

SEVERE WIND HAZARD ASSESSMENT **QUEENSLAND**

Executive Summary: A Guide for Policy and Decision Makers



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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.

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



Mr Greg Leach

Commissioner, Queensland Fire and Emergency Services

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.

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.



Meaghan Scanlon MP

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

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 disasters 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 tsunamis. This enables decision makers in government, industry and the community to make evidence-based decisions so that they can be better prepared for, respond to and reduce the impact of these potentially devastating events.

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 an updated evidence base with which to work with councils and communities to continue to reduce the impact of tropical cyclones and, importantly, progress



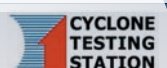
Dr James Johnson
CEO, Geoscience Australia

our understanding of how future climate might 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 an assessment of the hazard posed by them.

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 a complex and ongoing area of work, this assessment provides an important guide to improve resilience and prepare for worst-case scenarios. It gives local communities the best chance to plan ahead, in order to minimise the potential effects of major weather events.



Executive summary

Introduction and background

The Severe Wind Hazard Assessment for Queensland (SWHA-Q) arose as a project to better understand the potential impacts of severe 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 Review¹, 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 on 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 Queensland Government’s broader Queensland 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 tropical cyclones 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.

“We should prepare for more intense and destructive cyclones due to climate change.”

Climate Council, The Compounding Cost of Climate Inaction, 2021

“TC frequency has declined slightly, but the proportion of intense TCs has increased markedly. For example, taking a Southern Hemisphere perspective, the seven most intense TCs in the satellite era (1979 onwards) have occurred since 2004, and the five most intense have occurred since 2015.”

**Insurance Australia Group and National Center for Atmospheric Research - USA,
Severe Weather in a Changing Climate, 2020**

“Climate change may mean fewer total cyclones but an increase in the number of more intense cyclones.”

CSIRO Report into Climate and Disaster Resilience, 2020



“There remains uncertainty in the future change in tropical cyclone frequency (the number of tropical cyclones in a given period) projected by climate models, with a general tendency for models to project fewer tropical cyclones in the Australia region in the future climate and a greater proportion of the high intensity storms (stronger wind speeds and heavier rainfall).”

Bureau of Meteorology, Climate Change in Australia, 2015

“Tropical cyclones are projected to decrease in number, but increase in intensity.”

Royal Commission into the National Natural Disaster Arrangements, 2020

Timeline of Tropical Cyclone Debbie

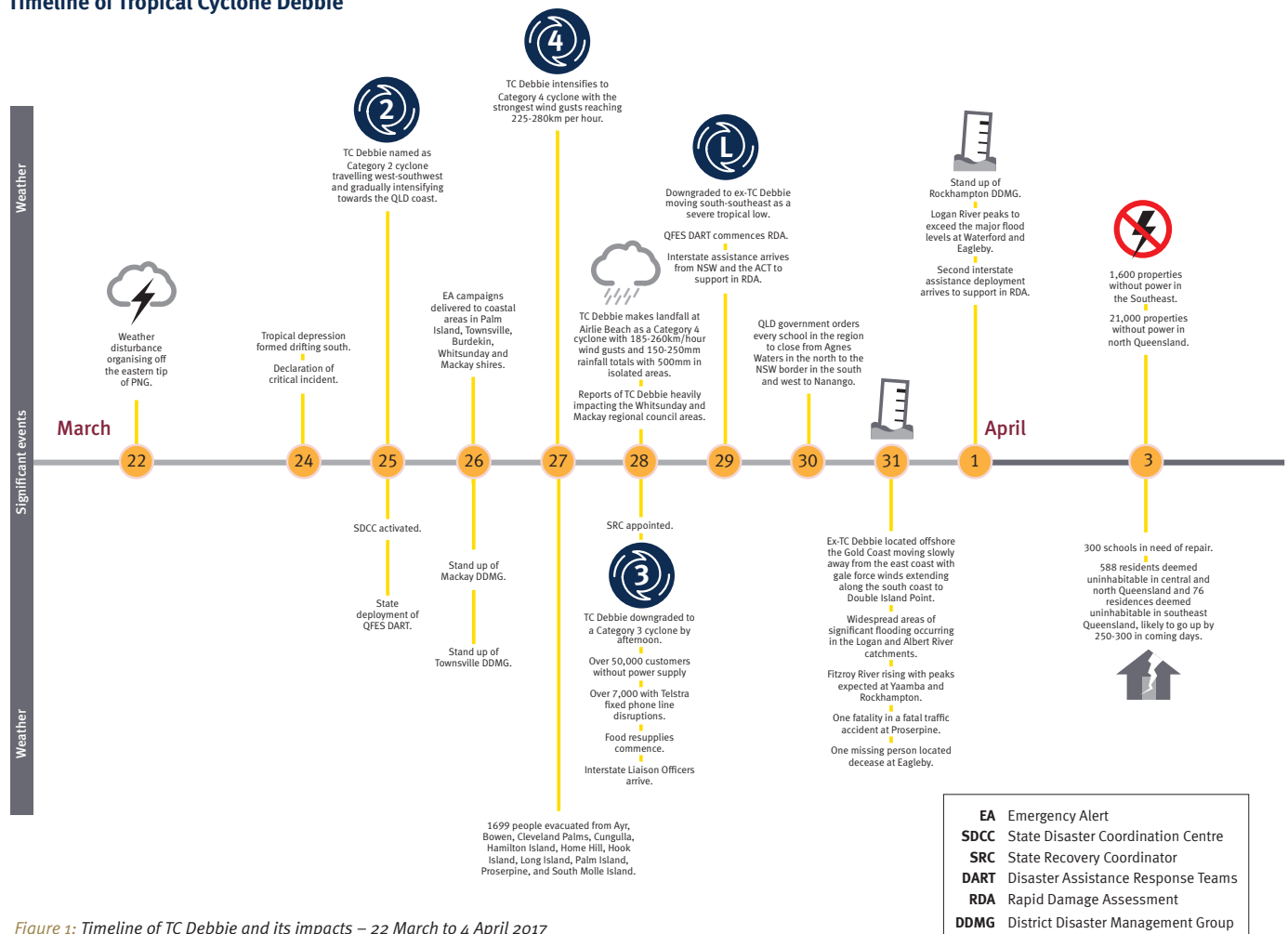


Figure 1: Timeline of TC Debbie and its impacts – 22 March to 4 April 2017



Strategic background

The Queensland Government's disaster management objectives and strategies³ 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 natural 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.

