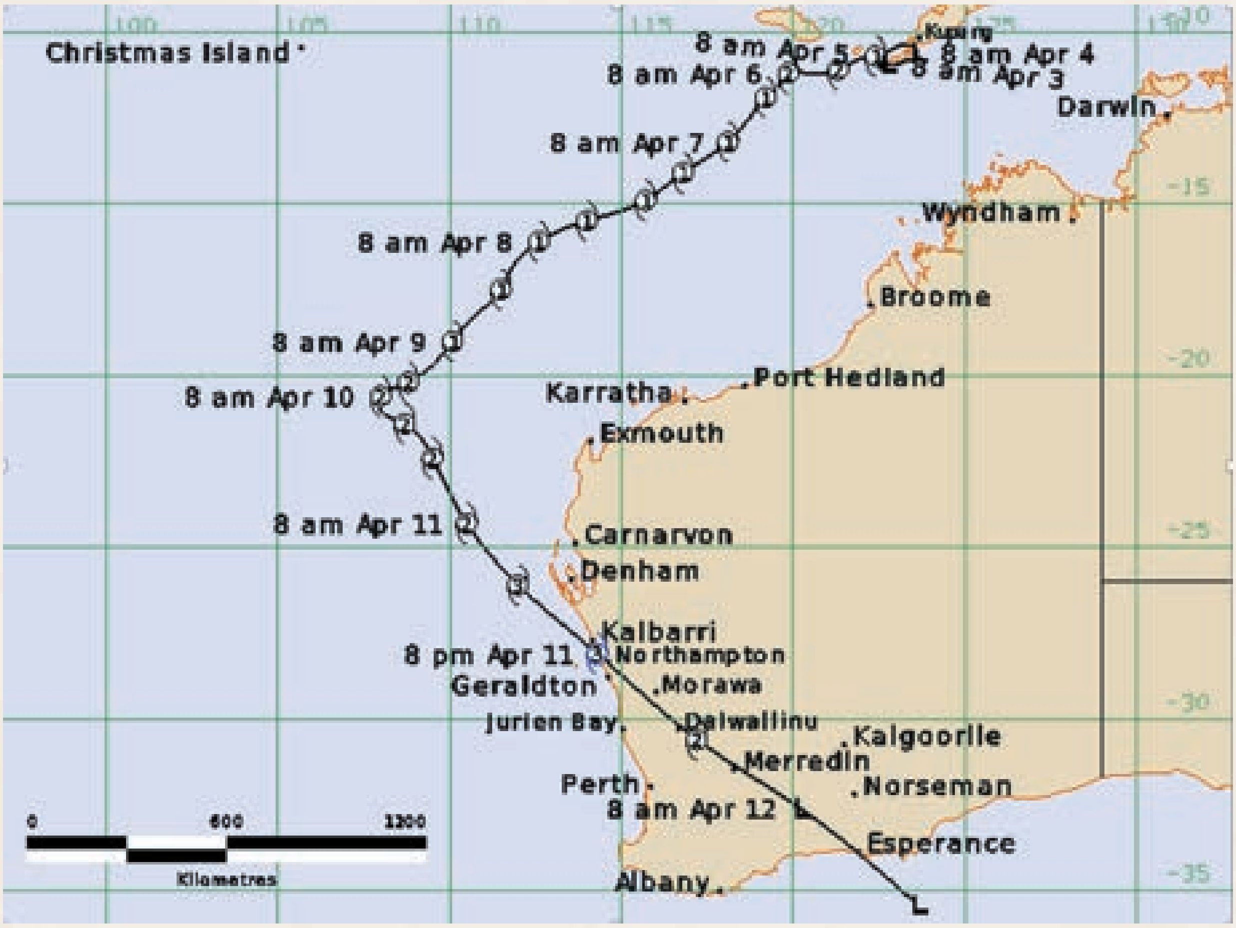


Figure 40: Track of TC Seroja (Bureau of Meteorology)

Analysis of BOM and other data indicated that the maximum 0.2-sec gust wind speed over land was between 46 and 51 m/second (166 to 184 km/h) at Kalbarri, which is around 80 to 90% of the minimum design wind speed for Importance Level 2 buildings in Wind Region B (see figure 17 on page 28). In Queensland, Wind Region B extends from south from Bundaberg to the border with New South Wales.

Damage investigations of buildings were conducted by the Cyclone Testing Station (CTS), the WA Department of Mines, Industry, Regulation and Safety, Building and Energy Division (Building and Energy), and the WA Department of Fire and Emergency Services (DFES).

Data from DFES Rapid Damage Assessments and information obtained during the CTS and Building and Energy damage investigation were combined to determine the extent and causes of damage to buildings in the affected areas. Around 10 % of buildings in Kalbarri and Northampton had damage classified as 'severe' or 'total'. The performance of roofs significantly influenced the level of overall damage to buildings. Many newer houses in Kalbarri had structural damage for wind speeds less than the design (Figure 41).

Figure 41: Damage to roof cladding and roof structure (CTS)

The main cause of severe structural damage to houses in Kalbarri was the combination of large suction forces on the roof and a rapid increase in internal pressure created by an opening in the building envelope (Figure 42). The opening could occur from a wind load failure of a door or from wind-borne debris breaking a door or window. Designers that use AS/NZS 1170.2 can choose between using low internal pressures from a table applicable to sealed buildings, or higher internal pressures from a table for buildings with openings. Houses in Wind Regions A and B that are designed using AS 4055 have N wind classifications that are based on low internal pressures. Because the tie-down connections in the roofs of many of the buildings were designed assuming low internal pressure, they were not strong enough to cope with the higher loads that were applied when a door or window broke.

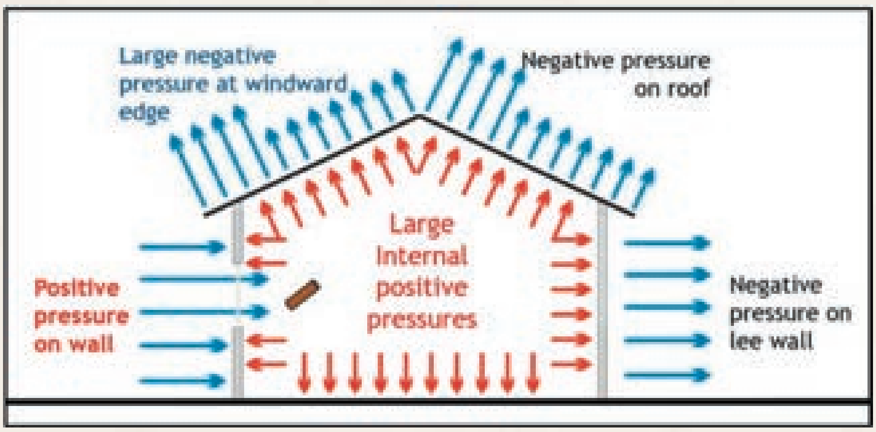


Figure 42: Schematic of pressures acting on a structure with a windward wall opening (e.g. broken window)

Some buildings were damaged because structural elements had deteriorated. Regular maintenance on buildings of all ages is recommended, and components and systems upgraded as necessary.

TC Seroja has reminded the community that severe tropical cyclones affect towns and cities in Wind Region B. To protect these communities, buildings must be designed and built to resist all of the characteristics and impacts of tropical cyclones including, high winds, wind-borne debris, wind-driven rain and storm surge.

AS 4055 is used to determine the wind classification for most houses. The minimum standard of construction in Wind Region B is the appropriate N-classification – N2 or higher. However, a house can be constructed to an equivalent C-classification, which will mean the house has more robustness in tropical cyclones when there may be a lot of wind-borne debris, as there was during TC Seroja. The stronger tie-downs will minimise the chance of roof damage if windows or doors are damaged by wind-borne debris.

The design wind speed for C1 wind classification is the same as the design wind speed for N3, but the design pressures for C1 are higher as they assume that a window or door could have been broken by wind-borne debris. The following table gives equivalent C wind classifications for each of the N wind classifications. The design wind speed is the same for across classifications, but the C classification means the roof structure should be strong enough to cope if a window or door breaks during a cyclone.

N Classification	C Classification
N3	C1
N4	C2
N5	C3
N6	C4

Boughton, G., et.al. (2021), *Tropical Cyclone Seroja Damage to buildings in the Mid-West Coastal Region of Western Australia,* Cyclone Testing Station Technical Report 66, James Cook University, Australia.
https://www.jcu.edu.au/__data/assets/pdf_file/0004/1801606/Technical-Report-66-Cyclone-Testing.pdf/_noproxycache

4.3 Gladstone

The city of Gladstone plays a vital role in the local, state and national economies. The Port of Gladstone is the fifth largest multi-commodity port in Australia and the world's fourth largest coal-exporting terminal. Impact from a significant natural disaster, such as a tropical cyclone, with regional impacts, could have potentially far reaching social and economic consequences for the Central Queensland region and the state. As such, the selection of Gladstone for an evaluation of potential cyclone impact was essential in delivering the objectives of this project.

For Gladstone, the selected scenarios approach from opposite directions, to highlight the different impacts arising from different scenarios, including the choice of track and intensity. The selected tracks approach from the north and south east respectively, which leads to major differences in the path of the most intense winds over Gladstone and, in the case of the Category 5 scenario, the region.

4.3.1 Category 3 cyclone: scenario 001-04162

The Category 3 event approaches Gladstone from the north, following a track similar to early forecasts of TC Marcia, 2015 though at lower intensity (TC Marcia made landfall as a Category 5 cyclone in Shoalwater Bay). The cyclone crosses the southern end of Curtis Island then passes directly over Gladstone. This places a band of strongest winds to the south of the main urban areas towards the Tannum Sands area. The storm moves through and weakens rapidly before moving back offshore near Tewantin in Noosa Shire.

Figure 43: Regional wind field for scenario 001-04162, a Category 3 cyclone impacting Gladstone, Qld.

Figure 44: Local wind field for scenario 001-04162, a Category 3 cyclone impacting Gladstone, Qld.

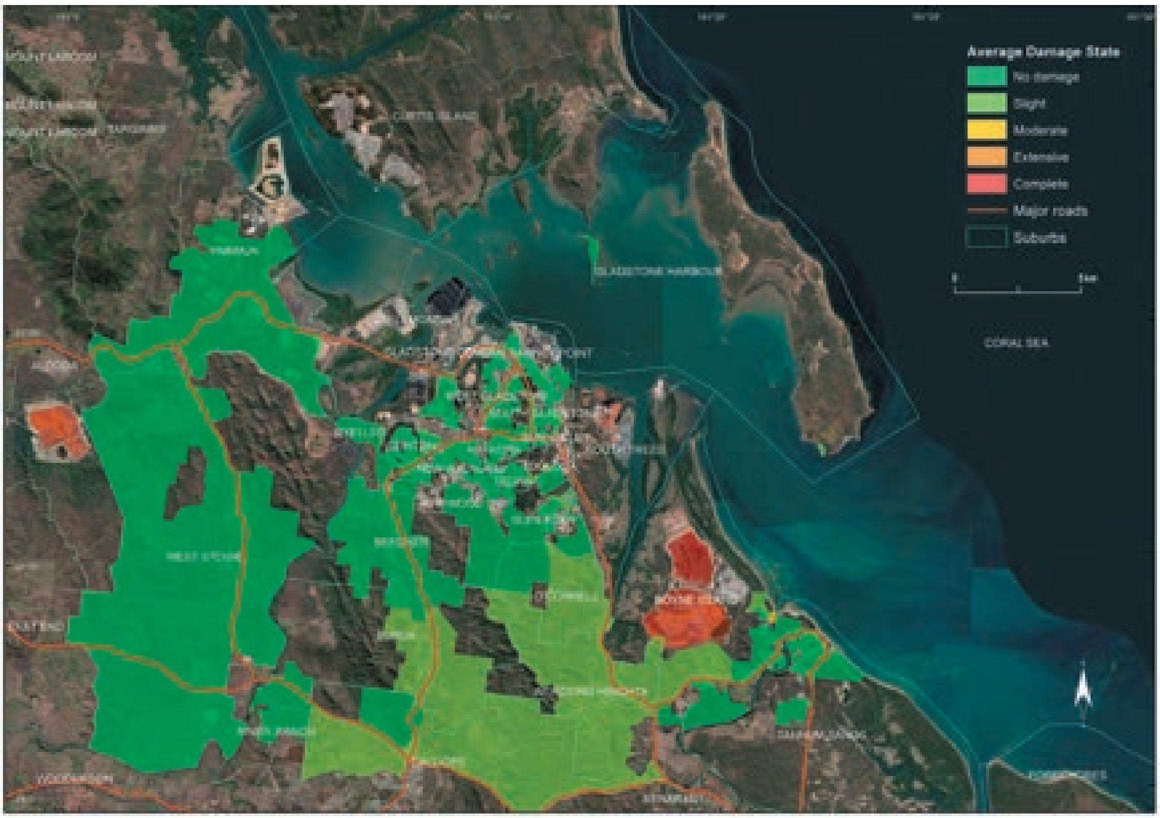


Figure 45: Aggregated residential building damage states for mesh block areas, for scenario 001-04162, a Category 3 cyclone impacting in Gladstone, Qld.

Because the strongest winds pass to the south of Gladstone, most areas of Gladstone are exposed to winds of less than 120km/h. Southwards towards Tannum Sands, local wind gusts may reach 190km/h. Because the majority of Gladstone experiences winds well below the design threshold of 250km/h (Gladstone is in Wind Region C in the Wind Loading Standard) in this scenario, there is very low structural damage to the residential housing. A few small pockets of moderate damage would be expected around Boyne Island, where there are locally higher winds and a significant proportion of pre-1980s housing (around 20%). Because the majority of houses are located back from the foreshore in Tannum Sands, and therefore not exposed to the strongest winds, the damage actually remains low.

Of the nearly 110,000 houses in the region (the analysis region in this case extends from Rockhampton to Bundaberg), only 500 would sustain major damage (Moderate, Extensive or Complete), and the majority of those are in Gladstone or the neighbouring Banana Shire. However, broadscale impacts from consequential rainfall and riverine flooding would certainly be in line with that experienced during ex-TC Oswald, 2013.

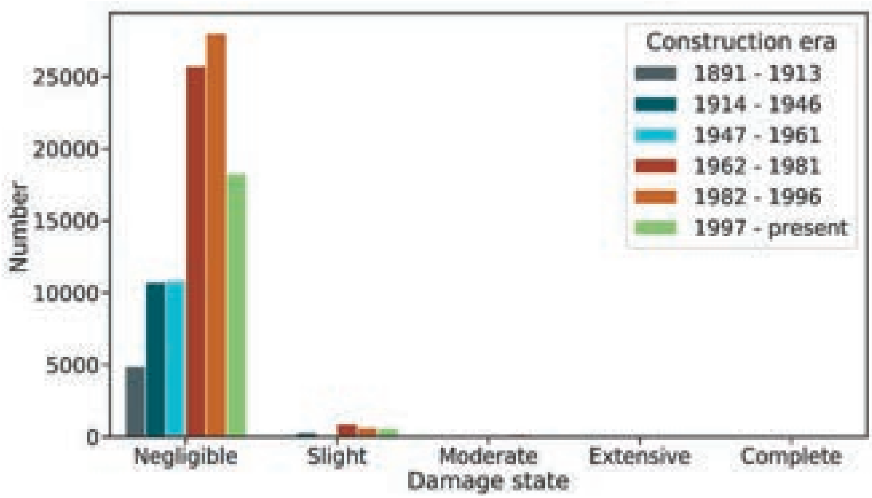


Figure 46: Count of buildings in each damage state, grouped by construction era, for scenario 001-04162, a Category 3 cyclone impacting Gladstone, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	6,616	55	5	13	5
1891 - 1913	4,869	82	11	15	6
1914 - 1946	10,719	263	18	30	3
1947 - 1961	10,853	102	10	1	0
1962 - 1981	25,723	878	65	52	13
1982 - 1996	28,010	619	138	36	2
1997 - present	18,263	585	76	17	0
Total	105,053	2,584	323	164	29

Table 7: Count of residential buildings in each damage state, classified by construction era, for scenario 001-04162, a Category 3 cyclone impacting Gladstone, Qld.

4.3.2 Category 5 cyclone: scenario 003-08775

In this Category 5 scenario, the cyclone moves slowly across the Coral Sea, maintaining intensity at Category 5 level for several days. When well offshore of Yeppoon, it turns to the south-southwest and passes close to Rodds Bay to the south of Gladstone. It maintains intensity as a Category 5 cyclone as it traverses Curtis Island in a northerly direction, before moving inland just south of Yeppoon. This track would bring very strong winds to both Bundaberg and Rockhampton, as well as Gladstone.

In this scenario, communities between Bundaberg and Rockhampton, and as far inland as Blackwater, would experience major impacts which are historically analogous to those events experienced in North Queensland such as TC Debbie, 2017 and TC Yasi, 2011.

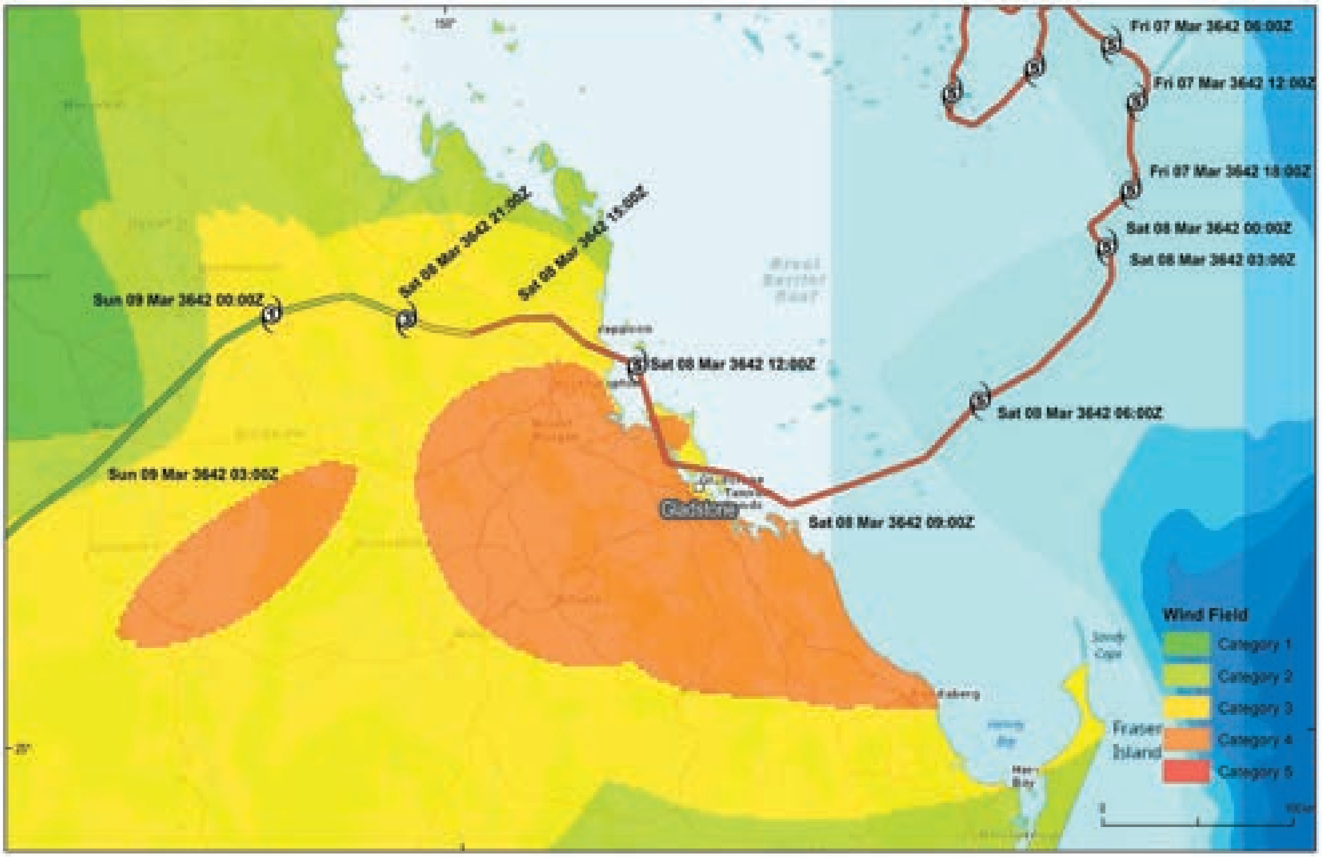


Figure 47: Regional wind field for scenario 003-08775, a Category 5 cyclone impacting Gladstone, Qld.

Because the track of the cyclone passes directly over Curtis Island in a northerly direction, the local winds in Gladstone remain comparatively lower than slightly further inland, in part due to the size of the cyclone's circulation. Maximum winds are around 140km/h in the suburban areas of Gladstone but are significantly higher in the outskirts – some areas are over 220km/h towards Boyne Island and Tannum Sands.

Figure 48: Local wind field for scenario 003-08775, a Category 5 cyclone impacting Gladstone, Qld.

The pattern of local winds is largely reflected in the areas of greatest damage towards Calliope, which on average experiences Extensive damage. Suburbs exposed to the south – Sun Valley, Toolooa and Glen Eden – also sustain Moderate damage. Overall, the majority of houses across the region suffer Negligible or Slight damage (over 90%). In Gladstone itself, around 10% of houses sustain Moderate or greater damage. With the track of the cyclone also impacting Bundaberg and Rockhampton, those cities sustain extensive damage to over 10% of the housing population as well (Figure 48 and Figure 49).

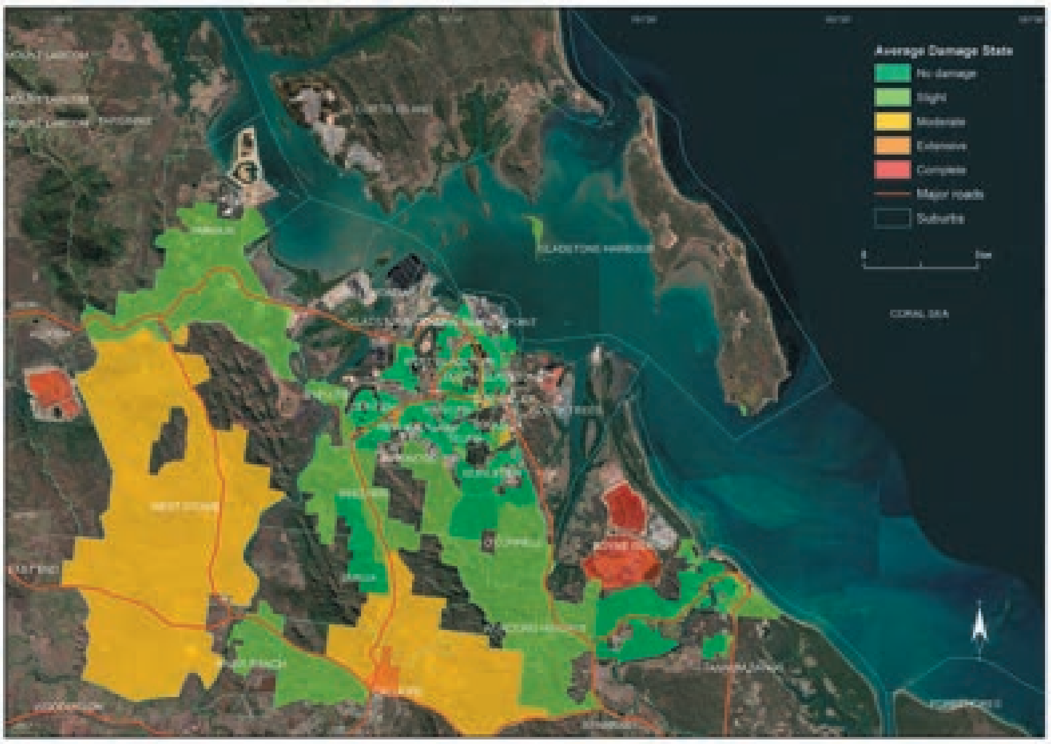


Figure 49: Aggregated residential building damage states for mesh block areas, for scenario 003-08775, a Category 5 cyclone impacting in Gladstone, Qld.

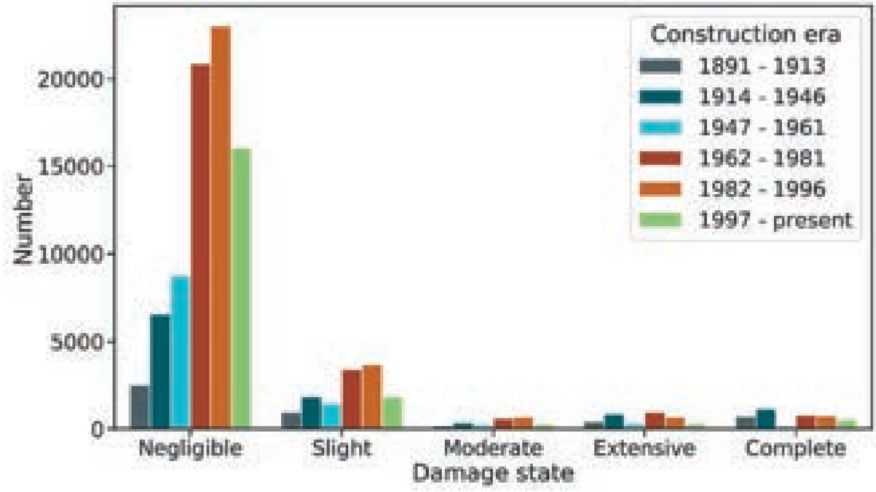


Figure 50: Count of buildings in each damage state, grouped by construction era, for scenario 003-08775, a Category 5 cyclone impacting Gladstone, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	3,891	1,485	207	515	520
1891 - 1913	2,496	970	158	430	714
1914 - 1946	6,575	1,850	326	834	1,121
1947 - 1961	8,779	1,460	240	313	163
1962 - 1981	20,864	3,406	610	954	789
1982 - 1996	23,027	3,690	670	669	749
1997 - present	16,032	1,835	254	285	535
Total	81,664	14,696	2,465	4,000	4,591

Table 8: Count of residential buildings in each damage state, classified by construction era, for scenario 003-08775, a Category 5 cyclone impacting Gladstone, Qld.

In both these scenarios, the geographic location of Gladstone, with Curtis and Facing Islands offshore and small ranges to the south, means there is significant reduction in local winds over the major urban areas of Gladstone. This situation leads to lower damage levels in the city, but nearby communities may still suffer significant impacts. In both these scenarios the Boyne Island/ Tannum Sands areas suffer proportionally greater damage. There are likely to be other scenarios where the track of the cyclone means Gladstone's geographic location does not provide any protection, which could lead to substantially greater damage than what has been presented here.

The inland extent of Category 3 and 4 wind speeds in this scenario would cause major damage to most houses around Monto, Biloela and other parts of the Banana Shire (refer Table 9). These regions are not in the cyclonic wind loading regions, so even modern houses are not designed for the maximum wind speeds this scenario would generate (over 230km/h). Areas adjacent to the cyclonic regions should be aware there is a small probability that extreme winds could impact their communities and would bring major damage should such a scenario occur.

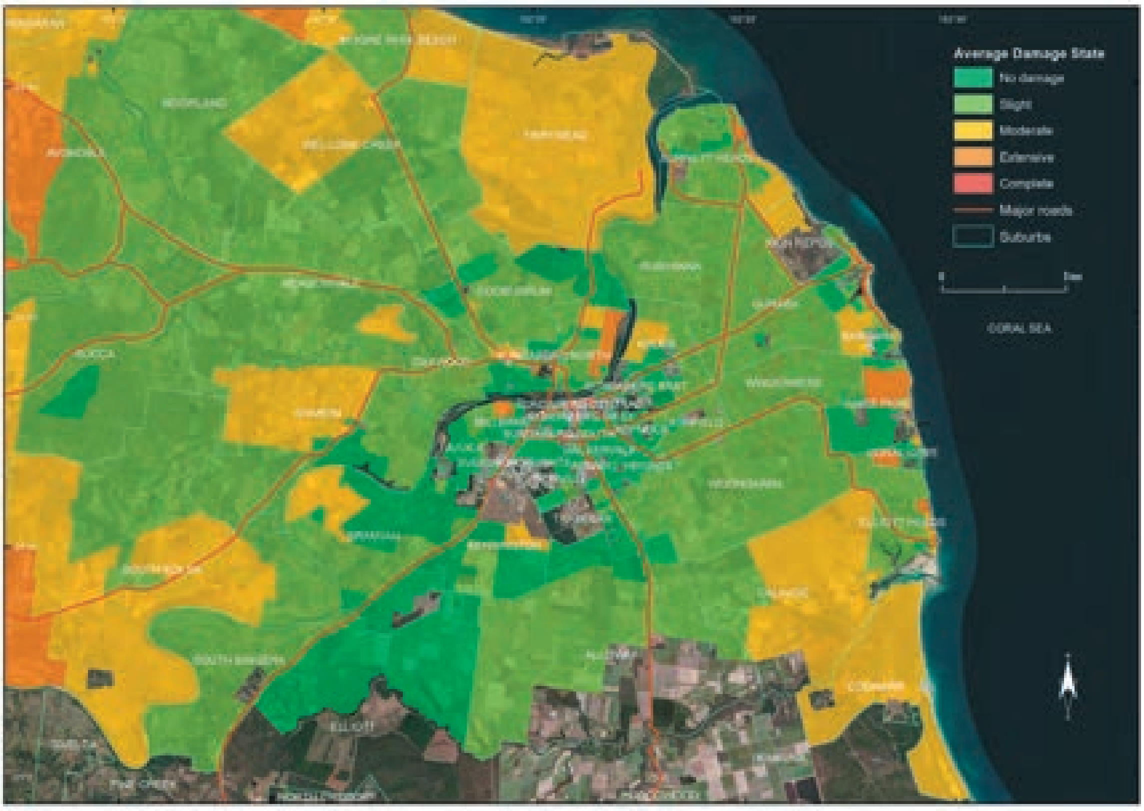


Figure 51: Aggregated residential building damage states for mesh block areas, for scenario 003-08775, a Category 5 cyclone impacting in Bundaberg, Qld.

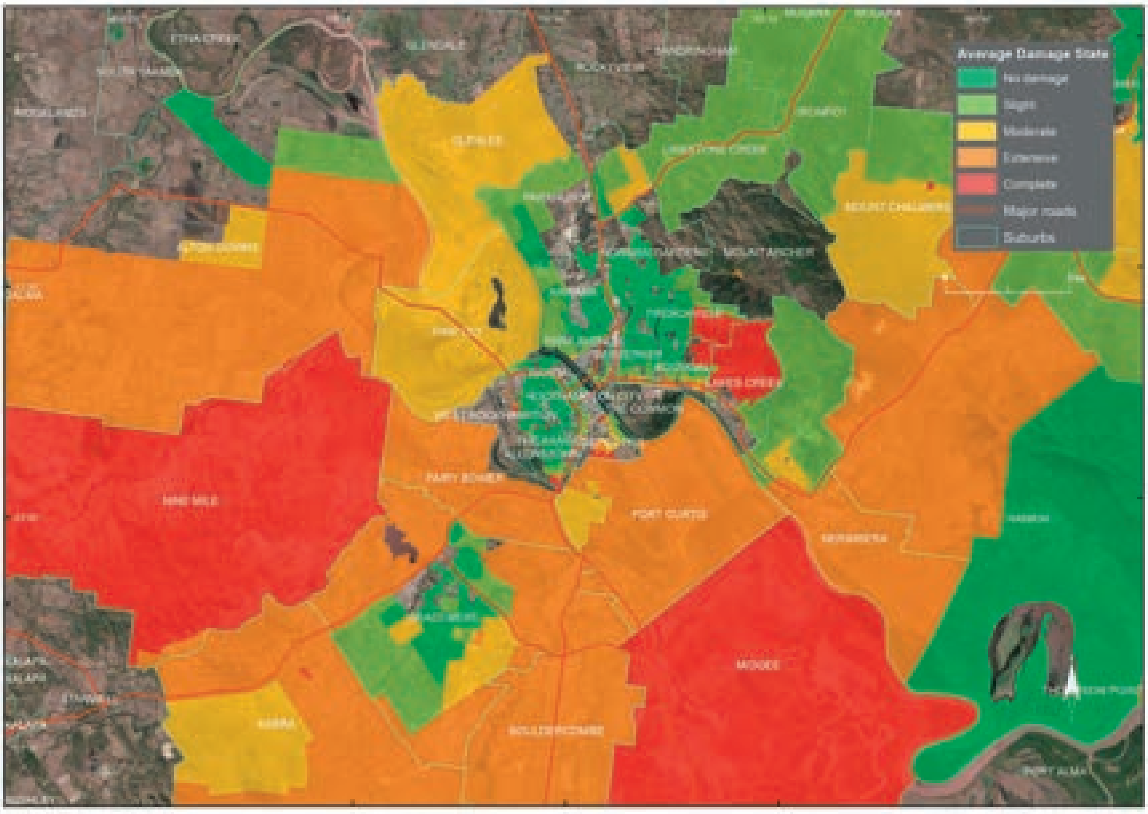


Figure 52: Aggregated residential building damage states for mesh block areas, for scenario 003-08775, a Category 5 cyclone impacting in Rockhampton, Qld.

Further afield, both Bundaberg and Rockhampton would be impacted (Figure 51 and Figure 52), though to a lesser extent than Gladstone and surrounds, relative to the overall population of each of these cities. In the Bundaberg region, some 2,000 houses would be moderately damaged or greater. Most of these are in the coastal areas between Burnett Heads and Elliot Heads, and in North Bundaberg where there is an older housing population. The rural areas between Bundaberg and Agnes Water would also be significantly impacted. In Rockhampton, the most heavily impacted areas are on the southern outskirts of the city, towards Gracemere and Port Curtis, which are exposed to higher winds.

This situation of one cyclone impacting multiple major regional centres would likely strain emergency services responding to the event. Resources typically deployed from Gladstone to neighbouring districts may not be available due to local need, requiring resources from further afield. This could potentially increase response time. Additionally, it would mean that evacuation prior to landfall could not proceed to Rockhampton, as that city would also be under threat from the approaching cyclone.

LGA	Negligible	Slight	Moderate	Extensive	Complete
Banana (S)	3,842	805	369	938	2,127
Bundaberg (R)	28,115	4,676	565	840	521
Gladstone (R)	15,282	3,232	625	628	479
Livingstone (S)	10,039	679	79	186	60
North Burnett (R)	1,271	279	135	305	321
Rockhampton (R)	23,115	5,025	692	1,103	1,083

Table 9: Distribution of residential building damage across local government areas for scenario 003-08775. NB (S) = Shire, (R) = Region.

4.4 Mackay

Given the events of the 1918 cyclone and TC Debbie, 2017, Mackay was an obvious choice for this study. It is a historic and regionally important centre whose industries, such as mining and agriculture, contribute significantly to the wider Queensland economy. As with Gladstone, direct impact to Mackay and the surrounding region from scenarios such as those evaluated below could have significant social and economic impacts, as was evident in the immediate aftermath of TC Debbie.

Figure 53: Shute Harbour is littered with debris following Cyclone Debbie. Source: AAP (Dan Peled)

Case study: Economic impacts of Tropical Cyclone Debbie

On Tuesday, 28 March 2017, TC Debbie crossed the Queensland coast as a Category 4 system around Airlie Beach, then tracked southwest over the next few hours before being downgraded to a tropical low the following day. TC Debbie inflicted significant structural damage to properties in the Whitsunday Islands, Airlie Beach and Proserpine and delivered a substantial amount of rainfall across the central coast, highlands and coalfields all the way down to the south east coast regions of Queensland and into New South Wales, resulting in major flooding impacts to many communities in these areas.

TC Debbie caused damage and distress to households, businesses and public facilities, and the recovery and repair took an extended time. At the time of writing, some areas are still in recovery or unable to recover due, in part, to the compounding effects of multiple disasters since 2017 (e.g. the Central Queensland bushfires and the impact of COVID-19).

This case study focuses on the impact of the cyclone on overall economic output (as measured by Gross State Product - GSP). This primarily involves examining the impact on Queensland's resources and agricultural production, as well as on the state's tourism sector. Impacts on the State Budget include the costs to rebuild damaged roads and local government infrastructure, providing assistance to individuals, families and businesses impacted by the disasters.

The Queensland budget statement in 2018 highlighted that direct economic damage caused by TC Debbie was significant with key sectors impacted including coal exports, agricultural production, as well as tourism in the Central Queensland region. It has been estimated that losses included $1.5 billion in lost coal sales and approximately $500 million in agriculture, with major adverse impacts on sugar cane and winter horticulture supplies to southern Australia. Infrastructure damage was estimated at over $1 billion.

Overall, the loss to economic output due to TC Debbie is estimated to have been around $3.5 billion or approximately 1% of GSP. Losses have been spread across several financial years but were predominantly felt in FY2016-17 and FY2017-18.

Coal exports

Unlike the 2010-11 natural disasters, when losses were estimated to have reached $6 billion largely due to mine flooding, there were no occurrences of substantial damage to mines or ports infrastructure. The largest impact on coal exports was due to damage to rail networks, which included:

- the Goonyella network, closed from 28 March to 26 April
- the Blackwater network, closed from 29 March to 10 April
- the Moura network, closed from 29 March to 12 April
- the Newlands network, closed from 28 March to 13 April.

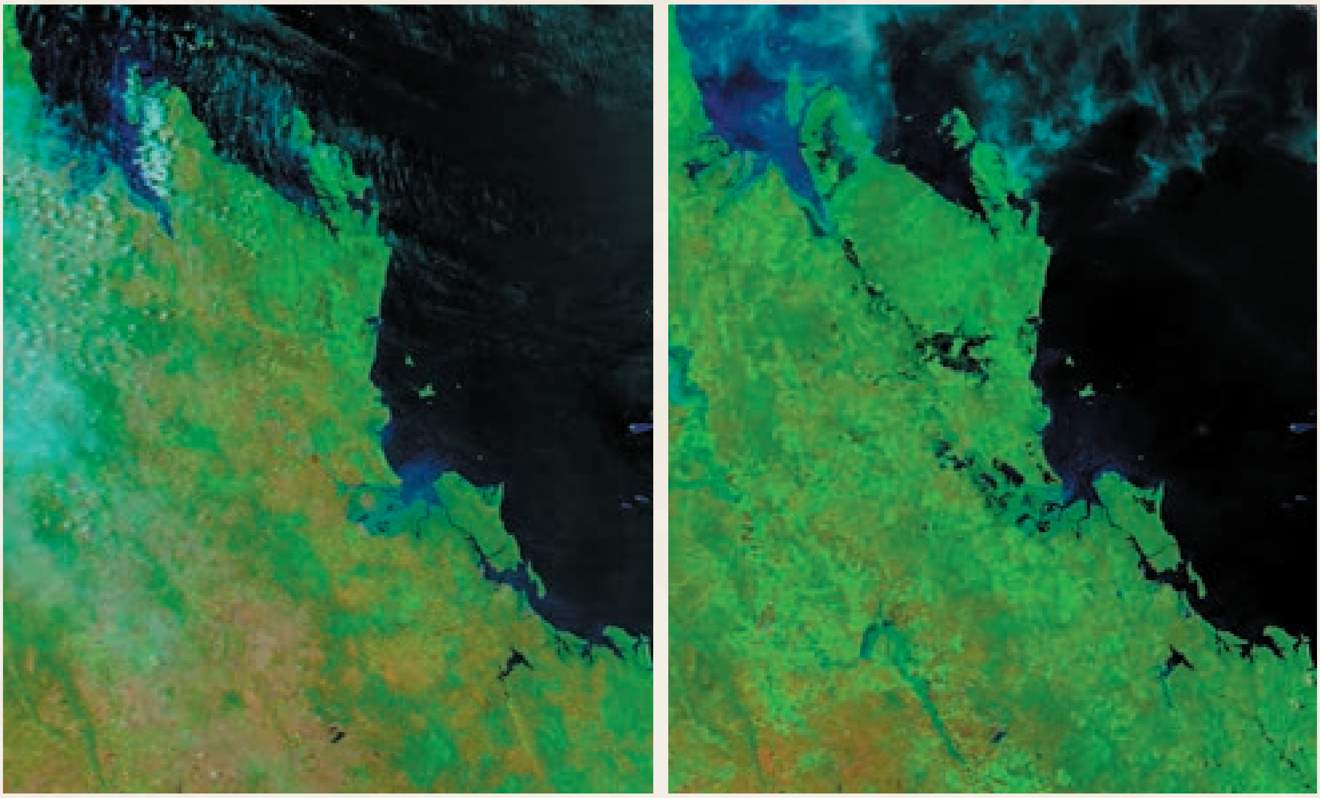
Overall, these closures resulted in a net loss in exports of around 10 million tonnes in June quarter 2017, with approximately two-thirds hard coking coal and the remainder thermal coal.

Agriculture

The Mackay-Isaac-Whitsunday region is a significant agricultural region, with $1.1 billion of agricultural production annually, equating to 9.4% of the Queensland total. The region's most valuable agricultural products in that year were beef ($485 million), sugar ($354 million), vegetables ($176 million) and grain sorghum ($64 million).

Queensland Treasury estimates that losses in the nominal value of sugar exports due to TC Debbie were around $300 million in the 2018 calendar year. Sorghum exports reduced by $37 million in 2017-18.

However, better water availability boosted wheat and chickpea production and exports in 2018 and dried shelled beans exports in 2017-18. In addition, despite some impact on fences and other farm infrastructure, graziers in the affected regions largely welcomed the rain and subsequent fodder growth accompanying TC Debbie, following a sustained period of drought (as highlighted in the NASA images on the adjacent page).



Images captured by NASA's Aqua satellite on 11 February 2017 and 31 March 2017 when waterways were swollen in the Fitzroy Basin. The first image shows the region before the cyclone passed through and deluged the region with rain. Both images were made with visible and infrared light in a combination that highlights the presence of water on the ground. Water is generally dark blue or black in this type of image, but the rivers here appear light blue because they carry large amounts of suspended sediment. While water had not yet inundated Rockhampton when the image was acquired, a large volume of flood water was visible upstream (on the left side of the second image). Source: NASA (Jeff Schmaltz)

Tourism

TC Debbie directly impacted the Whitsundays tourism region, including Airlie Beach and Whitsunday Island resorts.

Overnight visitors spent an estimated $709 million in the Whitsundays region in 2016 (3.6% of the Queensland total), including spending by 243,000 international and 396,000 domestic tourists.

Queensland Treasury calculated that losses to overseas and interstate tourism exceeded $200 million. The loss of key resort capacity included:

- Hamilton Island: some structural damage to the resort which partially re-opened on 8 April, then gradually returned to full capacity by late August 2017
- Daydream Island: decided to bring forward $50 million redevelopment, reopening in mid-2018
- Hayman Island: closed and unable to accept new reservations until mid-2018.

Sound pricing of risk and strong investment performance put the Queensland Government Insurance Fund (QGIF) in a good financial position to support the immediate response and recovery to TC Debbie, with investments held exceeding the provisioning for claims. $500 million was drawn from the QGIF surplus to assist in funding the government's response to TC Debbie.

The Queensland Government contributed $110 million towards a joint $220 million funding package (The Queensland Betterment Fund) under the Commonwealth and state funded Natural Disaster Relief and Recovery Arrangements (NDRRA) Category D following TC Debbie. Betterment projects principally comprise works to increase the resilience of roads, culverts and floodways damaged as a result of repeated natural disasters. More resilient infrastructure allows communities to stay connected and recover quicker after a flood. It ensures roads and bridges can stay open, water treatment plants and sewerage infrastructure can keep operating, and businesses, including primary producers, who rely on vital transport routes, can stay on track.

Adapted for use from information provided by Queensland Treasury to Queensland Government's State Natural Hazard Risk Assessment 2017.

4.4.1 Category 3 cyclone: scenario 007-06470

This scenario has a severe TC moving slowly southwards along the coast, persisting as a Category 4 or 5 cyclone for several days before making landfall just to the south of Mackay. After making landfall, the cyclone moves back offshore briefly, then back onshore. Because of the landfall location, the strongest winds are confined to areas south of Mackay, so the township experiences maximum winds of 150-160km/h.

Mackay is surrounded by low plains to the south towards Sarina and west along the Pioneer River, meaning there is little topographic enhancement of the winds across the region. There are some small hills to the north towards Dolphin Heads, but these are not steep enough to generate strong topographic accelerations.

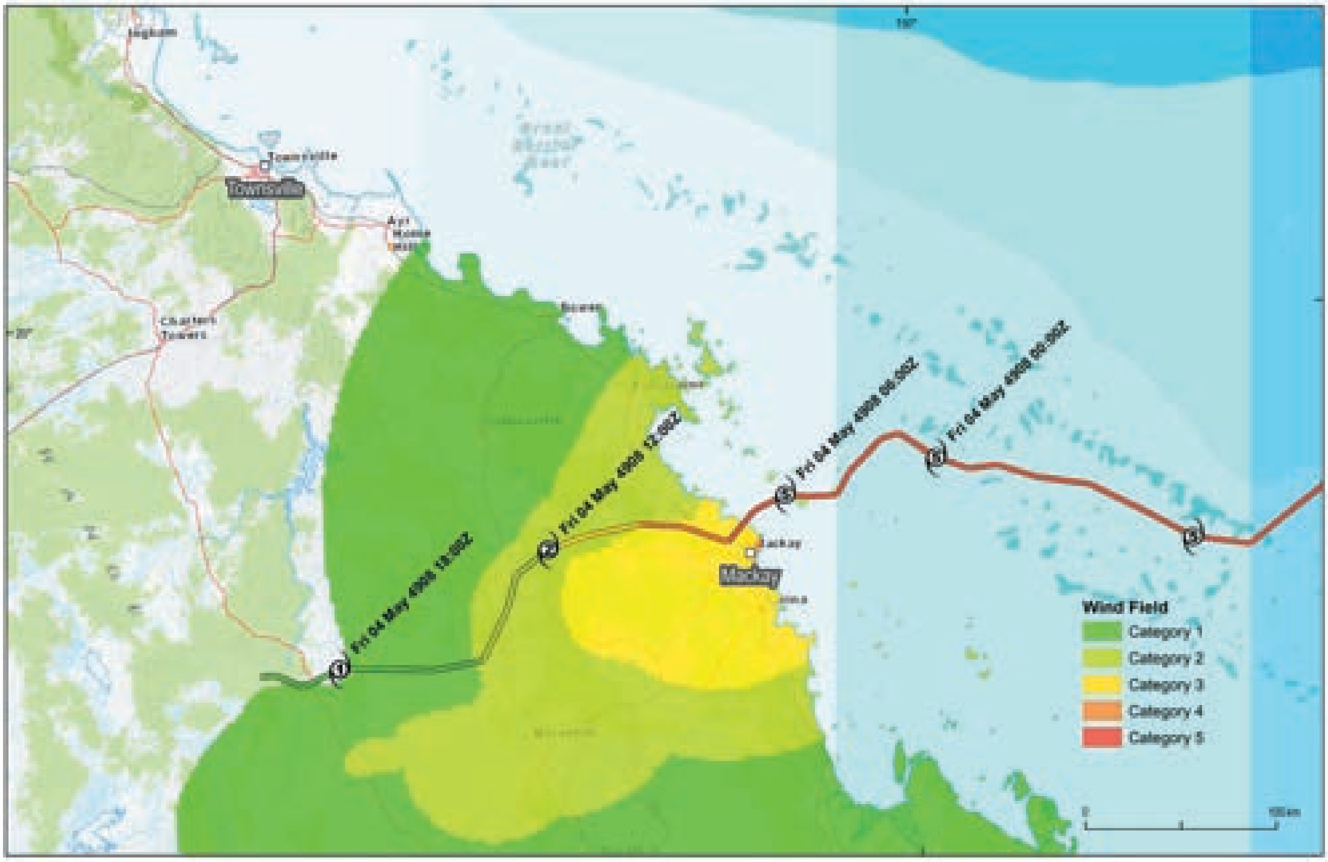


Figure 54: Regional wind field for scenario 007-06470, a Category 3 cyclone impacting Mackay, Qld.

Figure 55: *Local wind field for scenario 007-06470, a Category 3 cyclone impacting Mackay, Qld.*

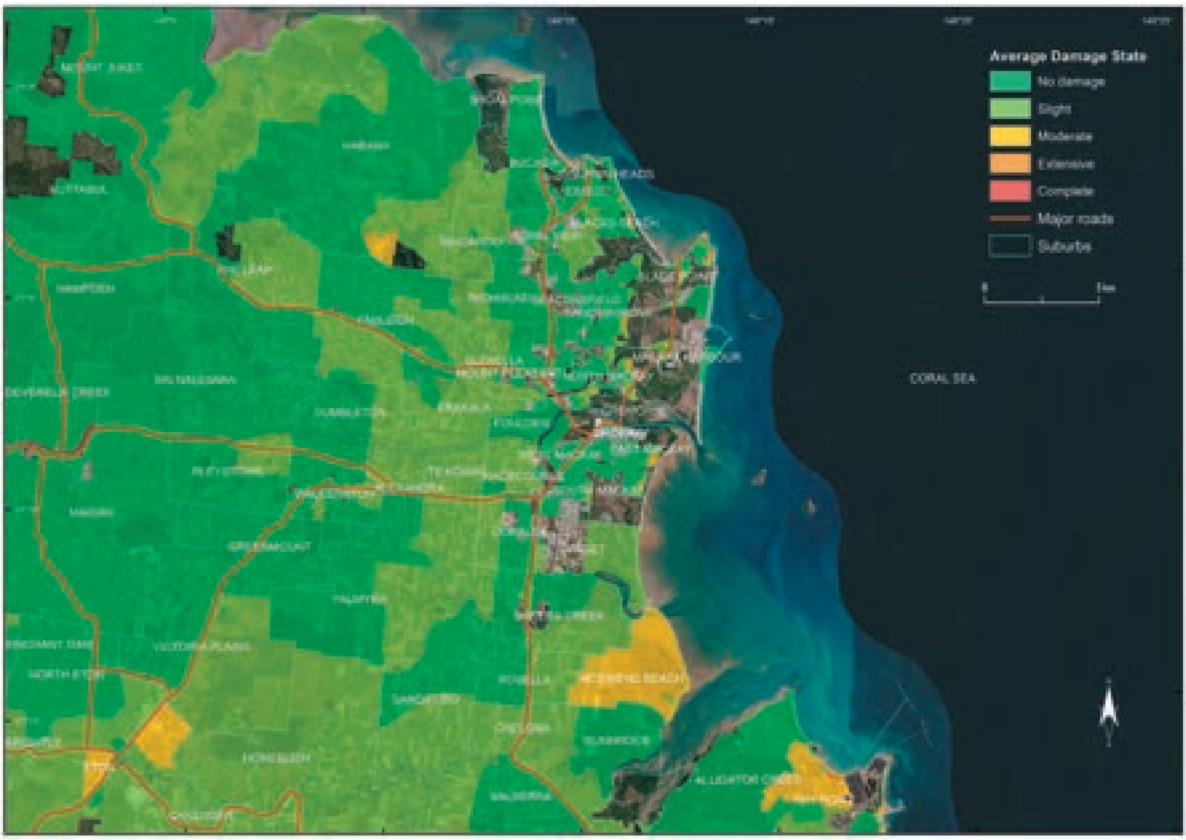


Figure 56: *Aggregated residential building damage states for mesh block areas, for scenario 007-06470, a Category 3 cyclone impacting Mackay, Qld.*

As most parts of Mackay experience winds well below the design level, there is little significant damage in this scenario. Some eastwards-facing areas, such as East Mackay and McEwens Beach, sustain Moderate damage, but this could also be linked to the construction era in these areas.

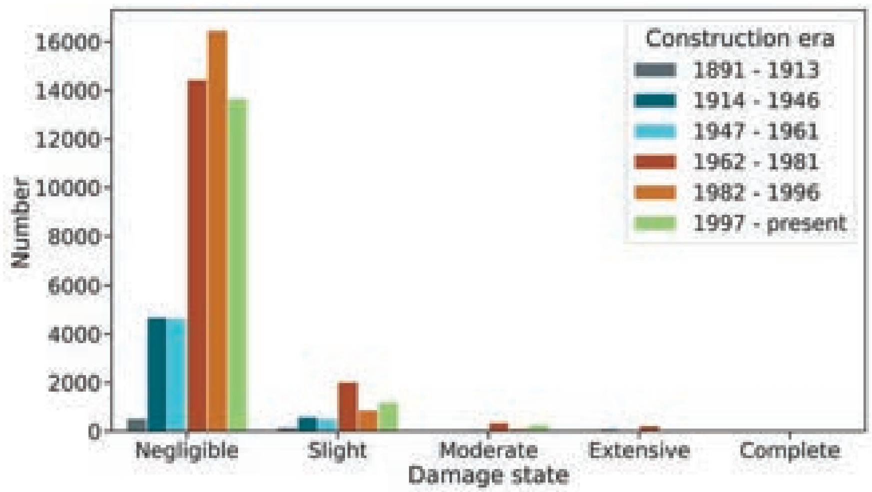


Figure 57: Count of residential buildings in each damage state, grouped by construction era, for scenario 007-06470, a Category 3 cyclone impacting Mackay, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	1,251	133	15	14	3
1891 - 1913	524	150	12	21	3
1914 - 1946	4,694	595	61	91	26
1947 - 1961	4,669	535	91	47	11
1962 - 1981	14,453	2,025	361	226	40
1982 - 1996	16,485	872	103	33	3
1997 - present	13,669	1,193	272	46	1
Total	55,745	5,503	915	478	87

Table 10: Count of residential buildings in each damage state, classified by construction era, for scenario 007-06470, a Category 3 cyclone impacting Mackay, Qld.

4.4.2 Category 5 cyclone: scenario 007-03074

This scenario was selected as an analogue to the 1918 cyclone (see case study in Chapter 2), to understand the impacts on modern-day Mackay. The cyclone moves slowly over the northern Coral Sea, intensifying slowly and attaining Category 5 intensity two days prior to landfall. The cyclone turns towards the coast in the morning and accelerates towards the coast, making landfall just north of Mackay overnight. This track leads to winds in excess of 270km/h along the shorefront in East Mackay and South Mackay. Areas towards Dolphin Heads would also experience winds over 200km/h. The highest wind gusts of 280km/h would be experienced further south, around McEwens Beach and Hay Point. Within the urban area of Mackay however, wind speeds are reduced to around 180km/h or less, due to upwind shielding effects.

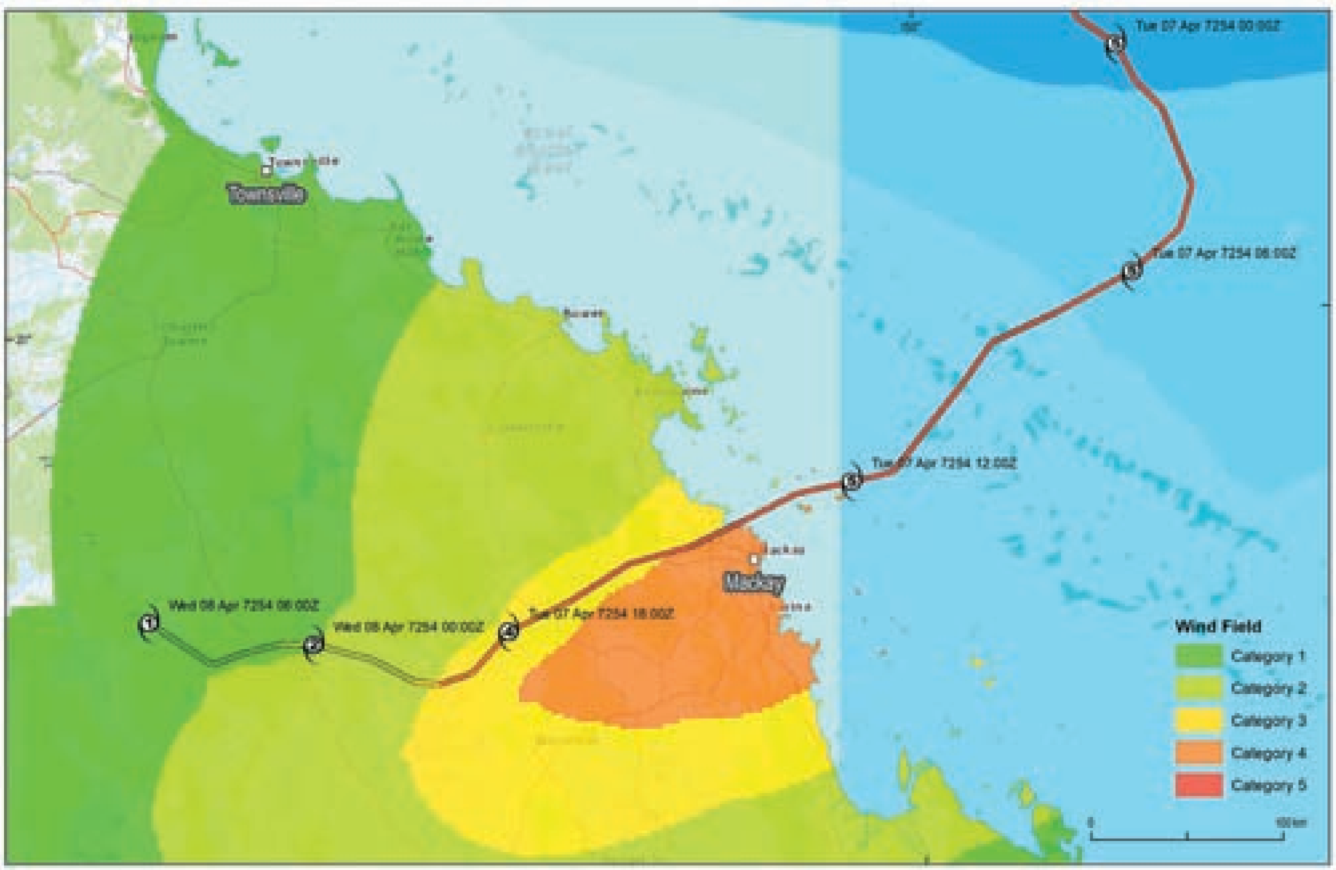


Figure 58: Regional wind field for scenario 007-03074, a Category 5 cyclone impacting Mackay, Qld.

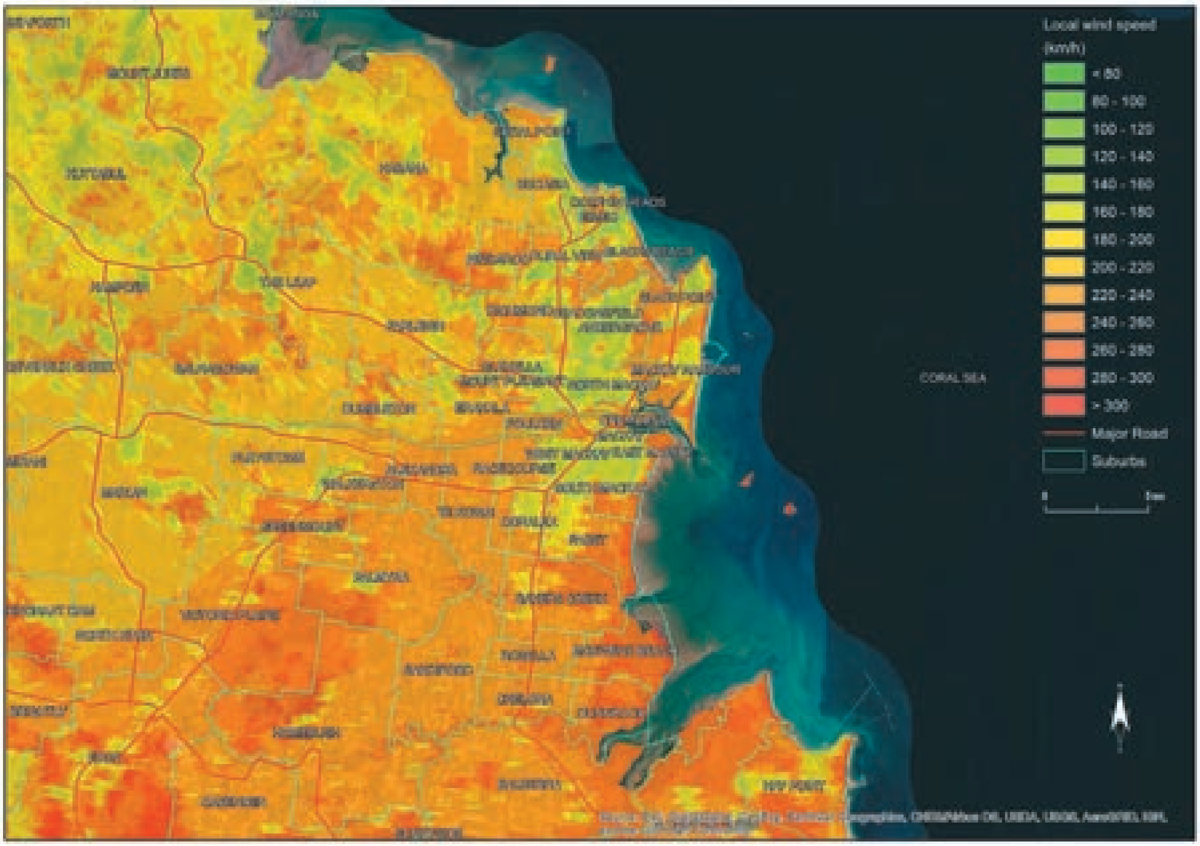


Figure 59: Local wind field for scenario 007-03074, a Category 5 cyclone impacting Mackay, Qld.

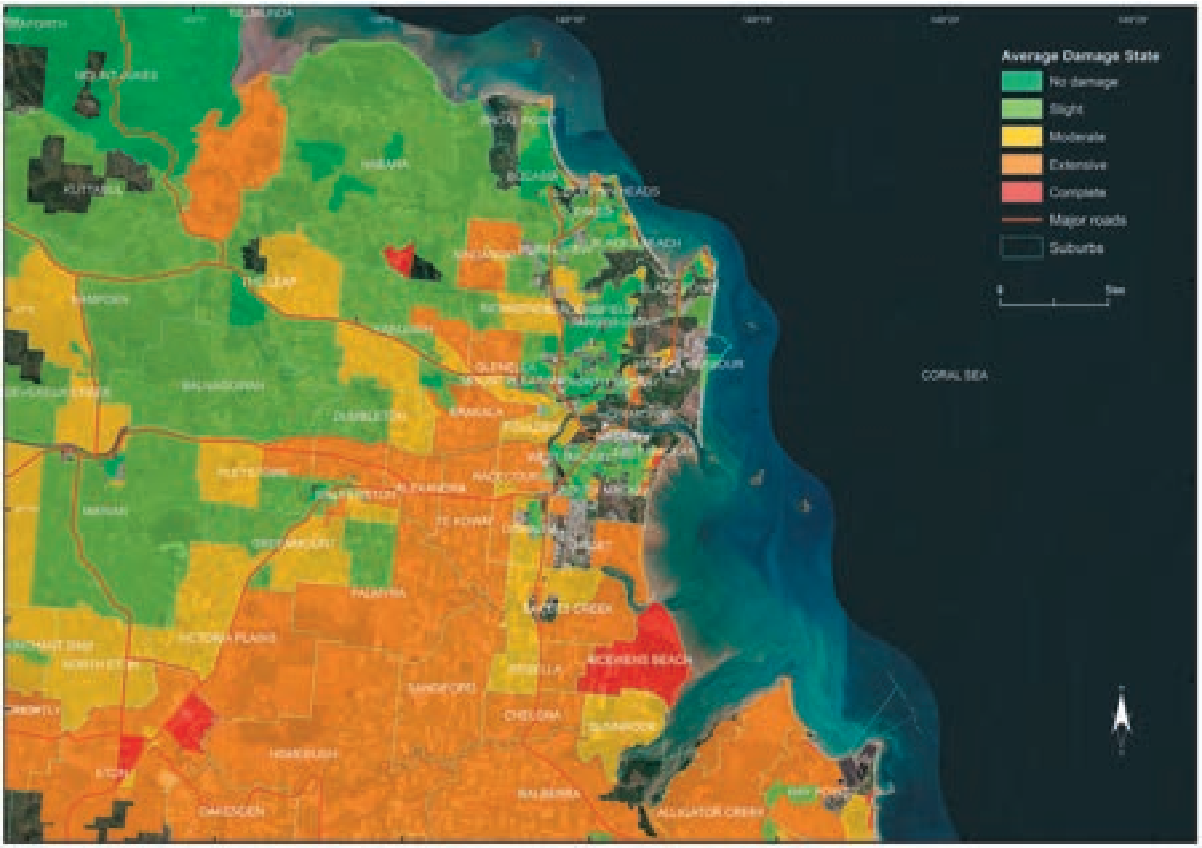


Figure 60: Aggregated residential building damage states for mesh block areas, for scenario 007-03074, a Category 5 cyclone impacting Mackay, Qld.

The worst damage in this scenario is focused in East Mackay and to the south west of the city more broadly. Some areas to the north, such as Slade Point and Dolphin Heads, also sustain major damage, but only along the immediate foreshore areas. However, as with the Category 3 scenario, older construction types (i.e. pre-code era construction) are disproportionately overrepresented in the higher damage states. While the spatial distribution of damage to the south and west of Mackay looks significant, it must be remembered that the population in these areas is low, and likely composed of older construction. Nearly one third of the damaged houses are in the Isaac Regional Council to the south of Mackay.

It is worth highlighting that the case study in Chapter 2 on the 1918 Mackay Cyclone details the potential impacts from storm surge and consequential flooding that are not able to be represented here. As with TC Larry, 2006 and TC Yasi, 2011 in Innisfail, there is always the potential for significant impact from storm surges, sometimes in excess of wind damage, that can occur during unfavourable tides. It was this potential scenario which led to significant concern at all levels of Queensland's disaster management arrangements during the lead up to landfall from TC Debbie, 2017.[13]

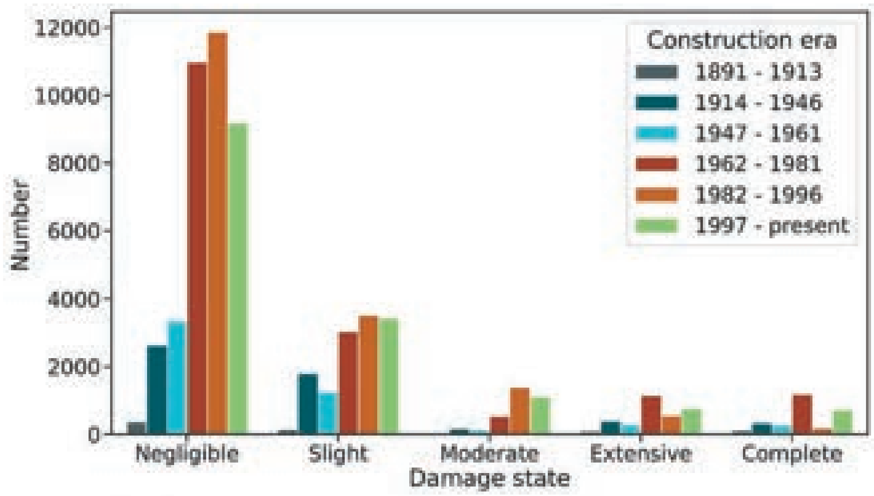


Figure 61: Count of residential buildings in each damage state, grouped by construction era, for scenario 007-03074, a Category 5 cyclone impacting Mackay, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	851	315	57	82	99
1891 - 1913	361	134	28	79	96
1914 - 1946	2,635	1,797	161	386	332
1947 - 1961	3,359	1,260	123	284	266
1962 - 1981	10,972	3039	535	1,142	1,188
1982 - 1996	11,876	3,512	1,388	546	174
1997 - present	9,175	3,426	1,109	754	717
Total	39,229	13,483	3,401	3,273	2,872

Table 11: Count of residential buildings in each damage state, classified by construction era, for scenario 007-03074, a Category 5 cyclone impacting Mackay, Qld.

4.5 Townsville

Townsville is both Queensland's and Australia's largest urban centre north of the Sunshine Coast. With a population of more than 180,000 it is the administrative centre for North Queensland, hosting a significant number of government, community and commercial activities. The city is also a major industrial centre, home to one of the world's largest zinc refineries and many other similar industrial activities. The Port of Townsville is currently being expanded to accommodate an increasing volume and size of cargo and passenger ships which seek to capitalise on North Queensland's resources and tourism industries. It is an increasingly important city and port for the Commonwealth, including for defence, due to its strategic proximity to Asia.

Townsville has a long history of cyclone and other disaster related impacts with 24 cyclones passing within 50km of Townsville Airport since 1907 (Figure 18). The scenarios selected for Townsville are analogous to two significant cyclone events for the Townsville region, including TC Althea, 1971 and TC Charlie, 1988 the impacts of which are outlined below.

TC Althea, which impacted Townsville on 23 December 1971 was at the time considered to be one of the strongest cyclones to affect the Queensland coast, and remains arguably the most intense cyclone to ever impact Townsville. There were three deaths in the city, at a time when the population was 71,265, and damage costs in the Townsville region reached $500 million (2012 normalised figure). Many houses were damaged or destroyed (including 200 homes owned and maintained by the Queensland Government Housing Commission) through wind impact alone. Ninety per cent (90%) of the houses on Magnetic Island were damaged or destroyed. Two associated tornadoes damaged trees and houses at Bowen.

A 2.9m storm surge was recorded in Townsville Harbour with the maximum storm surge of 3.66m to the north at Toolakea. This storm surge occurred at low tide, however the surge and large waves caused extensive damage along The Strand and at Cape Pallarenda. There was a major flood in the Burdekin and Haughton catchment at the time, but fortunately the consequential floods were short lived.

TC Charlie made landfall close to Ayr on 1 March 1988, killing two people. At Ayr, rainfall exceeded 912mm in 24 hours resulting in 2m deep water flooding many houses. Four houses were partly unroofed, and others sustained damage to facades and windows. The area where the TC made landfall was sparsely populated which limited structural damage however there was widespread sugar cane damage. Total crop losses were $30 million (2020 normalised figures) most of which was caused by the associated flooding.

As with the Monsoon Trough Event of January 2019, natural disasters can cause major disruption to Townsville as a modern city with significant flow on effects to the regional and state economies. A cyclone and the associated consequential hazards, such as those modelled in the following pages, would be particularly challenging to both the city, wider region and state.

Figure 62: Boats washed up on Palmer Street after Cyclone Althea. Source: CityLibraries Townsville Local History Collection

Figure 63: Damaged houses in Pallarenda, after Cyclone Althea. Source: CityLibraries Townsville Local History Collection

Figure 64: The suburb of Pallarenda, after Cyclone Althea in December 1971. Source: CityLibraries Townsville Local History Collection

4.5.1 Category 3 cyclone: scenario 005-03821

The selected Category 3 scenario for Townsville approaches the city from the northeast, reaching Category 5 intensity offshore, but weakening prior to landfall. The wind field model generates, for some coastal areas around Cape Cleveland and on Magnetic Island, wind speeds over 220km/h (Category 4), but winds at Townsville Airport only reach Category 3 intensity. The cyclone decays rapidly as it moves inland and southwards, passing Charters Towers to the east, but there are still gale force winds in that township.

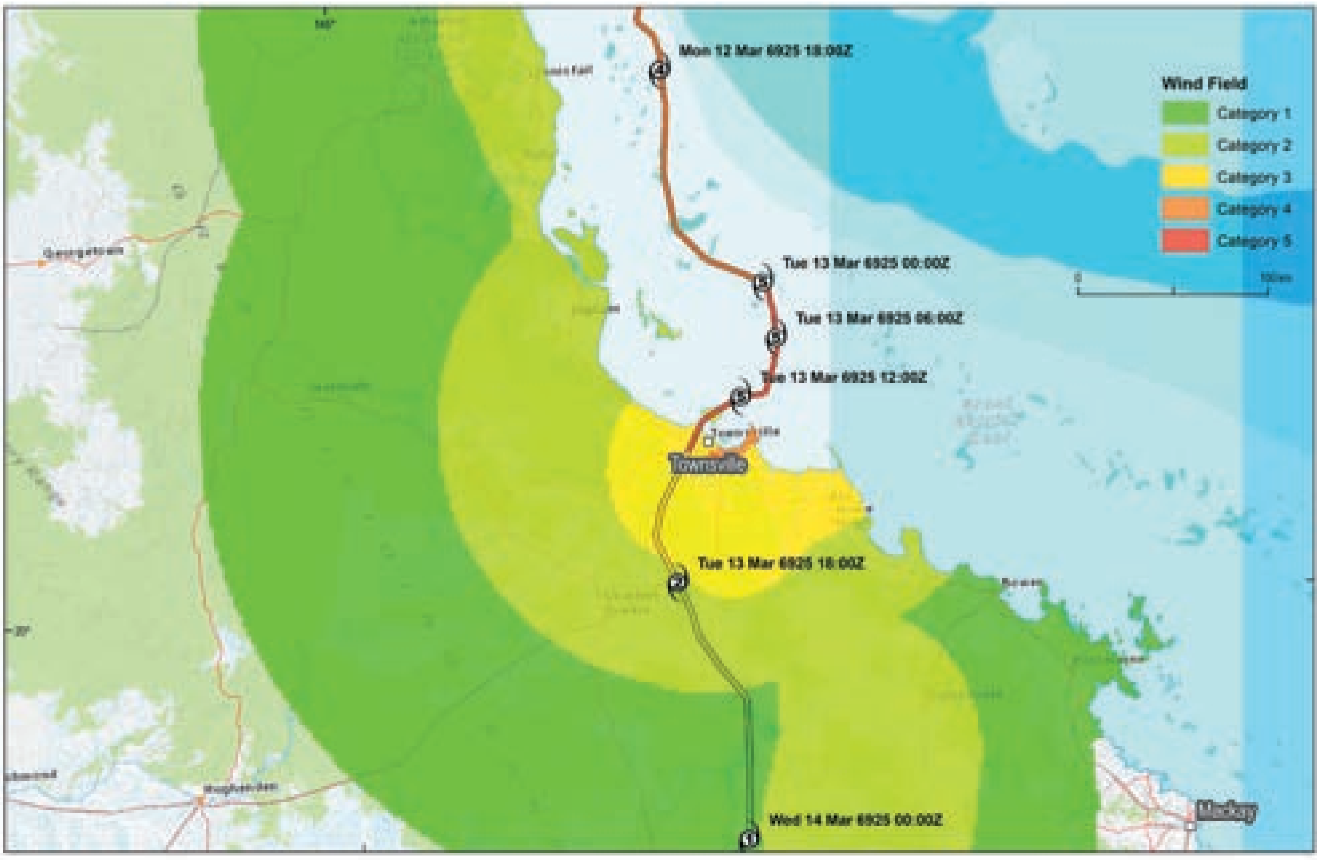


Figure 65: Regional wind field for scenario 005-03821, a Category 3 cyclone impacting Townsville, Qld.

At the local scale, most suburban parts of Townsville experience modelled maximum winds of 120km/h, though areas on the edge of suburbs do experience higher winds, especially around the foot of Mt Stuart, as the eyewall passes over this area. The South Townsville area may expeience winds up to 200km/h as it is exposed to the open waters of Cleveland Bay to the south east.

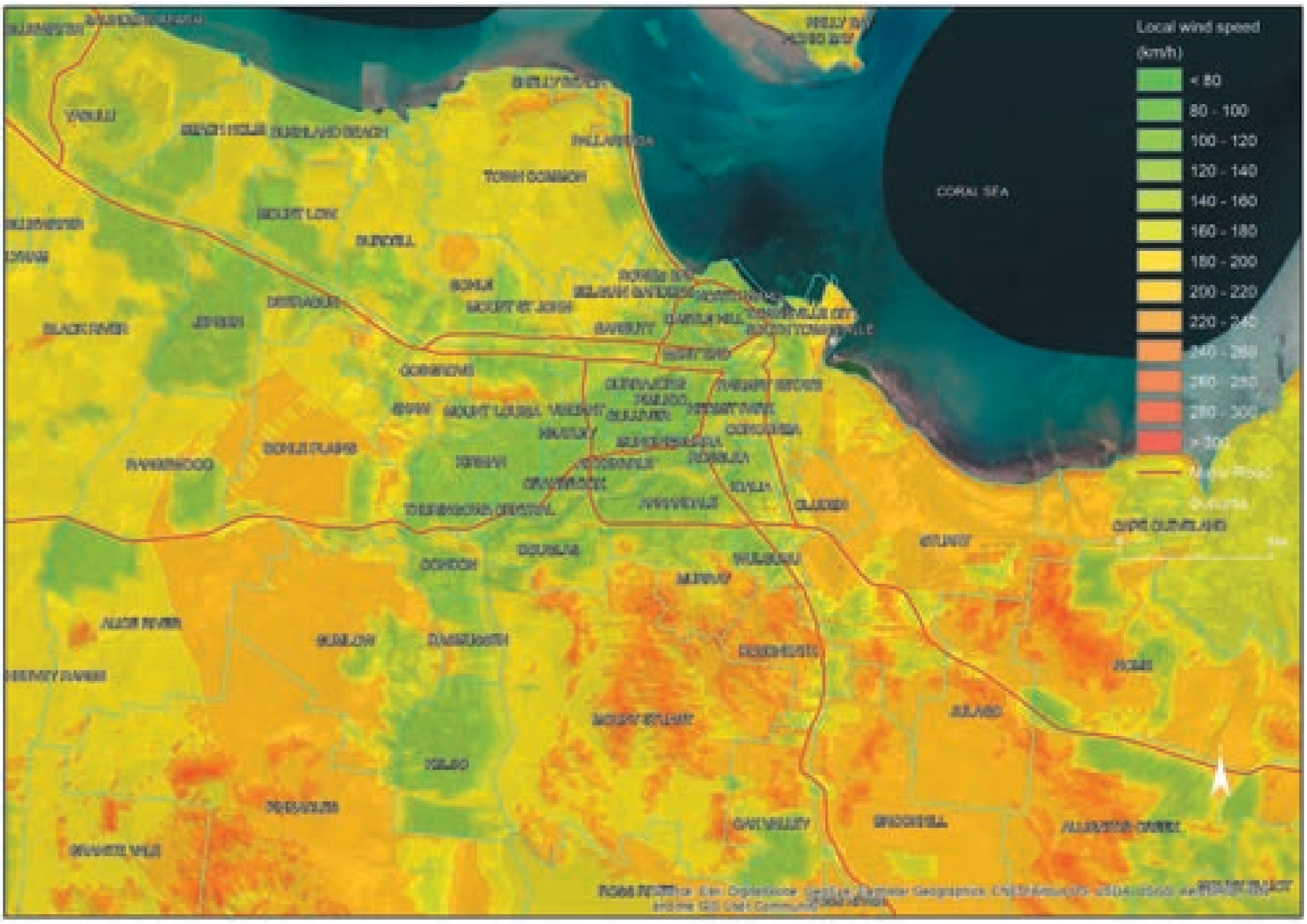


Figure 66: Local wind field for scenario 005-03821, a Category 3 cyclone impacting Townsville, Qld.

