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Mitigation of Residential Wind Risk in South East Queensland

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ABSTRACT

The region of South East Queensland represents a large concentration of population, business activity and infrastructure that is important to the economy of Queensland and Australia. The region is also subject to severe storms that can generate damaging winds, particularly as a result of thunderstorm and tropical cyclone activity. This risk posed by severe wind is not well understood, nor are the optimal strategies for managing and potentially reducing this risk.

The Severe Wind Hazard Assessment for South East Queensland (SWHA-SEQ) project has had the central objectives to gain an improved understanding of the current wind risk in this region and to develop actionable information that could inform future strategies to manage and reduce this risk. It has also included other related issues associated with future climate, strata title vulnerability, the implications of strong growth in the region and the identification of places of last resort. The project has had fifteen partners that have included local government, insurance, emergency management, State government more broadly and the research community. The two-year project commenced in October 2020 and was completed in December 2022.

This paper presents a summary of part of the research undertaken along with the outcomes in the areas of wind hazard, residential exposure definition, house vulnerability assessment, risk and mitigation. Key findings are summarised in the areas of the spatial variability of risk across the region, mitigation of vulnerability at property level, and the effectiveness of prioritised retrofit in South East Queensland.

1. Introduction

South East Queensland (SEQ) is a rapidly developing region with the 2022 population of approximately 3.8 million projected to increase by 40% to 5.3 million residents by 2041. Severe storm events can cause significant and widespread impacts that may pose serious challenges to emergency services. These events may also have broader economic and social implications, with damage and recovery costing the State substantially, and with potential long-term implications for residents. An understanding of the current risk and how it may change due to the effects of climate change, increasing exposure (built, population and business) and vulnerability (buildings and infrastructure) is required to inform the most effective strategies for risk mitigation, adaptation and for increasing resilience.

In this project wind risk and mitigation have been studied in the heavily populated coastal part of SEQ with a focus on residential homes. It has built on two recently completed projects; one examining the potential consequences of tropical cyclones on Queensland communities (Arthur et al, 2021) and the second assessing the vulnerability and mitigation opportunities for a range of Australian house types (Ginger et al, 2021). The magnitude of the simulated SEQ scenario impacts of the former highlighted the risk in the region and the latter developed tools for quantitatively assessing the effectiveness of

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retrofit measures. The SWHA-SEQ project (Edwards et al, 2022) has assessed in a quantitative manner the present risk to a range of house types in various local hazard environments. Various levels of retrofit for each house type have been developed and applied to assess the reduction in risk and associated benefit versus cost for a home owner. Furthermore, the risk has been assessed spatially across the region and various programs of incentivised retrofit explored. This included forecasting the risk reduction outcomes for each and at what total grant cost. This research has entailed the development of an improved understanding of the wind hazard in the region, the nature of the building stock and the vulnerability of various house types, with and without mitigation. Each of these elements and the outcomes of their application are described in this paper.

2. Study Region

The study region covered the six coastal councils in SEQ from Noosa in the north to the NSW border in the south (Figure 1) and at the time of the 2021 Census had a residential population of 2.93 million. There are an estimated 907,000 separate residential homes with approximately a further 400,000 households living in some form of strata title property. The study region is home to approximately 56% of Queensland's population.