Tropical cyclones are one of the costliest and most fatal weather disasters on our planet. Indeed, 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 Queensland's local governments and disaster districts. The QERMF is a holistic disaster risk management model 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 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 improved 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 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 severe wind hazard, complementing 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. 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 its potential to shift under Queensland's 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 their decision-making.



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 severe 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 severe tropical cyclone under 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.

To communicate the potential impacts of severe tropical cyclones across the diverse regions 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 (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 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.⁵
- **Tropical Cyclone Impact Model (TCIM)**, which provides operational information on severe wind impacts based on Bureau of Meteorology published cyclone track forecasts.⁶
- **Tropical Cyclone Dashboard**, a visualisation tool for current and future cyclone hazard that support users to understand the results of this assessment for current and projected severe wind events across all local government areas, disaster districts and 200 individual locations across Queensland.⁷

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.⁸ Importantly, the Tropical Cyclone Dashboard also serves this function for Queenslanders more broadly.

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.



Project scope parameters

Notably, for this project, a quantitative assessment of the damage arising from hazards associated with tropical cyclones such as water ingress and storm surge was out of scope due to project constraints. However, and where possible, the analyses within this report offer a limited qualitative assessment of the additional potential impacts from storm surge, wind driven debris and/or riverine flooding. This seeks to aid stakeholders by providing a fuller consideration of cyclonic hazards and risks.



Figure 2: Damage to buildings in Yeppoon in the aftermath of Tropical Cyclone Marcia, 2015. Source: QFES



The history of tropical cyclones in Queensland

The eastern Australian coastline from Cape York Peninsula to Coolangatta (Figure 3) has experienced many tropical cyclones over the past 100 years, with many severe tropical cyclones causing major destruction to communities, such as TC Althea at Townsville in 1971 and TCs Larry and Yasi at Innisfail in 2006 and 2011 respectively.

There are extensive historical records of other tropical cyclones, including TC Mahina, one of the most intense tropical cyclones ever to occur in the Southern Hemisphere which made landfall in Far North Queensland in 1899 (Nott et al., 2014; Townsend, 2020; see also Appendix I in *Technical Report One*). There are also records of tropical cyclones making landfall in South East Queensland in the 1950s (The Great Gold Coast Cyclone, 1954), and numerous cases of tropical cyclones 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 tropical cyclone 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 4 and Table 1) as a cyclonic region. South East Queensland is defined in AS/NZS 1170.2 as an intermediate region, recognising that tropical cyclone winds are possible but rarer.

Note: At the time of this report’s preparation, AS/NZS 1170.2 2011 was in the process of being reviewed and updated for expected release sometime in 2021. This will likely include some changes to current wind region mapping.

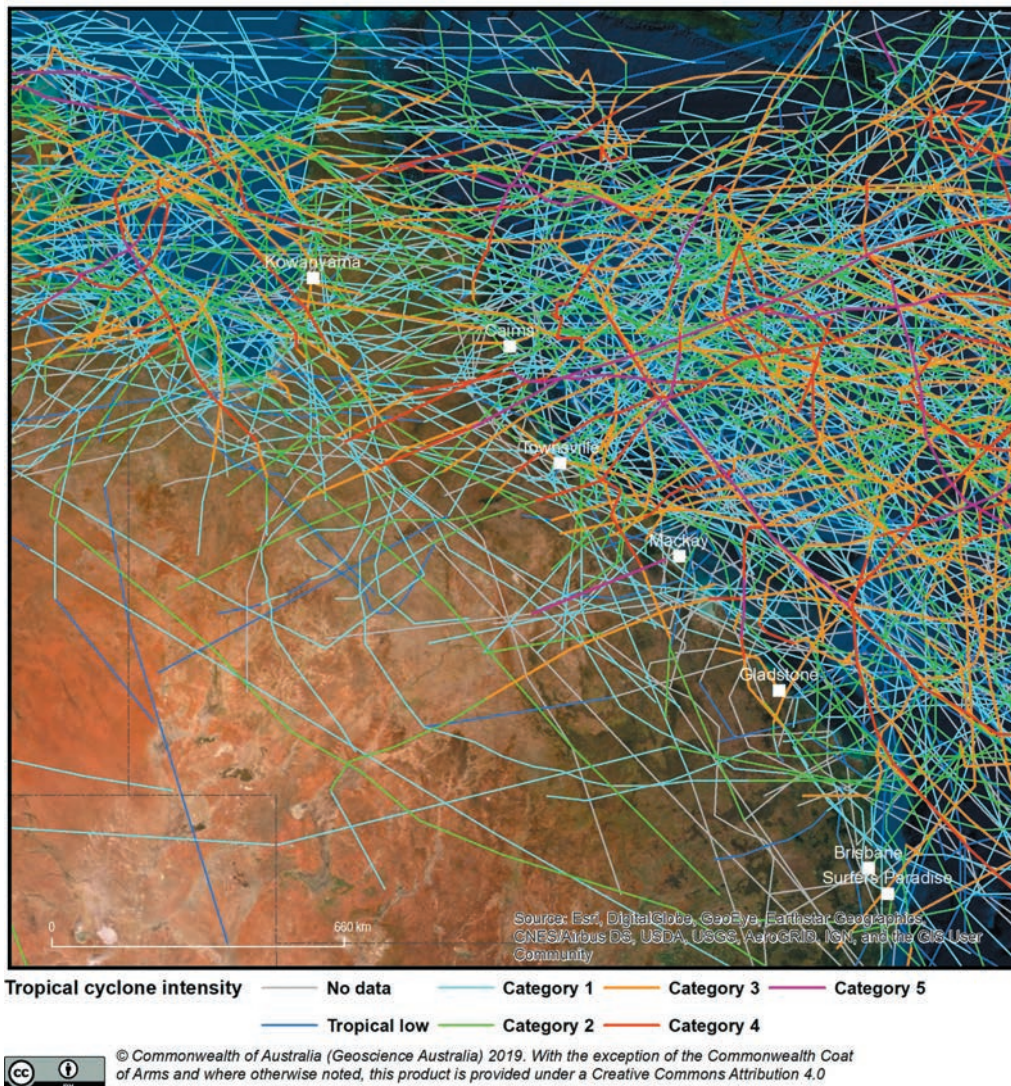
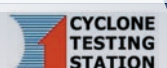


