QUEENSLAND 2024

STATE EARTHQUAKE RISK ASSESSMENT

Queensland Government

Foreword

Queenslanders are well versed on the impacts of disaster events, particularly to our communities, the environment and the economy. Some disasters are becoming increasingly complex and extreme, exacerbated by continued population growth and our globally interlinked economies.

Although Queensland has not experienced a damaging earthquake in recent times, it is important to acknowledge that they are possible and will happen in the future. Earthquakes remain a rare yet constant risk to all communities across Queensland.

This assessment is an update to the 2019 Queensland State Earthquake Risk Assessment, updating our understanding of earthquake hazard across Queensland.

Recognising and understanding disaster risk to our communities is the first step towards fostering resilience. This aligns with the global emphasis on prioritising the understanding of disaster risk, as outlined in the Sendai Framework for Disaster Risk Reduction 2015-2030. By adopting this approach, we can effectively work towards building resilience and mitigating the impacts of disasters.

Queensland is susceptible to various natural hazards that can have severe repercussions for our communities - in the past decade we have witnessed many unprecedented natural disasters. These incidents serve as a strong reminder of the importance of effectively communicating appropriate risk information across all three tiers of the Queensland Disaster Management Arrangements (QDMA): local, district, and state. By doing so, we can enhance preparedness and ensure the safety of our communities.

Nikki Boyd MP

Minister for Fire and Disaster Recovery and Minister for Corrective Services

Steve Smith AFSM

Commissioner, Queensland Fire and Emergency Services

At the local level, it is essential to establish consistent risk information across all tiers of QDMA. This effective communication enables communities, government entities, emergency services, and all emergency management partners to make informed decisions.

As the Minister for Fire and Disaster Recovery and the Commissioner of Queensland Fire and Emergency Services (QFES), we greatly appreciate their unwavering commitment to building safer and more resilient communities. We extend our special thanks to Geoscience Australia and The University of Queensland for their partnership with QFES on this initiative. We also acknowledge the ongoing cooperation of local governments, whose collaboration has been instrumental in our collective efforts. Together, we can continue to work towards a safer and more resilient Queensland.

We strongly urge all Queenslanders who may be impacted by disaster risk to consider the information and strategies provided in this invaluable assessment and use it to inform management of risks applicable to their interests and responsibilities.

Table of Contents

Summary

As reported in the State Disaster Risk Report 2023, the risks associated with earthquake activity remain Queensland's ninth natural hazard risk priority.[1]

The area which includes Gladstone in the north, extending south to incorporate the Greater Brisbane area and Ipswich, and west to include areas bordering the Great Dividing Range, continues to be assessed as the area of highest risk from significant earthquake occurrence and impact in Queensland.

As with the 2019 State Earthquake Risk Assessment, this takes into consideration several factors which include:

- Density of population in this area. The population of Local Government Areas (LGAs) within this area accounts for close to two-thirds of Queensland's total population and the highest average annual growth rate since 2022.[2]
- The cross dependency of critical infrastructure within this area. A significant proportion of the State's transport and logistical network, power generation and transmission capability operate within this area.
- The Queensland Energy and Jobs Plan. Part of the Queensland Government's $11 billion investment in renewable energy will go towards the construction of a new pumped hydrogen plant near Gympie, renewable energy training centres in Brisbane and Beenleigh, and a potential export-scale hydrogen facility at Gladstone Port. These projects will generate over 5,000 job opportunities for regional Queenslanders.[3]
- Economic activity. The Gross Regional Product (GRP) of LGAs within this zone accounts for approximately 60% of Queensland's total GRP.[4]
- The historical record of earthquake activity and a higher level of seismic hazard as defined in the National Seismic Hazard Assessment.[5]

As such, this area is assessed as Queensland's highest priority area for significant earthquake risk.

The risk in other areas of Queensland cannot be discounted. The economic and industrial activity in the areas of Mackay to Townsville, such as the construction of the world's largest pumped hydrogen plant in Mackay and the manufacturing hubs for renewable energy in Townsville, are assessed as the second priority area for significant earthquake risk. This area also has a historical record of earthquake activity, and regional towns and cities have a population of older buildings vulnerable to earthquakes. These buildings have often high heritage value with damage translating to an economic risk for those communities.

As this 2024 State Earthquake Risk Assessment shows, there is a continuing need for research into earthquake hazard and risk in Queensland given the gaps in our knowledge and the associated uncertainty. The recent location revision of a significant earthquake in 1918 in the South-East Queensland region for example gives us pause to consider the implications for a recurrence of such a significant earthquake.[6]

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

Key agencies:

- Queensland Fire and Emergency Services
- The University of Queensland
- Geoscience Australia.

Introduction

Purpose and intended audience

Earthquakes strike without warning. We cannot predict where and when an earthquake will occur, but we can understand the hazard and risk to inform effective disaster risk management and be better prepared for events. While widespread destruction due to 'great' earthquakes (as observed in plate boundary regions such as New Zealand) is highly unlikely within Queensland, the consequences of even moderate events can be devastating and have significant and prolonged impacts on the community.

Queensland is not immune to earthquakes with hundreds recorded annually, however, the general level of awareness of earthquakes is very low, presenting risks to community safety.

It is this context that sets the stage for the 2024 State Earthquake Risk Assessment (SERA) and the companion Tsunami Guide for Queensland (TGQ). These are intended as overarching assessments of earthquake and tsunami risk, for use by all levels of Queensland's Disaster Management Arrangements (QDMA) to inform the development of risk-based disaster management and business continuity plans. Both of these reports are an update to previous iterations released in 2019, utilising new data and information which has become available since the release.

The SERA assessed risk in line with the Queensland Emergency Risk Management Framework (QERMF), providing a comprehensive overview of earthquake risk in Queensland. The QERMF is the Queensland Disaster Management Committee's endorsed approach for disaster and emergency risk management, providing a method for identifying, assessing and communicating risk across all levels of Queensland's disaster management arrangements. It is intended for use by entities working across Queensland's disaster management arrangements and is designed to provide advice and guidance on prioritising and treating risk. It is intended that the SERA be used by disaster managers at the local, district and state level to inform the development and implementation of disaster risk assessments.

As with the 2019 State Earthquake Risk Assessment, QFES has collaborated with Geoscience Australia and The University of Queensland for this 2024 update. Overall, the assessment seeks to complement and build upon existing local and district level earthquake risk assessments by providing updated and validated information relating to the changes in understanding of Queensland's earthquake potential.

When undertaking a disaster risk assessment, it is recommended to apply a scenario-based approach, to understand how an earthquake would impact the area of concern. The SERA is a state level assessment and so the risks and impacts discussed are general and not specific to any location in Queensland. The Geoscience Australia Earthquake Scenario Selector Tool (EQ SST) provides a number of plausible earthquake scenarios across Australia, with 22 individual scenarios available for Queensland.[7] Local, district and state disaster managers can use the SERA to understand these general risks and apply them to a specific area of concern through scenario analysis.

General Context

What is an earthquake?

Earthquakes are vibrations within the earth caused by rocks breaking under stress. The underground surface along which the rock breaks and moves is called a fault plane. The hypocentre of an earthquake is the point where it originated within the earth inclusive of depth. The earthquake epicentre is the point on the earth's surface directly above the hypocentre (refer Figure 1).

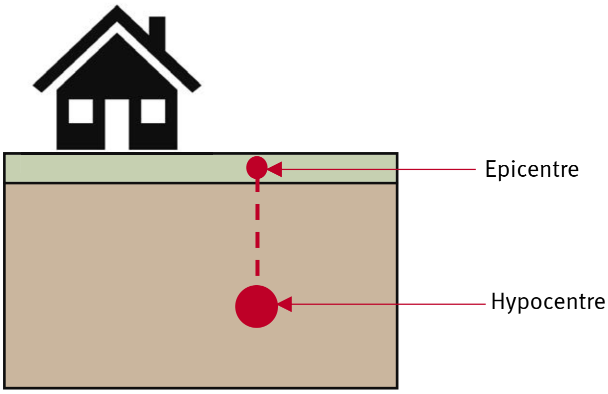


Figure 1: Illustration of the earthquake epicentre and hypocentre

The amplitude of the shaking caused by an earthquake depends on many factors, such as the magnitude, distance from the epicentre, depth of hypocentre, topography, and the local ground conditions.

The size or magnitude of an earthquake is determined by measuring the amplitude of the seismic waves recorded on one or more seismographs, and the distance of the seismographs from the earthquake. These observations are put into a formula which converts them to a magnitude, which is a measure of the energy released by the earthquake. For every unit increase in magnitude, there is a thirty two-fold increase in the energy released. For instance, a magnitude 6.0 earthquake releases 32 times more energy than a magnitude 5.0 earthquake, while a magnitude 7.0 earthquake releases approximately 1024 times (32 x 32) more energy than a magnitude 5.0, as shown in Figure 2.

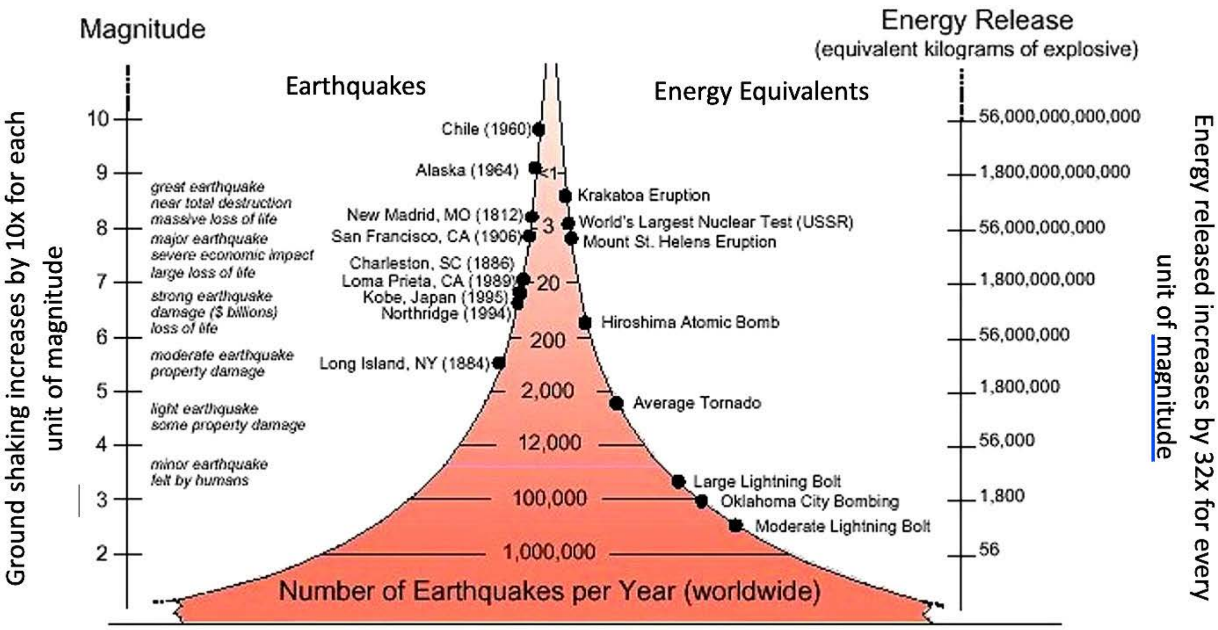


Figure 2: Illustration of earthquake magnitude. Source: United States Geological Survey (USGS)

Earthquake magnitude was traditionally measured on the Richter scale, however modern monitoring and alerting centres worldwide are now calculating magnitudes in terms of moment magnitude (Mw), where moment (energy) release is proportional to the fault area multiplied by the average displacement on the fault. This measure is used globally as it is more uniformly applicable than the Richter scale.

The effects of an earthquake are rated using the qualitative Modified Mercalli (MM) intensity scale, which ranges from I (imperceptible) up to X (destruction of most masonry structures). The intensity felt at a location depends on many factors such as distance from the hypocentre, nature of the local strata overlying bedrock, local topography, physical damage and an observer's level of alertness and activity at the time of an earthquake. The descriptions of the MM intensity scale can be seen in Table 1.

Table 1: The Modified Mercalli Intensity (MMI) scale. Source: Geoscience Australia

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight
VII	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Liquefaction or other permanent ground deformation (e.g. surface rupturing, lateral spreading the movement of soil on gently to steeply sloping saturated soil deposits, occurring often on river banks and hills) may occur in large earthquakes, usually magnitude 6.0 or greater. This shaking causes the wet sediment to lose its strength and stiffness and begin to flow. Liquefaction may cause buildings to topple, and the sediment may erupt at the surface from craters and fountains. Earthquakes as small as moment magnitude of 4.5 can trigger liquefaction in extremely susceptible soil deposits, however soil profiles which are suitable for building structures are not likely to experience liquefaction until a moment magnitude of 5.[8]

Large undersea earthquakes that cause permanent displacement on the ocean floor can cause a tsunami, or a series of waves, which can cross an ocean and cause extensive damage to coastal regions. Earthquakes can also trigger underwater landslides that in turn can result in more localised tsunami.

Earthquakes in Australia

Although the Australian continent is located entirely within the Indo-Australian tectonic plate, it is not devoid of tectonic earthquake activity, which typically occurs where tectonic plates meet. Earthquakes in Australia are usually caused by movements along faults as a result of compression in the earth's crust.