This area of locally higher winds is reflected in the resulting modelled damage states, with suburbs to the south east of the city centre, such as Wulguru and Cluden, sustaining Moderate damage. The model output has the remaining suburbs (95% of houses) largely unaffected, as the wind speeds in the urban areas remain well below the design level (250km/h) for post 80s construction. The modelled damage is largely restricted to mostly in the Townsville area. There are another 100 houses across the Burdekin and Charters Towers region that sustain major damage (moderate or higher).

It is worth noting that in comparing the modelled damage outputs with damage survey data from TC Yasi (Boughton et al., 2011), the modelled damage appears to under-represent the extent and level of damage. For example, the estimated winds impacting Townsville during TC Yasi were in the order of 140km/h. Structural damage to older homes including loss of roof structure as well as minor damage to modern homes was observed. Similarly, if considering the level of reported damage to older homes (pre-1980s) in the Tully region from TC Yasi (Boughton et al. 2011) for wind speeds less than 200km/h, the modelled output for the areas in South Townsville are potentially underestimated.

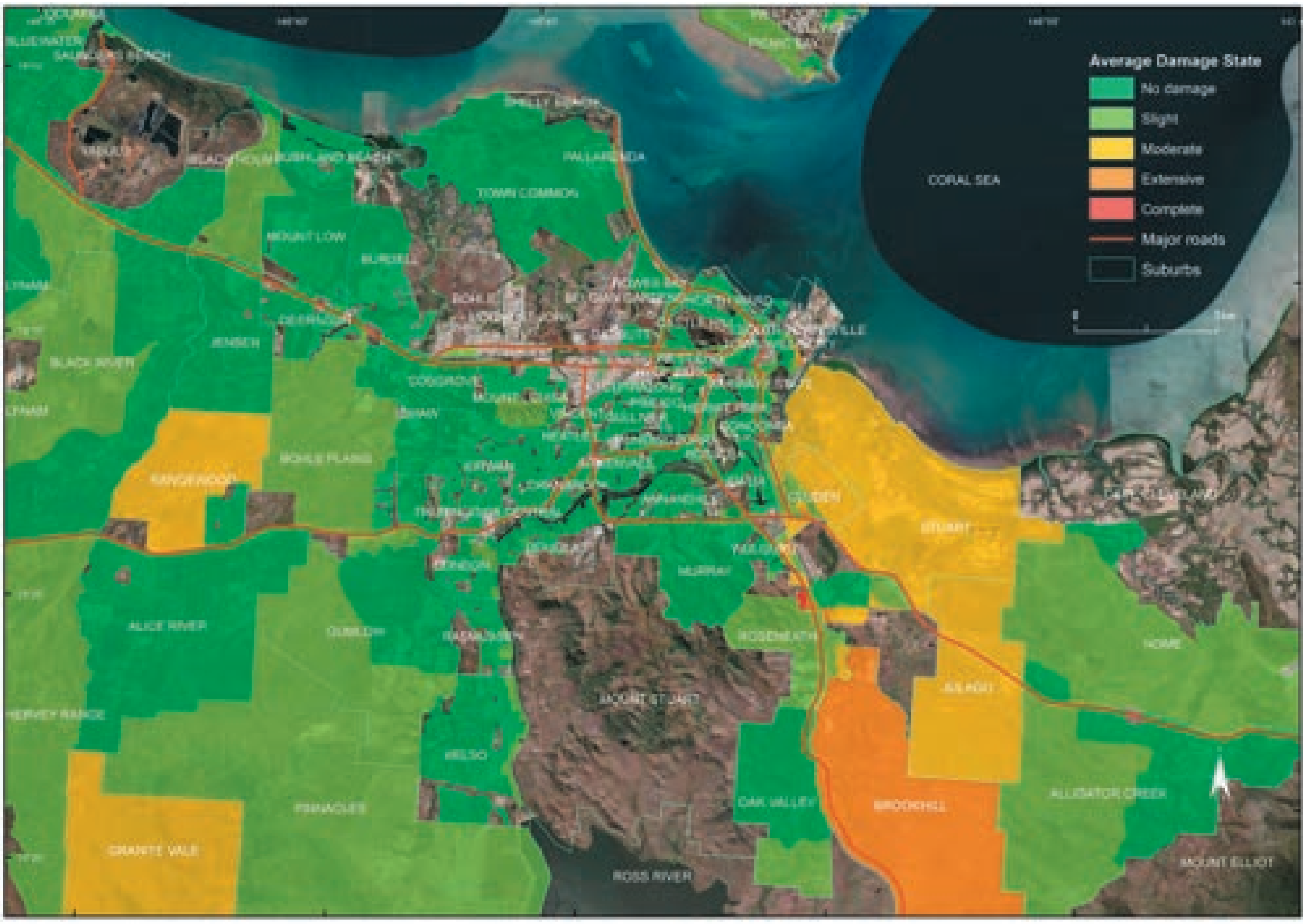


Figure 67: Aggregated residential building damage states for mesh block areas, for scenario 005-03821, a Category 3 cyclone impacting in Townsville, Qld.

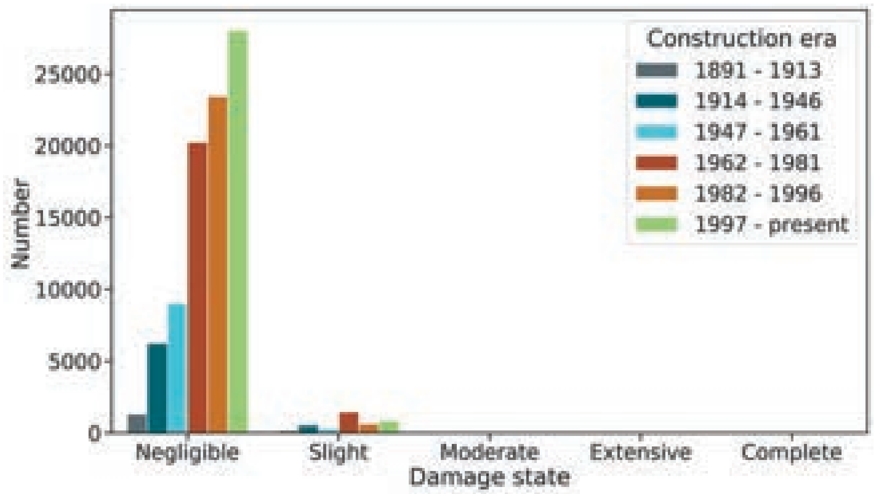


Figure 68: Count of buildings in each damage state, grouped by construction era, for scenario 005-03821, a Category 3 cyclone impacting Townsville, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	2,997	1,016	130	292	111
1891 - 1913	1,324	159	18	37	21
1914 - 1946	6,236	539	49	61	12
1947 - 1961	9,063	291	23	18	3
1962 – 1981	20,266	1,474	89	67	6
1982 - 1996	23,457	642	46	1	0
1997 - present	28,049	849	31	1	0
Total	91,392	4,970	386	477	153

Table 12: Count of residential buildings in each damage state, classified by construction era, for scenario 005-03821, a Category 3 cyclone impacting Townsville, Qld.

4.5.2 Category 5 cyclone: scenario 011-01326

The modelled Category 5 scenario for Townsville is a large, intense TC that tracks east to west and passes to the north of Townsville, making landfall close to Rollingstone and maintaining a modelled intensity over 200km inland impacting communities within the Tablelands, Charters Towers and Flinders Shire. The large size of the cyclone means Category 4 winds are widespread to the south of the storm's track. The cyclone also moves slowly as it passes to the north of Townsville, which would lead to sustained periods of extreme winds in the city and neighbouring communities.

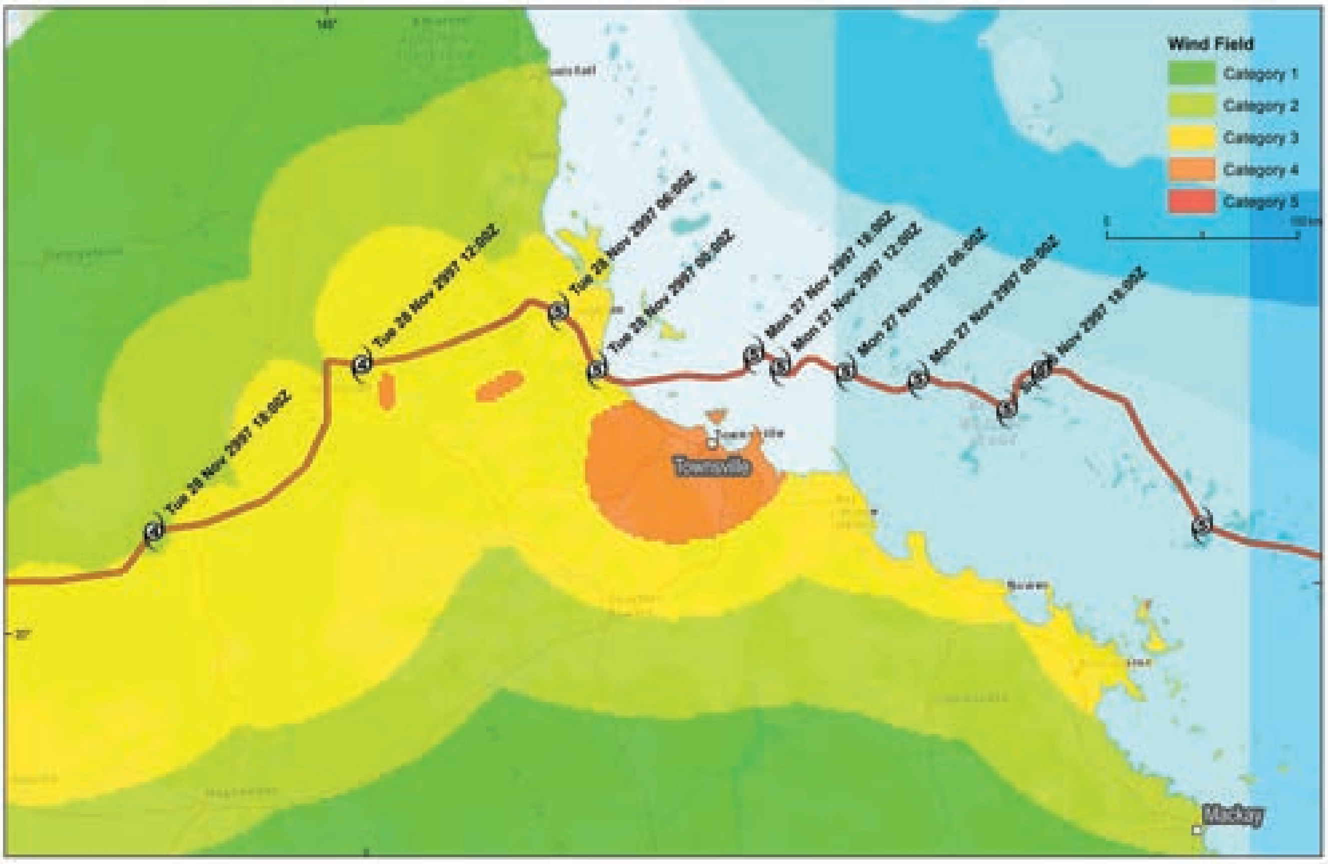


Figure 69: Regional wind field for scenario 011-01326, a Category 5 cyclone impacting Townsville, Qld.

Local wind speeds in Townsville are substantially higher on the eastern edge of the city. Cluden and South Townsville once again experience the highest winds of over 240km/h, with some locally higher pockets around Mt Stuart. Some areas adjacent to the Ross River towards Kelso are also exposed to winds in excess of 240km/h.

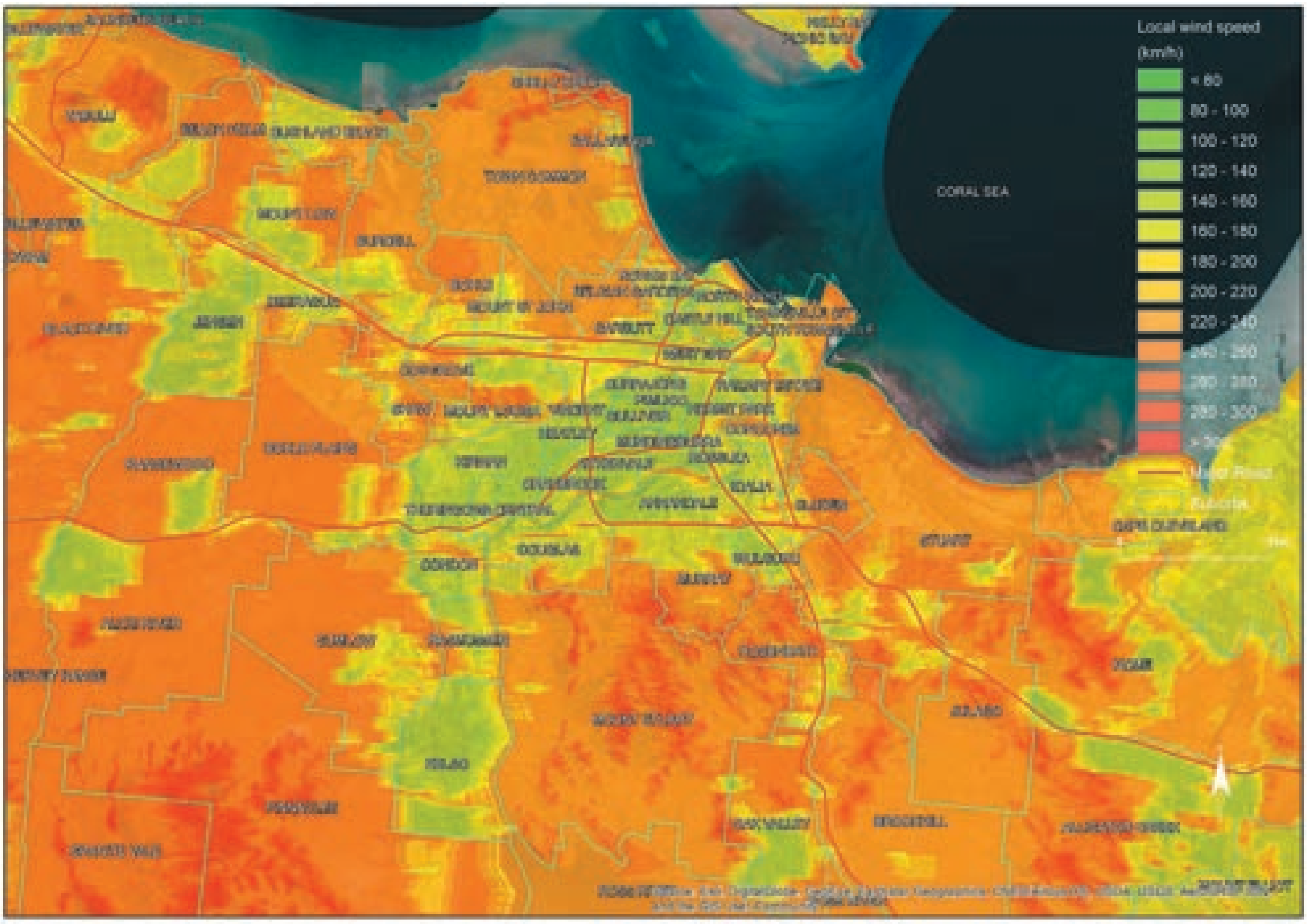


Figure 70: Local wind field for scenario 011-01326, a Category 5 cyclone impacting Townsville, Qld.

Areas adjacent to the coast sustain the greatest damage from Pallarenda to South Townsville, as the strongest winds in this scenario would be blowing off Cleveland Bay. There are also areas along the Ross River (Mundingburra, Rosslea) that would suffer major damage. Some areas further upstream towards Kelso would also see significant damage, reflecting the narrow band of high winds identified in the wind speed maps (refer Figure 70). This would total around 9,000 houses sustaining Moderate damage or higher across the region. It needs to be remembered that the modelled outputs are only considering structural damage. Numbers of homes uninhabitable could be considerably higher due to other drivers of damage such as wind driven debris, water ingress and flooding.

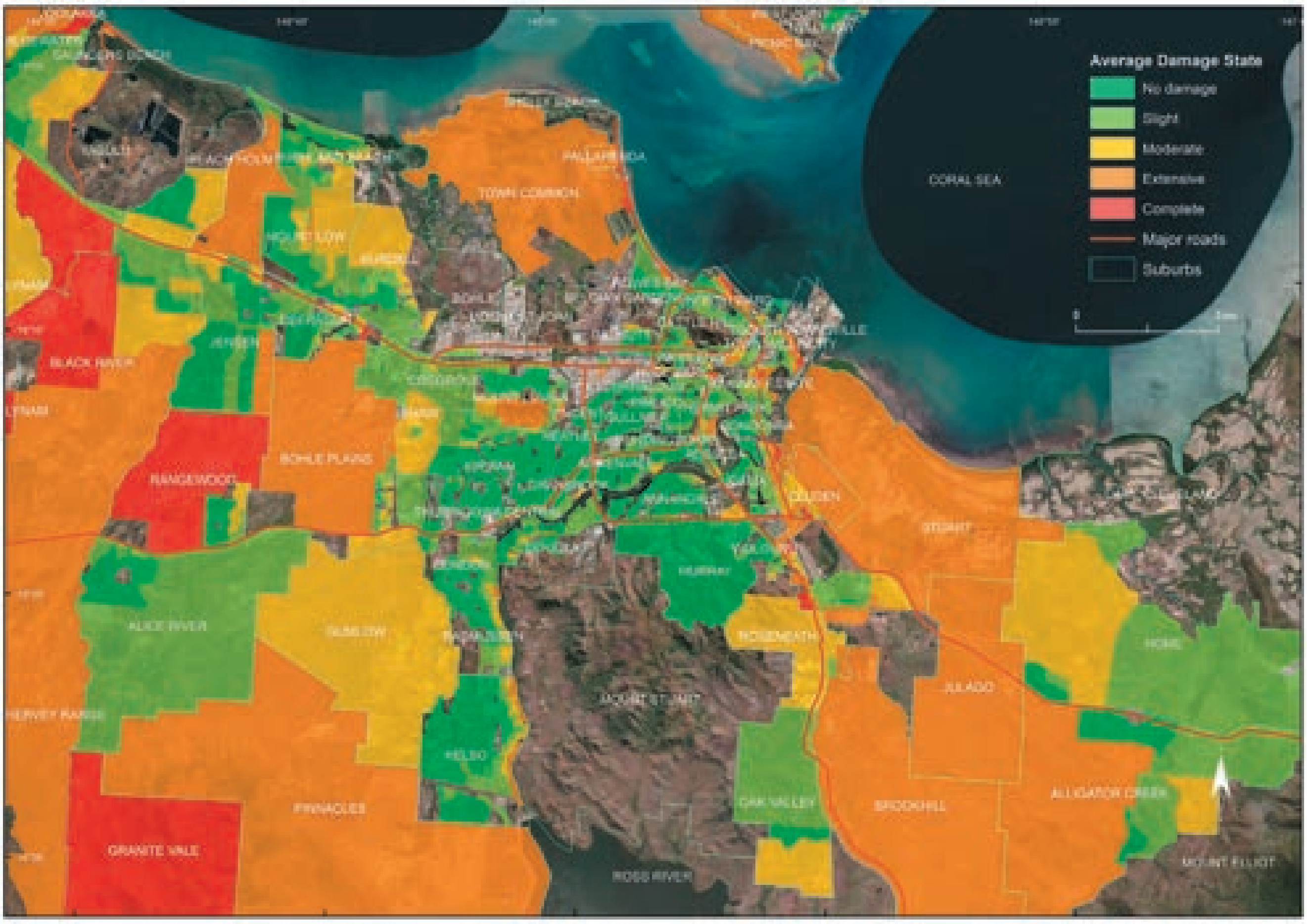


Figure 71: Aggregated residential building damage states for mesh block areas, for scenario 011-01326, a Category 5 cyclone impacting in Townsville, Qld.

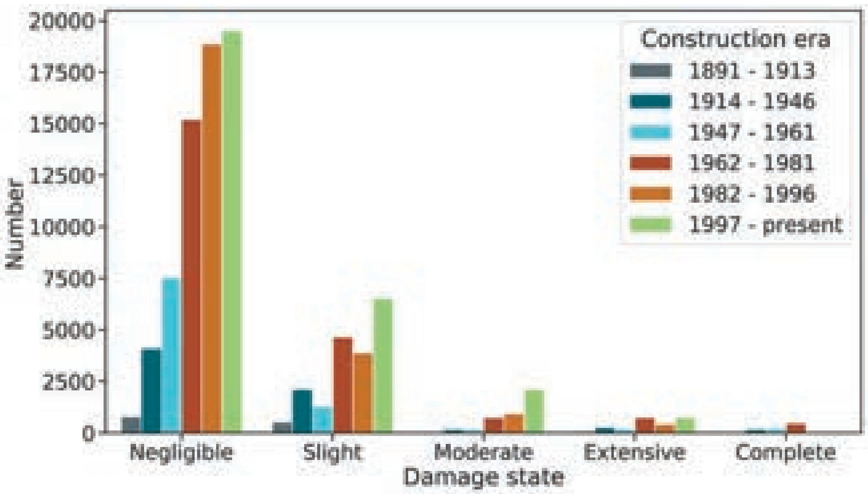


Figure 72: Count of buildings in each damage state, grouped by construction era, for scenario 011-01326, a Category 3 cyclone impacting Townsville, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	685	2,342	208	684	553
1891 - 1913	807	533	54	79	71
1914 - 1946	4,105	2,133	175	279	177
1947 - 1961	7,542	1,287	165	189	198
1962 - 1981	15,223	4,662	755	757	472
1982 - 1996	18,867	3,886	940	441	12
1997 - present	19,517	6,531	2,120	746	16
Total	66,746	21,374	4,417	3,175	1,499

Table 13: Count of residential buildings in each damage state, classified by construction era, for scenario 011-01326, a Category 5 cyclone impacting Townsville, Qld.

Further inland, around 10% of houses in the Charters Towers area sustain Moderate or higher damage in this scenario, predominantly in the northern outskirts of the town. To the north and south, Hinchinbrook and Burdekin suffer comparatively little major damage, despite similar wind speeds impacting all three regions (up to 250km/h). This again emphasises the efficacy of higher building standards in the cyclonic regions (within 50km of the coast) in reducing the likely structural damage. Conversely, the annual exceedance probability of these winds being experienced inland around Charters Towers is less than 0.15%, compared to around 1% in Townsville (see Chapter 5 for further details).

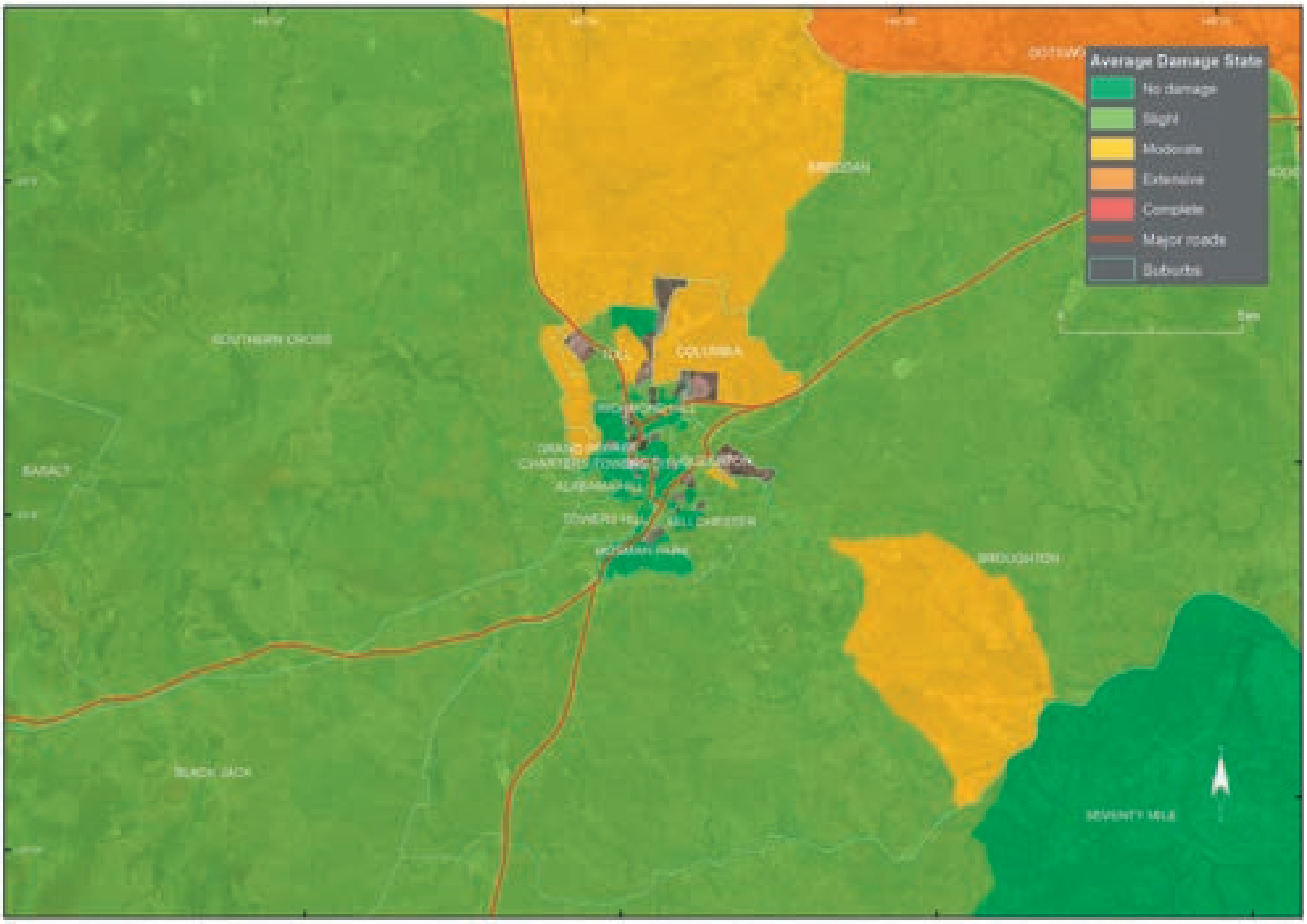


Figure 73: Aggregated residential building damage states for mesh block areas, for scenario 011-01326, a Category 5 cyclone impacting in Charters Towers, Qld.

LGA	Negligible	Slight	Moderate	Extensive	Complete
Burdekin (S)	10,164	1,035	75	82	13
Cassowary Coast (R)	6,645	25	0	0	0
Charters Towers (R)	582	343	142	151	36
Hinchinbrook (S)	4,549	836	25	27	5
Palm Island (S)	218	0	0	0	0
Townsville (C)	42,655	19,007	4,171	2,915	1,445
Whitsunday (R)	1,933	128	4	0	0

Table 14: Distribution of residential houses in each damage state, grouped by local government area for scenario 011-01326, a Category 5 cyclone impacting Townsville, Qld. Note that some local government areas are not fully covered in this analysis, so the total number of houses shown here may be less than the actual number. NB (S) = Shire, (C) = Council, (R) = Region.

4.6 Cairns

The city of Cairns has a mix of old (pre-code) and modern construction – nearly one third of the houses in Cairns were built prior to the implementation of building codes in the 1980s, much of which is found in the inner suburbs. Urban growth through the 1980s and 1990s and into the 2000s means that the majority of outer suburbs are modern construction subject to stricter building codes.

Cairns is a major regional hub providing services and support to communities across Far North Queensland and contributes significantly to the Queensland economy as one of the major tourism centres for the state.

The Cairns region's experience with tropical cyclones is an understandable justification for the inclusion of the city and the surrounding communities of Mareeba, Port Douglas and Atherton. The historical analogues used for these scenarios are those of TC Yasi, 2011 and TC Ita, 2014 as both these cyclones had significant destructive potential and impacts to those communities they struck, but they both fortuitously missed the major population centres for the region (i.e. Townsville and Cairns).

TC Yasi is one of the most powerful cyclones to have affected Queensland since records commenced. Previous cyclones of a comparable force measured intensity include the 1899 cyclone Mahina in Princess Charlotte Bay (Appendix I), and the two 1918 cyclones at Mackay and Innisfail (Chapter 2). It is an important analogy for the Category 5 scenario presented here as, being such a strong and large system, Yasi maintained a strong core after making landfall with the 'Very Destructive Winds' and 'Destructive Winds' persisting many hundreds of kilometres (>200km) inland as the cyclone tracked westwards across northern Queensland (Figure 74). Damaging winds and heavy rain persisted until the cyclone finally weakened to a tropical low near Mount Isa around 10pm on 3 February 2011.

As later discussed, the potential for cyclones to maintain destructive potential far inland presents a major challenge for the region with the terrain and built environment exceptionally conducive to the hazard. Impact from a significant tropical cyclone with an unfavourable track, in line with that of TC Yasi, would present catastrophic short to major long-term challenges for the region.

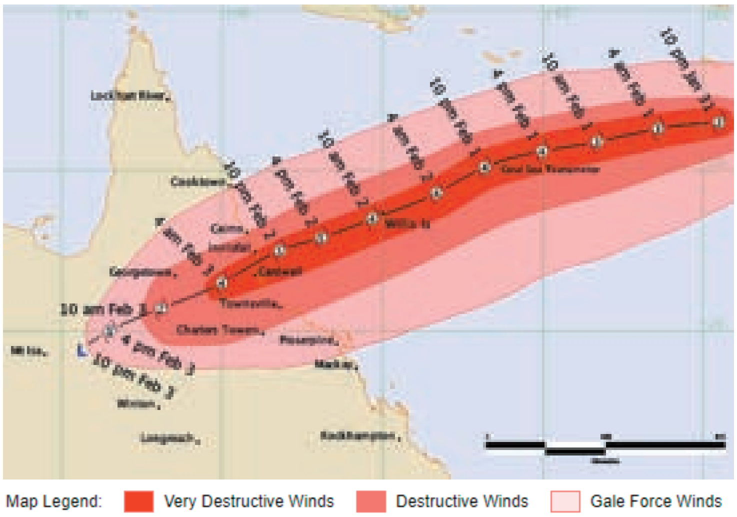


Figure 74: Track and Intensity Information for TC Yasi.
Source: reproduced with permission from the Bureau of Meteorology, Queensland

4.6.1 Category 3 cyclone: scenario 013-01524

This scenario forms in the northern Coral Sea and tracks south-southwest almost directly towards Cairns. The eye of the cyclone makes landfall to the north of the city near Palm Cove as a marginal Category 4 cyclone, but maximum wind gusts at Cairns Airport only reach 210km/h. The cyclone passes to the south, then drifts inland as it decays over the following 24 hours (Figure 75).

Figure 75: Regional wind field for scenario 013-01524, a Category 3 cyclone impacting Cairns, Qld.

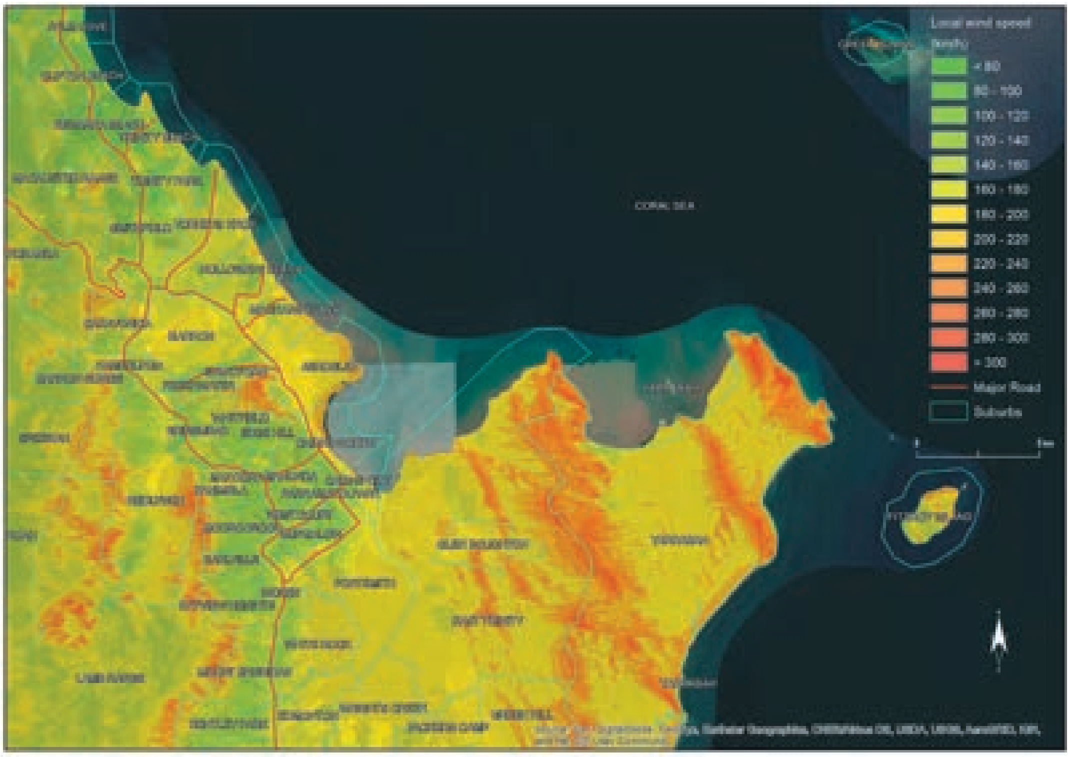


Figure 76: Local wind field for scenario 013-01524, a Category 3 cyclone impacting Cairns, Qld.

The strongest local winds in this scenario are seen around the airport, with gusts along the shore of just over 220km/h (Figure 76). Some areas to the north of the airport (Machans Beach, Holloways Beach) experience wind gusts around 180km/h, but further north winds are lower. Through the suburban areas, winds are broadly below 120km/h, however some suburbs along the Whitfield range would see slightly higher winds as the winds accelerate over the ranges.

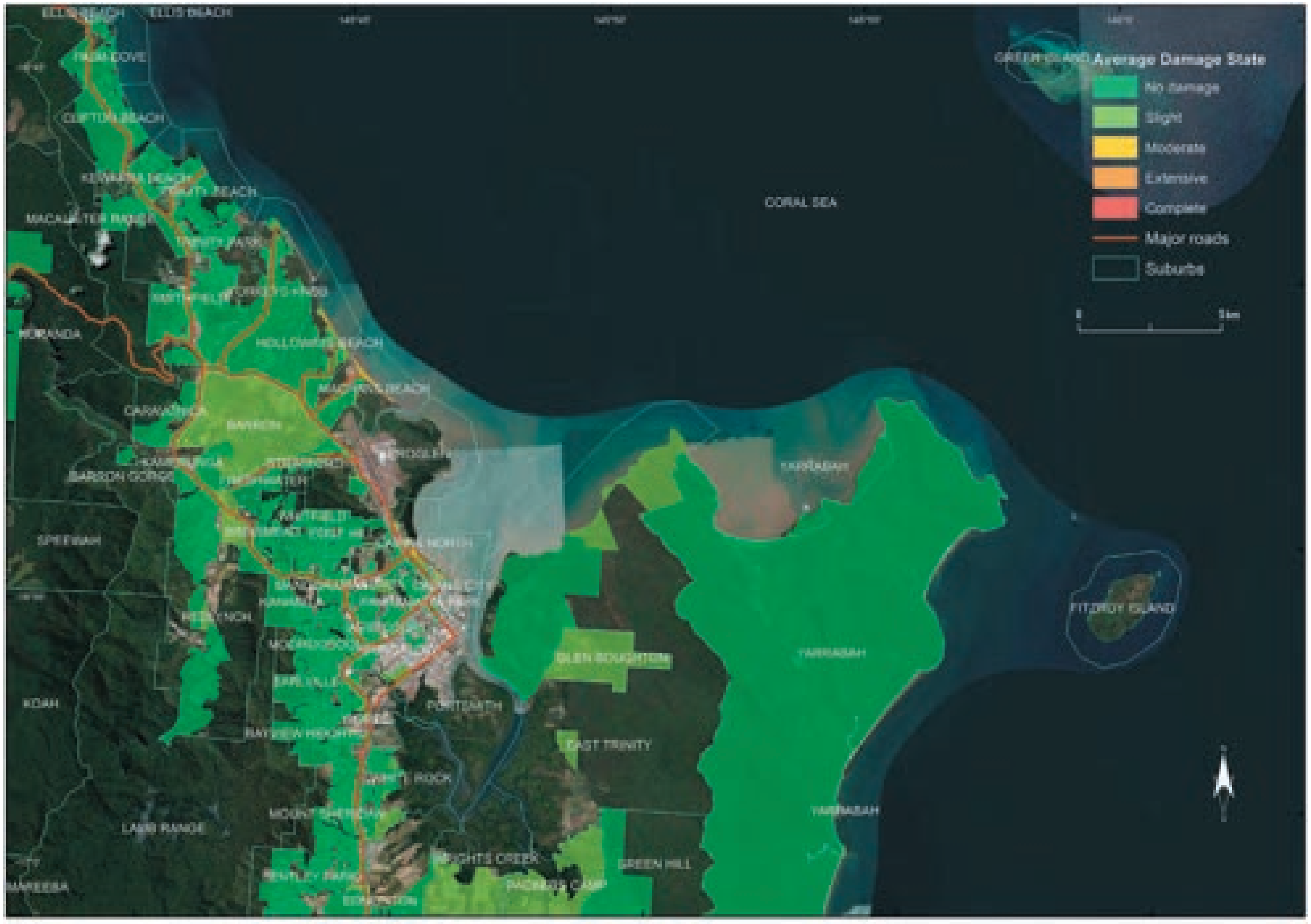


Figure 77: Aggregated residential building damage states for mesh block areas, for scenario 013-01524, a Category 3 cyclone impacting Cairns, Qld.

Only two areas sustain significant damage in this scenario – the Holloways and Machans Beach area and Cairns North, just south of the airport. These areas are exposed to the strongest winds, so this is not a surprising outcome. The vast majority of remaining houses experience winds that are below the design level, so damage is generally negligible. Even those houses along the Whitfield Range that experience some of the highest wind gusts in this event are largely undamaged, as these are modern houses built to appropriate standards for their site. There is little damage in other regional centres such as Mareeba and elsewhere over the Atherton Tablelands.

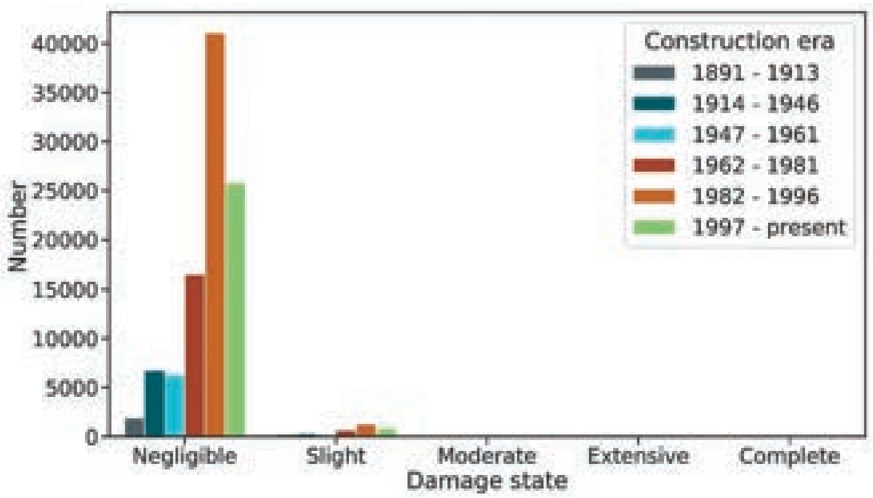


Figure 78: Count of residential buildings in each damage state, grouped by construction era, for scenario 013-01524, a Category 3 cyclone impacting Cairns, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 - 1890	2,940	46	2	7	0
1891 - 1913	1,882	243	4	10	1
1914 - 1946	6,781	319	13	38	2
1947 - 1961	6,293	233	52	21	0
1962 - 1981	16,528	646	58	28	2
1982 - 1996	41,094	1,279	79	3	0
1997 - present	25,796	877	142	51	0
Total	101,314	3,643	350	158	5

Table 15: Count of residential buildings in each damage state, classified by construction era, for scenario 013-01524, a Category 3 cyclone impacting Cairns, Qld.

4.6.2 Category 5 cyclone: scenario 013-03564

For the modelled Category 5 scenario in Cairns, the selected track has multiple impacts on the coastline. The cyclone drifts slowly across the Coral Sea for several days before heading towards Cooktown. It brushes past Cooktown, where maximum winds reach 190km/h, and then accelerates towards Cairns, making landfall almost directly over the CBD of the city. Maximum winds at the airport are around 290km/h. As the cyclone moves rapidly inland, Category 3 to Category 4 winds persist several hundred kilometres inland with significant damage to communities as far south as Charters Towers where 108 homes are completely destroyed.

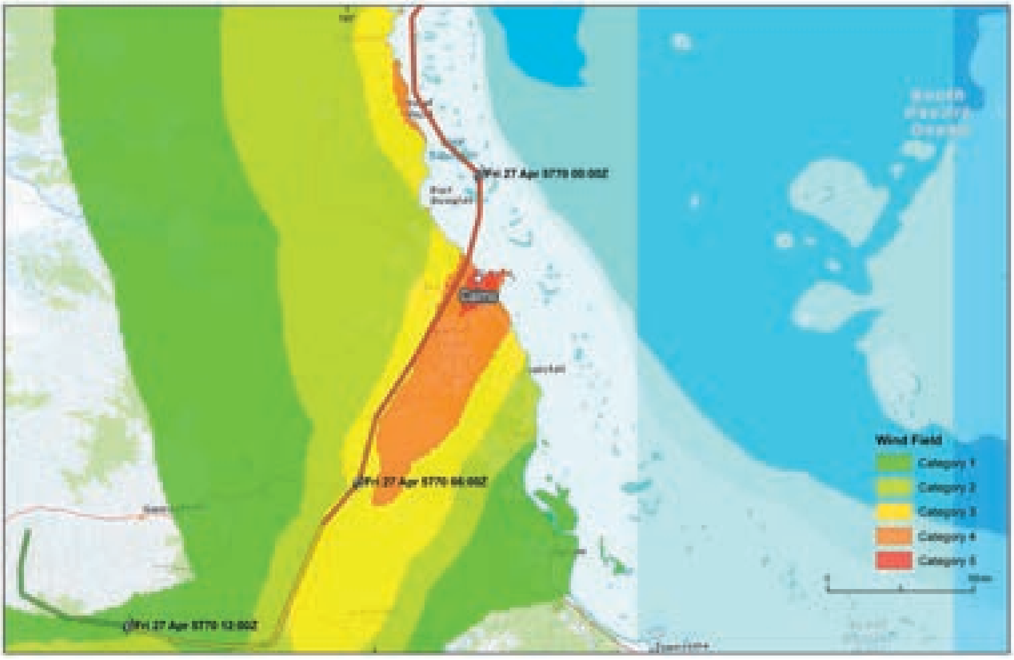


Figure 79: Regional wind field for scenario 013-03564, a Category 5 cyclone impacting Cairns, Qld.

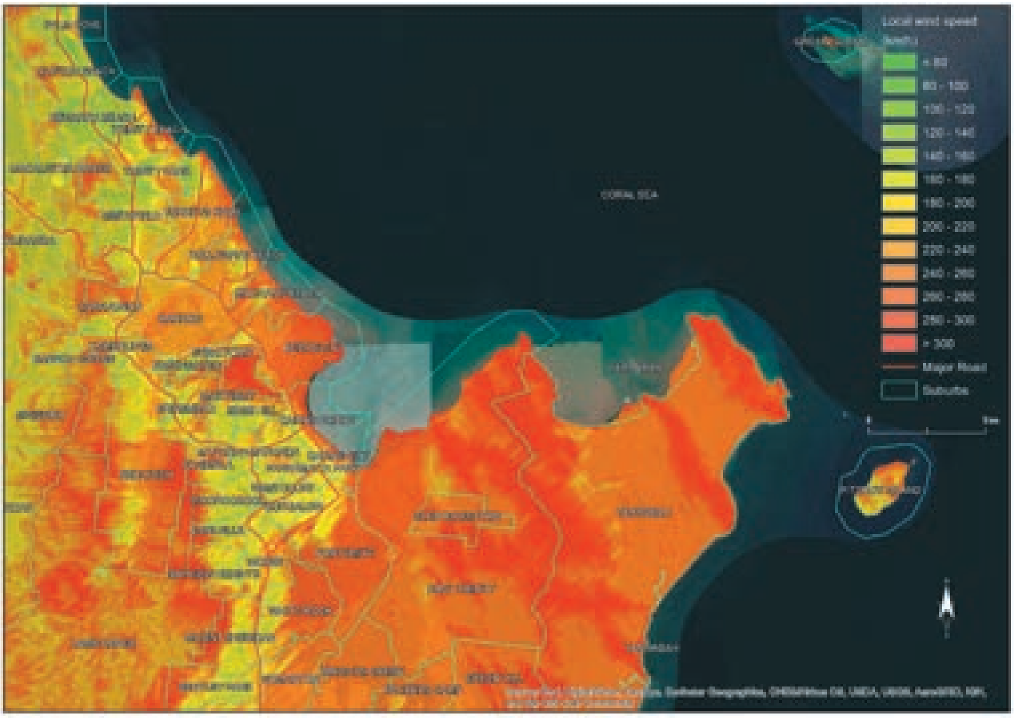


Figure 80: Local wind field for scenario 013-03564, a Category 5 cyclone impacting Cairns, Qld.

As with the Category 3 scenario, the strongest winds in this scenario are centred around the airport and southwards, towards the city. Extreme wind speeds (over 300km/h) are likely along the foreshore, as well as eastwards towards Yarrabah. The local accelerations are due to the steep topography around Mount Whitfield and along the range to Mount Sheridan, potentially seeing wind speeds in these areas exceed 300km/h. Throughout the lower lying areas of Cairns, maximum winds are around 140-180km/h.

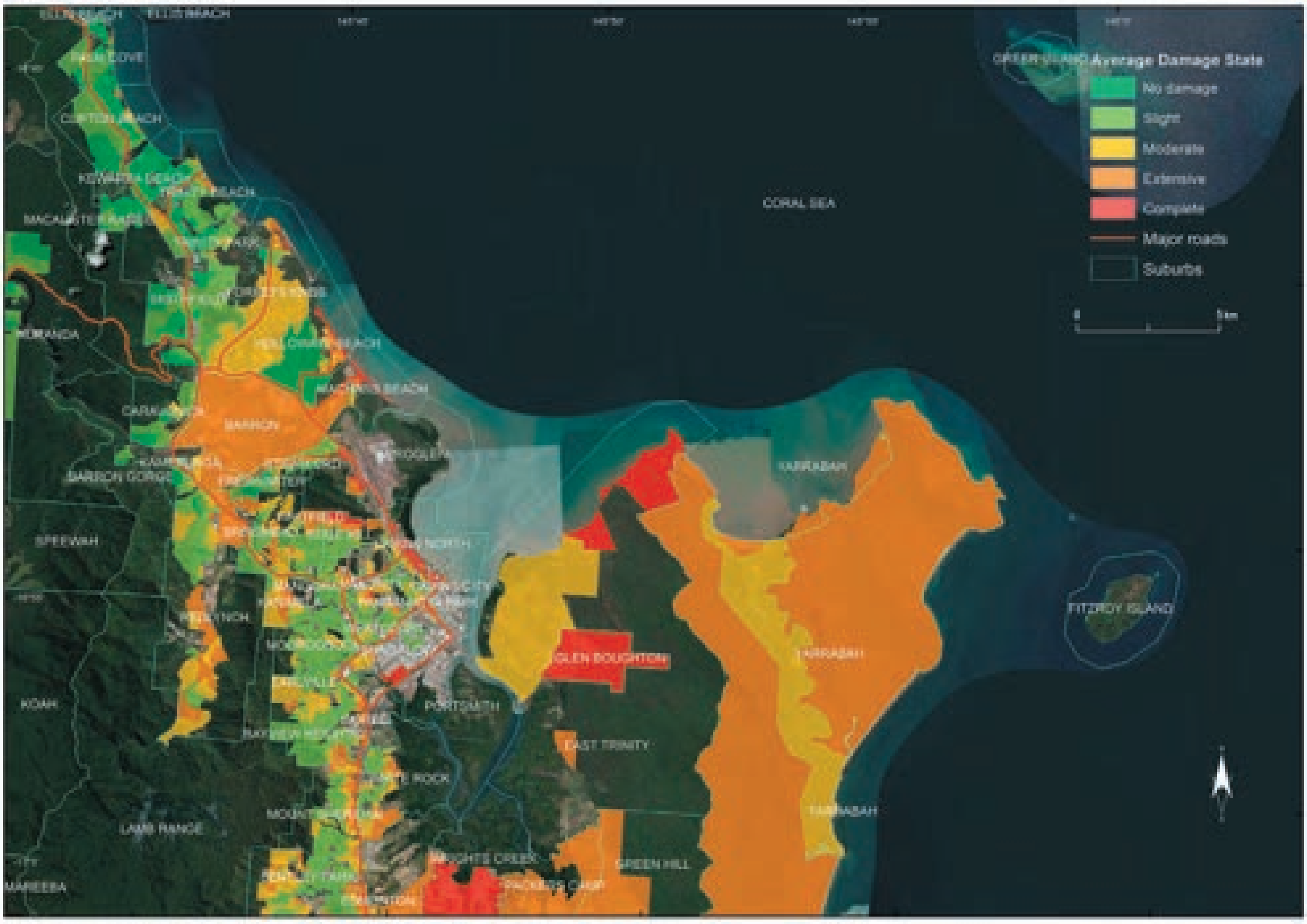


Figure 81: Aggregated residential building damage states for mesh block areas, for scenario 013-03564, a Category 5 cyclone impacting in Cairns, Qld.

Suburbs along the coastline from Trinity Beach to the city sustain the greatest damage, with an average damage state of Complete. Suburbs along the foot of the Whitfield Range, and also around Redlynch, sustain significant damage as well despite being of modern construction – the local wind accelerations result in a greater chance of exceeding the design wind loads for the site.

Further south, towards Edmonton and Gordonvale where the landscape opens out, some suburbs also sustain major damage as the open terrain does not reduce local winds. There may also be a significant proportion of older properties (e.g. older rural houses) in these areas which would contribute to the estimated damage.

For Port Douglas, this scenario fortuitously passes that area at such a distance that there is little damage inflicted. The Port Douglas region experiences isolated areas with winds over 220km/h, but major damage is restricted to only a handful (‹ 10) of exposed older houses.

The Mareeba and Tablelands Shires sustain major damage, with nearly one third of the 10,000 houses being classified as Moderate or Greater damage – especially around Malanda and Yungaburra. The Category 3 regional winds extend well inland over the Tablelands and, with only one third of houses built after the 1980s and to Wind Region C standards, this outcome is not surprising. This impact analysis is expanded further on the following pages and highlighted in Figure 82 and Table 16.

The community of Yarrabah also suffers major damage, bearing the brunt of the eyewall of the cyclone. Most of the houses are exposed to winds in excess of 280km/h, and nearly 60% of the houses are either extensively damaged or destroyed.

Given that this scenario only models wind impact to residential buildings, it should be noted that there would likely be significant to extreme additional impacts from associated wind-driven rain, flash flooding and landslips (due to the complex terrain), riverine flooding and storm surge along the coastal strip and in estuaries (as with TC Yasi, 2011). There is also the consideration of impact to life-line infrastructure (e.g. power and telecommunications) that would greatly exacerbate the scale of impact to communities, and the ability to respond and recover in the aftermath.

Overall, over 20,000 houses would sustain major damage (Moderate, Extensive or Complete) across the Cairns region from wind impact alone. The scale of impact and over such an extensive area would pose an extreme challenge in the emergency management context especially when considered in the wider context of likely additional impacts.

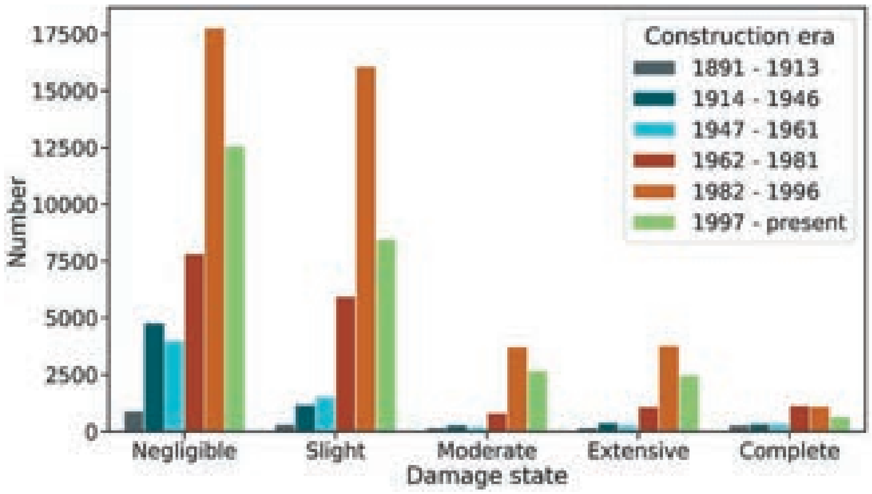


Figure 82: Count of residential buildings in each damage state, grouped by construction era, for scenario 013-03564, a Category 5 cyclone impacting Cairns, Qld.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1840 – 1890	2,089	287	188	211	187
1891 - 1913	893	313	178	176	300
1914 - 1946	4,785	1,174	292	390	334
1947 - 1961	4,019	1,548	221	283	350
1962 - 1981	7,830	5,943	829	1,096	1,145
1982 - 1996	17,769	16,061	3,730	3,786	1,109
1997 - present	12,572	8,484	2,666	2,484	660
Total	49,957	33,810	8,104	8,426	4,085

Table 16: Count of residential buildings in each damage state, classified by construction era, for scenario 013-03564, a Category 5 cyclone impacting Cairns, Qld.

4.6.2.1 Inland impact analysis

More broadly across the region, communities in the Atherton Tablelands would sustain major damage, as the track of the cyclone leads to extreme winds well inland (Figure 79). Even this far inland, local winds could exceed 280km/h due to the acceleration over the steep topography in the region (Figure 83). As much of the area is outside Wind Region C of the Wind Loading Standard (the cyclonic region), even modern residential housing is unlikely to escape damage from winds much greater than around 215km/h.

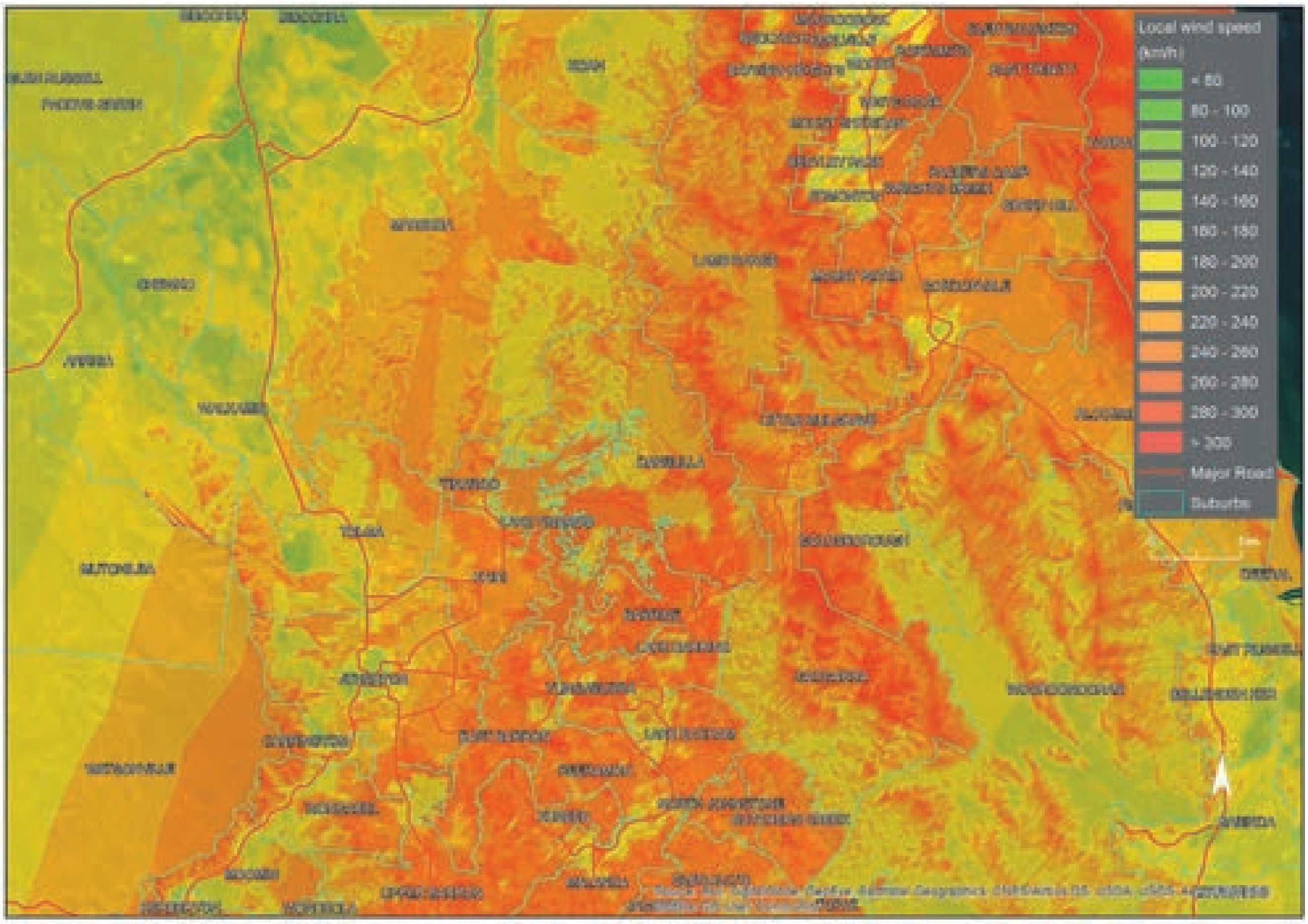


Figure 83: Local wind field for scenario 013-03564, a Category 5 cyclone impacting Cairns, Qld over the Atherton Tablelands.

Figure 84 shows the spatial extent of the high damage across the Tablelands. The lower damage along the coastal strip can be seen in the lower right corner, where the winds are substantially lower. The narrow swath of damage over the Tablelands almost misses Atherton but the smaller communities further east (Malanda and Yungaburra) are severely damaged.

Table 17 presents the distribution of houses in each damage state across the impacted local government areas. Even though Mareeba misses the direct path of the cyclone, there are nearly 700 houses moderately damaged or greater throughout the shire. In the Tablelands Shire, nearly 5,500 houses are moderately damaged or greater. Such a situation would rule out using the inland region for either evacuation or temporary accommodation in the lead up to or directly after the cyclone for Cairns' impacted population.

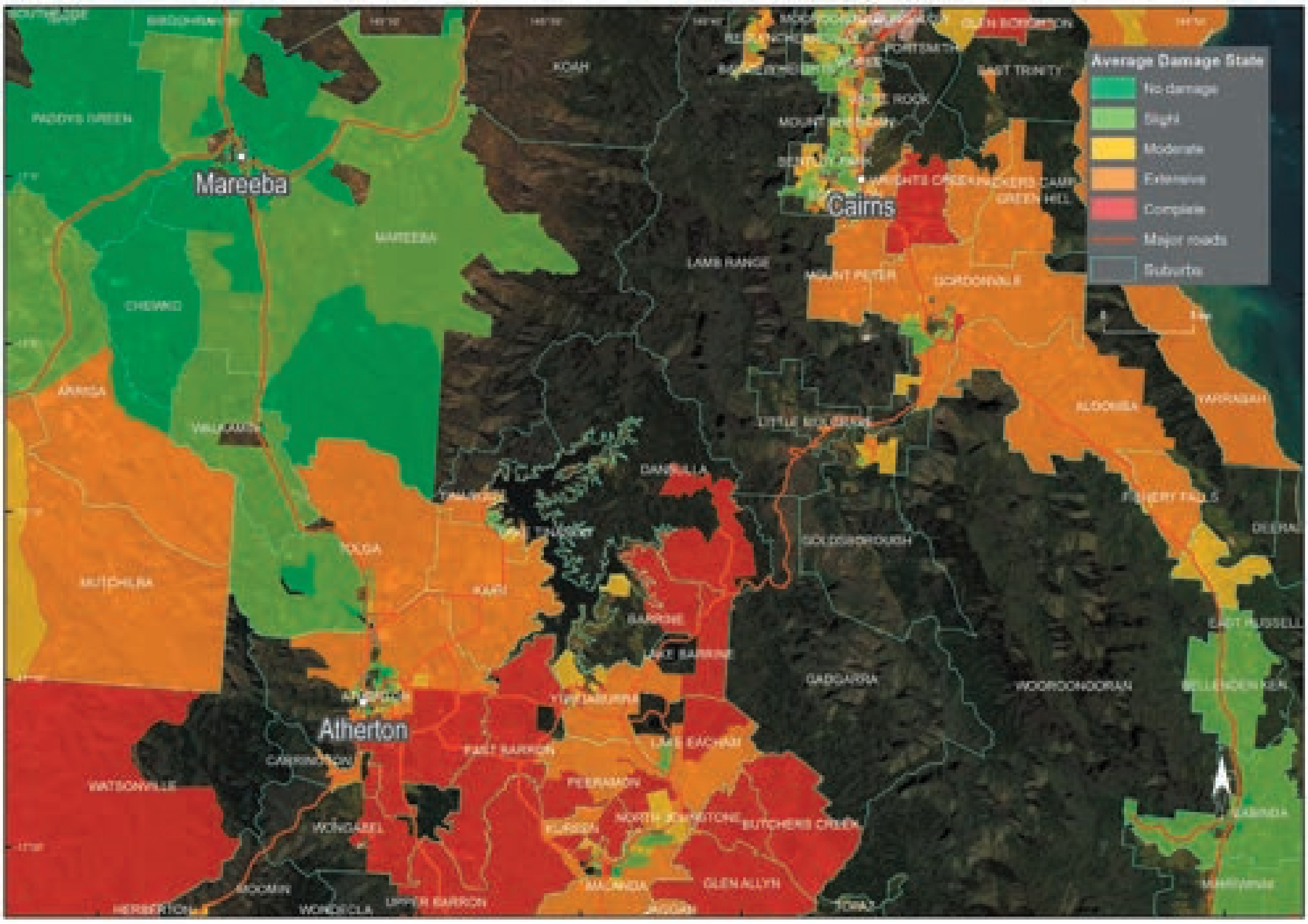


Figure 84: Aggregated residential building damage states for mesh block areas, for scenario 013-03564, a Category 5 cyclone impacting the Atherton Tablelands, Qld.

LGA	Negligible	Slight	Moderate	Extensive	Complete
Cairns (R)	11,667	29,769	6,489	6,074	1,369
Cassowary Coast (R)	15,677	147	7	12	2
Charters Towers (R)	1,137	3	1	5	108
Cook (S)	2,211	48	69	43	11
Douglas (S)	4,153	96	1	0	0
Hinchinbrook (S)	5,442	0	0	0	0
Hope Vale (S)	221	0	0	0	0
Lockhart River (S)	159	0	0	0	0
Mapoon (S)	29	0	0	0	0
Mareeba (S)	6,422	1,089	242	225	220
Napranum (S)	179	0	0	0	0
Tablelands (R)	2,611	2,539	1,235	1,867	2,367
Wujal Wujal (S)	48	7	0	0	0
Yarrabah (S)	1	112	60	200	8

Table 17: Distribution of residential houses in each damage state, grouped by local government area for scenario 013-03564, a Category 5 cyclone impacting Cairns, Qld. Note that some local government areas are not fully covered in this analysis, so the total number of houses listed in each LGA may be lower than actual. NB (S) = Shire, (R) = Region.

Impacts of TC Larry, 2006 and TC Yasi, 2011

Figure 85: A road sign bent by the wind in Innisfail after Cyclone Larry in March 2006. Source: ABC

Figure 88: Houses and apartment blocks with their roofs blown off in Innisfail after Cyclone Larry struck in March 2006. Source: AP (Mark Baker)

Figure 86: Furniture blown from the Hotel Castor at Mouilyan after Cyclone Larry struck in March 2006. Source: Robert Rough

Figure 89: Cardwell in the aftermath of Cyclone Yasi. Source: Townsville Bulletin

Figure 87: The aftermath of Cyclone Yasi as it crossed the Far North Queensland coast. Dozens of luxury boats were smashed together at the Port Hinchinbrook marina in Cardwell. Source: Marc Mccormack

Figure 90: Dunk Island devastation from Cyclone Yasi. Source: HeraldSun (AAP)

4.7 Kowanyama

Tropical cyclones in the Gulf of Carpentaria often have meandering tracks and can linger in the region for several days. The most recent tropical cyclones that developed in the Gulf of Carpentaria, TCs Nora and Owen, 2018 and TC Trevor, 2019 are all good analogues for the scenarios presented for Kowanyama and Pormpuraaw. However, it is TC Nora that has delivered the greatest impact to Queensland communities from a cyclone with genesis in the Gulf of Carpentaria in recent memory. It is a good case study for the emergency management sector to consider when seeking to understand potential cyclone impacts beyond the east coast context.

Case study: TC Nora – a Gulf of Carpentaria cyclone with regional impacts

TC Nora affected Far North Queensland and the north-eastern Northern Territory during March 2018. Nora developed from a tropical low which formed near the Torres Strait on 19 March. The system initially moved quickly to the west-northwest, and then began tracking slowly south-westwards over the Arafura Sea while gradually developing. A turn to the east on 22 March brought the tropical low into a favourable environment for strengthening and the system reached tropical cyclone intensity later that day. Nora then underwent a period of rapid intensification as it moved south-eastwards into the Gulf of Carpentaria. The storm peaked on 23 March as a high-end Category 3 tropical cyclone with sustained winds of 155km/h. TC Nora made landfall north of Pormpuraaw at about 1pm on 24 March as a Category 3 system. Nora weakened steadily as it tracked southwards along the coast and was downgraded to a tropical low the following day. Nora's remnants meandered over land for several days before moving back over the Gulf of Carpentaria and dissipating on 28 March.

TC Nora was responsible for major impacts across large parts of Far North Queensland. Strong winds knocked down many trees and power lines in the towns of Pormpuraaw, Kowanyama and Mapoon, blocking roads and cutting power to more than 500 homes. Damage was caused to houses, council buildings, personal property and other buildings.

Very heavy rainfall occurred across most of Cape York Peninsula and Far North Queensland. Many communities became isolated by floodwaters after roads were either blocked or damaged. Extreme rainfall occurred in parts of Queensland's east coast, including 593mm in just 24 hours in Port Douglas. Flash flooding occurred in Cairns as a result of the intense rainfall, with the torrential rain causing landslides in areas such as the Kuranda Range, blocking major highways in the region. Many people had to be rescued by emergency services after becoming trapped by floodwaters.

Agricultural losses in crops and livestock, as well as damage to infrastructure, were also sustained when farms were flooded. The total economic impact of TC Nora is estimated to have exceeded A$32.5 million.

Damage sustained in Pormpuraaw post the transit of TC Nora. Widespread flooding occurred across the region cutting major access routes such as the Burke Development Road, pictured here. Source: Queensland Police Service

4.7.1 Category 3 cyclone: scenario 002-00483

Both the scenarios for Kowanyama have long lived tracks in the Gulf prior to making landfall. For the Category 3 scenario, the cyclone actually makes landfall as a Category 4 cyclone well to the south of the community, then travels north to pass just east of Kowanyama.

Maximum winds are around 160km/h across the community, well below the regional design wind speed for the Gulf Coast. As the detailed building survey revealed, all the houses in Kowanyama are modern construction so should sustain little structural damage at the wind speeds indicated for this scenario.

It should be noted that for the damage state maps below, for both Kowanyama and Pormpuraaw, that the aggregation areas are large due to the low total number of houses in the region (total 553 identified in the NEXIS database and the CfAT survey). This means that the maps may give the impression of little damage, when there may well be small regions of significant damage, especially for the Category 5 scenarios.

Additionally, nearly all the houses identified across these two communities are modern construction, so would be expected to perform well under loads from Category 3 wind speeds.

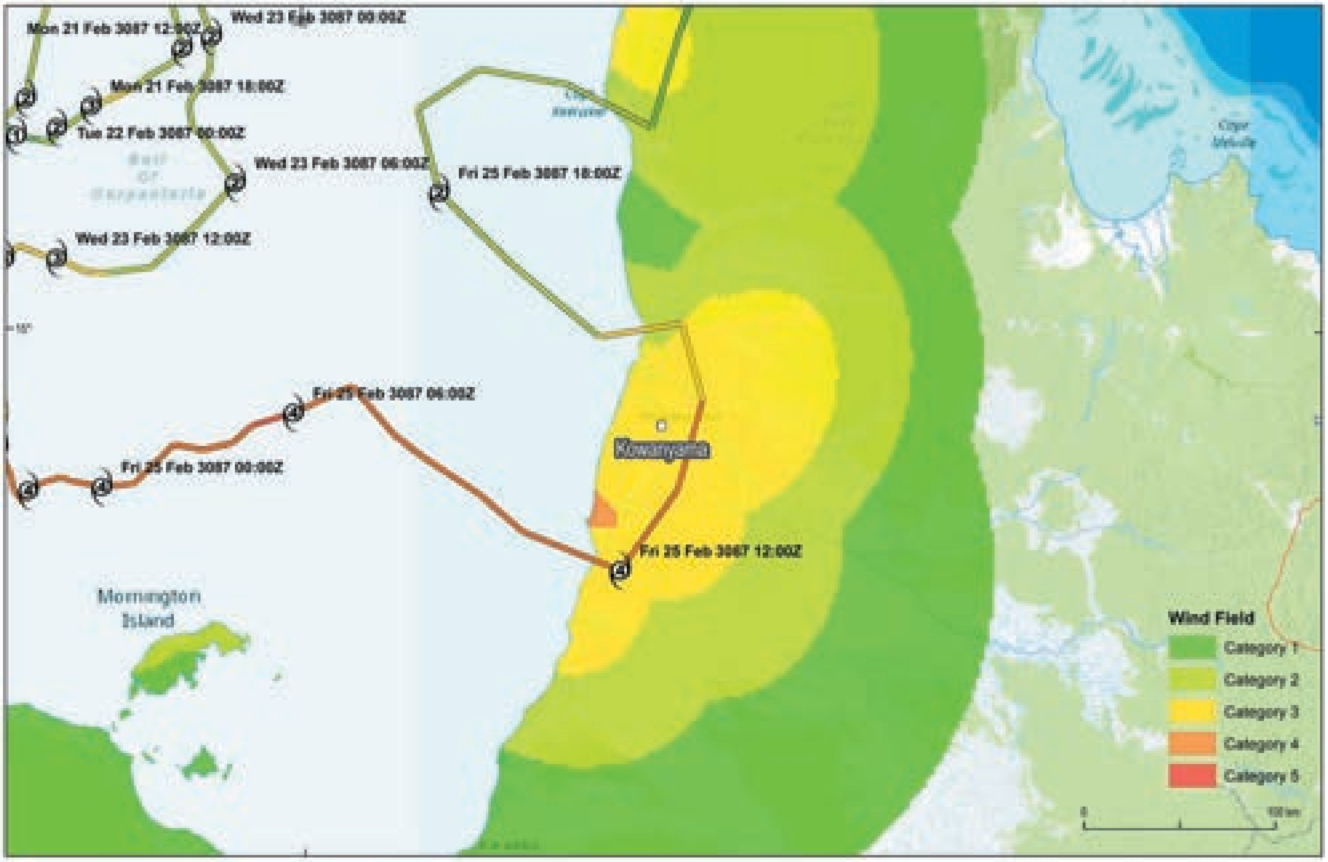


Figure 91: Regional wind field for scenario 002-00483, a Category 3 cyclone impacting Kowanyama, Qld.

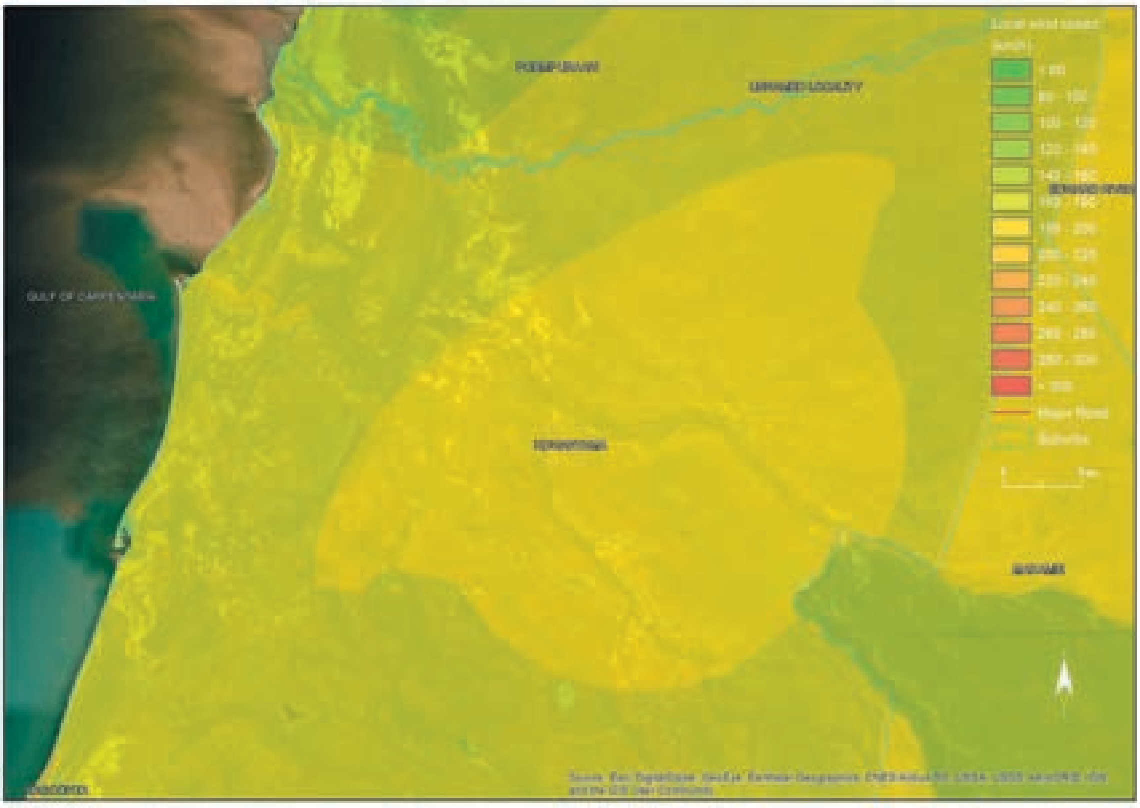


Figure 92: *Local wind field for scenario 002-00483, a Category 3 cyclone impacting Kowanyama, Qld.*

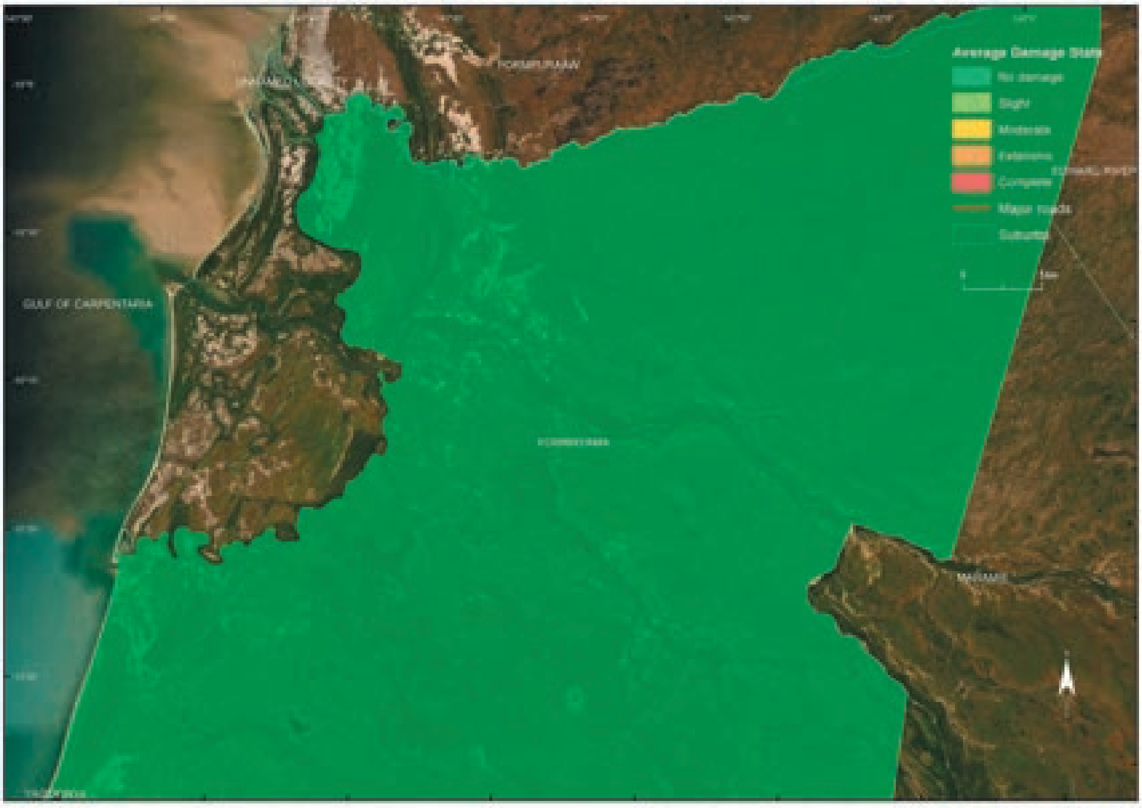


Figure 93: *Aggregated residential building damage states for mesh block areas, for scenario 002-00483, a Category 3 cyclone impacting Kowanyama, Qld. Note that the spatial aggregation covers very large expanses in this part of Queensland, so any variation in damage within the community may not be discernible on this map.*

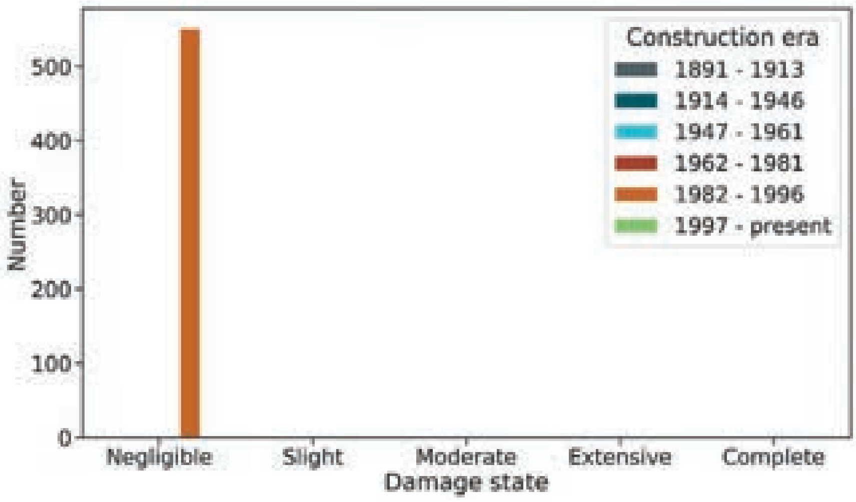


Figure 94: Count of residential buildings in each damage state, grouped by construction era, for scenario 002-00483, a Category 3 cyclone impacting Kowanyama, Qld. Note nearly all houses in Kowanyama are modern construction.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1891 - 1913	0	0	0	0	0
1914 - 1946	0	0	0	0	0
1947 - 1961	0	0	0	0	0
1962 - 1981	2	0	0	0	0
1982 - 1996	551	0	0	0	0
1997 - present	0	0	0	0	0
Total	553	0	0	0	0

Table 18: Count of residential buildings in each damage state, classified by construction era, for scenario 002-00483, a Category 3 cyclone impacting Kowanyama, Qld.