Figure 3: Historical tropical cyclones in the Queensland region 1907 - 2018. Tracks are coloured by the estimated intensity category, based on minimum central pressure. Source: Bureau of Meteorology / IBTrACS (Knapp et al., 2018)



Wind loading regions

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

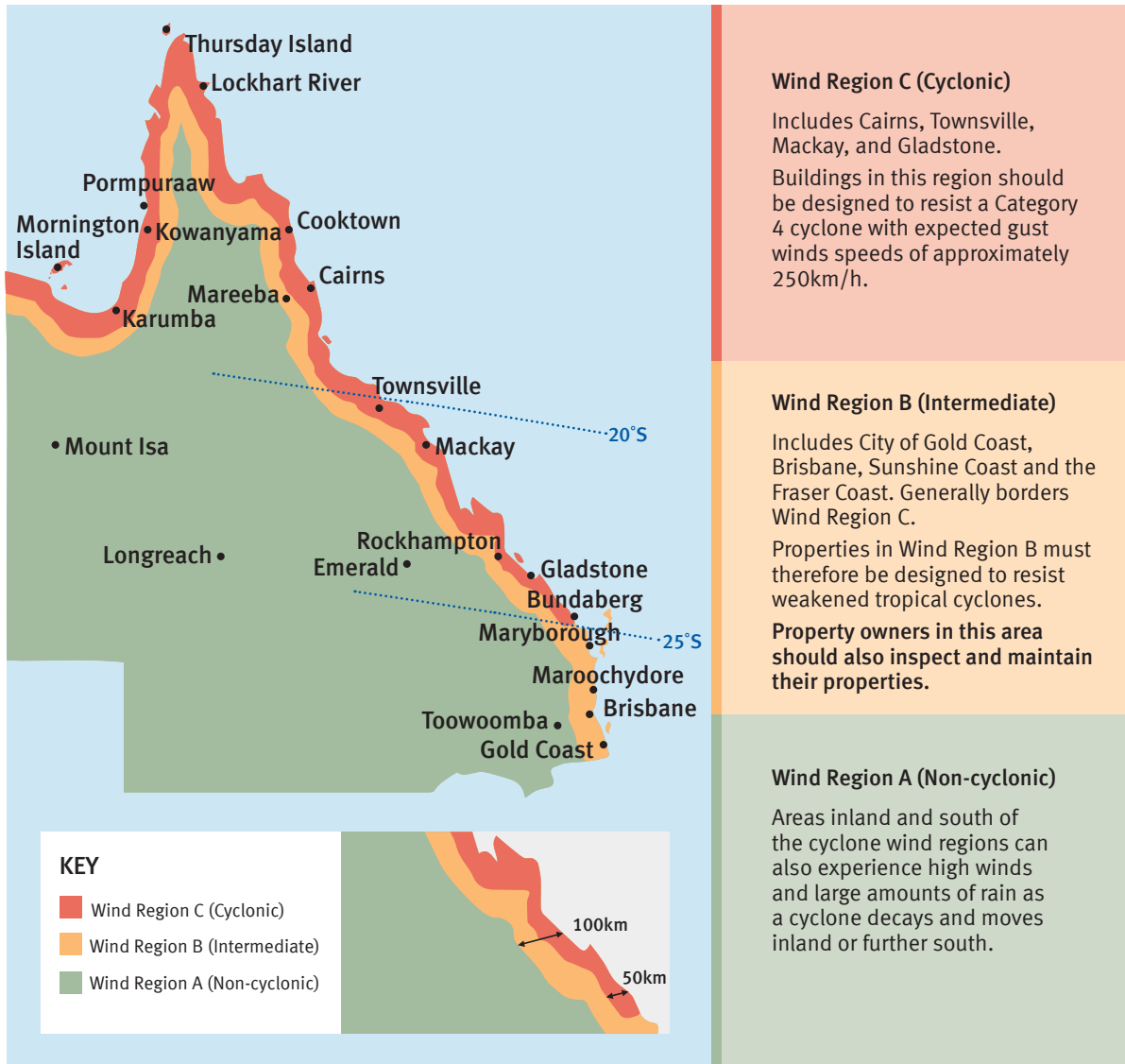


Figure 4: AS/NZS 1170.2 2011 Wind Regions for Queensland, with key locations marked (after AS/NZS 1170.2, 2011).

Wind region	Design gust wind speed		Tropical cyclone category
	metres/second	km/h	
A1-A4	45	162	2
B	51	184	3
C	69	248	4

Table 1: AS/NZS 1170.2 minimum design wind speeds for residential houses and tropical cyclone category.



The assessment

Assessment methodology

An absence of historical examples of severe wind impacts on many townships along the Queensland coastline has provided 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 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 (refer Technical Report 1) and therefore the underpinning catalogue, the nature of the scenarios is fundamentally similar with the key difference being the likelihood associated with each scenario. 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.

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 tropical cyclone track information derived from climate models to provide guidance on possible tropical cyclone activity under projections of climate change (Siqueira et al., 2014). This coupling of TCRM and climate models has informed the development of *Technical Report Two: Hazard Assessment for Future Climate Scenarios in Queensland*.

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Scenario selection

Two tropical cyclone events were modelled for each location for this project – a Category 3 and a Category 5 – with “favourable” tracks for impact analysis. In all scenarios, consideration was given to regional historical analogues for the selected synthetic tracks to better relate the scenario outputs to known or “lived” events. 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 accounts for the future climate of fewer tropical cyclones but more intense occurrences, highlighting the different impacts arising from different events. It is important to emphasise and understand that each individual tropical cyclone event will be different and lead to different impacts.

Impact assessment development

In line with the principles of the Queensland Emergency Risk Management Framework (QERMF)⁹ and those used by Geoscience Australia, disaster impact is quantified as a product of *Hazard*, *Exposure* and *Vulnerability*, as shown in Figure 5.