The Australian continent is generally in a state of compressive stress, arising largely due to collision of the Indo-Australian tectonic plate with its neighbouring Pacific plate to the north and east of the country (refer Figure 3).[9]

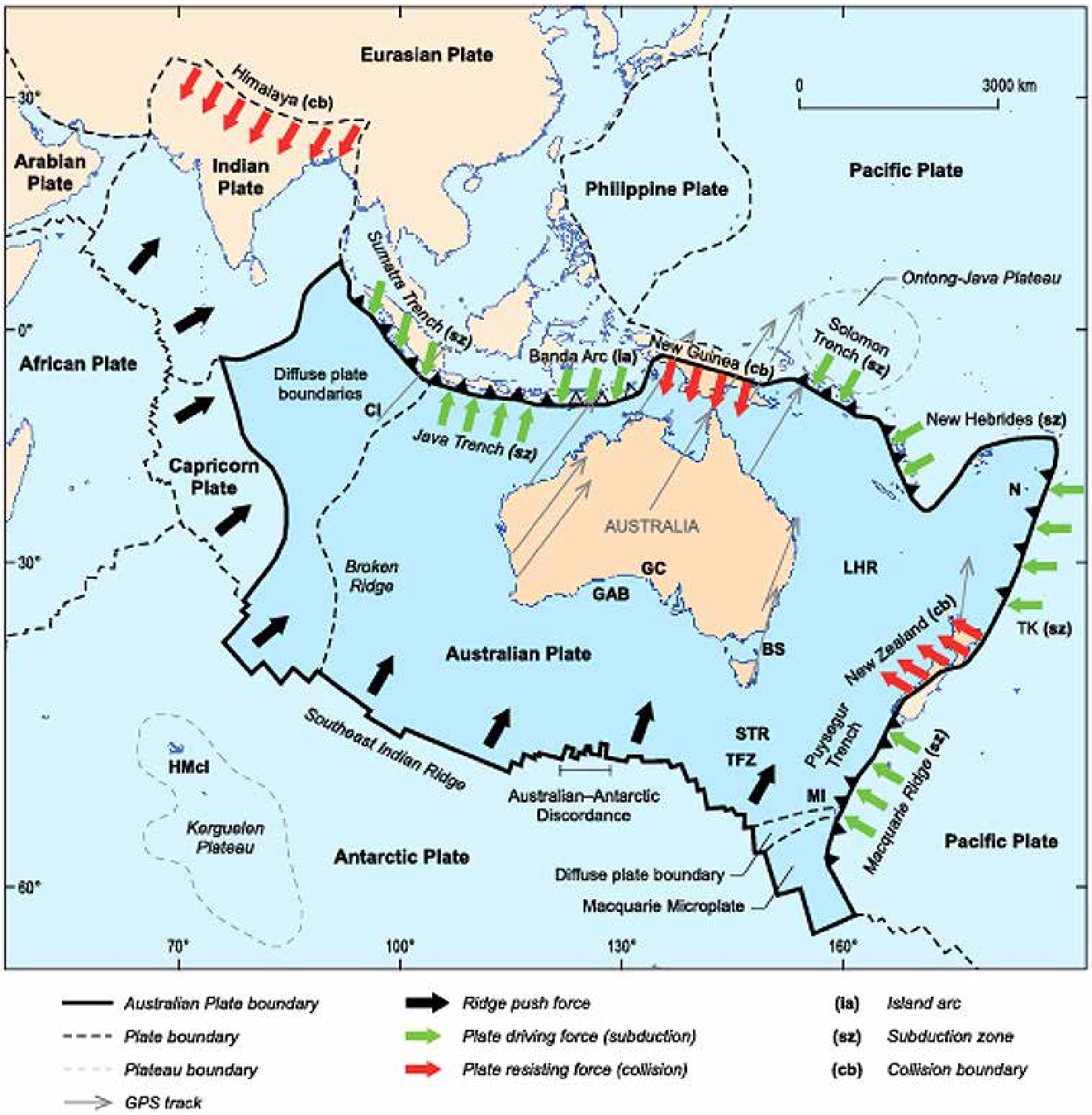


Figure 3: Map of the crustal plates and their key boundaries surrounding the Australian Plate. Red arrows are the plate motion vectors and velocity. GPS measurements show that Australia is moving to the north-northeast at a rate of around 7cm per year. Source: Geoscience Australia

BS- Bass Strait; CI- Cook Islands; GAB- Great Australian Bight; GC- Gawlor Craton; LHR- Lord Howe Rise; HMcI- Heard and McDonald Islands; MI- Macquarie Island; STR- South Tasman Rise; TFZ- Tasman Fault Zone

Analysis by GA through the 2023 National Seismic Hazard Assessment (NSHA23) indicates that across Australia, an earthquake of magnitude 6.0 or greater can be expected every 10 to 15 years on average. Along the eastern seaboard of Australia, a magnitude 6.0 earthquake may be expected to occur approximately once every 200 years. Approximately two earthquakes of magnitude 5 or greater occur within the Australian continent each year.[10] Since European settlement, more than 20 earthquakes have caused damage to property or exceeded magnitude 6.0 in Australia.[11]

Earthquakes with magnitudes of less than 3.5 seldom cause damage, and the smallest magnitude earthquake known to have caused fatalities in Australia is the magnitude 5.4 Newcastle earthquake in 1989.[12] The costs from this event were significant at the time (at $862 million) and recent analysis by the Insurance Council of Australia shows that this event is the third most costly catastrophe in Australia (at $6.54 billion; 2022 valuation), behind Cyclone Tracy in 1972 (at $7.4 billion) and the 1999 Sydney hailstorm (at $8.85 billion).[12] Smaller magnitude earthquakes can cause damage with magnitude 4.0 earthquakes occasionally toppling chimneys or other damage which could potentially cause injuries or fatalities. For the very shallow earthquakes common in many parts of Australia, with a hypocentre depth of less than 10 kilometres, people who are near the epicentre and on average density ground will usually experience higher MM intensities (illustrated in Table 1).

Geological conditions also influence the maximum MM intensity experienced. The Australian Seismic Site Conditions Map (ASSCM) (Figure 4) provides information on different geological contexts which may influence the MM intensity at different locations.[13] The site classes represent different geological materials, ranging from Class B representing hard rock through to Class E representing mud and intertidal areas. Areas consisting of sedimentary deposits (softer – generally Class D, DE, E) will experience one to two units MM intensity higher on average. Particularly alluvial sedimentary deposits, often found in old riverbeds and floodplains, may cause infrastructure to collapse and has a higher likelihood of liquefaction. In conjunction with topography, low lying valleys or basins with sedimentary geology may experience liquefication and higher MM intensity, as well as certain hilltops and ridges.[13]

Australian Seismic Site Conditions Map

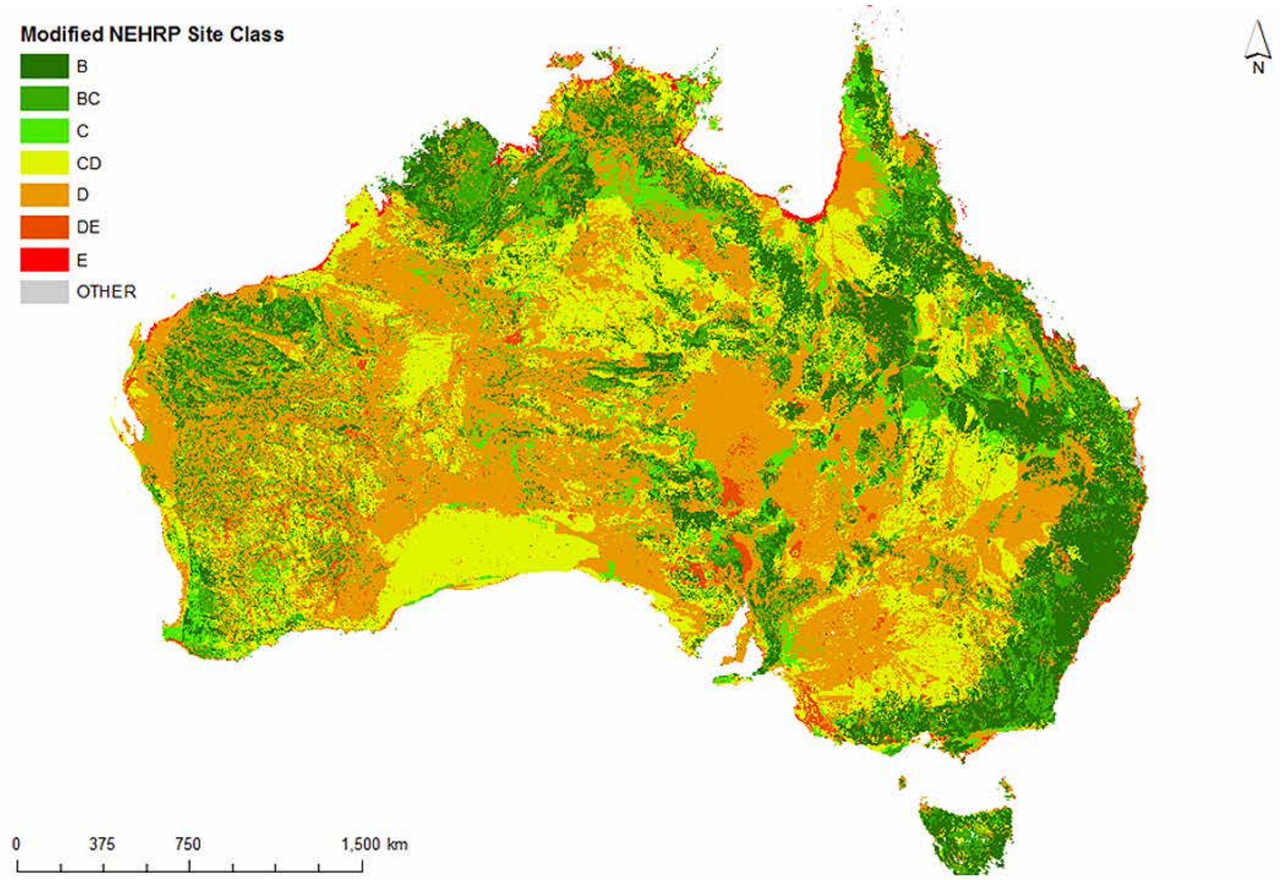


Figure 4: The Australian Seismic Site Conditions Map (with weathering index applied). The site classes are used to characterise their potential site response for earthquake hazard purposes and were originally defined by the United States National Earthquake Hazard Reduction Program (NEHRP).

Earthquake monitoring

Earthquake monitoring in Australia is achieved through networks of seismometers which are managed by various entities. Geoscience Australia monitors earthquakes using the Australian National Seismograph Network (ANSN). This is a network of over 100 seismic stations across Australia, islands in the Pacific, Southern and Indian Oceans, and the Australian Antarctic Territory. Some of these stations are a part of the International Monitoring System (IMS) of the Comprehensive Nuclear-Test Ban Treaty Organisation (CTBTO) to support detection of nuclear tests, and are also used to detect Australian earthquakes. The Australian National University operates the Australian Seismometers in Schools program which consists of around 50 seismometers in schools across Australia.[14] Privately run monitoring networks exist in some states, along with a growing number of amateur in-home seismic monitoring devices which have the potential to aid in earthquake detection.[15]

The National Earthquake Alert Centre (NEAC) at Geoscience Australia uses data from the ANSN and other networks globally to alert the public and emergency managers of Australian earthquakes above magnitude 3.5, and overseas earthquakes above magnitude 6. The global networks are particularly important for detecting major subduction zone earthquakes that may be tsunamigenic. More information on the NEAC products and services are detailed in the Response section in the Risk Treatments and Controls chapter.

Earthquakes have a much longer history than that which has been recorded since European settlement. The pre-historical record includes earthquakes with magnitudes larger than seen in the historical era. Earthquake geologists have been mapping potential neotectonic features (features that show displacement in the landscape suspected to be related to large earthquakes) that have formed over the last 5-10 million years. These features are recognised through field mapping, subsurface geophysical imaging, the interrogation of digital elevation model data and palaeoseismic investigations. The Australian Neotectonics Features Database contains data and information on these features across the Australian landscape.[16]

Overall, Australia experiences a seismic activity rate:

- among the highest for similar, stable continental regions,
- comparable with eastern North America and China,
- considerably higher than northern Europe, south-western Africa and much of continental South America east of the Andes.
- lower than plate boundary regions, with return periods – or frequencies – of the largest magnitude earthquakes estimated to be in the thousands of years. [17, 18]

The Queensland Context

Earthquakes pose a much lower threat to Australian communities than many other populated regions of the world. The relative youth of our building stock, combined with current building codes and standards, greatly reduces the likelihood of widespread destruction, however localised earthquake damage may still be severe or fatal within an affected community, particularly in older buildings.

Written reports of moderate intensity earthquakes have been published in Queensland since the first decades of European settlement. The first-known such publication refers to an earthquake occurring on the Cape York Peninsula in 1866. Further anecdotal evidence of Queensland earthquakes also exists in the oral histories of Indigenous inhabitants, demonstrating that seismic events of significance have long been recognised in the State.[19]

Figure 5 indicates the locations of all known earthquakes within the State from 1866 to 2023. The largest recorded Queensland earthquake occurred in 1918 with an estimated magnitude of 6.0 and a felt area exceeding three million square kilometres.[20] The epicentre of this event has recently been reevaluated, originally believed to have been located offshore of Gladstone, recent research suggests it originated inland near Camboon, southwest of Gladstone.[6] Recurrence of this earthquake has the potential to cause significant damage and economic consequences.