4.7.2 Category 5 cyclone: scenario 006-07657

As with the Category 3 scenario, the chosen Category 5 cyclone moves slowly around the Gulf of Carpentaria for several days before passing almost directly over Kowanyama. Even in this scenario, the local wind speeds in the community itself are less than 200km/h, as the strongest winds in this case are to the north of the track. There is little variation in the local wind speeds, as the landscape is quite flat, with little variation in vegetation. Notably, the winds are strongest at the mouth of the Mitchell River to the west of the township. As with the preceding scenario, little damage would be expected to houses as the local wind speeds do not exceed the design levels for the region. However, it should be considered that a cyclone with a track and progression similar to this scenario would likely yield regional impacts in line with that described in the previous TC Nora case study.

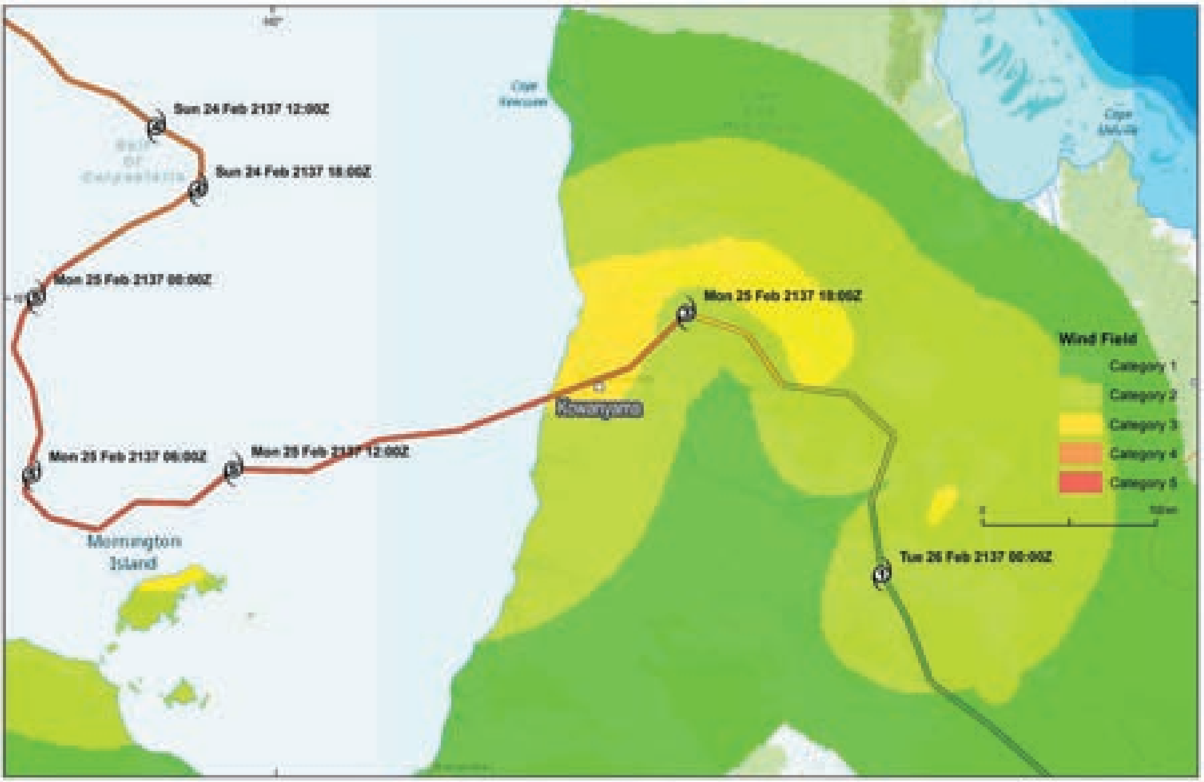


Figure 95: Regional wind field for scenario 006-07657, a Category 5 cyclone impacting Kowanyama, Qld.

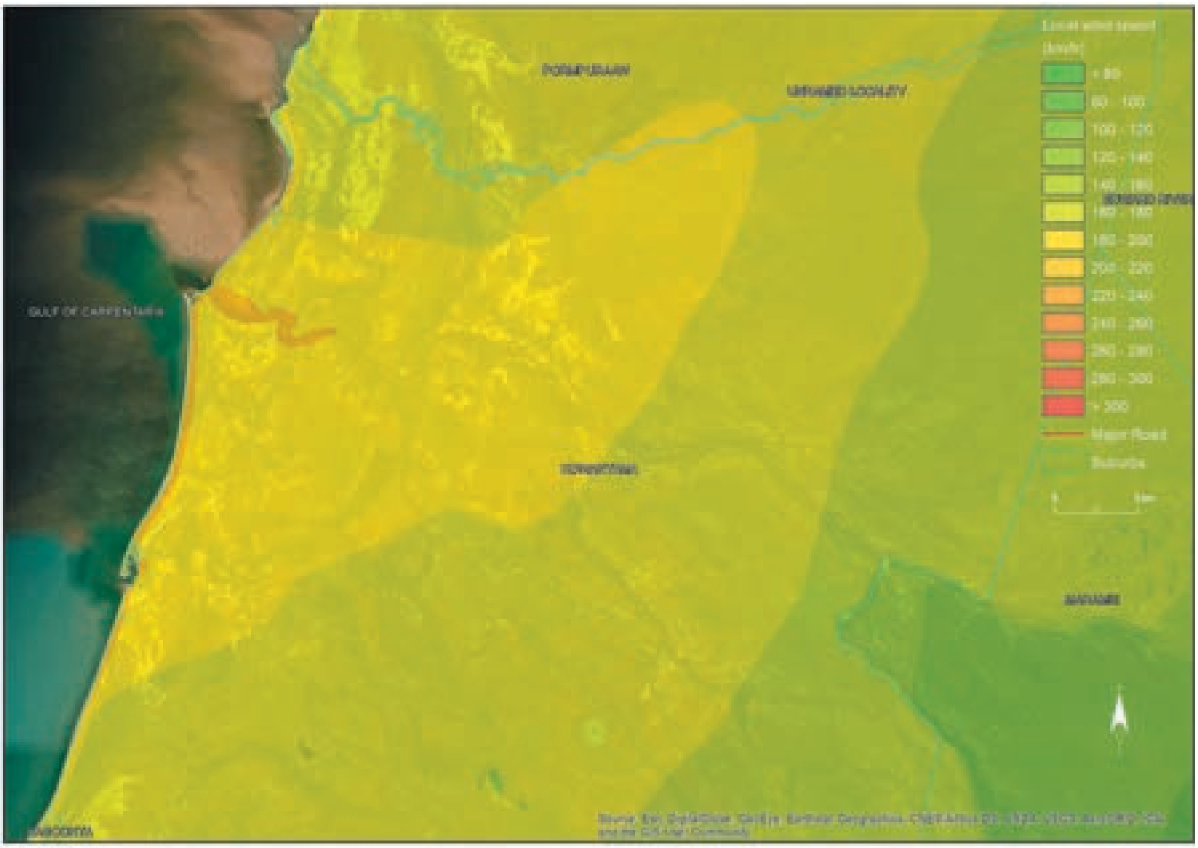


Figure 96: Local wind field for scenario 006-07657, a Category 5 cyclone impacting Kowanyama, Qld

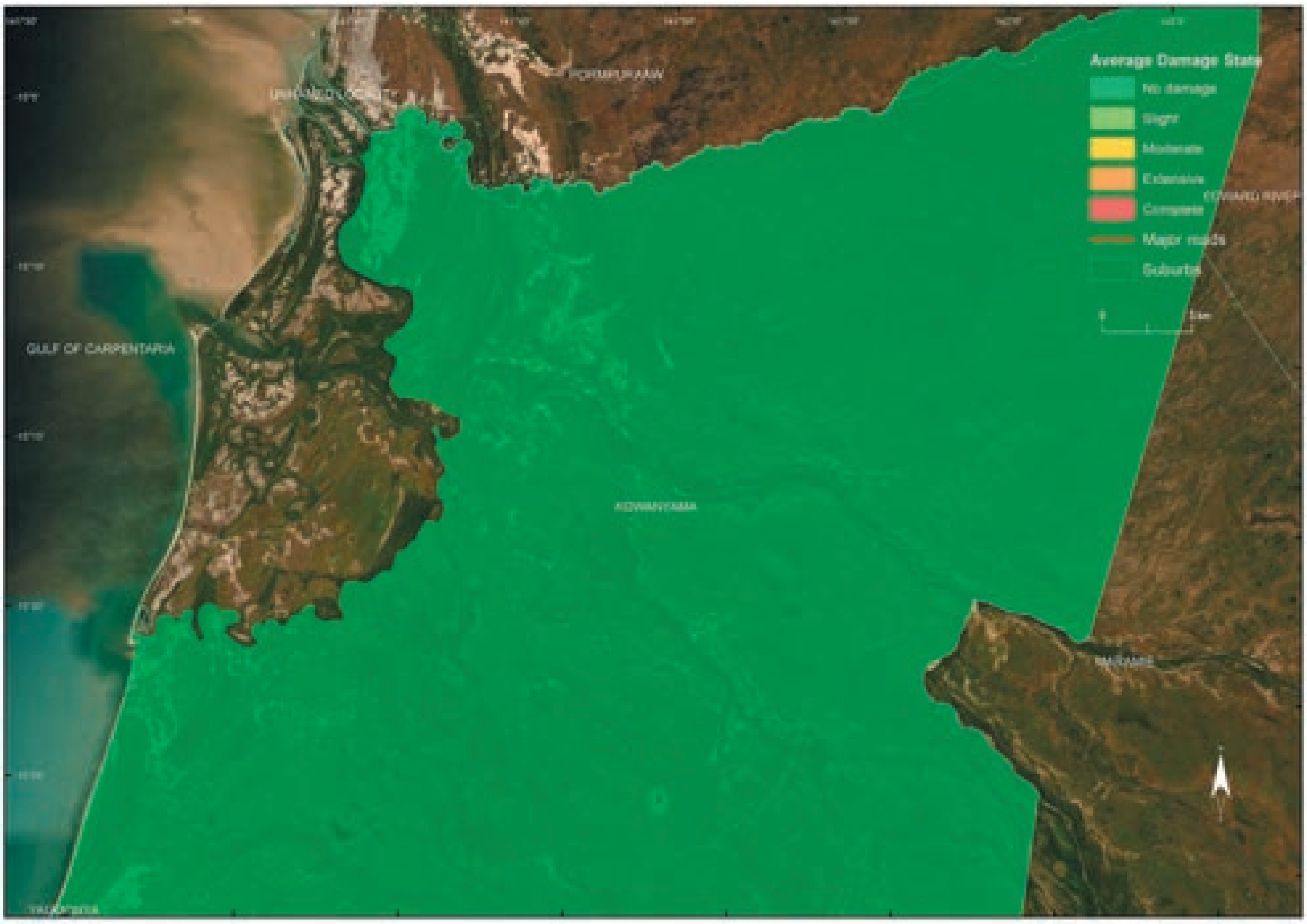


Figure 97: Aggregated residential building damage states for mesh block areas, for scenario 006-07657, a Category 5 cyclone impacting Kowanyama, Qld. Note that the spatial aggregation covers very large expanses in this part of Queensland, so any variation in damage within the community may not be discernible on this map.

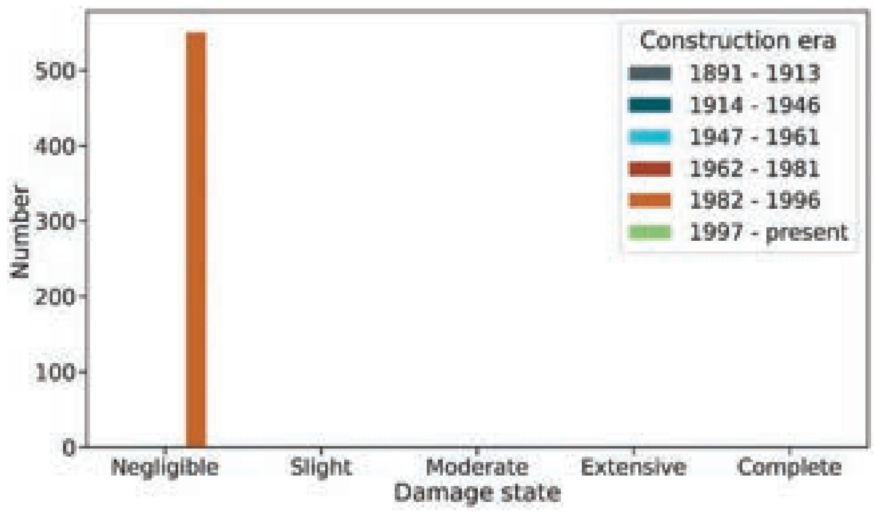


Figure 98: Count of residential buildings in each damage state, grouped by construction era, for scenario 006-07657, a Category 5 cyclone impacting Kowanyama, Qld. Note nearly all houses in Kowanyama are modern construction.

	Damage state				
Construction era	Negligible	Slight	Moderate	Extensive	Complete
1891 - 1913	0	0	0	0	0
1914 - 1946	0	0	0	0	0
1947 - 1961	0	0	0	0	0
1962 - 1981	2	0	0	0	0
1982 - 1996	551	0	0	0	0
1997 - present	0	0	0	0	0
Total	553	0	0	0	0

Table 19: Count of residential buildings in each damage state, classified by construction era, for scenario 006-07657, a Category 5 cyclone impacting Kowanyama, Qld.

4.8 Pormpuraaw

Like the tracks for the Kowanyama scenarios, the scenarios for Pormpuraaw meander across the Gulf of Carpentaria for some time prior to making landfall. This is analogous to recent cyclonic events in the region, such as TC Nora, 2018.

4.8.1 Category 3 cyclone: scenario 015-09711

For the Category 3 scenario, the cyclone spends several days in the Gulf after forming over Cape York Peninsula. The cyclone attains Category 5 intensity in the days prior to landfall near Pormpuraaw but weakens rapidly just before landfall, dissipating south east of the community less than a day after making landfall.

Figure 99: Regional wind field for scenario 015-09711, a Category 3 cyclone impacting Pormpuraaw, Qld.

The local winds across the region are around 160km/h (Figure 100), apart from the coastline where gusts may briefly reach 200km/h. These winds are below the design criteria for the region, so little damage would be expected. About 10% of the houses may sustain slight damage (Figure 102 and Table 20).

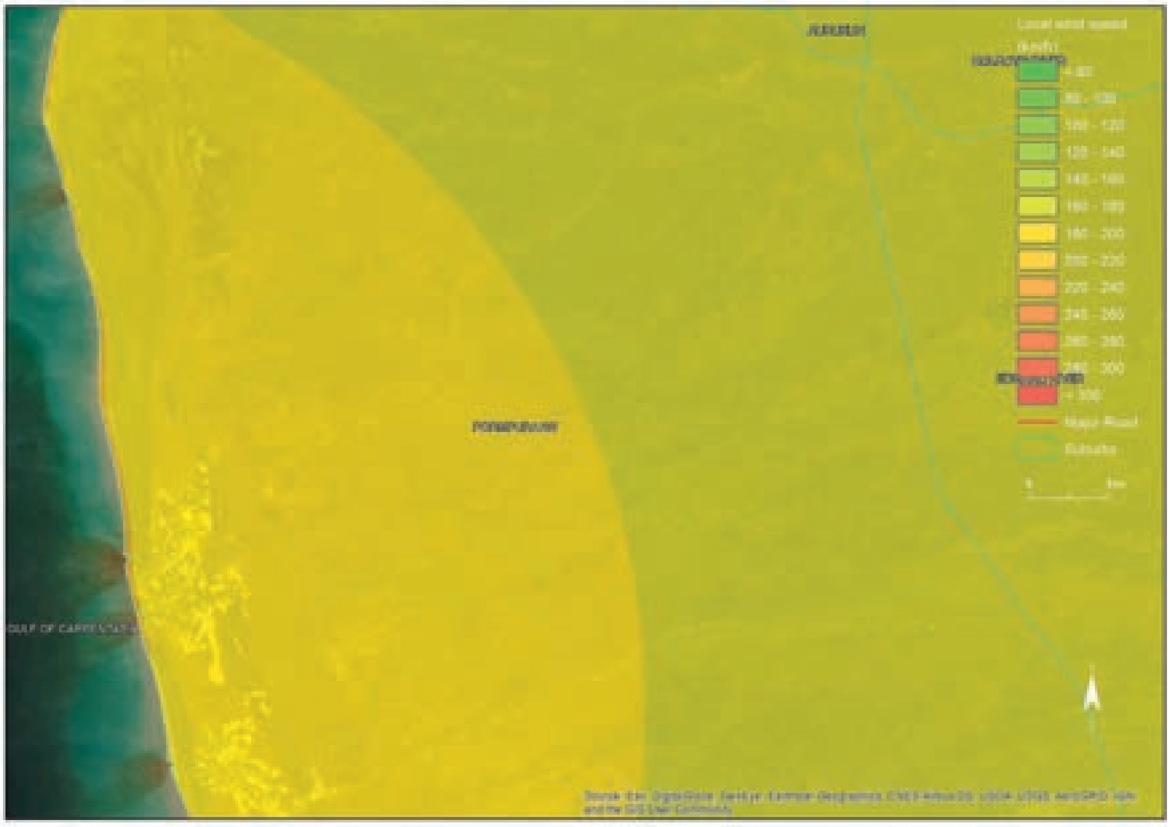


Figure 100: Local wind field for scenario 015-09711, a Category 3 cyclone impacting Pormpuraaw, Qld.

Figure 101: Aggregated residential building damage states for mesh block areas, for scenario 015-09711, a Category 3 cyclone impacting Pormpuraaw, Qld. Note that the spatial aggregation covers very large expanses in this part of Queensland, so any variation in damage within the community may not be discernible on this map.

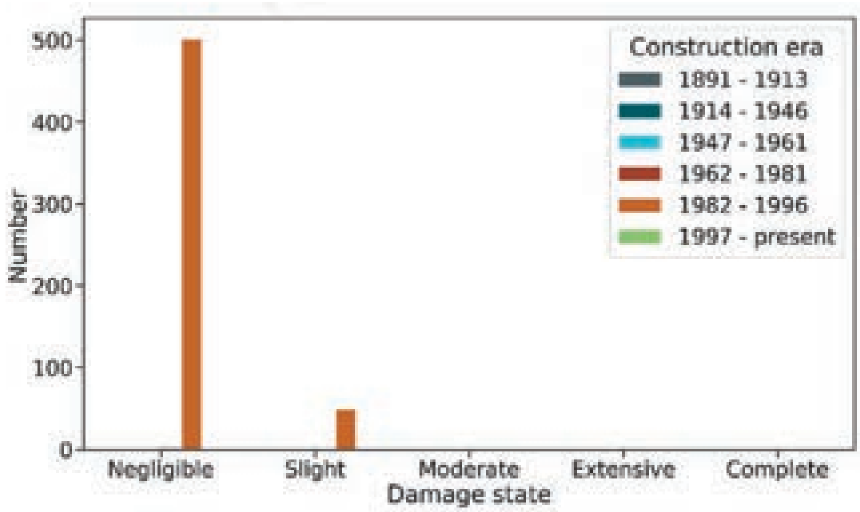


Figure 102: Count of residential buildings in each damage state, grouped by construction era, for scenario 015-09711, a Category 3 cyclone impacting Pompuraaw, Qld. Note nearly all houses in Pormpuraaw are modern construction.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1891 - 1913	0	0	0	0	0
1914 - 1946	0	0	0	0	0
1947 - 1961	0	0	0	0	0
1962 - 1981	2	0	0	0	0
1982 - 1996	502	49	0	0	0
1997 - present	0	0	0	0	0
Total	504	49	0	0	0

Table 20: Count of residential buildings in each damage state, classified by construction era, for scenario 015-09711, a Category 3 cyclone impacting Pompuraaw, Qld.

4.8.2 Category 5 cyclone: scenario 004-03396

The selected Category 5 scenario for Pormpuraaw is shorter lived than the other scenarios used for the Gulf communities. The storm intensifies quickly to attain Category 5 within four days of development, then tracks directly across the Gulf of Carpentaria towards Pormpuraaw. Just prior to landfall, it takes a sharp turn to the south and makes landfall closer to Kowanyama but still bringing intense winds to Pormpuraaw.

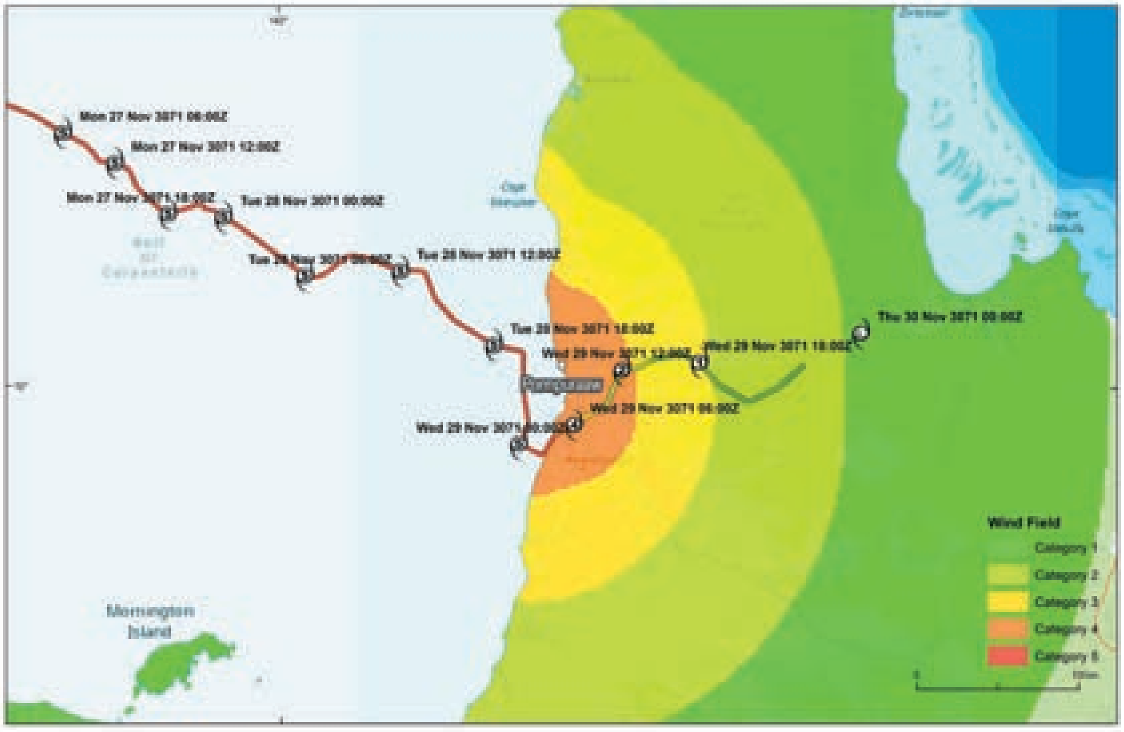


Figure 103: Regional wind field for scenario 004-03396, a Category 5 cyclone impacting Pormpuraaw, Qld.

The local winds in the region peak at over 240km/h (Figure 104), slowly reducing further inland. However, within the community maximum winds are generally below 200km/h. Within the community, the majority of houses sustain very little damage, with around 10% suffering moderate damage in this scenario (Figure 106 and Table 21).

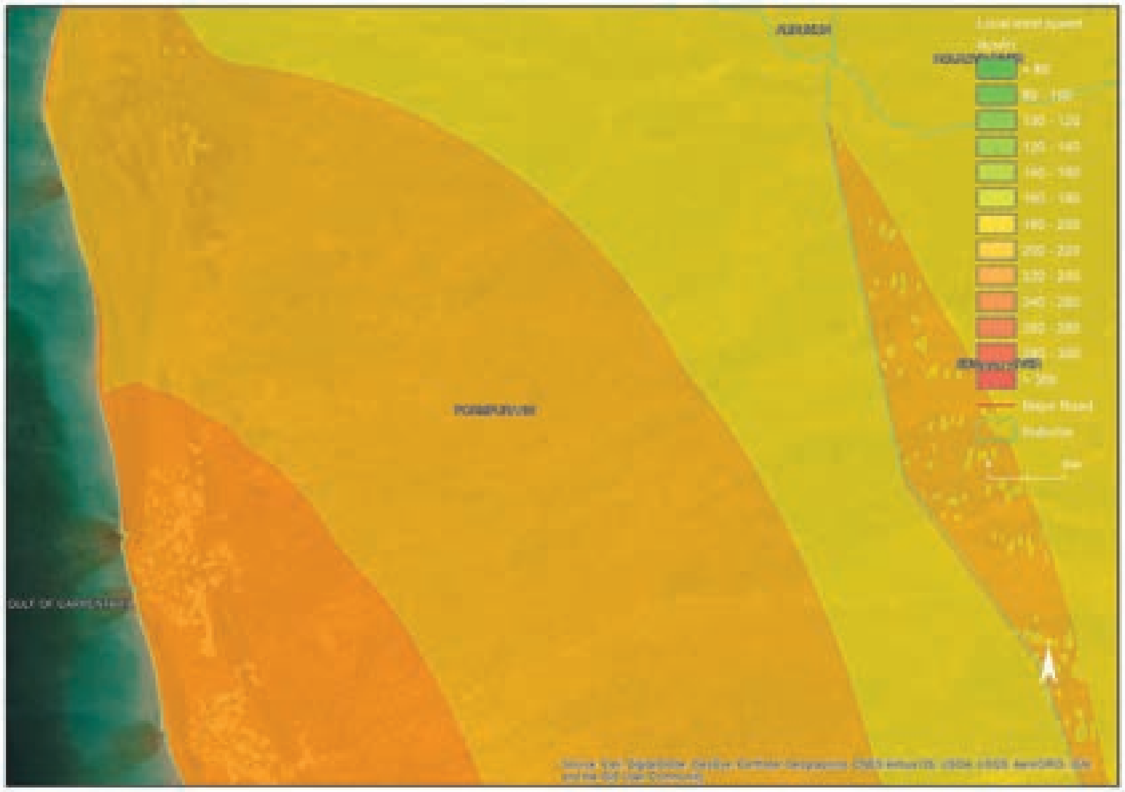


Figure 104: Local wind field for scenario 004-03396, a Category 5 cyclone impacting Pormpuraaw, Qld.

Figure 105: Aggregated residential building damage states for mesh block areas, for scenario 004-03396, a Category 5 cyclone impacting Pormpuraaw, Qld. Note that the spatial aggregation covers very large expanses in this part of Queensland, so any variation in damage within the community may not be discernible on this map.

	Damage state				
Construction era	**Negligible**	**Slight**	**Moderate**	**Extensive**	**Complete**
1891 - 1913	0	0	0	0	0
1914 - 1946	0	0	0	0	0
1947 - 1961	0	0	0	0	0
1962 - 1981	0	1	0	1	0
1982 - 1996	239	258	51	3	0
1997 - present	0	0	0	0	0
Total	240	258	51	4	0

Table 21: Count of residential buildings in each damage state, classified by construction era, for scenario 004-03396, a Category 5 cyclone impacting Pompuraaw, Qld.

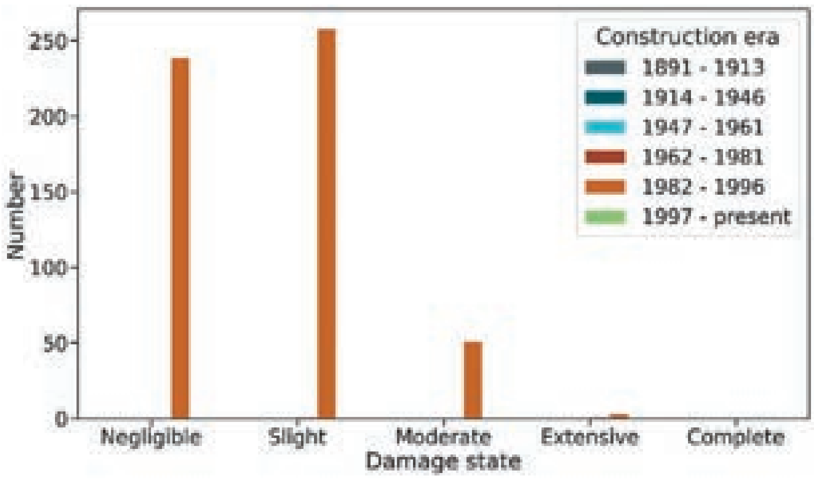


Figure 106: Count of residential buildings in each damage state, grouped by construction era, for scenario 004-03396, a Category 5 cyclone impacting Pormpuraaw, Qld. Note nearly all houses in Pormpuraaw are modern construction.

4.9 Discussion

The differing levels of resilience across Queensland communities are highlighted through this scenario-based analysis by the comparative impacts of severe TCs on the most northern communities and the Gold Coast. For the Category 3 events, most communities sustain low to moderate levels of damage. But in the south (below the Wind Region C & B demarcation), a Category 3 cyclone would be a catastrophic event as the wind speeds exceed the regional design levels for South East Queensland. Contrasting that with Kowanyama and Pormpuraaw, which are characterised by mostly modern public housing, there is essentially negligible wind damage in the case of the Category 3 cyclones, and some moderate damage sustained in the more severe Category 5 scenarios. Where houses are built to modern standards, we expect little damage from events that are below the regional design levels. However, the cities and towns along the east coast are a mix of older and newer construction, leading to worse damage outcomes.

While the likelihood of a Category 3 or 5 cyclone impacting the Gold Coast is very low, from an emergency management perspective, the consequences of even a Category 3 event would be catastrophic and require a far greater response and recovery effort compared to a similar intensity cyclone in northern parts of the state. It must also be considered that lower intensity cyclones (Category 1 or 2) may present considerable impacts to South East Queensland communities and, as such, an increased focus on cyclone preparedness - similar to the level of preparation for severe storms - would be beneficial in this region.

A common outcome for all scenarios is the greater likelihood of significant damage on the outskirts of the communities and for isolated houses fully exposed to the full force of the wind. This becomes very clear for the Category 5 cyclone scenarios, where most houses on the outskirts suffer major damage, while those in the centre of built-up areas suffer comparatively lesser damage. The shielding effect, where buildings provide some protection to neighbouring downwind buildings, drives this result, especially in areas where building density is higher.

However, it must be reemphasised that modelling of this nature cannot account for impacts from wind-driven rain or debris. As such, where housing density is high, we should expect significant damage from debris, (Boughton,1999) especially in communities south of Bundaberg where preparation measures, such as clearing yards and securing loose items, are not widely practiced. Also, the modelling has not examined storm surge impacts, which would be quite significant along coastal foreshore areas in the Category 5 scenarios.

Conversely, the spatial distribution of building ages across communities, especially large cities, means inner suburbs are generally more vulnerable, due to predominantly older housing stock in those areas (see Appendix F). Even though they may not experience the strongest winds because of the shielding afforded by surrounding housing, the greater vulnerability may lead to substantial damage.

A higher concentration of buildings may lead to an increase in debris generation, which can increase damage significantly. Also, as observed in other jurisdictions (Western Australia), older suburbs have a greater proportion of houses with potentially hazardous materials (asbestos-containing materials) which, even with only moderate damage, would present major challenges to the post-event clean-up. (Boughton et al., 2021)

Finally, and as previously mentioned, it is worth emphasising that these scenarios may underrepresent the potential for impact, based on previous observations of damage from events such as TC Yasi, 2011 and TC Larry, 2006. The models for hazard, exposure and vulnerability are constantly updated based on new research and observations. It is recommended that the scenario outputs within this report are revisited regularly following any and all refinement and calibration of aspects such as wind field footprints and vulnerability models.

Several of the communities analysed have residential housing across areas of complex terrain, where local effects can lead to significant acceleration of the winds around slopes and ridges. This is especially the case in the Cairns and Gold Coast scenarios where the acceleration of the wind speeds is greatest in the hinterland areas. This may consequently lead to impacts well away from the coastline where the strongest winds are typically expected. Access and resupply to these areas in the aftermath of the event would be challenging with debris, landslips and consequential flooding likely to compound the issue.

While building policy standards provide guidance for residential construction according to a range of site conditions, terrain categories and topographic classes[14], it is important to note that these considerations are not key considerations in land use planning. As such, there are no development restrictions directly related to cyclonic or severe winds especially in coastal or hinterland areas. This has the potential to increase exposure-related risk and, ideally, should be addressed in line with other hazards such as bushfire and flooding, where disaster management, land-use planning and building policy all work together to place significant restrictions on development in these areas. The IGEM Cyclone Debbie Review highlighted the requirement to:

"...better integrate the disaster management sector with those at both local and state level involved in land use planning. The amount of property damage from Debbie emphasises the importance of getting this right in future planning. We heard that better guidance from the disaster management sector was needed."

This issue has been reiterated more recently by the Royal Commission into National Natural Disaster Arrangements Recommendation 19.3, Mandatory consideration of natural disaster risk in land-use planning decisions; that:

"State, territory and local governments should be required to consider present and future natural disaster risk when making land-use planning decisions for new developments."[15]

By association, (that is, through the impact of climate change on disaster related risk) this issue is already the subject of an action under the Queensland Climate Adaptation Strategy, which seeks to:

"...ensure climate change is considered in state and regional planning instruments."

In this context 'planning instruments' is applied in the broad sense to capture land-use planning, regional planning, development assessments and building policy.

There are benefits improving community understanding of severe wind and providing further guidance on preparation and response, similar to existing guidance for bushfire and flooding. Many households may not be aware of their risks, nor prepared to respond to an event where the wind speeds are forecast to exceed the design thresholds of their own dwelling or the wider community, which could have catastrophic consequences, especially for highly populated areas and those wanting to leave early but have limited access to transport. This is evidenced from an account of a Cairns woman who survived TC Yasi:

"We were not told about the seriousness and the danger of death until it was too late to leave by public transport. We would have chosen to fly south rather than die in our home unable to leave. I did not want to die in the tidal surge and not be found for my family to bury. We should have been given a choice. We said our goodbyes and prepared for death" (Woods et al., 2014).

It is an unfortunate reality that the scale of impact, the tyranny of distance, and general constraints in capability and capacity will require new thinking to improve the safety of Queensland's more rural and remote communities. Queensland's more rural and remote communities would greatly benefit from preparing and planning for not only significant direct impact, but the possibility of major systemic impacts such as being without essential services (e.g. power) and outside assistance for some time (greater than a week). This is arguably longer than what is currently being prepared for across many Queensland communities. This is demonstrated by one account of a Cardwell man who survived TC Yasi:

"Quite a lot of resources arrived quite quickly for the main town areas, which was necessary because most people are concentrated in those areas, and they did need help. BUT so did the other people not living in the immediate town area, many of those areas were largely forgotten for quite some time and had to fend for themselves for more than a week after the cyclone. Resources were not being distributed to outlying areas even though they suffered loss and damage to as great a level as those in the towns" (Woods et al., 2014).

There have been several severe cyclones in recorded history along the Queensland coast that have caused major impacts, but at a time when the populations were much lower (see Table 4). Researchers also have suggested there is an element of complacency among residents and key decision makers who believe they have previously experienced severe TC impacts, when in fact they have only experienced lower winds on the outer edge of a cyclone (Pooley, 2005; Roberts et al., 2014).[16]

Many emergency managers plan for and provide evacuation guidance to the community for areas susceptible to storm surge and riverine flooding. With similar appreciation, emergency managers are encouraged to consider susceptibility of the community to severe winds and develop evacuation planning strategies, importantly with consideration of the compound relationships of storm surge, flooding and severe winds that could impede otherwise well-established plans. The experiences of the United States in this regard during recent major hurricanes (cyclones) is well summarised by the account of Lt-Gen Russel L Honoré, US Army - Commander of Joint Task Force Katrina:

> *"Before Katrina, it was a longstanding tradition in our country for political officials to wait until the last minute to warn, to take action, to evacuate. No more. With [Hurricane] Irene, you had mass evacuations – mandatory ones – issued days ahead of time. That was the right thing to do."*[17]

Discussions about the need for evacuation plans that traverse local and state borders remains a challenging issue, and has been recently highlighted in the Royal Commission into the National Natural Disaster Arrangements (Recommendations 12.2 through 12.7).[18] With the scale of potential impacts demonstrated by this study, in areas such as South East Queensland, this issue requires ongoing discussion across all levels of Queensland's disaster management arrangements and with other jurisdictions.

Overall, thorough consideration of the issues outlined above can help to build resilience (prevention), enhance preparedness immediately ahead of an imminent severe TC event, and alleviate the compound challenges of coordinating preparations and response. Chapter 6 outlines further considerations that are applicable to assessing the risk associated with these scenarios with Chapter 8 providing a consolidated list of conclusions generated by this study.

Figure 107: An aerial view of damage caused by Hurricane Andrew, circa 1992. Source: AP and Miami Herald

Figure 108: Aftermath of Hurricane Katrina, 2005. Source: Reuters

5 HAZARD ASSESSMENT FOR CURRENT AND FUTURE CLIMATE SCENARIOS

5 Hazard assessment for current and future climate scenarios

Climate change is expected to influence the frequency, intensity and behaviour of tropical cyclones (TCs) globally, with most researchers agreeing there will be a global decline in TC frequency, but a shift towards more intense events (Knutson et al., 2020). There are multiple lines of evidence suggesting long term trends in TC frequency and intensity are already observable. For example, Callaghan and Power (2011) find a statistically significant decline in severe landfalling TCs at centennial scales along the Queensland coastline. Holland and Bruyère (2014) reported that global intensity distribution has *"developed bimodal characteristics … growing consistently from 1965 to the present"* though regional trends are less clear.

There is greater uncertainty in the projected changes at a regional level (Knutson et al., 2020 and references therein). It is these regional changes that will influence the likelihood of TC-related extreme winds across Queensland. To quantify the changes in likelihood, we use a statistical model of tropical cyclones that can generate a large collection of tracks that are similar to the historical record of cyclones, but events that are not identical to those historical events. Using this model, it is possible to generate many thousands of years of TC activity, which enables us to better explore the likelihood of TC-related extreme winds. For example, there have been only 24 cyclones pass within 50km of Townsville since 1907, and the highest wind speed recorded since observations began in 1940 was 196km/h in TC Althea, 1972. Using a statistical model allows us to extend the record of TCs to many thousands of years, enabling robust calculation of the likelihood of extreme winds.

In a similar manner, we can leverage the information extracted from regional climate models to inform the evaluation of the likelihood of extreme TC related winds. Details on the approach and the findings of this study are described in the companion report to this main study *'Hazard assessment for future climate scenarios in Queensland: Evaluating the impact of climate change on TC-related extreme winds'* and will be reported in further detail in subsequent scientific publications.

In summary, it is more likely than not that some communities across Queensland will see an increase in the likelihood of extreme TC events into the future but, for most, the reduced annual frequency of TCs across North Queensland will see the AEP wind speeds reduced into the future. Most communities are unlikely to experience significant change in the modelled wind hazard at the 1:500 AEP level. While there is uncertainty relating to the regional changes in the modelled TC-related wind hazard in South East Queensland, the existing wind loading design standards for all buildings are lower than areas north of Bundaberg, and the level of exposure is significantly higher.

This assessment finds that all of Queensland's coast has been impacted by severe tropical cyclones in the past, and indicates that all of Queensland's coast is susceptible to severe tropical cyclone impacts into the future. This reinforces the importance of considering the resilience of evacuation facilities and other building assets used for coordinating emergency management activities, especially in South East Queensland. The Building Code of Australia specifies a 1:2000 AEP for structures essential to post-disaster recovery, and there is evidence of an increase in wind speeds at these likelihoods. Even at lower wind intensities, issues relating to water ingress impacting the functionality of the facility must be considered.

Further investigation into the changes of TC activity, especially around the intensity of events would be beneficial, given some of the shortcomings noted in the detailed companion report. Additionally, climate change impacts on TC activity is a prominent area of climate research, so we are likely to see continued developments in the science into the future that will help to refine the projections of hazard.

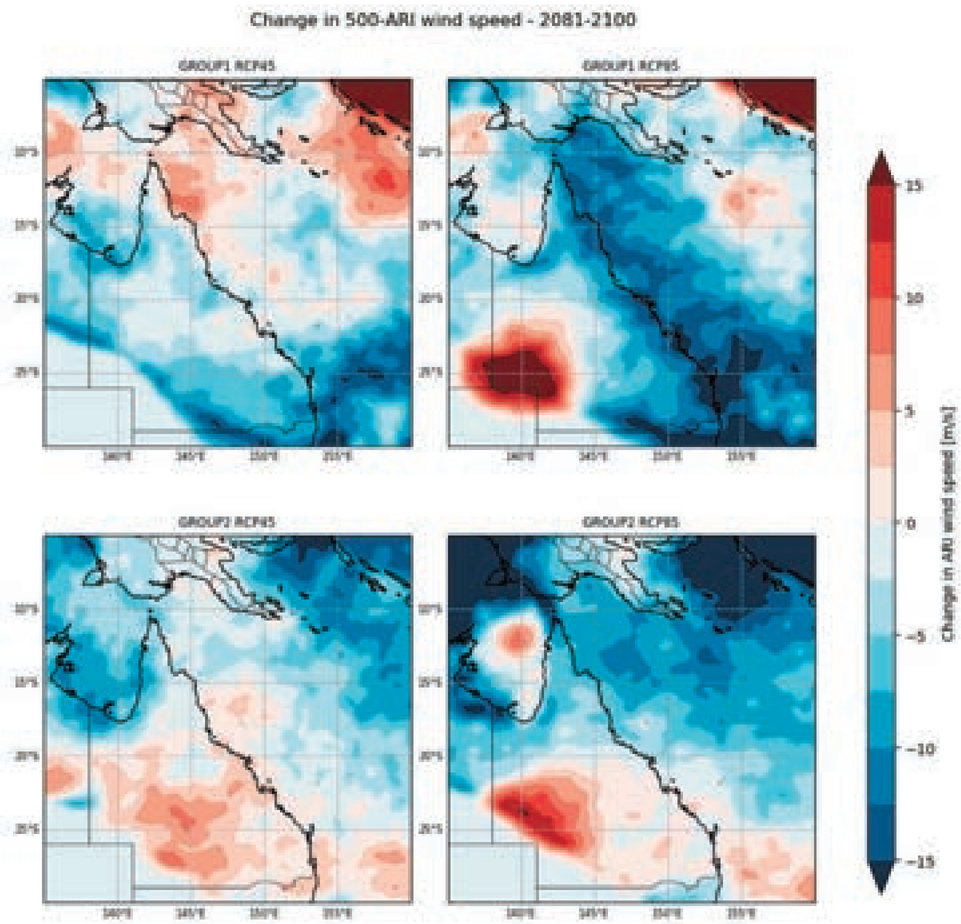


Figure 109: Example result from the Hazard Assessment for Current and Future Climate. Change in 0.2% AEP wind speed for Queensland for the period 2081-2100.

Regionalisation of modelled TC wind hazard for regions and locations in Queensland

Two different approaches were employed to assess the modelled changes to TC wind hazard across regions and locations in Queensland: the region-based approach and the point-based approach.

The region-based approach utilises the maximum gust wind speed generated by the associated wind fields of the TC events within a region. The region-based hazard profile indicates the spatially aggregated hazard across an entire region – that is how often a TC event exceeding a given magnitude is expected to occur anywhere within a region such as a Local Government Area (LGA).

This approach was used to inform the TC risk for:

- LGAs
- regional plan areas
- river basins
- bio-regions and
- disaster districts.

The modelled region-based hazard profile is useful for broad-scale risk management and preparedness. The point-based approach utilises the specific TC winds from the hazard profile influencing a certain location represented by a pair of spatial coordinates (latitude and longitude). No spatial aggregation was used.

The point-based risk is more appropriate to inform the modelled hazard profile of specific locations represented by a pair of spatial coordinates taken from cities, towns and communities. For both region-based and the point-based approaches modelled wind speeds were ranked and return intervals were calculated as Average Recurrence Interval (ARI) and Annual Exceedance Probability (AEP). Then, in order to scale future ARI and AEP curves to current curves, the difference between the future climate runs (2041-2060 and 2081-2100) to the reference period (1981-2020) was summed to the current (based on historical TC tracks) curves.

The modelled current and future hazard profiles for Queensland's LGAs (region-based) and Queensland's cities and towns (point-based) are included at Appendix D.

The Queensland Government's Tropical Cyclone Dashboard

The Tropical Cyclone Dashboard (TC–) is an interactive visualisation platform of modelled current and future TC hazard to support the SWHA-Q and the Queensland Government's Climate Adaptation Strategy (Q-CAS). It allows users to understand the modelled change in likelihood of TC-related winds across a range of regions and over 200 locations across Queensland. The TC– is composed of drop-down menus, maps, plots and tables whereby users can customise, visualise and export modelled current and future TC wind hazard information summarised for Queensland's regions and locations.

The TC– integrates the Queensland Future Climate projections and the SWHA-Q modelled current wind hazard to understand the modelled change to severe wind hazard posed to Queensland based on the frequency and intensity of TCs.

The SWHA-Q aims to better understand the potential impacts of modelled current and future TCs across Queensland's regions and locations and better communicate the modelled projected changes in cyclone behaviour across Queensland. As such, the TC– aims to inform Queenslanders about the outcomes of the SWHA-Q through a user-friendly interface where users can interactively visualise and access modelled current and future TC wind hazard profiles for several regions and locations.

The *Tropical Cyclone Dashboard* is hosted on the Queensland Future Climate website to provide access to the SWHA-Q model's output and was designed to facilitate the visualisation of modelled current and future TC wind hazards. It does not supersede building code advice nor imply design values. Users are advised to seek expert advice to support their interpretation of these results for their intended purpose. Depending on the use-case, a locally specific detailed tropical cyclone hazard and risk analysis may be required to support the specific application.

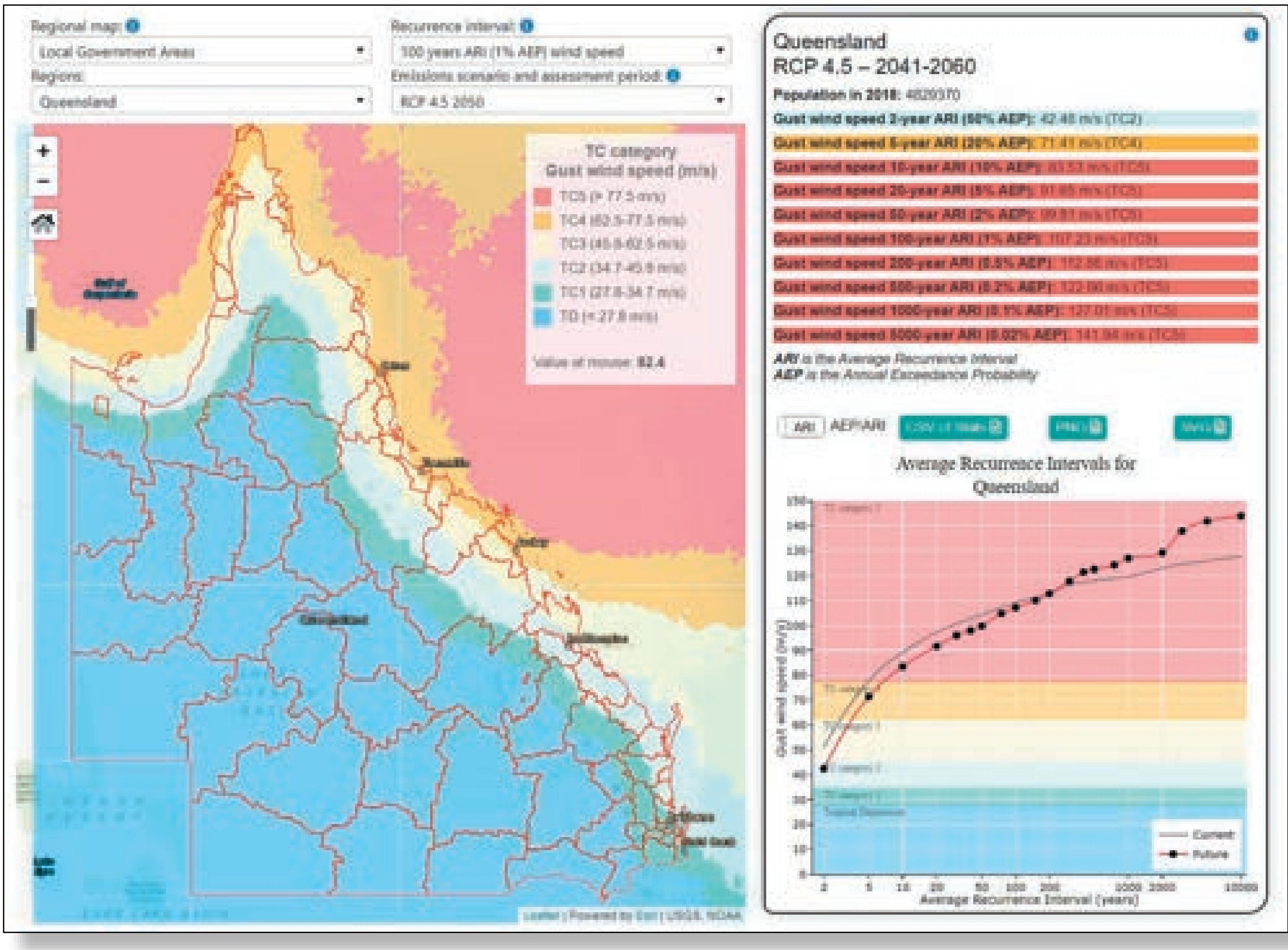


Figure 110: Screenshot of Queensland Tropical Cyclone Dashboard.

6 IMPLICATIONS FOR EMERGENCY MANAGEMENT IN QUEENSLAND

Australian Government
Geoscience Australia

Queensland Government

CYCLONE TESTING STATION

6 Implications for emergency management in Queensland

The Severe Wind Hazard Assessment for Queensland (SWHA-Q) project has developed a suite of scenarios to enable state emergency and disaster management stakeholders to undertake capability analyses, inform mitigation strategies and enhance intelligence and planning capabilities (Arthur et al., 2020). Having realistic and alternative scenarios allows for the conduct of capability analysis to assess current and future capabilities and concepts (Chim et al., 2010; Fitzsimmons, 2018). Using a set scenario provides a measurable and consistent baseline for analysis. Considering several scenarios, different mitigation strategies, preparedness, response, recovery and capability options can be analysed to provide a flexible approach (Burns and Miller, 2014).

While some emergency managers may have experience with Category 3 tropical cyclones (TCs), many may not be with Category 5 TCs and their potential impacts. Scenarios can be a useful way of improving the judgement of decision makers that are less experienced with these events and can help to challenge the assumptions held by more experienced decision makers (Klein, 2015).

Scenarios can help to identify the broader context in which problems need to be solved and strategic, coordinated planning developed (Australian Government, Department of Home Affairs, 2019). Using credible scenarios enables emergency managers to improve planning for response and recovery processes. When linked with exposure vulnerability and damage data, scenarios can also inform mitigation strategies by having an event or events to plan against (Productivity Commission, 2014). This project uses Category 3 TCs, reflecting the historical experience and likelihood for Queensland communities, and Category 5 TCs to explore credible worst-case scenarios, for which there is very limited experience (Arthur et al., 2020).

As direct impact to a major populated area from a severe TC has not been observed since the 1970s, most fatalities linked to TCs can been attributed to flooding, rather than wind-related impacts such as building damage. There have been 192 fatalities since 1970 (Coates et al., 2017), of which 68 were in TC Tracy, 1974. As buildings have become more resilient to cyclones, people sheltering in these modern buildings are also much safer. TC George, 2007, was the most recent case of deaths directly linked to building damage, but that was attributed to the incorrect application of building standards for the site of the buildings (Western Australian Courts, 2015). Due to the low numbers of fatalities, and the absence of concurrent building damage information, there are no suitable casualty models available for TCs. As such, this report does not provide estimates of casualties for the scenarios examined.

Another important consideration is the duration of the cyclone. A slow-moving cyclone will subject buildings to excessive wind actions and cyclic loading for a longer period of time compared to a fast-moving cyclone. This means there would be a greater risk of building failure in the case of a slow-moving cyclone compared to a fast-moving cyclone, even if the intensities were similar. Some of the events analysed in Chapter 4 are slow-moving storms, where these effects may lead to greater damage than estimated from the maximum wind speed alone.

There are additional factors that influence a building's susceptibility to cyclone damage that must be considered when developing strategy and mitigation plans. These include the standard of construction applicable when the building was erected, the standard of any subsequent alterations and additions to the building, the deterioration of the building over time determined by the level of maintenance, and external impacting factors such as termite attack and damage from falling trees and flying debris.

Damage investigations and related research provides empirical data on structural and material failures that, when analysed with impacting hazards, can identify the expected broad levels of damage across exposure populations, deficiencies in codes and standards and the resilience of building materials. This provides vital input to inform emergency management strategies and identification of mitigation options.

Hazard and vulnerability modelling enable decision makers to evaluate the impacts of natural hazard events, such as earthquakes, severe storms and cyclones, on communities, with the objective of reducing the risk posed to life, critical infrastructure, property and the environment and the associated economic loss. Modelling enables an evidence base to be developed upon which plans can be based (Fitzsimmons, 2018) and, when combined with vulnerability and damage, evidence can also be instructive in forecasting likely consequences that may not have previously been experienced and help to identify gaps in the understanding of existing emergency management response and recovery capabilities (Arthur et al., 2020).

The scenarios generated from this project can be used to identify and verify current and future capability needs for agencies involved in managing the cyclone hazard. Generating scenarios allows for the analysis of different mitigation strategies, preparedness, response and capability options. Understanding the impacts reduces uncertainty and enhances decision making, enabling emergency managers to make a more proportional response for pre-deployments rescue, damage assessments and initial recovery.

For years, post event investigations have analysed impacts resulting in many recommendations across agencies and research institutions. Periodical assessment of the level of adoption of these recommendations maximises existing knowledge. Implementation, especially where regulations or codes and standards are affected, can take considerable time and past insights can be 'lost' without periodic follow-up and review.

6.1 Risk assessment

While this report deals primarily with the impacts to residential buildings in the study areas, the following section outlines some of the other critical potential impacts that may arise from the occurrence of a severe TC. It is important to note that this section continues the focus on severe wind impact but references the potential for additional impacts from other consequential hazards such as flash and riverine flooding, landslips and coastal inundation (storm surge). These hazards should always be considered as potential exacerbators of risk or as delivering additional impacts not present with the impact of severe wind, i.e. cyclone-associated riverine flooding impacting a community that was outside of the cyclone's path (e.g. Rockhampton post TC Debbie, 2017).

The key observations for cyclone prone communities across Queensland align with the six exposed element categories outlined within the Queensland Emergency Risk Management Framework (QERMF). Assessing hazard interaction and the impact of hazard characteristics on exposed elements provides a clear understanding of a region's or community's vulnerabilities. This section highlights those elements susceptible to the characteristics of the hazard under the current and the projected future climate.

This list of potential exposures and risk treatments and controls (where applicable) is not exhaustive or prescriptive. The risks, impacts and controls identified throughout this section were developed in consultation and collaboration with relevant stakeholders from across the Queensland Disaster Management Arrangements (see Appendix A for a list of contributing stakeholders). Elements highlighted below may not be applicable to every local government area (LGA) within Queensland and should be validated by each Local and/or District Disaster Management Group (LDMG/DDMG).

6.1.1 Critical infrastructure

While critical infrastructure operators have a leading role in managing and maintaining their infrastructure assets and networks, critical infrastructure resilience to natural disasters is a shared responsibility. The below assessment illustrates a the benefits of encouraging this shared responsibility and empowering disaster-resilient communities.

A disaster-resilient community, according to the Queensland Strategy for Disaster Resilience, is one where people in that community have (among other elements):

- an awareness of the hazards and risks that affect them in their local area, including an awareness of who and what is most vulnerable, and understand what actions they need to take in order to prepare for and mitigate these risks
- taken action to anticipate disasters and protect themselves, their assets, and to commit the necessary resources to organise themselves before, during and after a disaster, and
- an understanding of the mechanisms and processes through which recovery assistance may be made available.

"We should not expect critical infrastructure to be completely resistant to damage, or for essential services to be immune to disruption. Individuals and communities should be aware that they may lose power, water and electricity (including information-technology services) and may be unable to access essential goods such as food at critical moments."[18]

Note: It is important to consider that restoration of critical infrastructure following broad scale impact, including both power and telecommunications, will be prioritised based on greatest need and/or criticality of downstream assets, i.e. size of population affected or if impact includes loss of power to a major hospital where redundancy is insufficient to maintain services.

6.1.1.1 Power

Transmission and sub-transmission network

- LGAs in Queensland, especially those on the east coast, can be intersected by multiple transmission lines (275kV and associated 132kV and 110kV sub-transmission lines) running along several corridors emanating from sources of generation (i.e. power stations) to transmission substations.
- Resilience to sustained destructive cyclonic winds is variable across the transmission and sub-transmission network as vulnerability is dependent on various factors, including the design and age of the infrastructure and topographic exposure. However, given the bulk of the network runs parallel to the coast, significant portions of the network could be exposed to destructive wind gusts, with some sections traversing significant topography (e.g. sections of the Great Dividing Range) which will exacerbate sustained wind speeds due to multiplying effects (Figure 111).

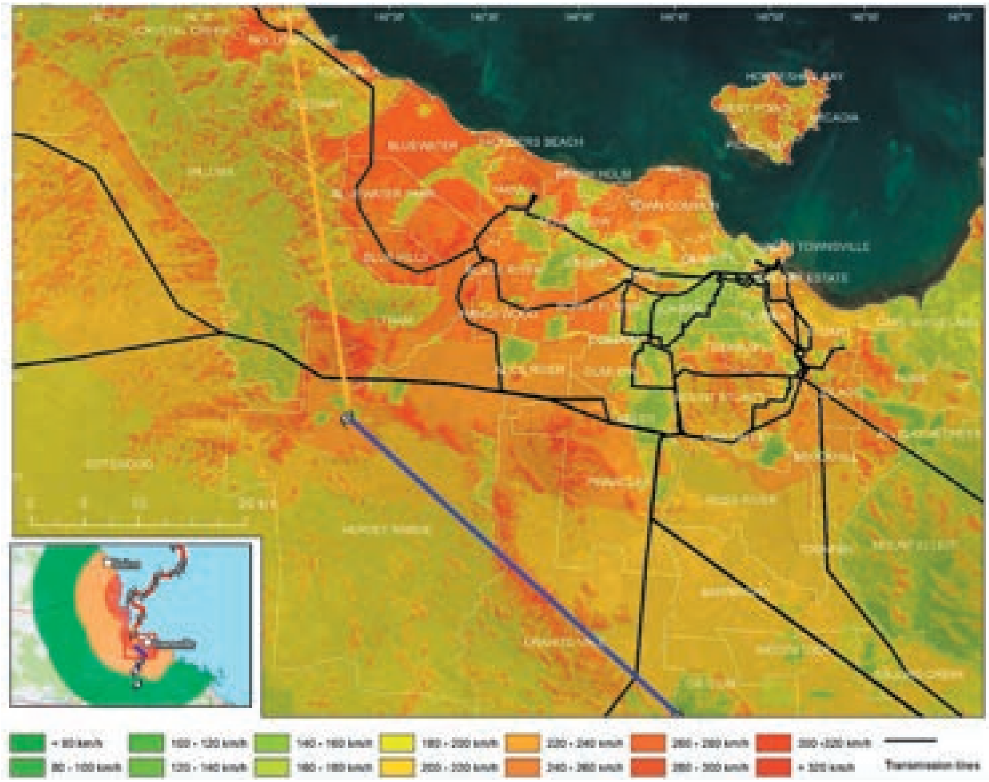


Figure 111: Overview of the transmission and sub-transmission network superimposed over the local wind field for Scenario 005-03821. Note the position of the network in areas where there is significant acceleration of the cyclonic winds over areas of steep terrain or complex topography.

- From the 275kV transmission network emanate sub-transmission (132kV and 110kV) lines which provide power to further downstream distribution substations. These transmission and sub-transmission lines are the backbone of the east coast transmission network and provide the main feed for power across the communities and heavy industries (such as mining) in Queensland.
- A high level of resilience to sustained wind speeds is factored into the design standards applied to the transmission and sub-transmission network, with the network in Central and Northern Queensland designed to withstand Category 5 cyclones. Feeder lines that run parallel to the coastline may be more vulnerable to destructive cyclonic winds (›Category 3) from a system travelling on a western trajectory.

Distribution network

- Because of their design and exposure to debris, high voltage lines (11kV and 22kV), which distribute power to critical infrastructure, suburbs, homes and businesses within communities, are vulnerable to direct impact from sustained destructive winds.
- Therefore, disruption to sustained destructive winds is almost certain to be significantly greater than that of the general transmission network. Historically, significant disruption periods have been observed on a large scale across LGAs impacted by severe TCs, with full restoration of power to communities taking three to four weeks.
- Consideration should be given to the high-voltage lines within rural and hinterland areas of coastal LGAs when planning local disaster response generally, these are the only feeds into communities and the area may be extremely difficult to access in severe to extreme conditions (e.g. flooding and loss of access).

Other considerations

- Historically, impacts such as those described above have occurred during cyclone events within Queensland (e.g. TCs Larry 2006, Yasi 2011 and Debbie 2017) with disruption to the distribution network lasting between seven to 21 days.
- High levels of antecedent or subsequent rainfall may result in extreme overland flow/flash flooding, leading to possible landslips in high risk areas (such as range or hinterland areas) and may yield additional impacts to the electricity network (e.g. undermining of towers, exposure of substations). Any consequent moderate to major flooding may present additional challenges not only in terms of direct impact but also indirectly where access routes to and from asset locations are impacted.
- Green debris and impacts from other windborne debris cannot be discounted when considering the potential impact to, and ultimately the vulnerability of, the whole power network.
- Caution should always be exercised around fallen power line wires which have the potential to remain live and cause additional casualties within the community.
- Rooftop solar panels are vulnerable to high winds and damage from debris. Even where solar power is not impacted, the inability of many buildings to disconnect from the grid means that they cannot utilise this power, unless an isolation switch has been installed.
- Solar panels may also still 'generate' even when mains power has been disconnected. This means all panels should always be treated as live until inspection by a qualified person can declare the panels to be safe. Possibility of significant risk to residents should therefore be considered in these circumstances. This may affect the ability of SES crews and other emergency services to aid households (e.g. tarping activities) until declared safe.
- Recent events have indicated that communities and individuals are often not adequately prepared for the disruption to power, water and telecommunications, which can inhibit access to information technology, essential services and the conduct of basic domestic tasks (e.g. cooking, washing).

This risk is compounded where persons or households have moved into a community within the last five years and are not aware of the hazards or risks present. There has also been an observable increase in risk as the digital interdependence of systems continues to grow.

A lack of preparedness within individuals and communities has the potential to significantly constrain local disaster response and recovery as attention and efforts are diverted to aid households with no redundancy in power, water or essential goods. There is an increased and misplaced expectation that Emergency Services and critical infrastructure owners and operators are required to provide this redundancy to households and communities.

It is worth noting that the preparedness of communities in South East Queensland is likely to be lower than communities in Central or Northern Queensland, due to the lower frequency of events in this region.

Figure 112: Fallen transmission lines as a result of Tropical Cyclone Yasi, 2011. Source: Powerlink

6.1.1.2 Risk treatments and controls

- Powerlink and Energy Queensland will pre-deploy damage assessment and restoration teams and equipment to areas likely to be impacted (where and when it is safe to do so). They will coordinate the movement of these resources and inform DDMGs of these plans.

  Note: Powerlink has a service level agreement (SLA) with Energy Queensland (Ergon) in Central and North Queensland to complete emergency and routine work on Powerlink assets.

- Powerlink has several plans to support a response. These include:
  - Network Incident Management plans
  - Crisis and Emergency Management plans
  - Hazard specific plans.
- Energy Queensland has several plans which all interact and support a response. These include:
  - Fault Response Escalation Framework
  - Emergency Management Distribution Plan
  - Flood Risk Management Plan.

  The Emergency Management Distribution Plan includes requirements to liaise with the relevant and affected disaster management groups. The Fault Response Escalation Framework dictates the business response structure whether it is a local, regional or whole of business response. Depending on which structure activates to respond will determine the trigger for notification to the disaster management groups.

- Generally, restoration of supply times is challenging to evaluate, with the response to the event dependent on the scale of impact and the ability for field crews to safely access sites (of which there may be the requirement for an Emergency Services escort). Disruption to supply chains and transportation routes (affecting the ability to access damaged sites and other infrastructure as well as hindering opportunities to fly/drive in additional Energy Queensland/Powerlink resources to assist the response) may also hamper restoration efforts.
- Much of the critical infrastructure operated by council and state government (e.g. hospitals) is fitted with or for generator back-up in the event of power outages. Discussions with disaster management stakeholders across Queensland suggests that levels of fuel reserves, resupply arrangements and operational maintenance available before, during and after impact is highly variable across Queensland. Accordingly, the current standard of back-up generation across all regions may be insufficient to maintain services greater than the recommended 72 hours.
- Non-council owned services, utility providers and essential infrastructure asset owners may not have the necessary capability and expertise to maintain operations and services during an event.
- Presence of rooftop solar may affect the ability of SES crews and other emergency services to aid households (e.g. tarping activities) until declared safe. Specific training for emergency responders in this area would be beneficial.
- Strengthening smart grid and distributed generation polices to improve the resilience of networks would be beneficial.
- Individuals and communities have a responsibility to understand that natural disasters such as tropical cyclones can lead to disruptions and prepare for those circumstances. They should access information made available to them by local governments as to the risks to which they are exposed, understand how these risks could affect their situation and their households and, where necessary or appropriate, mitigate those risks and be prepared to manage any consequences.

6.1.1.3 Telecommunications

- Mobile communications network has been problematic during significant past storm events due to direct and indirect (power) impacts to communication towers and repeater locations across many LGAs.
- Generally, LDMGs expect that the impact of sustained destructive cyclonic winds will lead to telecommunications outages through direct impact to telephone lines, mobile communication towers and emergency services radio towers. While the towers themselves are unlikely to topple, attached antennae and point to point communication dishes are highly vulnerable.
- Vulnerability will vary due to level of exposure but location of infrastructure on topographically high features may exacerbate vulnerability (i.e. hinterland and mountainous areas).

- Variability in battery redundancy to Telstra exchanges and mobile towers coupled with the possible prolonged disruption period in relation to power, may result in the total loss of communication services in some areas.
- Prolonged power outages can also lead to the inability to charge mobile communication devices highlighting the benefit of individuals and households being prepared for such a possibility.
- Rollout of the National Broadband Network (Nbn) continues across Queensland with Nbn nodes in regional centres and fixed wireless towers in rural areas as the primary access points to the network. Nbn has noted that the biggest challenge during an event is power management and access to sites; the network is totally reliant on power with varying levels of redundancy across the network.
- Elements of fixed wireless towers can be highly vulnerable to destructive cyclonic winds.
- Poor mobile coverage and potential loss of Nbn services in low lying areas will restrict the emergency management sector's ability to communicate with impacted communities.
- Impacts on point to point communications, emergency services radio towers and financial services such as ATMs/EFTPOS would significantly impact provision of basic goods and services. Disruption to emergency communications would affect ability for these services to deliver a coordinated response. Cordless voice over internet protocol (VoIP) phones will cease to work in the event of power outages.

6.1.1.4 Risk treatments and controls

Telstra

- Telstra has mitigation and resiliency programs in place to address aged infrastructure and minimise disruption periods. This includes battery redundancy on exchange and towers locations, but this is highly variable. Redundancy varies across LGAs and the wider districts. Some infrastructure is supported with battery redundancy while others are supported by fuel generators, which are often maintained by councils under contract.
- If redundancy fails, Telstra has indicated the network will be supported through the deployment of emergency capability (e.g. TREK, TECK, 3G repeater trailer, COWS and MEOWS) Community Recovery Hubs (Store on Wheels - SOW) can be deployed to support the community in the recovery phase.
- In the event of a broad area impact, local emergency planners should consider the potential of being prioritised after regions with greater need. Consideration should therefore always be given to the issue of broad area impact and capability being deployed elsewhere.
- Telstra's Global Operations Centre provides 24/7 monitoring across all Telstra networks, including working with emergency services and field groups to establish restoration priorities during emergency incidents.
- Coordination of effort within the LGA will be done at the DDMG level where Trained Field Service Managers and Telstra Countrywide representatives with appropriate delegations are present.
- Presence of a Telstra representative with 'adviser status' to liaise with DDMG on restoration timelines and disposition of resources (including redundancy) during the event.
- Direct Access to Emergency Services Liaison Officer (ESLO) at SDCC is via DDMG.
- Telstra has strict protocols on working in disaster affected areas (Black, Amber and Red Zones). Due to the persistent nature of flooding and access issues post-impact, restoration may take some time due to these protocols.
- Currently, all field staff must have an emergency services escort. In the response and recovery phase, the ability to secure adequate escorts may be limited and uncoordinated, and therefore may extend the restoration timeline.

Nbn

- Nbn will pre-deploy teams and equipment to areas likely to be impacted which is coordinated through the district. However, response to outages is managed through a prioritisation pathway, informed both by LDMG priorities and scale of impact to the network.
- Nbn is working with all Disaster Districts to secure a representative/liaison officer to the DDMG across all stages of the prevention, preparedness, response and recovery (PPRR) disaster management approach.

- Commercial arrangements are in place to access generators where internal redundancy is not in place or has failed.
- Field crews are trained to manage these events, but capacity is likely to be the key issue. Restoration of supply times is challenging to evaluate, with the response to the event dependent on the ability for field crews to safely access sites and scale of impact.
- Nbn will seek assistance with access to sites (escorts into exclusion zones, assistance with clearing access tracks in extreme circumstances) and will look to LDMGs to provide any intelligence they have about access generally (e.g. road closures) and any flood or other modelling that may be available to help Nbn manage resources.
- Nbn is seeking LDMGs' input into the areas that need to be prioritised for service restoration so Nbn can build that into network restoration plans.

Other considerations

- Key messaging is distributed to ABC Radio and other local radio stations as a redundancy to key messaging broadcast via social media.
- Other disaster management group aligned agencies (e.g. Department of Transport and Main Roads, Ergon, Queensland Rail) have good redundancy of communications across HF, VHF and Sat-Comms (weather dependent). This allows communications across the district and LGAs.
- While towers dedicated to hosting emergency services radio networks are themselves unlikely to topple, attached antennae and point to point communication dishes are highly vulnerable. Loss of power and failure in redundancy will compound vulnerability and hinder emergency services' ability to communicate.
- Emergency services HF and Sat PTT Satellite Radio are the key redundancies if the communications network goes down. Vehicles that can act as repeaters are distributed throughout the regions. Communications can then be relayed through other means (e.g. landline phones) in extremis.
- Council and BoM own and operate sensors that relay river levels and rainfall to inform operations (e.g. rainfall gauges and water level gauges) Failure of power and communications network will have significant impacts on this infrastructure and conversely operational planning and response.

6.1.1.5 Water supply and wastewater services

- Water supply services can be interrupted post cyclone impact and during associated flooding events through multiple scenarios including isolation of pump stations and treatment plants, volume of green debris and turbidity issues, damaged pipelines and extended power outages. It is likely that this will affect the supply and treatment of water to communities across the short to medium term.
- Water supply measures in rural areas (i.e. water tanks) are highly vulnerable to high winds. Poorly secured water tanks can present significant risks to surrounding structures as they can easily become a major component of wind driven debris.
- Extreme stress on the wastewater treatment network through high rainfall & flash flooding is likely to lead to untreated outflows across LGAs. Contamination of drinking water supply is a possibility through sewerage overflows. There are many examples across Queensland of inundation of treatment plants resulting in raw sewerage entering waterways during past events.
- In relation to events such as ex-TC Oswald and TCs Larry or Yasi, key areas of concern were isolation of treatment plants, access to equipment, and loss of power and communications to plant supervisory control and data acquisition (SCADA) systems to determine the efficacy of schemes during an event.

6.1.1.6 Risk treatments and controls

- Water service providers (WSPs), where not managed by local government, will have set mitigation, response and redundancy measures regarding continuation of supply in the event of power outages and contamination.
- Response and recovery measures for loss of supply in rural areas, where access is constrained, should always be considered.

6.1.1.7 Fuel infrastructure

- Local governments will often hold a limited supply of fuel at council depots that could maintain operations across the LGA at BAU levels for ~24 to 48 hours. However, in the event of broad area impact from a severe TC and flooding, it is likely that avenues of resupply will be cut limiting the ability to transport, distribute and resupply sites of need (e.g. generators at pumping stations). Localised power outages may also hamper the ability for these locations to operate.
- It has been noted that, as with the supply of additional generators, fuel supply in previous disruption related events has been controlled by critical infrastructure owners and operators across the affected regions (especially those areas where mining or heavy industries are located). This can significantly impact the availability of additional redundancy in the event of broad scale power outages.
- If service stations are impacted by power outages or lack of resupply of fuel through isolation, then emergency services vehicles and other vehicles associated with response and recovery may need to access local government supplies. Adequacy of fuel reserves in the lead up to an event is often cited as a key issue in response and recovery with demand outstripping supply.

6.1.1.8 Risk treatments and controls

- Resupply sub-plans to Local or District Disaster Management Plans should be stress tested to understand their effectiveness in extreme events and map any capability or capacity gaps. Linking this with a broad scale redundancy exercise, facilitated by Energy Queensland and across all levels of Queensland's disaster management arrangements would be beneficial.
- All local governments', districts' and regions' plans would be strengthened by addressing the prospect that there could be no resupply of fuel for the first 72 hours post impact.
- Memorandums of Understanding with local fuel suppliers (e.g. service stations) to isolate supply for council and emergency services vehicles/generators in the event of widespread power outages have proven effective in previous events.