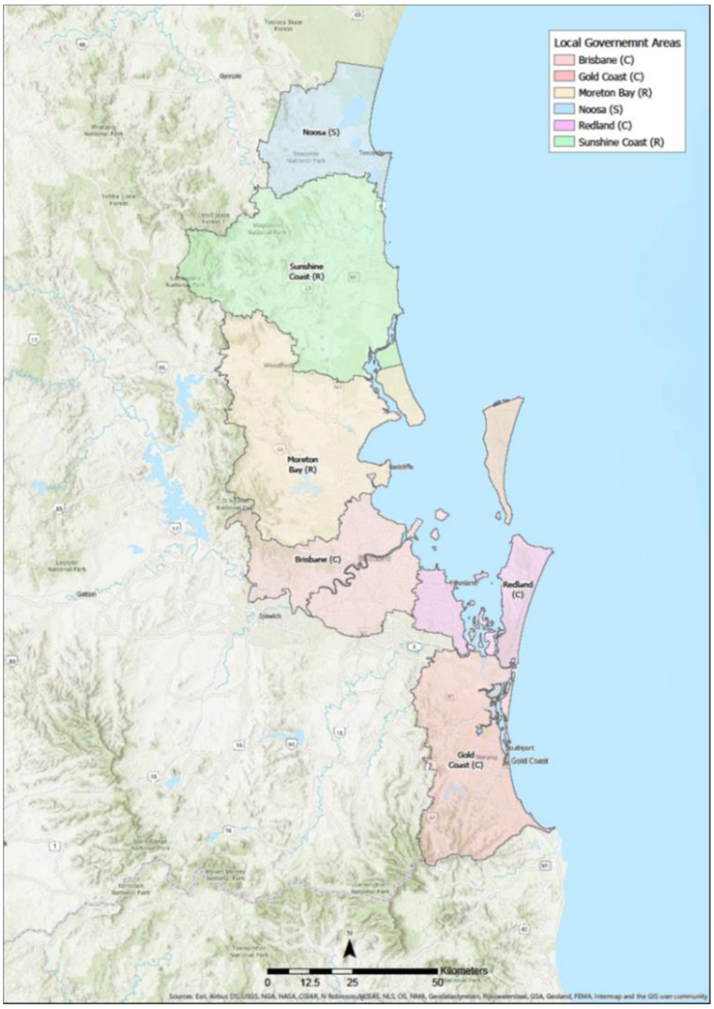

Figure 1: Study region of the Severe Wind Hazard Assessment for South East Queensland project.

3. Risk Assessment Framework

The research work undertaken to develop information in the SWHA-SEQ project utilised the risk assessment framework commonly used in the financial sector. The elements that were developed and brought together to assess impact, risk and mitigation are summarised in Figure 2. The first three elements of hazard, exposure and vulnerability are fundamental inputs which translate to derived information on scenario impacts, long term risk and mitigation effectiveness. Significantly, local scale community resilience measures were incorporated in SWHA-SEQ to include the coping, recovery and adaptive capacity of households in prioritising risk mitigation initiatives.

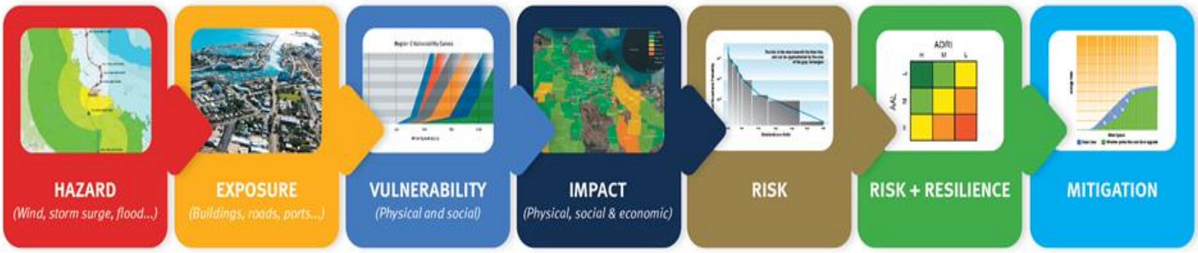

Figure 2: Risk framework that combines the primary elements of hazard, exposure and vulnerability to develop information on event impact, risk and the effectiveness of mitigation measures.

4. Wind Hazard in SEQ

Wind hazard in South East Queensland is dominated by severe thunderstorms and tropical cyclones, with other synoptic storm types contributing. The rarity of tropical cyclones (TCs) in the region presents challenges in quantifying the magnitude of the hazard they represent and there is also uncertainty in assessing the spatial distribution of thunderstorm hazard.