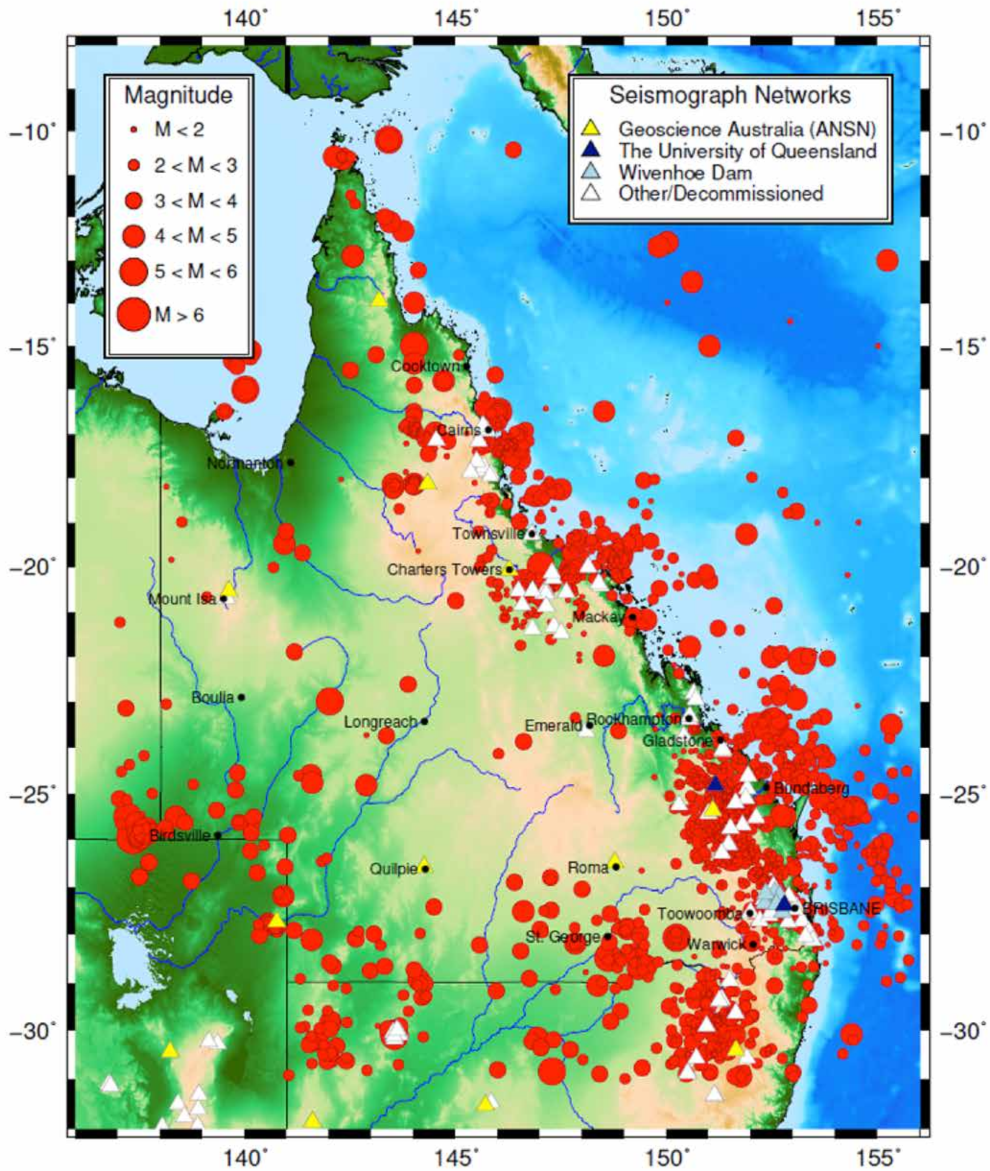


Figure 5: Record of earthquake occurrence within Queensland since 1866. The map highlights a bias in recording associated with the location of settlement activity and the placement of seismographs across Queensland. Thus, it is likely that the map does not truly reflect the record of Queensland's earthquake history, especially in the central and west regions of Queensland. Source: Dr Dion Weatherley, The University of Queensland

Structural damage to buildings and some infrastructure is inevitable for such an event, requiring inspection and potentially repair prior to the re-establishment of normal business. Infrastructure such as refineries, ports, and power and transport networks may experience disruptions ranging from a few days to weeks depending on the severity of damage. Given the significant contribution of Gladstone to the Queensland economy, the indirect losses from such an interruption may far outweigh the direct insured losses incurred.

The region surrounding Gayndah in Central Queensland is of particular note, having experienced damaging earthquakes over magnitude 5.5 in 1883 and 1935, with commensurate aftershocks occurring for many years after.

Central Burnett also remains one of the most active regions of the State, with the most recent notable earthquake being the 2015 Eidsvold magnitude 5.2 earthquake. Aftershocks of this event continued to be recorded some four years later.

Notable Queensland earthquakes of magnitude 5.0 or greater have occurred in the locations provided in Table 2 below.

Table 2: Locations of notable Queensland earthquakes of magnitude 5.0 or greater. Source: Geoscience Australia.

Date	Location	Magnitude	Depth
April 2020	Offshore northeast of Bowen	5.0	10km
August 2016	Offshore northeast of Bowen	5.8	7km
August 2015	Offshore east of K'Gari (formally Fraser Island)	5.3	13km
July 2015	Offshore east of K'Gari	5.4	13km
February 2015	Eidsvold, Bundaberg	5.2	13km
July 2011	Bowen, Mackay	5.3	7km
November 1978	Heron Island, Yeppoon	5.2	12km
December 1974	Offshore of Mackay	5.1	6km
June 1965	Goondiwindi	5.3	28km
September 1954	St George	5.3	10km
May 1928	Lakefield National Park	5.7	10km
May 1925	NE of Mornington Island	5.5	10km
June 1918	Offshore Gladstone*	6.0	15km

**The 1918 earthquake re-evaluation is not yet incorporated into the GA catalogue*

While infrequent, moderate to large earthquakes present risk to communities and infrastructure within Queensland; there is evidence of events of greater than magnitude 6.5 having occurred over the past 5-10 million years. Identification of large pre-historical earthquakes is incomplete across Australia, and research continues to uncover further evidence. Nationally, around 400 fault scarps thought to have hosted large earthquake events have been identified, with around 16 in Queensland. Figure 6 shows the current record of these features in Queensland, noting that more continue to be identified over time. The features are clustered around Gladstone (in the vicinity of the 1918 earthquake) and the southeast of Queensland. The southeast Queensland features were identified as recently as mid-2023 demonstrating that there is a continuing need to understand the earthquake hazard in Queensland and to determine the likelihood of a repeat large earthquake in the region.

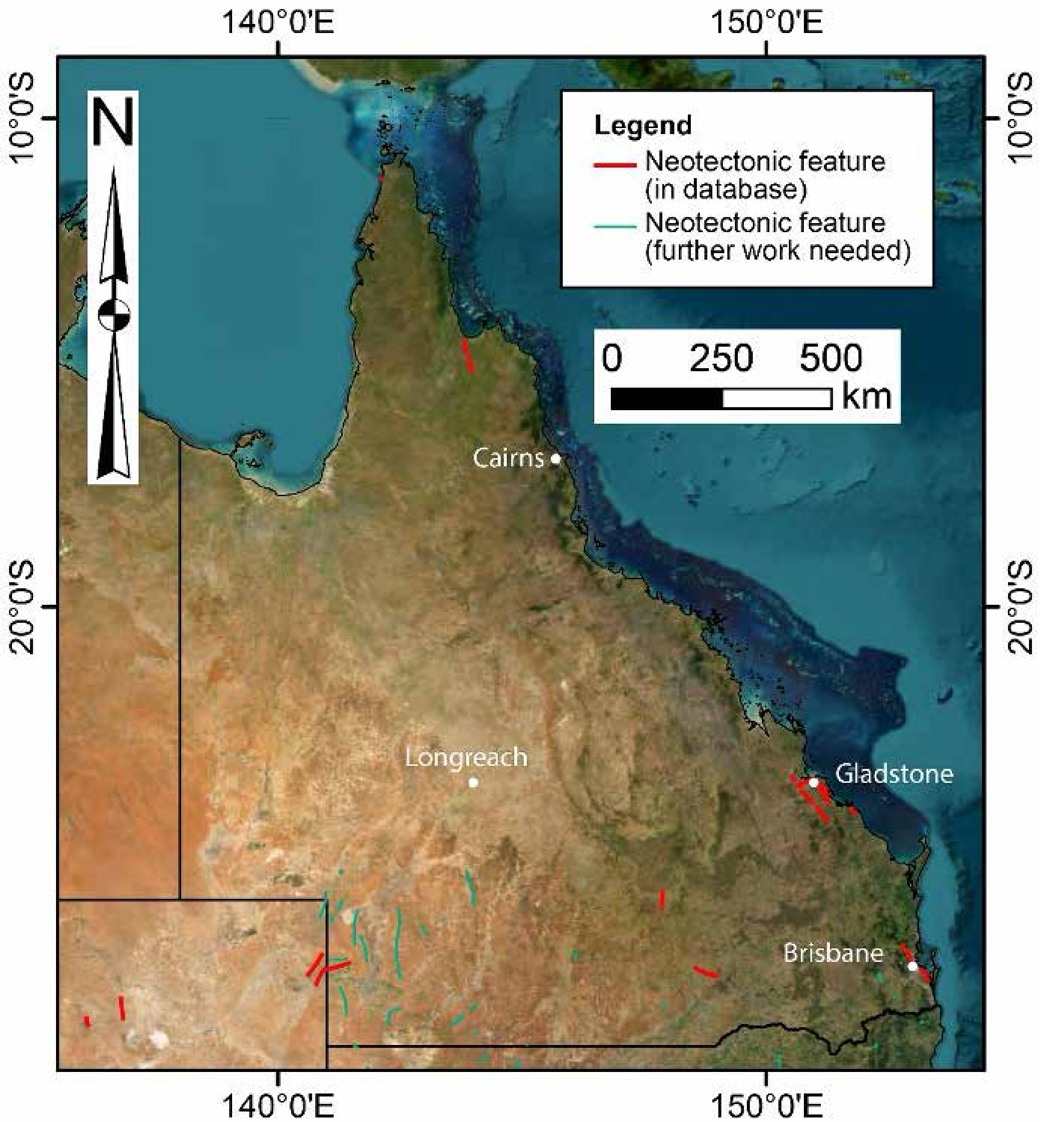


Figure 6: Neotectonic features in Queensland. Source: Australian Neotectonic Features Database.

Queensland has vast areas underlain with sedimentary basins such as flood plains and coastal areas, which may suffer ground shaking of increased intensity and duration compared with regions underlain with bedrock. Such local site amplification may increase the shaking intensity by as much as one MM intensity unit compared to adjacent regions underlain by competent rock. This local site amplification of ground shaking may result in quite localised damage within a wider community that is otherwise relatively unaffected.

It is vital that seismic hazard to Queensland communities is diligently assessed and factored into preparedness activities of governments and emergency services. This assessment is an important component of such preparedness activities, providing a factual basis for assessing the seismic hazard to which Queensland communities are exposed.

Case Study - The Great Queensland Shake 1918

On 7 June 1918 the magnitude 5.9 to 6.05 'Great Queensland Quake' was reported by newspapers at the time to have caused severe damage to the settlements of Bundaberg, Rockhampton and Gladstone. The quakes were felt as far north as Mackay, as far west as Charleville and as far south as Grafton in New South Wales. This is shown by the isoseismal map in Figure 7. The overall impacts from this event have remained unknown, as little information was recorded at the time. Originally, the earthquake was believed to have occurred offshore near Lady Elliot Island (northeast of Bundaberg), however new research has re-evaluated this event suggesting that it instead originated inland at Camboon, southwest of Gladstone.[6]

This earthquake exhibited a greater magnitude than the 1989 Newcastle earthquakes and highlights Queensland's vulnerability to earthquakes. If a similar event were to occur today, it would likely have devastating consequences for the local community and significant economic repercussions across the state.

Other significant earthquakes in Queensland's historical record include a magnitude 5.7 earthquake that struck Ravenswood, located 80 kilometres south of Townsville on 18 December 1913, and a magnitude 5.9 earthquake that damaged the settlement of Gayndah on 28 August 1883.