6.1.1.9 Transport infrastructure – road, rail, air and maritime

- Physical infrastructure of the transport network (e.g. stations, hubs, depots) will likely suffer a varying level of impact dependent on age, location and type of construction. Non-hardened infrastructure associated with bus and light rail stops, such as glass shelters, poles and signage, will likely suffer significant damage and add considerably to the potential for wind-driven debris.
- Networks will be suspended in the lead up to impact and will only resume if conditions meet OHS/WHS minimum standards (within operator guidelines).
- Aerodrome infrastructure (e.g. hangers and communications infrastructure) are likely to be impacted by severe cyclonic winds (>Category 3 sustained) and possible inundation from any resulting major rainfall and flooding event. Dependencies on power and communications are likely to increase vulnerability.
- Isolation of airports, aerodromes and airfields due to flooding of the surrounding road networks and the associated impact on resupply operations to communities and critical infrastructure during an event is also of note.
- Notices to Airmen (NOTAMs) prohibiting movement of aircraft are likely to be in place for some days post the impact of a severe TC within an area. The NOTAM in place post TC Debbie, 2017 persisted for two days and grounded all commercial, medical (i.e. Royal Flying Doctors) and defence aircraft.

6.1.2 Access and Resupply

6.1.2.1 State and local road network

- State and local road *are* after networks to be affected by an event across the short term. Disruption should be expected to last days as a result of impact from flash flooding of creek systems, green debris and landslips, fallen powerlines, and scour damage to roads from fast moving flood waters.
- Road networks near coastal areas are highly vulnerable to scour damage through storm surges impact, with the potential to measurably affect access & resupply as well as any potential necessary evacuations.

Figure 113: Serious damage around Sarina Range due to landslips from ex-TC Debbie. Source: Loretta MacGregor

- The potential for significant debris loads in rivers may result in impacts to state and local bridges requiring closure until inspection can deem the structure safe for use.
- Historically, such as ex-TC Debbie, there were long-term impacts to local connector routes and bridges that prevented direct access into some communities for >12 months.
- Resupply of supermarkets & petrol stations is likely to be measurably affected thereby impacting the supply of key essentials to communities at large.

6.1.2.2 Transport networks (bus and rail)

- Expect short to medium term disruption across the transport network (bus, light rail, rail networks) dependent on the level of impact to power, communications and potential loss of access. Interruption of service to the bus and light rail networks should also be expected in the event of flooding.
- Heavy rail has historically high levels of resilience, but rail lines can be impacted by scour damage through fast flowing flood waters/overland flow. Services will cease when winds reach ~90km/h and not resume until inspection of the network has been completed.

6.1.2.3 Maritime

- Marine and beach infrastructure (such as pontoons, jetties, revetment walls along the canals) is likely to be affected. Marinas can channel storm tide exacerbating potential impact to associated infrastructure. As an example, there are approximately 700km of canals in Gold Coast – failure or loss of canal revetment walls will likely result in significant damage to property.
- Vessels that have broken their moorings may present both navigational and contamination issues, with the clean-up and recovery of stricken or sunken vessels requiring significant capacity over a protracted period.
- Debris within the river system is likely to cause additional damage and flooding through narrowing or blockage of channels.
- Port infrastructure is highly vulnerable to storm tide and fast outflows from rivers and estuaries with a significant debris load. Resupply via sea in the event of impact and infrastructure failure would be extremely difficult without temporary repairs.

6.1.2.4 Aerial transport

- Helicopter and airline transport is highly likely to affected by high winds, low visibility and damage to and/or closure of infrastructure. This is likely to lead to disruption of response & rescue services and civilian transport. Given that resupply and evacuation operations, via designated and emergency landing-zones, is critical during the response and recovery phase, it is essential that the infrastructure associated with this means of transport is restored, or redundancies brought online, as soon as possible.

6.1.2.5 Risk treatments and controls

- DTMR operates the 13 19 40 system of pre-event warnings and event closures to inform local governments and the community.
- There are a number of alternative access routes and methods that would mitigate access issues to affected areas if the major road routes are significantly impacted or rail, air services and water transport is disrupted.
- It would be highly unlikely for all resupply avenues to be impacted at the same time although this cannot be discounted in the event of major regional or state-wide impact as was observed during TC Debbie, 2017.
- Local governments are the stewards of the local road network. Survey and clearance operations are conducted by council workforce. Roads are reopened in consultation with DTMR. However, access across creeks and rivers will only be possible once DTMR inspection has been completed. Prioritisation is dependent on level of regional impact.
- For state roads, rapid damage assessments and surveying to assess impact, damage and whether the road can be opened to essential traffic as soon as practicable is undertaken by DTMR engineers only.
- It is likely that an event of this magnitude will impact the road network in other areas due to catchment wide flooding as was observed during TC Debbie, 2017. Extended disruption periods and further disruption to access and resupply should be anticipated as DTMR is likely to prioritise major access routes, regional centres and industrial/commercial hubs before smaller and outlying communities. This could contribute to the isolation of these communities for some time.
- Individuals and communities in areas affected by cyclones should be instructed to stay off the road network for as long as practicable to allow emergency services and other responding agencies and personnel to conduct their jobs as quickly as possible. These instructions, given prior to and immediately after the event, can significantly minimise any potential delays to restoration and recovery efforts due to other vehicles on the road.

6.1.2.6 Evacuation management

- In the event of direct forecast impact from a tropical cyclone with a likelihood of additional storm surge impact, there may be a requirement for the directed evacuation of residents from coastal areas to temporary shelter outside of forecast impact zone. In some scenarios, this may see tens to hundreds of thousands of people being directed to shelter locations a significant distance inland. This scenario has a higher likelihood of occurrence in southern or South East Queensland (i.e. in Wind Region B) where the population is not used to cyclone impact and the building stock is not suited to shelter in place orders.
- The possibility of mass panic arising in a population not familiar with potential cyclone impacts should be considered in planning. Evacuations requiring a mass egress of residents using the road network will likely increase the potential for major traffic incidents, diverting resources from evacuation management. Clear and consistent messaging both in terms of the impending event and traffic conditions may help to mitigate this issue.
- Analysis of evacuation management arrangements across the state have shown that most LDMGs and DDMGs, supported by relevant state entities and NGOs (e.g. Red Cross), would have the capability to coordinate and manage moderate scale evacuations where this is deemed a necessary action.
- However, most guidance currently provided for evacuation is concerned with predicted storm tide and levels of possible inundation, not wind. Storm-tide evacuation zones have been mapped across much of the state and are publicly accessible through council websites or disaster dashboards.
- Most LDMGs advise the public to only consider evacuating for wind if they live in a pre-1980s home or feel concerned for their safety. Advice provided for those who choose to evacuate is to always go to family, friends or colleagues outside threatened areas.
- Where evacuation centres and public cyclone shelters are available, they are deemed as places of last resort, with LDMGs electing to open them only when necessary. The use of these facilities is largely reserved for vulnerable residents (such as the elderly without family in the region, the disabled, or those in storm tide areas that cannot evacuate to family and friends).
- Direct impact to a major population centre from a severe category tropical cyclone has not been seen since 1971 with the impact of TC Althea. Such events, if they were to occur today, may overwhelm Local and District preparation and response

arrangements. Planning should consider the potential of managing a mass evacuation and/or impact to a significant population centre. State and Commonwealth agencies would be requested to assist with managing extreme events of the magnitude explored within this project.

6.1.3 Community and social

6.1.3.1 Demographics and vulnerable persons

- People who have moved to the regions within the past five years and may be less likely than longer-term residents to understand the regional hazard profile or take preparatory action.
- In terms of proportion of the population, expect higher levels of impact to vulnerable persons (e.g. elderly, those with a disability, homeless persons, pregnant women, and those with chronic illnesses or those awaiting urgent treatment) from loss of power, telecommunications and isolation.

  Current treatment strategies outline that self-evacuation prior to impact is relied upon as the measure to prevent impact to vulnerable populations with access to evacuation centres or places of refuge a last resort option.

- Across many communities there are large numbers of those above the age of 65 who are not in aged care facilities but are receiving care at home via at home service providers. The same is true of those with a disability who are registered under the National Disability Insurance Scheme (NDIS). The NDIS outlines that service providers do not have a mandated duty of care in the event of a disaster or emergency with emergency services listed as first responders for any and all emergency situations.

  Current strategies involve the coordination of communications out from Queensland Health Hospital and Health Services (HHSs) to those service providers and recirculated by the LDMG where possible.
- Inconsistent messaging regarding impending disaster impact causes confusion. Provision of services and advice to people by multiple agencies can result in them being contacted numerous times, sometimes with conflicting information.
- Social isolation of vulnerable people also presents issues within the community. Some vulnerable people may not understand cyclone risk and may not be informed of support services available. Cultural and linguistic barriers can also exist which increases social isolation and vulnerability to all-hazards.
- Where individual preparedness actions have been insufficient to mitigate impact, the provision of key pharmaceuticals and supply of power and clean water (e.g. for at home dialysis), care of medically dependent persons can require extensive resources from burden on HHSs, emergency services, and LDMGs to manage during response and recovery phases.
- Privacy concerns can make it challenging for governments and support agencies to identify people who require redundant power, water or oxygen to maintain life support systems.
- Retirement and lifestyle communities are not required to meet the same design standard as formal aged care facilities. These communities may not have the same level of preparedness as formal aged care facilities (public and private). As a result, the level of vulnerability of the infrastructure associated with these communities, and their residents, may be much higher than those within formal aged care facilities or those managed by regulated aged care services.
- Advice from stakeholders across Queensland suggests that those who have moved to Queensland from areas with different climates may be at greater risk during disasters. This may increase further for residents and tourists whose comprehension of English language is low.
- Aboriginal and Torres Strait Islander communities are generally more vulnerable during disasters due to a lower state of preparedness and health relative to the wider community.
- Tourists to Queensland may not be prepared for extreme weather events and climatic conditions in the State. While disasters affect all people, residents are more likely to be accustomed to be more accustomed to and better prepared for disaster events.

6.1.3.2 Social infrastructure

- While school infrastructure is built to Importance Level (IL) 3 (1:1000) versus residential structures built to IL2 (1:500), it is important to note that regardless of differences in importance levels, many essential buildings will not be able to remain fully functional post impact. Elements such as wind-driven rain via aspects of the building envelope (e.g. flashings and windows), and disruption to power, water and telecommunications may result in the building being in a non-operational or impaired state. Areas prone to flash and riverine flooding as well as storm tide risk will likely see higher levels of impact.

- Region wide school closures in the event of a severe cyclone warning should be expected across the short term. This is likely to extend into the medium term where school infrastructure has been significantly impacted. Department of Education must certify that schools are fit to reopen. If there is widespread damage across multiple regions where repair and rebuild activities are required, this may also delay community recovery efforts due to the schools being closed. It is worth noting that due to the higher levels of structural resilience, many schools in Queensland have a secondary role as shelters or places of refuge.
- Community centres, and sporting and social clubs, which act as hubs for community activity or provide support services may suffer similar levels of impact as has been modelled for residential buildings. The age and level of maintenance of these structures tends to be highly variable and can suffer significant damage from sustained destructive winds, major flooding and heavy rainfall. Exposure of asbestos (where present) within these buildings would lead to closures until resolved. Consequentially, these facilities may remain in a non-operational state across the medium term.

6.1.4 Medical and public health

6.1.4.1 Hospitals

- Manifestation of an event of the magnitude explored within this study would likely trigger evacuations of local hospitals to other regional hospitals outside of the forecasted impact area. During Cyclone Yasi, 2011, a Code Brown (an Australian disaster category signifying an external emergency) was declared in a number of South East Queensland hospitals. The two tertiary hospitals in Brisbane (The Royal Brisbane and Women's Hospital with 1,000 beds and The Princess Alexandra Hospital with 700 beds) were planned to accommodate approximately 100 patients each by enacting internal disaster plans. Nine hospitals, both private and public, were organised to receive (and did receive) patients from Cairns.

  Queensland Health disaster management guidelines mandate that all health facilities are required to have plans for evacuation of their facility and establishment of alternative care facilities. Health facilities that are geographically isolated are required to consider long-distance evacuation in their planning arrangements, while HHSs are responsible for establishing pre-standing arrangements to manage the evacuation of these facilities and reception of patients elsewhere. Hospitals also need to identify facilities that may be used as a temporary medical facility, if the major facility is closed.
- A tropical cyclone is likely to impact the availability of health professionals and personnel from supporting agencies due to the closure of access routes and the likelihood of these people being personally impacted by the event (e.g. school closures, damaged homes).

  All health managers include an estimated time of arrival to usual place of work within business continuity plans but include a back-up location if prevented from reaching that location. Managers will also forward load key personnel to likely places of impact or surge demand prior to the event.

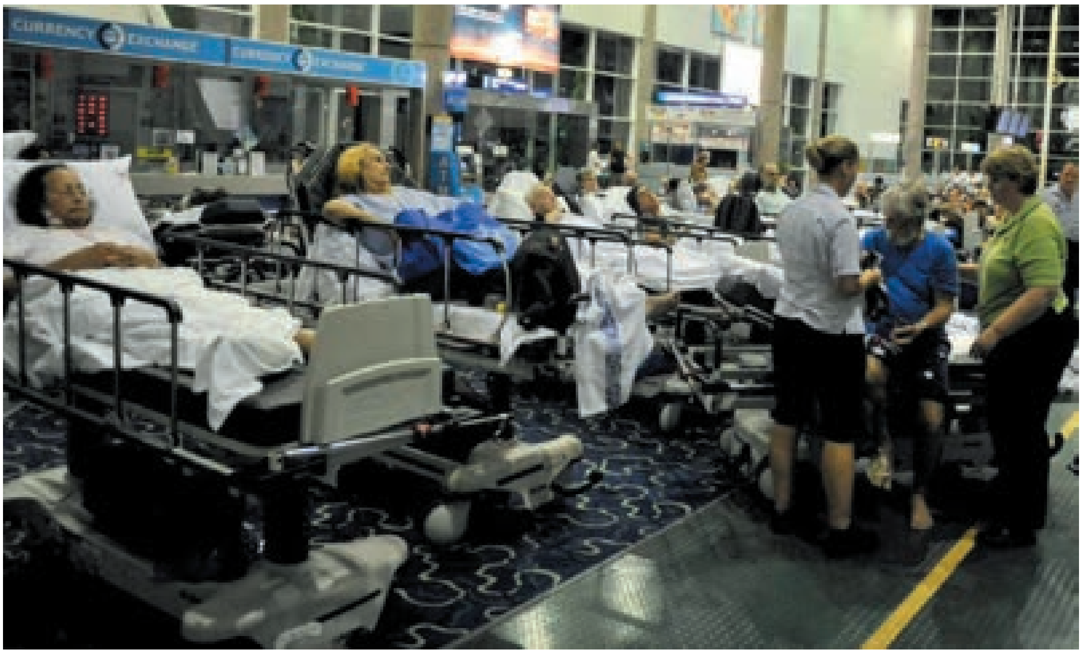


Figure 114: Hospital patients wait in the international terminal building at Cairns Airport before being loaded onto RAAF C-17 and C-130 aircraft and evacuated to Brisbane ahead of Cyclone Yasi on February 2, 2011. Source: Paul Crock (AFP)

- While hospital infrastructure must be built to IL4 (1:2000) many hospitals have been built in stages over several decades and therefore resilience to sustained destructive winds and heavy rainfall will not be uniform. Many HHSs have undertaken an evaluation of their infrastructure through the Hospital Safety Index Project and therefore understand what locations, if any, may be impacted. It is important to note that this evaluation only applies to public health infrastructure, and private health infrastructure may not be as resilient.
- Most hospitals in Queensland operate with ›24 hours of redundant power and water. There are different processes across the state in how the state in how resupply (of fuel and water) would be managed in the event of prolonged outages and other broadscale regional impacts.
- Pre-planning for potential critical infrastructure failure – particularly power and water – may warrant consideration for early evacuation of critical patients e.g. ventilated and haemodialysis dependent patients, and those with existing chronic respiratory conditions.

6.1.4.2 Aged care facilities

- Historically, aged care facilities and services, together with their residents, have experienced significant impact with incidences of poor telecommunications and therefore messaging, issues with consumable supply chains and, in extremis, full evacuation of sites for the safety of staff and residents. Most of these issues have resulted from limited business continuity planning with respect to natural hazards and can be resolved through development of better preparation and response measures within the aged care sector.
- Evacuation of vulnerable persons at short notice can lead to significant problems in terms of coordination and control and may exacerbate pre-existing conditions leading to, in extreme cases, premature death as a result of movement away from stable conditions.

6.1.4.3 Public and mental health

- In addition to direct effects on individuals, cyclones create additional risks to health due to damage to power infrastructure. Backup power for hospitals and aged care facilities may not be reliable during the response and recovery phases due to a range of factors including precursor events or system faults.
- Loss of power results in a loss of refrigeration of food, increasing the risk of food-borne illness if not effectively managed. Hot weather also increases the risk of food-borne disease due to stresses in food production, particularly for chicken and eggs. Salmonella outbreaks are more common in hot months. These risks can be mitigated through more careful food handling practices.
- Loss of refrigeration can cause damage to certain medicines, such as insulin and vaccines, reducing their efficacy.
- Loss of power can also result in the shutdown of water treatment plants and, depending on the availability of reserves in the system, may require the issuing of boil water notices. These risks will be managed by drinking water providers. Sewerage pumps may also cease to operate, leading to sewage overflows into the environment which may require advice to the community to avoid at risk areas.

Figure 115: Australian Army personnel help evacuate residents on February 1, 2011, from the Garden Settlement Retirement Village in Townsville in north Queensland in preparation for TC Yasi. Source: Stewart McLean (AAP)

- There is ongoing concern relating to people entering flood waters and handling or becoming exposed to dangerous material/debris. There is a higher prevalence of waterborne diseases and Dengue Fever post event impact, an outbreak of which would pose a significant challenge for HHSs already managing a significant community recovery effort.
- A misconception about disaster resilience in regional and remote communities (i.e. "we're tough out here"; "we look after ourselves") can hamper efforts by the disaster management groups to reduce mental health impacts. Events such as tropical cyclones may intensify pre-existing mental health conditions at an individual level or lead to conditions such as post-traumatic stress disorder (PTSD). Recent studies by Geoscience Australia have demonstrated that of those directly impacted by disasters, >25% experienced moderate to severe psychological distress as a direct result of the disaster.
- People may be required to stay with family, friends or in temporary public housing for an extended period after the hazard impact when their homes have become uninhabitable or isolated, or the local environment has been rendered unsafe to be reoccupied. This type of accommodation would be required after a destructive cyclone and the subsequent widespread failure of major infrastructure elements such as water and power supply. Such prolonged recovery at an individual and community level can increase the likelihood of PTSD and mental health issues.
- Increased hardship due to financial or economic impacts at a local and regional level (loss of property, employment and support services) may further affect the mental health of individuals within an affected community.
- Heatwaves are not often considered in the same context as other severe weather events such as tropical cyclones. However, observations of the climatic conditions in the aftermath of events such as TC Yasi, 2011, ex-TC Oswald, 2013 and TC Marcia in 2015 have shown that extreme heat events have occurred within the regions on the western or northern side of tropical cyclones. Accordingly, this can make an already extreme situation even worse.
- For example, Cardwell's hottest night on record occurred on 28 March 2017 during the approach of severe TC Debbie to coastal areas further south. As cyclones traverse the state, they can generate the conditions necessary for severe and extreme heatwaves across a broad area. This is explored further within the Queensland State Heatwave Risk Assessment through an in-depth case study on the impact to the Rockhampton and Gladstone regions following TC Marcia. While this link between cyclones and heatwaves may have been present throughout history, the study of this phenomenon is only relatively recent.

6.1.4 Environment

6.1.4.1 Marine ecology

- TCs cause significant perturbations in marine ecosystems, including coral reefs. Not only coral cover, but also the abundances of fish and other coral-associated organisms that depend on structurally complex habitat may decline when reef structures are flattened. The ecological effects of storms on coral reefs can have legacies of years to centuries.
- Any flooding associated with a severe wind event can wash pollutants into marine waters, damaging coral reefs and other ecosystems.
- However, notably, any rains and floods associated with severe wind events, can mitigate the threat of above average sea-surface temperatures and marine heatwaves, and associated elevated risk of coral bleaching and other damage to marine species and ecosystems. Indeed, increased rain and associated cloud cover can provide shading over the coral reefs, cooling water temperatures.

6.1.4.2 Riparian ecology

- Storms may cause massive changes to coastal environments, particularly on sedimentary shorelines, often causing the translocation of sediment from the beach and dunes, and the landwards movement of the coastline. These large habitat changes are usually accompanied by impacts to faunal assemblages, best documented for benthic invertebrates, seagrass meadows and algal communities.
- Higher wave energy during storms may translocate and disperse large sediment volumes. As such, habitat heterogeneity (i.e. the spatial variation in seafloor properties) can be reduced after storms, which can lower the variability in faunal species composition at sites.
- Disturbance caused by storms can detrimentally affect populations of benthic species. Accordingly, storms can lower species' richness and abundance, and biomass of invertebrates.
- Floodwaters associated with severe weather events also have a role in dispersing weed propagules.

6.1.4.3 Terrestrial ecology

- TCs are significant natural disturbance phenomena for forest ecosystems, such as those in the Wet Tropics of north east Australia, especially for forests adjacent to the coast.
- Fragmented forests within the Wet Tropics (located within either an agricultural, urban, linear infrastructure or non-woody matrix) are particularly vulnerable to impacts of TCs and their associated strong winds, largely due to their high forest edge to area ratios.
- Cyclonic disturbance, alongside potential positive impacts for biodiversity, promotes the risk of forest fires and the spread of invasive species, including soil pathogens, weeds and feral animals, especially in fragmented forests in otherwise cleared areas.
- In 2018, parts of the Wet Tropics rainforest, previously not considered vulnerable to fire, burnt for several days after a fire broke out in areas where the forest canopy had sustained damage from two previous TCs. Opportunistic vines that had grown into the cyclone-damaged canopy carried the fire from forest floor up into the tops of the trees, demonstrating the potential for complex compound effects of severe wind and TC events.
- When TCs (and other extreme events) displace or kill wildlife, the recovery can take many years. Research shows that populations of species can suffer dramatic declines or even completely disappear after an extreme event such as a TC. These populations include those of common species that play an important role in maintaining ecosystem integrity.
- Notably, alongside the many negative impacts, research indicates the possibility of a significant number of positive or neutral responses to extreme events. This is a reminder that natural disturbances from extreme events often play a crucial role in the natural dynamics of an ecosystem.
- Often it is invasive species that stand to benefit from extreme events, such as cyclones.
- Of all extreme weather events, cyclones are the most impactful for birds, fish, plants and reptiles (while mammals and amphibians were most responsive to other events such as drought).

6.1.4.4 Environmental risk analysis

- The shifting frequency, intensity, and/or behaviour of extreme weather events, such as cyclones, droughts and floods, is causing unpredictable and immediate changes to ecosystems and obstructing existing management efforts.
- Some of the negative responses that species can have to extreme events include dramatic population declines and even local population extinctions. For example, research shows that populations of lizard species have been wiped out due to cyclones.
- In fact, notwithstanding the potential negative impacts of any extreme event on any species, research has shown that birds, fish, plants and reptiles can tend to respond very negatively to cyclones (while mammals and amphibians can tend to be more negatively responsive to other events such as droughts).
- Indeed, species will respond, often negatively, to extreme events.
- However, cases of extreme events benefiting species, including threatened species, do occur, such as rainforest frogs becoming less susceptible to a fungal pathogen after cyclones reduced rainforest canopy cover.
- Sometimes species will respond neutrally or ambiguously with, for example, changes in diet or foraging behaviour, or changes in the types of species in an area. Some of these changes can be long-lasting.
- This highlights that natural disturbances from extreme events often play a crucial role in the natural dynamics of an ecosystem.

6.1.4.5 Risk treatments and controls

Prevention and mitigation

- A more resilient landscape has a better chance of withstanding cyclone impacts and recovering more quickly. Securing landscape resilience to cyclonic events in prone protected and other natural areas of Queensland is strengthened by natural resource management investments in the following areas:
  - landscape connectivity
  - river repair
  - protecting coastal assets
  - cyclone resilient farming and forestry
  - building community capacity
  - education for the future
  - mitigating climate change.

- The one failsafe option for helping species cope with extreme events is to retain high-quality and intact habitats, as these are the places where species are most resilient to exposure to intensifying extreme events. Intact habitats are contiguous areas of water or native vegetation that can span various altitudes, temperatures and rainfall patterns. These places can also act as important refuges for species that rely on long breaks between extreme events to recover.
- Where intact habitat protection is not possible, restoring land and seascapes can also help species to adapt to extreme events.
- Ecological restoration that helps species to adapt to extreme events can also benefit humans. For instance, coastal communities can use oyster reefs or seagrass beds to guard against flooding, which often accompanies severe wind and TC events.
- Identifying properties that determine resilience and recovery of ecosystems constitutes a research priority for sedimentary shorelines and beyond, given the knowledge gaps that exist.
- The functional consequences of altered storm regimes for coastal ecosystems are largely unknown, including the continued provision of ecosystem services such as coastal protection and fisheries. Thus, ongoing work should prioritise investigations of how ecological processes in coastal ecosystems respond to extreme events and which features may determine their resilience and recovery would be beneficial.

Preparedness

- Recognising the importance of planning for extreme events is essential for helping species cope with climate change. Building resilience to extreme events may also provide an opportunity to reduce the vulnerability of humans too.
- All levels of government, industry and local communities are under increasing pressure to plan for extreme climate events. Planning efforts can be strengthened when they address the important cultural, social, economic and ecological contributions of species and ecosystems.

Response

- Responses to environmental impacts in protected and other natural areas require cooperation, collaboration and coordination across government, business and community organisations.
- Disaster relief and recovery funding for critical natural asset repair (such as restoration, and ongoing management, of catchment, riparian, coastal and/or in-stream vegetation for demonstrated benefits in terms of wind, storm surge and/or flood protection) would be of benefit.

Recovery

- Identify and monitor actual and potential impacts on the environment and associated recovery operations and provide strategic advice to inform recovery efforts.
- Identify, advocate and pursue cross-sector recovery solutions that will achieve multiple objectives, including reducing future impacts on the environment by using natural safeguards and environmentally resilient design in the built environment.
- The Australian Government considers certain assets ineligible (other than in exceptional circumstances) for assistance under the Disaster Recovery Funding Arrangements (DRFA). This includes environmental asset clean up and restoration of natural vegetation (such as natural banks, waterways, rivers, beaches, forests, undeveloped public land) except where these relate to the immediate protection of an eligible public asset. In a similar vein, environmental initiatives are specified as ineligible for community recovery funding under the DRFA. As such, advocating for evidence-based reform of these arrangements is essential to ensuring environmental recovery is appropriately resourced at a national level.

Protecting the Great Barrier Reef – A Queensland Government Priority

6.2 Impacts of tropical cyclones on the Great Barrier Reef

Queensland's acclaimed natural environment and the substantial economic contribution that it provides must be sustained for future generations. Accordingly, the Queensland Government's priorities[19] include protecting the Great Barrier Reef and the significant benefits that it provides to Queensland's economy and communities. A 2017 Deloitte estimate suggests that the Great Barrier Reef has an economic, social and icon asset value of $56 billion. According to this estimate, it supports 64,000 jobs and contributes $6.4 billion to the Australian economy overall, with 33,000 Queensland jobs supported and $3.9 billion contributed to the Queensland economy in 2015-16 alone (Deloitte, 2017).

The reef is of special significance to Aboriginal peoples and Torres Strait peoples, with cultural sites on many of its islands and underwater. As the world's largest and most complex reef system and one of Australia's natural wonders, the reef is home to an extensive array of life including a number of rare and threatened species (Queensland Government, 2020). It was listed as a World Heritage Site in 1981.

Caused by unusually warm sea surface temperatures during the summer season, mass coral bleaching occurred on the reef in 2020, following consecutive years of bleaching in 2016 and 2017. The full extent of this event, and its effect on the ecosystem including coral-dependent fish, is under investigation. The unprecedented nature of three mass coral bleaching events within five years cannot be overstated. It confirms the urgency of ensuring the reef can be sustained as a living natural and cultural wonder of the world (Australian Government and Queensland Government, 2018). Intensifying climate change impacts are the most significant threat to the Great Barrier Reef.

The Queensland Government is implementing a range of local actions to enhance the reef's resilience and ability to recover from major disturbances, particularly addressing water quality, coastal development and marine park uses, and climate change.

The government is also supporting programs to model current and future severe wind and TC events. Cyclones were responsible for 48% of coral loss recorded by the Australian Institute of Marine Science's Long-term Monitoring Program between 1985 and 2012.[20] Between 2004 and 2018, 10 cyclones of Category 3 or greater crossed the Great Barrier Reef Marine Park. Impacts were most severe in the southern half of the region, causing significant damage to coral reef habitats.[20]

6.2.1 Recent impacts of TCs Yasi and Hamish

Research indicates that cyclonic winds and floodwaters can have severe impacts on coral reef ecosystems. Floodwaters entering the Great Barrier Reef can cause stress to inshore ecosystems through reduced salinity, increased turbidity and elevated concentrations of nutrients and agricultural chemicals. Prolonged exposure can lead to death in some species, especially sessile (attached) organisms such as corals and seagrasses. Corals and seagrasses provide essential habitat and food for many other species such as fish, turtles and dugong; their loss can have flow-on effects through the system.

TCs affect coral reefs in different ways. Cyclones cause exceptionally strong winds which generate powerful waves that crash onto shallow reef areas and create damaging turbulence in deeper areas. Flood plumes, caused by the intense rainfall that often accompanies cyclones, can expose large areas to stressful changes in water quality. Particularly intense and large cyclones, such as TC Yasi, can also cause destructive currents as huge amounts of water are driven by sustained winds and waves. Through the direct forces of waves and currents, and the impacts of sand and rubble tossed around by underwater turbulence, cyclones can cause extensive damage to corals and the underlying reef structure.

At reefs exposed to the full force of a cyclone, there can be near-complete destruction of the coral community and associated species, leaving a barren and pulverised reef substrate, as shown in Figure 116. For weaker cyclones, or at reefs further from the centre of intense cyclones, damage is generally less severe. Patches of reef may still be denuded by the cyclone's force, but these are usually outnumbered by the many patches of surviving coral.

Two examples, one of a westward travelling cyclone (TC Yasi, 2011) and one of a southward travelling cyclone (TC Hamish, 2009), are further discussed to highlight the potential for cyclones to cause significant and potentially devastating damage to the reef.

6.2.1.1 TC Yasi, 2011

The damage from TC Yasi's transit across the Great Barrier Reef was extensive. Coral damage was reported across an area of approximately 89,090km^2 of the Great Barrier Reef Marine Park. In total, approximately 15% of the total reef area in the marine park sustained some coral damage and 6% was severely damaged. Most of the damage occurred between Cairns and Townsville, as shown in Figure 117. Reefs beyond the northern limit of the destructive wind band (around Port Douglas) appear to have escaped severe damage, although tourism operators reported minor damage at some sites.

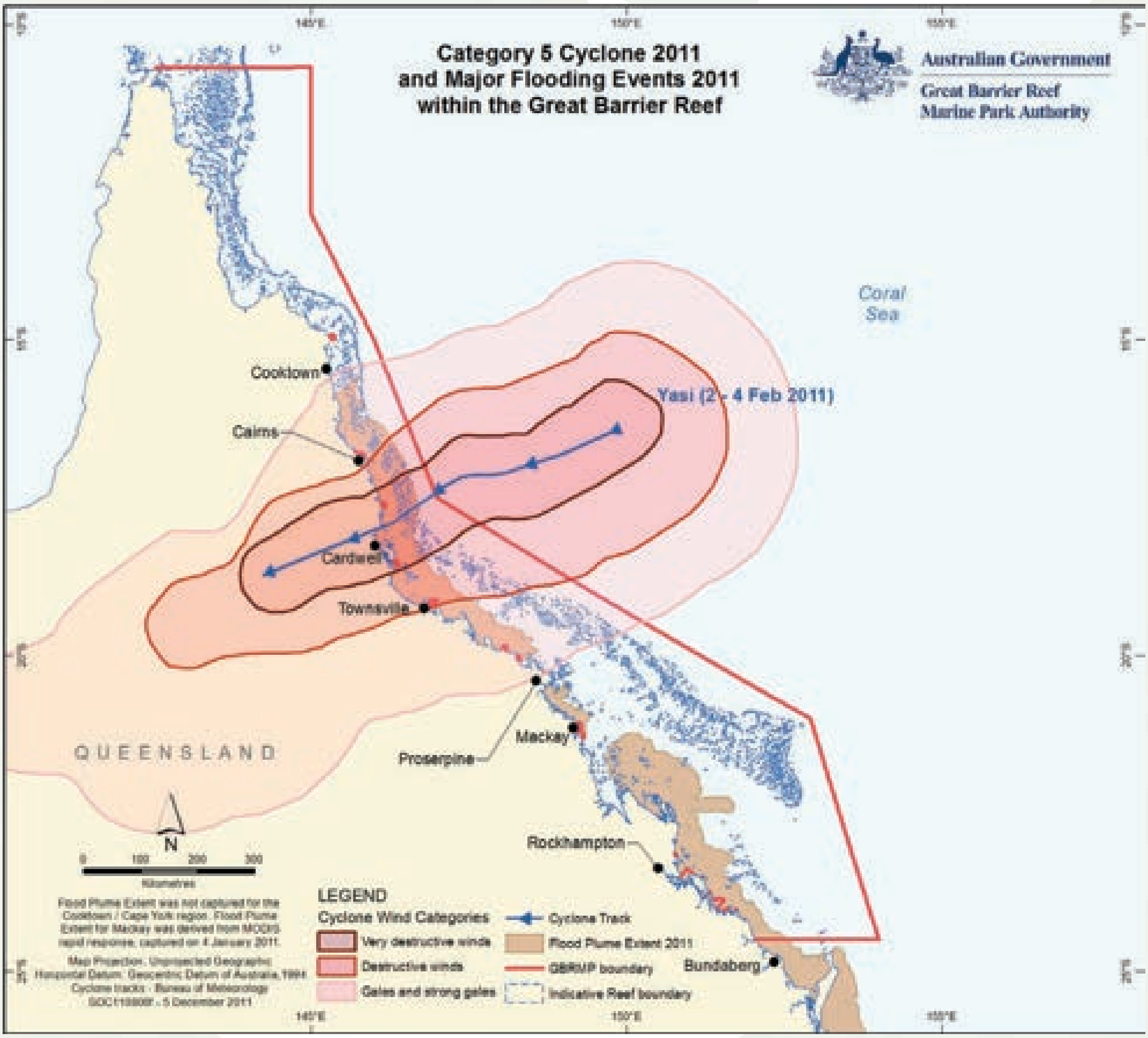


Figure 116: Map outlining the transit of TC Yasi, 2011 in relation to the extent of the Great Barrier Reef.

6.2.1.2 TC Hamish, 2009

Along TC Hamish's 500km track parallel to the Queensland coastline, the eye passed over a substantial portion of the Great Barrier Reef, resulting in some of the worst damage to the area in recent history. Unlike most cyclones which travel from east to west in the region, and impacting only a small area of the reef, Hamish moved alongside the reef for nearly its entire lifetime, as illustrated in Figure 118. The Bureau of Meteorology estimated that about one quarter of the area was impacted by the storm, with some parts being within 30km of Hamish's eye when it was a Category 5 cyclone.

According to post-storm surveys of the reef, the damage done to the coral was extensive, with upwards of 70% losses in the hardest hit spots. Nearly all of the exposed coral was destroyed by turbulent waters. However, in places where the coral was slightly sheltered, there was little to no damage. Some areas were completely stripped of all living tissues, leaving only bare limestone. According to the initial recovery estimates, it would take the reef between eight and 15 years to recover from Hamish if nothing hampers growth. However, recovery has been hampered by the three aforementioned bleaching events.

The Queensland Climate Adaptation Strategy (Q-CAS) and, under that strategy, the Emergency Management Sector Adaptation Plan for Queensland (EM-SAP) 2018[21] highlights that a healthy natural environment is fundamental to successful adaptation, providing critical ecosystem services and support for community wellbeing. It also highlights that adaptation should therefore avoid detrimental impacts on the natural environment, as part of the imperative to protect and enhance its health.

It is in this general context, and in the particular context of the importance of the Great Barrier Reef and its increasingly threatened status, that this assessment has considered the current, and (at Appendix C of Technical Report Two) projected, hazard posed by severe wind to the reef, alongside a brief general overview of the current and projected hazard posed to Queensland's natural environment.

Figure 117: There can be near complete destruction of coral communities at reefs exposed to the full force of a cyclone as shown in this photo taken on Myrmidon Reef in February 2011, post the impact of TC Yasi.

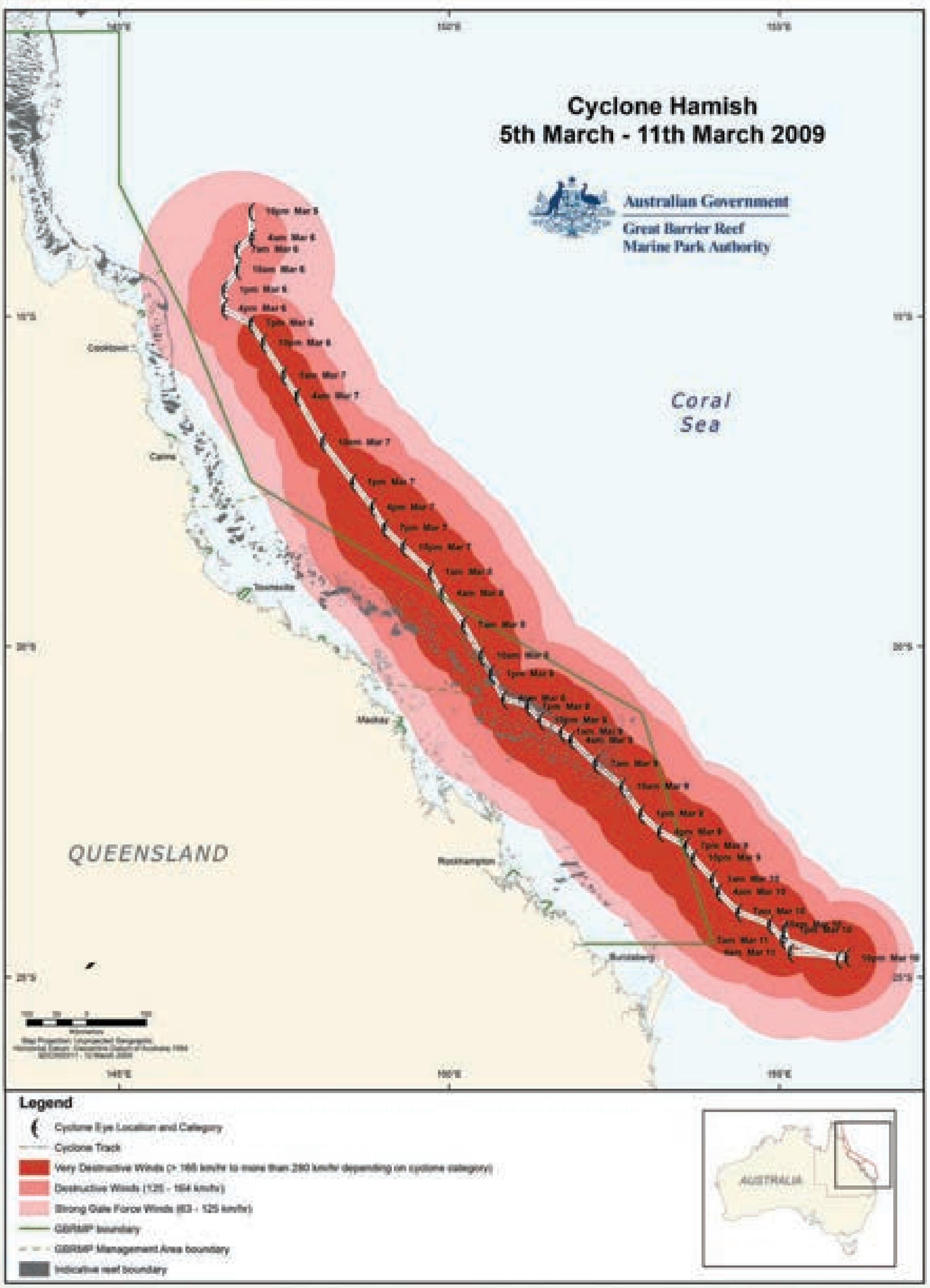


Figure 118: TC Hamish tracked parallel to the Queensland coastline for 500km, with the eye passing over a substantial portion of the Great Barrier Reef, resulting in some of the worst damage to the area in recent history.

7 IMPACT REDUCTION AND RISK MITIGATION

7 Impact reduction and risk mitigation

There is a misconception that because a house is built to the wind design standard that it will not be damaged by wind speeds at the design level.[23] The National Construction Code (NCC) establishes minimum acceptable requirements for buildings with a focus on life safety. It references standards that establish minimum design loads compatible with Annual Exceedance Probabilities set in the NCC and design and construction standards with factors of safety that will deliver minimum acceptable reliability presented in the NCC.

The intention is to protect occupants during a rare, relatively extreme event. However, it would be expected that houses may suffer some level of damage, while still providing a safe shelter for occupants through the design event. To this end, it is important that buildings are maintained to ensure they remain structurally sound after construction, and especially following significant wind events (Boughton et al., 2017).

The cyclone risk associated with a given building is related to its design, construction and maintenance, its exposure in terms of shielding, topography, proximity to the coast, its location in relation to a cyclonic region and the intensity and duration of the cyclone. The risk expressed in terms of loss covers both life safety aspects as well as loss due to damaged materials and non-structural aspects.

Case study: Establishment of design wind speeds for cyclonic regions of Australia

Prior to 1975, the design wind speeds for cyclonic regions across Australia were based on an extrapolation of available anemometer records from just a few decades of data (Melbourne, 1989). Figures 116 and 117 show the design wind speeds from the 1973 and 1983 versions of the Australian wind loading standard.

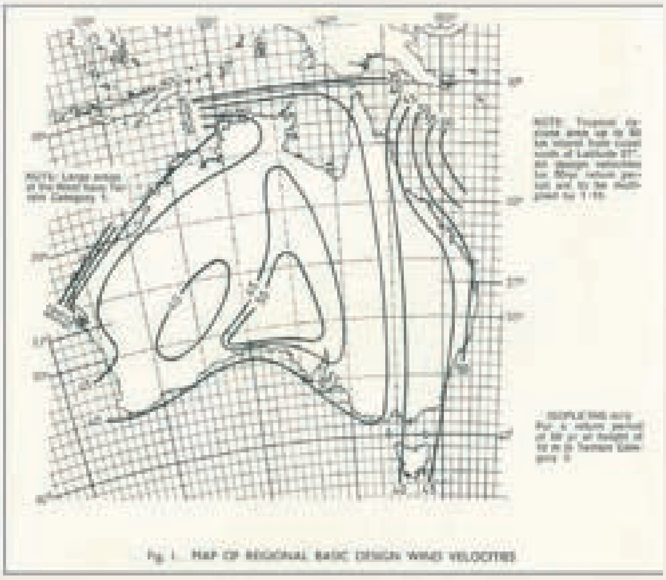


Figure 119: 50 year (permissible stress) design wind speed map in AS1170 Part 2-1973. Source: William Melbourne (Monash University), 1989 paper

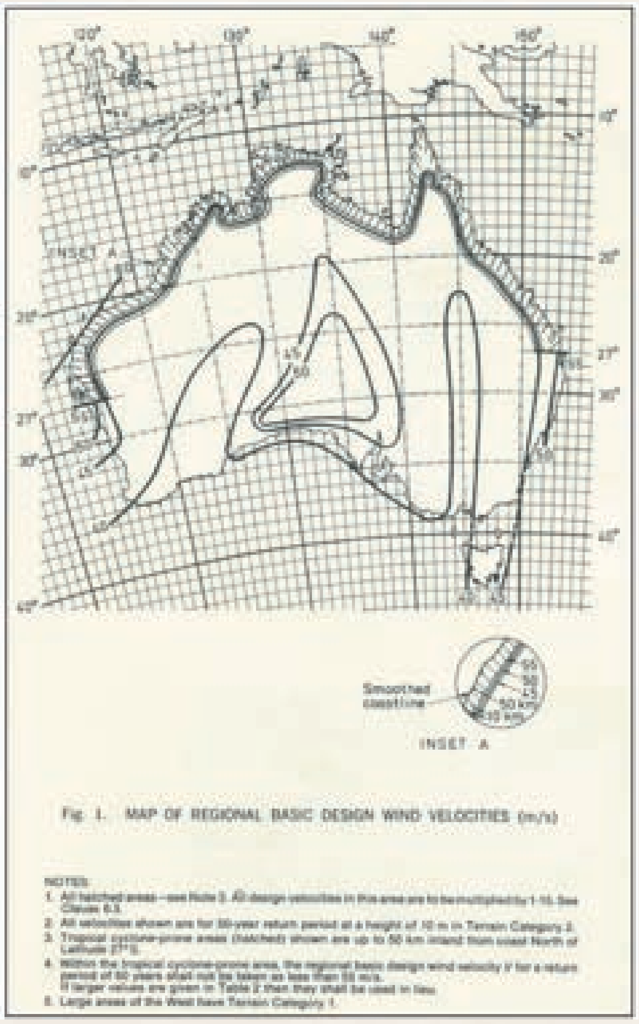


Figure 120: 50 year (permissible stress) design wind speed map in AS1170 Part 2-1983. Source: William Melbourne (Monash University), 1989 paper

Figure 121: The suburb of Alawa, after Cyclone Tracy hit - Christmas Day 1974

Due to the impact of Cyclone Tracy there was a large change in the building codes brought about by a significant increase in design wind speeds in the northern regions. To overcome the lack of observational data that would support such an increase in design wind speeds, Monte Carlo modelling was used to simulate more data points. The various Monte Carlo simulations and direct wind speed analysis gave a spread of results along the coastline but unfortunately led to the 1983 version overestimating the wind speeds (notwithstanding all the mentioned caveats) as shown in Figure 122.

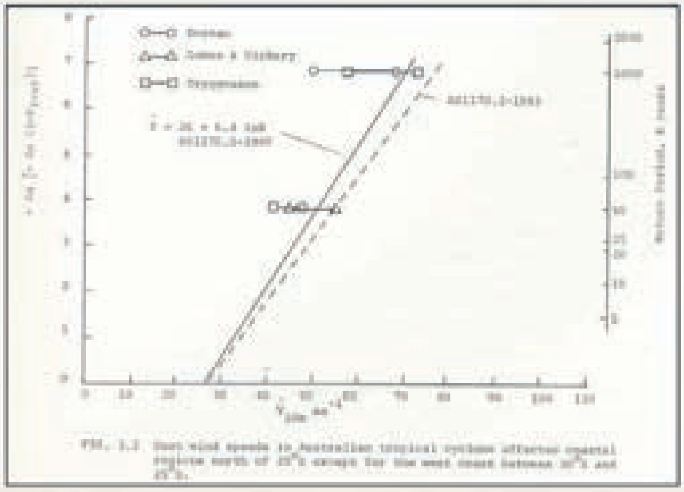


Figure 122: The 1983 to 1989 change (reduction) in design wind speeds for East coast of Australia plotted against the simulation outputs (Melbourne, 1989).

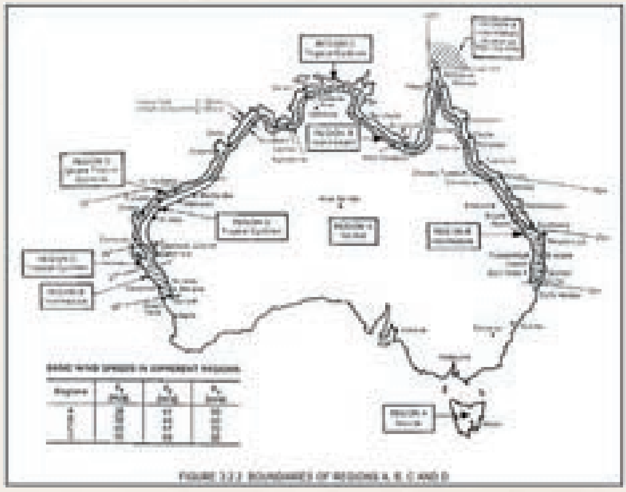


Figure 123: Design wind speed map in AS/NZS 1170.2:1989.

In his 1989 paper, William Melbourne of Monash University noted that there is “not a sudden step change in extreme wind speeds between tropical cyclone affected regions and the remainder”. The presented outputs of the Monte Carlo simulations highlighted the effect of tropical cyclones in the Brisbane region (27˚S to 30˚S). Melbourne documents, in his commentary on the wind standard, that a linear interpolation was recommended for the design wind speed from 25˚S to 30˚S (Region A). the NCC Standards Committee modified this to a halfway step change in wind speed which became Region B, as shown in Figure 123.

George Walker, in a 2010 revision of his 1980 paper, notes that following Cyclone Tracy there was a realisation that tropical cyclones are more akin to earthquakes than non-cyclonic events in terms of infrequent occurrence with a wide range of intensities and the capacity to engulf whole (and multiple) communities in a single event. He notes that in the development of the design wind speeds, there was a balance between the economic cost of protection and the social and economic cost of failure, where there is a degree of protection (e.g. depending on building type, location) for anticipated frequency, not guaranteed protection. Walker concluded that fundamental considerations in relation to cyclone resistant construction such as the acceptable degree of damage and the significance of community size can be expected to be the subject of continuing discussion and study which may have significant impacts on building regulations and practice in the future.

The various states and territories, via the Australian Building Codes Board (BCA), detail the societal risk for the ultimate limit state strength of a structure in the Building Code of Australia. The level of risk is evaluated depending on the location and type of structure. For example, a hospital has a higher level of importance (Level 3) that an isolated farm shed (Level 1). The BCA defines low rise residential construction as Importance Level 2. Figure 124 is an extract from the NCC Guide to the 2019 BCA, but no definitions of levels of impact or hazard are provided. However, with the great increases in population (houses) over the last 40 years in wind regions B and C, in making the broad assumptions of ‘Moderate’ hazard to life and ‘Substantial’ or ‘Extreme’ level of impact, an Importance Level of 3 for housing could be derived. This would have the added benefit of improving the design criteria to reduce wind driven rain.

Importance Levels must be assigned on a case by case basis.

Example

A hospital may be of Importance Level 4 if it is the only hospital in an area. The same hospital may be of Importance Level 3 if it is one of many in an area.

A general method for the determination of the Importance Level of any building is to assess the hazard to human life and the impact on the public in the event of building failure as follows:

Building Importance Levels

Hazard To human life	Impact on the public I (Low)	Impact on the public II (Moderate)	Impact on the public III (Substantial)	Impact on the public IV (Extreme)
A (Low)	Level 1	Level 2	Level 2	Level 3
B (Moderate)	Level 2	Level 2	Level 3	Level 3
C (Substantial)	Level 2	Level 3	Level 3	Level 4
D (Extreme)	Level 3	Level 3	Level 4	Level 4

The annual probability of exceedance varies with the type of action.

Example

Building failures due to earthquake or cyclone may be widespread and therefore have more impact on the public than say thunderstorms, that affect relatively smaller areas.

Figure 124: Extract from NCC 2019 Guide to BCA Volume One, p16.

Investigations conducted into previous cyclones demonstrate that houses built pre-1980s under perform and offer less protection compared to those houses built to post-1980s standards. However, although a house is built to prescribed standards, its continued performance is reliant on being maintained during its life to that code. Houses not originally built to current standards cannot be expected to perform to the current design levels, irrespective of the maintenance level. Even houses that are not damaged structurally can still be damaged by wind-driven rain. The only way to increase performance of these older residential buildings is to retrofit to modern standards. Additionally, modern houses still have failures due to weak points from windows and doors (Harwood et al., 2016). To reduce the impact of a cyclone on houses a number of treatment strategies are available, including:

- engineering
- maintenance
- community preparedness
- incentivisation.

These are further explored in section 7.1.

7.1 Prevention

7.1.1 Engineering solutions for improving resilience

Improved performance of housing can be achieved by focusing on good design and construction of new buildings and retrofitting of older buildings.

Australian Standards for design and construction of new houses provide a minimum acceptable level of construction. Additional resilience can be achieved by exceeding the minimum acceptable requirements. For example, homeowners can choose to build to a higher wind classification and improve the resilience of windows, cladding and building tie-downs and bracing. Houses with simple roof lines that require fewer flashings have improved resilience to wind-driven rain. Standards are continually being reviewed and revised to clarify requirements and ensure they remain up-to-date with evolving building technologies and community expectations.

Unless financial incentives are offered, major retrofitting to improve the resilience of houses to cyclones is not generally being widely implemented (Smith et al., 2016). This is due to several factors identified during previous studies and from discussions during this project:

- Although acknowledged as a way of reducing impacts from a major cyclone, the costs to conduct a full retrofit are often prohibitive when current insurance premiums were taken into account (Australian Competition and Consumer Commission, 2019). However, the recently implemented Queensland Government Household Resilience Program[24] has provided financial incentives, and in some cases, reduced the cost of structural upgrades.
- Major retrofits are less likely to be implemented on rented properties.
- The cost of undertaking retrofits or major maintenance work to improve resilience are not always recouped when selling a property.
- Some sectors of the community are not interested in undertaking mitigation options.

Based on these considerations, improvements in regular building maintenance and use of temporary window and door shutters are likely to have a greater uptake and at a lower cost. These observations and findings are consistent with other reports (Boughton and Falck, 2007; Boughton et al., 2017; Henderson et al., 2018).

Additions such as carports, patios, garages and awnings have all demonstrated the potential to cause damage to the house and other buildings should they become airborne in tropical cyclones (TCs) (Boughton, 1999; Henderson et al., 2006).

Research and other studies have shown that effective strategies to upgrade/retrofit existing houses include the following:

- Replace roofing and, at the same time, check and upgrade tie-downs throughout the roof structure. These structural improvements are particularly important in older houses or if the roofing material is changed, e.g. from tiles to sheet metal.
- Use an external tie-down system on a roof with cladding in good condition (e.g. over-battens).
- Replace older garage doors with doors that comply with AS/NZS 4505 and strengthen the supporting structure.
- Strengthen tie-downs and bracing in free-standing or attached structures such as roofed patios and carports.
- Protect windows and glass doors with permanent or temporary screens or shutters.
- Replace hollow core external swinging doors with solid core doors and robust door furniture.

7.1.1.1 Water ingress

During any TC, wind-driven rain can enter a house through weep holes, gaps around windows and doors, through worn seals on opening panes of windows and doors, over eaves, valley or box gutters, or through flashings. Investigations of damage to houses following TC Larry, TC Yasi, and TC Debbie (Boughton et al., 2017) indicated that damage to buildings from wind-driven rain was more widespread than structural damage. It can lead to loss of ceilings, damage to wall linings and floors, which involve extensive and expensive repairs and considerable inconvenience to occupiers.

For example, the James Cook University Cyclone Testing Station (CTS) report on damage to buildings during TC Debbie noted:

"Many occupants of newer buildings reported significant damage from wind-driven rain entering through windows and doors or under flashings even though there was no structural damage to the building." (Boughton et al., 2017)

Some of the recommendations from the CTS to minimise damage from wind-driven rain are relatively simple, low-cost treatments:

- fix flashings to roofs and walls in accordance with AS 1562.1
- replace worn window and door seals
- seal the top of valley gutters
- install overflows at both ends of box gutters
- install overflows in eaves gutters (minimum size 25mm to avoid blockage by leaf matter; note – slots in stamped eaves gutters are not sufficient)
- temporarily or permanently block gable and eaves vents
- cover weepholes with external rubber flaps or install internal one-way valves – alternatively, residents/occupants could tape plastic on the inside of the lower part of the window or glass door frame to catch water that has come through the weephole under wind pressure and hold it until the pressure drops and the water can return to the outside of the window.

7.1.2 Maintenance and retrofitting

A key factor identified from briefings and reviews of past events is that maintenance is an important, cost effective and efficient mitigation option. The majority of post cyclone reports for Western Australia and Queensland highlight that **most damage is occurring from a lack of simple maintenance tasks.**

For example, 86% of claims from one insurer arising from TC Larry and TC Yasi were for minor damage, with the majority preventable (Harwood et al., 2016; Smith et al., 2016). The findings from past reviews, briefings and the Queensland experience reinforces that *"maintenance is likely to be the most achievable impact reduction method"* (Harwood et al., 2016; Henderson et al., 2018; Smith et al., 2016). However, maintenance is only able to keep the performance level of the house close to its current level which may be inadequate (Boughton, pers. comm.).

Buildings deteriorate with age which can be accelerated by factors such as salt spray, moisture, rust and termites (Figure 125). As part of a maintenance program, the inspection and maintenance of structural elements within the roof space, steel bolts and screws, verandah posts and house stumps should be conducted for all buildings following any event with high wind loads, when replacing roof sheeting, or every seven to ten years (Boughton, 1999; Boughton et al., 2017). Where sub-standard building elements are identified, retrofitting should be undertaken. These inspections should be conducted by qualified builders, building surveyors or structural engineers (Boughton et al., 2017).

Figure 125: Examples of corroded battens and screws for properties near the coast. Source: CTS

The Queensland Department of Housing and Public Works has created and administered a successful grant program to assist in the retrofitting of older homes in cyclone regions to improve the houses' resilience. The grant details several mitigation strategies that vary in cost and effectiveness. The major strategy is to upgrade the connections within the roof and walls to improve the connection strengths to resist wind uplift. Another effective strategy is to have window shutters and strengthened doors to reduce the likelihood of a breach in the building envelope. This reduces wind driven debris entering the home and the chance of the interior of the building being pressurised, which increases the load the building has to resist.

The Queensland Building and Construction Commission (QBCC), CTS and Queensland Reconstruction Authority (QRA) provide online guidance. These resources form a key part of any reconstruction plan following a cyclone impact and as a preventative (mitigation) plan before cyclone season and when any major renovations are undertaken on a property.

7.1.2.1 Resources

Many people are not aware of the level of maintenance required to uphold or improve the resilience of their home. Following TC Larry, 2006 and TC Yasi, 2011, the QBCC, CTS and the Queensland Government produced a range of material to support household preparedness and resilience. These resources form a key part of any reconstruction plan following a cyclone impact and are an effective tool for a preventative (mitigation) plan before cyclone season and when any major renovations are undertaken on a property.

Of note are the following developed resources:

- In 2009, 'Cyclones… Is your home ready? A Homeowner's Guide' was prepared by CTS with support from the Northern Territory, Queensland and Western Australia Governments.
- In 2011, immediately post TC Yasi, QRA, with the assistance of the CTS, produced the guide: Planning for a stronger, more resilient North Queensland – Part 2 Wind resistant housing.
- CTS has produced a series of YouTube videos (5-10 minutes each) for both homeowners and builders to provide information on repairing cyclone damaged roofs. These videos can be found at: https://www.jcu.edu.au/cyclone-testing-station/videos-And-resources.
- QBCC also has important links to information on rebuilding after cyclones (such as the 'Repair Checklist' and 'Tiedown designs' PDFs) at http://www.qbcc.qld.gov.au/home-maintenance/rebuilding-after-natural-disaster.
- In 2019, QRA commissioned the CTS to update cyclone and storm tide resilient building guidance for new Queensland homes. These guides, along with the Flood Resilient Building Guidance for Queensland Homes are located at: https://www.qra.qld.gov.au/resilient-homes.

The Queensland Tropical Cyclone Preparedness Guide has been developed as a companion to this report, and seeks to update, distil, and further disseminate the information developed by the CTS in the material developed since 2009. This guide and further information on household disaster preparedness can be found at: www.getready.qld.gov.au

Finally, the ongoing education of builders, local government staff (building surveyors) and the trades/engineering/manufacturing industry around updates to codes, standards and practices would support appropriate ongoing maintenance (Henderson et al., 2018).

7.1.2.2 Essential government buildings

During cyclone response and recovery, it is critical that essential buildings remain fully functional. Essential buildings include Local Disaster Management Centres, emergency services facilities, local government centres (administration centres, works depots and welfare evacuation centres) and health facilities.

There is a mix of importance levels designated to emergency services buildings. For example, many emergency service buildings are designated Importance Level 2 rather than Importance Level 4 under the National Construction Code (Australian Building Codes Board, 2019), which mandates they are designed to a 1:500 rather than a 1:2000 annual exceedance probability for cyclonic wind. This is in part because of the ability to relocate emergency services personnel and equipment to alternative facilities. Buildings that house Incident Control Centres (ICCs) or regional headquarters generally play a key role in maintaining a community during the initial and short- to medium-term recovery phases and need to remain functional through the initial response phase, which places these facilities in Importance Level 4.

Regardless of differences in importance levels, many essential buildings will not be able to remain fully functional as elements such as wind-driven rain via aspects of the building envelope (e.g. flashings and windows) that are NCC compliant, and disruption to power, water and telecommunications may result in the building being in a non-operational or impaired state.

The argument to increase the importance levels could be made for many public and commercial buildings that provide essential services (e.g. petrol stations, groceries, pharmacy), especially for smaller or more remote communities where there is only one of those services. Of course, the increased costs of doing so, would remain a key consideration.

Queensland has dedicated public cyclone shelters which are multi-use buildings (recreation centres or community facilities) that can provide refuge during a severe TC. The requirements of shelters occupied after the cyclone (welfare centres) differ from the requirements for shelters occupied during the event. These shelters for use during a cyclone constitute important infrastructure that, if not appropriately designed and maintained, can result in injuries/loss of life to many (Department of Housing and Public Works, 2017).

Importance Level	Building types
1	Buildings or structures presenting a low degree of hazard to life and property in the case of failure
2	Buildings or structures not included in Importance Levels 1, 3 and 4
3	Buildings or structures that are designed to contain a large number of people
4	Buildings or structures that are essential to post-disaster recovery or associated with hazardous facilities

Table 22: Importance Levels of buildings and structures. Source: NCC, 2019

Importance Level	Annual probability of exceedance for non-cyclonic wind	Annual probability of exceedance for cyclonic wind	Annual probability of exceedance for earthquake
1	1:100	1:200	1:250
2	1:500	1:500	1:500
3	1:1000	1:1000	1:1000
4	1:2000	1:2000	1:1500

Table 23: Design events for safety. Source: NCC, 2019

Queensland developed the Design Guidelines for Australian Public Cyclone Shelters in 2002. These guidelines were reviewed by Western Australia, Northern Territory and Queensland Governments. They were subsequently endorsed by the Queensland State Disaster Management Group in 2006 (Department of Public Works, 2006) and are now supported by the 2018 *Queensland Public Cyclone Shelters Maintenance Guideline* (Department of Housing and Public Works, 2018).

The term 'cyclone shelter' has been inconsistently used to refer to buildings that do not meet the current Design Guidelines for Australian Public Cyclone Shelters. This can create public confusion and an unrealistic sense of security. There is a need to have a clear and consistently used definition of a cyclone shelter to help build community understanding and maintain confidence (Department of Housing and Public Works, 2017).

7.1.2.3 Debris management

The collection and securing of debris that can be potential missiles during a cyclone is essential for reducing the impact of a TC or storm (Figure 126 below). The impact of debris can disrupt the integrity of a house whether it is built to standard or not. It was found that one quarter of the insurance claims for TC Yasi could have been reduced or eliminated by removing debris (Smith and Henderson, 2016). Many local governments have some form of debris/footpath clean-up programs both pre- and post-cyclone.

Ideally, local governments or other entities could undertake inspections after pre-cyclone clean up campaigns and provide advice to property owners regarding items that could become dangerous debris. In some areas, legislative power may be available to address debris issues and gain access to conduct inspections. However, the capacity to undertake this may be a limitation.

Figure 126: Complete penetration through window during TC Yasi (inset shows missile).

Figure 127: Very large wind-borne debris and the house it hit in TC Yasi.

7.1.3 Community engagement

The tangible outcomes of this project can help the community to better understand and appreciate the impact of cyclones, especially community members who have never experienced a severe TC. Traditionally, community engagement has mostly focused on the hazard and warnings rather than vulnerabilities, impacts and mitigation options. Linking the vulnerabilities with impacts allows community members to identify mitigation options and understand the benefit of different mitigation measures.

One issue potentially hindering the community's understanding of TC impacts is a mistaken belief that they have experienced a severe cyclone – because at some point it was a Category 5 – when in fact the winds they experienced were actually Category 2-3 or less where it has impacted them: over time memories of severe TCs fade and complacency can set in (Pooley, 2005; Roberts et al., 2014).

7.1.4 Incentivisation

As has been noted in other research and reports, building owners are likely to only carry out mitigation if there is an incentive to do so (Australian Competition and Consumer Commission, 2019; Urbis, 2015). Besides reducing premiums and other incentives, there are additional factors that motivate property owners which are addressed in other areas of this chapter. At the time of writing, the Australian Competition and Consumer Commission (ACCC) concluded its *'Northern Australia Insurance Inquiry'* which sought to investigate the effectiveness of insurance in the region. The ACCC's report contained 38 recommendations to governments and industry but importantly for this study, the report confirms that insurance affordability is a key issue in North Queensland (ACCC, 2020).

The issue of insurance costs versus other economic drivers has been raised in many forums and solutions are required across all stakeholders including government, insurance, building and construction, and communities. For example, homeowners are discouraged from investing in mitigation activities when house prices are falling, upfront costs and insurance premiums are high (with no reduction for those mitigation activities), or they are renting. Recent reporting (ACCC, 2020) reinforces that by recognising *"the reduction of risk with a reduction in premiums individuals would be more encouraged to undertake mitigation"*. Stakeholders will be more likely to invest in mitigation and upgrades if risks can be quantified and related directly to the particular stakeholder's situation.

Mitigation option	Cost per household	Total benefit per household	Benefit-Cost Ratio	Payback period
Community awareness campaign	$55- $136	$440 - $820	3.2 - 14.8	1 -6 years
Opening protection - self installed (low cost scenario)	$1,660	$1,990 - $6,400	1.2 - 3.9	4 - 21 years
Roofing option - strapping only (low cost scenario)	$3,000	$12,900 - $38,800	4.3 - 12.9	2 - 4 years
Roofing option - over-batten system (medium cost scenario)	$12,000	$13,500 - $39,400	1.1 - 3.3	5 - 37 years

Table 24: *Benefit cost ratios for cyclone mitigation. Source: Hutley, 2015*

Three recent initiatives to incentivise homeowners are highlighted in the following case studies.

Case study: Suncorp Cyclone Resilience Benefit

In 2016, Suncorp launched its Cyclone Resilience Benefit (CRB), which it promotes as rewarding certain consumers in North Queensland with premium reductions of up to 20% for making their homes more cyclone resilient. The research underpinning the CRB was drawn from the James Cook University's Cyclone Testing Station. Suncorp also provides a cyclone resilience benefit to eligible properties in Northern Territory and north Western Australia.

For a property to be eligible to receive a CRB it must be north of the Tropic of Capricorn and within 100km of the coastline and meet the criteria of improved building features or cyclone mitigation measures present. The initiative rewards consumers that undertake any of the five mitigation measures which demonstrate a property's improved ability to withstand the impacts of cyclones. These measures relate to aspects of a home such as upgrading the roof, windows, doors, shed, as well as cyclone preparation in general (for example, moving unsecured outdoor furniture inside).

CRB has been designed to reward both customer behaviour as well as investment in structural improvements which strengthen homes against cyclones. Customers who report that they only carry out cyclone preparation activities around the home (such as trimming trees) and/or minor non-structural improvements qualify for the lower levels of the CRB and as a result receive only a small premium reduction. In order to qualify for the highest levels of the CRB, a customers' house must be built before 1980, have an upgraded roof and potentially upgrades to building openings such as windows and doors. Currently 18% of the more than 40,000 Suncorp customers who receive the CRB have reported these structural upgrades and are receiving an average reduction of $315 – which represents 13% of the average home insurance premium.

Case study: Queensland Government Household Resilience Program Grant Scheme

In 2018, the Queensland Government's Department of Housing and Public Works established a Household Resilience Program, targeting lower income property owners to undertake upgrades to houses to improve the structural resilience of their pre-1984 homes against cyclones. The Department worked with James Cook University's Cyclone Testing Station to enable a set of upgrade options. Eligible homeowners can apply to receive a state government grant to cover 75% of the cost of improvements (up to a maximum of $11,250 including GST). The program covers improvement options such as roof or garage door replacements, roof tie-down systems and general property maintenance.

As at November 2019, the Queensland Government had awarded 1,748 grants, with an average grant approval of $10,370. The Queensland Government estimates that works completed under the program have resulted in average insurance premium savings of 8.21%.

The Insurance Council of Australia has noted that the homes upgraded due to the Household Resilience Program were 63% less likely to suffer a total-loss, and insurers decreased premiums for these retrofitted homes by an average of around 10%.

In May 2020, the Queensland Government announced a $21.25 million expansion of the program, with $10 million provided by the Australian Government and $11.25 million additional funding from the Queensland Government.

In October 2020, the Royal Commission into the National Natural Disaster Arrangements recognised the Queensland Government's actions to incentivise mitigation citing the Household Resilience Program as a best practice example alongside other measures such as the Roma flood-levee and the Lockyer Valley voluntary land-swap post the 2011 Queensland floods.

Case study: RACQ's Cyclone Mitigation Discount

In 2016, RACQ launched a scheme offering premium discounts of up to 20% to certain consumers in north Queensland under its Cyclone Mitigation Discount program. Property owners in north Queensland may be eligible for RACQ insurance premium discounts if a home they own and/or live in has undergone work to reduce its risk of cyclone damage, for example:

- the installation of roofing options such as over batten systems and/or strapping
- the installation of opening protection
- a complete roof replacement or a complete retrofit to the current building code.

The offer of a premium discount to an eligible RACQ customer is subject to the structural changes made. In 2017-18, the average cyclone mitigation discount in Queensland was $350.00.

Case studies adapted from the Australian Competition and Consumer Commission's Northern Australia Insurance Inquiry, 2020.

7.2 Preparedness

7.2.1 Community preparedness

Members of the community can prepare for an approaching cyclone season by undertaking annual checks of the critical elements in their house and other structures on their property and undertake repairs or retrofits if necessary (similar in philosophy to checking the car before a long trip). These checks will highlight any issues that require maintenance. Undertaking annual checks and appropriate repairs will incrementally improve the resilience of their houses.

Homeowners/occupiers can use templates such as those available through the associated *Tropical Cyclone Preparedness Guide for Queensland* developed for this project to develop or refine their cyclone preparation plans for both preparation before the cyclone season and in the days immediately before an approaching cyclone.

A suitable plan to improve the resilience of houses and households will include:

- identify a place in the house to shelter and make sure it is prepared and accessible
- decide when to take down non-permanent structures e.g. shade sails
- trim overhanging trees
- clean up loose items from yard
- plan to evacuate early if located in a storm tide zone – people should not shelter in their home
- plan to fit temporary shutters or screens to windows and doors
- strategies for preparedness if away at the time preparations need to be made.

7.2.2 Risk assessments

The scenarios developed for this project and the respective impacts provide a more detailed insight for state, district and local risk assessments.

As an example, the City of Gold Coast used the Category 5 scenario for their risk assessment which formed part of the implementation of the QERMF Risk Management Process. The depth of information identifying the vulnerabilities and impacts allowed a greater appreciation of the cyclone risk, with ongoing management strategies developed by council to begin the process of mitigating the identified risks (Connery, L., 2019, pers. comm.).

Consideration should be given to using the scenarios in this report, and those available through the newly developed and aforementioned TCRM scenario selector tool[25], as the baseline for future risk assessments to ensure a consistent assessment. This will provide a robust measure for capability analysis and risk reduction.

7.2.3 Capability

Credible worst-case scenarios need to be challenging to ensure that capability gaps can be identified, assessed and measured. Using the same scenarios provides a consistent baseline for capability development and analysis. Hallett et al., (2018) suggests that “the use of scenarios is key to understanding requirements and the effectiveness of existing and proposed capabilities”. The respective scenarios show agencies how a cyclone event can impact capabilities. For the scenarios provided in this report, current capability can be analysed, and gaps identified. Where gaps are found, capability targets can be then developed for the state, district and local levels. Furthermore, the closure of the gaps can be measured through Monitoring, Evaluation and Learning (MEL) frameworks.

7.2.4 Plans, exercises and training

Plans and planning are a fundamental part of emergency management. Planning activities bring representatives together to develop and build relationships and generate a shared understanding of each other’s roles, priorities, capability limits and trigger points. The resulting plan should be exercised regularly and updated by lessons from exercises and events, and through reviews. Key to this is to recognise that it is not just about the plan but the planning process (AIDR, 2020).

Having realistic worst-case scenarios such as those developed for this project enhances planning. For example, one of the findings from TC Debbie was that:

“…worst case planning is valuable and at times needed. Decisions based on a ‘worst case’ should be considered very carefully before being applied. A finer-grained approach to risk-based planning where information is shared between decision-makers at different levels would benefit all” (IGEM, 2017, p. 77).

The tangible and credible scenarios developed in this project can be used for various training courses and as a foundation from which to develop exercises. The Category 5 scenarios can be used to conduct strategic whole of government level training and exercising. Part of the SWHA-Q project involves the development of a multi-jurisdictional capability to conduct modelling and develop scenarios. While it is recommended that the scenarios for this project be adopted as a consistent baseline, the generation of other scenarios at the tactical and operational levels allows for further option testing.

7.3 Response

Effective disaster response in Queensland is underpinned by the successful coordination of different levels of government, key agencies and decision makers. A state-level plan that outlines the response arrangements for a severe tropical cyclone impact would help to clarify the understanding of roles, responsibilities, processes and procedures that are available to manage an event. This clarification improves transparency and working relationships between entities.

Specifically, the Category 5 cyclone impact scenarios detailed in this report support the development of a state contingency plan (CONPLAN) to cover the two distinct phases of 'preparation into response' (during the initial cyclone forecast and pre-impact) and 'response into recovery' (covering the immediate aftermath of cyclone impact and the transition into recovery).

Such a plan would provide an overview of considerations required to deliver timely response to a major forecast event and support the effective management of the initial response and transition to recovery (Department of Defence, 2014). This would provide decision makers with contextual information to guide:

- initial response planning
- response assumptions
- estimated impacts
- suggested priorities and timelines
- estimated resource requirements
- projected shortfalls
- suggested external resource request triggers.

This report has highlighted several significant constraints in capability that are present in cyclone preparedness and response across Queensland relating to evacuation management and life-line infrastructure redundancy. These constraints could be largely addressed through the development of an overarching state CONPLAN that is able to be contextualised for use at each level of Queensland's disaster management arrangements. Such an approach has been adopted recently through the development of the Queensland Bushfire Plan which, as a sub-plan to the Queensland State Disaster Management Plan, outlines Queensland's arrangements for managing bushfire across prevention, preparedness, response and recovery.

Developing plans based on multi-scenario assessments (considering varying avenues of cyclone approach and intensity) for each major regional centre would enable decision makers to consider a wider range of response options available across all levels of Queensland's disaster management arrangements. Regularly testing and exercising such a plan before a disaster strikes would reduce the risk to communities and increase the likelihood of successful response during an event.

Additionally, such contingency planning may assist local governments in determining the additional requirements for extra building surveyors (experienced in cyclone areas), environmental health officers and streamlining of building/construction approvals to accelerate reconstruction.

The development of plans at the respective level will enhance the ability for decision makers to provide a response commensurate with potential impact in the event of a TC. This may be in the form of pre-deployment of resources such as incident management teams and an Urban Search and Rescue (USAR) for rapid damage assessment and rescue, as well as those resources required by critical infrastructure owners and operators to restore the provision of life-line infrastructure (e.g. power, telecommunications, water) to affected communities in the aftermath of the event.

7.4 Recovery

7.4.1 Initial and short-term

Although building codes have reduced the potential impact to buildings in terms of life safety, there would certainly be major damage if a regional centre or town was impacted by a severe TC. The restoration of basic functionality following a cyclone may take longer than several weeks as experienced in Innisfail post TC Yasi, 2011 and Airlie Beach post TC Debbie, 2017.

During the initial recovery, houses need to be protected quickly and properly. Unlike a bushfire where an area cannot burn again for some time, another severe weather event could impact within days. This situation came close to occurring when TC Wati moved into the Coral Sea in mid-March 2006, only days after TC Larry made landfall over Innisfail. A key consideration during initial repairs is how short-term repairs are completed, such as the use and fixture of tarpaulins. Tarpaulins can act as a parachute or lift roofs off. Therefore, they need to be securely tied down and battened.

Accommodation is a critical aspect of the recovery process. Damage to residential buildings affects accommodation availability for the community, fly in, fly out workforce (i.e. Central Queensland mining communities), response teams, recovery elements and the reconstruction workforce. Following the impact of TC Tracy on Darwin in 1974, the repair and reconstruction effort was extensive. With the loss of 90% of the accommodation, many people not directly involved in the recovery effort were evacuated to reduce the accommodation shortage, which can have a medium to long term impact on the community (Mason and Haynes, 2010).

The management of debris removal is another key factor. Following a cyclone, items such as roofing materials, green waste, damaged furniture, wet carpets, if not houses themselves, will place a major impost on removal, disposal and storage. If debris is not removed and disposed safely, it can hinder response efforts and delay recovery. Additionally, if debris is not removed quickly and fully it can cause further damage during the next severe storm or cyclone. Further complications can occur from the presence of contaminated materials (e.g. asbestos-containing materials) that may be present in older houses.