To develop an understanding of the likelihood of extreme TC-related winds, a statistical model of TCs was used to generate a large collection of synthetic TCs analogous to the historical record of TCs in the region. Geoscience Australia's Tropical Cyclone Risk Model (TCRM) (Arthur, 2021) was used to simulate the wind fields in standard conditions of TC's representing 10,000 years of TC activity in the Coral Sea. From these the probabilistic wind hazard due to cyclonic activity spatially across the study region was assessed.

For thunderstorms and synoptic storm types, an extreme value analysis was carried out on observed wind measurements at all Bureau of Meteorology Automatic Weather Stations (AWSs) within the study region and neighbouring areas. Each measured gust was standardised to an equivalent 0.2-second gust at 10 m height in flat, open terrain. As the observational records were short the data from the 15 AWS considered was aggregated into a 'superstation' (Holmes, 2002) that enabled analysis of all data as though it were one site with the this wind hazard component treated as spatially uniform.

The 'superstation' thunderstorm and synoptic wind hazard profiles were blended with the corresponding TC hazard profiles at each station, then spatially interpolated using ordinary kriging to provide an overall estimate of the likelihood of extreme winds across South East Queensland. The results for Brisbane Airport are shown in Figure 3. The dominant source of wind hazard in South East Queensland for the most frequent events (exceedance probabilities greater than 1:50) was found to be thunderstorm-generated wind gusts. For rarer events having exceedance probabilities less than 1:200 TC becomes the dominant source of extreme gusts. The wind hazard in standard conditions was translated to local wind hazard utilising local wind multipliers to account for terrain roughness, topographic influences and upwind shielding.

5. Exposure Development

The exposure development process for this project aimed to address the challenges that exist in Queensland for building exposure where information on residential building construction is not routinely captured by Local or State government. The approach entailed improving the statistical metrics used in Geoscience Australia's National Exposure information System (NEXIS) (Power et al, 2017) to develop a consistent and representative exposure definition where specific information is not available. The process is described schematically in Figure 4 and, firstly, entailed characterising suburbs into residential construction profile types for which desk-top survey work was subsequently undertaken. The survey obtained representative samples from which building characteristic statistics were developed for each suburb category. Finally, NEXIS was regenerated using these characteristic statistics for the study region. The incorporation of the new statistical suite along with available Local Government Area (LGA) information resulted in a significant uplift of NEXIS, and is now available to users through the Australian Exposure Information Platform (AEIP). The result has been what is considered a representative definition of the estimated 907,000 residential houses in the study region.

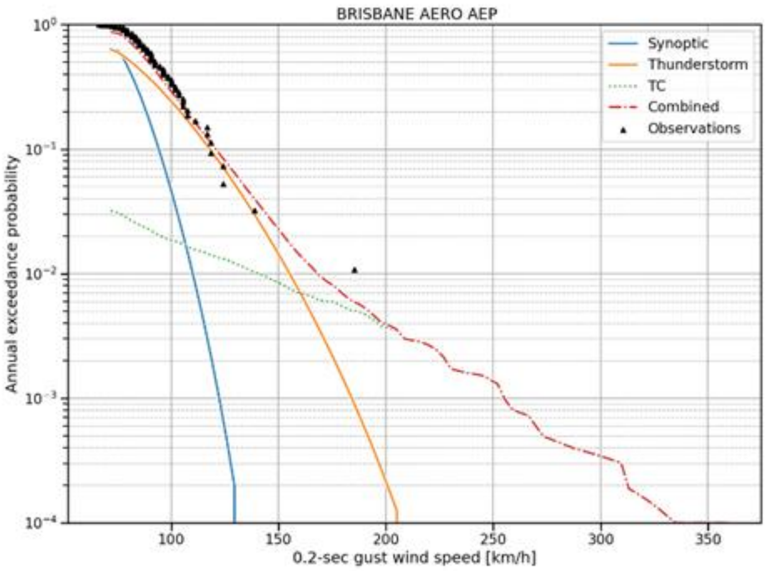

Figure 3: Combined wind hazard profile for Brisbane Airport composed of synoptic, thunderstorm and tropical cyclone winds. Thunderstorm and synoptic Annual Exceedance Probabilities (AEP) are based on a fitted Generalised Pareto Distribution to the 'superstation' observations, and the TC based on plotting position estimation of AEP. Black triangles indicate exceedance probability of observed wind speeds.