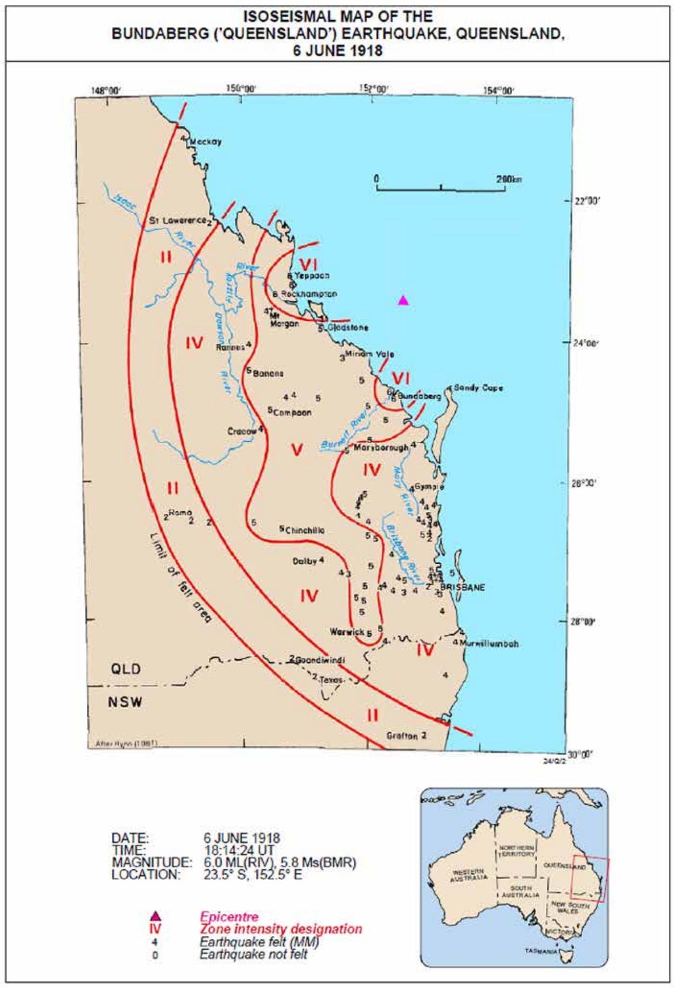


Figure 7: Isoseismal map of the 'Great Queensland Quake of 1918' showing the extent to which the occurrence of the earthquake was felt across Queensland and New South Wales. Note the epicentre of the earthquake occurred a significant distance offshore and yet high levels of associated seismic shaking were felt over a broad area of Queensland. Source: Everingham, McEwin and Denham (1982). Atlas of isoseismal maps of Australian earthquakes, Bureau of Mineral Resources, Geology and Geophysics Bulletin 214

EARTHQUAKE SHOCKS.

TREMORS IN QUEENSLAND.

LARGE AREA AFFECTED.

BRISBANE, Friday. — A great part of Queensland, at about a quarter past 4 o'clock this morning, experienced distinct earth tremors. The official reports show that the tremors extended from the Tambourine Mountains in the south, to St. Lawrence in the north, and to Roma in the west. The duration of the shock in Brisbane and suburbs is variously reported to have been from two to ten seconds. In other places, however, the trembling lasted as long as five minutes.

Houses were shaken and crockery rattled. Many residents left their houses in alarm in the Darling Downs and Burnett districts, and Central Queensland felt the shock pretty severely. In some places the buildings shook violently, and glassware was thrown off the tables. No serious damage has been reported. Three shocks were experienced at Rockhampton, and several in other places.

Figure 8: Newspaper extract from 1918 earthquake event detailing the impacts from Gayndah earthquake of 1883.

Hazard

The National Seismic Hazard Assessment (NSHA) defines variations in the level of earthquake ground shaking hazard across Australia. Having access to this data allows higher hazard areas to be identified so mitigation strategies can be developed for at-risk communities, making them more resilient to seismic events. The NSHA is updated regularly – most recently in 2023 - reflecting new data, information and scientific methods, and to align with the update cycle of the earthquake loading standard of the National Construction Code. The NSHA is calculated using the OpenQuake software which had been developed through a global collaborative effort through the Global Earthquake Model (GEM) Foundation. The OpenQuake software is used for national seismic hazard assessments in New Zealand, Canada and the United States for example, as well GEM's global seismic hazard assessment.[21]

Queensland has overall, the lowest forecast earthquake hazard in Australia (Figure 9). This is due to the difference in the crustal regime in Queensland in comparison to other areas in Australia, such as Western Australia. The highest hazard areas in Queensland are in the Far North given the higher ground shaking that is associated with active-plate boundary events in the Banda Sea and New Guinea region. The other higher hazard areas are in the region south from Gladstone towards the NSW border. As noted earlier, there is relatively higher seismicity in this area in comparison to other parts of Queensland.

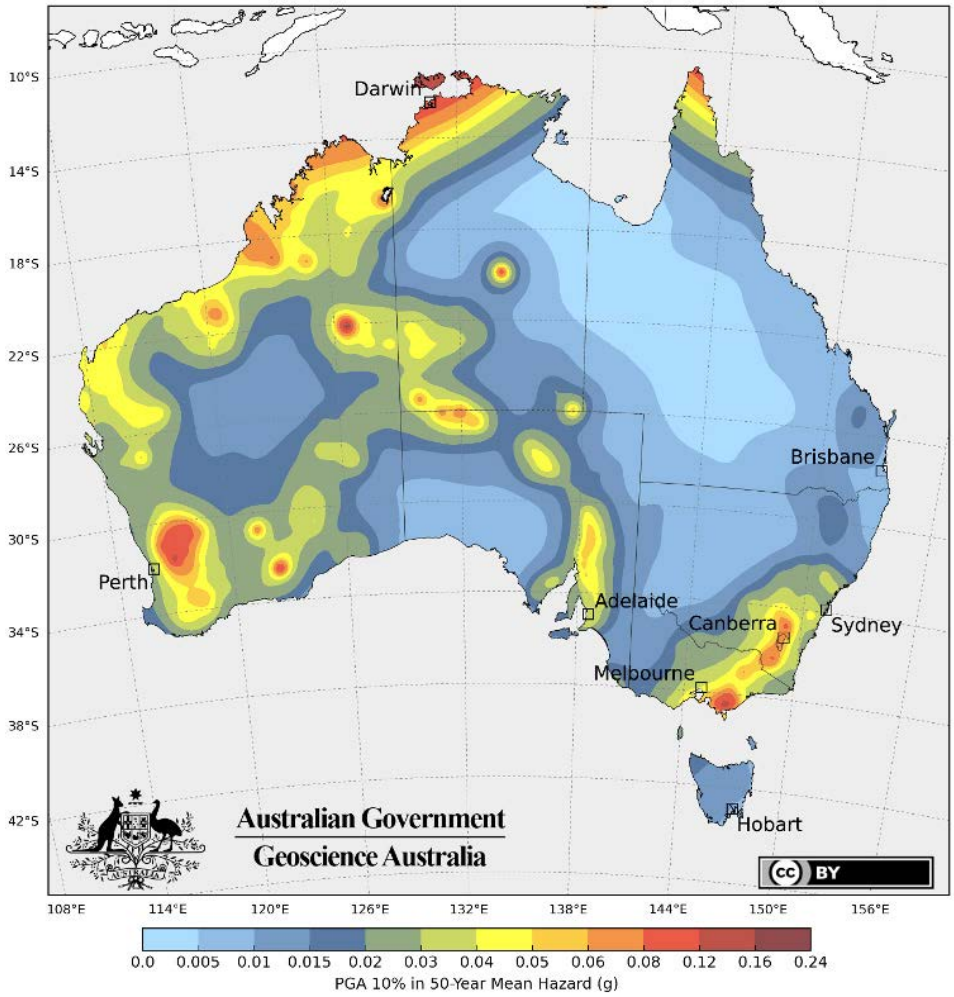


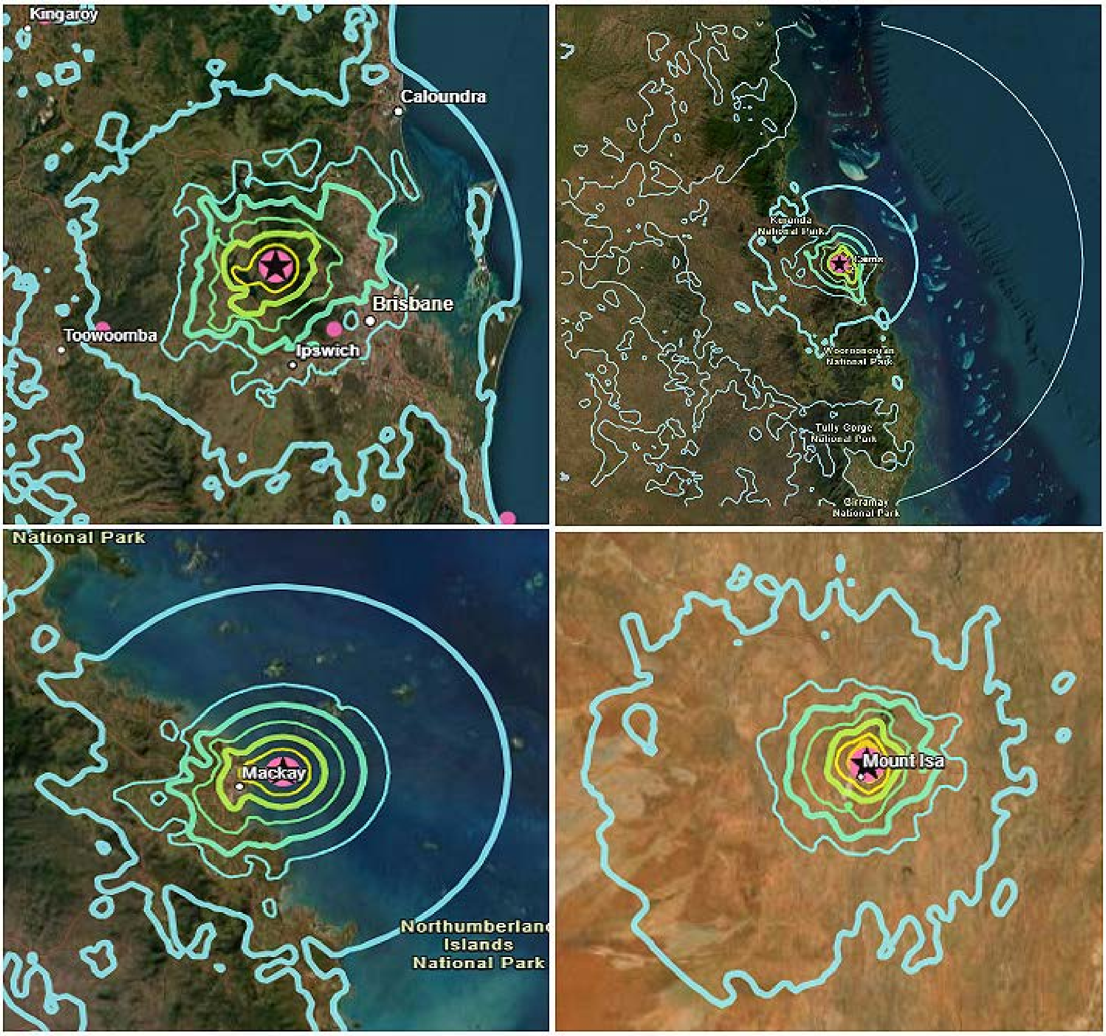
Figure 9: NSHA23 hazard map indicating the mean Peak Ground Acceleration (PGA) (expressed as a proportion of the acceleration due to gravity, g) for 10% probability of exceedance in 50-years on AS1170.4 Site Class Be (equivalent to V530 = 760m/s). Source: Allen, Griffin, Clark, Cummins, Ghasemi and Ebrahimi (2023).

Seismic hazard assessments such as this are necessary for building construction and major infrastructure design and construction. For emergency managers, hazard is more typically understood through scenarios which then support disaster risk management activities. Geoscience Australia has developed a suite of credible scenarios which can be used by emergency managers for these purposes.[22] Figure 10 illustrates some examples across Queensland. The scenarios are available through the GA Earthquake Scenario Selection Tool (EQ SST). Table 3 below describes the average return period (a smaller return period correlates with a higher probability), maximum intensity and magnitude for Scenario 1 (worst-case) and 2 (most likely) for each of the 22 Queensland locations available. The average return periods for these events are based on an area of 100 x 100 km (i.e. 10,000km2). Earthquakes of this magnitude could occur anywhere within this area with equal probability.

Table 3: Earthquake scenarios from the GA EQ SST for 22 Queensland locations. The scenarios are based on the NSHA18. There are minor changes to these scenarios for the NSHA23, which models a slightly higher overall hazard. QFES advises that these scenarios remain credible for disaster risk management purposes.

Location	Scenario 1			Scenario 2		
	Average return period (years)	Maximum MMI	Magnitude (Mw)	Average return period (years)	Maximum MMI	Magnitude (Mw)
Cairns	3,900	6.66	4.9	33,000	7.46	5.7
Townsville	5,800	6.71	4.9	31,000	7.38	5.5
Charters Towers	6,700	6.98	5.1	42,000	7.49	5.7
Bowen	7,200	6.87	5.1	45,000	7.43	5.7
Mackay	6,800	6.29	5.1	49,000	7.06	5.7
Moranbah	9,500	6.95	5.1	59,000	7.49	5.7
Mt Isa	9,800	7.18	4.9	110,000	7.77	5.9
Emerald	9,500	6.98	5.1	59,000	7.49	5.7
Rockhampton	2,200	6.42	4.7	16,000	7.19	5.3
Gladstone	4,800	6.96	5.1	35,000	7.48	5.7
Bundaberg	3,200	6.99	5.1	21,000	7.49	5.7
Maryborough	14,000	7.39	5.5	60,000	8.15	6.1
Gympie	51,000	7.49	5.9	9,500	7.05	5.5
Noosa	12,000	7.25	5.5	2,400	6.49	4.9
Kingaroy	9,500	7.1	5.3	51,000	7.52	5.9
Dalby	5,900	6.98	5.1	37,000	7.49	5.7
Roma	5,100	6.71	4.9	27,000	7.39	5.5
Toowoomba	30,000	7.44	5.7	4,100	6.84	5.1
Wivenhoe	7,500	7.03	5.3	41,000	7.49	5.9
Brisbane	13,000	7.38	5.5	55,000	8.14	6.1
Warwick	1,800	6.4	4.7	11,000	7.19	5.3
Gold Coast	5,800	6.56	4.9	29,000	7.28	5.5

Local and District disaster management groups should focus earthquake risk assessments and associated exercising and planning on the scenarios available through the EQ SST. A user guide for the EQ SST is available at Appendix A, outlining how the scenarios can be used for exercises and planning. These credible scenarios are based on modern definitions of earthquake hazard. Scenarios with magnitudes greater than those available in the EQ SST – and therefore rarer - would lead to biases in risk assessments and are likely to suggest catastrophic consequences. It is worth noting that the NSHA23 does not provide probabilities for earthquakes above a magnitude 7.45 for onshore regions within Queensland, and magnitudes equivalent to Queensland's largest recorded earthquake (M5.9 – 6.05, in 1918) are assessed to have an annual probability of 1 in 100,000. Earthquakes are low probability events and the probability of occurrence of these credible scenarios is low, especially in comparison to hazards better known to Queenslanders.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.05	0.3	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.02	0.13	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 10: MMI contours for Scenario 1 for Brisbane, Cairns, Mackay, and Mount Isa (from top left to bottom right). Source: Geoscience Australia Earthquake Scenario Selector Tool (https://portal.ga.gov.au/persona/hazards).