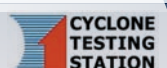
In this project:

- *Hazard* refers to the maximum gust wind speed generated by tropical cyclone 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 2 geography, that is, 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 5: The function of hazard, exposure and vulnerability information that is used to determine impact.



Assessment results

The scenarios described in the report can be used to improve planning for severe tropical cyclone events and their impacts. This includes developing a better understanding of how the capabilities of emergency services and supporting elements may be impacted in actual events.

The report's consideration of the impacts of tropical cyclones on the Great Barrier Reef, and projected shifts in the hazard posed by tropical cyclones under climate change, serve to add to our understanding of how reef managers might best go about their management planning into the future. The consideration of impacts to Queensland's natural ecosystems serves to illustrate the need for comprehensive disaster management and climate adaptation approaches. Indeed, approaches that 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.

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 tropical cyclones in these communities. These scenarios add another layer of decision support information to the emergency management sector and, where the hazard stands to shift, and especially where its shifting status under future climate remains uncertain, they serve as compelling illustrations of the need for Queenslanders to identify and manage their climate risk. The scenarios allow the emergency management sector to better frame questions 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 tropical cyclones, this scenario information has previously been used to guide preparations ahead of tropical cyclone 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 enable emergency management services to exercise events across more communities, using consistent information on the consequences across the state.

Impact of tropical cyclones on communities



Figure 6: 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: QFES



For the purposes of this project, potential impact has been assessed against the occurrence of severe tropical cyclones. This is because people, infrastructure and the natural environment (see Figure 6) 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. The assessment is applicable Queensland-wide but should be applied and tailored at the local and district level by considering the information within SWHA-Q *Technical Report One*, as well as considering future tropical cyclone occurrences under climate change as outlined in SWHA-Q *Technical Report Two* and the associated digital resources.

A significant issue with the resilience of Queensland communities is highlighted through this scenario-based analysis by the comparative impacts of severe tropical cyclones on the most northern communities and the Gold Coast (highlighted in Table 2 & 3). For the Category 3 events, most communities sustain low to moderate levels of damage. However, in the south (i.e. below the AS/NZS 1170.2 Wind Region C demarcation as shown in Figure 4), a Category 3 cyclone would be, by any standard, a catastrophic event as the wind speeds exceed the regional design levels for South East Queensland (see Figures 7 & 8). 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 scenarios, with some moderate damage sustained in the more severe Category 5 scenarios.

The numbers of residential buildings reported in Tables 2 and 3 for each damage state should be taken as a guide only.

Category 3 Scenarios			
LGA	Total Number of Dwellings Estimated Uninhabitable ¹⁰	Uninhabitable Dwellings as a Percentage of Total Dwellings in the Study Area ¹¹	Estimated Number of Persons in Uninhabitable Dwellings ¹²
Gold Coast	97,862	55.29%	245,634
Gladstone (Region)	516	0.48%	1,295
Mackay	1,480	2.36%	3,715
Townsville (Region)	1,016	1.04%	2,550
Cairns (Region)	513	0.49%	1,288
Pormpuraaw	-	-	-
Kowanyama	-	-	-

Category 5 Scenarios			
LGA	Total Number of Dwellings Estimated Uninhabitable	Uninhabitable Dwellings as a Percentage of Total Dwellings in the Study Area	Estimated Number of Persons in Uninhabitable Dwellings
Gold Coast	138,839	92.21%	348,486
Gladstone (Region)	11,056	10.29%	27,751
Mackay	9,546	15.33%	23,960
Townsville (Region)	9,091	9.35%	22,818
Cairns (Region)	20,615	19.75%	51,744
Pormpuraaw	-	-	-
Kowanyama	55	9.94%	138

Tables 2 & 3: Comparison tables highlighting the difference in potential impact of the Category 3 and Category 5 scenarios. Note the level of impact present in the Gold Coast compared to all other study areas. This is indicative of the resilience outcomes in Northern Queensland comparative to South East Queensland.