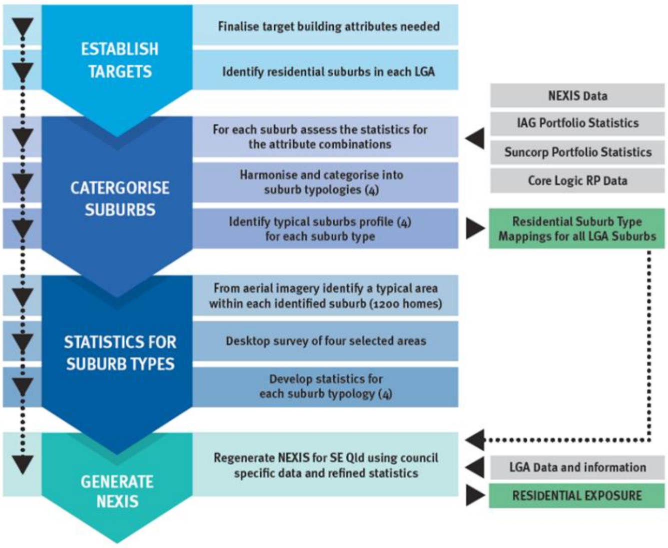

Figure 4: Schematic of methodology used for residential home exposure development entailing characterising the 500 suburbs in the study region into four types, improving the building construction statistics for each type through a desktop survey of 5,000 homes, and regenerating NEXIS for the region.

6. House Wind Vulnerability and Mitigation

Five residential house types were selected for detailed vulnerability and mitigation study:

Type 1:	Pre-modern code with sheet metal roof, timber framing and wall cladding
Type 2:	Pre-modern code with tiled roof and brick veneer walls
Type 3:	Pre-modern code with sheet metal roof and brick veneer walls
Type 5:	Modern code with sheet metal roof and brick veneer walls
Type 6:	Modern code with tiled roof and brick veneer walls

The Type 4 house initially selected of sheet metal roof and reinforced concrete block walls was dropped as it was not observed in the desk-top survey areas, and so did not feature in the regenerated NEXIS exposure. The vulnerability assessment involved defining each selected house type in terms of structural system and component strengths and the modelling of these houses to wind hazard using the vulnerability modelling software referred to as ‘Vulnerability and Adaptation to Wind Simulation’ (VAWS; Geoscience Australia 2020). This software package has been developed over several years in a collaborative effort between the Cyclone Testing Station and Geoscience Australia (Smith et al, 2020).

Figure 5 shows the VAWS outputs for the Type 1 house. For each wind speed increment the Damage Index for each of 100 realisations of the house (circles) were averaged to give the average Damage Index across the population of houses (black asterisks). The failure modes are also indicated in Figure 5, grouped by vulnerability outcomes, and are described as follows:

1. Roof structures severely damaged at or below design wind speed due to dominant opening occurring (e.g. a failed door or a breach from debris impact). Approx. 55% of houses.
2. Water ingress damage well before design wind speed and severe structural damage at design wind speed. Approx. 15% of houses.
3. Severe structural damage at design wind speed. Approx. 30% of houses.