Local government waste management facilities may not have the capacity for large amounts of waste.

For example, following TC Marcus, which impacted Darwin in March 2018, waste facilities struggled to cope with the volume of refuse material being disposed, further compounded by the vast quantities of green waste generated by the cyclone's impact.

Further, this has the potential to substantially reduce the life of a waste management facility, with 10 years lost from some waste management facilities in the wake of ex-TC Oswald 2013. Livingstone Shire Council has developed a robust waste management strategy based on the experiences and learnings of TC Marcia, 2015. This strategy includes designating football ovals and other community infrastructure as temporary waste management facilities for green waste and non-toxic household debris/refuse until such time as local government capabilities can catch up (Livingstone Shire Council, 2017, pers. comm.).

7.4.2 Medium to long term recovery

The impact of a cyclone offers the opportunity to reconstruct a community in a more resilient way, to "build back better". Examples of this including using suitably qualified and experienced builders and engineers to assist with reconstruction and repairing older properties to meet modern design criteria.

> *"Consideration also needs to be given to changing the way damaged buildings are evaluated and repaired after a disaster. New Zealand has acknowledged that the earthquake recovery process provides an opportunity for creating a more resilient city, not just restoring what was lost"* (Miller, 2014).

The community is reliant on the restoration or replacement of key infrastructure to establish a sense of normality. Services required to deal with the damage and disruption to key infrastructure and the built environment in general are provided by the building sector including insurers, builders, subcontractors and suppliers.

7.4.3 Reconstruction

Despite the urgency of reconstruction, it is essential that proper planning takes place. Reconstruction activities carry complications beyond regular building and development activities. Impacted communities, legislation and relationships between organisations (including insurers) all have an impact on how the reconstruction takes place. Implementation and monitoring of reconstruction are affected by the environment in which it occurs. Some of the key issues that may arise in each phase are considered in the following sections.

7.4.3.1 Regional familiarity

During the reconstruction phase following a major TC impact, those involved need to be aware of the requirements of the current building codes and standards. If builders/designers are from outside the cyclone prone area, they may require training to ensure they become familiar with the current requirements for the region (Henderson et al., 2006). For example, a technical building expert with experience in north east Queensland construction techniques and standards was placed in Proserpine following TC Debbie, 2017. This person assisted with advice to builders and owners and in providing estimates of reconstruction times (Henderson et al., 2018).

7.4.3.2 Build back better

The "build back better" principle underpins recovery in the built environment. "Build back better" encourages consideration of sustainable practices, which means investing in planning, designs, materials and community-led processes that enable reconstructed assets, buildings and homes to be more resilient in the event of future disasters. During all reconstruction or renovation work current codes and standards, such as Australian Standard 1684 Part 3 – Cyclonic areas and SAI SAA HB 132.2 – Structural Upgrading of Older Houses – Cyclone Area, should be applied (Boughton and Falck, 2007). This should form a key part of any reconstruction plan following a TC impact.

Ensuring residents are engaged in the recovery and rebuilding effort will also likely see improved outcomes for those residents impacted.

7.4.3.3 Mental health recovery

Consideration to the mental health and emotional recovery of residents is critical. The stories of people who lived through TC Yasi, such as the below example of a woman from Ingham, demonstrate the significant and protracted emotional distress that can be associated with experiencing cyclone events:

> *"Don't want to go through it again. Life more precious, material things don't matter, don't buy things for fun anymore, don't want them. Get upset thinking of going through it again, frightened of loss of loved ones, feel sad for people with destroyed homes"* (Woods et al., 2014).

It is critical that mental health recovery services support all members of the community, with particular consideration of populations outside the urban centres. The support networks of friends, family and the community have a positive effect on recovery and these networks should be acknowledged and supported (Woods et al., 2014).

7.5 Research

Collection, availability and use of high-quality data improves management and response to disasters. Model effectiveness requires ground truthing with post event impact assessment and analysis. On both the hazard and exposure impact sides, immediate post event investigations collect data that guides the continuing development of hazard models and informs on the adequacy of current codes and standards, and the level of compliance in construction and house maintenance.

The CTS and Geoscience Australia have been conducting post event investigations over many years. Work is ongoing to have post event damage investigations seen as a vital element in ongoing risk reduction. The amount of information that has been gained through post-cyclone impact assessments supports the continuation and expansion of this work. Findings have been instrumental in numerous changes to building standards and codes as well as identifying industry training targets.

Within 24 hours of the impact of TC Vance on Exmouth, authorisation was given for CTS to investigate damage to buildings in Exmouth. The result was a very detailed report with many recommendations that were not only applicable in Western Australia but nationally. Similarly, CTS damage investigations of TCs Larry, Yasi and Debbie resulted in essential data to enable building code changes.

Conducting this research improves understanding of the types and parts of buildings that perform well, and therefore identifies areas for improvement in construction and material specification to reduce impacts in the future. For success, the deployment must happen immediately post event, before clean up is underway and vital evidence removed.

Figure 128: James Cook University Cyclone Testing Station researchers dismantling SWIRLnet tower in Proserpine following TC Debbie, 2017.

8 SUMMARY

8 Summary

The Severe Wind Hazard Assessment for Queensland set out to achieve the following objectives:

- explore the likely impacts of severe tropical cyclones (TCs that are Category 3 or higher) that have not yet occurred
- understand the impact of climate change on the frequency and intensity of TCs
- build the capability and capacity for understanding impacts of future TCs across the emergency management sector in Queensland
- highlight the practical actions that will enable decision makers and communities exposed to cyclone risk to reduce the impact.

To do this, the project analysed 14 credible scenarios for coastal Queensland communities, representing a mix of Category 3 and 5 TC events. These 14 scenarios were chosen from Geoscience Australia's Tropical Cyclone Hazard Assessment database (consisting of physically and statistically plausible, randomly generated TC events) in consultation with Queensland Fire and Emergency Services (QFES) and the respective local governments. Whilst this project has modified the tropical cyclone hazard analysis from the TCHA to more accurately model the physical characteristics of tropical cyclones and therefore the underpinning database, the selection of scenarios was based on the Category of the event rather than its likelihood and are therefore consistent with the TCHA database. These credible scenarios were selected to assist emergency managers in developing strategies for response and recovery. During the selection process consideration was given to:

- historical analogues for the event
- potential for significant associated hazard impact (i.e. flood and storm surge)
- multiple impacts along the coastline and to inland communities.

The Hazard-Exposure-Vulnerability-Impact paradigm was used to simulate impacts of these events, with the focus on impacts of severe winds, for residential housing only. Other cyclone related hazards, such as flash and riverine flooding and storm surge, will require a separate analysis.

While Chapter 4 (especially section 4.9) and Chapter 6 have summarised the key issues and conclusions arising from the scenario analysis, the following summary highlights the overall key conclusions, including areas for further consideration, from the project itself. These are:

1. The analysis and risk management considerations made in this project reinforce a number of findings related to emergency management in Queensland previously highlighted in reviews of past TC events. Many of these remain, including the critical importance of building maintenance to reduce damage, and the communication of unmanaged risk and residual risk across all levels of Queensland's disaster management arrangements.

2. While cyclones are expected in South East Queensland (SEQ) and are considered within residential building design criteria, any severe TC (Category 3 and above) impacting SEQ is likely to result in catastrophic outcomes, since the design criteria for houses is below that of moderate Category 3 cyclones. Relevant comparisons of the risk for SEQ have recently been observed in Western Australia with the impact of TC Seroja on the community of Kalbarri and the surrounding region (which is within AS/NZS 1170.2 Wind Region B).

   The increasing density of population, coupled with a revised understanding of the vulnerability to severe winds in SEQ, highlights an increasing potential for catastrophic impacts across this region. As such, further study is currently underway to help understand the main drivers of risk in SEQ.

   As a precautionary measure, preparedness activities across the emergency management sector in Queensland would benefit from a shift in focus from North Queensland to include the entire eastern seaboard when managing cyclone risk.

   A coordinated cyclone preparedness program, in liaison with Bureau of Meteorology, QFES, Queensland Reconstruction Authority, and local governments and other key entities would assist communities to better understand and embrace their responsibilities in preparing for cyclone risks.

3. Although a house may be built to a certain wind design standard, this does not make it impervious to damage by wind speeds below the design level. The National Construction Code (NCC) establishes minimum acceptable requirements for buildings with a focus on life safety. Where houses are built to modern standards, we expect little damage from events that are below the regional design levels.

   Cities and towns along the east coast are an uneven mix of older and newer construction, leading to worse damage outcomes in all scenarios. A common outcome for all scenarios is the greater likelihood of significant damage on the outskirts of the communities and for isolated houses fully exposed to the full force of the wind.

The age profile of suburbs is a dominant driver of damage likelihood for the lower intensity events, with buildings constructed prior to the 1980s (and therefore the implementation of modern building codes) significantly more vulnerable. For example, in the Mackay Category 3 scenario, pre-1980s buildings make up over nearly 90% of the total number of Extensively or Completely damaged houses, despite comprising less than half the total population of houses in the region.

For the Category 5 scenarios, modelling indicates that most houses on the outskirts of towns suffer major damage, while those in the centre of built-up areas suffer comparatively less damage. This is due to a shielding effect, where buildings provide some protection to neighbouring downwind buildings, especially in areas where building density is higher. This modelling does not, however, account for damage from wind-driven debris.

4. Post-TC reports for Queensland and Western Australia conducted by the James Cook University Cyclone Testing Station highlight that most damage to residential and commercial buildings is preventable and due to a lack of basic maintenance. Increasing access to cyclone maintenance and repair information for homeowners, alongside an increase in public and private sector grants or incentivisation programs, is a pathway to achieving significant risk reduction.

5. Retrofits or adapting existing buildings to modern building standards are generally perceived as too costly without some form of incentivisation. Examples of such initiatives demonstrate the potential to reduce building vulnerability in Queensland, and illustrate that expanding on initiatives that systematically target the most at risk communities would be beneficial. It is acknowledged that this would require significant modelling of community risk at a scale greater than this study.

6. This analysis has not included assessment of the damage arising from water ingress or wind-driven debris. Even during low-end cyclones, wind-driven water ingress and debris is a major contributor to building damage. As such, communities and households should ensure that appropriate measures are taken to prevent and prepare for wind-driven debris, such as clearing yards and securing loose items.

   This project has also not quantitatively examined storm surge impacts, a potential and significant compounding extreme along coastal and foreshore areas.

7. Within the context of this report, severe TC winds are considered as being Category 3 or higher. While some communities and emergency managers may have experience with Category 3 TCs, to most, the impacts of a landfalling Category 4 or 5 TC will be largely unfamiliar. As discussed in section 7.1.3 of this report, some residents also hold a misguided belief that they have previously experienced severe tropical cyclone wind impacts, and so need to do little in terms of preparation, when in reality they may have just “caught the edge of one”, experiencing lower wind speeds than the reported maximum. Strategies to rectify these misconceptions and help communities better understand the potential impacts – and therefore better plan for them – would be beneficial.

8. In SEQ, no community has experienced the direct effects of a landfalling cyclone since 1954. As such, community preparedness and prevention activities can and will affect the outcome of each future event. Where levels of prevention and preparedness activities are high (e.g. ongoing maintenance and retrofit of buildings, clearing of debris and preparation of emergency kits), the levels of impact will be commensurately lower. The opposite statement is also true, and claims data from leading insurers in Queensland shows that lack of preparedness for severe weather events is a significant cause of loss in SEQ.

9. Facilities considered essential to community functioning such as schools, hospitals and evacuation centres should be assessed against the National Construction Code to ensure that their post-disaster operation is not unacceptably hindered by the disaster impact.

10. The need for evacuation plans that traverse local and state borders remains a challenging issue and has been recently highlighted in the Royal Commission into the National Natural Disaster Arrangements (Recommendations 12.2 through 12.7). With the scale of potential impacts demonstrated by this study, and the recent events of TC Seroja in Western Australia, this issue should be prioritised for discussion across all levels of Queensland’s disaster management arrangements and in partnership with other jurisdictions.

11. Accommodation is a critical aspect of the recovery process. Damage to residential buildings affects accommodation availability for the community, response teams, recovery elements and the reconstruction workforce.

During the initial recovery, houses need to be protected quickly and properly. Unlike a bushfire where an area is unlikely to burn again for some time, another cyclone, storm or flood event could impact within days. Initial and short-term repairs, such as the use and fixture of tarpaulins, should be undertaken with consideration of forecast weather and the potential for additional severe weather events to occur.

12. While critical infrastructure operators have a leading role in managing and maintaining their infrastructure assets and networks, critical infrastructure resilience to natural disasters is a shared responsibility. This report highlights a continuing need to promote this shared responsibility and encourage disaster resilient communities.

At the local level, more work could be undertaken to ensure a greater level of critical infrastructure redundancy, particularly that of power and fuel. Disaster management groups should strive to maintain a level of power, telecommunications and fuel redundancy that allows for the maintenance of basic services to the community post-disaster impact stretching in to weeks rather than days.

13. Ideally, local governments or other entities would be able to undertake inspections after pre-cyclone clean up campaigns and provide advice to property owners regarding items that could become dangerous debris. While legislative power may be available to address debris issues and gain access to conduct inspections, the capacity to undertake this may be a limitation. There may be differences in the preparedness of northern and southern Queensland communities with respect to general preparedness in the lead up to TC impacts. As an example, the collection and disposal of debris that can be potential missiles during a TC is essential for reducing impact, and is well practiced in North Queensland communities, which have more frequent experience with these events.

14. Following a cyclone, items such as roofing materials, green waste, damaged furniture, wet carpets, and houses themselves, will place a major impost on removal and storage. If debris is not removed and disposed safely, it can hinder response efforts and delay recovery. Additionally, if debris is not removed quickly and fully it can cause further damage during the next severe storm or cyclone. Further complications can occur from the presence of asbestos-containing materials and other hazardous materials. Currently, the management and disposal of these materials is the responsibility of local governments. However, this can overwhelm local capability and capacity. Accordingly, the State Government may consider the benefits of taking a more 'hands on', coordinated, strategic role to support local government recovery efforts.[26]

15. The consideration of TC impacts on Queensland's natural ecosystems illustrates the need for comprehensive disaster management and climate adaptation approaches. Indeed, approaches that go beyond the built environment to encompass managing the risks posed to our biodiversity and ecosystems, and the ecosystem services they provide to Queenslanders, stand to bolster Queensland's resilience to both natural hazards and climate change, more broadly.

16. While the scenarios in this assessment are aimed at supporting the emergency management sector, they also serve as compelling illustrations of the need for Queenslanders to carefully identify and manage their physical climate and disaster risk, as part of their broader climate risk management. Queenslanders should therefore seek current leading practice guidance for climate risk management and planning for long-term, uncertain, pervasive change.

17. Greater effort should be made to allow immediate access to TC- and storm-affected areas to organisations such as the James Cook University Cyclone Testing Station and Geoscience Australia, prior to recovery efforts commencing. The quantity and quality of information that has been gained through post-cyclone impact assessments supports the continuation and expansion of research following a TC event. By capturing raw information on damage, more can be learnt about how to reduce the impact of future cyclones.

18. QFES and other emergency management organisations would benefit from an enhancement of intelligence capabilities, including collection and processing of data to refine the understanding of vulnerability and potential damage from severe winds and other related hazards.

Continued community engagement and refinement of the emergency management sector's technical understanding of vulnerability to extreme winds detailed in the risk management considerations will contribute to risk reduction across Queensland's communities.

Future iterations of this assessment and other associated studies will continue to explore the changing nature of cyclone risk in greater detail and, as a result, continue to improve our understanding of Queensland's risk from tropical cyclones and associated hazards.

The effects of climate change on cyclone activity is a prominent area of climate research given the consequences of these events and is advancing rapidly. Future generations of global circulation models and regional climate models will help to refine our understanding of the projected changes of tropical cyclone frequency, tracks and intensity, and therefore the likelihood of extreme tropical cyclone-related winds across Queensland.

If further research, analysis, assessment or advice is required after reviewing this document to understand the TC risk for a particular area, a collaborative approach with the stakeholders listed below is recommended to ensure consistency in evaluating the hazard in line with state and national assessments.

Key agencies:

- Queensland Fire and Emergency Services
- Department of Environment and Science
- Geoscience Australia

Appendix A: Glossary

Abbreviation	Definition
BoM	Australian Bureau of Meteorology
CCAM	CSIRO Cubic Conformal Atmospheric Model
CONPLAN	Contingency Plan
CTS	James Cook University Cyclone Testing Station
DDMG	District Disaster Management Group
DEM	Digital Elevation Model
DES	Department of Environment and Science
EM	Emergency Management
GA	Geoscience Australia
GBRMPA	Great Barrier Reef Marine Park Authority
GCM	General Circulation Model
Hs	In physical oceanography, significant wave height (Hs) is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves recorded (H1/3). Significant wave height is an important parameter for the statistical distribution of ocean waves. The most common waves are lower in height than Hs.
IBTrACS	International Best Track Archive for Climate Stewardship
LDMG	Local Disaster Management Group
LGA (C) (R) (S)	Local Government Area Council Regional Shire
NCC	National Construction Code
NEXIS	National Exposure Information System
QFES	Queensland Fire and Emergency Services
QRA	Queensland Reconstruction Authority
RCM	Regional Climate Model
RCP [27]	Representative Concentration Pathway
SA	Statistical Area Levels (Australian Bureau of Statistics)
SES	State Emergency Service
SWHA-Q	Severe Wind Hazard Assessment for Queensland
SRTM	Shuttle Radar Topography Mission – generated the most complete high-resolution digital topographic database of Earth
TC	Tropical Cyclone
TCIM	Tropical Cyclone Impact Model
TCLV	Tropical Cyclone Like Vortex
TCRM	Tropical Cyclone Risk Model

Appendix B: Tropical cyclone intensity categories

Tropical cyclones are categorised on the basis of the 10-minute mean wind speed, measured at 10 metres above open, flat terrain (e.g. at an airport). Gust wind speeds are indicative and can be significantly higher over hills and ridges and around structures. For this project, we used the following classifications to select events.

	Maximum 10-minute mean wind speed (km/h)	Typical maximum wind gust (km/h)	Typical maximum wind gust (m/s)	Typical central pressure (hPa)
Tropical low	‹ 63 km/h	‹ 90 km/h	25 m/s	
Category 1	63 – 88 km/h	‹ 125 km/h	‹ 35 m/s	› 985 hPa
Category 2	89 – 117 km/h	125 – 164 km/h	35 – 45 m/s	985 – 970 hPa
Category 3	118 – 159 km/h	165 – 224 km/h	46 – 62 m/s	970 – 955 hPa
Category 4	160 – 199 km/h	225 – 279 km/h	63 – 77 m/s	955 – 930 hPa
Category 5	› 200 km/h	› 279 km/h	› 78 m/s	‹ 930 hPa

Table 25: Tropical cyclone categories, indicative maximum wind gusts and minimum central pressure. Source: Bureau of Meteorology (2018)

Appendix C: Local government impact summaries

These tables report the aggregated number of houses in each damage state (Appendix H), within each local government area (LGA) within the analysis extent for each scenario.

Notes:

- only residential houses are counted
- the analysis extent may not completely cover LGAs that are not the focus of the scenario, so the totals may not reflect the actual number of houses in the LGA
- some houses may not be included in the analysis as they have not been classified in rural or residential areas
- for the Gold Coast scenarios, only the Gold Coast LGA was included in the analysis.

Gold Coast Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Gold Coast (C)	11,461	67,670	25,568	48,716	23,578

Gold Coast Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Gold Coast (C)	1,132	10,600	3,407	34,977	100,455

Gladstone Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Banana (S)	7,583	670	137	29	0
Bundaberg (R)	34,657	31	21	10	2
Gladstone (R)	18,590	1,549	103	107	27
Livingstone (S)	11,017	29	0	0	0
North Burnett (R)	1,953	290	62	18	0
Rockhampton (R)	31,253	15	0	0	0

Gladstone Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Banana (S)	3,842	805	369	938	2,127
Bundaberg (R)	28,115	4,676	565	840	521
Gladstone (R)	15,282	3,232	625	628	479
Livingstone (S)	10,039	679	79	186	60
North Burnett (R)	1,271	279	135	305	321
Rockhampton (R)	23,115	5,025	692	1,103	1,083

Mackay Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Isaac (R)	7,684	1,232	375	72	1
Mackay (R)	35,360	4,260	540	406	86
Whitsunday (R)	12,701	11	0	0	0

Mackay Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Isaac (R)	5,283	1,096	1,255	724	1,000
Mackay (R)	21,316	12,314	2,139	2,547	1,872
Whitsunday (R)	12,630	73	7	2	0

Townsville Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Burdekin (S)	10,935	398	15	19	2
Charters Towers (R)	6,670	0	0	0	0
Hinchinbrook (S)	924	260	68	2	0
Palm Island (S)	5,437	5	0	0	0
Townsville (C)	218	0	0	0	0

Townsville Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Burdekin (S)	9,707	1,493	112	84	34
Cassowary Coast (R)	6,645	25	0	0	0
Charters Towers (R)	2,783	1,404	155	186	33
Hinchinbrook (S)	4,233	616	7	9	0
Palm Island (S)	218	0	0	0	0
Townsville (C)	35,979	25,289	4,238	3,247	1463
Whitsunday (R)	1933	128	4	0	0

Cairns Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Cairns (R)	53,969	1,635	124	96	5
Cassowary Coast (R)	15,840	5	0	0	0
Charters Towers (R)	1141	113	0	0	0
Cook (S)	2,382	0	0	0	0
Douglas (S)	4,250	0	0	0	0
Hinchinbrook (S)	5,424	18	0	0	0
Hope Vale (S)	221	0	0	0	0
Lockhart River (S)	159	0	0	0	0
Mapoon (S)	29	0	0	0	0
Mareeba (S)	7,629	425	100	44	0
Napranum (S)	179	0	0	0	0
Tablelands (R)	9,684	1,418	126	18	0
Wujal Wujal(S)	55	0	0	0	0
Yarrabah (S)	352	29	0	0	0

Cairns Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Cairns (R)	11,667	29,769	6,489	6,074	1,369
Cassowary Coast (R)	15,677	147	7	12	2
Charters Towers (R)	1,137	3	1	5	108
Cook (S)	2,211	48	69	43	11
Douglas (S)	4,153	96	1	0	0
Hinchinbrook (S)	5,442	0	0	0	0
Hope Vale (S)	221	0	0	0	0
Lockhart River (S)	159	0	0	0	0
Mapoon (S)	29	0	0	0	0
Mareeba (S)	6,422	1,089	242	225	220
Napranum (S)	179	0	0	0	0
Tablelands (R)	2,611	2,539	1,235	1,867	2,367
Wujal Wujal (S)	48	7	0	0	0
Yarrabah (S)	1	112	60	200	8

Kowanyama Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Kowanyama (S)	306	0	0	0	0
Pormpuraaw (S)	247	0	0	0	0

Kowanyama Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Kowanyama (S)	306	0	0	0	0
Pormpuraaw (S)	247	0	0	0	0

Pormpuraaw Category 3 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Kowanyama (S)	306	0	0	0	0
Pormpuraaw (S)	198	49	0	0	0

Pormpuraaw Category 5 scenario

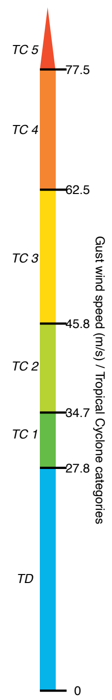
LGA	Negligible	Slight	Moderate	Extensive	Complete
Kowanyama (S)	161	144	0	1	0
Pormpuraaw (S)	78	115	51	3	0

Appendix D: LGA and cities and towns tropical cyclone risk heatmaps

Recurrence of Tropical Cyclones across Queensland's LGAs (historical)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

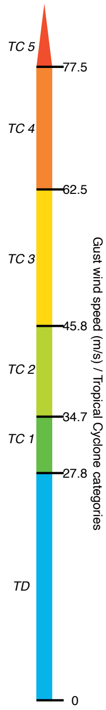
Local Government Areas	2 50	5 20	10 10	20 5	30 3.33	40 2.5	50 2	75 1.33	100 1	150 0.67	200 0.5	300 0.33	400 0.25	500 0.2	750 0.13	1000 0.1	2000 0.05	3000 0.03	5000 0.02	10000 0.01
Aurukun Shire	17.4	32.6	47.9	63.4	71	76.6	81.1	86.1	88.1	91	92.5	95.4	96.6	97.8	99.6	100.6	103.6	109.9	110.1	113.2
Balonne Shire	0	0	0	4.7	7.1	9.5	11.3	16	20.4	26.3	29.8	36.4	38.7	39.7	48	51.1	58.3	65	66.2	90.6
Banana Shire	0	6.3	13.2	22.4	29.1	34	37.9	45.1	49.8	57.3	61.5	67.6	74.4	81	83	87.6	93.9	96.2	101.7	102.5
Barcaldine Regional	0	6.6	13.5	21	25.9	28.6	31.2	35.2	38	42.6	45.7	50.4	55.1	59.1	61.5	62.3	67	70.5	70.7	74.9
Barcoo Shire	0	0	1.9	4.2	6.2	7.9	9.3	13.3	16.3	19.6	23.2	26.2	29.1	31.1	33.6	38.5	48.4	54	54.8	57
Blackall Tambo Regional	0	1.6	5.9	9.8	13.2	16	19.1	23.4	27.8	30.8	33.4	37.3	39.5	41	44.8	47.6	56.5	57.4	62.7	67.5
Boulia Shire	0	0	3.8	6.9	8.9	10.7	12.1	15	17.1	20.5	22.6	26.7	27.8	28.8	32.2	33.8	35.4	37.1	38	46
Brisbane City	0	0	7.7	16.7	24.3	29.5	34.4	42.7	49.3	57.4	62.6	68.8	74.2	75.4	78.1	82.9	89	98.9	99	100.8
Bulloo Shire	0	0	0	0	0	1.5	2.3	3.6	4.9	7.3	9.9	14.8	19.5	24.1	29.8	31.6	52.7	61.6	61.7	62.5
Bundaberg Regional	0	5.6	12.5	23.5	32.5	37.7	41.9	52.1	57.2	64.4	70.2	77.2	80.5	85.4	92.2	96.9	103.9	108.9	111.5	116
Burdekin Shire	4.9	17.7	32	50.4	61.8	68.7	73.7	79.9	86.5	91.5	95.7	101.2	104.5	107.3	111.1	114.6	117.8	120.5	121.4	123.1
Burke Shire	5.1	17.5	30.2	44.9	53.1	60.3	65.4	74.1	79	82.9	85.8	91.3	95.1	98.4	104.4	107.1	109	110.2	111	113.8
Cairns Regional	8.1	20.2	33.6	49.9	60.7	67.1	70.8	78.8	83.1	89.6	93.1	98.8	100.8	101.8	105.5	107.3	115	116.3	116.9	118
Carpentaria Shire	13.2	25.6	36.1	53.5	62.5	67.2	70.7	77.7	81.7	86	87.7	89.8	91	91.9	93.9	95.8	96.6	99.7	103.3	108.2
Cassowary Coast Regional	7.2	20.1	33.5	52.4	61.8	68.5	71.8	79.4	84.6	91.4	94	99.7	101.9	103.8	105.6	107.2	112.5	114.9	116.9	117.4
Central Highlands Regional	0	8.7	17.8	27.7	34.2	38.4	41.6	48.4	52.4	56.9	60.4	66	69.9	71	74.8	83	87.6	89.4	96.7	97.8
Charters Towers Regional	6.8	21.7	35.2	51.5	61.7	67.3	70.8	78.4	81.7	86.7	89.6	95.5	97.6	99.2	101.4	103	107	109.6	110.2	112.9
Cherbourg Aboriginal Shire	0	0	6.2	13.6	19.3	22.6	24.8	30.2	34.1	39.1	43.7	51.4	54.4	58	63.8	65.7	70.5	71.8	81.6	100
Cloncurry Shire	0	6.1	10.9	16.4	20	22.4	24.2	27.5	29	31.3	33.6	35.5	36.9	38.2	43.3	45.7	55.4	56.3	62	63.8
Cook Shire	33.4	59.6	74.9	86.3	91.2	94.1	96.5	99.1	101.2	103.4	104.6	106.9	108.7	109.5	112.5	113.9	118.6	119.5	119.6	125.1
Croydon Shire	5.8	13.4	20.8	27.8	32	34.6	37.3	42.4	46.6	50.8	54	57.2	60.4	62.9	67.6	68.3	75.6	77.4	77.7	81.4
Diamantina Shire	0	0	0	2.5	4.2	5.4	6.3	8.9	11.3	14.3	16.1	22.2	25.4	29.7	31.4	34	40.7	42.7	48	49.3
Doomadgee Aboriginal Shire	3.6	13.8	24.2	36.2	43.9	49.7	53.5	61	66	71.7	74.3	78.8	81.5	85.9	89.3	90.9	102.3	104.5	106.8	110.7
Douglas Shire	9.4	21.8	33.9	48.2	56.9	62.7	67.6	75	80.1	85.7	89.9	95.2	97.9	99.2	102.9	103.5	108.7	112.2	113.8	118.9
Etheridge Shire	7.4	17	24.6	31.9	37.6	41.7	44.5	49.8	53.1	56.2	61.1	65	68.7	70.4	74.7	75.2	79.1	82.9	84.6	90.9
Flinders Shire	2.3	9.5	16.9	24.5	29.6	32.8	35.2	41.7	44.8	51.2	54.9	58.9	62.6	65	69.6	72.1	77	84.8	86.2	87
Fraser Coast Regional	0	6	13.9	26.6	36.1	44.1	50.2	59.3	65.2	71	76.3	84.3	86.5	88.4	91.6	94.8	101	102.6	105	105.8
Gladstone Regional	0	7.8	15.3	26.7	35.4	41.6	47.2	57.2	63.4	71.1	77.5	84.8	88	91	96.5	98.5	102.9	107.4	112.7	116.8
Gold Coast City	0	0	6.3	13.7	21.2	26	30.3	38.2	42.9	53.9	59.7	67	72.8	74.4	81.2	81.9	88.6	95.4	96.6	100.1
Goondiwindi Regional	0	0	2.4	8.3	13.3	18.4	21.5	28	33	39.5	45	50.2	53.7	56.7	61.6	63.3	69.4	75	76.8	77
Gympie Regional	0	3.6	10.5	21.7	29.8	34.7	39.3	49.3	56.6	64.3	69.2	74.6	78.9	82.7	86.1	89.6	97.7	103.5	105.3	105.9
Hinchinbrook Shire	5.5	16.9	28.6	43.1	53.6	59.5	64.4	70.9	76.9	83	86.1	92.7	97	99.8	102.6	104.4	111.3	112.3	113.3	123.8
Hope Vale Aboriginal.Shire	10.5	24	37	51.2	58.7	63.9	69.4	75.9	79.6	85.3	89.1	93.3	95.9	97.2	100.9	102	109.8	112.4	112.8	121.9
Ipswich City	0	0	5.5	12.7	19.6	24.5	28.1	35.8	41.2	47.4	50.7	57.8	62.7	66.6	73.5	74.8	81.1	84.9	93.8	98.8
Isaac Regional	4.4	18.3	34.5	53	61.4	66	69.5	76.7	80.3	84.3	88.1	92.5	94.7	97	99.7	101.4	104.9	109.9	114.7	118.2
Kowanyama Aboriginal Shire	10	20.4	30.4	44.9	54.9	61.3	65	70.9	74.4	79.4	81.5	84.6	86.6	89.1	91.2	91.8	95.6	100.7	106	107.2
Livingstone Shire	2.3	11.7	22.9	38.3	49.7	56.1	60.1	68.9	75.9	82.6	86.3	92.1	95	96.3	100.2	101.8	105.1	109.4	116.5	118.6
Lockhart River Aboriginal.Shire	15.5	29.6	41	54.2	62.4	67.4	70.1	75.7	79	82.8	87.1	91.8	95.4	96.8	99.8	101.7	106.6	113.8	114.8	124.4
Lockyer Valley Regional	0	0	5	12.4	18.3	23.1	27.4	34.6	38.9	47	51.4	57.5	61.5	65.1	69.8	74	79.1	82.1	82.5	82.7
Logan City	0	0	6	13.3	20.5	26	29.2	36	41.5	50.4	54.7	62.1	65.7	70.5	77	80	86.4	91	93.3	101.5
Longreach Regional	0	2	5.8	10.1	13.8	16.7	19.1	23.7	26.5	30.2	32.1	35.1	36.3	38.5	47.5	49.3	57.4	59.1	60.3	61
Mackay Regional	4.7	17.9	35.3	60.1	70.7	77.1	81.6	86	89.3	93.3	96.3	100.7	104.2	105.8	108.1	109.1	116.4	117.4	123.2	127.9
Mapoon Aboriginal Shire	14.8	29.9	42.2	56.6	65.4	71.4	75.2	81.7	84.9	89.7	93	96.1	98.2	99	101.1	101.5	108.4	110.4	110.8	118.7
Maranoa Regional	0	1.7	6.4	11.6	15.9	18.9	22.4	28.8	33.2	39.7	44.3	49.3	51.4	54.1	59.3	67.3	70.6	74.7	85.7	90.5
Mareeba Shire	13.4	26.3	37.5	50.8	59	64	68.4	76.4	80.3	84.6	88.9	92.8	96.8	98.5	101.7	106.1	114.9	116.3	116.3	117.5
McKinlay Shire	1	7.1	11.8	17.4	21	22.9	24.7	28.3	30.3	33.1	35.4	37.6	40	42.8	44.4	47.8	54.7	56.4	57	61.7
Moreton Bay Regional	0	0	7.4	16.3	23.4	27.9	32.5	41.1	47.8	56.1	62.7	68.6	71.7	73.5	81	83.2	87.9	92.7	93.2	95.5
Mornington Shire	5.2	16.4	29.4	46.9	59.1	65.2	69.6	78	81.7	86.1	89.7	92.8	94.5	95.2	96.6	97.8	102.7	105.8	106.3	106.3
Mount Isa City	0	8.2	15.1	21.9	24.9	27	28.6	30.6	32.9	35.4	38.5	41.3	43.8	45	50.2	53.1	58.5	61	63.8	68.5
Murweh Shire	0	0	5.1	9.4	11.9	14.2	16.9	22.4	25.7	30.5	34.4	39.4	42	45.2	51.6	55.5	60.6	66	70.2	75.4
Napranum Aboriginal Shire	16.8	32.4	45.8	60.2	68.3	72.9	76.7	83.3	86.2	90.8	93.5	96.8	98.1	98.9	100.9	101.9	104	105.1	106.4	115.5
Noosa Shire	0	2.2	8.8	18.3	25.1	29.5	33.6	41.9	48.2	58.6	62.9	67.8	71	76.9	79.8	83	97.7	101.7	103.3	106.8
North Burnett Regional	0	5.5	12.1	22.8	30.2	35.7	39.5	47.4	52.9	62.1	65.3	69.7	74.4	78.3	83.3	87.7	98.1	103.5	110.6	112.3
Northern Peninsula Area.Regional	13.5	30.4	45.7	61.4	67.7	72.5	76.6	81.2	84.6	89.1	91.2	96.2	98	98.8	101.8	102.5	104.3	108.6	108.9	109
Palm Island Aboriginal.Shire	4.9	15.8	27.4	40.6	49.5	57.5	62.4	71.3	75.6	81.3	84.2	90.1	92.5	95.8	102	103	110.3	115	120.1	120.3
Paroo Shire	0	0	0	1.9	3.5	4.9	5.8	8.7	11.3	15.1	18.9	25.7	29.2	32.4	36.3	38.2	61.4	64	66.5	70.1
Pormpuraaw Aboriginal Shire	12	24	36.4	53.1	61.9	67.4	70.8	77	79.9	84	86.3	89.1	89.8	91	93.2	94.9	99.8	103	105.2	105.5
Quilpie Shire	0	0	1.9	4.4	6.4	7.8	9.9	14	16.4	20.8	23.7	26.8	30.1	32.8	38.2	40.9	50.3	56.7	60.1	62
Redland City	0	0	7	14.8	21.9	27.1	31.6	40.1	43.5	54.3	60	66.5	70.6	71.6	75.4	79.6	89.4	97.2	99.3	107.1
Richmond Shire	0.7	7.2	12.2	18.4	22.2	24.8	26.5	29.9	32.1	36.6	39.5	45.5	48.3	49.6	53.6	55.9	63.6	66.4	67.9	71
Rockhampton Regional	0	8	15.7	25.8	32.5	37.6	42.1	50.4	55	62.9	67.7	72.9	77.4	79.3	87.3	90.1	97.5	102	104.2	111.5
Scenic Rim Regional	0	0	5.7	12.9	20.8	25.7	30.1	38.6	43.1	51	56.6	65.4	67.9	69.9	76.4	77.4	87	93	94.4	97.4
Somerset Regional	0	0	7.3	16.7	24	29.4	34.3	40.4	47.9	55.7	59.6	65.6	68.5	72.6	81.2	82.8	88.7	93.9	97.2	99.5
South Burnett Regional	0	1.5	7.8	16.8	23.6	27.9	31.4	37.9	42.6	51	56.8	63.2	67.5	69.9	76.3	78.5	89.2	95.1	96.8	102.9
Southern Downs Regional	0	0	3.7	10.4	16.5	21.7	25.4	32.6	37.7	45.1	49.6	55.1	58.6	61.2	67.2	71.9	75.9	82.4	84.9	94.2
Sunshine Coast Regional	0	1.2	8.3	18.2	24.5	30	34.3	43.6	50.9	58.3	63.1	68.8	72.3	74.6	79.4	81.3	92.3	95.3	99.3	106.8
Tablelands Regional	7.7	19.9	32.2	48.5	57.8	62.4	65.7	74.2	79.7	85.1	87.5	90.8	93	95.2	97.9	99.7	102	105	106.3	106.7
Toowoomba Regional	0	0	5.8	14.5	20.9	26.4	30.4	37.7	41.8	49.4	54.4	61.8	65.3	69	76.4	77.6	82.6	85.3	92.7	96.3
Torres Shire	14.7	34.5	52.8	67.5	75.1	79.6	82.7	88.5	91.4	95.5	97.5	100.9	104.2	105.2	106.9	107.8	109.7	112.8	116	116.7
Torres Strait Island.Regional	14.6	35.4	53.8	68	75.4	79.7	82.7	88.1	90.8	95	96.5	98.7	100.3	101.3	106.6	108.5	111.9	113.9	114.6	114.6
Townsville City	5	17.2	31	47.6	57.4	65.8	70.1	78.2	83	91	96.6	99.6	102.5	105.1	109.4	109.9	111.9	112.2	118.7	122.4
Weipa Town	13.2	25.3	35.5	46.9	53.4	57.7	61.2	66.1	70	74	75.9	79.7	80.8	81.6	83	84.5	89.4	93.4	93.6	105.6
Western Downs Regional	0	1.7	7.3	15.7	22	27.6	29.9	36.5	41.9	48.5	54	60.3	62.2	64.6	70.5	71.3	84.3	89.6	92.1	95.7
Whitsunday Regional	5.8	21.5	42.6	66.9	77	83.1	88.4	93.9	96.8	101.6	104.2	108.1	109.3	111.3	114.3	117.8	121.1	121.5	124.7	125.9
Winton Shire	0	3.8	7.5	12.2	15.9	18.8	21.2	25.2	27.9	32.3	34.4	37.8	39.8	41.8	44.6	49.8	57.6	60.4	61	76.7
Woorabinda Aboriginal Shire	0	5.7	11.8	19.3	24.7	28.4	30.8	35.5	38.4	44.7	49.6	55.5	58.5	61.3	66	71.5	84.2	85.7	86.2	90.9
Wujal Wujal Aboriginal.Shire	8.2	19	28.6	40.3	46.6	51.9	54.9	61.3	65	69.5	72.8	75.4	80.3	82.5	88.8	89.8	93.6	94.6	96.2	97.7
X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Yarrabah Aboriginal Shire	7.5	18.7	30.1	44.4	54.4	61.6	66	72.8	78.2	83.7	88.5	92.5	94.6	96.7	100.8	103.3	105.9	107	110.4	115



Recurrence of Tropical Cyclones across Queensland's LGAs (RCP4.5 – 2041–2060)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Local Government Areas	2	5	10	20	30	40	50	75	100	150	200	300	400	500	750	1000	2000	3000	5000	10000
	50	20	10	5	3.33	2.5	2	1.33	1	0.67	0.5	0.33	0.25	0.2	0.13	0.1	0.05	0.03	0.02	0.01
Aurukun Shire	12.6	23.8	40.1	55.4	61.3	67.7	73.7	79.2	84	88.7	90.1	95.2	100.4	101.3	104.8	109.1	115.2	124.5	127.8	132.5
Balonne Shire	0	0	0	3.1	4.9	6.3	7.4	10.9	14.1	19.5	22.4	30	31.6	33.6	39	43	49.4	55	55.3	94.1
Banana Shire	0	5	10.8	19.8	25.9	31	35.3	41.2	46.2	53.7	59.4	66	74.4	82	84	84.3	91.3	91.3	91.4	94.5
Barcaldine Regional	0	5.1	10.7	17.2	22.4	25.5	28.4	32.1	34.5	39.6	42.1	47.2	52.1	54.3	56.9	58.1	66.9	71.2	74.4	82.2
Barcoo Shire	0	0	0.8	3.2	5	6	7.4	10.9	12.6	14.3	16.6	18.1	19.5	21.6	26.7	33.7	43.9	51.4	52.8	54.7
Blackall Tambo Regional	0	0.4	4.8	7.8	9.8	12.2	15	18.1	22.9	25.1	28.1	32.5	36.4	37.6	41.7	43.5	54.3	55.3	56.4	63.5
Boulia Shire	0	0.6	1.7	5.2	7.1	9.2	11.7	16	19.7	25.4	26.5	29.6	30.2	31.4	35.1	38.9	39.9	45.8	51.4	59.4
Brisbane City	0	0	5.5	13.3	19.6	24.7	29.6	36.5	42.6	50.8	55.9	63.4	72.2	73.9	77	81.4	83.5	87.3	91.3	96.1
Bulloo Shire	0	0	0	0	0	0.1	0.1	1.8	2.8	3.8	5	9.6	13.1	17.4	23.6	26.3	52.5	62.7	68.1	81.6
Bundaberg Regional	0	4	9.2	19.2	28.7	34.1	37.9	48.1	53.1	59.2	64.6	68.2	70.3	75.9	83.6	88.6	88.9	89.2	102.4	110.6
Burdekin Shire	4.9	14.2	28.2	46.3	57.7	64.1	68.2	74	80.8	85.1	88	93.9	96.7	99.6	103.7	107.4	109.6	111.6	113.1	116.9
Burke Shire	5.1	8	19.4	35.5	43.5	51.9	56.2	68.9	74.7	79.8	83.3	92.2	98.5	102.5	112.2	114.1	119.3	125.7	130.6	138.7
Cairns Regional	5.5	13.2	26.7	43.8	54.6	61.7	65.7	73.9	78.7	86.9	89.8	96.9	98.1	99	101.2	103.8	110.7	111.7	118.7	121.9
Carpentaria Shire	8.4	15.5	26.5	43.1	51.6	56.2	59.3	68.4	73.6	80.1	83	86	86.4	87.2	90.4	93.1	97.8	103	105.9	108
Cassowary Coast Regional	4.5	13.7	27	47.3	57.5	63.8	66.6	74.5	79.8	86.5	89.1	95.2	96.2	100.3	103.6	106.2	115	116.3	118.9	136.4
Central Highlands Regional	0	6.7	15.3	24.9	31.5	35.6	38.3	44.4	49.2	54	57.9	63.1	66.1	67.8	71.3	79.4	81.3	86.2	94.9	97
Charters Towers Regional	4.3	15.9	29.8	46.6	56.7	62.4	65.3	72.5	74.8	78.5	80.6	85.5	87.4	89.8	95.4	101	105.5	106.9	107	109.9
Cherbourg Aboriginal Shire	0	1.6	4.2	10.8	15.8	18.3	20.7	25.5	29.7	34.9	39	47.5	48.9	52.2	57.4	58.5	64.1	67.2	73.4	83.4
Cloncurry Shire	0	3.1	6.3	11.8	16.8	20	22.3	26.4	28.3	31.1	33.8	35.5	37.6	40.5	46.1	50.3	61	61.8	63.6	69.9
Cook Shire	22.1	52.5	68.2	79.5	84.8	87.5	90.3	93.1	95.6	100.1	101.8	106.9	108.9	109.6	114	116.9	117.7	123.2	124.2	135
Croydon Shire	5.8	7.4	12.7	20.6	24.7	27.1	30.3	35	39.6	43.7	47.6	51.3	54.7	56.5	63	63.6	68.1	73.5	88.3	97
Diamantina Shire	0	0	0	0.9	3.1	4.5	5.4	8.1	10.1	13.4	15.3	22.4	26.3	32.4	36.3	37.6	44.5	49.3	53.4	59.1
Doomadgee Aboriginal Shire	3.6	7	13.9	27.2	35.6	41.8	45.4	53.5	59.5	67.3	71.4	75.6	79.8	86	91.1	95.7	105.2	107	108.2	114.1
Douglas Shire	6.4	14.8	27.3	41.6	50.1	56.5	61.4	68.8	74.8	79.9	83.7	87.7	90.5	93.4	96.7	97.9	104.8	107.6	110.6	118
Etheridge Shire	4.4	9.8	18.1	26.1	31.4	35.6	38.5	43.1	46.8	49.7	55	58.2	60.8	63	69.3	69.9	72.7	76.6	77.5	81.7
Flinders Shire	2.3	6.7	11.6	18.9	24.2	27.6	30.1	37.2	38.5	44.2	47	50.7	54.1	56.9	61.3	64.1	69.1	77.9	78.1	81.8
Fraser Coast Regional	0	4.2	9.8	20	30.1	37.2	43.7	52.7	58.9	64.4	67.5	75.3	79.5	82.5	83.7	86.3	92.9	93.6	95	95.2
Gladstone Regional	0	6	12.4	23.5	32	37.7	41.9	52.5	60	67.1	73.5	80.4	82.7	86.4	92.8	95.8	99.1	102.3	108.5	116.8
Gold Coast City	0	0	4	10.9	17.5	22.2	25.1	32.5	36.2	46.2	49.9	60.2	66.4	67.4	75.7	76.2	82.6	92.7	95.2	101.4
Goondiwindi Regional	0	0	2	6.1	9.5	13.1	15.8	22.4	26.5	32	37.6	42.7	46.9	49.5	54.2	56.9	66.7	66.8	66.8	82.9
Gympie Regional	0	1.6	7.4	17	24.5	29.1	34	43.8	51.6	58.4	63.2	68.6	72.1	76.3	79.9	88.1	90.2	94.1	97.4	97.7
Hinchinbrook Shire	5.5	12.4	23.3	39	49.1	54.8	60.2	67	72.9	79.5	82.7	88.7	93.2	96.8	100.7	104.8	113.9	114.2	115	127.6
Hope Vale Aboriginal.Shire	7.3	17.8	31.3	44.6	52	56.7	62	68.6	72.7	77.5	81.6	86.1	90.3	91.4	93	94.8	102.8	104.5	107.7	115.7
Ipswich City	0	0	3.3	10.1	16.1	20.3	23.4	31.5	36.4	40.9	43.5	49.7	55.4	60	67.1	68	73.7	78.5	95.7	104
Isaac Regional	4.4	15	32	51.5	59.9	65.3	69.1	75.7	79.8	84.6	87.6	92.1	94	95.7	98.6	99	102.5	110.5	111.1	116.4
Kowanyama Aboriginal Shire	4.2	12.7	21	34.9	44.1	49.9	54	59.7	65	72	73.7	79.9	82.7	84.8	84.8	84.8	87.3	89.9	97.8	98.6
Livingstone Shire	2.3	9.8	21.2	36.3	48.1	54.2	58.5	67.9	73.5	81.6	85.9	91.3	93.4	93.6	99.2	99.8	102.2	103.6	108.2	112.4
Lockhart River Aboriginal.Shire	11.6	22.6	35.3	49.6	58.6	64.1	67.4	73.3	76.2	79.1	83.3	88.6	91.8	92.5	99.2	101.2	105.4	113.4	116	116.4
Lockyer Valley Regional	0	0	2.8	9.7	14.5	18.5	22.1	29.6	33.9	41.1	43.5	48.5	53.7	57.1	59.2	63.8	78.3	79.9	81.8	82.5
Logan City	0	0	3.8	10.5	16.7	21.6	24.6	31.1	36.3	42.1	46.2	54.1	59.2	64.8	71.3	73.2	81.7	94.3	97.5	98.6
Longreach Regional	0	0.3	4.4	7.6	10.7	13.7	15.6	19.2	20.3	22.9	25.2	28.7	30	31.9	43.1	45.4	55.9	62.2	64.3	69
Mackay Regional	2.3	15.4	32.7	58.5	68.9	76	81.3	86.2	89.2	93.2	95.6	99.8	102.5	104.6	106.8	107.5	113.2	113.4	122.4	125.6
Mapoon Aboriginal Shire	10.3	22.5	35.9	51.3	59.8	66.1	70.6	77.9	81.5	85.4	89.6	97	98.8	99.5	106.1	110.7	115.7	127.2	127.8	139.6
Maranoa Regional	0	0.6	4.9	8.1	11.7	13.6	16.9	22.6	26.7	32	37.3	43.7	44.6	47.5	52.2	61.4	62.8	66.6	72	77.2
Mareeba Shire	9.3	17.8	30.8	44.5	52.2	57.6	62.4	71.3	75	78.9	83.7	88.6	92.3	93.7	98.2	102.2	110.9	115.1	115.3	115.4
McKinlay Shire	1	4.1	7.1	12	16.2	18.5	20.6	24.7	27.3	30.8	33.2	35.8	37.2	39.2	40.7	44.5	53.5	56.5	62.4	74.9
Moreton Bay Regional	0	1.9	5.1	12.8	18.8	22.5	26.5	35.3	42.8	50.5	56.6	64.4	67.2	68.8	78.2	79.8	81.7	83.7	86.5	88.4
Mornington Shire	5.2	8.1	17.6	33.9	49.2	55.1	60.3	70.2	74.9	83	87.3	91.3	95.2	95.5	96.2	98.4	107.3	112.1	125.9	127
Mount Isa City	0	4.1	9.3	18.7	22.2	24.6	26.6	27.9	29.7	31.8	35.4	39.1	41.8	42.6	48.6	50.6	52.1	53.7	58.6	65.6
Murweh Shire	0	1.6	4.2	7.4	8.8	10.6	13.2	17.1	20.9	24.8	27.9	31.7	35.5	38.5	47.7	50.6	53.9	58.4	61.9	68
Napranum Aboriginal Shire	12.6	24	39	54.3	63	67.7	71.6	78.3	83.3	88.9	92.4	96.2	98	101.6	104.6	106	112.3	113.9	123.2	139.2
Noosa Shire	0	2.4	6.4	14.3	20.5	24.8	29.5	37.3	44.7	53.9	56.3	61	64.4	72	78.4	78.5	93.7	99.3	99.6	103.8
North Burnett Regional	0	4	8.5	19.3	26.2	31.6	35.8	43.9	49.4	57.4	60	63.5	68.2	70.9	75.7	82.1	86.9	92.9	104.3	112.9
Northern Peninsula Area.Regional	13.5	24.5	40.7	58.2	64.8	69.1	73.3	79	82.7	86.9	91.4	97.6	100	100.5	101.8	105	106.7	119.6	120.3	120.6
Palm Island Aboriginal.Shire	4.9	11.9	22.7	36.4	45.9	53.5	57.2	66.5	70.8	76.9	78.5	83.9	86.6	91.7	99.2	99.9	113.4	117.7	122.6	134.6
Paroo Shire	0	0	0	0.6	2.1	3.1	3.9	5.6	7.2	9.3	12	18.4	20	22.7	28.5	29.7	55.6	57.1	75.8	83.1
Pormpuraaw Aboriginal Shire	7.3	15.4	27.5	43.7	52.7	56.8	61.4	67.7	72.6	77.6	79.3	83.2	86.2	86.3	89.8	93.7	108.4	112.6	115	118.8
Quilpie Shire	0	0	1	3.5	4.8	5.6	6.8	10.3	12.1	14	15.5	18.3	23	26.9	35.3	38.3	51.2	65.7	67.7	72.7
Redland City	0	0	4.9	11.7	17.7	22.3	26.4	35	37.9	46	53.5	59.8	66.6	67.6	70.4	73.7	84.3	88.3	94.6	97.1
Richmond Shire	0.7	4.4	7.6	12.8	15.7	19.1	20.9	24.8	27	32	34.4	39.1	41.6	44.1	45.9	48.6	53.5	53.5	53.5	66.2
Rockhampton Regional	0	6.5	13.3	23.6	30.6	35.2	40.1	47.8	52.3	59.6	65.1	71.2	74.7	76.7	83.7	87.4	95.2	98.4	101.1	103.1
Scenic Rim Regional	0	0	3.3	10.4	17.2	20.8	25.3	33.5	37.9	43.6	48.7	56.3	60.1	61.5	67.5	69	78.7	93	95.5	111.3
Somerset Regional	0	1.9	5	12.9	19.5	23.4	28.1	34.6	42.3	49.4	53.5	58	62	64.2	73.5	74	83.8	93.4	98.8	98.9
South Burnett Regional	0	2	5.3	13.3	18.2	22.6	26.5	33	37.1	46.2	50.8	55.4	58.6	61.8	67.1	67.7	81.8	86.8	87	89.1
Southern Downs Regional	0	0	1	8.1	13.5	17.5	20.3	28.2	33.2	40.2	43.1	44.8	46.5	49.3	54.4	61.4	70.2	76.9	78.9	94.7
Sunshine Coast Regional	0	2.2	5.9	14.3	20.1	24.5	28.4	38.6	47.3	53.5	58.2	63.6	68	70.4	73.2	75.4	88.3	89.4	91.6	101.6
Tablelands Regional	5	12.5	25.3	43.6	53.3	58.1	62	69.9	76.5	80.7	81.9	84.1	85.9	89.1	93.6	96	100.1	107	112.2	112.8
Toowoomba Regional	0	0	3.7	10.7	16.3	20.8	23.9	32.1	35.9	43.5	48.5	53.4	56.8	60.5	69.2	73.2	77.8	82.1	91.5	94.7
Torres Shire	14.7	28.1	47.9	64.2	71.7	76.2	79.5	85.6	88.7	92.4	96.7	99.2	101.9	105	105.9	106.1	118	119.5	125.8	128.9
Torres Strait Island.Regional	10.6	30	50.1	64.6	72	75.8	78.8	84.6	87.1	91.9	93.1	94.8	97.2	98.9	105.1	108.5	110.5	121.4	126.6	134.8
Townsville City	5	12.9	26.5	43.4	52.2	60.8	65.1	72.2	75.4	82.2	87.4	90.5	92.6	97	101.3	102.4	106	111	118.4	126.4
Weipa Town	13.2	18.4	29	41.5	48.6	54	57.5	62.4	66.4	70.2	74.8	77.3	80.3	84.6	87.2	88.3	93.4	97.2	101.4	121.6
Western Downs Regional	0	0.1	5.3	11.2	16.7	22.4	23.9	31.3	36.3	42.7	47.7	51.9	55.7	58.1	65.4	67.6	76.2	80.2	80.6	81.5
Whitsunday Regional	3.5	17.6	39.2	65	74.7	80.7	85.6	91.3	93.1	97.3	98.6	101.2	101.9	102.6	106.3	109.2	111	113.6	118.2	124.2
Winton Shire	0	2.4	5.6	8.8	11.9	15.1	17.7	20.8	23	26.7	28.2	31.4	33.5	35.2	39	44.6	58.9	63.3	64.5	87.6
Woorabinda Aboriginal Shire	0	4.7	10	16.8	22.3	25.8	28.3	32.4	35.8	41	45.3	49.5	52.9	55.6	62.1	67.8	79.8	80.5	81.2	82.9
Wujal Wujal Aboriginal.Shire	5.3	13	22.9	35.2	41.3	46.5	49.9	56.6	60	64.2	67.3	68	74.9	76.5	81.1	82.3	87.2	87.5	91.6	99.4
Yarrabah Aboriginal Shire	4.8	12.5	24	39.3	49	56.5	60.6	69.3	73.5	79.8	85.1	89.4	92.7	96.3	100.4	100.6	102.4	108.2	111.2	118.5



Recurrence of Tropical Cyclones across Queensland's LGAs (RCP4.5 – 2081–2100)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Local Government Areas	2 50	5 20	10 10	20 5	30 3.33	40 2.5	50 2	75 1.33	100 1	150 0.67	200 0.5	300 0.33	400 0.25	500 0.2	750 0.13	1000 0.1	2000 0.05	3000 0.03	5000 0.02	10000 0.01
Aurukun Shire	13.2	26.3	41.9	56.6	63.2	69	73.6	78.9	81	83.9	85	90.7	93.2	95.4	98.3	100.3	105.9	114.4	118.3	141.5
Balonne Shire	0	0	0	1.4	2.8	4.2	5.1	7.6	10.5	15.9	19	26.7	30.1	31.4	38.1	44.7	55.2	71	78.7	98.1
Banana Shire	0	0.8	2.9	9.9	18.4	25	29.2	37.3	43.5	52.4	57.5	64.1	71.9	81.3	85.9	87	99.3	101	107.9	109.3
Barcaldine Regional	0	2.8	7.9	14.8	20.6	24.3	27.7	31.9	35.2	41	43.9	48.3	52.5	55.6	59.7	61.2	67.4	71.6	75.4	88.8
Barcoo Shire	0	0	0.9	2.7	4.7	5.9	7	10.4	12.8	14.7	17.4	19.2	22.1	25.5	33.5	38.1	48.9	55.6	56.2	68.8
Blackall Tambo Regional	0	1	2.8	5.5	7.4	9.8	12.5	16.2	21.3	24.2	26.6	30.2	33.3	35.1	38.6	39.5	45.8	46.4	49.8	60.6
Boulia Shire	0	0.7	1.9	4.6	6	7.9	9	11.2	13.5	16.6	17.5	21.4	23.4	24.2	25.7	28.5	33.6	38.4	44.3	109
Brisbane City	0	0	1.7	9.6	14.7	18.5	22.9	28.8	37.2	45.3	49.6	55.6	62.2	63.6	65.8	69.2	76.8	85.8	93.5	98.3
Bulloo Shire	0	0	0	0	0	0.1	0.1	1.1	2.4	3.8	4.5	9.1	13.9	19.9	27.6	30.4	59.1	68	72.5	83.7
Bundaberg Regional	0	1	2.6	9.7	18	24.2	29.3	41.2	46.2	54.3	60.8	67.9	71.1	77.8	85.8	95.7	97.5	99.2	103.9	111
Burdekin Shire	4.9	10.1	23.4	42.9	55.5	62.2	68	73.8	81.2	86.2	89.2	99.2	102.2	104.9	108.9	113	118.7	118.7	118.8	120.2
Burke Shire	5.1	8.1	18.6	36.4	44.2	52.1	55.1	65	69	71.8	74.4	79	82	86.8	95.8	99.1	103.5	107.9	108.9	115.4
Cairns Regional	4.9	13.8	28.8	46.1	58.2	65.8	69.4	77.9	82.3	90.5	94.2	101.8	102.4	104.1	109.1	110.5	120.4	124.8	129	139.8
Carpentaria Shire	9.2	18.9	28.9	45.3	54	58.1	60.9	68.2	72.9	77.9	79.8	84.1	86.4	87.8	89.2	91.3	95.6	98.4	99.9	103.2
Cassowary Coast Regional	3.4	13.3	28.5	48.7	58.6	65.1	67.9	76.8	81.9	88.4	90.8	97.7	98.8	102.9	106.5	109.5	123.5	127.3	131.1	131.2
Central Highlands Regional	0	1.7	5.9	18	25.8	31.1	35.4	43.9	49.4	53.7	57.2	62.6	67.2	69	73.6	82.8	84.7	91.3	102	102.8
Charters Towers Regional	3.1	14	29.1	46.5	57	62.9	66.4	74	76	81.1	83.5	88.3	89.8	91.8	95	97	104	108.8	112.5	114.8
Cherbourg Aboriginal Shire	0	0.2	0.6	6	9.4	12.1	14.4	20.7	25.4	29.9	35.2	44.9	46.5	52.5	58.1	59.8	66.8	68.2	77.4	88.6
Cloncurry Shire	0	3.7	6.9	11.3	14.8	17.9	19.8	23.2	25.2	29.3	31.1	32.5	34.9	36.8	42.6	43.6	53.3	53.5	53.8	101.2
Cook Shire	23.3	55.3	72.6	85.8	91.4	94.2	96.8	100.1	103	106.4	108.3	111.3	113.2	114.3	118.8	119.8	121.5	122.6	139.6	145.2
Croydon Shire	5.8	9	15.8	23.2	27.5	30.1	32.7	37.4	41.2	45.1	49	51.2	53.9	56.6	62.1	63.3	68	70.2	72.3	72.4
Diamantina Shire	0	0	0	0.9	3	4.1	4.6	7.1	8.9	11.9	13.3	19.2	21.8	27.2	29.5	32.9	40.1	41.3	49.5	53.8
Doomadgee Aboriginal Shire	3.6	7.1	14	28	36.5	41.7	44.9	52	56.4	63.8	67	69	74.3	77.9	79.5	82.4	92.4	102.5	103.2	105.1
Douglas Shire	6.1	15.9	29	44.4	52.9	59.1	65	72.3	78.5	85	88.6	95.2	98.5	102.4	104.9	105.4	113.2	115.8	118.2	128.3
Etheridge Shire	3.8	11.7	21	28.7	34.2	38.5	41	45.5	48.5	50.9	57.1	61	64	67.8	73.6	74.5	78.3	83.3	85.6	89.7
Flinders Shire	2.3	6.2	12.3	20.4	27.1	30.7	33.5	40.6	42.8	49.5	51.9	55.1	59.1	61.7	66.7	68.9	70.4	78.7	79.1	80.2
Fraser Coast Regional	0	1.5	3.9	10.7	19.4	28	34.6	43.6	50.1	58	63.2	73.4	73.8	76.3	79.1	83.9	89	91.8	92.9	95.9
Gladstone Regional	0	1.5	2.3	11.7	22.8	30.1	35.9	46.8	54.6	62.7	69.6	80.4	83.8	90.3	96.4	99.7	101.9	107.6	112.6	123.4
Gold Coast City	0	0	2.3	8.1	14	17.5	20.2	25.7	29.5	41.2	45.5	54.4	58.7	62.8	70.5	72.2	80	93.8	94.4	95
Goondiwindi Regional	0	0	1.1	3.2	6.4	9.5	11.5	17.7	21.4	28.6	35.6	41.3	45.6	48.6	54	56.4	62.3	62.9	64	64.8
Gympie Regional	0	1.2	3.3	9.2	15.4	21.6	26.6	37.6	46.7	54.3	58.6	65	72.3	75.2	82.1	86.2	86.3	92.5	94	95
Hinchinbrook Shire	5.5	11.5	23.2	39.5	48.8	54.7	59.6	66.4	72.7	79.1	82.7	88.4	93.6	97.1	98.6	100.6	106.1	111	112.8	132.2
Hope Vale Aboriginal.Shire	7.3	18	33	48.7	57.6	64	69.8	77.7	81.2	86.4	91.6	96	98	99.8	103.8	105.1	112.9	114.1	117	124.3
Ipswich City	0	0	1.1	7	12.2	15.5	17.6	25.3	30.5	37.4	41.5	46.1	50.6	54.3	60.2	60.2	69.2	80.5	88	99.1
Isaac Regional	4.4	5.2	22.6	45.7	54.8	60.1	64.5	73.7	77.9	84.3	88.5	93.3	94.5	96.5	102.9	103.7	112.6	120.5	123.5	135.9
Kowanyama Aboriginal Shire	6.3	14.7	23.2	37.1	46.1	52.4	56.8	63	66.2	71.5	77	79.1	80.9	82.6	85.1	86.9	87.2	92.8	99.1	99.3
Livingstone Shire	2.3	2.5	8.3	25.8	38.7	46.9	51.5	62.3	70.1	78	84.1	90.4	92.4	93.6	99.7	102.9	105.7	106.2	112	118.1
Lockhart River Aboriginal.Shire	11.8	24.4	37.3	52.6	62.1	68.1	71.7	77.7	82.4	88.7	92.7	98.1	101.6	103	106.8	109.3	114.9	120.9	121.8	122.2
Lockyer Valley Regional	0	0	0.5	6.4	10.2	13.4	17.2	23.4	29.1	37.9	41.5	46.3	49.8	53.7	55.3	60.6	68.7	74	75.2	78.1
Logan City	0	0	1.8	7.6	12.8	17.1	19	23.9	30	39	42.5	50.2	52.7	56.8	63.5	65.9	83	90.9	91.7	93.7
Longreach Regional	0	1.4	3.6	7	10.4	13.5	15.6	20.2	22	24.9	28.5	31.1	32.8	34.8	45.3	46.6	57.2	61.8	63	63
Mackay Regional	4.7	6.5	21.6	50.6	62.5	71.2	76.5	82	86.5	90.8	93.4	101.2	103.6	105.9	107.7	109.3	120.8	131.1	138.2	140.8
Mapoon Aboriginal Shire	9.9	23.6	37.5	52.8	61.9	67.6	72.1	78.7	82.6	86.4	90.5	93.6	96.6	98.2	99.6	100.8	105.8	111.4	114.6	118.7
Maranoa Regional	0	0.7	1.7	3.9	6.9	8.9	12.2	18.9	23.6	31.2	36.7	42.2	44.8	46.9	52.2	60.6	61.4	63.3	77.7	82.2
Mareeba Shire	9.4	20.9	33.5	47.1	55.5	61.1	66.2	75	78.6	82.6	87.3	94	98.3	99.5	102.3	109.1	120.1	121.6	121.7	121.9
McKinlay Shire	1	4.7	8.5	14	18.1	20.3	22.2	25.5	28	31.8	34.5	36.1	37.9	39.8	39.9	42.5	45.5	47.5	48	52.5
Moreton Bay Regional	0	0.3	0.8	8.7	13.1	16.6	20.3	29.9	36.6	46.3	52.2	56.4	61	62.9	67.6	68.9	71	82.9	83.9	86.4
Mornington Shire	5.2	8.6	18.6	35.6	49.1	55.3	59.6	66.8	71.2	75.3	78.4	82.9	85.6	85.8	89.2	89.7	92.9	100.1	102.5	105.9
Mount Isa City	0	4.5	8.3	15.6	19.3	21.7	23.4	25	26.7	29	32	35.4	39	40.5	44.2	46.2	49.6	54.7	60.7	100.9
Murweh Shire	0	0.4	1.2	4	5.7	7.4	9.8	14	18.4	24	27.3	32.8	35.7	37.6	45.6	48.6	50.9	55.2	61.7	74.7
Napranum Aboriginal Shire	12.7	25.9	40.8	55.6	64.7	69.3	72.7	78.9	82	87.9	91.1	94.4	97.4	98	98.4	99.1	108.9	110.3	114.5	148.8
Noosa Shire	0	1.1	2.9	8.6	13.8	17.6	22.7	30.4	39.7	48.6	52.8	58.2	62.2	69.7	72.5	73.6	92.2	99.8	101	102.8
North Burnett Regional	0	0.7	1.9	9.2	17.2	24.8	29.7	38	44.8	55	58.2	64	69.4	73.8	76.8	82.2	93.8	96	108.9	111.3
Northern Peninsula Area.Regional	13.5	24.4	41	59.1	65.4	71.2	75.5	80.2	83.7	87.5	91	97.7	99.5	99.7	103.7	106.2	109.6	112.5	113.2	116.2
Palm Island Aboriginal.Shire	4.9	10.2	21.6	36.1	45.5	53.9	57.9	67.1	70.5	76.6	78.9	85.2	86.5	91.5	98.4	100.9	108.6	120.2	127.7	134.9
Paroo Shire	0	0	0	0	0	1.8	2.3	4.1	5.9	8	10.8	17.2	19.7	22.6	27.8	29.7	59.8	71.8	79.7	85.1
Pormpuraaw Aboriginal Shire	8.2	17.8	29.4	46.2	54.6	59.7	63.8	68.7	71.4	74.5	76.1	79	80.1	81.5	86.9	87.8	100	105.3	105.7	105.9
Quilpie Shire	0	0	0.8	2.5	4	4.6	5.8	9.6	10.6	12.3	15.1	19.7	25.1	29.5	35.9	39.2	52	62.6	65.6	70
Redland City	0	0	2.1	8.5	13.8	17.7	20.7	27.7	30.7	40.4	47.7	51.8	57	57.2	57.7	61.2	82.9	92	93.4	94
Richmond Shire	0.7	4.8	9	15.6	19.5	22.8	24.9	29.1	31.3	36.7	39.2	43.6	46.9	48.7	50.6	52.3	59.3	59.6	60.1	63.1
Rockhampton Regional	0	1.6	3.9	13.6	22.1	27.9	33	44	49.8	58.1	62.8	69.4	73.8	74.3	82.2	86.1	100.6	107.1	110.2	112.7
Scenic Rim Regional	0	0	1.7	7.2	13.5	16.5	19.7	26.4	31.1	39.2	45	53.4	55.8	58.9	64.9	66.3	72.6	91.2	92.2	97
Somerset Regional	0	0.5	1.4	7.8	12.4	17	22.3	28.5	37.5	46.7	50.5	55.2	56.5	59.2	66.1	70	75.7	85.3	91.7	92.3
South Burnett Regional	0	0.6	1.7	6.7	10.7	15.4	19.4	27.3	31.8	40.8	46.2	51.7	56.1	58.4	66	67.1	83.6	91	91.9	94.2
Southern Downs Regional	0	0	1	4.8	9.9	13.4	15.7	22	27.7	37	41.2	43.5	46.4	48.3	54.5	62.2	66.4	69.2	71.9	87
Sunshine Coast Regional	0	0.9	2.4	9.1	13.4	17.9	21.7	32.5	41.5	47.9	53.3	59.9	63.2	64	65.9	67.5	78.2	81.9	94.2	97.5
Tablelands Regional	4.3	13.4	27.9	45.4	55.2	60.2	62.9	70.9	77	81.8	84.1	88.2	92.1	95.2	98.6	99.6	108.5	112.6	118.7	119
Toowoomba Regional	0	0	2.2	6.6	10.3	14.7	18.4	26.9	32.1	40.1	45	51.1	53.7	56.1	67.6	68	69.7	75	84.6	87.3
Torres Shire	14.7	27.4	48.4	65.4	73.6	78.4	82	89.1	91.4	95.8	98.7	104.7	107.5	108.7	110.4	113	116.3	118.7	128.9	134.6
Torres Strait Island.Regional	14.6	28.8	50.1	67.2	75.7	80.5	83.9	88.9	92.5	98.2	100.2	101.5	102.7	105.4	110.5	114.1	115.3	125.5	129.9	130.1
Townsville City	5	10.5	23.9	42.1	51.4	60.1	64.6	72.6	77.8	84.4	90.6	93.7	95	98.5	102.8	104.7	107.4	110.6	123.1	127.2
Weipa Town	13.2	19.7	30.6	42.7	49.7	54.1	57.8	63	66.7	70.2	73.5	77	80	80.4	80.5	83.7	92	96.7	100.6	140
Western Downs Regional	0	0.6	1.5	5.1	9.8	16.4	18.1	25.6	31.7	37.6	43.5	50.1	52.3	54.7	62	62.2	78.8	85.5	91.7	94.2
Whitsunday Regional	5.8	9.8	30.4	58	68.9	75.7	82.1	88.7	91.4	97.7	100.5	104.2	105.7	108.8	113.5	117.5	121.5	121.6	123.4	124.6
Winton Shire	0	1.6	5.2	8.9	12.4	16.8	20	24.6	26.8	31	32.6	35.6	37.5	38.7	41.7	47.1	55.2	57.6	58.5	73.2
Woorabinda Aboriginal Shire	0	0.7	3.5	9.7	15.7	20	23.9	30.2	34.8	40.9	45.3	52	54.5	57.2	63.3	71.7	86.3	88.3	91	98
Wujal Wujal Aboriginal.Shire	5.1	13.8	23.7	36.8	43.9	49.1	51.6	58.5	62.7	67.3	71.2	73.4	77.9	80.4	88.4	90.9	96.9	98.6	102	109.7
Yarrabah Aboriginal Shire	4	12.7	25.8	41.1	52.2	59.9	64.5	73.1	78.4	85.3	89.2	95.2	98.8	100.3	105.6	107.3	109.8	110.5	119	132.4

Gust wind speed (m/s) / Tropical Cyclone categories

Category	Gust wind speed (m/s)
TC 5	above 77.5
TC 4	62.5 – 77.5
TC 3	45.8 – 62.5
TC 2	34.7 – 45.8
TC 1	27.8 – 34.7
TD	0 – 27.8

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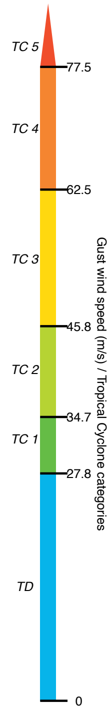
Recurrence of Tropical Cyclones across Queensland's LGAs (RCP8.5 – 2041–2060)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