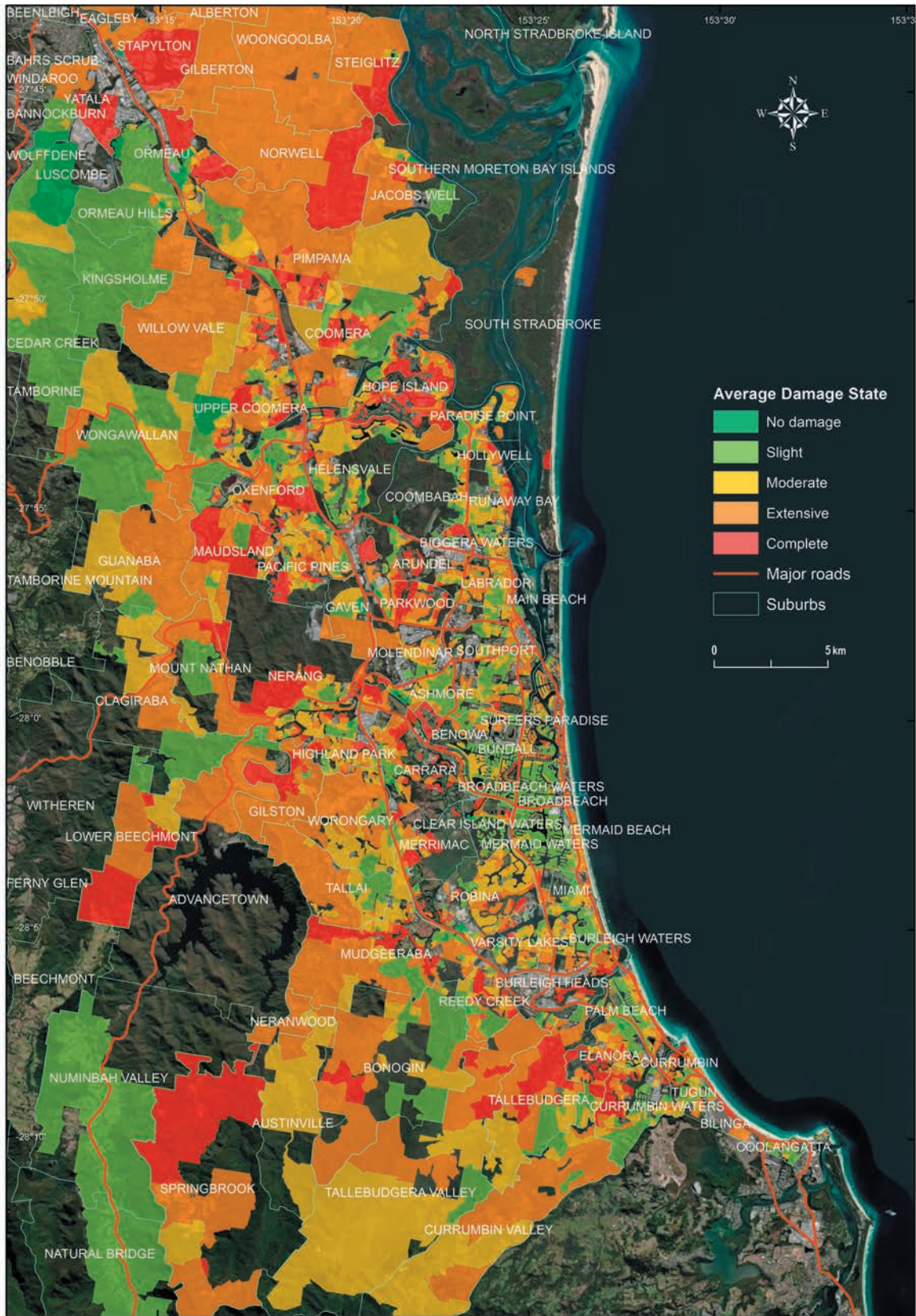


Figure 7: Aggregated residential building damage states for mesh block areas, for scenario 001-00406, a Category 3 cyclone impacting Gold Coast, Qld.

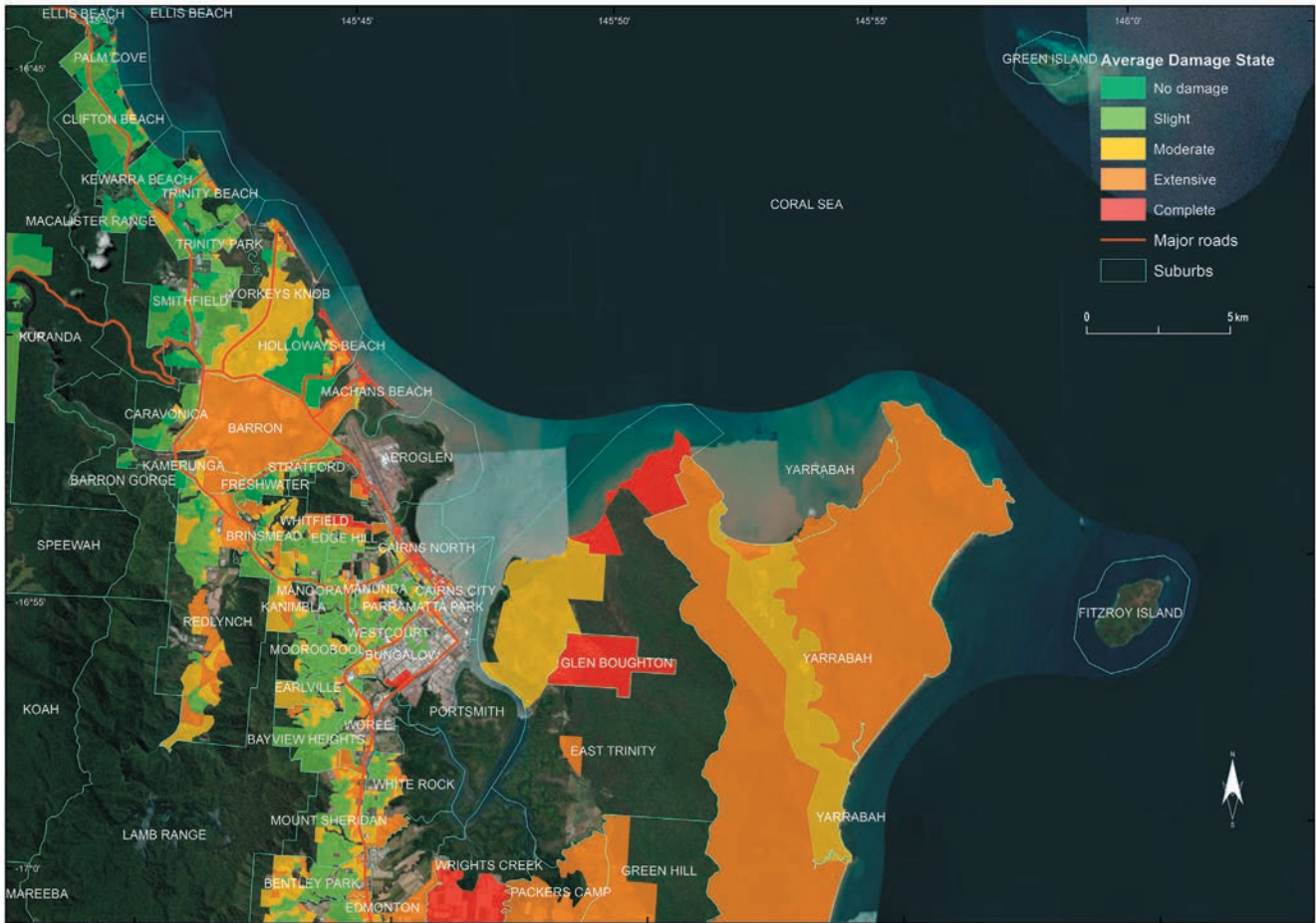


Figure 8: Aggregated residential building damage states for mesh block areas, for scenario 013-03564, a Category 5 cyclone impacting in Cairns, Qld.

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 (See Section 4 and Appendix H of *Technical Report One* for all results).

Notes:

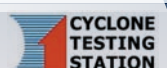
- only residential houses are counted
- the analysis extent may not completely cover LGAs that are not the focus of the scenario, so the totals may not reflect the actual number of houses in the LGA
- some houses may not be included in the analysis as they have not been classified in rural or residential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

Cairns Category 5 scenario

LGA	Negligible	Slight	Moderate	Extensive	Complete
Cairns (R)	49,957	33,810	8,104	8,426	4,085



Tropical cyclone impact across Queensland – 1918 to 2011



Figure 9: Looking south down Sydney Street post the impact of the 1918 Mackay Cyclone.