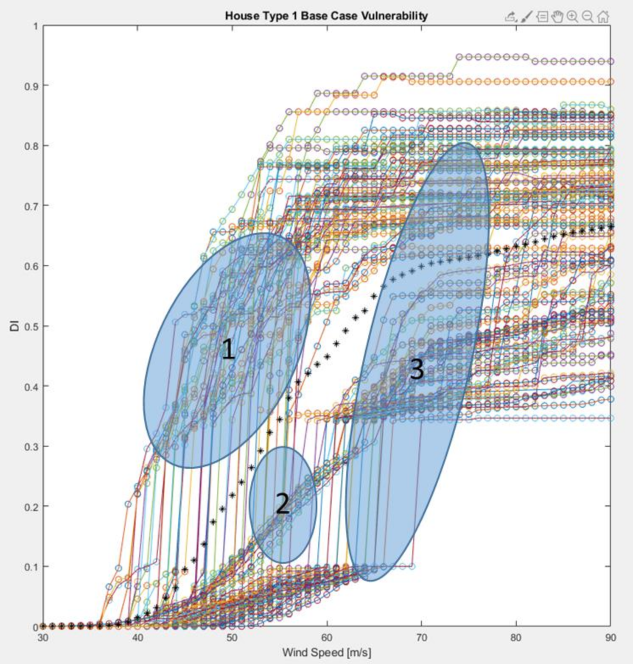

Figure 5: Vulnerability outputs for the base case of Type 1 house. Groups of house simulations showing different failure modes are indicated by the numbered ellipses.

Wind vulnerability was also reassessed with VAWS for each of three levels of retrofit explored; 1) window and door protection (resulting in no internal pressurization), 2) roof structure upgrade assuming no internal pressurisation, and 3) both measures applied together. The retrofit for modern homes only considered window and door protection. Using the “As-Is” vulnerability and that for each of the range of retrofit levels the damage related risk for each house type was also assessed. For convenience the local wind hazard was categorised as in the wind loadings standard for housing (AS4055, Standards Australia, 2021). Table 1 summarises the results for the three older pre-code house types and it can be noted that the building damage related wind risk in the most common N2 wind environment of approximately 0.1% Average Annual Loss (AAL) is high. It was also found that this risk increased by an order of magnitude when local wind hazard increased to N4. However, on the positive, the application of full retrofit was found to reduce this risk by more than this increase for all three house types.

Table 1: Average Annual Loss as a percentage of full reconstruction cost for a range of retrofit option for legacy house types. Level 1 retrofit is window and door protection, Level 2 is roof structure upgrade assuming no internal pressurisation and Level 3 is both Levels 1 and 2 combined.

Local Wind Hazard Category	**AAL Loss for Type 1 House Retrofit Level [% of rebuild]**				**AAL Loss for Type 2 House Retrofit Level [% of rebuild]**				**AAL Loss for Type 3 House Retrofit Level [% of rebuild]**			
	As Is	**1**	**2**	**3**	**As Is**	**1**	**2**	**3**	**As Is**	**1**	**2**	**3**
N2	0.082	0.024	0.029	0.004	0.141	0.087	0.015	0.003	0.110	0.044	0.081	0.005
N3	0.251	0.089	0.097	0.021	0.437	0.277	0.058	0.019	0.338	0.165	0.243	0.029
N4	0.907	0.285	0.333	0.072	1.698	1.007	0.195	0.069	1.205	0.490	0.892	0.103

The benefit versus cost was also assessed for the three levels of retrofit investment considered. Benefits were avoided building damage, contents loss and temporary accommodation costs. These are summarised for the three older pre-code house types in Table 2. For those homes in N2 hazard environments (which were the majority of the study region houses), retrofit resulted in a substantial risk reduction but may not be justified economically based on the cost. This is even with the construction cost economies that are being realised in the Queensland *Household Resilience Program*. For N3 or greater local hazard, retrofit may be viable for home owners if broader benefits are considered, construction economies are achieved, and incentives are provided.

Table 2: Benefit versus cost for retrofit of legacy house Type 1 to Type 3. The M3 value is the average factor for the local hazard classification and reflects the influence of terrain roughness, topography and upwind shielding on local wind speed.