Impacts

Assessing hazard interaction and the impact of hazard characteristics on exposed elements provides a clear understanding of vulnerabilities. This risk assessment highlights those elements susceptible to the characteristics of the hazard. At a local or district level, the EQ SST scenarios can be used to assess the vulnerability of exposed elements. This section provides a broad overview which can then be considered as required at the local and district level.

The key observations for communities across Queensland are presented below, grouped by exposed element categories. This list is not exhaustive and will not be applicable to every Local Government Area within Queensland.

Essential Utilities

Key points

- Water supply and sewerage systems are highly vulnerable to damage.
- Restoration of power and communications following disruption will depend on the level of damage, site accessibility, availability of response personnel and equipment, and identified priorities.
- Aged in-ground gas and liquid fuel lines are vulnerable to rupture.
- Fuel and water tanks without baffling are vulnerable to damage or failure.

Power

- Significant but short-term disruption to the transmission network akin to that experienced in Newcastle, NSW, to be expected in areas of severe shaking (> MMVII-VIII).[23]
- The 2012 5.1 magnitude earthquake on the 19th of June 2012 in Gippsland, Victoria provides a good example of the potential impact on the power network. This earthquake resulted in approximately 1955MW of generation loss across Victoria and South Australia. This loss was a result of five major generating units being tripped across Victoria and South Australia. Three of these units tripped because of vibration protection systems activating, one unit was manually tripped, and the change in frequency in the power network caused the final system to trip.[24, 25]
- Damage to transmission line towers (high and low voltage), porcelain components and insulators, slippage of power pole mounted and ground-based transformers, equipment support structures and damage to buildings in substations could have significant impacts on supply.
- Terminal switching and zone substations are highly likely to have damage to vulnerable components, including buildings' housing control equipment.
- Power poles may be displaced or toppled by earthquakes through ground movement, liquefaction and/or secondary landslides. The subsequent effect on other lifeline infrastructures, especially water supply, sewerage systems and telecommunications, would be significant should power be lost.
- In response to the 1989 Newcastle event, operational recovery saw high voltage supply restored to major industrial customers 1.5 hours after the incident. Restoration of supply for general distribution began within 30 minutes, with all bulk supply points energised after 2.5 hours. Subsequently, damage then had to be assessed, plant safety assured, and repairs commenced so that normal levels of reliability could be returned to the community. This phase of restoration took three weeks to repair most major circuits and many months to complete.[23]
- For an event of similar magnitude in Queensland, restoration of supply times is challenging to evaluate, with the response to the event dependent on the ability for field crews to safely access sites. Powerlink has a service level agreement (SLA) with Energy Queensland in Central and North Queensland to complete emergency and routine work on Powerlink assets. However, damage to the supply chain and transportation routes (affecting the ability to access damaged sites and other infrastructure as well as hindering opportunities to fly/drive in additional Powerlink resources to assist the response) may hamper restoration efforts.

- General availability of spare parts for repairs is also likely to be an issue in the event of significant damage to transmission assets. Transformer trips are likely to be easily rectified, however the primary equipment failures (e.g. porcelain insulator failures) would take longer to rectify.
- Should cities and towns be without electricity for an extended period of time, this could have a severe impact on other infrastructure such as roads and transport hubs due to their interlinked reliance on electricity.
- Many factors influence how wind turbines respond to seismic events. Whilst wind turbines are generally erected in regions where earthquakes are rare or weak, they are constructed to industry standards to withstand a certain degree of seismic activity. The vast size of these structures increases the potential of significant damage if they were to break apart or collapse from an earthquake event.[26, 27]

Communications

- Communications Systems failure during earthquakes can occur through three main causes:
  - Destruction of key components
  - Damage to critical supporting infrastructure
  - Congestion.
- The interdependency of communications networks and other key community infrastructure (including government services and governance infrastructure) on power may lead to protracted disruption issues.
- Prolonged power outages will lead to the inability to charge mobile communication devices which may compound communication issues. The 2011 Tohoku Earthquake and Tsunami is a prime example of this. Immediately after the tsunami, 8,000 mobile base stations were rendered inoperable. However, within 24 hours, this number near doubled as prolonged power outages caused backup power systems to deplete.[28]
- Vulnerability of telecommunication towers is relatively low in terms of direct impact and damage. The damage, however, can be significant in the event of secondary hazards such as liquefaction or landslides.[29]
- Performance of the network is likely to suffer due to extreme congestion (volume of people making calls or trying to access the network) for some hours after the event.[29]
- Battery redundancy may also present a significant problem if loss of power is sustained. As an example, post the 2011 Christchurch earthquake, battery redundancy designed to last up to 24 hours ran down within six hours. Further, access to the network may decline because of failure in battery redundancy.
- Network performance will improve to usable, and then to near-normal levels if generators and cell towers on wheels (CoWs) are deployed. Generator re-fuelling may present major logistical challenges due to road conditions and availability of generators and fuel. Diesel is likely to be quarantined for generator and emergency services vehicle use.
- Cordless voice over internet protocol (VoIP) phones will cease to work in the event of power outages.
- Microwave dishes and other point to point communications infrastructure are likely to suffer misalignment due to intense ground shaking.
- Emergency services and local government Ultra High Frequency (UHF) and Very High Frequency (VHF) radio infrastructure generally have high levels of resilience across all hazards inclusive of earthquakes. Where the Government Wireless Network (GWN) is present, loss of power may affect the network. Any disruption of emergency services communication towers would affect the ability for these services to deliver a coordinated response.
- In-ground cables, including optical fibre cables (such as that of the National Broadband Network) and electricity cables, are susceptible to damage by earth movements experienced in earthquakes and landslides, especially through lateral shear. Any ground movement that exceeds design specifications is likely to require assessment of the cable and potential replacement of cable networks.
- Loss of power and communications to electronic funds transfer at point of sale (EFTPOS) terminals would affect the community's ability to access basic goods and services.
- Disaster recovery may be impacted as loss of communications restricts the ability to distribute recovery goods and personnel.[28]

- Disruption and restoration timelines will depend on a variety of factors including:
    - extent of devastation within the affected area
    - access to and from damaged infrastructure
    - availability of requisite components to repair damaged infrastructure
    - capability and capacity of critical infrastructure owners and operators to respond to the event
    - prioritisation of reconnection, with government and industry infrastructure likely to be prioritised over community.

Water and wastewater

- The most significant exposure of infrastructure to earthquake damage is the in-ground infrastructure of water supply and sewerage, particularly where pipes are old and brittle.
- Water supply and sewer systems (to a lesser degree) are vital to community wellbeing. Brittle material, especially unlined asbestos cement (AC) and cast iron, may be particularly susceptible to fracture. A significant amount of such pipe has been used in the water supply reticulation networks in all areas of Queensland. Rupture of significant segments of the pipe network could reduce the availability of potable water to the community and firefighting water to emergency services.
- Asbestos contamination within drinking water (while unlikely to be hazardous to the population through ingestion) would likely attract intense media attention, be of concern at the State level and require immediate action. [30]
- Above ground pipelines may also be affected by intense ground shaking. Vulnerability is greatest at the point of connection due to differential movement.
- Reservoirs have the potential to be impacted by landslips, subsidence or liquefaction, potentially impacting water supply.
- Pumping equipment is vulnerable due to dependence on power (where back-up generation is not available). Equipment (depending where located) could be at risk of land slips, subsidence or liquefaction. Resulting in considerable delays to the resupply of drinking water to towns.
- Widespread damage to the water reticulation network could take considerable time to resolve and disruptions to mains water supply could be expected across the medium to long term, where replacement of the pipeline is protracted.
- A key vulnerability for all utilities is in the resilience of their supervisory control and data acquisition (SCADA) computer systems. They may fail initially because of the misalignment of their numerous antennae, but such disruption could be quickly rectified if access allows.
- Some referable and tailings dam infrastructure may be vulnerable to intense ground shaking, although catastrophic collapse is highly unlikely.
- Gravity fed water supply would continue to operate only if the connecting infrastructure is not damaged.
- The vulnerability of water tanks and associated infrastructure is further discussed in the fuel infrastructure section outlined below.
- It should be noted that new dams and reservoirs can often trigger earthquakes. Due to changes in stress caused by either the weight of water, or increased groundwater pore pressure decreasing the effective strength of rock below the reservoir.[31]

Fuel

- Underground gas and oil pipelines traversing areas with seismic hazards (e.g. faults) have a moderate chance of rupture and low chance of complete breakage. The probability of rupture and breakage will depend on the precise nature of assets and the earthquake event.
- In-ground infrastructure exposed to earthquake shaking and those elements in the softer soils are more likely to be damaged than those in solid rock. Aged below ground gas and oil infrastructure such as pipelines (of non- polyethylene construction), wells and other infrastructure may be vulnerable to intense ground shaking leading to ruptures. Such ruptures may lead to disruption to services, contaminated drinking water and/or environmental damage. In some cases, buried pipelines are warped or broken by permanent ground deformation (ruptures) as seen in Figure 11 from a cluster of magnitude 6 earthquakes in Tennant Creek, Northern Territory in 1988.[32] Pipes may also be warped or broken by shaking, liquefaction, lateral spreading, or landslides related to an earthquake.

- Domestic gas supply is likely to experience medium term disruption in the worst affected areas.
- Depending on the quantity of in-ground oil and gas storages, and ignition sources such as downed powerlines, there may be a high risk of fire with the releases of oil and gas from infrastructure and pipeline ruptures.
- Large metal fuel tanks are susceptible to damage caused by the liquid inside the tank sloshing from side to side, under action from intense shaking, placing stresses on the tank walls. Damage or failure, often referred to as 'elephant's foot buckling', can occur as a result.
- Pipe connections to the tank also can suffer damage or be sheared off by differential movement.
- Hydrogen can be stored as either compressed gas, cold/cryo compressed or in liquid form. All options will be at potential risk of a tank rupture or a pipeline into/out of the tank shearing off as a result of ground movement.

Figure 11: Gas pipeline warped by ground rupture from the Tennant Creek Earthquake in the Northern Territory 1988.

Roads and Transport

Roads and Rail

Key points

- Road and rail networks are vulnerable to considerable protracted damage from earthquake and landslide which may affect response and recovery activities.
- Fixed wing aircraft movements may be disrupted due to impacts on associated on-ground infrastructure.
- Port facilities, where available, may become the priority route for access and resupply, providing these have not been damaged.

- Major road and rail networks across the State may be susceptible to shaking induced settlement and lateral spreading, resulting in considerable surface damage. Choke points such as bridges and railway crossings tend to be the most vulnerable to this lateral spreading.
- Heavy goods and logistical transport are likely to be affected in the short to medium term. Resulting in difficulty in the resupply of essential items such as perishable foodstuffs, fuel, emergency power generation, machines and personnel needed for repairs and chemicals for water treatment.
- People providing services may be cut off from those with needs (e.g. meal preparation and home care services).
- Emergency services will be impacted due to restricted access.
- Some track formations may settle while other rails may buckle laterally or fracture, as seen in 1968 for the Meckering earthquake in Western Australia (Figure 12).[33] As with roads, the most vulnerable points are level crossings, bridges (especially those built prior to publication of AS1170.4- 1993), cuttings, embankments, and overpasses.
- All tracks and rail bridges will require extensive inspections including the use of a track inspection vehicle before recommissioning.
- Sections of railways may be blocked by landslide debris or affected by embankment fill failures.
- Signalling and control equipment reliant on electricity and telecommunications may fail for the associated disruption period.
- Rail administration buildings, rail yards and depots close to port facilities or built on soft soils may experience extensive damage.
- Typically, road and rail tunnels are not highly vulnerable to rare Queensland earthquakes. Vulnerability is greater for shallow cut and cover tunnels than for bored tunnels. For shaking similar to that caused by the Newcastle earthquake, cut and cover structures in soft soil have a significant chance of damage to tunnel linings. Problems may be experienced with tunnel portals and with slope failure adjacent to tunnel approaches.
- Liquefaction of loose granular soils may also cause damage to the approaches to tunnels. For lower magnitude earthquakes (more likely but still rare), with less severe ground shaking, structural damage is unlikely though problems may still be encountered with critical mechanical ventilation systems that are poorly restrained, fire prevention systems, and back-up emergency generation where generation units demount in the shaking. Damage could also be sustained in vertical tunnel access structures such as stations for underground trains where stairways, escalators and suspended ceilings dislodge making them temporarily unusable.
- Disruption to operations may have regional or state financial and supply chain impacts.
- Many parts of the Australian transportation system are aging and not designed with current seismic risks in mind making them susceptible to failure in the event of a seismic event.[34]

- Transport infrastructure such as roads, highways and bridges could be severely impacted by liquefaction, lateral movement and/or buckling and subsidence of land, delaying the delivery of vital goods and services to affected communities. This was seen in the 1968 Meckering earthquake in Western Australia (Figure 13), where the main highway between Perth and Adelaide was impassable due to multiple scarps and cracks. Scarps protruded as high as 2.5 m due to ground on the east being thrust over the west.[35]
- Impacts on bridges depends on many structural aspects such as abutment type, number of spans, type of super and substructure, length and width of bridge, skew, number of hinges at joins and bends, column foundation types, and design year.
- Significant damage to transport hubs caused by liquefaction and subsidence of land can impact the delivery of goods to affected communities.
- Transport hubs tend to be places of mass gathering and, as such, damage to this infrastructure may result in a corresponding increase in casualty numbers.
- Transport infrastructure such as bike paths and walkways may be severely impacted by ground shaking, land subsidence and liquefaction (especially paths adjacent to waterways).
- Bridges along walkways/bikeways could buckle or become unattached from their foundations, severely restricting movement of people who cycle or walk as inspections and repairs are undertaken.