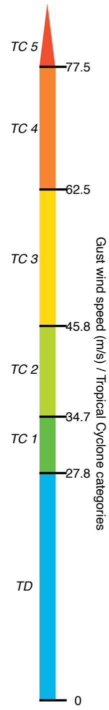
Local Government Areas	2 50	5 20	10 10	20 5	30 3.33	40 2.5	50 2	75 1.33	100 1	150 0.67	200 0.5	300 0.33	400 0.25	500 0.2	750 0.13	1000 0.1	2000 0.05	3000 0.03	5000 0.02	10000 0.01
Aurukun Shire	11.9	22.1	37.4	51.2	57.4	62.5	66.7	72.6	74.1	77.5	81.4	85.6	88.1	88.5	94	94.4	97.9	103.4	104.1	110
Balonne Shire	0	0	0	1.9	4.2	6.4	7.5	12.3	16.2	21.8	24.5	31.4	34.3	35.5	44.5	48.5	54.4	60	62.9	83.8
Banana Shire	0	2.5	5.2	12.8	19.8	25.4	29	36.1	40.8	46.3	50.4	57.1	64.2	73	73.6	78	80.3	87.1	100.7	102.3
Barcaldine Regional	0	3.7	9.2	16.1	22	24.8	27.4	31.1	34.4	39.7	42.5	45.3	48.5	51.9	56.2	59.2	64.2	64.6	64.8	66.8
Barcoo Shire	0	0	0.9	2.7	4.6	6	6.7	10.4	13	16.5	18.8	20.7	23.6	26.5	30.1	32.9	41.6	46.1	60.9	61
Blackall Tambo Regional	0	1.3	3.4	5.9	8.1	10.5	13.3	16.9	20.9	24.2	27.2	31.4	34	36	40.8	45.2	53.1	53.4	54	64
Boulia Shire	0	0.6	1.7	4.9	6.8	8.4	9.9	12.8	14.9	18.5	20.5	24.5	25.6	27.9	31.6	34.3	40.3	40.6	40.9	41.8
Brisbane City	0	0	5.2	13.7	21.2	27	31.9	40.7	46.9	52.6	60.1	68.5	71.3	71.8	74.7	77.6	84.2	90.7	93.6	100.7
Bulloo Shire	0	0	0	0	0	0	0	1.6	2.7	4.6	7	10.3	13.8	17.1	21	24.8	46.7	54.1	55.1	68
Bundaberg Regional	0	2.3	5	12	20.9	26.5	30.8	41.2	46.5	54	58.4	62.3	64.9	67.1	73.5	80.6	86.4	88.8	95.2	96.7
Burdekin Shire	4.9	12.9	27.9	47.7	59	65.3	69.6	75.2	82.1	86.8	90.1	93.1	96.4	100	104	109	112	113.2	115.7	116.9
Burke Shire	4.3	5.1	16.8	34.9	43.5	51.1	56.8	67.5	74.5	80.3	84	92	95.7	97	99.8	100.2	101	101	101.6	102.1
Cairns Regional	4.9	18.2	31.4	46.4	55	61.5	65.3	72	76.3	81.5	84	90.1	92.6	93.7	97.9	99.6	106.8	107.3	108.2	109.2
Carpentaria Shire	8.3	16	26	42.3	49.6	52.4	55.3	62	65.8	69.2	71.5	73.8	76	77.7	78.9	80.1	84.9	90.7	98.1	98.3
Cassowary Coast Regional	3.8	17.4	31.7	50.4	58.1	65.1	67.9	74.6	80.2	87.3	90.1	94.8	95	95.4	96.8	99.1	104	104.8	107.3	108
Central Highlands Regional	0	3.5	9.1	20	26.6	30.6	33.2	39.9	44.1	49.1	51.3	56.5	62.3	63.2	70.4	80.3	80.3	80.5	91.9	96.3
Charters Towers Regional	3.4	16.6	32.1	49.3	60.1	65.4	68	75.2	78	81.8	83.9	89.2	91.6	96.2	98.9	100.9	106.5	107.7	110.1	125.9
Cherbourg Aboriginal Shire	0	1.1	2.9	8.1	13.8	17.5	19.9	25.7	29.5	34.8	38.9	46.7	50.1	53.6	58.7	60.4	63.9	67.2	73.7	100.7
Cloncurry Shire	0	2.9	6.1	10.9	15.5	18.4	21	24.7	26	29.5	32.4	34.4	34.6	35.2	39.5	42	46.5	47.6	49.5	50.1
Cook Shire	21.6	52.9	68.2	78.7	83.4	85.9	88.2	91.2	93.5	95.3	95.9	100.1	103.4	103.8	106.1	107.1	108.6	110.4	111.1	112
Croydon Shire	5.8	7.8	13.9	21.3	26.4	28.7	31.6	36.3	40	43.4	45.5	48.2	50.4	53.5	58.5	59.5	63.4	79	82.4	89.5
Diamantina Shire	0	0	0	1.5	3	4.2	5	7.4	9	11	13.2	18.8	25	28.9	29.2	29.6	39.6	46.3	51	53.5
Doomadgee Aboriginal Shire	3.6	4.8	11.1	26.3	34.8	42.4	46.8	55.4	61.9	66.9	70.7	76.6	80.5	84.1	89	90.9	96.1	97.9	98.8	102.1
Douglas Shire	6.3	18.8	31.5	44.8	52.4	57.7	63.2	69.6	73.9	79.6	83.8	88.9	91.5	93.9	94.3	94.7	96.4	100.4	102.8	110.3
Etheridge Shire	3.9	12	20.5	28.5	34.5	38.8	41.1	46.6	49.5	52.7	58	62.3	65.9	68	73.2	73.6	74.5	75.2	76.2	78
Flinders Shire	2.3	6.7	13.9	22	27.8	31.1	33.6	40.7	43.4	50.8	55.4	58.6	63.5	67	70.7	72.4	73	80.3	94.6	110.2
Fraser Coast Regional	0	2.7	6.9	16	25.3	32.9	39	49	55	59.7	67.1	76.6	77.3	78.1	80.9	82.4	84.2	87.4	88.5	90.1
Gladstone Regional	0	3.2	6	14.6	22.4	28.8	34.2	43.6	50	55.6	62.9	69.2	73.5	75.2	80	85.3	86.5	87.7	101.9	115.7
Gold Coast City	0	0	4	11.8	19.7	24	28.8	37	40.9	52.9	59.2	68.2	74.1	76.3	81.5	81.8	83.2	85.1	85.1	88.9
Goondiwindi Regional	0	0	1.9	5.7	10.1	14.5	18	23.9	29.6	37	42.5	47.4	50.6	52.7	58.2	59.5	71.9	74.8	75	75.4
Gympie Regional	0	2.1	5.7	13.4	22.6	27.9	32.1	43.6	50.8	57.8	62.7	69.8	72.4	77.9	79.7	83.7	86.8	91.3	93.2	93.9
Hinchinbrook Shire	5.5	13.9	26.9	42.6	53	58.8	64.1	69.8	73.9	79.5	83.6	89.8	93.8	95.6	98.6	99.4	103.8	106.8	109.5	116.5
Hope Vale Aboriginal.Shire	7.3	20.2	34.4	48.3	55.2	58.2	63.2	69	73.4	77.8	82.1	85.9	87.6	88	91.7	92.6	96	100.9	104.6	115.3
Ipswich City	0	0	2.7	10.2	17	23.3	27.4	34.5	39.4	45	48.1	57.5	63	67.3	72.2	73.3	78.1	80	84	90.4
Isaac Regional	4.4	9	25.9	43.8	52.4	57.3	60	67.1	70	74.4	78.4	84.2	85.8	88	89.7	92.3	95.6	101.8	104.4	122.1
Kowanyama Aboriginal Shire	10	12.1	19.9	31.8	40.6	46.7	49.8	54	55.5	62.4	66.3	69.7	71	74.6	77.3	77.5	78.3	83	102.1	105.6
Livingstone Shire	2.3	4.8	11.5	27	37.9	44.5	47.6	55.4	64.1	71.3	75.3	81.1	84	84.7	86.5	88	90.3	96	99.8	100.5
Lockhart River Aboriginal.Shire	11	22.8	35.6	50	58.6	63.7	67.1	72.3	75.9	78.4	82.9	87.3	90.8	92.3	93.6	96.3	102.2	110.1	111	124.1
Lockyer Valley Regional	0	0	2.1	9.4	15.3	21	25.8	32.1	36.9	45.5	50.1	55.9	58.1	61.8	66.3	69.3	72.8	76.2	81.3	88.5
Logan City	0	0	3.4	11.1	18.5	23.9	27.9	34.3	39.8	49.4	53.4	61.3	67.4	71.3	78	79	83.8	83.8	84	96.9
Longreach Regional	0	1.6	4.1	7.3	10.6	14.1	16.1	20.8	23.1	27	27.5	31.7	32.7	34.4	44.4	46.3	52.9	53.9	56.3	62.5
Mackay Regional	4.7	10	25.2	50.1	60.5	66.8	71.4	75.2	79.1	82.2	85.3	90.5	93.8	96.4	100.6	100.8	112.9	115.2	119.8	121.6
Mapoon Aboriginal Shire	14.8	21.7	33.8	48.6	57	62.8	66.8	72.7	76.3	81.6	84.7	87.2	89.8	92.6	97	97.2	98.2	98.2	102.2	102.6
Maranoa Regional	0	1	2.7	5.5	9.4	12.8	16.7	24.6	28.7	35.4	39.2	43	46.3	48.8	52.9	61.6	65.4	71	78.4	79.2
Mareeba Shire	9.1	21.7	33.9	45.8	53.7	58.3	62.1	70.1	73.9	76.7	80.6	84.7	89	92	95.9	98	107.6	107.7	109.7	110.5
McKinlay Shire	1	4.4	7.8	13	17	19.1	21.7	25.4	28.1	32.2	33.4	37	39.2	41.7	43.7	47.9	55.8	58.5	60.8	62.5
Moreton Bay Regional	0	0	4.8	12.3	19.8	24.4	30.3	40.1	45.4	51.1	57.3	62.9	66.9	68.3	76	76.5	78.9	81.3	87.5	102.8
Mornington Shire	5.2	5.5	13.9	32.6	46.6	53	58.8	68.9	72.4	78.7	82.6	85	89.5	89.9	92.8	96.7	101.3	101.8	102.5	110.4
Mount Isa City	0	2.5	7.6	17.2	21.7	24.4	26.6	28.6	31.5	34.5	35.8	39.3	41.6	42.7	47.3	49.1	50.2	52.6	54.2	58.6
Murweh Shire	0	0.8	2	5	6.7	9	11.2	16.5	20.1	25.4	29	33.5	38.1	41.3	48.4	52.2	56.4	58.3	64.3	67.7
Napranum Aboriginal Shire	11.1	23.3	37	51.9	59.2	62.9	66.9	71.6	75.1	79.5	83.6	90.8	93	95.1	95.6	96.1	96.9	97	97.5	100
Noosa Shire	0	2	5.4	12.2	19.6	24.5	28.9	37.9	44.2	53.8	58.2	65.2	69.7	74.1	75.6	78.6	90	91.4	94.7	94.8
North Burnett Regional	0	2.2	5.3	11.7	21.1	27	30.9	39.2	45	52.8	54.6	59.1	62.6	64.7	68.6	71.4	85.9	98	109.4	112
Northern Peninsula Area.Regional	13.5	22.2	36.1	54.5	61.1	66.1	70.6	74.8	78.8	82.2	84.5	89.2	90.1	90.2	94	95.9	96	99.2	99.8	106.9
Palm Island Aboriginal.Shire	4.9	13	25.4	40.2	49.5	57.1	62.3	70	73.6	80.4	83.1	91	94.5	97.8	102.6	102.9	105.6	117.5	120	121.2
Paroo Shire	0	0	0	0.6	1.2	2.5	3.4	5.4	7.2	9.9	13.8	17.6	19.7	23.7	29.1	34.6	59	62.8	66.6	71.6
Pormpuraaw Aboriginal Shire	6.7	14.7	24.5	39.4	46.9	52.4	55	61.9	66	70	73	75.8	75.9	76	79.2	81.9	92.9	96.4	97.5	104.2
Quilpie Shire	0	0	0.9	2.9	3.9	4.6	5.9	9.2	11.2	14.2	17.2	19.9	23.7	25.8	32.7	35.3	44.7	49.2	53.4	65.2
Redland City	0	0	4.7	12.8	19.4	25.3	30	37.9	41.9	52.9	57.5	66.7	73.4	73.5	73.6	75.7	84.3	84.6	86.8	97.1
Richmond Shire	0.7	5	9.3	16.1	19.9	22.5	24.6	28.7	30.8	35.9	40.5	45.6	49.3	51.1	55.7	58.1	66.6	68.8	71.9	76.3
Rockhampton Regional	0	3.4	6.6	14.8	22.5	28.1	32.9	39.3	42.9	51.1	56.6	63.7	66	68	75.3	79.4	86.4	92.3	98.2	99.9
Scenic Rim Regional	0	0	2.8	10.4	19	24.1	28.8	37.1	42.3	48.4	55.7	64.3	67.4	69.2	76.3	77	85.6	87.1	89.6	91.8
Somerset Regional	0	1.5	4.1	11.9	18.9	24.8	31.2	37.8	45	53.3	55.6	59.8	62.8	65.7	74	77.2	80.1	83	85.8	88.6
South Burnett Regional	0	1.5	3.9	9.6	17.4	22.2	25.6	32.8	37.7	45.2	50.3	57.4	61	64.8	68.1	69.2	77.8	82.2	83.9	90.4
Southern Downs Regional	0	0	0.6	8.1	13.9	19.1	23.2	30.9	36.2	42.8	47.5	53.5	57.3	58.3	62.9	65.5	77.1	77.2	77.2	86.6
Sunshine Coast Regional	0	2	5.3	12.9	20.6	26.3	30.7	40.8	48.6	53.5	59.9	61.2	67.8	69.5	75.1	78.4	85.3	87.5	89.1	96.2
Tablelands Regional	4.4	17.3	30.4	46.1	54.3	58.6	61.3	69.5	74.5	80.3	82.3	84.7	86	88.6	89.4	92.8	96.6	97	97.6	104.9
Toowoomba Regional	0	0	2.9	10.2	16.4	21.9	26.7	35.5	40.3	47.3	50.1	57.9	60.4	62.8	71.2	71.6	73.4	79.1	81.8	81.9
Torres Shire	14.7	25.3	42.3	60.5	69	72.6	75.3	80.8	83.2	87.5	90.1	91.8	96.3	97.4	97.8	97.8	100.7	101	101.7	109.8
Torres Strait Island.Regional	14.6	27.1	44.7	61.2	69	73.2	75.9	81.3	84.5	88.2	89.9	92.3	95.3	96	100	100.8	104.6	109.4	115.3	116
Townsville City	5	13.3	28.2	46.7	56.4	65.3	69.1	76.1	80.2	87.2	92	94.7	98.7	105.3	109	110	116.9	118.8	126.6	133.7
Weipa Town	13.2	17.8	27.4	38.5	45.1	48.8	51.6	55.2	59.8	64.2	66.8	70.6	73	74.3	76.4	79.7	84.7	90.1	93.1	100.4
Western Downs Regional	0	1.3	3.5	8.4	14.9	21	24	31.3	37.7	43.5	49.2	53.8	55.2	59	63.9	65.2	74.5	80.2	82.2	91.9
Whitsunday Regional	5.8	13.5	35.3	60.9	70.6	75.1	80.3	85	86.9	91.2	94	96.9	98.2	99.7	103.1	106.6	110.8	112.8	122.9	128.5
Winton Shire	0	2.1	5.6	9.3	13.3	16.6	19.4	23	25.9	31.5	33.7	36.6	39.7	40.7	42.5	48.4	58.7	66.8	80	100.1
Woorabinda Aboriginal Shire	0	2.3	5.1	11.9	17.4	20.8	23.5	28.1	29.8	35.3	40.4	46.6	48.2	51.9	58.4	65.1	77.4	78.3	79.8	87.1
Wujal Wujal Aboriginal.Shire	5.3	16.2	27.1	38.3	44.2	48.5	51.2	57.8	61	63.6	66.4	69	73.9	75.5	80	81	84.9	86.3	86.7	86.9
Yarrabah Aboriginal Shire	4.3	16.9	28	41.7	50.9	56.5	60.6	66.6	70.8	74.9	78.8	81.8	84.6	87.9	93.3	95.6	96.5	100.5	101.1	102.5



Recurrence of Tropical Cyclones across Queensland's LGAs (RCP8.5 – 2081–2100)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Local Government Areas	2 / 50	5 / 20	10 / 10	20 / 5	30 / 3.33	40 / 2.5	50 / 2	75 / 1.33	100 / 1	150 / 0.67	200 / 0.5	300 / 0.33	400 / 0.25	500 / 0.2	750 / 0.13	1000 / 0.1	2000 / 0.05	3000 / 0.03	5000 / 0.02	10000 / 0.01
Aurukun Shire	14.4	17.4	31.7	50.1	58.7	65.2	71.5	77.5	81.8	87.5	90.6	94.7	94.7	95.2	95.9	96.1	97	112.9	114.3	116.9
Balonne Shire	0	0	0	0.8	1.7	3.4	4.1	7.9	11.2	14.9	18.5	24.5	27.3	29.4	38.6	42.3	50	59	60.7	79.5
Banana Shire	0	0.3	0.9	7.7	15.3	21.1	24.6	31.2	35.9	42.4	46.2	54.1	61.9	71.1	73	77	80.8	81.5	81.8	81.8
Barcaldine Regional	0	2	6.1	12.9	18.5	22.4	25	29.4	32.4	37.9	40.5	44.1	48.2	52.6	55.2	56.2	56.5	57.1	57.9	58.3
Barcoo Shire	0	0	0.8	2.4	4.6	6.6	8.4	14.1	19	23.1	30	32.4	34.8	37.3	42.1	43	51.3	58.7	64	64.7
Blackall Tambo Regional	0	0.8	2.1	4.2	6.7	8.8	12.4	16.6	20.7	24	26.8	30.9	31.4	33.8	39.8	43.8	51.2	51.5	52.2	56.5
Boulia Shire	0	0.3	0.8	4.8	7.1	9.3	12	15.6	17.7	22.1	25	30.9	33.8	35.3	38	40.6	43.6	44.3	45	45.3
Brisbane City	0	0	1.6	6.6	11.1	13.9	17.7	24.6	29.1	35.5	43.3	48.6	53.4	53.9	55	68.1	77.6	87.5	90.7	92
Bulloo Shire	0	0	0	0	0	0	0	2.6	4.2	8.4	13.3	19.9	26.2	31.2	33.5	36.1	56.2	69.3	83	83
Bundaberg Regional	0	0.1	0.3	3.7	11.2	17.5	22.3	32.9	39.9	46	51.5	55.8	63.3	66	75	82.7	89.9	92.4	96.2	107.9
Burdekin Shire	4.9	7.1	19.9	36.9	48.8	54.5	58.9	63.4	70.1	75.8	79.5	83	87.1	92.8	97.8	103.7	108.2	110.6	111	112.4
Burke Shire	5.1	5.3	9.1	29.2	38.7	47.9	53.6	63.6	69.4	74.4	80.3	91.3	98.1	101.3	108.6	110.5	111	111	112	125.6
Cairns Regional	6.8	8.1	18.5	35.7	46	52.8	56.8	63.5	67.7	74	77.9	84.6	87.1	87.9	90.8	92.4	99.3	99.8	100.9	104.9
Carpentaria Shire	9.2	13.2	21.6	39.4	48.3	52.5	56.8	65.1	72.5	81	84.1	88.6	90.6	91.9	94.6	97.8	101.5	104.5	110.4	116.6
Cassowary Coast Regional	7.2	7.6	19.9	40.3	48.7	55.6	58.6	65.5	71.2	79.2	82.9	89.3	90.3	90.4	90.7	93.2	99.6	102.9	109.3	112.2
Central Highlands Regional	0	0.7	4.7	16.1	23.1	26.6	29.4	36.5	39.5	44.7	46.6	50.9	56.1	57	61.1	68.9	69.4	74	85.7	89.8
Charters Towers Regional	6.8	8.7	24.4	41	50.7	56.2	59.2	66.6	70.2	73.1	75.7	80	82.7	84.5	88.4	90.4	93.7	96.7	96.9	109.8
Cherbourg Aboriginal Shire	0	0	0	3.2	6.4	8.9	10.6	15.1	17.9	22.6	27.6	36.3	40.3	44.2	50.5	51.3	52.5	53.2	71.2	94.9
Cloncurry Shire	0	1.7	4.5	8.9	14.1	17.9	21	25	27.1	29.7	32.8	35	36.6	37.3	42	44.9	52.5	53.6	55.8	72
Cook Shire	33.4	41	60.1	71.4	76.8	79.7	83.5	88.3	92.2	95.4	96	100.1	101.7	102.7	106.6	106.9	117.2	118.6	118.8	121.2
Croydon Shire	4.4	5.8	9.9	18.7	23.4	25.8	29	33.9	38.7	42	45.1	47	49.3	52.8	59.9	61.3	73.5	80.4	81.1	85.2
Diamantina Shire	0	0	0	1.5	3.6	5	6.6	11.9	16.4	24.9	28.8	35.4	40.1	44.4	45.1	45.8	50.2	53.3	58	62.9
Doomadgee Aboriginal Shire	3.6	4.5	6	20.2	30.1	37	41.3	51.6	59.8	65.5	68.6	76.9	79.4	85.2	89.9	93.3	100.4	104.4	104.8	107
Douglas Shire	6.6	9.4	18	32.7	41.1	47	52.4	59.1	64.4	70.7	74.6	80.4	82.5	84.4	86.2	87.3	92	101	106.5	107.6
Etheridge Shire	5.9	7.4	15.4	24.7	30.8	34.6	37.4	42.3	45.8	48.5	53.7	57.6	61.7	63.6	67.9	68.8	72.7	77	81.7	83.7
Flinders Shire	2.3	4.1	10	18.2	24.1	27.8	30.8	37.6	40.7	46.9	50.7	54.2	58.1	60.8	64.1	65.2	68	76.7	76.8	90.8
Fraser Coast Regional	0	0.5	1.4	5.2	12.2	18	23.9	34.4	44.5	50.8	57.9	69	69.8	71	74.1	75.1	83	83.7	84	84.9
Gladstone Regional	0	0.2	0.6	8	17.1	23.5	28.6	38.3	45.3	52.9	59.8	68.2	71.5	76.4	84.6	86.2	88.8	89.8	91.8	103.6
Gold Coast City	0	0	2.1	4.5	10.6	13.8	16.5	21.9	24.2	33.6	40.8	48.9	56.1	58.1	65.5	67.8	76.9	80.1	86.2	88.5
Goondiwindi Regional	0	0	0.4	1.2	5.4	9.3	11.2	14.1	18	25.1	31.7	37	41	43	47.7	48.8	57.8	63	66.9	81.9
Gympie Regional	0	0.2	0.7	5.1	10.4	14.6	18.2	27.9	35.1	43.7	49.7	53.7	56.7	61.9	67	70.4	77.5	82.8	85.1	90.7
Hinchinbrook Shire	5.5	7.3	18.1	33.7	44.1	50	54.6	60.5	65.1	71.1	74.8	82.9	88.1	90.5	93.1	96.4	101.8	103.9	108.4	119.6
Hope Vale Aboriginal Shire	7.5	10.5	19.2	34.8	42.9	46.8	51.5	57.2	61.8	67.8	71.6	77	79.2	82.1	85.9	86.9	95.5	101.5	103.9	109.8
Ipswich City	0	0	1.1	3	9.2	13	15.5	21.1	24.8	29.1	33.4	42	46.8	53.3	62.5	67	78.3	78.4	78.6	85.4
Isaac Regional	3.9	4.4	19.4	37.8	46.2	50.6	53.4	60	63.2	66.8	71.2	77.9	79.5	81.5	85.4	86.6	93.3	102.7	107.5	127.8
Kowanyama Aboriginal Shire	7.2	10	15.3	29.7	40.2	47.7	52.7	61	64.8	72.7	76.7	83.7	85.6	89.6	90.3	91.2	94.6	100.9	103.7	105.8
Livingstone Shire	2.3	3.7	6	21.7	32.5	38.4	42.6	51.3	57.8	64.6	68.9	75.3	79.4	80.9	84.6	88.4	91.9	94.3	100	106.4
Lockhart River Aboriginal Shire	13.8	15.5	27.2	42.3	51.6	56.7	59.2	64.5	67.5	69.6	73.6	78	81.7	82.5	83.3	87.2	98.9	108.1	109.2	137.5
Lockyer Valley Regional	0	0	0.6	2.4	8.3	11.3	14.9	19.3	23.1	30.2	36	42	44.7	51.4	57.2	60.2	62.3	67.3	70.3	83.4
Logan City	0	0	1.6	3.8	9.8	13.6	16.1	20.2	24.4	31.9	35.3	45.1	48.7	52.9	62.6	69.4	83.3	88.1	88.7	99.9
Longreach Regional	0	1.1	3	6	9.8	13.3	16.2	21.4	24.6	28.8	30.9	34.4	35	36.6	47.5	47.9	51	52.8	52.8	53.4
Mackay Regional	4.7	4.8	17.2	42	51.8	58.1	62.2	67	71.4	75.2	79	83.9	88.5	93.2	95.7	97.6	105.4	107.5	111.6	128.9
Mapoon Aboriginal Shire	14.8	15.2	27.9	45.2	54.3	60.7	64.4	70.9	74.8	81.2	86.3	90.1	93.7	96	99.2	99.8	100.5	101.6	102.1	112.6
Maranoa Regional	0	0.2	0.6	2.5	5.2	7.4	10.6	19.7	23.7	30.9	35.7	41	42.5	45.3	47.5	58.4	60.3	63	70.4	73.8
Mareeba Shire	10.2	13.4	25.5	38.6	46.3	50.7	54.3	62.5	65.7	69.3	74	79.2	81.6	83.4	89.9	93	103.5	104.8	104.8	105
McKinlay Shire	1	2.4	5.8	11.6	16.5	18.2	20.7	24.8	27.3	30.7	32.1	35.3	38.1	40.3	43.5	48.2	55.3	63.9	65.5	80
Moreton Bay Regional	0	0	0.9	5.6	10.1	12.5	16	22.9	28.6	35	41.3	47.3	54.2	55.6	63	65.7	67.8	70	78.2	82.4
Mornington Shire	4.9	5.2	8.3	26.1	41.3	49.7	57.1	68.1	73	79.8	86.4	91.4	95	97.2	100.8	103.5	112.6	117.8	119.5	121
Mount Isa City	0	1.7	4.6	13	18	21.4	23.3	26.9	29.6	33.8	35.9	38.9	41.2	42.7	47.1	50.7	52.1	53.1	56.5	63.5
Murweh Shire	0	0.2	0.5	3.4	4.7	6.7	9.2	13.9	17	22.6	26.5	31.1	35.6	39.5	47.5	52.4	54.8	56.5	60.4	64.2
Napranum Aboriginal Shire	15.6	16.8	31	48.9	57.1	61.8	65.7	71.2	75.8	80.7	86.8	93.1	95.8	98	101.5	102.1	104.4	108.4	109.3	111.7
Noosa Shire	0	0	0.1	4.9	9.4	12	14.8	23.2	29.5	37.6	41	46.5	50.3	57.2	59.4	66.2	78.4	81.6	82.3	82.6
North Burnett Regional	0	0.3	0.9	4.1	12.2	18.5	22.5	31	36.9	45	48	54.5	58.3	64.1	68.2	73	89.2	91.7	99.2	102.4
Northern Peninsula Area.Regional	13.5	16.6	29.3	48.6	56.8	61.9	66.5	70.9	74.5	78.5	81.8	87.5	89.7	90.5	92.4	94.9	94.9	97.1	97.5	98.3
Palm Island Aboriginal.Shire	4.9	7	17.3	31	40.1	47.8	52.7	61.4	64.8	71.2	74.7	83	85.9	89	94.7	97.7	105.2	110.4	111.6	121.2
Paroo Shire	0	0	0	0.2	0.4	1.7	2.6	4.5	6	7.9	11.2	16.5	18.9	22.5	30.8	35.8	60	62.1	70	71.7
Pormpuraaw Aboriginal Shire	9	12	20.2	38.5	47.8	54.3	58.2	67.1	74	79.4	82.4	84.1	85.3	85.4	88.7	90.7	101.5	102.2	105.1	105.2
Quilpie Shire	0	0	0.7	2.2	3.8	4.6	6.4	10.4	13.4	18.3	21.9	25.5	31.4	35.2	42	44.5	55.8	58.6	64.1	73.5
Redland City	0	0	1.9	4.5	9.8	13.5	16.6	22.5	24.5	33.5	40	48	53.8	56	61.4	64.2	81.5	83.4	86.7	97.6
Richmond Shire	0.7	2.7	6.9	13.8	17.9	20.8	22.8	27.7	29.6	33.9	37.6	43.1	45.5	47.6	52.6	55.9	67	73.2	79	84
Rockhampton Regional	0	0.5	2.4	11.1	18.6	23.6	27.9	34.7	38.1	45.9	50.8	56.3	60.3	62.4	72.5	77.3	86.4	90.8	92.9	93.4
Scenic Rim Regional	0	0	1.6	3.6	10.6	13.6	17	22.8	25.8	32.7	38.7	47.6	51.2	53.4	60.6	64.8	82.4	88.3	88.4	88.7
Somerset Regional	0	0	0	5.5	9.9	13.2	16.9	21.7	29.3	37.4	40.7	48.1	51.1	55.1	61.5	68.4	71	73.7	84.4	84.7
South Burnett Regional	0	0	0	3.5	7.6	11.9	14.4	20.1	25.2	33.6	39.1	47.5	50.5	53.5	58.9	59.9	70.5	77.6	77.7	89.1
Southern Downs Regional	0	0	0.6	2.6	7.5	11.4	14.1	18.6	22.7	29.1	34.1	39.8	44	47.5	50.2	56.4	58.8	63.2	69	95
Sunshine Coast Regional	0	0.2	0.6	5.9	9.9	13.2	16.2	24.2	32	38.2	42.5	44.6	50.2	54.1	58.9	62.4	68.6	79.4	88.4	93.3
Tablelands Regional	7.1	7.7	19.7	37	46.3	50.6	53.2	61.4	66.3	73.4	75.3	78.4	79.8	82.9	83.5	85.3	89	97.3	99.1	102.7
Toowoomba Regional	0	0	1.7	5.1	8.7	12.2	14.9	21.2	24.5	33.8	37.8	47.3	48.4	50.4	59.9	61.1	66.1	73.5	75.3	80.1
Torres Shire	14.7	19.3	34.6	54.2	63.3	67.7	70.8	76.5	79.5	84.4	87.2	89.3	93.1	93.7	95.9	98.4	104.9	105.7	107.2	107.9
Torres Strait Island.Regional	14.6	21	36.3	54.1	62.3	66.6	70	75.9	79.2	83	84.5	86.5	87.2	89.9	95	96.6	102.4	110.8	111.6	114.2
Townsville City	5	7.1	20.2	36.4	45.9	53.8	56.9	63.9	69.1	77.3	83.5	86.5	89.7	94	99.5	101.5	105.9	111.2	113.1	115.6
Weipa Town	12.2	13.2	22.1	35.8	42.7	47.4	51.2	56.1	60.4	64.9	66.8	71	73.1	78.1	85	87.2	93.6	93.8	93.9	118.1
Western Downs Regional	0	0	0.1	2.9	7.1	12.6	15	21.7	28	33.9	41.5	47.4	48.8	52.9	57.4	57.6	70	74	80.3	85.5
Whitsunday Regional	5.8	7.1	26.1	50.8	59.9	64.7	70.2	75.1	77.9	83.1	86.2	91	93	94.6	99	102.2	103.6	105.4	109.1	114.9
Winton Shire	0	1.7	4.4	8.2	12.8	15.7	19.7	24.7	27.8	33.9	37.4	42.2	44	45.3	47.1	52.3	58.9	64.7	70.6	82.4
Woorabinda Aboriginal Shire	0	0.8	2.1	8.7	14.2	18.3	20.8	24.9	27.2	32.8	36.7	43.1	44.6	47.3	51.7	58.2	71.3	72.4	73.4	84.9
Wujal Wujal Aboriginal.Shire	5.9	8.2	14.1	26.8	33.6	38.6	41.7	48.9	52.1	55.6	59	62.9	67.9	69	77.4	78.7	80.1	81.4	85.4	87.4
Yarrabah Aboriginal Shire	6.6	7.5	15.6	31.1	41.6	48	52.2	58.8	63.4	68.3	72.7	76	80.8	83.1	88.5	89.6	91.9	94.7	95.6	95.9

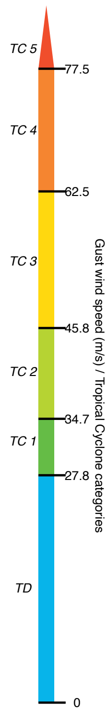


Australian Government
Geoscience Australia
Queensland Government
CYCLONE TESTING STATION

Recurrence of Tropical Cyclones across Queensland's cities and towns (historical)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

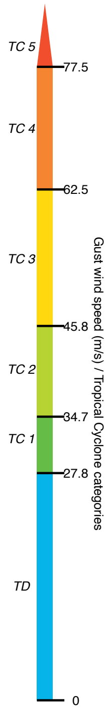
Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Allingham	4.3	14.3	24.2	35.3	39.4	52.6	64	74.6	76.9	85.3	89.3	92.7	96.7	101
Alpha	0	1.7	6.5	10.6	12	17.1	24.5	30.5	32.4	38	43.1	46.8	55	56.9
Aramac	0	1.4	6	9.8	11.4	16.9	22.5	28	29.2	33.6	37.6	43.3	49.5	51.5
Aurukun	12.3	23.5	33.4	45.9	49.6	59.8	70.6	78.4	80.7	84.6	89.8	92.2	95.1	103
Ayr	3.8	14.8	26.2	39.6	45.1	58.6	70.3	79.7	82.3	92.7	98.3	104.3	108.9	112.4
Badu	10.4	24.4	37.3	50.2	54.6	65.2	75.8	85.6	86.5	91.8	94.9	100.1	104	110
Balgal	3.8	13.8	23.5	33.8	37.8	50.5	65	73.8	76	83.6	88.8	94.5	109.2	111.4
Bamaga	11.6	26	38.6	50.4	53.7	63.6	72.3	78.1	80	86.8	92.3	96.8	102.9	106.2
Barcaldine	0	0	4.6	8	9.1	14.3	20	26.1	27.4	31	36.4	39.7	42.4	58.1
Bargara	0	4.3	10.3	18.7	21.9	34.3	46.3	59.1	62.4	70.2	78.6	88.8	99.7	100.8
Beaudesert	0	0	4.7	11.1	14.2	24.6	36.3	44.5	50.9	58.9	67.9	74.6	81.2	89.1
Biloela	0	3.7	8.8	15	17.3	25.4	33.6	43.3	46.5	57.3	67.8	72.1	82.4	100.1
Blackwater	0	4.3	9.9	15.9	17.9	24.2	31.2	37.5	40.3	48.5	58.5	67.6	75.8	81.3
Bloomfield	8.2	19	28.9	40.5	44	54.8	65.1	72.1	73.4	81	89.2	91.9	92.7	97.5
Bowen	3.9	15.2	27.9	43.3	49.3	64.3	78.3	86.4	88.6	94.9	102.9	106.7	110.1	117
Brandon	3.8	14.8	26.1	39.5	45	58.6	70	79.2	82.7	91.1	97.7	102.1	109.8	113.5
Brisbane	0	0	5.7	13	16.1	25.9	38	49.3	52.8	63.6	72.3	74.7	86.4	89.7
Bucasia	2.4	12.5	23.9	39.1	44.1	56.2	66.6	74.7	77.6	87.6	90	96.8	104	111.7
Buderim	0	0	7.3	15.7	18.4	29	41.6	53.5	56.3	64.9	71.3	81.2	86.5	96.5
Bulwer	0	0	7.1	15	18	29.2	42.7	55.4	59.5	68.4	73.7	81.2	84.7	93.8
Bundaberg	0	4.1	9.9	18	21.9	32.7	44.2	57.5	61	69.5	78.4	87.6	99.2	99.9
Burketown	1.5	9.2	16.6	24.5	27.4	34.7	42.1	50.8	54.4	62.5	67.4	75.9	78.6	94
Burnett Heads	0	4.3	10.3	18.8	22.1	34.2	46.8	58.4	62.2	70.8	79.4	86.6	99.1	99.6
Caboolture	0	0	6.3	14.1	17.4	27.5	40.2	48.7	53.2	63.4	72.7	80	82.6	88.9
Cairns	7	17.3	27.6	40	44.1	59.4	69.8	79.9	83.5	89.3	96.4	102.8	106.1	115.2
Caloundra	0	0	7.2	15.3	18.5	28.6	41.8	53.4	57.1	64	73.4	79.3	91.2	92.1
Camooweal	0	1.4	5.6	8.9	9.8	13.7	17.9	21.4	22.6	26.3	29.3	34.1	46.5	53.2
Capalaba	0	0	5.9	13.1	16.4	27.1	37.9	52	55.1	63.3	70.5	77.4	86.9	100.9
Cardwell	4.8	14.7	24.3	34.9	38	49.8	62.1	71.1	73.8	83.9	88.3	90.7	96.2	108.6
Charters Towers	0	10.3	18.1	25.9	28.8	37.7	48	55.4	59.6	67.6	72.3	75.6	91.2	92
Cherbourg	0	0	6	13.4	16.3	24.6	33.4	42.8	46.2	57.3	63.7	70.1	80.7	99.8
Chinchilla	0	0	3	8.7	10.7	17.1	25	32.7	34.6	45.5	55	61.6	79.4	86.2
Chuwar	0	0	5.1	12.1	15.2	25	36.2	46	48.8	61.5	67.9	74.9	84	93.1
Clermont	0	5.1	11	17	18.6	24.3	31.3	38.3	40.6	47.7	52	54.9	61.5	75.3
Clinton	0	5.5	11.4	18.8	21.9	31.9	44.5	56.8	60	69.8	77.7	88.2	94.8	97.9
Cloncurry	0	0	3.9	6.7	7.7	10.9	14.8	18.7	20.4	23.6	26.7	28.9	31.4	37.7
Coen	11.3	21.5	28.4	35.6	37.5	44.9	52.7	59.6	61.3	67.6	74.1	78	86.8	87
Cooktown	8.8	20.1	30.1	41	44.4	55.5	65	75.4	79.1	84.2	89	92.2	94.6	94.8
Coomera	0	0	5.5	12.2	15.4	26	38.1	50.2	54.1	65.3	72.3	76.5	87.8	89.6
Croydon	2.7	7.9	12.4	17.2	18.7	23.4	27.4	31.6	33.3	40.3	46.2	49.6	53	66.5
Dajarra	0	0	0	2.9	3.6	6.2	9.5	13.6	15	18.6	22.1	23.5	24.5	26.7
Dalby	0	0	3.2	9.3	11.2	19.2	27.9	36.2	39	50	58	64.6	76.4	87.4
Darnley Island	8.2	19.4	32.2	46.5	51	61.5	70.6	79.3	81.8	87.3	94.6	97.7	102.1	111.1
Deeragun	3.7	13.9	23.8	35.1	38.8	53.2	67.7	77.3	80.7	90.8	96.5	103	106.2	107.1
Doomadgee	0	8.5	15.1	22.2	24.6	30.9	36.3	41.7	43.4	50.2	57.1	59.7	67.9	71.5
Dysart	0	6.5	13.5	20.5	22.2	29.1	36.1	43.2	45.6	50	55.4	60.6	67.7	73.5
Eagle Heights	0	0	5.2	11.8	14.9	25.1	37.7	48.9	53.4	64.1	70.6	76.5	86.9	93.7
Edmonton	6.8	16.9	27.2	39	43.8	57.5	67.2	76.4	80.1	87.7	94.6	97.8	107.7	113.9
Einasleigh	3.1	9	14.6	20.4	22.5	27.6	34.5	41.4	43	49.9	55.2	58.5	66.2	67.3
Ellinthorp	0	0	2.3	8.3	11	19.9	29.4	39.6	41.4	48.9	54.3	66.4	71.4	72.4
Emerald	0	3.8	9	14.4	16.3	21.7	28.2	36.2	38.6	43.1	51.5	65	68.7	69.4
Emu Park	0	6.8	13.1	21.7	24.7	35.8	47.9	59.4	62	76.1	80	86.3	96.2	105.1
Fernvale	0	0	4.9	12.1	14.9	25.2	35.9	47.1	49.5	57.9	65.8	76.1	80.7	81.5
Forsayth	2.8	8.1	13.1	18.4	20.3	25.2	30.5	36.6	38.5	43.5	49.6	54.2	56.6	60.3
Gatton	0	0	4.1	10.8	13.4	23.9	32.9	43.4	46.8	56	61	65.5	76.4	78.8
Gayndah	0	1.1	7.1	14.3	17.1	25	34	43	46.1	55.7	63.6	74.4	91.5	102.8
Georgetown	3.3	8.8	13.4	19	20.9	26.2	30.3	36.4	38	42.7	45.6	47.8	54.7	65.9
Gladstone	0	5.7	11.6	19.2	22.1	32.7	45.7	56.9	60.5	69.7	78	87.1	96.2	97.2
Glamorgan Vale	0	0	4.8	11.9	14.9	24.8	35.5	46.3	50	57.5	65.8	75	79	79.5
Glenella	2.2	12.2	23.5	38.1	42.9	54.5	65.3	73.4	76.9	83.5	88.4	94.8	101.6	127.2
Gold Coast	0	0	5.5	11.9	15.1	26.3	36.8	50.7	54.7	63.9	71.3	79.4	83.9	87
Goondiwindi	0	0	0	4.1	5.5	10.9	17.6	27.1	29.1	39.1	45.6	52.8	60.2	69.8
Gracemere	0	6	12.1	19.5	22.3	31.6	41.8	52.1	56.2	65.1	75.1	82.6	86.6	95.8
Gregory	0	6	11	17	18.8	23.5	27.8	32.7	34.2	39.8	44.5	48.3	51.2	54.5
Gunpowder	0	2.9	6.6	10.4	11.9	15.6	19.9	22.8	24.4	27.9	34.5	36.8	55	61
Gununa	4.1	14.1	24.7	38.1	42.6	56.2	67.4	77	78.9	84.2	88	94.8	98.7	98.8
Gympie	0	0	7.5	15.6	19.2	27.7	40.5	53.2	55.7	64.3	71.2	82.9	94.9	100.4
Hervey Bay	0	3.8	10	18.8	21.8	34.9	45.8	56.7	61.3	71.1	76.6	89.7	92.5	100.7
Highfields	0	0	3.6	10.1	12.9	22.2	31.8	41.2	43.8	52.2	61.9	67.4	74.8	76.9
Home Hill	3.7	14.6	25.9	39.2	44	58.5	69.1	78.9	81.8	91.7	97.9	102.1	113.9	114.3
Hope Vale	8.9	20.3	30	40.9	43.9	55	64	71.7	73.9	83.4	88.8	93.8	95.3	95.8
Hughenden	0	4.5	8.7	13.2	14.9	21	26.2	33.8	34.9	40.6	47.1	53	63.1	71.7
Ingham	4.3	14.1	23.6	34.3	38.1	49.9	62.9	71.6	74	81.8	90.1	93.8	102.4	104.8
Inglewood	0	0	0	5.7	7.5	14.8	22.7	32.2	34.2	40	47.7	60.4	63.9	67.2
Injinoo	11.7	26.1	38.7	50.8	53.7	64.2	73	78.7	80.9	86.7	91.9	99.4	103.4	104.5
Innisfail	6.2	16.7	27	39.6	44.1	57.3	67.2	78	81.3	86.2	92.4	96.2	97.9	115.2
Ipswich	0	0	4.8	11.7	15.1	24.7	35.5	45.8	47.6	59.4	67.4	74.7	81.4	90
Julia Creek	0	2.1	4.9	7.7	8.7	12.6	16.5	22	23.1	28	30.4	33.4	35.8	40.6
Karumba	3.4	9.7	16.5	24.1	26.9	36.1	47.5	55.9	59.3	65.2	72.9	81.5	84.5	94.1



Recurrence of Tropical Cyclones across Queensland's cities and towns (historical)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

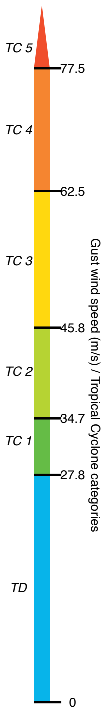
Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Kingaroy	0	0	5.3	12.5	15.2	23.7	32.6	40.9	42.6	54	65	72.9	82	97.4
Kooringal	0	0	6.8	14.2	17.3	28.6	40.5	54.4	58	66.8	74.2	81.4	92.3	95.1
Kowanyama	7.8	16.6	24.9	36.7	41.1	52.1	60.2	68.6	70.3	75.1	78.5	82.1	86.6	93.6
Kuranda	7.1	17.1	27.2	39.4	42.9	56.1	66.6	78.3	80.5	87.9	97.9	101.1	115.2	115.6
Laidley	0	0	4.1	10.8	13.6	24	33.7	44.1	46.6	55.8	60.5	68	72.4	77.8
Lockhart River	12.4	24.2	33.1	43.2	46.8	57.2	65.3	72.8	74.5	80	86.5	95.4	99.7	101.5
Lowood	0	0	4.8	11.9	14.5	25.1	35.5	46.9	49.6	57.3	64.3	74	77.9	82
Lucinda	4.6	15	25.3	37	41	54.6	66.4	75.6	79.2	87.7	93.4	97.6	105.2	113.1
Mackay	2.2	12.2	23.4	38	42.5	54.5	65.1	74.4	76.9	83.6	89.6	94.9	100.3	125.4
Macleay Island	0	0	6.1	13.1	16.1	27.9	38.7	51.6	54.9	64.1	71.6	82.4	95.9	104.9
Mapoon	13.1	26.4	37	50.5	55.2	67.2	77.7	85	86.7	93	97	99.9	106.7	118.7
Mareeba	6.6	15.8	25.1	35.6	39.1	50.4	60	68.7	70.8	77.6	81.7	87.2	103	104.7
Maroochydore	0	0	7.4	15.7	18.4	29.6	41.6	54.3	56.2	65.3	75.1	79.8	86.9	96.4
Maryborough	0	3	9	17.4	20.5	32.7	42.4	55.3	57.1	67.6	70.5	84	100.1	101.5
Maxwelton	0	2.9	5.9	9.2	10.3	14.7	20.3	25.3	27.1	32	36.5	41	43.5	46.4
McKinlay	0	0	3	5.4	6.3	9.8	13.6	18.7	20.2	24	28.1	29.7	33.3	34.6
Miles	0	0	2.6	7.7	9.5	15.6	23.1	31.6	34.4	42.2	50	55.7	78	85.1
Millchester	0	10.4	18.4	26	29	37.7	48.6	56.2	60.4	68.3	72.1	77.2	89.9	92.4
Monto	0	3.1	8.2	15.1	17.4	26.2	35.2	43	46.5	55.7	61.1	63.9	75.2	108.8
Moonford	0	3.3	8.3	15.1	17.5	25.8	35.9	44.4	46.4	57	62.8	65.8	75.1	109.8
Moranbah	0	7.9	15.7	23.1	25.3	31.6	40	47	48.5	55.3	63.5	67.4	77.4	92.1
Morayfield	0	0	6.2	14.1	17.2	27.5	39.7	49.4	52.3	63.6	72.8	78.8	82.6	88.7
Mossman	7.5	17.4	26.9	38	41.5	54.2	66.8	74.3	75.7	84.9	90.3	96.3	100.4	102.5
Mount Isa	0	0	3.3	6.2	7.2	10.2	13.8	18	19.5	22.9	26.8	29.9	32.1	32.3
Mount Morgan	0	5.4	11.4	18.4	20.7	29.5	38.7	49.1	53	59.3	72.1	83.1	93.2	93.7
Moura	0	2.9	7.5	13.3	15.4	22.1	29.2	37	39.9	49.9	58.6	63.8	72.6	97.4
Murgon	0	0	6.2	13.5	16.5	24.6	33.9	43.5	47.2	57.4	65	70.2	82.2	100.2
Myola	7.1	17.1	27.1	38.8	42.2	55.7	67.6	78.1	80	87.7	96.8	102.2	113.9	114.4
Nanango	0	0	5.4	12.4	15.5	24.4	33	41.9	45.4	54.4	63.1	70.1	93.5	97.3
Napranum	13.1	25.1	35	45.8	49.4	60	68.6	74.3	77	80.2	85.2	88.4	94.3	107.9
Nelia	0	2.5	5.4	8.4	9.4	13.7	18.5	24.2	25.8	29.3	31.9	34.9	37.3	38.5
Nerang	0	0	5.3	11.8	14.9	25.9	37.4	50.8	54.2	64.5	69.9	75.6	82.5	92.3
Nonda	0	2.7	5.7	8.9	10	14.2	19.6	25.7	26.9	32.3	34.5	38.6	39.4	42.5
Noosaville	0	0.6	7.9	16.3	19.4	30.2	43	56.6	58.1	67.3	75.2	88	98.9	103.2
Normanton	3.1	8.9	14.8	21.7	23.8	32.2	40	48.7	51.4	58.5	66.4	78.4	81.3	81.3
North Tamborine	0	0	5.2	11.8	14.8	25.2	37.8	49.4	52.6	63.3	70.7	76.8	87.5	93
Oakey	0	0	3.3	9.4	12.2	20.6	30.2	39.5	42.3	50.4	60.7	65.1	77.7	78
Palm Islands	4.6	15.1	25.9	38.1	42.9	57.8	70	78.9	81.6	89	102.4	107.6	111.5	113.3
Pentland	0	7.3	13.2	19.7	21.7	28.2	35.8	45.5	47.8	54.5	58.9	64	74.4	77.8
Pormpuraaw	9.1	18.7	28.7	41.4	45.4	59.4	68.3	76.6	78.1	82.1	87	88.5	93.4	94.3
Port Douglas	7.5	17.6	27.3	38.6	42.1	56	67.6	77.4	79.9	87.1	94.6	100.2	103.6	107.6
Prairie	0	5	9.6	14.7	16.4	22.6	28.8	35.6	37.7	44.1	51	55.9	62.4	68.4
Proserpine	3.3	14.2	27.1	42.4	47.1	59.7	70.7	80.2	81.8	89.2	93.6	100.2	107.3	108.2
Rainbow Beach	0	2.7	9	17.7	21	32.5	45.5	58.6	61.9	68.1	79	85.1	90.5	95.2
Redcliffe	0	0	6.3	14	16.7	26.7	40.2	52.7	56.2	63.6	71.8	77	80.2	89.8
Redlynch	7	17.2	27.3	39.5	43.5	57.3	67.7	77.9	81.9	89.1	96.7	101.6	109.6	111.2
Richmond	0	3.2	6.6	10.4	11.5	16.5	21.6	27.6	29.9	33.3	39.4	44.9	49.2	49.3
Rockhampton	0	6.2	12.3	19.9	22.7	32.4	42.9	54.2	57	66.1	74.4	82.2	90	92.5
Rose Hill	11.1	25.7	38.8	51.1	55.7	66.2	75.7	82.8	86.4	93.7	97.6	100.1	103	106.6
Rosewood	0	0	4.5	11.4	14.4	24.4	34.4	46.2	48	57	62.6	73.4	76.2	76.3
Russell Island	0	0	6	12.9	16.2	27.5	39	51.7	56.1	66.2	72.8	84.1	95.9	101.3
Saibai	8.4	20.3	30.5	40.8	44.4	53.6	61.2	69.3	71.2	77.6	82.5	87.1	94.3	94.9
Stanthorpe	0	0	0	6.7	8.9	17.8	27.2	34.8	36.8	43.7	53.9	68.2	75.7	78.3
Sunshine Beach	0	0.8	8	16.3	19.7	30.5	43.3	57	59.2	66.8	75.7	87.1	97.6	102.2
Tannum Sands	0	5.5	11.2	19.2	22	33	46.2	56	60.3	69.7	78.8	86.9	98.3	100.4
Taranganba	0	7	13.5	22.4	25.5	36.4	48.8	61.9	64.9	73.3	79.5	86.6	95.6	98.4
Taroom	0	0	4.5	9.5	11.2	17.1	24.5	31.8	35	40.2	57.7	68.7	79.3	87
Tewantin	0	0	7.9	16.2	19.4	29.8	42.9	55.8	58.5	66.5	74.8	88.9	99.8	104
Texas	0	0	0	4.8	6.7	13.5	21.3	29.5	33.7	40.1	48.5	56.2	64.7	68.6
The Monument	0	0	0	3	3.8	6.3	9.9	13.8	15.7	19.4	21	22.1	26.7	27.5
Thursday Island	11.2	25.8	38.9	51.3	55.6	65.9	75.3	83.9	85.8	93.4	97.8	100.5	102.5	107
Tieri	0	5.2	11.1	17.5	19.4	25.9	32.9	40.7	42.7	47.2	54.1	57.4	63.5	64.8
Tin Can Bay	0	2.5	8.8	17.3	20.9	31.9	44.4	57.3	59.8	67.9	74.5	82.4	87	97.6
Tinana	0	2.9	8.9	17.4	20.3	32.6	42.1	55	57.2	66.4	71.1	83.4	100.4	101.5
Toowoomba	0	0	3.4	9.8	12.6	22.1	31.6	41.4	43.9	52.5	62.7	65.7	70.3	74.2
Torrens Creek	0	6	11.2	17	18.8	24.8	32.1	39.7	42.4	48.9	53.1	55.8	68.2	69.6
Townsville	3.8	14.2	24.5	36.4	40.9	55.1	69.5	81.4	84.2	92.5	97.2	105.9	106.9	110.9
Tully	5.3	15.3	24.6	35.8	39.4	50.8	60.6	71.1	74.3	80.8	90.7	96.3	104.1	106.6
Umagico	11.7	26.1	38.6	50.6	53.6	63.6	72.7	78.8	80.2	85.7	91.7	98.2	104.7	104.8
Warwick	0	0	2.2	8	10.8	19.6	30.5	38.8	41.5	48.4	54	60.8	70.7	84.6
Wasaga	11.2	25.7	38.9	51.1	55.5	66.3	74.4	83	86.1	92.6	98.8	101.2	104.4	106.7
Weipa	13.2	25.2	35.1	46.2	49.5	60.2	68.7	75.1	76	80.6	83.2	88.4	93.4	105.4
Whitsunday	3.8	14.9	28.9	45.1	50.7	63.5	76.3	84.8	87.7	93	97.3	106.1	109.6	113.2
Withcott	0	0	3.5	9.9	12.7	22.3	31.8	41.8	45.1	53	63.1	68.8	73.1	75.5
Wonga	7.7	17.9	27.5	38.7	42.6	55.2	67	76	79.1	87	94.5	98.3	100.1	100.2
Woorabinda	0	3.5	8.3	14.2	16.5	22.8	28.4	36.6	39	48.8	57.2	62.6	79.9	83.2
Wujal Wujal	8.1	18.9	28.4	39.9	43.2	54	63.9	71.3	72.5	81.5	88.2	90.5	93.6	97.7
Yarrabah	7.2	17.7	28.3	41.3	45.4	61	72.2	80.8	83.7	91.9	96.9	103.2	106.7	114.3
Yeppoon	0	7.1	13.6	22.4	25.5	36.3	48.9	61.5	64.9	73.8	78.3	86.8	92.2	99.8



Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP4.5 – 2041–2060)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

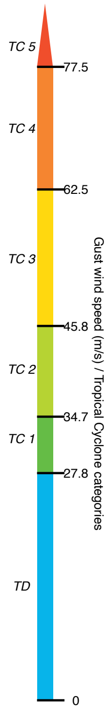
Cities and Towns	2 50	5 20	10 10	20 5	25 4	50 2	100 1	200 0.5	250 0.4	500 0.2	1000 0.1	2000 0.05	5000 0.02	10000 0.01
Allingham	2	10.4	20	31.7	36.3	49.3	60.9	70.5	73.1	82.8	87.2	91.8	97.1	100.8
Alpha	0	0.6	5.5	9.2	10.5	14.6	22.9	29.4	31.3	37	42.3	43.9	48.2	50
Aramac	0	1.8	4.9	8.1	9.2	14.2	19	22.6	24.2	28.8	31.4	37.5	52.2	54.8
Aurukun	8	16.5	27	39.3	43.5	53.4	65.8	77	79.3	85.1	91.8	99.9	109.5	119.6
Ayr	1.8	11.8	23	36.2	41.7	54.7	66.6	75.5	78.9	88.7	92.4	99	101.9	104.2
Badu	7	19.9	32.6	46.5	51	61.2	71.7	83.3	84.8	93.3	100	107.4	119.4	127.8
Balgal	1.6	10	19.5	30.1	34.6	46	61.3	69	71.8	80.3	86.5	94.1	115.7	117.6
Bamaga	8.3	21	34.3	47.1	50.7	61.1	70.1	76.2	79.7	87.9	93.3	98.9	108.7	118.6
Barcaldine	0	1.4	3.6	6.6	7.3	12	17.5	20.4	20.8	25.1	29.9	35.1	40.2	61.8
Bargara	0	2.6	7.9	15.4	18.3	30.7	40.4	52.9	55.6	63.5	69.8	77	78.2	78.6
Beaudesert	0	0	1.5	8.9	11.7	21	32.1	37.7	44	52.6	60.7	70.7	83	105.5
Biloela	0	2.6	7.2	13.2	15.7	24.4	32.5	41.3	43.7	55.2	68.3	70.9	78.8	81.3
Blackwater	0	3.3	8.5	14.1	16.2	22.1	28.5	33.7	37	44.6	56.2	63	68.8	87.7
Bloomfield	5	12.9	23.2	35	38.3	49.7	60	66.4	67.1	75.5	81.3	84.7	86.1	100.4
Bowen	1.9	12.8	26.1	41.6	47.3	62.8	74.8	82.9	83.2	87.9	96.8	98.1	104.4	114.9
Brandon	1.8	11.6	23	35.9	41.6	54.6	66.2	75.2	78.6	86.2	91	95.3	102.4	108.5
Brisbane	0	0	3.6	10.5	13.3	21.6	33.2	42.4	47.2	58.4	68.8	69	76.8	84.3
Bucasia	0.7	10.7	22.3	38.4	43.7	55.8	66	76.5	79.6	90.9	92.6	97.8	107.2	113.4
Buderim	0	2	5.2	12.5	15.7	24.3	37.7	49.5	51.8	60.1	66.5	76.9	85.5	106.2
Bulwer	0	1.9	5	12	14.4	25.1	37.1	51.3	56.7	68.6	71.7	76.4	78.5	82
Bundaberg	0	2.5	7.8	14.2	18.9	29.4	39.1	50.9	54.6	61.2	66.6	74.4	74.7	74.8
Burketown	0	4.3	9	16.9	19.6	28.5	36.7	44.4	48.7	59.1	60.8	69.2	72.7	111.3
Burnett Heads	0	2.7	8.1	15.3	18.9	31	41.5	51.5	56	64	72.5	72.6	73.2	78.8
Caboolture	0	0	4.2	11.2	14.5	23	35.2	44.8	49.5	60	71.5	77.9	80.2	81.7
Cairns	4.1	11.4	21.3	35.7	39.5	54.7	65.7	79.3	83.1	87.4	92.9	99.6	100.3	107.2
Caloundra	0	1.9	5.2	12.5	15.8	24	37.5	49.2	52.4	61	69.6	73.7	85.2	90.5
Camooweal	0	1.3	3.5	7.2	8	12.3	16.2	19.2	20.8	23.7	27.7	33.2	41.7	49.3
Capalaba	0	0	3.9	10.4	13.5	23	32.7	44.5	47.1	60.9	65.7	68.8	77.6	86
Cardwell	2.5	10.2	19.5	31.4	34.8	46	59.2	71.5	73.3	86.3	90	97	103.2	129.1
Charters Towers	0	7.9	14.8	22.6	25.4	34	44.8	53.5	56.9	61.3	63.5	66.6	76	82.7
Cherbourg	0	1.6	4.2	10.6	12.4	20.6	29.2	37.9	42.1	51.1	56.1	63	71.4	83.7
Chinchilla	0	0	1.7	6.5	8.3	12.7	20.3	28.8	30.6	39.9	48.2	56.9	74.6	76.3
Chuwar	0	0	3	9.8	12.7	20.7	31.6	39.2	41.8	53.4	63.2	68.4	81	98.9
Clermont	0	4	9.6	15.8	17.2	23.3	31.1	38.2	39.4	44.5	48.5	52.6	55	67.9
Clinton	0	4.2	9.8	17.2	20.5	30.6	42.4	55.5	59.2	69.6	81.1	97	98.2	100.3
Cloncurry	0	0.6	1.6	4.6	5.7	9.2	13.6	19.8	21.3	26.3	27.8	30.6	32.4	35.4
Coen	7.5	16.4	23.6	31.4	33.4	41.2	48.7	57.2	59.1	65	75.7	82	90.5	90.6
Cooktown	5.5	14.4	24.8	35.4	38.1	49.5	59.3	70.9	74.8	80.9	85.5	87	88.2	90.3
Coomera	0	0	2.9	9.6	12.5	21.5	32.6	41.1	45.6	60.6	68.3	71.7	81.8	82.3
Croydon	0	4.4	7.2	11.6	13.3	18.2	23	27.6	29.1	35.9	43.5	44.6	49.8	62.9
Dajarra	0	0	0.6	1.8	2.8	5.3	10.5	17.4	18.7	19.5	23.6	25.9	27.3	30.2
Dalby	0	0	1.6	7	8	15.2	23	31.1	33.9	45.6	51.5	62.1	74.8	83.3
Darnley Island	5.8	16.9	30.8	44.8	49.3	60.2	68.7	77.6	79.2	84	93.8	95.5	99.9	107.1
Deeragun	1.5	10.4	20.3	31.7	35.5	49.8	63.7	71.8	73.5	80.5	86.3	97.8	107.5	111.1
Doomadgee	0	4.2	8.5	16.8	19.5	26.2	31.4	36.2	37.7	47.3	57.7	60.5	64.5	71.1
Dysart	0	5.2	12	19.5	21	27.8	35.7	42.1	44	47	53.4	59.4	65.6	66
Eagle Heights	0	0	2.3	9.4	12.2	20.9	32.9	41.3	44.8	58.6	66.2	72.7	85.2	95.9
Edmonton	4	11.1	21	34.4	40.1	53.5	63.3	73.4	78.5	87.7	91	94.8	106.3	115.8
Einasleigh	0	5.2	9.4	15.2	17.6	23.4	29.1	35.3	36.1	42.3	49.1	52.3	64.9	69.5
Ellinthorp	0	0	2.1	6.4	9	15.9	25.4	34	34.6	41.8	44.7	58.8	60.5	62.4
Emerald	0	2.8	7.8	12.7	14.5	19.9	26.6	32.7	34.2	39.2	49.6	65.2	68.2	77.6
Emu Park	0	5.3	11.3	20.2	23.5	33.5	45.5	56.1	60.5	75.1	79.2	83.5	85.1	96.4
Fernvale	0	0	2.9	9.7	12.5	20.6	32	41.5	42.6	52.2	60.6	71.8	75.8	84
Forsayth	0	4.7	8.3	13	14.9	19.8	25.1	31.4	33.4	39.3	42	45.9	47	48.9
Gatton	0	0	2	8.4	11.1	19.4	28.6	38.4	39.5	49.8	52.6	62.6	73.9	75.2
Gayndah	0	1.9	5.1	11.9	14.5	21.9	29	37.3	40.3	48.4	54.2	69.4	80.7	91.3
Georgetown	0	4.9	8.6	13.9	15.6	21	25.7	30.6	32.1	35.6	39.1	39.7	42.3	57.8
Gladstone	0	4.3	9.8	17.5	20.8	31.1	42.5	54.8	59.1	69.7	81.3	93.6	103.3	104.3
Glamorgan Vale	0	0	2.7	9.5	12.2	20.4	32.2	40	43.4	50.9	59	69.8	73.9	87.5
Glenella	0.4	10.4	21.9	37.4	42.4	54.3	64.7	75	78.4	84.1	89.9	98	101.7	122.3
Gold Coast	0	0	2.1	9.4	12.2	22	31.6	44.6	48.5	58.6	64.8	70.3	75.2	83.3
Goondiwindi	0	0	0	2.5	3.7	8	13.8	22.4	23.6	33.5	40.7	47.7	57	65.7
Gracemere	0	4.7	10.7	18.9	20.9	29.8	38.9	48.3	53.2	65.9	75.9	81.5	82.3	91.8
Gregory	0	2.4	6	12.3	14.6	20.3	24.3	28.7	30.8	34.8	42.4	46.6	47	47.6
Gunpowder	0	1.4	3.8	7.8	9.4	14.7	19.3	22.2	24.3	29.2	34.8	37.9	59.1	79.4
Gununa	0	6.5	14.7	29	33.7	48.9	62.4	73.9	75.8	81	86.8	96	109.7	111.9
Gympie	0	2	5.4	12.8	16.1	23	36.3	49.1	50.5	61.4	67.5	78.1	88.2	99.3
Hervey Bay	0	2	7.3	15.2	17.4	29.9	41	53.4	56.9	65.2	71.7	82	84	86.2
Highfields	0	0	1.6	7.7	10.4	17.5	26.8	36.1	38	45.2	54	62	72.4	72.4
Home Hill	1.6	11.5	23	35.8	40.7	54.9	65.3	76.1	78.3	85.3	92.7	96.1	106.6	107.2
Hope Vale	5.6	14.8	24.7	35.1	38.5	49.4	58.7	66.4	68.3	76.6	80.9	86.4	92.2	97.7
Hughenden	0	2.8	6	9.2	10.6	16.1	22.1	29.9	31.1	35.4	40.7	46	55.5	66.6
Ingham	2	10.2	19.1	31.4	35.3	46.9	61.1	69.3	72.1	80.7	90.7	96.4	109.5	112
Inglewood	0	0	0	3.7	5.5	11.3	19.1	27.3	29.7	34.1	38.5	52.5	56.7	67.8
Injinoo	8.4	21	34.4	47.7	50.5	61.5	70.7	77.4	80.5	87.6	93	101.3	108.3	121.5
Innisfail	3.6	11.1	21.5	35.4	39.8	53	62.9	74.5	78.2	81.8	87.2	93.7	99.3	116.4
Ipswich	0	0	2.7	9.5	12.5	20.4	31	38.9	41	50.6	59.6	66.9	78.6	101.9
Julia Creek	0	1	2.8	5	5.7	9.1	13.2	20.1	21	24.9	25.7	29.6	30.3	32.2
Karumba	0	4.8	9.1	15.3	18.4	28.3	40.6	49.1	53	61.6	70.2	80.3	82	96.9



Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP4.5 – 2041–2060)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

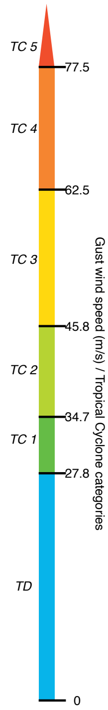
Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Kingaroy	0	1.4	3.6	9.8	11.5	19.9	28.7	37.3	38.6	48.5	58.9	67.1	75.5	88.9
Kooringal	0	0	4.8	11.3	13.7	24.1	35.3	48.8	53.5	63.5	68.4	70.6	73.6	75.5
Kowanyama	4.1	9.7	16.7	28.4	32.5	43.7	51.7	60.3	63.6	67.4	69.2	69.4	70.2	81.9
Kuranda	4.2	11.2	21	35.1	38.7	50.6	62.6	77.1	79.9	87.6	95	97.9	114.5	116.1
Laidley	0	0	1.9	8.6	11.2	19.4	30.7	38.5	39.3	48.5	50.8	64.9	71.1	76.7
Lockhart River	9.1	18.9	28.2	39.5	43.6	54.9	63.2	70	71.5	76.4	83.5	94.5	96.4	103.3
Lowood	0	0	2.8	9.6	11.9	20.5	31.8	41.4	41.8	50.1	58.2	71.1	74.3	84.8
Lucinda	2.4	10.9	21	33.4	37.8	51.1	63	72.4	77.2	87.2	94.2	100.1	103.6	119.2
Mackay	0.4	10.4	22	37.5	42.3	54.6	65	75.1	78	84.1	89.9	96.1	101	115.6
Macleay Island	0	0	4.1	10.3	13.1	23.4	33.1	44.4	48	59	68.2	80	88.9	90.8
Mapoon	9.3	20	31.2	45.2	50.4	62.3	73.8	81	84.9	93.2	100.4	103.2	114.6	129.6
Mareeba	3.8	10	19.2	31.2	35.3	46.8	56.7	65.8	68.5	75.7	82.7	85.5	98	101.1
Maroochydore	0	2	5.3	12.8	15.5	24.9	37.7	50.5	51.2	60.2	71.3	75.7	85.5	106.6
Maryborough	0	1.2	6.7	14	16.4	28.6	37.6	50.7	53.3	64.9	67.6	77.9	93.3	93.7
Maxwelton	0	0.7	3.8	6	6.8	10.3	15.5	20.9	22.5	27	31	33.1	40.8	47.5
McKinlay	0	0.4	1.2	3.7	4.3	7.3	11.7	17	19.6	25	29.8	30.2	31.4	32.8
Miles	0	0	1.4	5.7	7.2	11.7	18.3	28	30.4	37.3	44.9	51	76	83.8
Millchester	0	8	15.1	22.9	25.6	34.2	45.6	54.3	57.7	62.4	63.2	65.6	76.2	84.1
Monto	0	1.9	6.2	12.9	15.1	24.3	34.2	41	42.8	53.3	58.7	60.9	70.7	111.3
Moonford	0	2.1	6.4	13	15.5	23.9	34.9	43.2	44.4	52.7	60	63.9	77.6	114.2
Moranbah	0	6.4	14.5	22.5	24.7	30.9	39.6	45.8	47.4	53.1	58.8	61.8	81.9	92.3
Morayfield	0	0	4.2	11.1	14.3	23.1	34.7	45.2	48.6	59.8	72.9	78.7	79.5	80
Mossman	4.6	11.6	21.4	33.6	37.2	49.4	62.9	69.4	70	78.1	82	88.3	97.9	98.2
Mount Isa	0	0.4	1.2	4.5	5.5	9.6	14.9	20.5	22.6	24.3	24.9	26.9	33.2	35.4
Mount Morgan	0	4.2	9.7	17.2	19.2	27.6	36.9	47.1	51.5	61.2	72.7	85.5	91.3	94.7
Moura	0	1.9	6.3	11.5	13.6	20	27.1	33.9	36.5	45.6	54.9	59.7	67.3	93.4
Murgon	0	1.6	4.3	10.8	12.9	20.9	29.7	39.1	43.8	52.2	58.9	65.4	76.4	83.4
Myola	4.3	11.3	20.8	34.5	38	50.7	64.2	76.6	79.5	87.2	95.4	99.5	113.3	117.5
Nanango	0	1.3	3.5	9.8	12.3	20.1	29	37.8	41.3	49.8	54.6	59.2	87.8	93.7
Napranum	9	18.1	28.5	40.5	44.3	56.6	65.2	72.4	75.6	83.4	88.2	95.5	99	121.5
Nelia	0	1.2	3.2	5.5	6.1	9.6	14	19.7	22.4	25.5	26.8	28.8	35.4	39.9
Nerang	0	0	2	9.2	12	21.6	31.6	44.8	47	57.1	63.4	68.2	70.6	92.1
Nonda	0	0.3	3.5	5.8	6.4	9.8	14.9	21.4	23.4	28.1	28.2	33.1	34	35.5
Noosaville	0	2.2	5.8	13.2	16.2	26.4	39.8	52	52.7	61.6	74.8	87.1	94.1	104
Normanton	0	4.5	8.1	14.3	15.7	25.6	33.8	42.7	46.1	54.3	66.7	79.2	83.3	89.2
North Tamborine	0	0	2.2	9.4	12.2	21.1	33.3	42.2	44	58.2	66.7	73.3	86.5	97
Oakey	0	0	1.4	7	9.6	16.4	25.7	34.3	37	43.9	52.5	60.5	78.9	81
Palm Islands	2.3	11	21.6	34.3	39.5	53.6	65	75.3	76	84.5	102	112.2	116	119.1
Pentland	0	5.3	10.1	15.9	17.8	24.4	32.2	40.3	42.5	47.9	52.2	58	60.6	62.4
Pormpuraaw	5	11.6	20.5	32.9	37.1	51	60.1	70.7	73.1	78.9	87.4	93	106.2	107.6
Port Douglas	4.6	11.8	21.6	34.2	37.6	51.2	63.1	72.3	73.9	79.8	88.2	94.9	102.5	105.4
Prairie	0	3.4	6.8	10.8	12.4	18.1	24.6	30.9	34.2	40.1	46.5	50.8	52.5	53.9
Proserpine	1.5	12	25.3	40.6	45.5	58.5	69.2	78	78.7	85.9	91.4	97.5	106.1	116.1
Rainbow Beach	0	0.8	6.6	14.4	17.3	28	41.6	54.9	57.3	63.1	75.1	80.6	81	87.9
Redcliffe	0	0	4.2	11.3	13.6	22.5	35.8	47.5	52.3	59.2	70.4	74.2	74.6	75
Redlynch	4.2	11.2	21.3	34.8	39.7	52.3	64	77.6	81.9	89.1	95.3	98.8	105.5	106.6
Richmond	0	1.3	4.3	7	7.7	11.3	16.6	23	24.6	28.6	35.2	41.1	43.5	47.5
Rockhampton	0	4.9	10.7	19.4	21.6	30.6	39.6	50.2	53.7	67.2	73.3	80.1	86.5	86.7
Rose Hill	7.8	20.9	34	47.5	52.4	63.2	73.1	79.8	85.3	95	99.9	105	111.6	135.6
Rosewood	0	0	2.3	9.1	11.9	19.8	30.5	39.3	41.7	48.3	52.5	68.2	74.6	85.5
Russell Island	0	0	3.9	10.1	13.2	23	34.2	42.9	49.1	59.8	69.5	80.4	96.1	100
Saibai	3.8	17.3	27	38.2	42.1	52.1	60.2	67.9	69.6	75	79.8	84.1	95.3	97.4
Stanthorpe	0	0	0	4.9	7.1	14.4	23.3	30.4	30.5	33.8	44.7	54.6	67.3	82.6
Sunshine Beach	0	2.2	5.8	13.3	16.3	26.4	40	51.8	53.6	61.9	75	86.8	91.9	102
Tannum Sands	0	4.2	9.1	17.5	20.3	32.2	43.7	54.9	59.1	69.2	82.2	92.4	106.7	109.7
Taranganba	0	5.6	11.9	20.8	24.4	33.9	45.8	58.9	61.6	71.7	75.8	82.2	94.4	98.3
Taroom	0	1.3	3.4	7.5	8.4	14	21	27	29.6	34.2	51	61.1	64.8	67.9
Tewantin	0	2.1	5.7	12.9	16.3	25.9	39.7	51.4	52.8	59.7	74.3	85.9	95.7	105.3
Texas	0	0	0	2.9	5	10.5	17.8	25.1	29.2	34.2	41	51.5	53.2	68.6
The Monument	0	0	0.6	1.8	2.8	5.4	10.3	17.5	19.9	20.5	21.6	24.3	32.7	44
Thursday Island	7.8	21	34	48	52.4	63	72.7	80.9	83.9	94.3	100.7	104.7	110	135.7
Tieri	0	4.1	9.9	16	17.5	23.6	31.5	38.1	39.5	44.3	53.4	56.5	57.7	61.2
Tin Can Bay	0	0.6	6.6	14.3	17.1	27.1	39.8	53.5	54.8	63.3	70.9	81	81.8	85.5
Tinana	0	1.1	6.6	14	16.1	28.4	37.4	50.8	53	64.7	68.7	76.9	92.8	93.4
Toowoomba	0	0	1.4	7.5	10.3	17.7	26.2	36.4	37.1	46.5	54.9	61	63.4	69.1
Torrens Creek	0	4.3	8.3	13.4	14.8	21	28.1	35.3	37.5	42.6	47.3	50.7	60.7	62.9
Townsville	1.6	10.9	21.1	33	37.9	51.8	65.5	75.4	77.5	82.6	87.9	97.5	98.7	104.9
Tully	2.8	10.3	19.7	32.1	35.9	46.6	57.2	67.6	71	77.8	86.9	92.9	104.4	105.2
Umagico	8.4	21	34.3	47.5	50.6	60.7	70.4	77.8	79.4	87.2	93	98.2	108.5	119.7
Warwick	0	0	0.3	6.1	8.8	15.3	26.9	33.8	34.2	39.2	44.5	53.7	66	82.8
Wasaga	7.9	20.9	34.1	47.7	52.5	63	71.8	80	85	92.7	102.1	104.6	110.3	133.8
Weipa	9.1	18.3	28.6	40.8	44.4	56.9	65.3	74	75.6	83.2	86.9	92.2	100.4	121.9
Whitsunday	1.9	12.7	26.6	43.5	48.8	61.9	74.2	81	83.4	87.7	92.5	101.2	106.5	107.8
Withcott	0	0	1.5	7.6	10.4	17.7	26	36.5	38.5	46.6	54.6	64.7	65.4	67.5
Wonga	4.7	12	22	33.6	37.7	51.1	62.4	69.9	72.7	80.1	88.6	92.3	98.1	98.7
Woorabinda	0	2.7	7.3	12.5	14.7	20.5	25	32.9	35.5	45.4	51.7	56.4	76.8	85.3
Wujal Wujal	5	12.8	22.9	34.7	37.8	49.2	59	65.7	65.9	75.6	81.4	84	89.5	102.5
Yarrabah	4.2	11.8	21.9	36.5	41.1	56.5	69.2	79.4	81.2	90.9	96.2	102.9	108.1	116.3
Yeppoon	0	5.7	12.1	20.8	24.4	34.3	46.3	58.5	60.7	72	74.8	82.6	91.9	100



Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP4.5 – 2081–2100)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Cities and Towns	2	5	10	20	25	50	100	200	250	500	1000	2000	5000	10000
	50	20	10	5	4	2	1	0.5	0.4	0.2	0.1	0.05	0.02	0.01
Allingham	1	9.4	19.7	31.6	35.9	49.6	60.4	70	73.1	82.1	87	91.6	96.2	104.8
Alpha	0	1.2	3.3	6.7	8	12.3	20	27.3	29.8	35.8	40.8	44.5	49.9	53.4
Aramac	0	1.4	3.7	7	8.2	13	19	23.4	25.1	30.4	34.3	39.6	53.9	55.4
Aurukun	8.6	18.1	28.7	40.4	44.7	54.6	65.7	76.2	77.8	82.9	89.9	97.1	105.7	117
Ayr	0	8.4	18.8	33.1	39.4	53	66.4	76.7	80.1	92.7	97.5	103.4	110.8	114.7
Badu	6	19.6	33.3	47.6	52.1	62.7	73.5	86.3	87.8	96	99.6	109.4	123.9	128.8
Balgal	0.3	8.8	19	29.6	34.6	46.1	60.9	69.8	72.1	82.1	88.1	88.3	111.9	116.9
Bamaga	8	21.1	35	48	51.8	62.5	71.8	78.1	80	87.6	95	102.6	111.2	116.1
Barcaldine	0	0.9	2.4	5.5	6.4	10.3	15.4	20.1	22.1	28.3	31.9	36.4	39.1	55.3
Bargara	0	1	2.7	7.9	9.7	21.3	34.8	49.7	53.8	64.1	68.9	79.7	83	88.5
Beaudesert	0	0	1.5	6	8.8	16.2	26.5	35.4	42.9	49.2	58.8	61.9	82.4	93
Biloela	0	0.7	1.8	5.9	8.7	19.6	29.8	40.6	42.9	54.9	69.3	71.5	92.9	96.9
Blackwater	0	1.4	3.6	8.8	10.8	18.6	25.7	32.1	36.7	45.9	55.2	67.3	73	77.1
Bloomfield	5.1	14	24	36.9	41.1	51.5	62.6	70.2	71.3	78.7	88.8	93.4	99.2	113.1
Bowen	0	7.7	19.2	35.8	41.9	58.3	73.4	81.7	82.8	91	99.7	102	108.6	118.3
Brandon	0	8.3	18.9	33.1	39.2	53.1	66.2	76.5	80.4	90.9	97	101.7	109.6	117.1
Brisbane	0	0	0.9	7.4	9.8	16.1	28	38.4	42.3	52.1	60.8	66.2	82	90.1
Bucasia	0	4.5	13.5	31.4	37	51.7	63	73.2	77.3	90.1	93.1	103.5	109.1	118.6
Buderim	0	0.5	1.4	8.2	10.3	19	32	45	47.6	54.7	60.8	67.8	78.5	100.8
Bulwer	0	0.4	1.1	8.4	10.5	19.5	31.6	44.8	50.7	59.7	61.1	63.8	68.6	86.9
Bundaberg	0	1	2.6	7	10.5	20.8	33.2	46.7	52.9	62.6	71.1	79.3	79.6	81.2
Burketown	0	4.5	9.4	17.6	20.6	29.2	37.5	44.1	48	51.4	51.8	56.7	59.8	83.5
Burnett Heads	0	1	2.7	7.8	10.2	21.7	35.6	48.4	53.6	65.1	71.8	77	79.3	83.2
Caboolture	0	0	0.5	7.7	10	17.5	29.9	40.3	44.1	54.5	60.9	67.7	71.6	78
Cairns	4	12.1	23.4	37.8	41.8	58.9	71	82.5	85.3	90.6	96.8	107.5	108.7	120.1
Caloundra	0	0.2	0.5	8.3	10.7	18.8	31.1	44.3	48.8	56.1	60.5	64.5	85.5	85.6
Camooweal	0	1.1	2.9	5.6	6.1	9.1	12.9	16.5	17.8	21.6	24.3	28.7	54.6	100.2
Capalaba	0	0	1.3	7.4	10.1	17.3	27.3	40.8	42.6	51.4	57.1	67.4	82	88.2
Cardwell	1.8	10.2	20.7	32.2	34.6	45.6	58.7	69.8	72	83.3	87.6	91.3	91.8	109.5
Charters Towers	0	6.3	13.4	21.8	24.6	33.8	45.4	53.7	56.9	59.4	63.2	64.3	81.5	81.8
Cherbourg	0	0.2	0.6	5.9	6.8	14.3	24.6	34.3	38.6	51.5	57.2	66.5	75.7	89.6
Chinchilla	0	0	1.2	3.5	4.7	8.5	15.6	24.4	25.7	38.1	46.6	57	78.8	93.5
Chuwar	0	0	0.7	6.7	9.3	15.3	26.7	36.4	38.6	48.9	55	58.8	79.2	87.4
Clermont	0	0.8	5.6	11.8	13.6	20	28	35.9	38.1	44.8	51.3	55.9	62.5	81.7
Clinton	0	0.2	2.5	8.5	11.6	23.7	38.3	48.4	53.3	64.3	78.3	92.3	104.8	107.8
Cloncurry	0	0.8	2.3	4.9	5.9	8.2	10.9	16.1	17.8	22.7	24.1	27	28.8	32
Coen	8.1	18.1	25.5	33.4	35.4	44.1	51.4	59.5	62.2	68	74.6	79.2	88	89.7
Cooktown	5.7	15.3	26	37.9	41.1	53.1	65.2	76.8	80.6	86.6	89.8	91.4	94.7	95.1
Coomera	0	0	1.8	6.9	9.4	17	26.3	37.6	42.5	54.9	63.3	64.9	84.6	89.8
Croydon	0	5.4	8.9	13.9	15.8	20.2	25.2	29	30.6	37.2	43.9	45.3	48.3	64.2
Dajarra	0	0	0.5	1.4	2.1	4.3	6.6	10.1	10.9	11.8	17	18.2	27.3	42.4
Dalby	0	0	1.3	3.9	4.4	11.1	18.8	25.9	29.3	43	50.7	62.2	71.8	86.5
Darnley Island	4.7	15.7	28.5	45.8	50.8	64.1	73.5	81.1	82.4	89.2	95.5	102.5	102.8	103.3
Deeragun	0	8.6	18.3	30.7	34.6	49.4	63.4	73	76.6	81.8	86.7	96.9	108.5	111.2
Doomadgee	0	4.2	8.1	16.7	19.6	25.9	30.5	33	34.1	41.5	49.6	53.9	55.2	60.1
Dysart	0	1.5	6.7	14.6	16.4	24.7	33.1	40.8	44.3	49.5	55.2	61.5	73.4	74.6
Eagle Heights	0	0	1.7	6.5	9.2	16.3	26.9	38.3	42.9	55.4	61.5	66.5	84.9	89.3
Edmonton	3.9	11.8	23.1	36.7	42.1	57	67.3	77	81.1	88.5	93.3	95.3	109.4	114.5
Einasleigh	0	6.3	11.6	17.7	20.4	26	31.5	37.8	39	46.8	53.6	58.4	68	69.3
Ellinthorp	0	0	1	2.9	6.1	12	20.6	31.6	33.1	41	43.5	55.5	57	57.8
Emerald	0	1.4	3.8	8.4	10.3	16.4	23.2	31.9	34.2	40.9	50.2	67.5	72.7	75.3
Emu Park	0	0.9	3.4	11.3	14.9	27.6	41.9	52.9	56	70.8	75.5	75.7	83.1	89
Fernvale	0	0	0.3	6.6	8.7	15.5	26.7	39.1	41.3	46.2	53.3	60.5	69.1	75.7
Forsayth	0	5.7	10.5	16	18	22.9	28.3	34.6	36.3	41.3	45.1	48.4	51.1	52.7
Gatton	0	0	1.8	5.4	7.5	14.9	24.6	35.7	37.8	46.2	49.5	52.4	63.8	71.4
Gayndah	0	0.4	1.2	5.7	7.7	15.9	25.7	33	36.5	47.2	56.2	66.4	78.8	96.3
Georgetown	0	6.2	10.8	16.6	18.4	24	28.4	34.6	36.6	40	44.7	47.8	50.9	61.7
Gladstone	0	0.3	2.4	8.5	11.9	24	37.9	48.4	52.2	65.1	78.1	91	105.4	107
Glamorgan Vale	0	0	0.3	6.4	8.5	15.2	26.4	38.1	41.8	44.7	52.9	55.7	71	73.9
Glenella	0	4.4	13.1	30.6	36	49.8	61.3	72.1	76	85.2	92.4	101.4	105.2	123.3
Gold Coast	0	0	2.1	6.8	9.3	17.6	25.7	39.4	45.4	56.3	63.7	71.4	78.2	82.4
Goondiwindi	0	0	0	0.5	0.7	5.7	10.7	19.9	20.9	31.8	38.2	45.4	51	58.3
Gracemere	0	0.6	3.4	10.3	13.1	24.2	36.6	46.4	51.1	62.4	73.2	80.6	85.7	99.1
Gregory	0	2.7	5.7	11.6	14	19.8	23.8	28.5	30.2	34.7	39.4	41.7	42.7	43.3
Gunpowder	0	1.5	3.9	6.7	7.9	11.3	16.1	20.2	21.5	24.6	30.1	32.6	57.1	83
Gununa	0	6.9	15.4	29	34.3	48.9	59.7	69	69.7	75.6	80.6	86.3	93.8	101.8
Gympie	0	0.7	1.8	7.2	9.8	17.9	31.6	46.1	48.5	57.1	65.7	77.5	83.9	91.2
Hervey Bay	0	1.1	3	7.9	9.8	23.4	34.9	47.3	52.4	64.6	70	78.7	81.9	83.8
Highfields	0	0	1.5	4.6	6.7	13.1	23.3	32.6	34.8	43.6	50.3	57.2	63.8	65.2
Home Hill	0	8.2	18.6	32.4	38.1	53.1	64.3	75.7	77.9	92.8	99.3	102.5	114.1	121.7
Hope Vale	5.8	15.7	26.2	38.1	41.5	54.5	64.6	71.8	74.4	83.1	89.2	99.4	100.8	104
Hughenden	0	2.6	6.2	10.3	12.4	19.4	25.8	34.1	35.2	40.3	46.4	50	55.7	60.3
Ingham	1.1	9.5	19.3	31.4	34.9	46.6	60	68.7	69.8	78.7	91.3	95	103.2	119.8
Inglewood	0	0	0	0.9	1.5	8.5	15.3	24.5	26.9	33.7	40	50.8	52.9	56.4
Injinoo	8.1	21	34.9	48.5	51.5	62.4	72.6	79.3	81.8	88.6	93.8	106.4	109.4	110.3
Innisfail	3.2	11.1	23.3	37.1	41.9	56.2	65.4	76.6	78.9	84	92.3	100	115.2	136.6
Ipswich	0	0	0.6	6.5	9.2	15.3	25.9	37	37.4	46.9	51.9	57.3	77.9	89.9
Julia Creek	0	0	3.5	5.8	6.6	10.5	15.4	21.2	22.1	27.3	27.8	28.9	30.3	32.7
Karumba	0	5.6	10.3	16.6	19.8	29	41.3	49.3	53.2	57.9	61.2	67	75.5	86.7



Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP4.5 – 2081–2100)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Kingaroy	0	0	0	5.6	6.3	13.8	23.9	31.8	35	47.6	57.3	67.3	81.9	97.3
Kooringal	0	0	1.7	8	10.4	18.5	28.7	42.6	47.3	55.2	55.6	68.3	80.3	83.4
Kowanyama	5	11.4	18.8	30.2	34.5	45.7	53.8	61.4	63.9	70.9	72.2	75.7	78.7	85.6
Kuranda	4.2	12.2	22.9	36.9	41	55.5	66.1	79.7	82.8	90.7	101.6	104	125.4	125.8
Laidley	0	0	0.1	5.5	7.8	14.9	25.3	36.3	38.4	45.6	49.2	56.6	63	64.5
Lockhart River	9.1	20.1	29.7	41.2	45.3	57.7	67.3	77.8	80	84.8	91.7	105.1	112.1	114.9
Lowood	0	0	0.3	6.4	8.1	15.7	26.5	39.3	40.8	45.1	51.2	58.5	67.6	76
Lucinda	1.4	10	20.8	33.4	37.5	50.7	62.8	73.5	77.2	84.3	93.8	95.2	99.6	114.4
Mackay	0	4.4	13.2	30.6	35.9	49.5	61.6	71.9	76	86	91.9	100.9	105.7	124.8
Macleay Island	0	0	1.7	7.4	9.8	18.1	27	39.7	43.5	50.5	56.9	74.2	88	93.3
Mapoon	9.4	20.9	32.6	46.1	51.5	63.7	75.9	81.6	82.4	89.7	94.5	98.1	103.3	115.7
Mareeba	3.8	11.3	21.2	33.9	37.1	49.6	60.2	67.7	69.7	77.1	83.2	86.1	99.4	102.7
Maroochydore	0	0.6	1.6	8.4	10.1	19.4	31.6	46.1	47.7	55.1	66.5	69.9	80.1	100.1
Maryborough	0	1	2.7	7.2	9.2	23.3	33.3	48.9	50.2	65	67	77.2	91.2	91.5
Maxwelton	0	1.2	4.4	7.5	8.3	13.3	20.5	26	27.3	31	36	36.3	41.3	44.5
McKinlay	0	0.7	1.7	4.1	4.6	7.4	12.3	16.8	19	23.3	27.7	28	28.1	29.3
Miles	0	0	0.9	2.6	3.7	7.7	14.3	23.9	27	35.3	44	53.9	78.7	89.8
Millchester	0	6.4	13.7	21.8	24.6	33.8	46	54.3	57.9	60.5	63.7	66.2	81.6	83.5
Monto	0	0.5	1.3	6.1	8	18.1	29.4	38.5	41.7	50.3	59.5	61.7	72.1	104.7
Moonford	0	0.5	1.4	6	8.2	17.6	30.8	41.3	43.6	53.1	59.3	62.8	79.1	116
Moranbah	0	2.7	8.7	17.3	20.1	27.8	37	44.4	46.6	53.4	60.8	65	82.3	93.3
Morayfield	0	0	0.5	7.7	9.9	17.5	29.6	41	43.6	53.2	61.8	66.3	71.3	79.5
Mossman	4.7	12.8	23	35.4	39.1	51	66.4	75.7	77.1	84.3	91.8	96.6	103.4	104.4
Mount Isa	0	0.6	1.5	4	4.8	7	10	13.3	15.1	19.4	21.2	24.9	30.3	93.5
Mount Morgan	0	0.3	3.1	9	11.8	22.6	33.8	44.8	49.3	56.1	69.6	83	105.2	111.9
Moura	0	0.7	1.7	5	7.2	16	25.8	33.4	35.5	44.8	55.3	59.6	74.7	106
Murgon	0	0.3	0.8	5.9	7.1	14.6	25.2	36.1	40.3	53	61.1	66.7	79.8	87.1
Myola	4.3	12.2	22.8	36.4	40	54.9	67.5	79.8	81.9	89.9	102.3	105.9	122.7	123.5
Nanango	0	0	0	5.7	7.2	14.7	24.8	32.8	37.4	47.6	52.7	58.5	84.1	94.1
Napranum	9.5	19.5	30.1	42	45.5	56.6	65.3	71.7	74.9	79.3	84	91.5	98.9	143.7
Nelia	0	0.8	4	6.5	7.4	12.1	18.1	23.4	24.8	28.2	29.8	32.9	36.5	37.9
Nerang	0	0	2	6.5	9.2	17.4	25.5	40.5	44.6	54.9	61.1	68.5	76.4	87.6
Nonda	0	1.1	4.2	7.2	7.9	12.6	19.7	25.8	26.6	31.4	32.9	34.2	35.1	36
Noosaville	0	0.9	2.3	8.1	10.3	20.4	34.5	47.6	49.8	58.9	67.6	83.1	93.2	100
Normanton	0	5.4	9.6	15.4	17	26.5	34.9	42.3	44.1	48.4	58.6	73.5	81.3	82.1
North Tamborine	0	0	1.6	6.5	9.2	16.5	27.2	39.3	41.8	55.1	61.8	67.3	86.2	89.5
Oakey	0	0	1.3	4	5.9	11.8	22.1	30.5	33.2	40.7	49	55.8	73.3	74
Palm Islands	1.2	9.7	20.8	34	38.9	53.8	64.6	74.6	76.3	84.9	100.1	108.9	124	132.2
Pentland	0	4.4	9.5	16.2	18.4	25.9	33.3	42.4	45.7	49.7	54.4	60.4	62.3	64.1
Pormpuraaw	5.9	13.5	22.4	35	39.3	52.9	61.5	69.5	69.8	73.6	79.1	89.8	91.6	99.6
Port Douglas	4.7	12.9	23	35.9	39.3	53.2	67.1	78	80.4	87.3	95.2	102.2	108.3	115.3
Prairie	0	2.8	6.9	11.5	13.6	20.7	27.7	34.2	36.9	43.6	49.1	53.8	54	54.1
Proserpine	0	6.3	17.2	34.2	39.5	53.8	65.4	76.2	78.9	88	93.3	100.6	108	114
Rainbow Beach	0	1.1	3	8.2	10.7	21.6	37.4	50.2	53.9	64.6	73.7	75.7	76.3	77.2
Redcliffe	0	0	0.9	7.8	9.7	16.8	30	42.5	46.7	52.5	60.5	62	71.3	77.5
Redlynch	4.1	12.2	23.2	36.9	41.5	56.9	68.1	79.8	84.5	92.7	99.1	104.9	111	119.8
Richmond	0	1.6	5	8.4	9.4	14.8	21.5	28.3	30.3	33.4	38.5	43.3	45	45.7
Rockhampton	0	0.7	3.4	10.6	13.5	25.3	37.3	48.1	51.5	63.5	71.8	78.7	91.8	92
Rose Hill	7.4	20.9	34.7	48.7	53.4	64.2	74.4	82.5	86.4	94.6	104.7	111.2	114.3	119.4
Rosewood	0	0	0.4	6	8.5	15	25	37.5	39.6	44.7	46.9	55.7	71	71.7
Russell Island	0	0	1.8	7.3	9.9	18	28.6	38.9	44.2	51.1	57.4	73.9	94.3	105.7
Saibai	3.8	16.7	26.7	38.7	43	53.3	63	71	72.2	79.4	85	87.8	95.7	97.1
Stanthorpe	0	0	0	2.1	3.2	11.2	19.3	28.1	29.1	34	43.7	58.4	69.6	71.2
Sunshine Beach	0	0.9	2.4	8.3	10.3	20.4	34.2	47.4	50.3	59.2	67.6	82.3	90.5	98.7
Tannum Sands	0	0.3	2	8.8	11.7	24.9	38.9	48.7	53.7	64.3	81.7	94.4	103.8	108.1
Taranganba	0	1	3.8	11.6	15.4	28.3	42.8	56	59.6	68.6	74.8	81	90.2	100.1
Taroom	0	0	0	3.3	4	9.8	17	24.8	27.6	32.5	50	63.9	64.6	68.4
Tewantin	0	0.9	2.3	7.9	10.4	19.9	34.9	46.6	50.3	57.8	66.3	83.3	93.5	101
Texas	0	0	0	1.4	2.2	8	14.5	22.5	27.8	32.8	39.5	47.9	50	54.6
The Monument	0	0	0.5	1.6	2.4	4.6	7.2	11.4	13.2	14	14.2	19.8	22.8	29.5
Thursday Island	7.4	20.9	34.9	49.1	53.4	64.2	74	83.8	85.1	94.7	105.2	110.1	113.3	118.7
Tieri	0	0.5	5	11.4	13.4	20.4	29	37.1	38.9	46.4	54.2	57.3	62.1	66.4
Tin Can Bay	0	1.1	3	8	10.4	21	36.3	48.3	50.5	62.6	68.2	74.8	76.6	79.5
Tinana	0	1	2.6	7.2	8.9	23.2	32.7	49.1	50.3	65	68.1	77.9	90.4	93.4
Toowoomba	0	0	1.5	4.4	6.6	13.4	22.6	33.2	33.8	42.3	52.2	54.4	56.6	61.5
Torrens Creek	0	3.5	8.1	13.6	15.8	23.3	30.1	37.6	40.2	45.4	50	54.7	63.1	65.4
Townsville	0.1	9	18.8	31.7	36.9	50.2	64.8	76.6	79.2	85	87.1	100	102.1	111.2
Tully	2.3	10.5	21.2	33.1	36.8	47.4	57.1	67.6	71.1	78.7	90.3	94.3	102.7	117
Umagico	8.1	21.1	35	48.2	51.7	61.8	71.8	79.3	80.5	87.7	92.6	103.9	111.4	120
Warwick	0	0	0.3	2.1	6.1	11.7	22.3	32	32.4	38.9	43.9	52.8	60.9	74.6
Wasaga	7.4	20.9	34.9	48.7	53.3	64.2	73.6	82.6	86.1	92.8	106.4	108.9	111.1	118
Weipa	9.5	19.6	30.2	42.1	45.9	57	66	73	73.3	79.3	82.1	91.4	98.5	139.4
Whitsunday	0	6.8	18.4	36.2	43.1	56.4	71	78.9	82.8	90.3	95.8	101.5	107.7	109.6
Withcott	0	0	1.5	4.5	6.8	13.3	22.6	33.5	35.6	43.2	51.4	56.2	58.5	60.9
Wonga	4.8	13.2	23.4	35.5	40	52.8	65.9	76.4	79.7	87.5	94.5	100.5	102.2	108.1
Woorabinda	0	0.9	2.3	6.4	8.5	16.2	23.8	34	36.6	47.3	54.1	60.7	83	87.7
Wujal Wujal	5.1	14	23.9	36.4	40.5	50.9	62	70.2	71.7	79.6	89.1	89.6	101	112
Yarrabah	4.1	12.4	24.1	38.5	43.2	59.9	73.1	82.7	85.6	95.9	100	107	111.8	121
Yeppoon	0	1.1	3.9	11.8	15.5	28.6	42.6	56.1	59.4	68.9	74.5	82.6	87.7	102.1

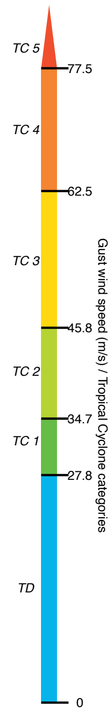
Gust wind speed (m/s) / Tropical Cyclone categories

TC 5 — 77.5
TC 4 — 62.5
TC 3 — 45.8
TC 2 — 34.7
TC 1 — 27.8
TD — 0

Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP8.5 – 2041–2060)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

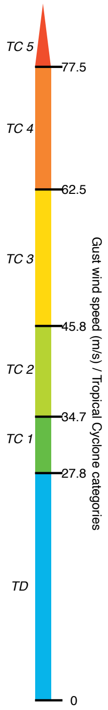
Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Allingham	2	12	22.7	34.5	39.1	52.9	62.9	71.7	73.7	83.5	88.5	93.9	96.8	97.3
Alpha	0	1.4	3.8	6.8	7.7	12.9	19.5	25.3	26.8	33.2	36.3	39	53.8	57.2
Aramac	0	1.5	4.1	7.3	8.7	13.3	19.9	24.8	26.7	28.5	29.7	34.3	38.7	42.6
Aurukun	7.9	15.6	24.5	35.8	38.9	49.2	60.1	69.3	72.8	77.9	85.7	89.1	93.7	97
Ayr	1	11.3	23	37.7	43.3	55.8	67.6	75.7	77.3	88.8	91.1	100.9	112.6	112.6
Badu	4.7	17.9	28.4	42.5	47.5	58.9	68.7	77.1	78.4	81.5	83.2	90.4	96.7	100.8
Balgal	1.3	11.2	22	33.6	38.3	50.9	66	73.4	74.8	81.9	87.7	94.4	111.9	116.3
Bamaga	7.4	18.7	30.3	44	47.9	57.9	67.1	72.8	74.9	79.2	85.3	90	99.2	110.7
Barcaldine	0	1.1	2.9	5.5	6.5	10.2	14.8	21.7	23.5	25.4	30.8	33.2	37.1	43.6
Bargara	0	1.2	4.6	9.6	12.2	24.4	37.1	49.6	52.1	54.2	62.9	69.8	76.7	77.2
Beaudesert	0	0	1.4	9.2	12.7	23.1	34.6	44	52	58.6	68.1	70.4	79.6	91.8
Biloela	0	0.5	3.7	7.7	9.4	18	27.6	37.2	38.8	47.1	56.8	60.4	62.3	78.7
Blackwater	0	1.1	4.7	10.1	12.2	18.5	25.3	32	34.7	43.6	54.6	66.1	76	78.1
Bloomfield	5.4	16.4	27.3	38.4	41.3	51.7	60.6	66.5	67.6	73.7	79.6	81.9	84.2	86.7
Bowen	0.6	10	22.5	38.9	45.2	59.2	71.7	76.8	77.6	81.2	89.9	95.2	95.6	110.2
Brandon	1	11.3	23	37.6	43.4	56	67.4	75.6	78.2	87.7	93.4	101.2	114.7	116.1
Brisbane	0	0	3.3	10.4	13.5	24.4	36.2	46.1	50	62	71.6	73.4	77.7	78.9
Bucasia	0	6.8	15.7	31	36.1	48.2	58.1	65.7	69.9	77.8	80.4	87.8	100.8	101.3
Buderim	0	1.8	4.7	11.3	14.5	26.3	39.8	50.4	54	58.5	69.5	80.4	81.4	83.2
Bulwer	0	0	4.8	12.2	14.9	27.8	39.9	52	56.5	66.1	70.8	79.7	90.6	101.9
Bundaberg	0	1	4.3	9	12.4	23.1	35	48.5	51.8	56.4	63.5	69.6	73.3	75.3
Burketown	0	2.8	7.4	16.5	19.9	29.4	37.1	46.6	52.3	57.3	61.9	73.4	82.5	96
Burnett Heads	0	1.2	4.4	9.7	12.8	24.1	37.8	49.2	53.8	54.1	62	66.7	73.9	74.6
Caboolture	0	0	4	10.7	13.9	25.9	38.4	44.2	47.5	60.2	66.9	77	78.9	89.9
Cairns	4.6	15.8	25.7	37.6	41	55.6	64.4	75	78.1	81.5	89.3	95	99.8	102
Caloundra	0	1.8	4.8	11.4	14.8	26.1	39.7	50.1	52.5	58	70.7	77.4	81.8	82.8
Camooweal	0	1	2.6	6.6	7.5	11.3	15.9	20.3	20.6	24.2	28	34.9	53.3	67.4
Capalaba	0	0	3.5	10.9	14.1	26.1	36	51.1	53.5	65	68.1	71.7	84.3	97.6
Cardwell	2.5	12.7	23.2	34.7	37.7	47.6	58.8	68.7	71.4	79.4	79.5	79.8	80.9	96.6
Charters Towers	0	7.6	15.4	24	27.1	36.3	45.6	55	58.7	67.1	73	73.3	80.2	107.8
Cherbourg	0	1	2.8	7.9	11.1	19.7	29.1	38.7	42	52.7	58.6	63.5	72.3	99.5
Chinchilla	0	0	0	4.6	6.2	12.9	20.7	28.9	31	41.9	52.4	59.2	77	85.3
Chuwar	0	0	2.5	9.7	12.6	23.4	35	44	46.7	61.6	65.9	73	76.6	82.6
Clermont	0	2	6.2	12.4	13.7	19.8	27.6	33.9	36.2	41.3	45.4	49.2	60	72.1
Clinton	0	1.7	5.1	10.4	12.6	21.1	34.4	46.7	51.1	59	66.2	79.2	84.3	87.7
Cloncurry	0	0.7	1.7	4.6	5.4	7.9	12.1	18.5	19.7	21.5	24.9	28.5	33.6	39.3
Coen	7.5	16.2	23.8	32.3	34.3	41.5	48.8	55.2	56.8	59.3	65.9	70.2	82.9	86.2
Cooktown	5.8	17.1	27.9	38.5	41.2	51.4	58.1	67.8	71.4	75.8	81.2	82.6	85.3	87.3
Coomera	0	0	2.9	10.3	13.8	24.8	37	50.2	53.8	66.1	73	74.4	78.6	78.6
Croydon	0	4.8	7.7	12.1	13.7	19.4	24.4	28.7	30.2	36.6	41.6	45.6	46.6	59.7
Dajarra	0	0	0.4	1.2	2.2	4.6	8	11.6	13.7	17.2	20.6	24.4	24.8	24.9
Dalby	0	0	1.9	5.7	7.5	15.5	25.2	34.6	36.5	47.5	55.7	59.1	70	72
Darnley Island	3.3	14.8	25.5	39.6	44.4	56.6	65.6	75.6	78.9	84.8	90.8	90.9	96.9	114.5
Deeragun	1.1	11.1	21.9	34.8	39	54.5	68.9	76.7	79.8	87.6	93.7	102.9	111	121.6
Doomadgee	0	2.2	7.1	15.9	18.8	27.1	34.6	40.9	43.2	48.6	54.4	54.9	56.5	57.8
Dysart	0	2.7	7.9	15.1	16.8	24.9	31.1	38.2	40.8	45.1	50.5	58.2	65.8	71.8
Eagle Heights	0	0	2.1	9.9	13.4	23.7	36.2	49	54.4	63.8	68.1	74.2	81.5	87.9
Edmonton	4.4	15.4	25.4	36.7	41.5	53.4	61.5	70.2	74.1	80.3	89.4	94.8	101.1	115.8
Einasleigh	0.6	6.8	11.9	18.4	20.9	26	32.8	39.4	41.4	49.4	55.1	56.8	61.6	62.2
Ellinthorp	0	0	2.1	6.2	9	17.9	28.3	38.3	40.2	46.4	50.7	59.3	60.4	61.7
Emerald	0	0.8	4.7	9.2	11.2	16.9	22.5	31.1	34.4	39.3	47.3	62.5	62.5	62.7
Emu Park	0	2.4	6	13	15.5	25.6	36.9	49.5	51.9	63.8	68	76.1	86.7	96.8
Fernvale	0	0	2.3	9.6	12.1	23.8	33.9	45	47.6	54.5	62.3	72.6	74.1	75.1
Forsayth	0	5.9	10.2	15.7	17.9	22.7	28.8	34.2	36.7	42.4	50	54.3	61.9	68.9
Gatton	0	0	0.7	8.1	10.7	22.3	32.2	42.6	45.8	53.6	56.4	60.7	73.5	81.2
Gayndah	0	1.1	3	7.5	9.8	18.2	28.3	36.7	39.4	47.4	56.1	67.6	82.6	96
Georgetown	0.4	6.4	10.4	15.8	18	24	28.9	33.9	36.2	40.5	43	44	55.6	66.9
Gladstone	0	1.8	5.2	10.6	12.8	21.5	35.2	46.7	51	59.7	68.5	80.9	89.9	92.7
Glamorgan Vale	0	0	2	9.3	12.1	23.6	33.5	43.9	48.4	56.4	62.4	70	71.5	72.4
Glenella	0	6.3	15.4	30.1	35.3	47	55.9	64.7	68.8	73.8	80.4	88.1	98.4	118.2
Gold Coast	0	0	2	10.3	13.6	24.6	36.6	50.4	56	63.4	70.9	71.4	76.7	76.8
Goondiwindi	0	0	0	0.5	3.5	8.7	14.9	24.7	28.2	36.8	45	53.3	56.6	69.2
Gracemere	0	2.1	5.6	11.2	13.6	23.3	32.4	42.1	45.3	54.4	66.1	74.3	82	85.4
Gregory	0	1	5.4	11.8	14.2	19.9	24.2	29.1	31	36.7	40.7	40.7	41.1	43
Gunpowder	0	1.2	3.3	6.7	8.6	13.1	17.5	21.5	23.3	27.3	34.1	37.1	46.2	46.7
Gununa	0	4.2	11.6	26.4	31.3	46.9	59.6	74.1	76.4	85.1	88.8	88.9	92.2	93.6
Gympie	0	1.6	4.1	9.6	13.5	22.5	37.4	48.7	52	61	64.5	78	87.5	93.4
Hervey Bay	0	0.8	4.9	10.9	13.1	26.9	37.1	49.2	53.8	62.1	66.1	70.6	76.3	79.1
Highfields	0	0	2.4	7.2	10.1	19.7	31.3	39.2	40.8	49.2	57.8	58.8	61.7	62
Home Hill	0.8	11	22.7	37.2	42.2	56.1	66	73.8	77.2	84.7	88.8	94.7	114.1	116.3
Hope Vale	5.9	17	28	38.4	41.3	51.2	59.1	65.5	67.3	75.7	81.9	88.8	90.2	93.2
Hughenden	0	2.9	7	10.9	12.6	19.7	25.4	34.5	35.5	41.4	48.6	52.5	61.3	73.2
Ingham	2	11.8	22.4	33.8	37.4	49.5	62.1	68.8	71.1	80.1	88	93.6	105.6	110.3
Inglewood	0	0	0	3.4	5.4	12.7	20.3	30.9	32.2	36.3	43.7	54.4	62.2	63.5
Injinoo	7.4	18.8	30.3	44.5	48	58.5	68	73.1	74.9	79.4	85.2	92.7	99	108.4
Innisfail	3.8	14.8	25.4	37.8	42	53.5	63.1	72.9	76.4	81.9	88.2	92.1	99.6	112.2
Ipswich	0	0	2	9.3	12.5	23.6	34.5	44.7	46.5	60.3	65.8	69.5	73.3	79.6
Julia Creek	0	1.3	3.4	5.6	6.4	10.9	13.8	20.8	22.8	28.1	30.8	36	38.6	38.8
Karumba	0	4.2	7.5	14.9	17	26.2	38.2	44.3	47.6	52.1	58	68.8	72.9	80.4



Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP8.5 – 2041–2060)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Kingaroy	0	0.9	2.3	7.9	10.5	19.9	29.4	39.2	40.2	50.8	59.2	65.8	75.5	86
Kooringal	0	0	4.5	12	14.8	27.3	38.3	52.8	57.1	66.4	70.5	72.7	85.4	86.4
Kowanyama	4	9.2	15.6	25.5	29.4	39.5	46.6	55.1	56.7	63.7	70	70.3	73.5	78.1
Kuranda	4.6	15.7	25.2	37.1	39.8	52.1	62.2	72.4	73.8	80.3	89	95.5	113.8	115.9
Laidley	0	0	0.2	8.3	10.9	22.6	32.3	42.9	45.4	54.2	56.1	60.5	66.1	71.2
Lockhart River	8.6	18.6	28.5	40.1	43.7	54.6	62.8	68.7	71	75.6	79.4	89.3	99.9	104.7
Lowood	0	0	2.2	9.3	11.7	23.6	33.6	44.8	47.8	54.6	61.7	69.4	71.5	72.8
Lucinda	2.3	12.6	24.1	36.7	41	53.9	64.2	72.3	76.8	84	87.2	92.1	97.3	104.8
Mackay	0	6.3	15.2	30.2	34.8	47.2	55.5	66	69.2	74.2	82	89.5	97.2	116
Macleay Island	0	0	3.8	11.1	14	26.8	37.3	50.9	53.4	67	70.5	78.7	87.2	98.4
Mapoon	8.5	18.7	29.1	43	47.6	59.2	70	76.4	78.8	85.6	92.5	95.5	98.5	112.2
Mareeba	4.3	13.9	23.3	33.5	36.8	47	55.2	62.4	65	70.5	76.5	86.2	106.8	109.2
Maroochydore	0	1.8	4.8	11.4	14.3	27	39.5	51.3	54.1	60.3	74.6	80.2	80.5	82.8
Maryborough	0	0	4.5	10	12.3	25	36.5	48.6	51.2	59.9	62.6	71.5	90.6	95.4
Maxwelton	0	1.3	4.5	7.6	8.6	12.7	19.4	24	26.1	32.1	36.8	39.4	46.1	62.4
McKinlay	0	0.6	1.5	3.8	4.6	7.6	11.1	17.3	19.4	24.9	27.4	29.3	31.3	31.9
Miles	0	0	1.2	3.6	5	10.8	19.4	27.9	30.7	38	46.4	54.8	75.5	84.4
Millchester	0	7.6	15.7	24.2	27.5	36	46.2	55.1	59.4	67.3	73.3	75.4	81.1	110.7
Monto	0	0	3.5	7.4	9.2	19.6	28.4	36.1	40.3	49.8	54.3	55	68.7	77.2
Moonford	0	0.1	3.5	7.3	8.8	18.8	29	37.7	39.8	49.6	56	56.2	68.4	88
Moranbah	0	4	9.7	17.8	20.3	26.6	35.2	42.3	43.2	51.4	57.6	61	72.9	95
Morayfield	0	0	3.9	10.8	13.8	26.1	37.7	44.7	46.3	60.8	68.3	74.9	79.3	90.6
Mossman	5	15.2	25.1	36	39	51.4	62.4	68.4	71	78.5	82	91	92.7	93.5
Mount Isa	0	0.4	0.9	4	5	8	11.8	15.6	17.2	20.6	27.1	29.9	31.5	33.2
Mount Morgan	0	1.7	5.2	10.4	12.6	22.1	30.9	38.8	42.9	47.3	62	73.3	84.9	85
Moura	0	1.1	3	6.9	9.3	15.2	23.1	28.8	31.5	40.7	46.5	51.3	62.6	86.3
Murgon	0	1.1	2.8	8	11	20	29.5	38.5	42.4	52.7	59.7	62.5	78.8	104.4
Myola	4.6	15.5	25.2	36.4	39.6	51.7	63.2	72.2	73.9	80.6	90.5	97.9	113.5	116.5
Nanango	0	0.9	2.5	8.3	10.8	20.9	30.3	38.9	42.9	48.3	58.9	61.7	84.9	90.5
Napranum	8.7	17.5	27.1	37.4	41	50.5	58.2	65	68	73.3	80.3	88.8	93.8	103
Nelia	0	0.8	4	6.6	7.6	11.8	16.9	22.3	23.9	28.6	33.4	39.4	45.7	46.1
Nerang	0	0	1.8	10.2	13.4	24.9	37.1	50.4	54.2	63	66.3	70.9	77.4	89.2
Nonda	0	1.1	4.3	7.3	8.2	12.6	18	24.1	25.3	32.1	34.6	39.8	40.4	55.8
Noosaville	0	1.8	4.8	11.1	14.5	25.9	39.8	53.5	54.8	65.7	73.7	84.6	94.4	101.6
Normanton	0	4.2	7.2	13.5	15.6	23.9	31	39.4	41.8	48.4	58.9	69.4	88.2	92.4
North Tamborine	0	0	2.2	9.8	13.3	23.7	36.2	49.3	54	62.8	70	76.1	82.2	87.3
Oakey	0	0	2.1	6.4	9.2	17.8	29.3	36.9	40	48	57	58.5	67	70.9
Palm Islands	2.2	12.6	24.4	38	42.9	58.2	68.9	77.8	80.5	90.1	102.8	102.9	108.6	112.8
Pentland	0	5.3	10.4	17.8	20.2	26.7	33.9	44.2	46.3	53	56.9	58.7	82.4	85.8
Pormpuraaw	5	10.4	18.4	29.5	33.2	45.4	54.7	64	64.9	69.5	74.3	77.1	81.7	94.3
Port Douglas	5	15.6	25.4	36.6	39.9	51.8	63.4	71.1	74.4	81.8	85.6	92.7	94.9	98.5
Prairie	0	3.4	7.6	12.6	14.3	21	27.8	35.3	38.2	46.3	53.3	58.2	74	86.7
Proserpine	0	8.8	20.4	36.7	41.2	52.9	63.1	71.3	73.2	80.6	84.4	90.8	110.9	111.6
Rainbow Beach	0	2	5.3	10.9	13.9	27.6	41.3	54.2	57.3	61.5	75.3	76.8	82.6	84.8
Redcliffe	0	0	3.9	11.3	13.8	25.2	38	49.4	54	60.5	68.6	76.4	81.8	90.8
Redlynch	4.6	15.7	25.4	37.3	40.9	53.2	64	72.8	76.6	81.7	88.1	97.7	103.5	103.6
Richmond	0	1.7	5.2	8.7	9.8	15.1	21.1	27.3	29.1	34	39.5	46.3	53.8	55.2
Rockhampton	0	2.1	5.8	11.5	14.1	23.9	33.1	43.7	46.1	55.3	64.4	73.6	85.3	86.8
Rose Hill	6.3	18.4	29.9	44.2	49.5	59.6	69.4	76.1	79.8	88.1	88.9	92.3	97.3	100.1
Rosewood	0	0	1.4	8.9	11.8	23.2	32.1	45.3	46.6	56.5	60.4	65.9	66.3	66.6
Russell Island	0	0	3.7	10.8	14.2	26.5	37.2	51	55.9	67	69.9	75.7	91.9	93.2
Saibai	4.2	15.3	22.8	34.1	38.8	48.2	56.4	64.8	67	71.4	77.7	84.7	93.3	102.5
Stanthorpe	0	0	0	5	7.5	16	25.3	34.3	35.5	42.5	52.1	69.6	72.9	79.3
Sunshine Beach	0	1.9	5	11.2	14.8	26.5	40.1	53.7	55.8	66.4	74.2	82.1	92.7	99
Tannum Sands	0	1.8	4.7	10.7	11.9	22	35.6	46.3	50.1	59.4	67.6	76.3	84.6	90.1
Taranganba	0	2.5	6.3	13.4	16.5	25.8	38	50.5	53.6	61	70.2	79.6	81.4	94.2
Taroom	0	0.5	1.4	4.4	5.7	11.9	20	26.8	28.8	34.9	52.7	62.7	70.7	83.8
Tewantin	0	1.8	4.8	11.1	14.3	25.4	40.2	52.4	55.5	65.9	71.8	85.8	98.2	102.8
Texas	0	0	0	2.3	5	11.7	19.3	28	31.2	39	47.5	56.6	65	66.2
The Monument	0	0	0.5	1.4	2.6	4.8	8.1	12.1	16	17.2	19.5	21.9	30.7	32.9
Thursday Island	6.4	18.4	30	44.3	49.4	59.1	68.6	77.3	79	87.8	88.5	92.8	97.9	100.4
Tieri	0	1.8	5.9	12.2	14.3	20.6	27.4	35.9	38.4	43.9	51.8	56.8	62.5	64.1
Tin Can Bay	0	1.9	5.1	10.4	14	26.5	40.2	53	54.9	61.8	70.9	73.5	81.2	91.1
Tinana	0	1.6	4.4	10.1	12.1	25.1	36.9	48.8	50.8	59	62.5	69.4	91.8	95
Toowoomba	0	0	2.4	7.1	9.9	19.5	31	39.5	41.8	48.7	58.3	58.7	63.3	69.6
Torrens Creek	0	4.3	8.8	14.8	16.8	23.6	30.4	38.6	40.7	46.5	52.9	57	74.6	76.5
Townsville	1.2	11.4	22.4	35.7	41.1	55.6	68.9	80	83.1	88.4	98.6	110.6	111	113.3
Tully	2.9	13.5	23.2	34.9	38.1	49.6	57.4	67.9	71.5	76	82.9	86.7	94.8	99.6
Umagico	7.4	18.8	30.3	44.4	47.8	57.7	67.7	73.3	74.6	78.8	84.7	91.4	100.4	109.2
Warwick	0	0	0.1	6.1	9	17.9	29.2	37.7	40.4	44.8	46.8	54	67.1	72
Wasaga	6.5	18.4	30.2	44.2	49.4	59.6	67.8	75.1	79.9	87.2	88.8	94.5	99.5	102.4
Weipa	8.7	17.6	27.2	37.8	41.2	50.9	58.4	66	67.6	72.6	78.8	84.9	89.5	101.4
Whitsunday	0.3	9.3	22.2	39.5	45.4	56.3	66.7	75.5	77.2	82.8	85.5	93.7	107.9	108.3
Withcott	0	0	2.4	7.2	10	20	30.8	40.1	43.4	49.8	59.2	61	66.3	71.3
Wonga	5.1	15.8	25.7	36.5	39.9	52.1	63.1	70.6	72.8	79.6	83.6	85.4	90	93.8
Woorabinda	0	0.4	3.6	8	10.6	17.1	22.3	30.2	32.8	42.3	50.1	54.1	71.7	72.1
Wujal Wujal	5.4	16.2	26.8	37.9	40.5	50.4	59.4	64.6	66.9	75.1	79.6	79.8	80.2	87.8
Yarrabah	4.7	16	26.3	38.8	42.5	56.4	66.4	73.5	77.2	82.4	90	94.2	94.6	95.2
Yeppoon	0	2.6	6.4	13.6	16.6	25.8	38.3	49.8	52.8	61.8	69.6	79.4	79.8	96.3

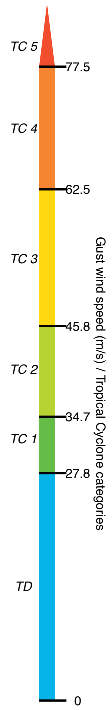


Australian Government
Geoscience Australia
Queensland Government
CYCLONE TESTING STATION

Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP8.5 – 2081–2100)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Cities and Towns	2 50	5 20	10 10	20 5	25 4	50 2	100 1	200 0.5	250 0.4	500 0.2	1000 0.1	2000 0.05	5000 0.02	10000 0.01
Allingham	0	6	15.2	27.2	31.2	44.7	55.4	64.6	68.2	77.4	84.4	91.2	94.8	100.8
Alpha	0	0.8	2.3	4.8	5.8	11.2	18.4	23.3	25.3	31.1	36.3	37.4	47.2	60
Aramac	0	1	2.6	5.5	6.8	12.1	19	25	27.7	28.6	30.8	35.6	44.6	49.6
Aurukun	3.5	10.2	19.9	34.5	38.6	51.1	62.1	73.2	76.9	83.1	85.9	86.4	86.5	99.1
Ayr	0	6	16.3	28.7	34.1	46.8	56.6	65.9	67.3	79.4	88.7	97.5	106.7	106.9
Badu	4.7	13.4	23.1	37.5	42.9	54.8	66.7	76	76.4	81.2	83.8	88.9	97.4	105.4
Balgal	0	6	14.9	26.1	30.5	42.1	57.1	65.5	67.4	76.3	78.3	84.3	103.8	114.2
Bamaga	4.9	13.7	24.1	38.7	43	54.3	63.2	70.2	71.8	76.5	80.7	86.8	97	98.9
Barcaldine	0	0.6	1.5	4.3	5.1	9.6	15.1	22.7	23.6	27.2	29.9	34.4	36.9	58.3
Bargara	0	0.1	0.3	2.8	4.4	16	29.5	43.9	45.5	54.4	64.4	74.3	81.7	81.7
Beaudesert	0	0	1.4	3.2	4.7	13.6	21.6	28.6	36.1	44.8	56.7	70.5	85.9	100.6
Biloela	0	0.3	0.8	4	6	14.9	23.1	33.4	35.2	46.3	59.2	60.2	65.6	77.6
Blackwater	0	0.9	2.5	7.2	9.1	15.5	22.6	28.7	31.3	37.9	48.5	56.4	65.6	70.9
Bloomfield	0	5.4	14.4	27.1	30.9	42.1	52.4	58.8	59.9	67.7	79	79.7	81.7	86.3
Bowen	0	5	15.7	31.3	36.8	49.9	62.3	70.5	71.6	77.4	87.8	89.2	90.2	100.7
Brandon	0	6	16.3	28.6	34.1	46.6	56.2	65.7	68.4	78.3	87.9	95.6	109.2	110.7
Brisbane	0	0	0.9	3	6.1	13.1	22.6	31.2	35	46.4	66.1	71.8	72.7	72.9
Bucasia	0	3.2	9.7	24.2	29.6	41.5	50	57.6	62.7	70.6	76.8	79.9	90.6	94.2
Buderim	0	0.1	0.4	4.8	6.8	13.4	24.9	35.4	38.4	44.3	53.3	67.3	73.7	84.2
Bulwer	0	0	1	5.3	6.9	14.8	24.2	37.1	42.4	49.3	59.6	67.4	88.6	88.8
Bundaberg	0	0.1	0.3	2.5	5	15.2	27.3	41.8	45.3	55.4	59.4	64.4	70.8	72.4
Burketown	0	0	4.3	11.3	14.6	24.6	32.6	42.6	46.7	51.6	58.1	70.2	78	95.9
Burnett Heads	0	0.1	0.2	2.7	4.9	15.8	30.7	44.1	47.8	53.2	64.2	70.5	76.2	81.4
Caboolture	0	0	0.6	4.5	6.7	13.4	23.9	30.5	34.5	47	54.9	63.1	71	77.7
Cairns	0	5.7	14.6	27.6	31.6	47.6	58.1	67.2	71	76.7	84.2	86.5	93.4	102.2
Caloundra	0	0.2	0.6	4.9	7.2	13.2	24.1	35.6	38.5	47.4	53.9	62.6	76.5	77.6
Camooweal	0	0.3	0.9	4.9	5.8	9.7	14.4	19	21.1	24.6	27.7	34.2	51.5	60.4
Capalaba	0	0	1.2	3.4	6.9	14.3	21.5	35.1	38.1	48	61	74.5	77.7	87.6
Cardwell	0	6	15	26.9	30.4	41	52.5	61.5	65	75.9	77.2	80.8	91.4	107.6
Charters Towers	0	4.3	10.9	18.5	21.5	29.9	38.9	45.6	49.8	57.4	63.6	65.8	72.9	76
Cherbourg	0	0	0	3.1	4.6	10.3	17.2	27.1	30.7	43.6	49.5	52.3	70.1	91.3
Chinchilla	0	0	0.4	1.2	2.4	6.4	12.4	20	21.3	35.3	47.8	58	73.9	80.8
Chuwar	0	0	0.7	2.7	6	12.8	21.7	30	32.3	48.3	61.5	67.6	69.4	72.2
Clermont	0	1.5	3.9	9.4	10.8	16.9	24.8	30.3	33.2	38.9	41.7	44.3	52.2	63.4
Clinton	0	0.5	1.4	6	8.6	17.9	30.3	43.9	47.1	54.5	60.3	74.1	77.6	87.4
Cloncurry	0	0.3	0.7	3.8	4.7	8.2	13.1	17.7	19.4	21.8	24.4	28.2	32.9	35.4
Coen	1.9	9.7	17.6	26.8	29.1	36	43.5	49.4	50.9	55.1	63.9	70.6	90.6	93.3
Cooktown	0	5.7	14.8	27.8	30.8	41.8	49.9	59.1	63.4	70.8	77.1	79.2	85.4	91.5
Coomera	0	0	1.7	3.8	6.2	13.8	22.1	33.5	38.2	50.1	58.3	70.5	83	88
Croydon	0	2.5	5.3	10	11.7	17.8	23.5	27.3	28.4	35.4	41.5	45.2	48.9	59.7
Dajarra	0	0	0.4	1.3	2.2	5.4	9.1	13.4	15.2	21.5	27.6	28.4	30.5	31.8
Dalby	0	0	0.3	0.8	2.8	8.1	14.2	23.9	25.5	39.2	49.7	52.9	64.5	71.4
Darnley Island	3.3	10.4	19.4	31.7	37	48.1	57.3	67.4	70	75.5	84.4	86	88.9	100.8
Deeragun	0	5.9	15.1	26.9	30.8	44.8	58	68.5	72.3	78.5	86.4	92.4	103.7	106.4
Doomadgee	0	1.5	3.9	11	13.9	22.8	30.5	37	39.2	44.9	54.5	56.7	56.7	58.1
Dysart	0	0.4	4.6	11.8	13.5	20.9	26.9	34	36.3	39.9	45.4	53.4	62	68.2
Eagle Heights	0	0	1.6	3.6	5.8	13.4	22.2	32.1	38.7	48.8	54.2	75.8	87.3	100.3
Edmonton	0	5.5	14.6	27.2	32.5	46.4	54.6	62.2	66.2	74.1	82.8	87.6	98.3	104.9
Einasleigh	0	3.1	8	14	16.6	22.5	29.2	35.6	37.6	43.8	52	56.4	69.8	70.3
Ellinthorp	0	0	0.5	1.6	3	10.7	16.6	26.6	27.5	37.2	37.2	51.5	54.6	64.6
Emerald	0	1	2.6	6.8	8.4	13.7	20.2	26.7	29.6	34.9	41.9	55.7	56.7	57.2
Emu Park	0	0	2.3	8.7	11.6	22.6	33.1	44.5	47.7	57.8	64	70	79.1	97.2
Fernvale	0	0	0.4	2.5	5.5	12.9	21	31.3	33.8	45.1	55.1	65	68.3	70.3
Forsayth	0	2.9	7	12.5	14.7	20.9	27	32.3	34.1	39.8	47.5	51.9	59.3	62.5
Gatton	0	0	0.1	1.8	4.8	13.1	19.7	29.6	33.6	45	49.6	52.5	61	70
Gayndah	0	0	0	2.4	3.6	11.2	20.2	28.2	30.8	39.8	49.2	60.3	72.8	89.4
Georgetown	0	3.1	6.9	12.8	14.8	21.6	26.4	33	34.2	39.4	40.8	40.9	50	68.2
Gladstone	0	0.6	1.5	6.3	8.4	18.1	31.2	43.2	46.9	55	62.1	74.3	85.5	89.9
Glamorgan Vale	0	0	0.4	2.4	5.7	12.8	20.7	30.1	34.9	44.8	55	63.8	67.2	69.3
Glenella	0	2.9	9.6	23.5	28.9	39.8	48.9	57.2	61.3	66.6	73	82.4	95.2	112.2
Gold Coast	0	0	2	3.9	5.3	14.3	20.8	33.5	40.3	48.5	57	64.4	78.5	81.5
Goondiwindi	0	0	0	0.5	1	4.5	8.3	17.1	20	29.2	34.9	41.3	42.6	54.1
Gracemere	0	0.8	2.1	7.9	10.5	19.7	28.9	38.3	40.9	49	63.1	70.5	74.8	84.6
Gregory	0	1.2	3.2	8.1	10.4	16.9	21.9	27.3	29	35.1	38.6	40.1	40.9	42.2
Gunpowder	0	0.7	1.9	5.4	6.7	11.1	16.9	20.2	22.6	28.8	36.1	39.8	50.9	56.2
Gununa	0	1.2	6.7	20.2	25.7	43.3	60.1	70.4	74.9	85.3	96.6	102	107.3	109.8
Gympie	0	0	0	3.7	6.2	10.8	24	35	37.7	46	53.3	65.6	72.8	81.4
Hervey Bay	0	0.2	0.6	3.9	5	14.9	28.2	40.9	46.6	54.1	61.5	75.3	83.6	87.2
Highfields	0	0	0.4	1.2	4.5	11.1	18.6	28.4	30.7	39.7	47.5	50.5	60.6	73.2
Home Hill	0	5.9	16	28.5	33.1	46.8	55.1	64.8	67.4	77	86.1	92.6	107.7	109.5
Hope Vale	0	5.9	15	27.5	31	41.7	50	56.8	59	69.6	77.5	85.4	89	89.1
Hughenden	0	0.8	5	8.6	10.2	17.4	23.2	32.3	33.4	39	46.5	50.3	62.9	73.4
Ingham	0	6	14.7	26.8	30.4	42.2	54.6	60.7	64.4	74.2	84.1	92.1	97.5	98
Inglewood	0	0	0	1	1.7	7.5	11.6	21.4	23.1	29	33.5	40.2	48.3	57.4
Injinoo	4.9	13.8	24	39	43.2	55.1	64.8	71.2	72.8	76.4	80.6	90.7	97.4	100.6
Innisfail	0	5.8	15.1	28.4	33.8	45.9	55.5	65.4	70.2	74.1	79.3	84.8	85.8	107.9
Ipswich	0	0	0.6	2.5	6	13	21.3	30.6	31.4	46	61.2	66.8	70	75.4
Julia Creek	0	0.9	2.4	4.7	5.8	10.5	13.6	21.4	22.8	30.6	31.6	36.9	39.5	40.7
Karumba	0	1.9	5	11.2	13.3	22.6	34.5	42.7	46.8	54	66.4	82.2	91.8	113.5



Recurrence of Tropical Cyclones across Queensland's cities and towns (RCP8.5 – 2081–2100)

Average Recurrence Interval (Years) / Annual Exceedance Probability (%)

Cities and Towns	2 / 50	5 / 20	10 / 10	20 / 5	25 / 4	50 / 2	100 / 1	200 / 0.5	250 / 0.4	500 / 0.2	1000 / 0.1	2000 / 0.05	5000 / 0.02	10000 / 0.01
Kingaroy	0	0	0	3.2	4.4	10.8	17.3	27.7	29.1	40.2	49.1	58	71	87.8
Kooringal	0	0	1.4	4.8	7.1	14.7	22.6	37	40.4	48	61.5	70.1	83.3	87.3
Kowanyama	0.3	5.6	11.8	23.2	27.8	41.2	52.4	61.7	66.2	73.4	78.4	79.8	83.3	96.4
Kuranda	0	5.4	14.3	27.2	30.6	44.2	54.5	64.8	67.1	73.6	80.3	83.9	106.9	113.1
Laidley	0	0	0.2	2	5	12.9	19.7	29.5	32.6	45.8	50.9	52.5	58.4	68.2
Lockhart River	3.3	11.6	20.6	33.1	36.6	47.9	56	61.2	63	67.4	72.7	91.8	100.8	119.8
Lowood	0	0	0.4	2.3	5.2	12.9	20.8	31.3	34.9	46.3	54.4	65.4	66.7	67.5
Lucinda	0	6.4	15.9	28.6	32.6	45.9	57.3	65.4	69.9	79.9	85.4	90.6	92.2	108.2
Mackay	0	2.9	9.4	23.6	28.6	39.9	48.4	57.6	61.5	67.3	73.7	84.3	95.8	113.2
Macleay Island	0	0	1.5	3.6	6.5	14.4	22	35.2	38.3	48.9	61.9	76.9	83.6	93.3
Mapoon	4.9	13	23.7	39.7	44.5	57.4	69.1	76.4	79.1	86.4	90.2	92.4	107	110.7
Mareeba	0	4.7	13.1	25	29	40	48.3	56.5	57.6	63.7	67.5	74	99.7	100.3
Maroochydore	0	0.2	0.5	4.9	6.7	13.8	24.7	36.4	38.2	45.7	57.9	66.5	67.2	82.9
Maryborough	0	0.1	0.2	3.5	4.7	14.1	25.4	38.9	39.6	48.8	61	68.7	94.2	100.8
Maxwelton	0	1.2	3.3	6.6	7.6	11.3	17.8	24	26.3	32.2	38.1	42.2	52.6	59.6
McKinlay	0	0.1	0.4	3.4	4.2	8	12.2	18.9	21.3	25.5	31.5	37.2	38.1	65.2
Miles	0	0	0.2	0.6	1.8	5.5	11.3	19.1	23.7	33.2	43	52.9	69.5	75.2
Millchester	0	4.3	11.1	18.6	21.5	29.7	39.3	45.8	50.1	57.4	64	67.2	71.7	71.8
Monto	0	0.1	0.3	3.5	4.8	13.9	23.3	31.8	35.6	46.2	51.8	60.5	73.3	80.4
Moonford	0	0.1	0.3	3.5	4.8	13.9	24.2	33.5	34.4	45.9	57.2	61.8	75.5	88.1
Moranbah	0	1.4	6	13.6	15.8	22.4	31.2	37.4	38.5	44.4	55	59.7	68.3	87.4
Morayfield	0	0	0.6	4.6	6.5	13.6	23.2	31.2	33.5	47.5	56.3	62	72.8	78.3
Mossman	0	5.1	13.9	25.9	29.6	42.9	54.3	60.7	62.2	69.9	74.8	87.1	89.6	94.6
Mount Isa	0	0	0.4	3.3	4.5	7.9	11.4	16.1	18.1	21.1	26.6	28.8	29.7	30.1
Mount Morgan	0	0.7	2	7.2	9.6	18.9	26.9	34.7	38.4	43	58.1	71.9	79.6	80.6
Moura	0	0.2	0.5	3.8	5.8	12.5	19.6	26.8	29.9	39.9	46.5	52.5	58.7	84.5
Murgon	0	0	0	2.9	4.6	10.5	18	27.8	31.7	43.7	51.3	52.2	72.3	88.9
Myola	0	5.4	14.2	26.5	30.5	43.6	56	64.2	67.1	73.3	79.9	86.6	105.6	111
Nanango	0	0	0	3.6	4.9	11	17.8	28	31.7	39.7	45.8	56	80.8	82.7
Napranum	4.5	11.6	21.9	34.7	38.9	50.2	59.5	65.7	68.5	75.1	86.7	95.2	98.7	120.8
Nelia	0	1.1	3	5.9	6.8	10.8	16.1	24.1	26	29.2	34.6	38.9	50.7	55.2
Nerang	0	0	1.8	3.8	5.1	14.2	21.6	33.8	38.2	48.8	54.6	68.1	82.7	93.8
Nonda	0	1.2	3.2	6.5	7.2	11.2	17.2	24.8	26	32.1	37.7	39.6	51	54.2
Noosaville	0	0	0	4.3	6.6	13.1	25.3	37.3	38.1	49.3	58.9	70	90.6	94.3
Normanton	0	1.9	4.6	10	12.3	20.8	27.6	37.8	40.1	49.1	60.4	79.7	87.3	93.3
North Tamborine	0	0	1.5	3.5	5.5	13.4	22.5	32.6	37.8	47.9	55.7	78.1	87.5	100
Oakey	0	0	0.3	0.8	4	9.7	17.6	26.3	29.1	39.2	45.4	52	64.3	68.8
Palm Islands	0	6.4	16.4	29.4	34.2	49.5	60.1	69.7	73.5	82.2	98	101.6	104.2	117.6
Pentland	0	2.9	7.3	13.8	15.9	22.5	30.8	40	42.2	48	50.1	53.6	59.6	74.7
Pormpuraaw	1	6.5	14.7	28	31.9	47.6	60	71.7	75	79.8	80.7	81.2	90	99.3
Port Douglas	0	5.3	13.9	26.3	30.1	43.3	54.8	63.5	67	73.3	79.6	91.2	94.4	99.6
Prairie	0	1.4	5.5	9.6	11.5	18.5	25.3	32.1	35.9	42.5	48	54.5	69.1	74.2
Proserpine	0	4.2	13.7	29.6	33.9	44.9	54.3	62.1	66.1	74.6	78	86.4	92.1	94
Rainbow Beach	0	0	0	3.7	5.6	14.8	26	41.5	45.2	47.8	63	66.3	69.6	72.3
Redcliffe	0	0	0.9	4.7	6.4	13	23.9	33.3	39	47	60.8	65.1	70.7	79.9
Redlynch	0	5.6	14.4	27.4	31.7	45.7	57	65	69.6	76.8	81.3	86.4	94.4	100.2
Richmond	0	1.5	3.9	7.2	8.2	13.3	18.6	26.7	28.5	33.7	42.4	48.3	56.5	68.7
Rockhampton	0	0.8	2.1	8.1	11	20.2	29.7	39.2	41.6	50.1	61.3	69	77.5	82.8
Rose Hill	4.9	13.7	24.1	38.6	44.9	56.2	67.5	72.6	77.3	86.2	88.1	91.8	92.7	99.7
Rosewood	0	0	0.4	2.4	5.6	12.9	19.5	31.3	32.8	45.2	53	61.1	62.3	67
Russell Island	0	0	1.6	3.7	6.8	14.5	22	34.9	40.1	50.5	61.1	77	89.4	91.5
Saibai	4.2	11.1	18	28.6	32.7	43.3	52.7	61.5	64	69	74	75.2	85.4	88.9
Stanthorpe	0	0	0	2	3	9.8	16	22.7	24.9	31.2	41.6	58.7	64.3	80.2
Sunshine Beach	0	0	0.1	4.3	6.8	13.3	25.6	37.7	38.9	49.2	58.7	68.4	88.7	93.6
Tannum Sands	0	0.4	0.9	6	7.6	18.5	32.2	44.1	47.2	55.4	65.1	74.6	80.5	83.8
Taranganba	0	0	2.7	9	12.5	22.8	34	46.3	48.1	54.2	64.5	72.2	78.2	85.1
Taroom	0	0	0	1.7	2.6	6.9	16.2	24.4	26.3	31.4	49.6	58	63.7	70.8
Tewantin	0	0	0	4.3	6.6	13	25.7	36.5	39.1	49.8	58.8	72.7	90	93.4
Texas	0	0	0	1.3	2.2	6.6	11.6	19.4	22.9	28.3	35.5	44.9	51.5	62.6
The Monument	0	0	0.4	1.4	2.5	5.7	9.2	14.5	16.5	22.9	29.3	30	35.5	36
Thursday Island	4.9	13.8	24.1	38.9	44.6	55.8	66.8	74.5	76.5	85.2	86.3	92.7	93.8	99.2
Tieri	0	1.2	3.1	9.3	11.2	17.6	23.4	31.7	33.6	37.8	44.8	47.2	52.4	54.3
Tin Can Bay	0	0	0	3.5	5.7	14	25.6	40.7	43.6	49.8	58.1	61.4	65.8	75.3
Tinana	0	0	0.1	3.6	4.6	14.1	25.2	39.3	39.8	48.5	61	67.1	94.8	94.8
Toowoomba	0	0	0.4	1.4	4.6	11.2	18.2	28	31	39.4	49.1	52.2	61.7	67.5
Torrens Creek	0	2.1	6.3	11.3	13.4	20.1	27.9	35.5	37.4	43.7	48.8	50.2	63.3	67.8
Townsville	0	6.2	15.5	27.7	32.5	45.3	59	70.8	74.7	81.3	87.4	99.3	99.7	101.5
Tully	0	6.1	14.3	26.7	30.2	41.8	50.1	61	64.4	70.7	76.5	80.6	83.2	93
Umagico	4.9	13.8	24	39	42.9	54.3	64.5	71.4	72.4	75.3	80.4	90	98.9	102
Warwick	0	0	0.1	1.8	3.4	10.7	18.3	25	27.8	35.6	37.5	47.4	66	75.3
Wasaga	4.9	13.7	24.2	38.8	44.6	56.6	65.8	73.1	76.6	84.4	87.9	92.4	94.3	100.8
Weipa	4.5	11.8	22	35.2	39	50.4	59.2	66.3	66.8	77	86.8	93.1	94.2	120
Whitsunday	0	4.5	15.2	32.1	37.7	48.1	58.1	66.7	69.4	76.8	81.4	90.1	91.5	92.8
Withcott	0	0	0.4	1.3	4.6	11.4	18.1	29.4	32.4	40.1	51	54	63	71.6
Wonga	0	5.2	13.8	25.9	29.8	43.5	53.8	63.2	65.3	73.3	82.3	91.8	93.4	94.3
Woorabinda	0	0.5	1.2	5.4	7.8	14.5	19.6	26.8	29.7	39.2	49.3	53.1	60.2	60.4
Wujal Wujal	0	5.4	14.2	26.6	30.1	41	51.1	57.5	58.8	69	78.6	79.3	81.3	88.6
Yarrabah	0	5.7	15	28.9	32.9	48.7	59	67.6	71	79.2	84.7	90.2	92.2	95.5
Yeppoon	0	0	2.6	9.2	12.5	22.6	34.3	45.7	47.8	54.1	64.1	73.3	75.5	87.5

Gust wind speed (m/s) / Tropical Cyclone categories

Category	Gust wind speed (m/s)
TC 5	77.5
TC 4	62.5
TC 3	45.8
TC 2	34.7
TC 1	27.8
TD	0

Appendix E: Site exposure wind multipliers

The influence of local topography, terrain and buildings on wind speed is a key component in estimating the impact from severe wind events. These local factors can modify the wind speed on spatial scales of less than 100 metres, by up to 50% in some circumstances, such as steep topography or heavily urbanised areas. These factors are accounted for by application of site exposure multipliers, which are set out in AS/NZS 1170.2 (2011). The calculation of these multipliers has been encapsulated in Geoscience Australia's Wind Multiplier software (Yang et al., 2014).

This software uses a digital elevation model (DEM) and a land cover model to derive the site exposure multipliers for conversion between regional and local wind fields for each cardinal wind direction. The DEM used to compute the wind multipliers was the SRTM-derived 1 Second Digital Elevation Model Version 1.0, produced by Geoscience Australia (Geoscience Australia, 2011).

Land cover data was derived from the Queensland Land Use Mapping Program (QLUMP[28], accessed June 2019, refer to Figure 129. The 25m land cover dataset was sourced from DFES, and classified Western Australia into seven key land cover types, with each element in the classification scheme assigned an aerodynamic roughness length and shielding factor (refer Table 26). The roughness lengths and shielding factors assigned to each category were based on the recommendations of AS/NZS 1170.2 (2011).

Small areas on the peri-urban interface were updated following site reconnaissance in July 2018 to account for new residential developments since the compilation of the land cover dataset.

The available land cover data varied in age between 2012 and 2017. Small areas on the peri-urban interface were updated following site reconnaissance in July 2018 to account for new residential developments since the compilation of the land cover dataset.

Land cover type	Roughness length (m)	Shielding factor
Forest	1	1
High density urban	0.8	0.88
Medium density urban	0.4	0.9
Low density urban	0.3	0.95
Open forest, heathlands	0.08	1
Grass (e.g. spinifex, northern grasslands)	0.02	1
Bare ground	0.006	1
Closed water bodies (lakes)	0.004	1
Salt flats	0.002	1

Table 26: Land cover categories used to calculate wind multipliers, and their assigned roughness length (m) and shielding factor.

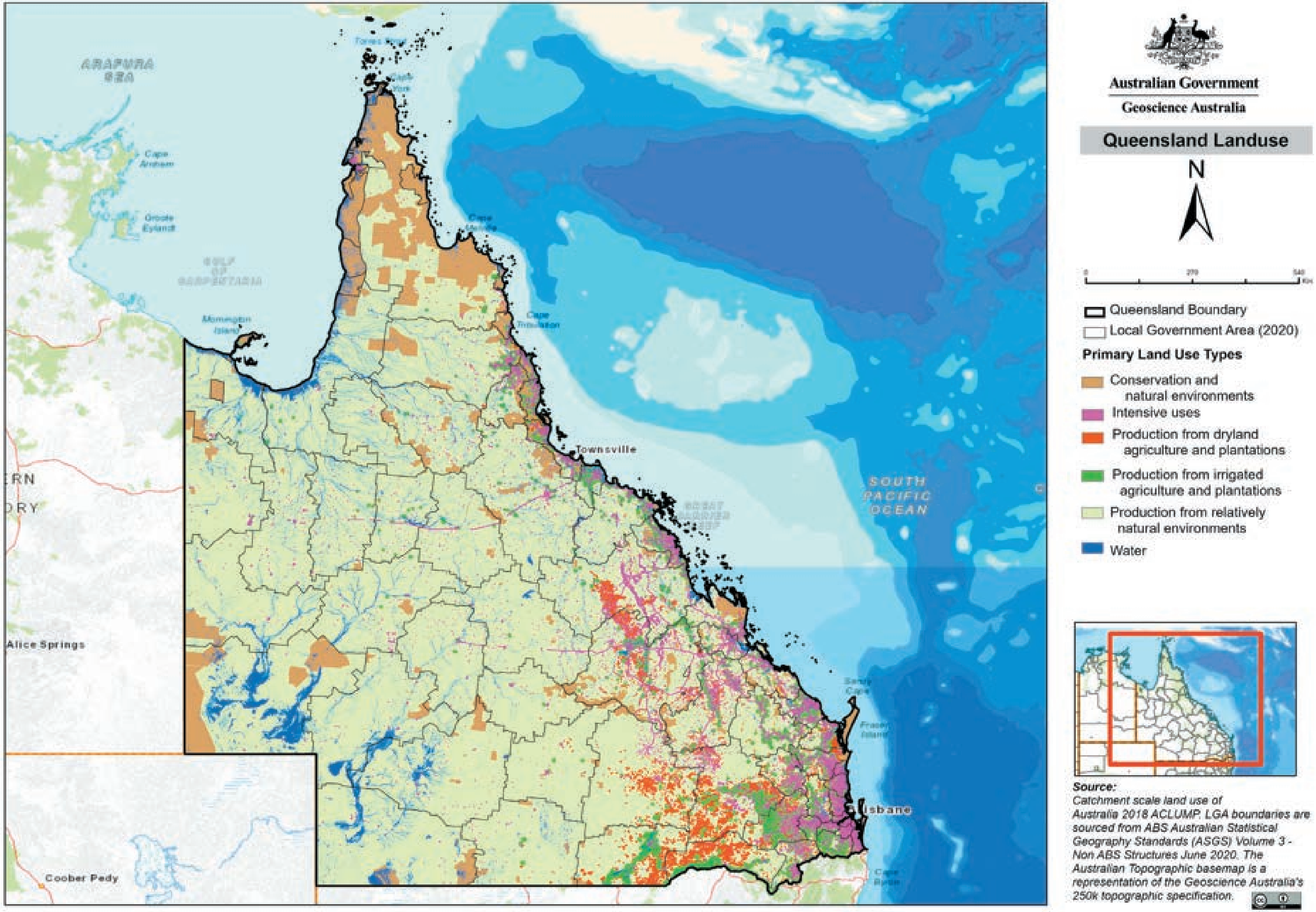


Figure 129: Land cover data from QLUMP used for the derivation of local wind multipliers.

Appendix F: Residential building exposure

The Severe Wind Hazard Assessment for Queensland SWHA-Q project utilised local council and Aboriginal communities building data to enhance the consistency of the National Exposure Information System (NEXIS) building data to improve better severe wind hazard assessment outcomes.

Introduction

Access to best available and consistent exposure information is key to better understanding potential impacts during severe wind events. Six Queensland local councils and three remote Indigenous communities made datasets available for SWHA-Q. All of these contributed in varying ways to improving Geoscience Australia's NEXIS building exposure dataset. These datasets were explored for their potential to improve the spatial and building attribute accuracy of the existing NEXIS building data. Suitable data elements were integrated into the NEXIS building application pre-processing workflows.

There were multiple data sources received, each containing building information of varying completeness, consistency and content, which are detailed below. These contributed varying amounts of information to land use, roof type, wall type, number of storeys and building location. Building use information in the form of zoning classification, land use description or individual building survey use information was available for each of the councils and communities. Land use and zoning information provides a level of consistency in which to derive individual building use classification. NEXIS building classification into either residential, commercial or industrial is key in order to apply other exposure elements associated with each building classification. This project only focused on residential buildings. The new data, for the most part, included a combination of parcel level data or ground-truthed building information from councils or building exposure specific surveys, such as those captured by Centre for Appropriate Technology (CfAT) as part of this project. This level of detail was not previously available to NEXIS.

The input data from local councils and communities replaced a number of existing NEXIS sources for these areas including: ABS Mesh Blocks, GNAF, Streetpro, TOPO250K building points and Australian Government Indigenous Programs & Policy Locations (AGIL) datasets.

Data sources

Received data and their use in NEXIS						
Source	**Land Use**	**Roof**	**Wall**	**Building Location**	**Footprints**	**Storeys**
Townsville City Council	*X*		*X*			*X*
Douglas Shire Council	*X*					
Gold Coast City Council	*X*					
Mackay Regional Council	*X*		*X*		*X*	*X*
Hinchinbrook Shire Council	*X*		*X*		*X*	*X*
Gladstone Regional Council	*X*					
Burdekin Shire Council	*(use prevented by licence restrictions)*					
CfAT Data	*X*	*X*	*X*	*X*	*X**	*X*
Qld Building Asset data (AON)						
Qld building points						

** Footprints captured post-survey*

Local council data

Townsville City Council provided a point feature class dataset representing building locations. The dataset also contained wall material, number of storeys and zoning classifications. Zoning information was used to improve and replace the existing derived NEXIS classification of the building. Due to time constraints, only land use was included in the final output; other inputs will be used in future versions.

Douglas Shire Council provided 21 spatial datasets including: library, transfer and pool facilities; zoning data; parks and gardens; footpaths; water and sewage; and world heritage areas within the local government area. The most valuable dataset was the zoning data. This dataset improves NEXIS's ability to categorise the use of a building at the parcel level with a more consistent approach.

City of Gold Coast provided four spatial datasets including development applications, land use, building structure and footprints. Land use data was the most valuable in this exercise, as it improves the classification of the building at the parcel level. Building footprints provide a more accurate building location and calculation of building area. Building structural information, including wall type and age, along with area, all contribute to an improved replacement value. All of these datasets improved upon a predominately statistical approach being applied in the Gold Coast area by NEXIS. However, on a closer analysis of the Gold Coast NEXIS building outputs pre and post data integration, there were no major differences when aggregated and compared at the meshblock level. Although integrating the data in the NEXIS building application better reflects what is seen on the ground.

Mackay Regional Council provided 16 spatial datasets including footprints, zoning data, aged care, child and community centres, hospitals, libraries, schools and shopping centre. The land use zoning at the cadastral parcel level provided the most benefit to improve the classification of buildings. Wall type, storeys and footprints were also extracted from this input data, improving building attributes and spatial accuracy. A large proportion of detailed building data (such as roof/wall type, storeys) applied to commercial or industrial buildings. This data will be later incorporated in the NEXIS building application but it is only residential buildings that are the focus of this project.

Hinchinbrook Shire Council provided a dataset containing building footprints and zoning data for a large part of the shire. The footprint data also contained valuable information on wall type and number of stories. Zoning data along with the footprint/storey inputs were used to improve the quality of the NEXIS building data for the Hinchinbrook area in a consistent manner.

Gladstone Regional Council provided parcel level zoning with land use descriptions data for the entire local government area of Gladstone. The land use description, within the zoning data, at the cadastral parcel level was valuable for improving the existing NEXIS building classification and ensures consistency for the entire LGA.

Burdekin Shire Council provided several datasets including parcel level zoning and land use, council and building assets point data. Due to licencing restrictions preventing Geoscience Australia from incorporating the Burdekin Shire Council data into the NEXIS building application, the council data was not used because it would require maintaining one version of the data for the project and a different version, excluding the council data, for future hazard assessments.

Remote Indigenous community building survey

As part of this project, CfAT was engaged to capture building exposure for three remote Indigenous communities: Yarrabah, Kowanyama and Pormpuraaw. Kowanyama and Pormpuraaw are located on the western coast of the Cape York Peninsular. Yarrabah is located on the east coast on Cape Grafton, 53km by road east of Cairns.

CfAT was provided with the building data information requirements, including schema and data dictionary and then worked with each of the communities on the ground to capture and provide detailed building data for all buildings in each community. The data received contributed to NEXIS building locations, roof type, wall type and land use. As these datasets used a schema provided by Geoscience Australia, extracting relevant information for NEXIS was a streamlined and consistent process. Previous inputs in these regions (except building location) were either non-existent or at very coarse scale, so the contribution from CfAT has removed the statistical assumption in these regions. These datasets will be used to improve the statistical profile in similar remote communities.

Queensland state building data

Queensland's state-level government property assets and building points were provided for use in the project. The building dataset contained more than 600,000 building points across the state, interpreted from imagery and TOPO250K sources. This excluded a number of regions surrounding Brisbane, including Gold Coast and Toowoomba LGAs. More than 300,000 of these building points were residential.

After comparison with the current NEXIS building dataset, it was identified that multiple building points (captured as part of a Geoscience Australia program for the state) were already included in the NEXIS building data. In the more populated areas, NEXIS provided additional information on numbers of dwellings compared to the state data. It was decided to not include this data as it would not enhance the NEXIS building data for this project.

Also provided was the Queensland Government Property Asset dataset, which provided detailed roof/wall/age information on buildings. However, as these did not contain residential buildings, they did not add value to this project and were not included.

NEXIS production

The above council and Indigenous community datasets were pre-processed and prepared along with the following datasets before they could be ingested by the NEXIS building application to produce the latest version, version 11, of national building exposure:

- Geocoded National Address File (G-NAF®) for spatial locations of known addresses supplied by PSMA Australia Limited
- Property Cadastre, CADLITE®, for cadastral parcel size and location supplied by PSMA Australia Limited
- ACT Cadastre parcel information and Building Footprints, ACT Planning and Land Authority (ACTPLA)
- SA Cadastre parcel information, Department of Transport Energy and Infrastructure (DTEI) South Australia
- NSW Cadastre parcel information and building locations Land and Property Management Authority (LPMA)
- Queensland Cadastre parcel information, Department of Environment and Resource Management (DERM)
- Northern Territory Building Footprints, Department of Lands, Planning and the Environment (DLPE)
- Western Australia Building Footprints and Land Property, Western Australian Land Information Authority Landgate
- Launceston, Glenorchy and Hobart Building footprints, Tasmanian Local Government Area
- Ballarat and Geelong Building footprints, Victorian Local Government Area
- Geoscience Australia's National Mapping 1:25,000 scale homestead data
- 2016 Australian Bureau of Statistics (ABS) Australian Statistical Geography Standard (ASGS) administrative boundaries and Census of Population and Housing Survey data
- ABS 2015-16 Survey of Income and Housing (SIH)
- Costing Modules for Residential Buildings, Altus Group Cost Management Pty Ltd, 2010
- CBD and Industrial Building Costing Modules, Turner & Townsend Pty Ltd, 2010.
- Rawlinsons Australian Construction Handbook, 32 edition, edited by Rawlinsons Quantity Surveyors and Construction Cost Consultants, Rawlhouse Publishing, Perth, W.A. including Building Price Index Quarterly updates
- Census of Land Use and Employment (CLUE), City of Melbourne
- Tasmanian Department of Primary Industries and Water, Office of the Valuer General
- South Australian Department for Transport, Energy and Infrastructure, Office of the Valuer General
- Geoscience Australian Building surveys: Adelaide, Brisbane, Melbourne and Sydney CBD Building Surveys; Newcastle, Wagga Wagga, Wetherill Park Building Survey; Urban Stormwater Climate Change Impact Study: Alexandra Canal; Kalgoorlie Earthquake Building Survey.