Local wind hazard classification *(average M3)*	**Vintage**	**Legacy**			**Legacy**			**Legacy**		
	House type	**1 (metal roof, weatherboard)**			**2 (tile roof, BV)**			**3 (metal roof, BV)**		
	Retrofit option	**1 (DIY)**	**2**	**3**	**1 (DIY)**	**2**	**3**	**1 (DIY)**	**2**	**3**
N2 *(0.752)*	**0.752**	1.07	0.09	0.08	1.46	0.20	0.16	1.93	0.05	0.13
N3 *(0.908)*	**0.908**	2.97	0.26	0.25	4.32	0.60	0.49	5.04	0.16	0.39
N4 *(1.11)*	**1.11**	11.3	0.97	0.90	18.7	2.38	1.91	20.8	0.54	1.39
N5 *(1.33)*	**1.33**	36.5	3.08	2.86	54.4	7.09	5.69	66.7	1.68	4.43
N6 *(1.54)*	**1.54**	86.5	7.44	7.00	114.7	15.6	12.7	151.5	4.39	11.0

7. Risk

Bringing together the elements of hazard, exposure and vulnerability, the overall wind risk was assessed for residential houses at the SA1 geography defined by the Australian Bureau of Statistics (ABS). The spatial variability of this risk is presented in Figure 6 and was found to vary greatly due to the local wind hazard and nature of building stock. Topography and close coastal exposure were found to have a marked influence as was the presence of canal estates that introduce open reaches of water in suburban areas.