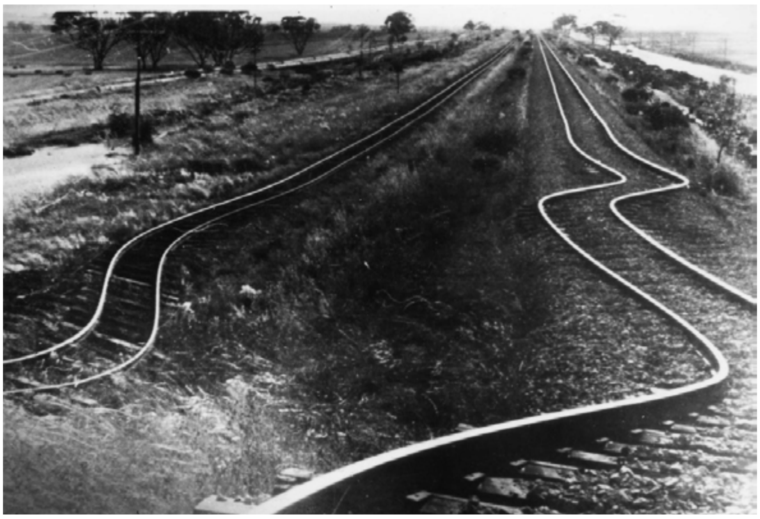


Figure 12: Rail line buckled by the shifting earth from the Meckering earthquake 1968. 1968 Meckering – Australian Earthquake Engineering Society (aees.org.au)

Figure 13: Road buckled by the shifting earth from the Meckering earthquake 1968. Source: West Australian Newspapers Limited.

Aviation transport and resupply

- Well maintained and well-constructed airfield pavement is largely resilient to most hazards but may be damaged from the most severe earthquakes as well as debris from damaged buildings. Support facilities such as terminals and fuel systems may also be damaged.
- Any surface damage to runway infrastructure or terminal buildings is likely to result in short-term disruption as these are expected to be a priority for repair to facilitate access and resupply where road and rail networks are significantly hindered.
- Significant demand and dependence on rotary wing aircraft to facilitate access/resupply in the short term is expected.
- Airports will become a priority to repair as these will become hubs for transportation aid and recovery workers.
- Several regional airports (including terminal buildings) are identified as having been built on reclaimed alluvial (soft) soils. Such areas have a higher probability of liquefaction and subsidence in intense shaking conditions. Localised liquefaction will cause runway pavement damage and 'sand boil' features.

Maritime transport and resupply

- Access to maritime infrastructure (such as industrial/ commercial ports) is likely to be affected resulting in economic disruption due to the issues previously identified.
- If port facilities are unaffected or services can be restored quickly, major resupply is expected to be facilitated via sea if disruption to the road and rail network is extensive.

Housing and community infrastructure

Key points

- **Vulnerability of poorly constructed and maintained buildings presents the most significant risk to public safety during an earthquake.**
- **Secondary (consequential) hazards such as fire, landslides, or infrastructure failure will exacerbate the risk to public safety.**
- **Buildings constructed prior to 1993 are at high risk of damage.**
- **Buildings constructed to comply with wind loading code for cyclonic areas are at least risk due to a high level of structural resilience.**

Demographics

- The exposure of people to earthquakes is directly related to the vulnerability of the building in which they are located at the time of the event. As the engineering adage states: earthquakes do not kill people, poor buildings kill people. Building vulnerability to earthquake shaking is discussed below.
- There is an underlying assumption that people know what to do in the event of an earthquake.
- Damage and loss of life associated with severe earthquakes are typically exacerbated by the impact of secondary hazards, especially fire, landslides, the loss of containment of hazardous materials and (rarely) dam failure. Fires are typically caused by ruptured gas lines and/or electrical short circuits. Where an earthquake is sufficiently severe to cause such damage, it also would have impaired the water supply system and blocked roads with fallen debris, making fires difficult to quickly contain.
- Low-socio economic areas within vulnerable areas of the State are likely to have a lower level of inherent resilience or means to affect individual recovery in the event of an earthquake.

- As earthquakes occur without warning and are inherently rare, an increase in vulnerability across all sections of the population is expected. Vulnerability will not be limited to those typically regarded as vulnerable (due to geographic location, medical or service needs, cultural background and language skills, age, or disability).
- Events such as earthquakes can have devastating physical and psychological impacts on otherwise able-bodied individuals. This can result in fatalities occurring from 'earthquake induced shock'. In the weeks after an earthquake event, increased rates of heart attacks, arrhythmia and high blood pressure have been reported. Similarly, high rates of post-traumatic stress, depression and other mental health issues have been documented in survivors. Post the 2011 Christchurch earthquake, the city's population dropped by more than 20,000 by June 2012, due to relocation to other parts of the country, and to Australia. The population returned to pre-earthquake levels six years after the earthquakes.[36, 37, 38]

Social infrastructure

- Many late 19th and early 20th Century masonry buildings exist within the central business districts of regional towns and cities (especially within historical or cultural quarters) which are highly vulnerable to intense shaking, as shown in Figure 14. Further, a considerable number of regional schools and hospitals are situated in these buildings.
- Many centres of governance and Local and State Government agencies are located within buildings built prior to 1993. Potential impacts of an earthquake on these buildings may lead to significant disruption to government and agency services across the medium to long term.
- Essential community, government and IT services are likely to be significantly disrupted across the medium to long term due to damage to buildings that house these services and/or depend on power, communications and other essential infrastructure.
- Landmarks, memorials and cemeteries important to the community at large may be significantly impacted by an earthquake of this magnitude.
- Community hubs such as churches, mosques, shopping centres and sports fields/clubs may be impacted and potentially rendered unsafe for extended periods of time.
- Aged Care and hospice facilities may require evacuation and urgent relocation while building repairs are undertaken.
- Community health may be adversely impacted as the likes of hospitals, clinics and GPs are offline as a result of sustained damage.
- As was seen in Christchurch and is discussed in the secondary impacts section, sharing of school resources may occur, putting strain on schools and childcare facilities not damaged.
- Homelessness may increase because of damage to social housing and emergency accommodation.

Building stock

- Significant variations in impact between urban and rural centres should be expected due to building age, construction methods and maintenance regimes.
- Intense ground shaking on soft soils (site class C, D to E)[13] can cause liquefaction (secondary hazard) which may result in subsidence or collapse of several buildings.
- The earthquake loading code was introduced following the events of Newcastle in 1989, therefore buildings built prior to 1993 are unlikely to have been built to account for any seismic hazard.
- The earthquake loading code applies to all buildings in Australia. Certain sole occupancy dwellings/residential buildings (Class 1) are deemed-to-satisfy for earthquake actions and require no specific earthquake design if they're designed and detailed for wind actions in accordance with certain Australian Standards, such as the Timber Framed Construction standard AS 1684. All residential, commercial, public and industrial buildings (building Classes 2 to 9) must conform to the standard enforced by the National Construction Code (NCC) 2022 Volume 1 Part B1 which refers currently to AS 1170.4-2007.
- Earthquake loads are expressed as an 'acceleration coefficient' which relates to a 10 per cent probability of exceedance in 50 years at 'rock' or 'firm' sites. This probability corresponds to an annual exceedance probability (the chance of the acceleration occurring once in a year, expressed as a percentage) of approximately 0.2 per cent, or an average recurrence interval, or ARI (the likelihood of occurrence, expressed in terms of the long-term average number of years) of approximately 500 years.

Earthquake building damage examples			
MMI V	**MMI VI**	**MMI VII**	**MMI VIII**
Portland and Broome, 24 June 2021	Boulder CBD, 20 April 2010	Greater Newcastle, 27 December 1989	Central Newcastle, 27 December 1989 and Christchurch, 22 February 2011
Items falling from shelving to the floor. Minimal to no building damage reported[40].	Collapse of vulnerable masonry and severe cracking to other masonry structures.	Severe damage to unreinforced masonry (URM) buildings, some damage to low ductility framed buildings, particularly irregular buildings.	Heavy damage to URM buildings, severe damage to irregular low ductility buildings.
			

Table 4: Damage associated with previous known events and certain MM intensity levels of shaking. Source: Geoscience Australia

Figure 14: Damage sustained in the town of Kalgoorlie-Boulder, Western Australia as a result of the magnitude 5 earthquake (20 April 2010). Source: Department of Fire and Emergency Services, Western Australia

- The NCC (2022) enforces a minimum standard which is outlined in NCC 2022 Vol 1 Part B1.2(c):
    - › 1 in 500 year event for small buildings (Class 1)
    - › 1 in 1000 year event for large buildings, such as apartments and schools (Class 2 to 9 buildings)
    - › 1 in 1500 year event for buildings with a post-disaster function.
- There is no requirement to retrofit any building that was designed and constructed prior to these standards unless new additions to the building increase its total volume by more than 50 per cent.
- Previously, the NCC stated that a building should be designed to the known seismic hazard within the area. However this was not enforced and, subsequently, there will be buildings that have only been designed to the minimum tolerable standard.[40]
- Public buildings constructed in stages require special consideration. Examples of this are schools or hospitals where the central structure was built prior to 1993 but subsequent additional structures or extensions are of modern construction.
- When buildings are constructed to or above NCC standards, it is possible for some building components to fail and cause harm. For example, air-conditioning units and solar panels mounted on the roofs of buildings may be dislodged.
- Poor maintenance of buildings and their components can also add risk. Many older buildings may not be in optimum condition due to poor or inadequate maintenance overtime. Disaster management groups would be prudent to seek structural engineering advice regarding buildings, especially older local government controlled or owned structures. Local government also may wish to advise owners of other critical and sensitive facilities (especially schools and hospitals) of the findings of this assessment.
- The age of construction of all elements of the built environment is a key contributor to their vulnerability. Residential buildings constructed before 2016, for example, will not have been explicitly designed to comply with earthquake loading standards of the NCC.
- Buildings constructed since 1982 will have been built to the appropriate wind loading code which will also provide a high degree of resilience to earthquake loads. For those north of Bundaberg, and within 50km of the coastline, there is a greater level of resilience due to the additional requirements for the cyclonic region.
- Similar age thresholds also can be applied to other elements of the built environment including water supply, power supply and sewer infrastructure. Some broad rule-of-thumb characteristics of dwelling structures can be linked to the age of construction as follows:

If built before the early 1950s (see Figure 15A for example):

- exterior and interior walls of timber and/or asbestos
- ceilings are timber or Canite (asbestos) board
- interior cupboards and fittings in solid timber
- high set on stumps two metres or more above ground level
- high pitched hip-ended metal roof
- small windows shaded by verandas or awnings
- brick walls are cavity brick construction.

If built in the 1960s or 1970s:

- greater mix of exterior wall material including brick and timber
- greater proportion of internal walls and ceilings of Masonite, Fibrolite or plasterboard
- large areas of louvers for windows
- windows shaded by small verandas or broad eaves
- increased use of particle board in interior cupboards and fittings
- floor levels above ground on piles up to 0.5 metres above ground
- high pitched metal roofs with an increase in gable ended shape
- brick walls are brick veneer construction.

If built since 1980 (see Figure 15B for example):

- increased use of brick in walls (brick veneer construction)
- interior walls of plasterboard (Gyprock)
- all interior cupboards and fittings of particle board
- large windows and glass sliding doors
- limited shading of windows by narrow eaves
- high pitched metal roofs with a small proportion of tiled roofs
- slab-on-ground construction.

Figure 15A: An example of a post-war house. Its timber frame makes it quite resilient to earthquake shaking, however the fibrolite roof could become a significant environmental hazard if it were damaged in an earthquake. Source: Adobe images

Figure 15B: An example of a contemporary house. Source: Adobe images

- The age-linked structural features described above provide an indication of the potential vulnerability of those buildings. Most dwellings in Queensland are constructed over a timber frame. Timber frame buildings behave in a ductile manner in earthquakes and can undergo large displacements because of their non-rigid construction. Solid brick or masonry walls are more susceptible to damage because of their rigid construction. Well-built timber buildings perform better than other forms in earthquakes. Poorly maintained buildings of both construction types may also be more susceptible to earthquakes.