Figure 11: Roof Loss in Norman Street, 1954 Great Gold Coast Cyclone.



Figure 13: Houses and apartment blocks with their roofs blown off in Innisfail after TC Larry struck in March 2006. Source: Mark Baker(AP)



Figure 15: The aftermath of TC 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 10: Storm surge at Tuesleys Jetty, Southport - 1954 Great Gold Coast Cyclone.



Figure 12: The suburb of Pallarenda, Townsville, after TC Althea in December 1971. Source: City Libraries Townsville Local History Collection



Figure 14: Cardwell in the aftermath of TC Yasi, 2011. Source: Townsville Bulletin



Figure 16: Dunk Island devastation from TC Yasi. Source: HeraldSun (AAP)



Current understanding of tropical cyclone wind hazard

Tropical cyclones in the Australian region are influenced by several factors, and in particular variations in the El Niño – Southern Oscillation. In general, more tropical cyclones cross the coast during La Niña years, and fewer during El Niño years.

Analysis of historical tropical cyclone data has limitations due to several changes in observing practices and technology that have occurred over time. With new and improved meteorological satellites our ability to detect tropical cyclones has improved, as has our ability to differentiate tropical cyclones from other tropical weather systems such as monsoon depressions, which in the past may have been incorrectly named as tropical cyclones. A particularly important change occurred in the late 1970s when regular satellite images became first available from geostationary satellites above the Earth's equator.

The time series of analysed tropical cyclone activity in the Australian region (south of the equator; 90-160°E) show that the total number of cyclones appears to have decreased (Figure 17). However, there was a change to the definition for tropical cyclones in 1978 which led to some systems which would previously have been classified as tropical cyclones instead being considered sub-tropical systems. The trend in the total number of all tropical cyclones from 1985 onwards shows no significant change.

The number of severe tropical cyclones (minimum central pressure less than 970 hPa) is dominated by variability with periods of lower and higher frequencies of occurrence. There is less confidence in the earlier intensity data with continuous satellite coverage commencing in 1979.

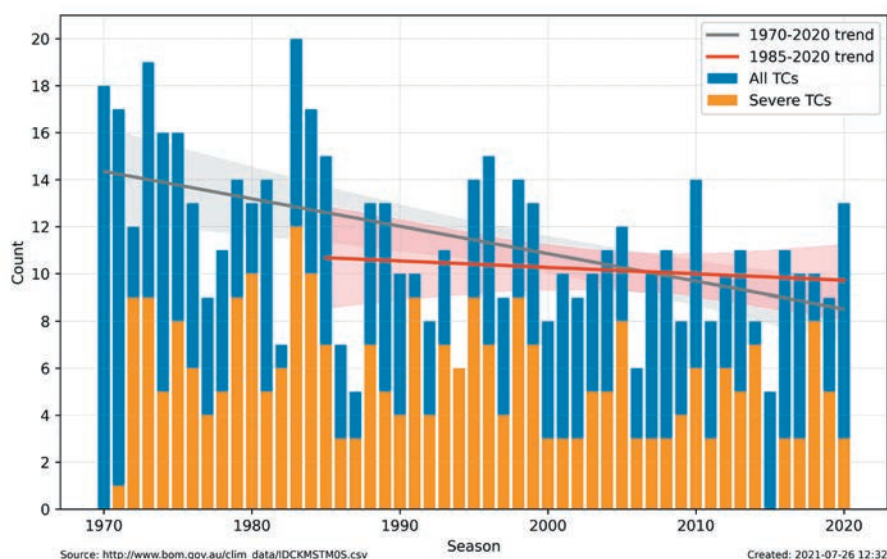


Figure 17: Graph showing the number of severe and non-severe tropical cyclones from 1970-2020 which have occurred in the Australian region. Severe tropical cyclones are shown here as those with a minimum central pressure less than 970 hPa. Source: Geoscience Australia and Bureau of Meteorology

Impact of climate change on tropical cyclone risk

Significant caveats accompany any assessment of the potential impact of climate change on the behaviour of tropical cyclones into the future. Indeed, research in this field is very much ongoing in nature. Specifically, the assessment detailed in *Technical Report Two* found that it is more likely than not that communities across Queensland will see an increase in the likelihood of extreme tropical cyclone events (i.e. greater than 1:1000 annual exceedance probability, or AEP) into the future. For most Central, Northern and Far Northern Queensland communities, the reduced annual frequency of tropical cyclones across North Queensland (i.e. within AS/NZS 1170.2 Wind Region C) will see the probability of exceeding a set wind speed reduce into the future. As highlighted in Figure 18, this assessment finds that most communities are unlikely to experience significant change in wind hazard at the 1:500 AEP level, i.e. the level applied to wind loading design standards for residential buildings across Queensland. While there is uncertainty relating to regional changes in the tropical cyclone-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 design standard for those structures essential to post-disaster recovery (Australian Building Codes Board, 2019), and there is evidence of an increase in wind speeds at these likelihoods. Notably, another recent study investigating shifts in tropical cyclone activity over Queensland also points towards an increase in the likelihood of more destructive tropical cyclones affecting South East Queensland (Bryère et al., 2020).

Given these findings, and other considerations, a more detailed analysis of the hazard posed for the South East Queensland region is warranted. Consideration of the appropriateness of the existing design criteria for buildings in the region that support post-disaster recovery operations is similarly warranted. Investment in upgrading these buildings might then be an option for delivering increased resilience. Notably, even at lower wind intensities, issues relating to the associated hazard of water ingress impacting the functionality of these facilities is possible.

Further investigation into projected changes in tropical cyclone activity, and the related exposure and vulnerability of communities would be beneficial, given some of the shortcomings noted earlier. A follow on project, the Severe Wind Hazard Assessment for South East Queensland (SWHA-SEQ) focuses on that region, in collaboration with insurance industry partners and others, and will, among other objectives, draw together the body of knowledge on wind hazard projections under climate change. The SWHA-SEQ project is scheduled to report on its research in 2022.