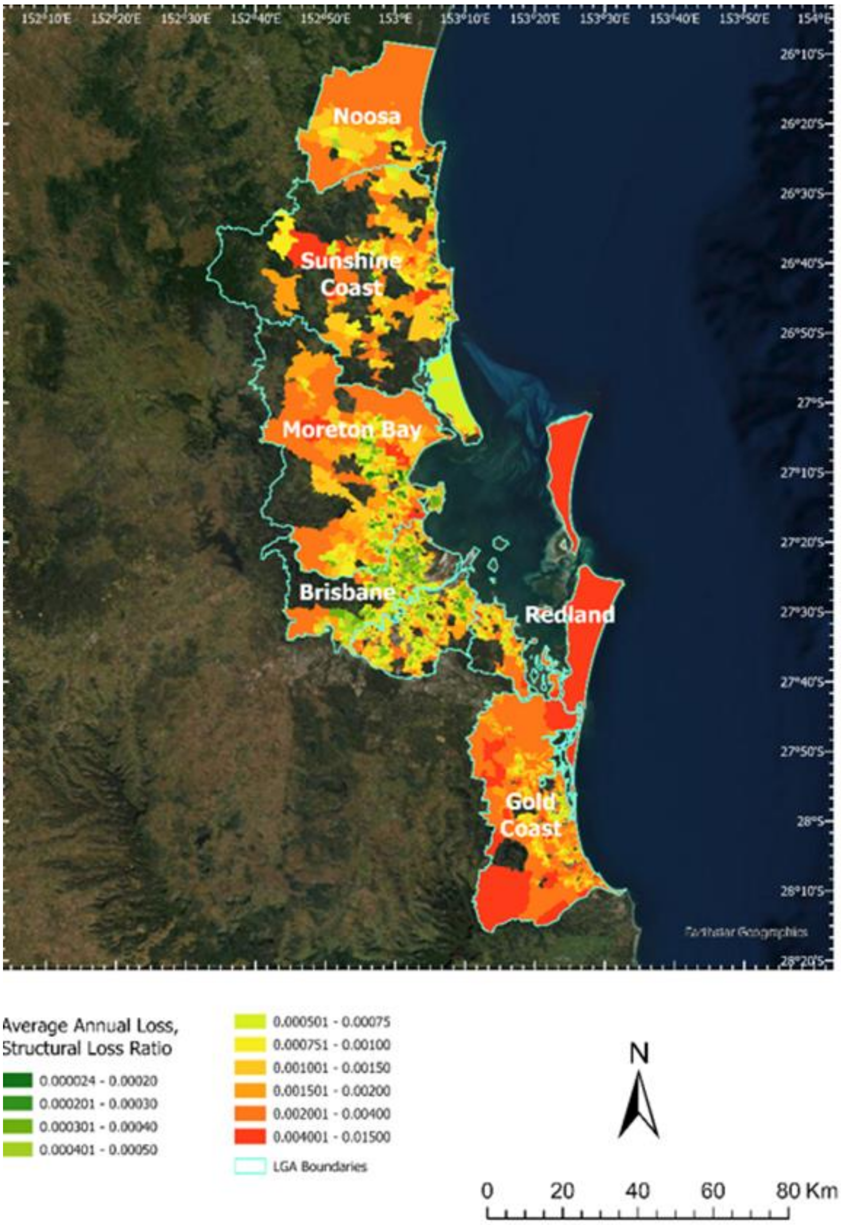

Figure 6: Wind risk to residential homes in the SWHA-SEQ study region expressed as Average Annual Loss of long term hazard exposure under present climate.

The residential wind risk for each of the six councils varied. The lowest was Brisbane City and the highest was the City of the Gold Coast that was larger by a factor of 2.3. The average risk results are summarised in Table 3 below.

Table 3: Baseline AAL for each of the six local government areas within the study regions and the % change in AAL from baseline effected by “What-if #2” retrofit scenario.

LGA name	Baseline AAL	% Change to the Median Risk
Noosa	0.00156	-9.92
Sunshine Coast	0.00140	-4.23
Moreton Bay	0.00107	-7.51
Brisbane	0.00088	-1.10
Redland	0.00162	-10.92
Gold Coast	0.00202	-4.01

8. Regional Scale Mitigation

Using the N3 local wind hazard environment as the threshold for retrofit viability, the number of homes in each LGA that could be potential candidates for retrofit incentivisation was assessed using a property level wind hazard assessment and the updated exposure information. The results are summarised for pre-code homes in Table 4. In terms of total number of houses, Brisbane City has the largest residential exposure in the study region (40.0% of homes) with the Gold Coast (20.6%) and Moreton Bay (18.1%) the next largest. For older pre-code homes in higher hazard environments as a proportion of the LGA, Redlands had the highest proportion (20.2%) followed by Noosa (16.6%). In total 69,000 pre-code study region homes (7.6%) and 121,600 modern homes (13.4%) were found to be in high hazard environments

Table 4: Analysis of wind hazard exposure of pre-code residential homes per Local Government Area and as a proportion of the entire study region.

Measure	Local Government					
	Noosa	Sunshine Coast	Moreton Bay	Brisbane City	Redlands	Gold Coast
Total Residential Homes	24,250	104,950	164,500	362,700	64,050	186,600
Proportion of the Study Region [%]	2.7	11.6	18.1	40.0	7.1	20.6
Percentage of LGA Pre-Code houses in N3/N4/N5	16.6	11.3	8.7	3.5	20.2	7.1
Percentage of LGA Modern houses in N3/N4/N5	23.3	23.7	15.9	5.3	13.0	20.1

Four retrofit schemes were applied to study region homes, the first two were blanket percentage applications to the housing stock, whereas the latter two were targeted to high risk properties and more vulnerable households. As an example, “What-if #2” targeted owner-occupied “legacy” buildings (pre-1980 buildings) in high wind hazard zones (N3+) and in lower resilience households. Lower resilience was defined as being located in an area having a lower two quartile Australian Disaster Resilience Index score (Parsons et al, 2020). It provided the same level of grant funding as the current Queensland *Household Resilience Program* of 75% cost share up to a maximum construction cost of

$15,000. It demonstrated that 17,400 older homes representing 85% of those eligible would be retrofitted in 4.9 years at a cost of $196m in grants. It would reduce the average wind risk across the region by 2.2% and by 11% in the LGA of Redlands. The wind risk reduction across each of the six LGAs is summarised in Table 3.