- The shape of the building can also affect how it handles earthquake shaking. While older high-set designs are especially well suited to the state's variable climate, they are likely to be more susceptible to earthquake shaking. Most tall structures that are not engineered to withstand shaking from side to side can be damaged or toppled by the inverted pendulum effect created during an earthquake where the amplitude of the shaking is greater at the top of the structure than at its base. So-called 'six pack' unit blocks which have a 'soft story' (i.e. the garages occupy the first-floor level with no internal walls) also are very susceptible to failure under earthquake loads.
- Consideration also must be given to non-structural components of buildings and the manner in which they have been installed. These include:
  - Architectural: partitions, suspended floors, walls, ceilings, appendages (e.g. awnings, parapets and verandas), masonry, glass and storage racks
  - Electrical: emergency power systems, communications systems, light fittings and switchboards
  - Hydraulic: life safety systems, fire suppression systems (including sprinklers) and hot water heaters
  - Mechanical: smoke control systems, boilers, flues, reciprocating and rotating equipment (e.g. chillers, pumps, and fans), ducts and piping systems and their supports
  - Transportation: lifts, escalators, conveyors and hoists
  - Examples of additional items that would meet this description include shelving, items installed in ceiling voids, cranes,building maintenance units and water storage tanks as shown below in Figure 16.
- The failure of non-structural architectural and service components to resist seismic forces from earthquakes can result in severe damage to buildings and their contents, and injury or death to occupants.[41]

Figure 16: Widespread damage resulting from a ceiling failure after a Canterbury earthquake.
Source: Geoscience Australia

Emergency shelters and places of refuge

- The identification of evacuation centres, cyclone shelters and places of refuge are done as a hazard specific activity. An evacuation centre used for flooding may not be appropriate in the case of a bushfire for example.
- Due to the relatively low risk of earthquakes in Queensland, when compared to wind or water events, identification of sites for refuge after an earthquake mat not be as mature as for other hazards.
- Ensuring that suitable buildings, built since 1993, with the requisite amenities would be a key activity to be undertaken as other designated places of refuge may be impacted and unusable post event.

Human and Social

Key points

- An earthquake may lead to a mass causality event, creating significant distress for the community.
- Sole reliance on external supply of utilities (e.g. power, water, fuel and sewerage) increases vulnerability.
- Backup equipment may fail if it is damaged during the event or not adequately built and maintained.
- Psychological trauma or distress should be expected across large proportions of the population.

- All hospitals and smaller community medical facilities, except those of recent construction (<5 years ago) are of concern as age and methods of construction are varied across all Local Government Areas.
- Many older hospital buildings of reinforced concrete frame with infill masonry construction will experience damage and will require structural inspection before further use. Some buildings housing critical care facilities will be rendered unusable.
- Dependency on power and water infrastructure increases vulnerability. Hospitals are generally provisioned with <24 hours of redundant power and water generation. However, it is not known how resupply would be managed in the event of broad area impacts.
- Equally, there is concern about functionality of redundancies in the aftermath of an event. Some emergency generation will be inoperable due to damage or later fail due to a lack of fuel if resupply is hindered.
- Newcastle resulted in 13 fatalities and 162 reported injuries. In complex urban environments, this figure is likely to be much higher. Hospitals and other medical facilities may have to react to a significant influx of causalities while facing a reduction in capability and capacity through direct or indirect impacts.
- Vulnerability of those persons located within these facilities is a concern. Evacuation of vulnerable persons at short notice may lead to significant issues regarding coordination, control, and exacerbation of pre-existing conditions. Fatalities may be expected as a result.
- Earthquakes may intensify pre-existing mental health conditions at an individual level or lead to conditions such as post-traumatic stress disorder (PTSD). Of those directly affected by the events of Newcastle in 1989, 25 per cent experienced moderate to severe psychological distress as a direct result of the disaster.[42]
- Prolonged power failure may cause food spoilage increasing health risks to the community.

Economy

Key points

- Heavy industry and manufacturing sites may suffer damage, become unsafe, and/or suffer significant productivity losses.
- Disruption to transport and logistics routes will likely have knock-on impacts to regional and state economies.
- Coastal tourism hotspots are likely to be vulnerable because of their construction type and location on softer soils. Vulnerability of tourists is also of concern.

Heavy industry and manufacturing

- Wide disruption to industry due to the direct impact from an earthquake with the addition of consequential impact from the dependency on power, communications and water may lead to considerable decrease in productivity.
- Depots of hazardous materials are of a concern at the State level and facilities within individual districts across the state should be reviewed on a case-by-case basis.
- Mining and associated infrastructure (such as railways and port facilities) may experience significant impact.
- Mines operating subterranean extraction are at particular risk.
- Loss of power to industrial centres such as heavy metal plants (e.g., alumina refineries), bulk fuel and gas depots could have major repercussions in terms of operations and, consequently, regional and state economies.
- Impacts to any of these industries would result in displacement of workers (local and transient) which is likely to have a significant impact to regional and state economies.
- Some industrial and commercial port facilities are located on reclaimed alluvial soils or estuarine deposits which are susceptible to subsidence through liquefaction. Rotation of some wharf retaining structures will also occur.
- Movement in wharf front rail systems for wharf cranes and other materials-handling equipment will render them unusable. Tall structures such as container cranes are especially vulnerable to being toppled. Disruption to operations may have regional or state financial impacts.

Transport and logistics

- Disruption to logistics routes (i.e., road and rail freight network, ports, coal rail network) would likely have significant regional and state economic impacts similar to those felt during previous severe tropical cyclones.[1]

Agriculture

- The potential for damage to agricultural infrastructure, such as grain handling facilities, cotton gins and saleyards, would have repercussions on local and regional economies and associated/supporting industries.
- Intense ground shaking may lead to significant damage to irrigation channels as agricultural areas of Queensland can be bisected by many hundreds of kilometres of channels and associated infrastructure.
- Direct impact will occur to the operation of fisheries if port facilities and associated infrastructure are affected.

Tourism

- Resorts across coastal areas are likely to be located on softer soils. Further, the age and varied methods of construction of these facilities is of concern. Resort owners and operators may not have considered catastrophic event occurrence within business continuity planning.
- Concern around the vulnerability and lack of resilience of tourists, especially those from non-English speaking backgrounds.
- Negative media coverage is likely to have a significant impact on the tourism industry within the affected area over the medium to long term.

Retail

- Loss of smaller locally owned companies which may permanently close due to significant damage and repair costs.

Environment

Key points

- Earthquakes and/or landslides can have devastating effects on wildlife and their habitats.
- Release of hazardous materials from damaged containers, pipes, or industrial sites is likely to have adverse effects on environmental health.

- Large infrequent shallow earthquakes, as is mainly seen in Australia, results in large surface ruptures resulting in infrastructure damage and habitat changes.[43, 44, 45]
- Earthquakes may cause changes to the course of rivers and environmental conditions. This was observed on the Cadell Fault near Echuca Victoria. Earthquakes of magnitude 7 or greater over the last 10,000 years changed the course of the Murray River forming the Barmah Forest, Australia's largest red gum forest.[46]
- Earthquakes which occur in areas of the Great Barrier Reef (for example the 2016 5.8 magnitude earthquake offshore from Bowen, Queensland) may cause considerable damage to the reef's structure.[47]
- Intense shaking may precipitate landslips in prone areas. This may contribute to further effects on power and communications infrastructure, populated areas, and result in the destruction of forestry and native habitat.
- Environmental health impacts arising from the disturbance of particulates, rupturing of hydrocarbon supply lines, and possible asbestos contamination from buildings would likely be of concern at the local, district and state levels.
- This can result in significant losses to biodiversity and environment, impacting animal behaviour and habitats across the medium to long term.[48]

Secondary Hazards

- Earthquakes can instigate multiple secondary hazards of which fires, caused by downed power lines or gas leaks, can be the most dangerous. This is most likely where water supply has been damaged and roads blocked by debris, making it difficult for emergency services to effectively respond.
- Although the risk of liquefaction is low, as the strength of an earthquake needed to cause liquefaction would be very rare in Queensland, there remains concern that any liquefaction would result in significant damage. There would be an increased risk of this impact for regions built on floodplains such as Brisbane, Townsville, Gladstone and Bundaberg.
- Liquefaction and lateral spreading could lead to the destabilisation of riverbanks, altering the capacity of rivers, and increasing the risk of flooding.
- There is potential for loss of life and serious injury, especially electrocution, from fallen power lines and exposed electrical circuitry. The demand to 'make safe' may overwhelm local capability and extend the duration of localised power outages.
- While rare, earthquakes have the possibility of damaging active fire systems (fire hose reels, hydrants, sprinkler/deluge/ gaseous suppression systems, warning systems (EWS/EWIS/ VESDA)) and passive fire measures (compartmentalization through fire doors/curtains). When these systems are damaged, a fires rate of spread increases, further reducing the structural stability of steel beamed buildings and leading to partial or complete collapse.[49]
- Toxic material can leak from ruptured containers or pipes, adversely affecting the health of people, animals, and the environment. Health problems also can arise from power outages, leaking sewage, interrupted water supply, air quality (e.g. asbestos) and from stress-related responses.
- Traffic accidents can be caused by debris on roads. Train derailments can also occur where the tracks have been distorted by the earthquake or from debris on the lines.

- Large earthquakes can trigger landslides in high to extreme landslide prone areas as shown below in Figure 17. Research in Aotearoa New Zealand indicated that landslides have resulted in more damage and higher fatalities than all other secondary hazards combined (landslide occurrence is not restricted to earthquakes and often relates to high rainfall).[50] The 2016 Kaikōura magnitude 7.8 earthquake led to thousands of landslides which caused major disruption to road and rail links.[51] In Australia, areas most prone to landslides are the hinterland areas along the eastern seaboard of Queensland, along with other areas of steep topography.[52] A recent example is the multiple resulting landslides from Tropical Cyclone Jasper (2024) in Far North Queensland, some of which cut off access to Cape Tribulation.
- The risk of liquefaction in areas dominated by softer soils (or other very susceptible materials such as engineered fill or mine tailings) should be considered and addressed. However, liquefaction generally requires severe to violent levels of shaking (› MMVIII).
- The risk of localised tsunamis (within 500 kilometres of the eastern seaboard) being generated by earthquakes (and the requisite undersea landslide) is low.[53]

Figure 17: Impact of a landslide triggered by an earthquake in the South Island of New Zealand. Source: Getty Images

What can be done to address the risks from earthquakes in Queensland?

What can be done to address the risks from earthquakes in Queensland?

This section highlights a range of mitigation strategies to address earthquake risk across all levels of Queensland's disaster management arrangements. Operational risks and treatment plans are addressed within district and local level risk registers and disaster management plans. It is prudent to maximise investment in the implementation of any mitigation strategy to address multiple hazards where possible, and to exploit synergies between these strategies to reinforce value across the community. Conducting feasibility assessments and/or cost-benefit analysis would also support the most effective deployment of resources.

Prevention

Risk reduction is multi-faceted, and it is accepted globally that the most effective method of earthquake risk reduction is through appropriate building codes and related maintenance. The Australian earthquake loading code (AS 1170.4:2007) is routinely reviewed by experts to consider updated hazard information and societal expectations relating to the performance of buildings and the accepted level of risk. Pre-code residential buildings represent a significant proportion of Queensland's building stock. Detailed building construction data and building age data would greatly improve the vulnerability input to a risk analysis.

Steps have been taken to define the building characteristics of a particularly vulnerable cohort of buildings to earthquake ground shaking - unreinforced masonry buildings – as an input to future earthquake risk assessments across Queensland. QFES collaborated with the Queensland University of Technology to survey pre-1940 unreinforced masonry buildings in 12 Queensland localities. The surveyed data has been aligned with national earthquake vulnerability research led by the University of Adelaide and Geoscience Australia through the Bushfire and Natural Hazards Cooperative Research Centre. The data is available through the Queensland Disaster Management Arrangements Data Sharing Group.

The value in this data is demonstrated with a case-study in York, Western Australia, which experienced ground shaking from the 1968 Meckering magnitude 6.8 earthquake. The Shire of York recognised the risk associated with heritage buildings in their town particularly given the high visitation levels they receive throughout the year, and subsequently undertook retrofit of key heritage buildings. Local governments in Queensland with similar heritage characteristics may wish to consider this data in their planning.

Following the Shire of York project, a resource was developed to assist local and state government or property owners in discussions with construction and design professionals to translate their retrofit objectives to cost-effective solutions that minimise disruption to building occupants. The resource is primarily focused on older unreinforced masonry, but the principles are informative for other high risk building types.[54]

Information available to researchers or disaster management practitioners is highly dependent on output from Commonwealth and State agencies. Earthquake hazard and risk research is relatively limited in Australia in comparison with other countries such as New Zealand, Japan or the United States. Further earthquake research is warranted in Queensland acknowledging that much of the available information has been developed for national purposes and therefore requires more specificity for regional and local application to support risk assessments. Examples include, but are not limited to,

- determining the adequacy of the coverage of the seismic monitoring sites noting the bias towards areas of settlement activity,
- micro-tremor studies to develop localised site classifications particularly for areas of strategic importance to Queensland's economy,
- the monitoring of smaller magnitude earthquakes to improve estimates of occurrence rates of larger earthquakes,
- geological studies to ascertain where and when Queensland has hosted large earthquakes in the last 5-10 million years (refer Figure 6), and
- reanalysis of early historical earthquakes with modern techniques.

Preparedness

At present, earthquake occurrence cannot be predicted or forecast, so no warnings are available. Preparedness can be enhanced through, the identification of assets that are likely to be vulnerable to ground shaking (including using the surveyed data described above), exercising using credible scenarios such as those available through the GA EQ SST, subscribing to the notification services available through Geoscience Australia's Earthquakes@GA and delivering community awareness and education initiatives.