Understanding the effect of climate change on tropical cyclone risk is particularly important due to the large societal impacts from these events. The task of confidently projecting future changes in tropical cyclone activity is extremely complex and remains the subject of ongoing global research efforts. Future generations of global and regional climate models will help to refine our understanding of the projected changes in tropical cyclone frequency, tracks and intensity and therefore the likelihood of extreme tropical cyclone-related winds across Queensland.

Finally, it is important to note that wind speed is only one aspect of tropical cyclones and their impacts. The intensity of heavy precipitation from all weather systems, including tropical cyclones, is likely to increase. Increased rainfall intensity from tropical cyclones is pertinent to Queensland since these storms have historically been associated with major flooding.

Similarly, increases in storm surges and extreme sea-levels are very likely to occur in association with tropical cyclones under future climate change. This change is independent of changes in tropical cyclone intensity and is directly related to increases in global mean sea-level due to global warming.⁴

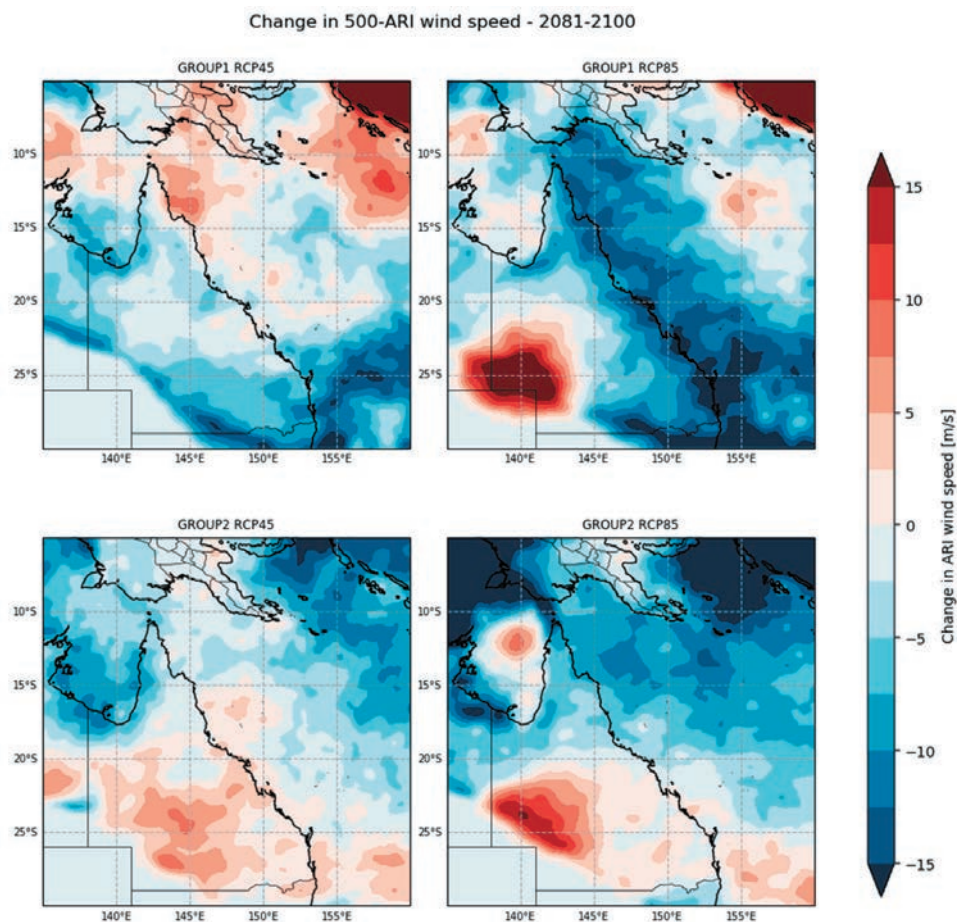


Figure 18: Example result from the Hazard Assessment for Current and Future Climate - Change in 0.2% AEP wind speed for Queensland for the period 2081-2100.



Cyclone impact across Queensland 2015 to 2018



Figure 19: Damage to buildings in Yeppoon in the aftermath of TC Marcia, 2015. Source: QFES



Figure 20: Serious damage around Sarina Range due to landslips from TC Debbie. Source: Loretta MacGregor



Figure 21: Shute Harbour is littered with debris following TC Debbie. Source: Dan Peled (AAP)



Figure 22: Roof damage sustained to holiday accommodation on Hamilton Island from TC Debbie. Source: Dennis Garrett (ABC News)



Figure 23: Damage sustained in Pormpuraaw post the transit of TC Nora. Source: Queensland Police Service



Summary and next steps

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

1. explore the likely impacts of severe (that is, Category 3 or higher) tropical cyclones that have not yet occurred
2. progress the understanding of the potential effects of climate change on the frequency and intensity of tropical cyclones
3. build the capability and capacity for understanding impacts of future tropical cyclones across the emergency management sector in Queensland
4. highlight the practical actions that will enable decision makers and communities exposed to tropical 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 tropical cyclone events. These 14 scenarios were chosen from the Tropical Cyclone Hazard Assessment database (consisting of physically and statistically plausible, randomly generated tropical cyclone events) in consultation with QFES and the respective local governments. The selection of credible scenarios aimed to assist emergency managers to plan for response and recovery and, most importantly, develop mitigation strategies by having an event or events to plan against. During the selection process consideration was given to:

1. historical analogues for the event
2. potential for significant associated hazard impact (i.e. flood and storm surge)
3. 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 tropical cyclone-related hazards, such as flash and riverine flooding and storm surge, will require a separate analysis.

Key conclusions

In considering the results detailed within Technical Reports One and Two – which are summarised within this document – the subsequent list provides a summation of the key issues and conclusions arising from the project. These are prioritised based on the scale of the issue outlined, as well as the potential for an increase in disaster resilience and risk reduction if these issues were either partially or fully addressed.

1. The analysis and considerations made in this project reinforce several findings related to emergency management in Queensland previously highlighted in reviews of past tropical cyclone events. Many of these remain extant, such as the criticality of building maintenance to reducing damage and the communication of risk to communities.
2. While tropical cyclones are expected in South East Queensland and are considered within residential building design criteria, any severe tropical cyclone (Category 3 and above) has the potential to result in catastrophic outcomes for communities in this region. This is due to a combination of legacy pre-code housing stock, along with the design criteria for modern houses in Wind Region B being below that of a moderate Category 3 cyclone (205km/h wind gusts).