9. Summary

The following findings have been made for coastal SEQ from the SWHA-SEQ project:-

- Thunderstorms are the dominant source of wind hazard for SEQ for more likely damaging winds whereas tropical cyclones are the predominant storm type for rarer winds.
- Wind damage related risk was found to be non-uniform across the study region and was influenced by the variability in wind hazard and the nature of the residential building stock.
- Retrofit measures were found to greatly reduce the wind vulnerability of both the legacy and modern house types.
- Building level retrofit was found to be uneconomic except for high vulnerability house types in high wind environments that represent 21% of the total housing stock. Incentives for property owner action for these appears necessary.
- The retrofit programs modelled demonstrated risk reduction outcomes through targeted incentive measures that may be justified by reduced community and government costs for EM response, community clean-up, recovery funding, health care and economic disruption.

References

Arthur, W. C. (2021). A statistical–parametric model of tropical cyclones for hazard assessment. *Nat. Hazards Earth Syst. Sci.*, 21, 893-916. doi: https://doi.org/10.5194/nhess-21-893-2021, 2021

Arthur, W. C., Martin, S., Wehner, M., Edwards, M., Dunford, M., Zannat, U., . . . Puotinen, M. (2021). Severe Wind Hazard Assessment for Queensland. Technical Report One: An evaluation of current and future tropical cyclone risk. *Queensland Fire and Emergency Services*, Queensland Government. Retrieved from https://www.disaster.qld.gov.au/qermf/Documents/QFES-Severe-Wind-Hazard-Assessment-ONE.pdf

Edwards, M. R., Arthur, C., Wehner, M., Allen, N., Henderson, D., Parackal, K., Dunford, M., Mason, M., Rahman, M., Hewison, R., Ryu, H., Corby, N., and Butt, S. (2022) Severe Wind Hazard Assessment for South East Queensland: Technical Report. Record 2022/45. *Geoscience Australia*, Canberra. http://dx.doi.org/10.11636/Record.2022.045

Geoscience Australia (2020). Vulnerability and Adaptation to Wind Simulation (VAWS). Retrieved from GitHub Repository: https://github.com/GeoscienceAustralia/vaws

Ginger, J., Parackal, K., Henderson, D., Wehner, M., Ryu, H., & Edwards, M. (2021). Improving the resilience of existing housing to severe wind events - final project report. Melbourne: *Bushfire and Natural Hazards CRC*. Retrieved from https://www.bnhcrc.com.au/publications/biblio/bnh-7922

Holmes, J. D. (2002). A Re-analysis of Recorded Extreme Wind Speeds in Region A. *Australian Journal of Structural Engineering*, 4(1), 29-40. doi: https://doi.org/10.1080/13287982.2002.11464905

Parsons, M., Reeve, I., McGregor, J., Marshall, G., Stayner, R., McNeill, J., . . . Morley, P. (2020). The Australian Natural Disaster Resilience Index Volume I - State of Disaster Resilience Report. Melbourne, Australia: *Bushfire and Natural Hazards CRC*. Retrieved from https://www.bnhcrc.com.au/publications/biblio/bnh-7099

Power, L., C. Charalambou, M. Dunford, R. Hay, and K. Orr (2017). Australia Exposed: Exposure information for ensuring Australia's community safety. *Fédération International des Géomètres Working Week 2017*, Helsinki, Finland

Smith, D., Edwards, M., Parackal, K., Ginger, J., Henderson, D., Ryu, H., Wehner, M. (2020) Modelling vulnerability of Australian housing to severe wind events: past and present, *Australian Journal of Structural Engineering*, 21:3, 175-192, DOI: 10.1080/13287982.2020.1744900

Standards Australia. (2021b). AS 4055:2021 - Wind loads for housing. Sydney: *SAI Global*. Retrieved from https://store.standards.org.au/product/as-4055-2012