The spatial confidence has not been captured as an attribute of the data; the underlying spatial accuracy of the individual buildings as an input is based on the source data. Building locations are acquired from the TOPO250K rural homestead data, building footprint data supplied by ACT, NT and WA state, and Victoria and Tasmania local government agencies, and PSMA G-NAF®.

Attribute data, if available and appropriate, is used from the source data listed above. Where attribute data is not available at the individual building, NEXIS creates statistics to apply to unknown buildings in similar areas of Australia.

NEXIS aims to capture all residential buildings across Australia. Due to the nature of the available data, NEXIS often identifies proposed or partially constructed buildings if the address and/or cadastre parcel has already been created.

NEXIS information is not intended for operational purposes at the building or individual feature level.

Exposure information was augmented with information provided by James Cook University's Cyclone Testing Station (CTS) on the proportion of building types in selected Queensland communities and input from CfAT through dedicated surveys of Kowanyama, Pormpuraaw and Yarrabah Indigenous communities.

Results

Land use/planning zone data between council areas are not consistent as each maintain their own schemas and classifications, which requires a degree of subjective interpretation in order to translate into NEXIS land use attribution. Within NEXIS, the spatial scale of the land use/planning zone classification is at the cadastre parcel level. Buildings on the same cadastre parcel receive the same classification. Buildings of mixed-use types, e.g. a multistorey building with commercial below and residential above, can only be managed as a single use in the NEXIS building application. The NEXIS building application classifies it as commercial or residential because the proportions of commercial/residential at the building level is not available in the data.

For each small-extent dataset that is integrated into the NEXIS building application, considerable time is required to analyse, standardise and manipulate the data to fit the NEXIS schema and geometry. This process has demonstrated that standardised procedures create challenges where input data is unique and requires individual interpretation. There also needs to be metadata and data dictionaries accompanying all received data sources to assist in this process. Very few of the datasets received contained any metadata or data dictionaries.

All council data or one-off specific survey data is gratefully received as it all value-adds to the NEXIS building application, especially where only coarse scale or derived data has been used. Although it is difficult to quantify the improvements this data adds because of its diverse and inconsistent nature, these small extent datasets do ensure NEXIS is consistent with what local councils are using. It also contributes to removing uncertainty from derived data methods used throughout data-poor regions in NEXIS.

Building age or year of construction is not consistently available at the local, state or national level. The age of a building can be used to inform or infer such factors as building standards for that period, type or style of construction, and if they may likely contain lead-based paint or asbestos. Building age is an attribute that needs further attention in the future.

The following maps identify the suburbs and weighted average, building age for each of the local governments in the project. At the suburb level, the current available building age data provides an overview of the diversity of construction eras within each area, however, access to more building specific data is needed to better represent the diversity of building age construction at the local level.

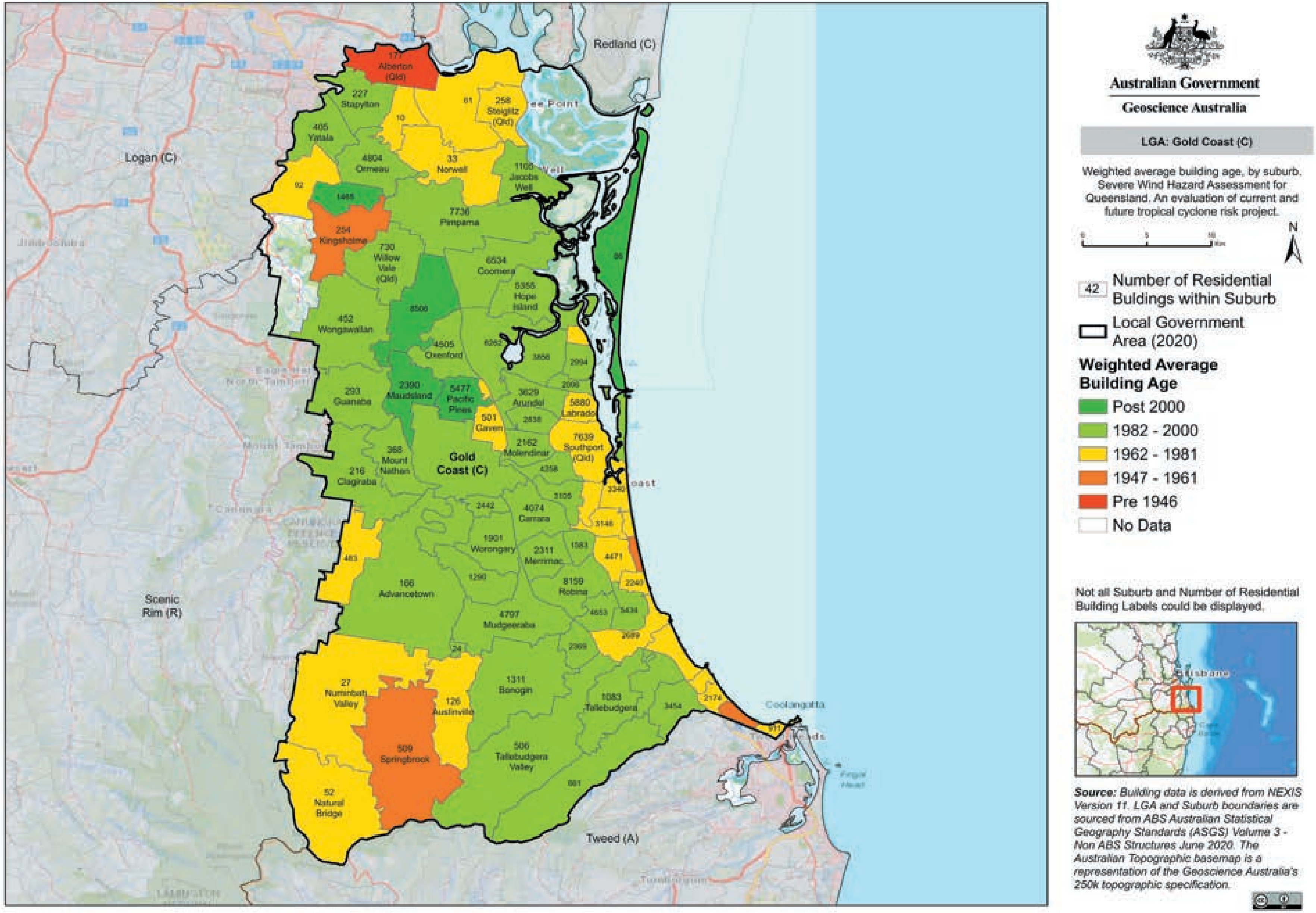


Figure 130: Weighted average building age, by suburb, Gold Coast.

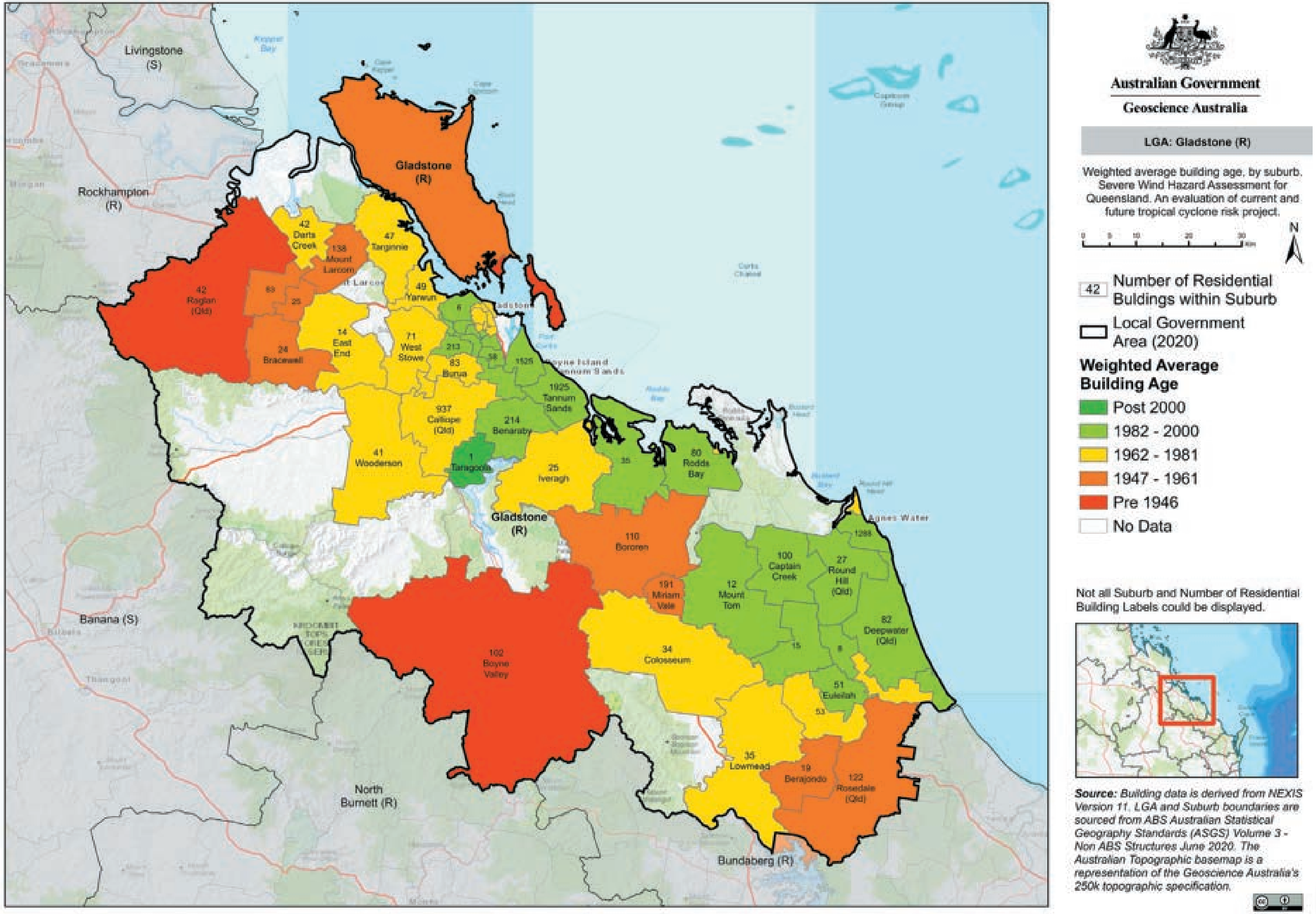


Figure 131: Weighted average building age, by suburb, Gladstone.

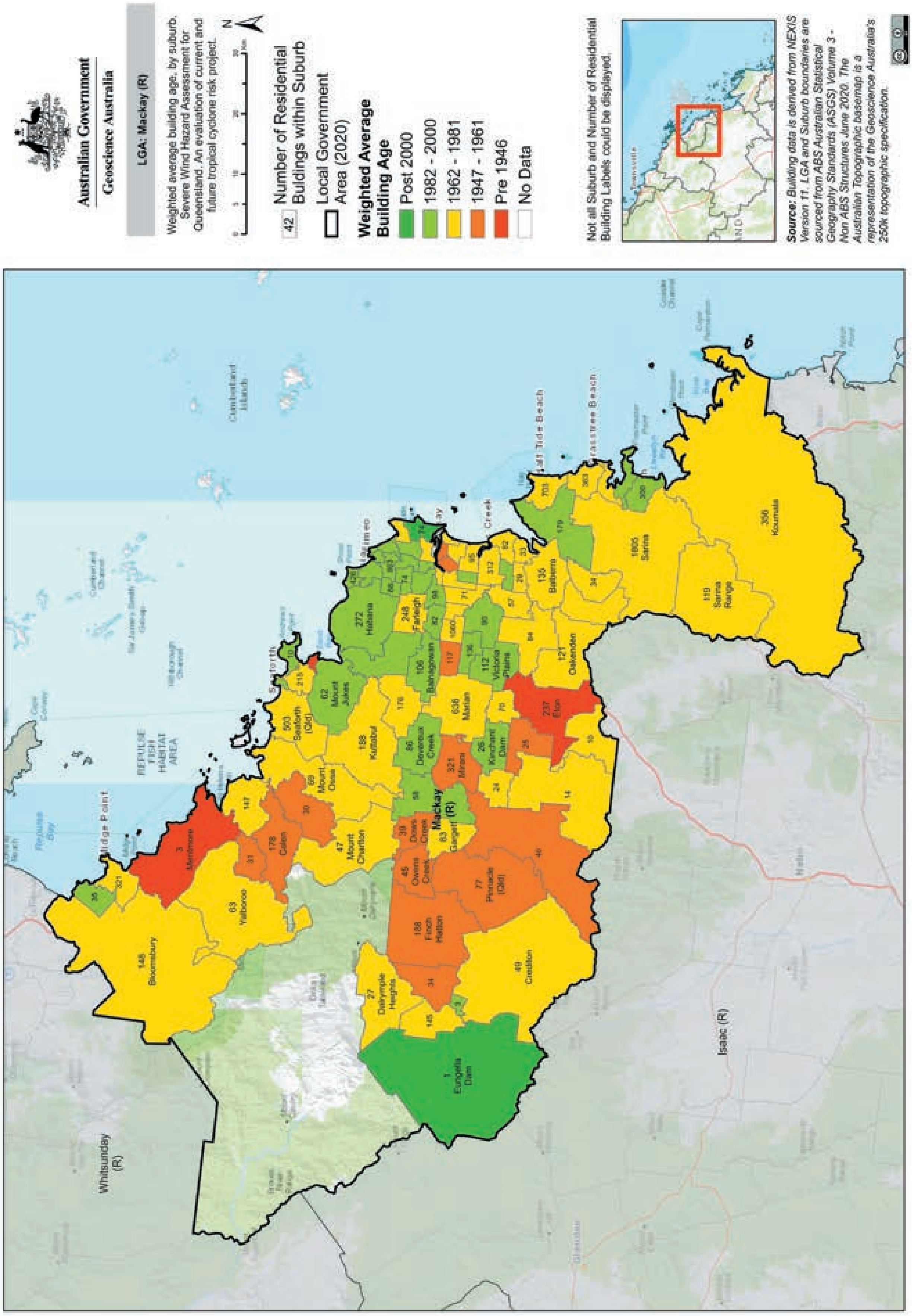


Figure 132: Weighted average building age, by suburb, Mackay.

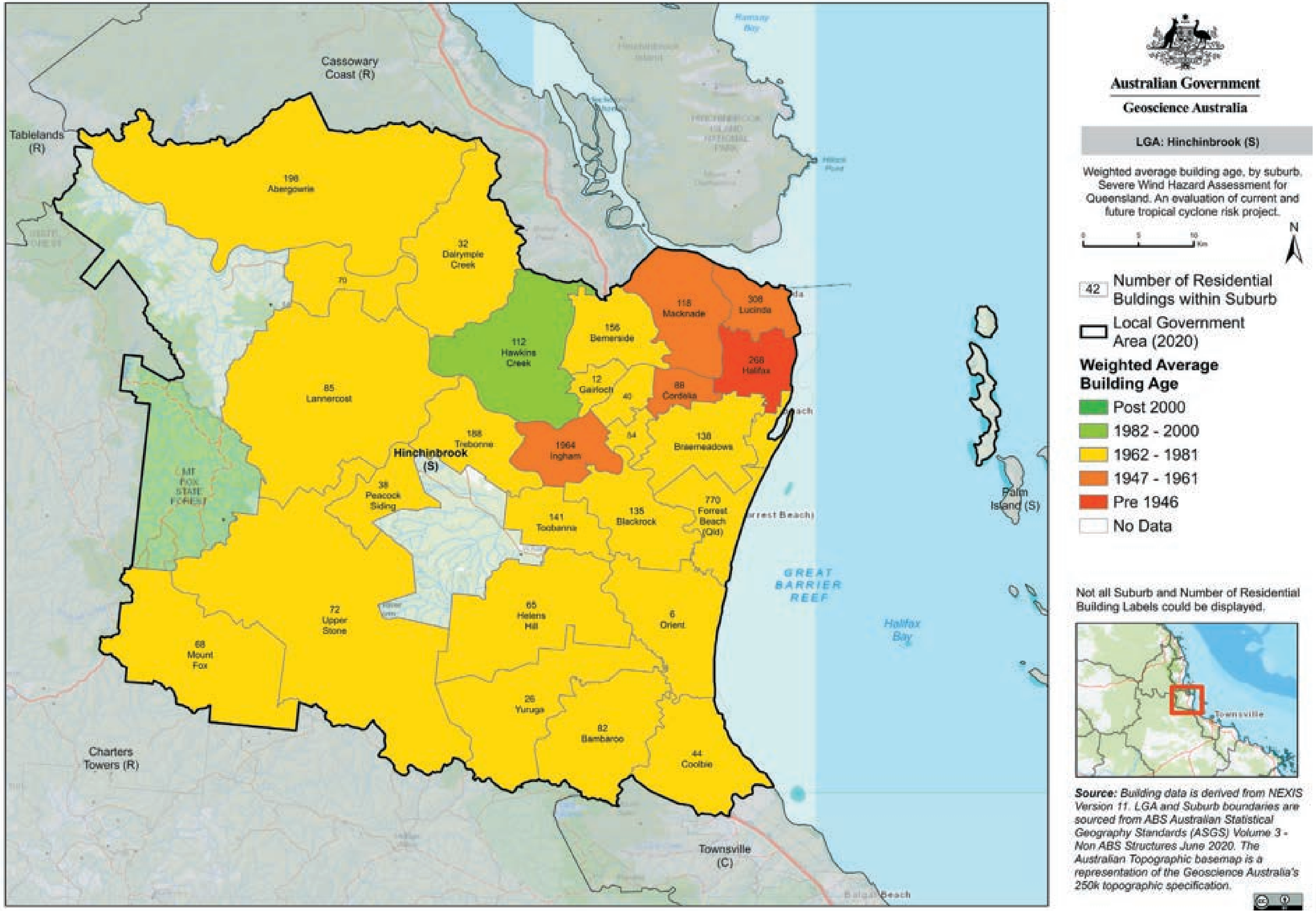


Figure 133: Weighted average building age, by suburb, Hinchinbrook.

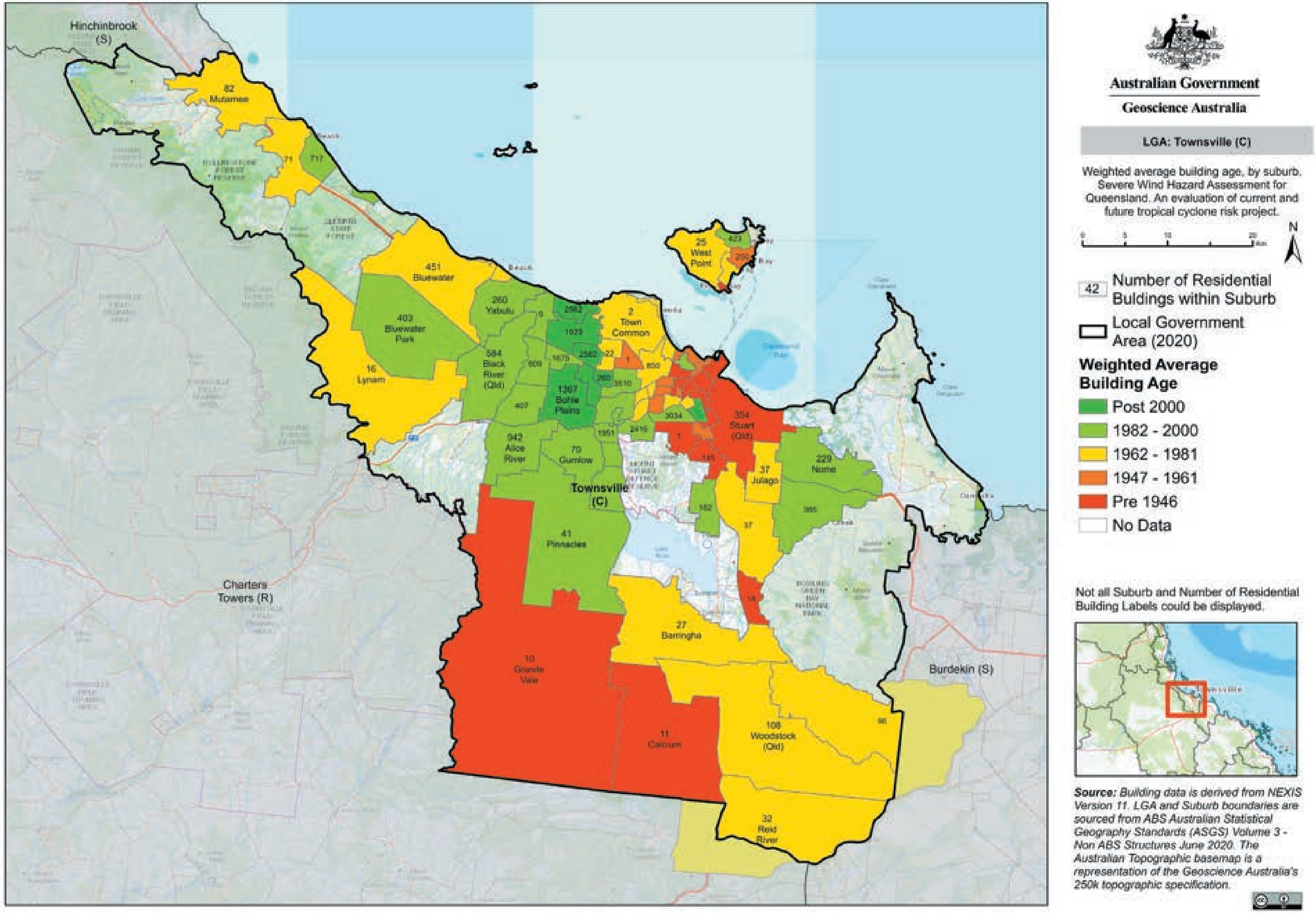


Figure 134: Weighted average building age, by suburb, Townsville.

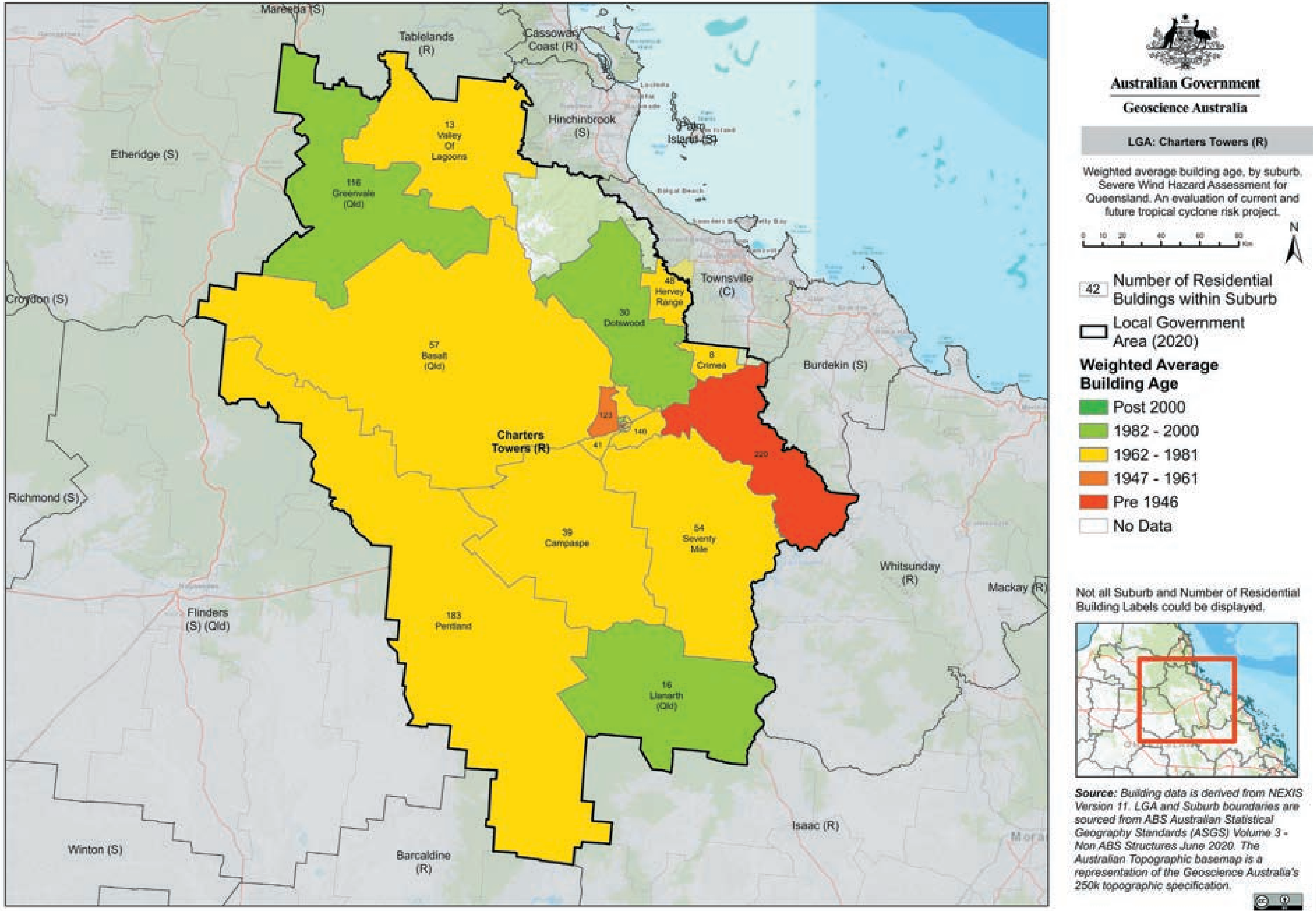


Figure 135: Weighted average building age, by suburb, Charters Towers.

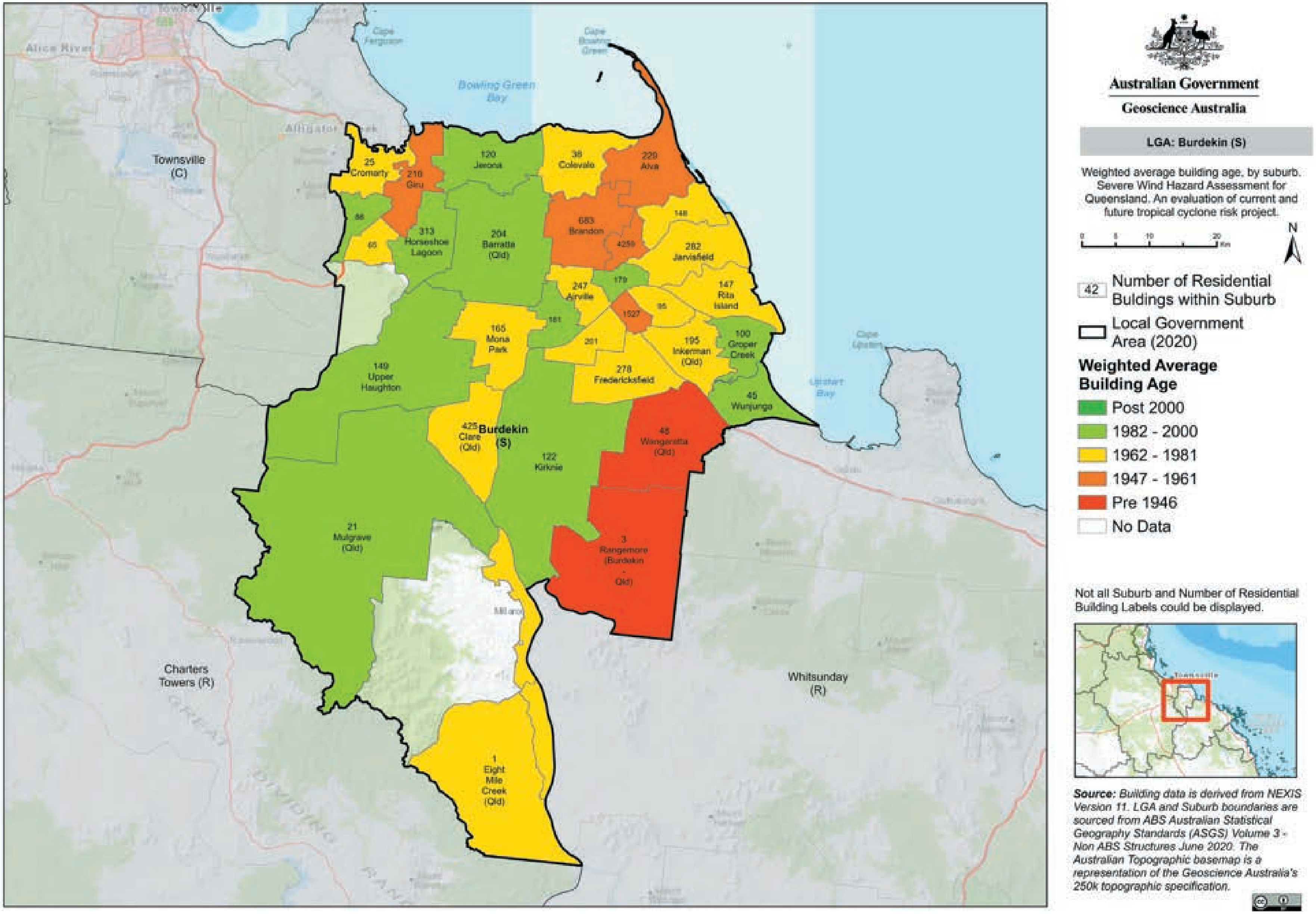


Figure 136: Weighted average building age, by suburb, Burdekin.

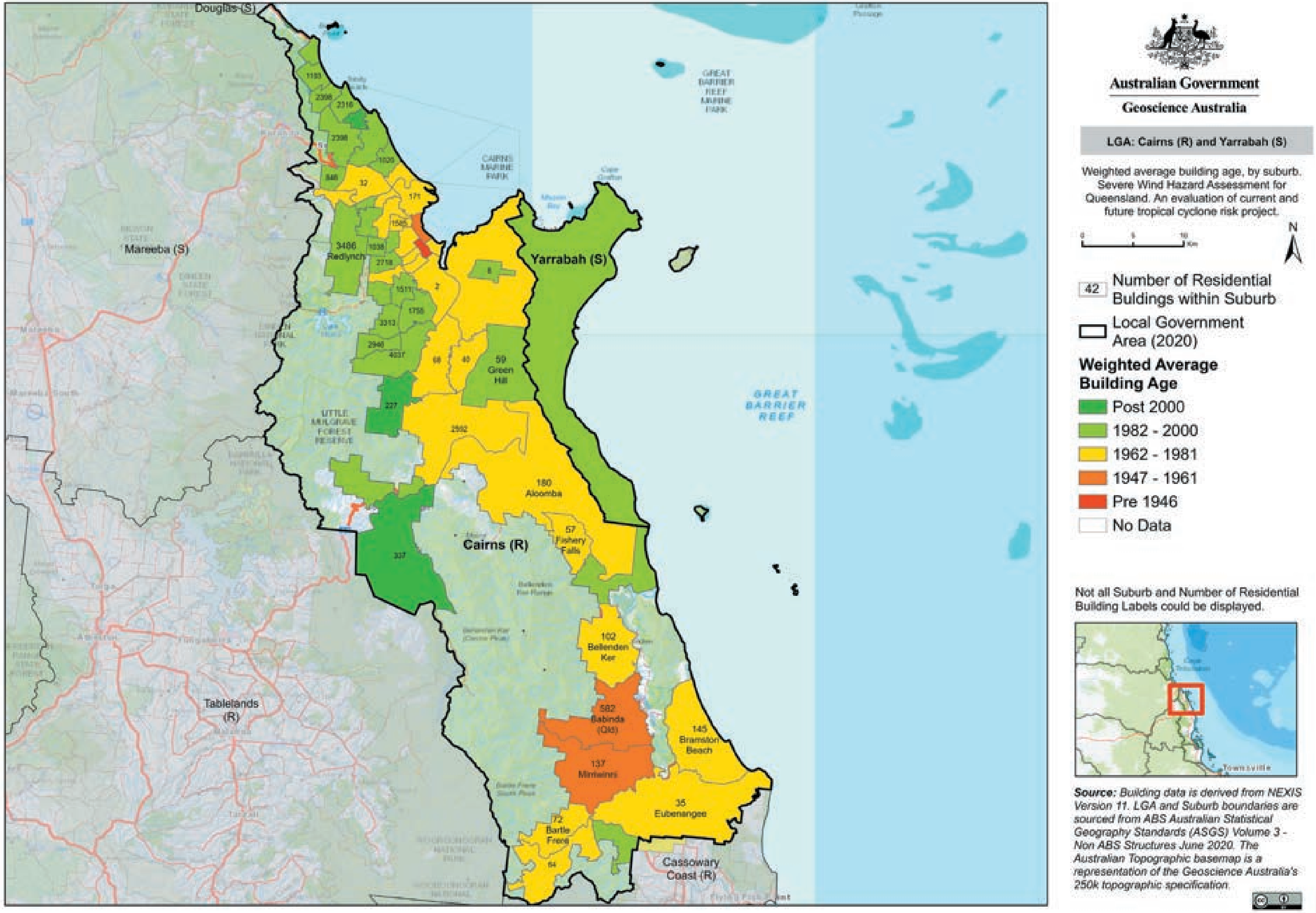


Figure 137: *Weighted average building age, by suburb, Cairns and Yarrabah.*

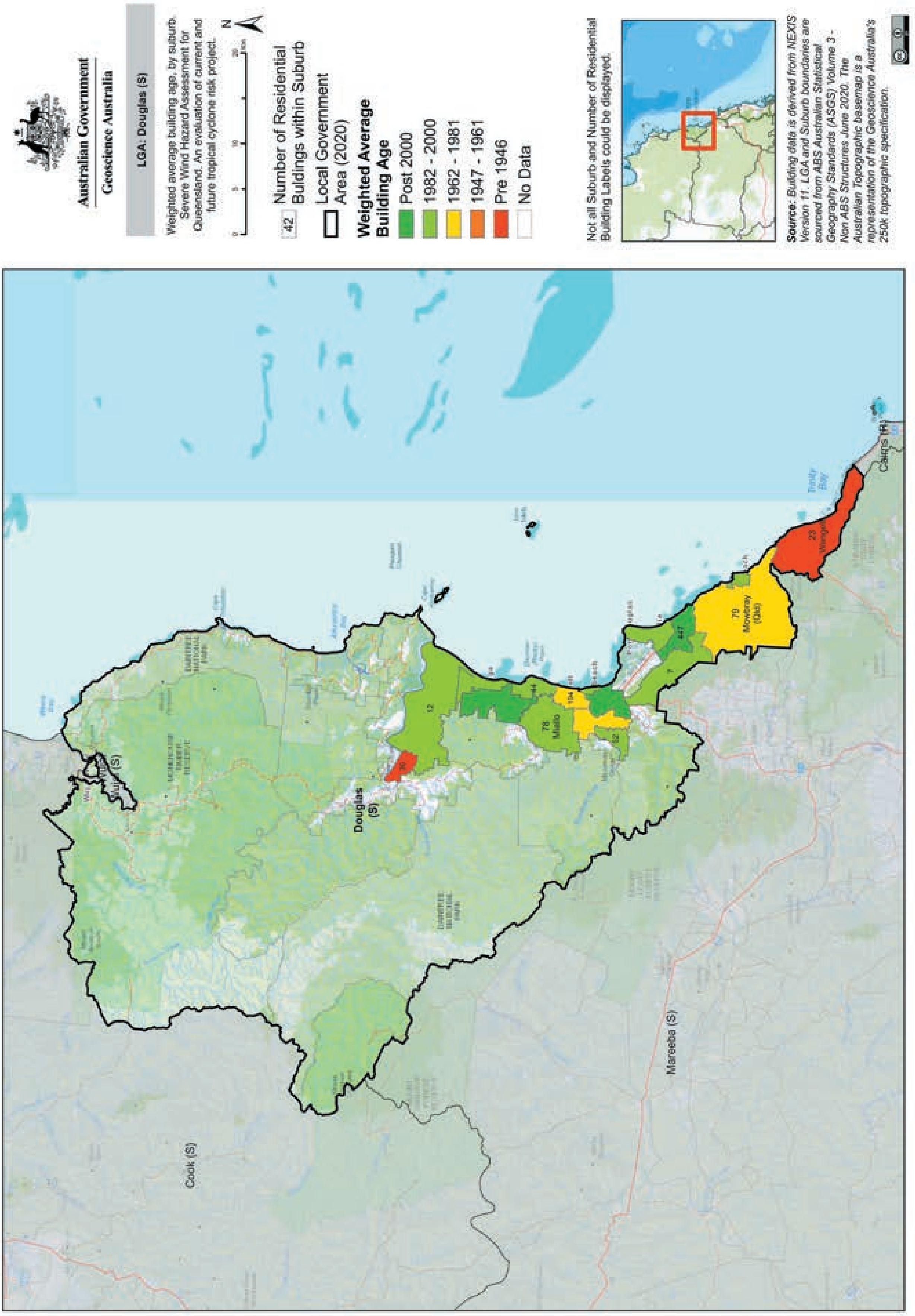


Figure 138: Weighted average building age, by suburb, Douglas.

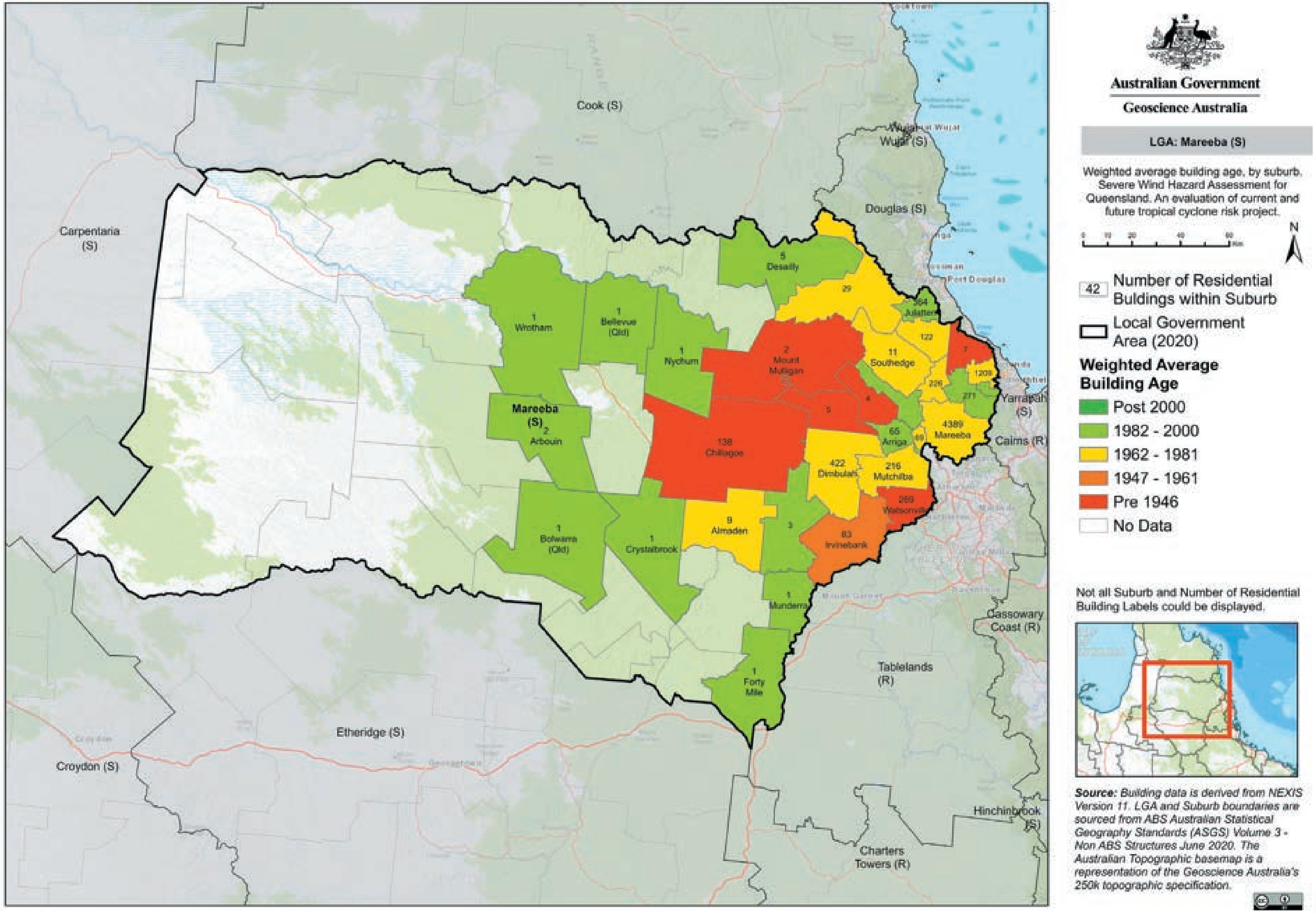


Figure 139: Weighted average building age, by suburb, Mareeba.

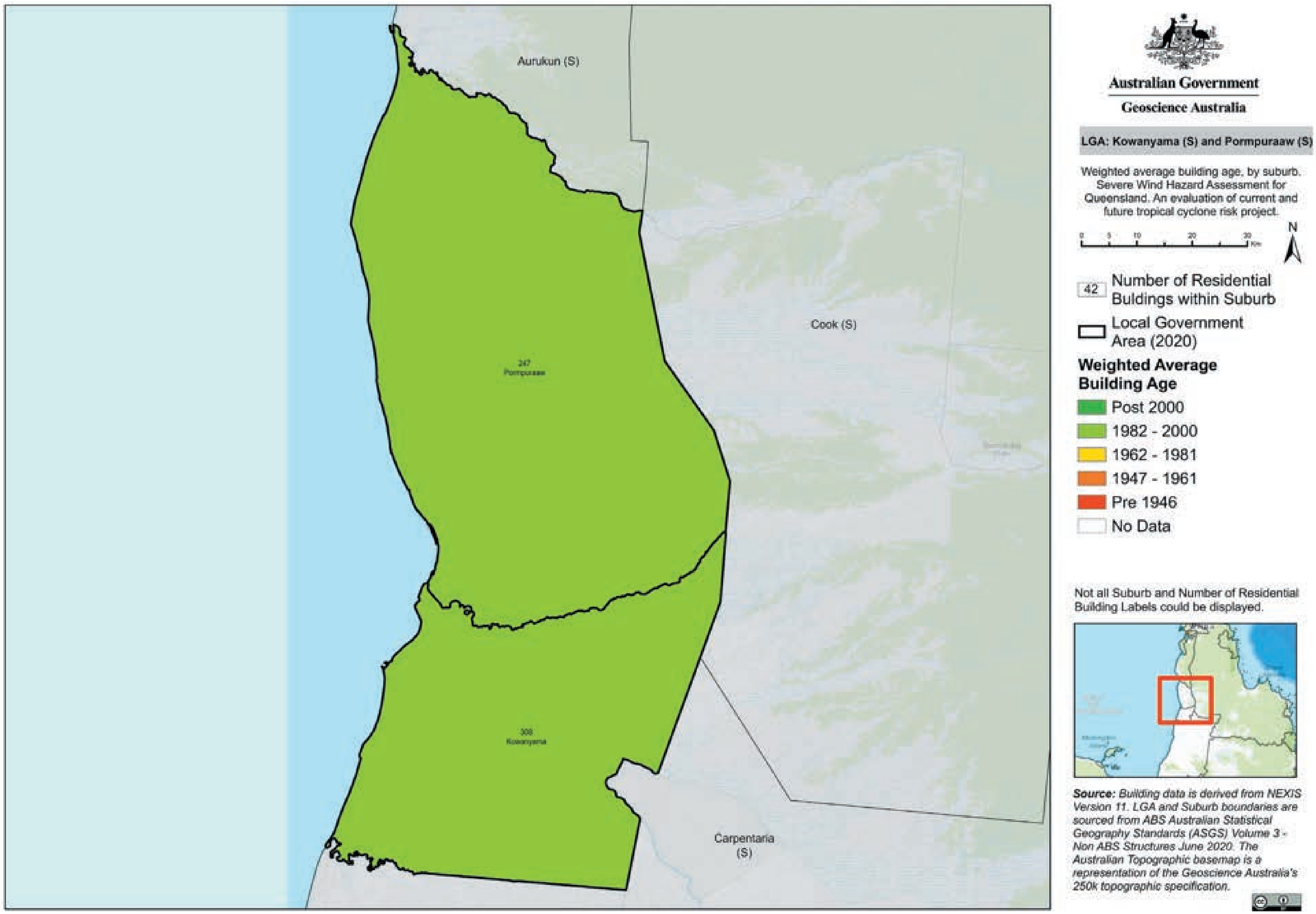


Figure 140: Weighted average building age, by suburb, Kowanyama and Pompuraaw.

Appendix G: Residential building vulnerability

Residential building vulnerability is based on the classification of housing into broad groups based on age and, for those constructed in line with AS4055, siting conditions. Simplified piecewise linear vulnerability curves for three residential house types (Type 1: pre-80s, Type 2: pre-1980s and Type 3: post-80s) in wind loading Regions B and C were provided by James Cook University's Cyclone Testing Station (Parackal, 2019). The Type 3 curves were further extrapolated by Geoscience Australia for AS4055 (2012) C1-C4 and N1-N6 site wind speed classifications as shown in Figure 141 and Figure 142.

It is important to note the curves are empirical and extrapolated from anecdotal damage vs wind speed relationships observed following severe storm surveys. The curves do not consider the full range of damage variability for each wind speed band and do not reflect all forms of loss associated with a property (e.g. fences and sheds). Minor levels of damage in the curves may not represent minor losses in functionality due to water ingress (e.g. via a small roof leak). As part of a current Bushfire & Natural Hazards Cooperative Research Centre (BNHCRC) project, CTS and Geoscience Australia are developing an advanced engineering-based set of vulnerability models for use in future iterations of this (and other public domain) work (see Smith et al., 2020 for more details).

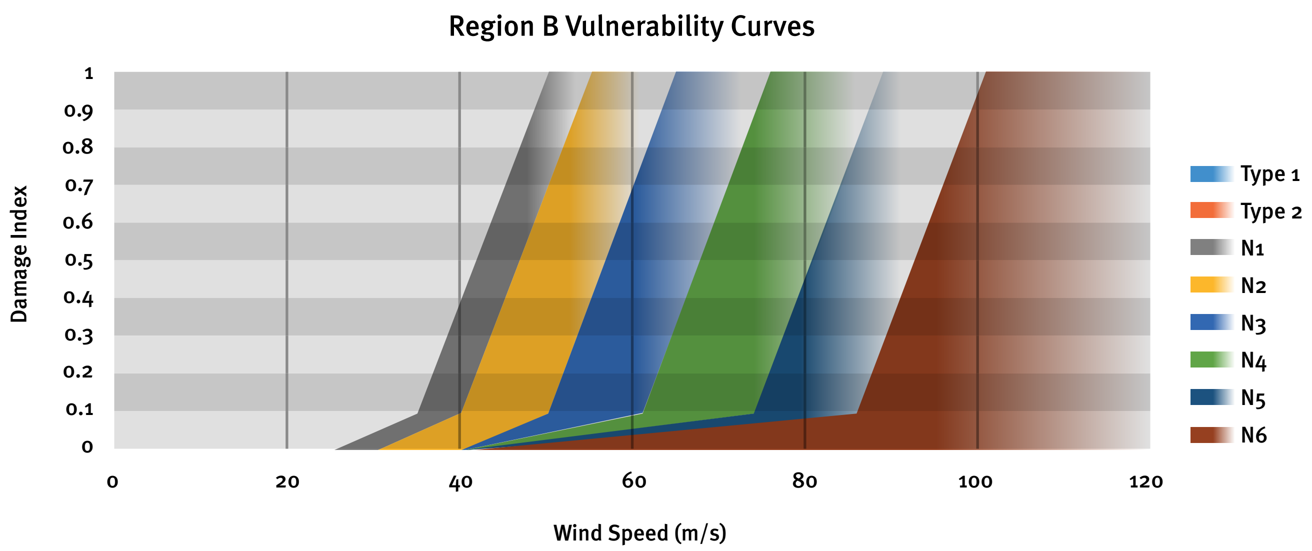


Figure 141: Vulnerability curves for residential houses in Wind Region B (AS/NZS 1170.2).

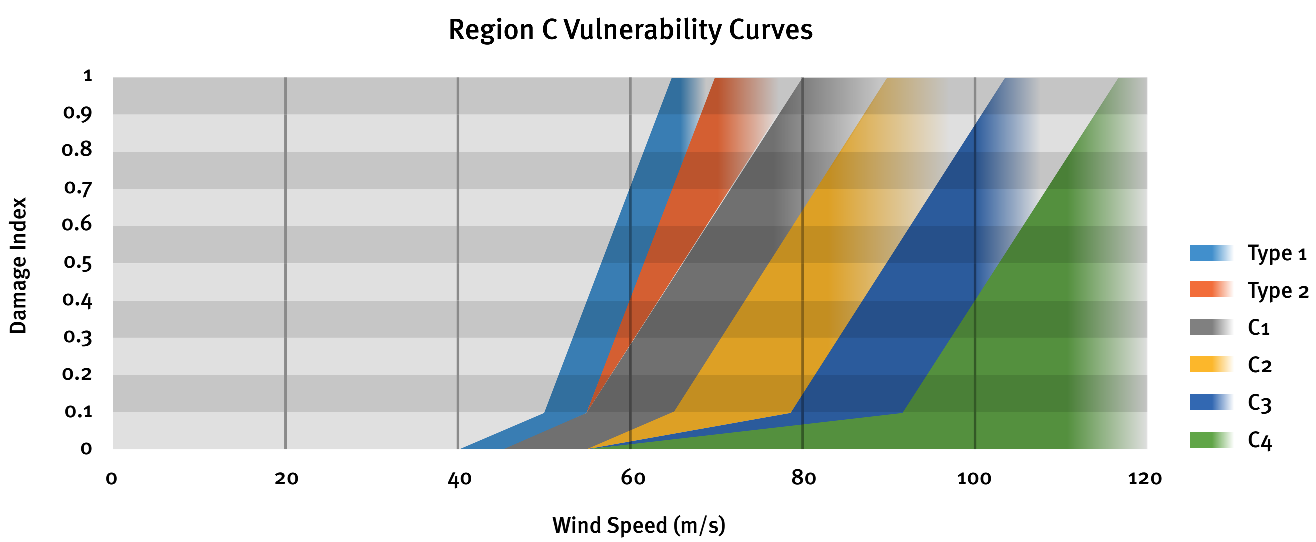


Figure 142: Vulnerability curves for residential houses in Wind Region C (AS/NZS 1170.2).

Appendix H: Damage state definitions

By default, HazImp[29] determines a damage index for individual buildings. The damage *index* is the ratio of the repair cost to the complete replacement cost of the structure. The damage *state* is a qualitative indication of the level of damage sustained to a building (or components of a building). The relationship between damage states and damage indices is building specific but for this project we have used a single set of ranges for all residential buildings.

A more quantitative assessment of damage state can be developed using fragility curves. Fragility curves describe the probability of being in a given damage state for an incident wind speed. However, reliable fragility curves for residential buildings in Australia are unavailable.

Damage states are not provided for non-residential buildings, as this would require unique building vulnerability curves for each structure due to the wide range of designs and construction methods.

Indicative damage state	Damage index range	Indicators of damage
Negligible	0.0 – 0.02	Little or no visible damage from the outside. No broken windows or failed roof deck. Minimal loss of roof over, with no or very limited water penetration.
Slight	0.02 – 0.1	Minor roof sheeting damage that can be covered to prevent additional water ingress. One window, door or garage door broken.
Moderate	0.1 – 0.2	Moderate roof sheeting damage, moderate window breakage. Some water damage to interior.
Extensive	0.2 – 0.5	Major window damage and roof sheeting loss. Major roof cover loss. Extensive damage to interior from water.
Complete	› 0.5	Complete roof failure and/or failure of wall frame. Loss of more than 50% of roof sheeting.

Table 27: Damage state definitions.

The damage state definition provides no guidance on habitability of residential buildings. As a guide, all buildings in a Moderate to Complete damage state should be considered as being potentially uninhabitable post impact.

Appendix I Case study: TC Mahina, 1899 - the Southern Hemisphere's most intense cyclone

On the morning of 5 March 1899, a tropical cyclone (TC) crossed Cape York Peninsula at Cape Melville, the eye passing over and between more than 100 vessels fishing along 200 kilometres of coastline. Eighty-three (83) vessels were wrecked, sunk, or grounded.[30] Of 40 vessels in or near Bathurst Bay, over which the cyclone's eye passed, only one vessel survived. Australia's deadliest cyclone caused 298 known deaths.[31] It holds the world record for a storm tide: 13 metres.[32] A schooner captain recorded a low pressure of 880hPa (recorded as 26inHg) in the eye wall, the lowest pressure recorded in a cyclone in the Southern Hemisphere and one of the lowest pressures recorded of any cyclone, hurricane or typhoon on landfall in the world.[33]

The 1899 pearling fleet disaster attributed today to a cyclone named Mahina,[34] was the subject of a PhD history thesis at the University of Queensland by Dr Ian Townsend, a summary of which is outlined below. One of the main purposes of the thesis was to review the historical data to understand whether current sources provide for the most accurate description of this cyclone and its impact.[35]

A search was conducted for all data, the sources were examined, and a methodology developed to determine which were credible.[36] The thesis found that most data used today to describe and model the 1899 cyclone do not represent the best evidence.[37] The data from the best evidence produce a more accurate description of this cyclone's behaviour and impact, and provide emergency managers and scientists with a potential case study for a worst-case cyclone impact on the Queensland coast.

The background

Most of the vessels impacted by the 1899 cyclone were associated with pearling fleets from Thursday Island in and around Princess Charlotte Bay. Although March was within the cyclone season, the short history of European settlement by the end of the nineteenth century gave fleet owners the impression that waters north of Cape Melville were not in the cyclonic zone and many did not insure their vessels.[38] Aboriginal communities within the immediate coastal areas, however, had experienced cyclones for generations and were prepared.[39] In the vicinity of Cape Melville at the start of March 1899, there were at least 1,000 mainly Indigenous persons on shore and about 1,000 people of various nationalities at sea.[40]

The cyclone was recorded by a number of experienced weather observers, including ships' captains whose safety and livelihoods depended on instruments including barometers, thermometers and compasses, and their observational skills. The data they produced provide an opportunity to learn from a rare and well-recorded event. Unfortunately, much of the data published today, including in scientific literature, does not accurately reflect what the most reliable observers originally recorded. This is partly because most data published to date first entered the literature from secondary sources, including newspapers in which the data can be distorted by errors of translation and transmission, particularly if conveyed by telegraph. Some data can also be shown to be based on rumour, or changed to protect reputations or to enhance a narrative.[41] The disaster and its reporting was complex with thousands of often contradictory pieces of published data. The amount of surviving credible data within this is relatively small, but it is available through historical inquiry and should be used to more accurately describe the event.[42]

The following is a brief description of part of the disaster from a selection of the best available evidence.

On the afternoon of Saturday, 4 March 1899, more than 100 vessels, mainly wooden schooners and smaller luggers, were anchored along 200 kilometres of coast, between Lizard Island south east of Cape Melville and Pelican Island about 90 kilometres to the north west of Cape Melville. Most were company fleets congregating in Bathurst Bay, under the lee of Cape Melville, and in the Claremont Group of islands in the north west part of Princess Charlotte Bay.

The captains of the larger schooners appeared unaware of the approaching cyclone until they read their barometers at 6pm. At that time, many reported a light to moderate breeze from the south east but after 6pm the wind and rain came more frequently in squalls. At 9pm, William Field Porter, captain of the schooner *Crest of the Wave* anchored in Bathurst Bay reported the wind blowing "fearfully hard, the glass going down fast."[43] About the same time, near Stapleton Island east of Cape Melville, the cutter Spray reported a nearby Japanese vessel being swept onto a reef and disappearing.[44]

After 10pm, many vessels, including the *Crest of the Wave* in Bathurst Bay, reported the wind so strong they were dragging their anchors. By midnight, most vessels on the exposed side of Cape Melville, east of Bathurst Bay and closer to approaching eye wall of the cyclone, were sinking or had sunk or run aground on reefs. At 1am Captain Porter on the Crest of the Wave, by then having dragged his anchor north out of Bathurst Bay, reported an air pressure of 28inHg (948hPa).[45] This is the equivalent to the lowest recorded pressure during Cyclone Tracy in Darwin in 1974, where wind gusts of 217km/h were recorded.[44] Porter was to record the pressure continuing to fall for another 3.5 hours.

The cyclone's eye wall began to cross Cape Melville after 3am, causing a number of luggers in Bathurst Bay to be swamped. Porter, then in deeper water well north of Bathurst Bay, did not experience the eye wall until around 4.30am, when he reported his lowest pressure: 26inHg (880hPa).[47] By then, the wind had pushed him to the very top of the cyclone's eye. Soon after reading his barometer in the eye wall, he briefly entered the calm eye, reporting a lull of a few minutes. The captains and crew of vessels still in Bathurst Bay and closer to the geometric centre of the eye experienced the eye for several hours but most drowned when the winds and sea returned from the north with the eye wall.[48]

Apart from the phenomenally low pressure recorded by Porter, the cyclone's main claim to fame is its world record storm tide. There have been numerous attempts to identify the site at which it was experienced (Barrow Point, Ninian Bay or Bathurst Bay) and to put an accurate value on the height of the sea level rise (between 12.192 metres and 14.6 metres).[49] Many of these studies cite each other but all are interpretations of an observation republished in an anonymous booklet six months after the disaster as a memorial to the Europeans who died.[50]

A European officer of the Queensland Native Police, Constable John Martin Kenny, had been on patrol with four Aboriginal troopers south of Cape Melville when the cyclone struck. He described being camped on "a ridge fully 40 feet above sea level and about half a mile from the beach" when "an immense tidal wave swept in shore and reached waist deep on the ridge" just after the wind veered to the north-east after 5am.[51]

Historical inquiry based on a range of material has identified the site at which Kenny camped, at the head of Bowen Bay, about 35 kilometres south of Cape Melville. The site was inspected as part of the thesis but, until archeological and geoscientific assessments are made and the ridge more precisely measured, the height of the storm tide cannot be corroborated solely from historical documents.

However, previous modelling shows the potential for a 8.279 metre storm surge on that section of coast.[52] Another study suggests wave setup as high as four metres was possible before the arrival of the surge.[53] Kenny reported the "tidal wave" arriving at just after 5am, which coincided with high tide on 5 March 1899.[54] Although these models did not take into account some of the new data revealed in the thesis, they suggest the storm surge, wave setup, high tide and the low atmospheric pressure contributed to a rise in the sea potentially exceeding 13 metres.[55]

The site was within the storm surge zone on the southern side of a cyclone that the evidence suggests approached from the east-north-east.[56] The campsite is at the mouth of a creek that drains a large catchment and enters the sea at the head of a shallow bay that was exposed to the strongest winds of the approaching cyclone. In this area, other accounts describe fish and seaweed some distance inland and most of the trees down.[57] The site was also within a 130 kilometre section of coast north-west and south-east of Cape Melville in which "everything in the shape of trees or grass had been swept clean."[58]

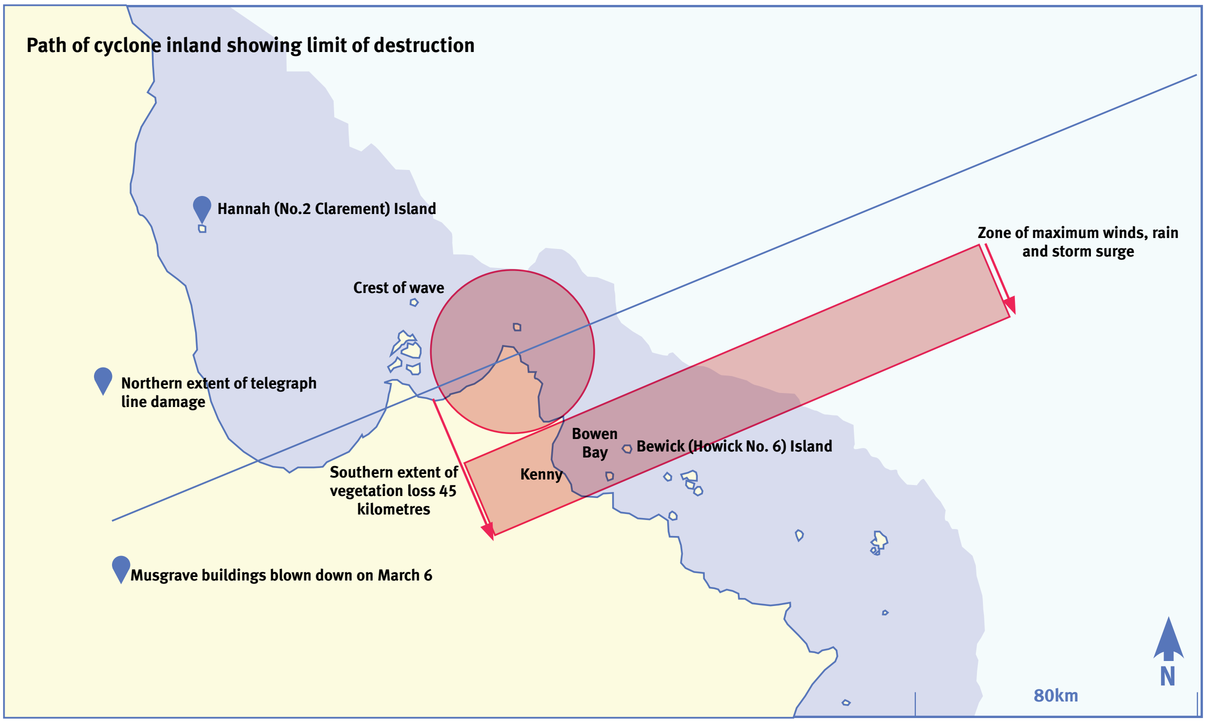


Figure 143: The estimated path of TC Mahina highlighting the areas referred to within the description of impact. Note the extent of storm surge impact inland given the relative height of the landscape above sea-level.

Implications for emergency management in Queensland

In Queensland, coastal development is often concentrated at the heads of bays and the mouths of rivers because, in the nineteenth century, they provided access and shelter for shipping. Urban development has since encroached closer to beaches and river mouths which share some similar bathometric and topographic features to Bowen Bay, including frontal dunes, estuaries, shallow bays and low-lying coastal land (sometime modified with canals or drains and flood barriers).

That the evidence for the 1899 cyclone – one of Australia's best recorded, pre-satellites – has been so poorly reflected in the scientific literature and in official databases raises questions about the accuracy of our knowledge of other historical cyclones (for example, the 1918 cyclones). There has been some scientific skepticism, for good reason, about the credibility of previously published historical data and this appears to have led to an increasing interest in synthetic models. The accuracy of all models, however, depends on the quality of data and the historical record. Emergency managers and meteorologists have long been asking for a review of the data in historical cyclone databases.[59] Credible primary sources exist and historical inquiry with appropriate methodologies can give scientists and emergency managers more confidence in data from historical events. A review of databases using an appropriate historical methodology would help ensure that our knowledge of past cyclones reflects the best available evidence.[60]

More work is needed to assess the updated data from the 1899 cyclone and apply them to models. It may be significant, for example, that a cyclone of this magnitude occurred within the Federation Drought; a period which appears to have coincided with a series of El Niño weather patterns.[61] If, as climate scientists predict, such conditions become more frequent, there may be a greater risk of rare events, such as the 1899 cyclone, also becoming more frequent.[62]

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Notes

1 https://www.igem.qld.gov.au/cyclone-debbie-review

2 https://www.qld.gov.au/environment/climate/climate-change/adapting/strategy

3 2016 Queensland Disaster Management Strategic Policy Statement

4 http://geoscienceaustralia.github.io/tcrm/docs/intro.html

5 Ibid.

6 https://longpaddock.qld.gov.au/qld-future-climate/

7 For more information, visit the Queensland Government's Disaster Management website: https://www.disaster.qld.gov.au/Pages/default.aspx

8 https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump

9 As part of the project, a new web interface to the simulation database has been developed and is publicly accessible at https://portal.ga.gov.au/persona/hazards. Please note that this database was developed to support the TCHA18.

10 https://www.disaster.qld.gov.au/qermf/Pages/default.aspx

11 https://github.com/GeoscienceAustralia/hazimp

12 https://journals.ametsoc.org/view/journals/mwre/142/9/mwr-d-13-00405.1.xml?tab_body=fulltext-display

13 https://www.igem.qld.gov.au/cyclone-debbie-review

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20 https://www.gbrmpa.gov.au/our-work/threats-to-the-reef/climate-change/storms-and-cyclones#:~:text=Cyclones%20were%20responsible%20for%2048,Great%20Barrier%20Reef%20Marine%20Park.

21 https://www.disaster.qld.gov.au/cdmp/Documents/Adaptation-Plan/EM-SAP-FULL.pdf

22 https://gbrrestoration.org/

23 Houses located in storm tide zones may suffer damage from storm tide, even if compliant with the wind loading design standards.

24 https://www.qld.gov.au/housing/buying-owning-home/financial-help-concessions/household-resilience-program

25 https://portal.ga.gov.au/persona/hazards

26 https://www.disaster.qld.gov.au/cdmp/Documents/Queensland-State-Disaster-Management-Plan.pdf

27 https://www.ipcc-data.org/guidelines/pages/glossary/glossary_r.html

28 https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump

29 https://github.com/GeoscienceAustralia/hazimp

30 Seven vessels grounded were later salvaged and 13 that were sunk, were raised. 63 were totally lost.

31 Ian Townsend, The Bathurst Bay Hurricane: Media, Memory and Disaster, PhD thesis, School of Historical and Philosophical Inquiry, The University of Queensland, Brisbane, 2020. See also Australian Institute for Disaster Resilience, "Cyclone Mahina 1899," Disaster Resilience Knowledge Hub, https://knowledge.aidr.org.au/resources/cyclone-cyclone-mahina-cape-york-queensland and Guinness World Records Limited, "Highest Storm Surge," Guinness World Records 2014, New York: Bantam, 2014, 107. An official death toll of 400 is stated, but there is no credible evidence that the number is significantly higher than 300.

32 Jonathan Nott, Camilla Green, Ian Townsend, and Jeffrey Callaghan, "The World Record Storm Surge and the Most Intense Southern Hemisphere Tropical Cyclone: New Evidence and Modeling," Bulletin of the American Meteorological Society, 95, No. 5, May 2014, 757–765; World Meteorological Organization (WMO), "Tropical Cyclone: Largest Storm Surge associated with Tropical Cyclone," WMO World Weather and Climate Extremes Archive, https://wmo.asu.edu/content/tropical-cyclone-largest-storm-surge-associated-tropical-cyclone.

33 Ibid.

34 The 1899 weather charts of Queensland Government meteorologist Clement Wragge never showed the disturbance he named Mahina crossing the coast. Later, Wragge revised his charts to have the disturbances Mahina and Nachon colliding over Cape Melville. The disaster was not generally associated with cyclone Mahina alone until the 1970s.

35 Townsend, The Bathurst Bay Hurricane, 2020.

36 Credible means that the data or information is as close to what was recorded or happened as can be learned from a critical examination of the best sources. See Louis Gottschalk, "The Historian and the Historical Document," in The Use of Personal Documents in History, Anthropology, and Sociology, prepared for the Committee on Appraisal of Research, Louis Gottschalk et al. (eds), New York: Social Science Research Council, 1945, 35.

37 Townsend, The Bathurst Bay Hurricane, 2020. Information can be distorted or misinterpreted each time it is repeated. The methodology shows that, generally, the sources closest to the event in time and space reflect the best evidence, and produce data more likely to corroborate each other. Each source and piece of data, however, needs to be tested.

38 "Hurricanes, Queensland Coast," Queensland Government Gazette 1897, Brisbane: T. P. Pugh's Printing Office, 67.

39 Townsend, The Bathurst Bay Hurricane, 2020, 123. Yiidhuwarra elder Daniel Gordon describes how the coastal people in the area "were taking notice of the tides and they knew there was something wrong … they went through all this during the past, so they moved it into a higher ground. There's a shelter at Cape Melville where they all moved to."

40 "Hurricane in the North," Brisbane Courier, 10 March 1899, 5. Walter Roth, "A Report to the Commissioner of Police on the Aboriginals Occupying the 'Hinter-Land' of Princess Charlotte Bay Together with a Preface Containing Suggestions for Their Better Protection and Improvement," 30 December 1898, A/19899, QSA, ID1154345, ii.

41 Most data cited today comes from secondary sources that can be traced back to Anonymous, The Pearling Disaster, 1899: A Memorial, Brisbane: Outridge Printing Company, 1899 (commonly called the Outridge booklet). Data from the Outridge booklet, published six months after the disaster, entered the scientific literature in 1958 when Brisbane meteorologist, Herbert E. Whittingham, used it to reconstruct the cyclone in H. E. Whittingham, "The Bathurst Bay Hurricane and Associated Storm Surge," Australian Meteorological Magazine, 23, 1958, 4-36. Because most Outridge data is from uncited sources, especially press reports, and earlier sources exist, Whittingham's analysis does not necessarily represent the best evidence or is complete. However, it appears to be the progenitor for much of the data in scientific literature today.

42 Townsend, The Bathurst Bay Hurricane, 2020. There are 14 sources assessed as credible for weather observations at Cape Melville during the 1899 cyclone. These include handwritten journals, government inquiries and reports, and newspaper accounts. However, the credibility of any source does not also confer credibility to the data it contains.

43 William Field Porter, "The Great Hurricane at Queensland. A Struggle for Life. An Aucklander and His Wife and Child. Forcing the Blacks to the Pumps," New Zealand Herald (Supplement), 1 April 1899, 1.

44 "The Late Hurricane. Return of the Warrego. Reports from the Boats," Brisbane Courier, 20 March 1899, 6.

45 "Log Crest of the Wave," in John Douglas, "Report of the Government Resident at Thursday Island for 1898," QVP, 1, 1899, 100.

46 Bureau of Meteorology, Report on Cyclone Tracy, December 1974, Canberra: Australian Government Publishing Service, 1977, 37–41.

47 Porter, "The Great Hurricane at Queensland," 1899.

48 Townsend, The Bathurst Bay Hurricane, 2020, 134-138. The best evidence shows eight Aboriginal people killed ashore, mainly by falling timber. The people of Flinders Island, Bathurst Head, Cape Melville and Barrow Point were aware a cyclone was coming and took shelter.

49 Ibid., 186.

50 Anonymous, The Pearling Disaster, 1899: A Memorial, Brisbane: Outridge Printing Company, 1899.

51 A. R. Vidgen, "Northern Hurricanes," Telegraph (Brisbane), 17 April 1899, 5. This is the original article that reproduced a verbatim copy of a letter quoting Kenny. The Outridge booklet account, which became the basis for nearly all subsequent accounts in scientific literature, was based on a version of this article published in another newspaper.

52 Camilla Green, Quantifying the Height of the Storm Surge of Tropical Cyclone Mahina, Bathurst Bay, Qld, 1899, Honours Thesis for the Degree of Bachelor of Planning, JCU, Cairns, June 2011, 74.

53 S. A. Hsu and Baozhu Liu, "Wave Setup during Hurricane Katrina and Tropical Cyclone Mahina," Mariners Weather Log, United States National Weather Service, 58, No. 3.

54 Paul Finger, Tides Officer, MSQ, email to Ian Townsend, 23 August 2018; John Broadbent, Coastal Impacts Unit, MSQ, email to Ian Townsend, 29 August 2018.

55 These previous studies did not have the best evidence for Kenny's position. Modelling based on the best evidence is yet to be completed.

56 Townsend, The Bathurst Bay Hurricane, 2020, 188. The estimate of the direction of the cyclone is based on combined credible observations.

57 Walter Roth, Northern Protector of Aboriginals, to Under Secretary, Home Office, "Report re Distribution of Gifts to Coastal Aboriginals," 9 April 1899, HOM/A23, QSA, ID847561, 2. Roth reported that, "… a far larger proportion of trees being down than up, these, the further we proceeded north, having fallen proportionately north of west."

58 John Douglas, "Report of the Government Resident at Thursday Island for 1898," QVP, 1, 1899, 100. "… between Bewick and Hannah Island everything in the shape of trees or grass had been swept clean."

59 See, for example, Alan Sharp, "Assessing Risk from Meteorological Phenomena Using Limited and Biased Databases," Australian Journal of Emergency Management, 23, No. 4, 2008, 11.

60 Townsend, The Bathurst Bay Hurricane, 2020, 203-204. See also K. J. Granger and D. I. Smith, "Storm Tide Impact and Consequence Modelling: Some Preliminary Observations," Mathematical and Computer Modelling, 21, No. 9, 1995, 20. "For emergency managers, it is imperative that appropriate information and estimates are available on which to base life-and-death decisions such as whether to order an evacuation of a settlement or not. More work is clearly needed to better understand the hazard, the attendant vulnerabilities and the consequent risks."

61 NOAA Physical Science Laboratory, Top 24 strongest El Niño and La Niña event years by season, 1895-2015. https://psl.noaa.gov/enso/climaterisks/years/top24enso.html

62 B. Kirtman et al., "Near-term Climate Change: Projections and Predictability," in T. F. Stocker et al. (eds), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC, Cambridge and New York: Cambridge University Press, 2013, 992.

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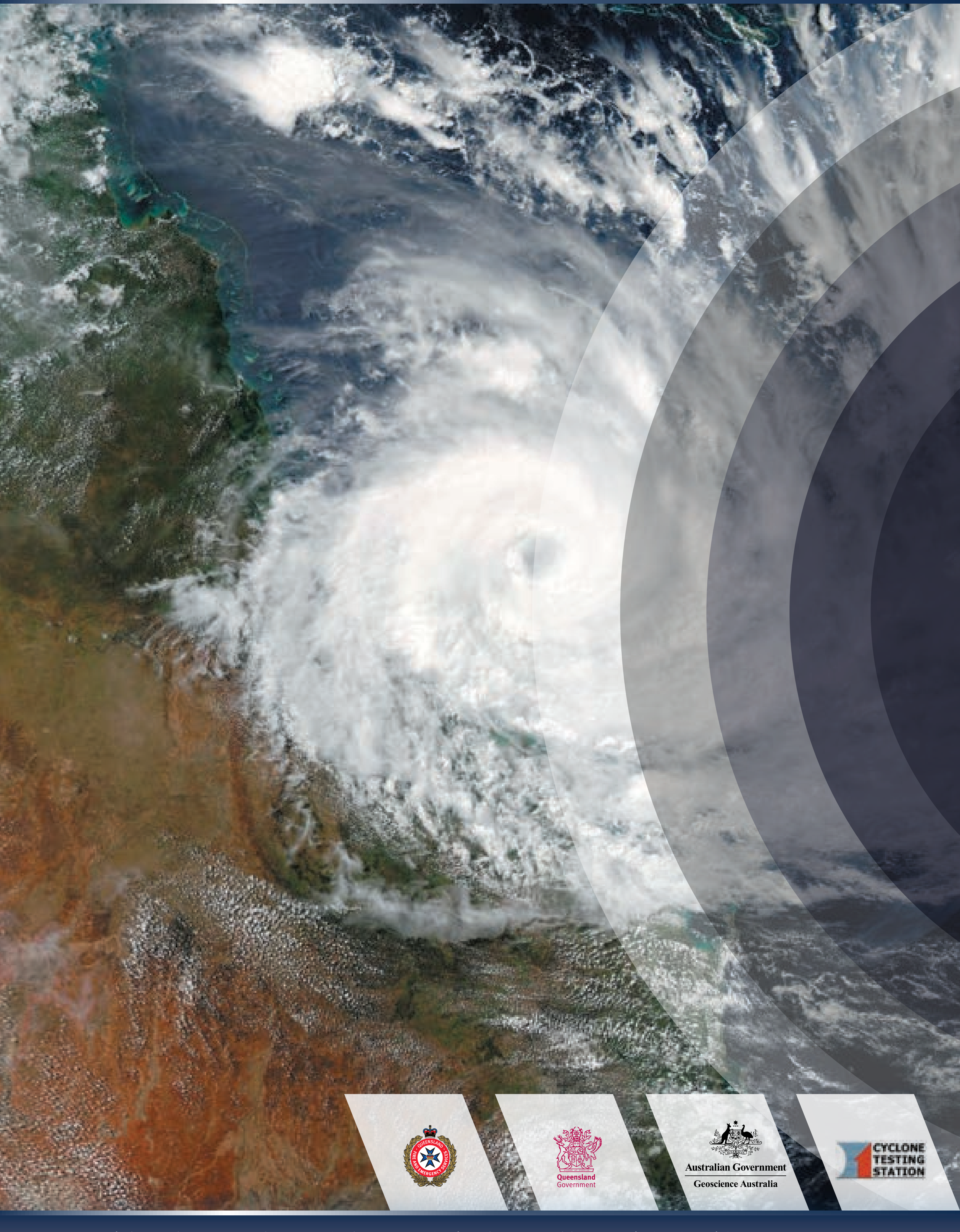

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