Relevant comparisons of the risk for South East Queensland have recently been observed in Western Australia with the impact of TC Seroja on the community of Kalbarri and the surrounding region (AS/NZS 1170.2 Wind Region B). The higher population density in South East Queensland, coupled with a revised understanding of the vulnerability to severe winds highlights the potential for catastrophic impacts across this region. As such, further study is currently underway to help to understand the main drivers of cyclone risk for South East Queensland.

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.

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. However, the 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.



For the Category 5 severe tropical cyclone scenarios, modelling indicates that most houses on the outskirts of town 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, noting this modelling does not account for damage from wind-driven debris.

For the Category 3 severe tropical cyclone scenarios, the age profile of suburbs is the dominant driver of damage likelihood, 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 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.

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 and where the regional design standards are lower than those of our coastal communities (refer to Figure 4).

Post cyclone 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 tropical 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.

4. 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 expanding these initiatives to 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.
5. It must be emphasised that modelling of the nature undertaken within this project cannot account for impacts from wind-driven rain or debris. 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.
6. Within the context of the report, severe tropical cyclone winds are considered as being Category 3 or higher. While some communities and emergency managers may have experience with Category 3 tropical cyclones, to most, the impacts of a landfalling Category 4 or 5 tropical cyclone will be largely unfamiliar. As discussed in section 7.1.3 of SWHA-Q Technical Report One, 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.

In South East Queensland, 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 South East Queensland.

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.

7. 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.



8. 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. Considerations put forward in SWHA-Q *Technical Report One* illustrate 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.

The following statement from the Royal Commission into the National Natural Disaster Arrangements summarises those considerations put forward in the risk assessment section of SWHA-Q *Technical Report One*:

“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 and for long durations.”

9. The consideration in this assessment of impacts of tropical cyclones to Queensland’s natural ecosystems serves to illustrate 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.
10. While the scenarios in this assessment are designed to support the emergency management sector, where the hazard posed by tropical cyclones stands to shift, and especially where its shifting status under future climate remains uncertain, they 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.
11. Greater effort should be made to allow immediate access to cyclone and storm affected areas to organisations such as the 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 tropical cyclone event. By capturing the raw information on damage, more can be learnt about how to reduce the impact of future cyclones. 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.

Based on the findings and key conclusions of this project, it is recommended that:

“A cross-sector working group is established to identify and prioritise mitigation and/or adaptation actions, based on this assessment and all future risk assessments, together with their relevant implementation strategies.”

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

The recently commissioned SWHA-SEQ focuses on that region, in collaboration with local government, the insurance industry and other partners. This project will draw together the body of knowledge on wind hazard projections under climate change and improve the understanding of vulnerability and potential impact for area of Queensland that encompasses 3.1 million people and over 60% of Queensland’s residential exposure. The SWHA-SEQ project is scheduled to report on this research in 2022.

The effects of climate change on tropical 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.



Appendices

Appendix A: Glossary

Abbreviation	Definition
ARI	Average Recurrence Interval. <i>As for return period – the average time between events of a given magnitude or greater.</i>
AEP	Annual Exceedance Probability. <i>The probability of an event of a given magnitude (or greater) occurring in any year. Can be expressed as either a probability with values ranging from 0 to 1, or as a percentage with a range from 0 to 100%.</i>
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
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	Representative Concentration Pathway
RP	Return Period. <i>The average time between events of a given magnitude. For example, the average time between events with a maximum wind gust of 150 km/h or greater.</i>
SA	Statistical Area Levels (Australian Bureau of Statistics)
SES	State Emergency Service



Abbreviation	Definition
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: List of contributing and participating agencies to SWHA-Q

1. Australian National University
2. Australian Building Codes Board
3. Brisbane City Council
4. Building Queensland
5. Bureau of Meteorology
6. Bushfire and Natural Hazards CRC
7. Cairns Regional Council
8. Centre for Appropriate Technology
9. Charters Towers Regional Council
10. City of Gold Coast
11. Department of Environment and Science
12. Department of Energy and Public Works
13. Department of Fire and Emergency Services, Western Australia
14. Department of State Development, Infrastructure, Local Government and Planning
15. Department of Transport and Main Roads
16. Douglas Shire Council
17. Energy Queensland Group
18. Geoscience Australia
19. Gladstone Regional Council
20. Great Barrier Reef Marine Park Authority
21. Inspector-General Emergency Management
22. Insurance Australia Group
23. Insurance Council of Australia
24. James Cook University Cyclone Testing Station
25. Kowanyama Aboriginal Shire Council
26. Local Government Association of Queensland
27. Mackay Regional Council
28. Mareeba Shire Council
29. Mutual Aid Group Gladstone
30. National Broadband Network
31. Noosa Shire Council
32. Optus
33. Police, Fire and Emergency Services, Northern Territory
34. Pormpuraaw Aboriginal Shire Council
35. Powerlink
36. Queensland Fire and Emergency Services
37. Queensland Government Insurance Fund
38. Queensland Health
39. Queensland Police Service
40. Queensland Reconstruction Authority
41. Suncorp Australia
42. Sunshine Coast Council
43. Redlands City Council
44. Tablelands Regional Council
45. Telstra
46. Townsville City Council
47. University of Queensland
48. Wet Tropics Management Authority
49. Yarrabah Aboriginal Shire Council



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 Science Advances 16 Dec 2020: Vol. 6, no. 51, eabd5109 DOI: 10.1126/sciadv.abd5109

⁵ <http://geoscienceaustralia.github.io/tcrm/docs/intro.html>

⁶ Ibid.

⁷ <https://longpaddock.qld.gov.au/qld-future-climate/>

⁸ For more information, visit the Queensland Government's Disaster Management website:
<https://www.disaster.qld.gov.au/Pages/default.aspx>

⁹ <https://www.disaster.qld.gov.au/qermf/Pages/default.aspx>

¹⁰ Based on the number of buildings in the 'Moderate' to 'Complete' damage states

¹¹ Based on the number of buildings in the 'Negligible' to 'Complete' damage states

¹² Indicative calculation based on the occupancy rate in 2016, which was 2.51 persons per dwelling - QGSO Dwelling Projections 2018