Community awareness and education initiatives can improve how earthquakes are recognised, increase understanding of expected impacts, and inform communities on how to respond during an event, leading to a greater understanding of this hazard. These initiatives should encourage anyone who feels an earthquake to fill in a Felt Report through Geoscience Australia's Earthquakes@GA site. By doing so, communities are supporting earthquake monitoring in Australia and the definition of earthquake hazard. The Australian Seismometers in Schools program affords the opportunity for some school students in Queensland to learn more about earthquakes. This is another important initiative to engage the public in earthquakes as the data from these seismometers is used by earthquake scientists to improve the available knowledge on earthquakes in Australia.

In the aftermath of the 2010-11 Canterbury Earthquake Sequence in Aotearoa New Zealand, a survey conducted by the Australian Earthquake Engineering Society found that residents have changed perceptions, beliefs and preparedness surrounding earthquakes. It was shown that people were increasingly more likely to think about preparing for earthquake events as being beneficial to their daily life, a belief that persisted ten years post event. It has been theorized that these earthquake experiences will likely influence long-term perceptions and beliefs, which should encourage greater preparedness.[55]

Risk can be reduced by educating the community about what to do in an earthquake. If inside, taking shelter under sturdy pieces of furniture, instead of running outside, is the ideal place to be should an earthquake occur. If outside, open flat areas are the safest places to gather during an earthquake. Buildings should be avoided if you are outside - masonry and heritage listed buildings are key buildings to avoid in particular, as these were constructed before appropriate earthquake standards were implemented and are most likely to suffer significant damage and/or collapse during an event.

Earthquakes can happen at any time whether at work, at school, or on holiday in Australia or overseas. Many Queenslanders travel overseas to locations that have a much higher earthquake hazard than Australia (popular destinations include New Zealand, Indonesia and Japan). Knowing what to do in an earthquake can protect you anywhere in the world.

Regular earthquake drills should be conducted in schools, starting at primary or pre-school level so that response in an earthquake becomes rapid and automatic. These drills could be conducted across Queensland schools independently, or as part of the Great ShakeOut drill that happens in October each year.[56] Similar drills should be extended to workplaces to avoid confusion should an event occur. It is perhaps more important to hold drills for low-probability events to avoid complacency. Numerous workplaces around the world participate in the Great ShakeOut, however with very limited participation from Australia. There are numerous resources available to support workplace drills through the Great ShakeOut site.

The Get Ready Queensland program focuses on funding programs which build resilience and preparedness for natural disasters.[57] There is potential that this could be used for targeted community campaigns, benefiting personal earthquake preparedness and community resilience.

The coordination of disaster operations and activities in response to a significant earthquake should be well articulated within Local and District Disaster Management Plans. This will help to improve coordination of relevant information and enable effective decision making. Undertaking risk assessments at the local or district level will help to understand what areas of the community have the greatest risk from earthquake. The Earthquake Impact and Risk Assessment for Perth and Supporting Infrastructure (EIRAPSI) and the Earthquake Risk and Mitigation Assessment in Tasmania are examples of this and may provide valuable information regardless of the geographic location.

Figure 18: Drop, Cover, Hide earthquake response.

Response

The National Earthquake Alert Centre (NEAC), operating 24/7 from Geoscience Australia in Canberra, provides a number of products and services for situational awareness to assist in earthquake response. These products are presented using the MMI which is commonly used to describe the damage and effects felt of an earthquake at a given location. The two key products include the FeltGrid and ShakeMap.

The FeltGrid is produced for any published earthquake for which GA receives one felt report within a gridded cell (at 20x20km, 10x10km, 5x5km, 1x1km scales). This includes small Australian earthquakes as well as large regional earthquakes which are felt in Australia - e.g., Banda Sea earthquakes felt in the Darwin area. GA's Felt Report service allows anyone to report their experience of an earthquake in terms that enable NEAC to calculate a (perceived) local shaking intensity at the reporter's location. This service is derived from the Did-You-Feel-It (DYFI) system developed by the USGS.

The ShakeMap, developed by USGS and adapted for Australian conditions by Geoscience Australia, is a spatial product displaying modelled ground shaking from an earthquake.[58] It is a useful tool for rapidly estimating the broad spatial extent of potential impact from an earthquake, expressed in terms of ground-shaking intensity. ShakeMap combines information from Felt Reports with seismic data, information about the regional geology, and models that estimate ground shaking for a given magnitude and distance from the earthquake. ShakeMap's are periodically revised as Felt Reports are received.

Using the FeltGrid and ShakeMap together, with other intelligence, emergency managers can better approximate areas where the greatest intensity ground shaking is expected, where in the community the ground shaking is being reported, and to what intensity. This is valuable information to aid assessment of response actions, especially to those areas of modelled high intensity and little to no community response.

Acknowledging that local governments are primarily responsible for managing events within their Local Government Area, it should be noted that an earthquake equivalent to a 1989 Newcastle or 1918 Gladstone event would almost certainly exceed local and district capability to respond. Therefore, it is likely that such an event would trigger a State level response, with the State Disaster Coordination Centre (SDCC) activating within hours of the event to provide support to affected groups as requested. It remains essential that such a response is coordinated at the Local level via Local and District Disaster Management Groups (LDMGs/DDMGs).

Possible impacts to power and telecommunication networks would likely impact the ability to feed timely and accurate information from local and district levels to the state. This supports the need for redundancy in communications to provide consistent information flows and continue an all hazards response.

Recovery

Aftershocks can continue over long periods, impacting the physical safety and mental health of communities. Strong aftershocks which occur relatively soon after the event may bring down damaged (yet still standing) buildings, where people may be sheltering.

The operation of evacuation centres after an earthquake impact and/or the provision of relief housing may be required for extended periods. After the impact of a destructive earthquake, the restoration of large numbers of damaged homes, businesses and public assets would likely take more than 12 months.

People may be required to stay with family, friends, or in temporary public housing for an extended period after their homes have become uninhabitable or isolated, or the local environment has been rendered unsafe to be reoccupied. This type of accommodation would be required after a destructive earthquake and the subsequent widespread failure of major infrastructure elements such as water and power supply. Most comprehensive insurance policies provide cover for earthquake damage, however, owners of damaged properties that are uninsured or underinsured would need to seek external support. The demand for repair services for buildings is likely to produce significant delays in work being undertaken, akin to those delays experienced during prior severe tropical cyclone impacts.

A post-event survey of the nature and distribution of damage is an essential step in improving the understanding of earthquake behaviour, building and infrastructure vulnerability and to support the continued development of knowledge and sharing of collected information. This should be undertaken as an integral part of the clean-up and recovery process and should be coordinated by the LDMG.

Following significant earthquakes, Geoscience Australia will seek local and state government support to monitor for aftershocks. This involves the rapid deployment of temporary seismometers, strategically located by seismic hazard experts to better characterise the earthquake for future hazard and risk assessments. There is community benefit to supporting this aftershock monitoring as demonstrated at Lake Muir, south west Western Australia with the 2018 magnitude 5.3 earthquake.[59] Monitoring of this event recorded over 700 aftershocks, which received heightened community interest and therefore enhanced community engagement efforts of local and state disaster managers. Similar equipment was deployed in Queensland following the Eidsvold magnitude 5.1 earthquake in 2015 and the Bowen earthquake in 2011.[60]

Following significant earthquakes, it is likely considerable interest will be expressed by both national and international academia, the insurance industry and public research agencies (such as Geoscience Australia) in studying the impact. This research activity should be coordinated and resulting outcomes be made available to local governments for planning purposes.

The development of strategies to address infrastructure recovery, business recovery and community welfare need to be considered to ensure the impact of an earthquake is not exacerbated by a lack of utilities, economic hardship and social dislocation. Lack of such services would prolong the community recovery process. An informed and prepared response is necessary, the below list provides additional Prevention, Preparedness, Response and Recovery (PPRR) treatments and controls in the event of an earthquake:

Technical definitions

Aftershock

An aftershock is a smaller earthquake that occurs in the same area in the days-years after a main earthquake. Aftershocks continue until the background seismicity resumes and decrease in magnitude and frequency over time. Shallow earthquakes are more likely to generate aftershocks than deeper earthquakes.

Amplitude

The amplitude is a physical recording of a given intensity measure (e.g. peak acceleration, peak velocity, etc.) measured on an earthquake recording (i.e., a seismogram).

Bedrock

Relatively hard, solid rock that commonly underlies softer rock, sediment, or soil.

Geomorphology

Geomorphology is the study of the character and origin of landforms, such as mountains and valleys.

Macroseismic Intensity

The Macroseismic intensity is a qualitative assignment (written as a Roman numeral) describing the severity of an earthquake in terms of its effects on the earth's surface and on humans and structures. Several scales exist, but the ones most commonly used are the Modified Mercalli scale and the European Macroseismic Scale (EMS-98). The Macroseismic intensity of a given earthquake is dependent on the location of the observation point relative to the earthquake epicentre, whereas the magnitude is one number for each earthquake.

Lateral spread

Lateral spread or flow are terms referring to landslides that commonly form on gentle slopes and that have rapid fluid-like flow movement, like water.

Liquefaction

A process by which water-saturated sediment temporarily loses strength and acts as a fluid, like when you wiggle your toes in the wet sand near the water at the beach. This effect can be caused by earthquake shaking.

Magnitude

The magnitude is a number that characterises the relative size of an earthquake. Magnitude is based on measurements on seismic instrumentation. Several scales have been defined, but the most commonly used are (1) local magnitude (ML), commonly referred to as "Richter magnitude", (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. The moment magnitude (Mw) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute for smaller local earthquakes than the other types. All magnitude scales should yield approximately the same value for any given earthquake.

Moment magnitude

Moment magnitude refers to the size of an earthquake in terms of how much energy is released. Specifically, moment magnitude relates to the amount of movement by rock (i.e. the distance of movement along a fault or fracture) and the area of the fault or fracture surface. Since magnitude scales are logarithmic, an increase of one unit of magnitude on the moment magnitude scale is equivalent to an increase of 10 times the amplitude recorded by a seismograph and approximately 30 times the energy.

Seismic moment

The seismic moment is a measure of the size of an earthquake based on the area of fault rupture, the average amount of slip, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting. Seismic moment can also be calculated from the amplitude spectra of seismic waves.

Seismic wave

A seismic wave is an elastic wave generated by an impulse such as an earthquake or an explosion.

Seismograph

A seismograph, or seismometer, is an instrument used to detect and record earthquakes.

ShakeMap

ShakeMap is a product of the USGS Earthquake Hazards Program in conjunction with the regional seismic networks. ShakeMaps can provide scenario and near-real-time maps of ground motion and shaking intensity following significant earthquakes. These maps are used by federal, state, and local organisations, both public and private, for post-earthquake response and recovery, public and scientific information, as well as for preparedness exercises and disaster planning.

Tectonic plates (Plate tectonics)

Plate tectonics is the theory supported by a wide range of evidence that considers the earth's crust and upper mantle to be composed of several large, thin, relatively rigid plates that move relative to one another. Plate movement creates stress which results in a buildup of energy. This energy is released in earthquakes along weaknesses (faults) which define the boundaries, but also occurs in the interior of tectonic plates such as Australia.

References

1. The State of Queensland (Queensland Fire and Emergency Services), 2023, 2023 State Disaster Risk Report, Queensland Government, https://www.disaster.qld.gov.au/__data/assets/pdf_file/0020/436070/2023-State-Disaster-Risk-Report.pdf.

2. The State of Queensland (Queensland Treasury) 2023, Queensland Government population projections, 2023 edition: LGAs and SA2s, Queensland Government, https://www.qgso.qld.gov.au/issues/13311/qld-government-population-projections-queensland-regions-2023-edn-update.pdf.

3. The State of Queensland (Department of Environment, Science and Innovation) 2023, Queensland Climate Action: Energy, Queensland Government, https://www.des.qld.gov.au/climateaction/sector-action/energy.

4. The State of Queensland (Queensland Treasury), 2021, Experimental estimates of Gross Regional Product, Queensland Government, https://www.qgso.qld.gov.au/issues/3316/experimental-estimates-gross-regional-product-2000-01-2006-07-2010-11.pdf.

5. Allen, T. I., J. D. Griffin, D. J. Clark, P. R. Cummins, H. Ghasemi, and R. Ebrahimi, 2023, The 2023 National Seismic Hazard Assessment for Australia: model overview, Geoscience Australia Record 2023/53, doi: 10.26186/148969.

6. Martin et al., 2024, Resolving the location and magnitude of the 1918 Queensland (Bundaberg) earthquake, Australia, Bulletin of the Seismological Society of America, submitted.

7. Geoscience Australia, 2024, Natural Hazard Scenarios (Beta), Australian Government, https://portal.ga.gov.au/persona/hazards

8. Green, R. A., and J. J. Bommer, 2019, What is the smallest earthquake magnitude that needs to be considered in assessing liquefaction hazard?, Earthq. Spectra 35, 1441-1464, doi: 10.1193/032218EQS064M.

9. Geoscience Australia, 2012, Shaping a Nation: A Geology of Australia, Australian Government, https://www.ga.gov.au/data-pubs/data-and-publications-search/publications/shaping-a-nation

10. Leonard, M., 2008, One Hundred Years of Earthquake Recording in Australia, Bulletin of the Seismological Society of America, 98(3), 1458-1470.

11. Brown, A. and Gibson, G., 2004, A multi-tiered earthquake hazard model for Australia, Tectonophysics 390, 25-43.

12. Insurance Council of Australia, 2023, Insurance Catastrophe Resilience Report 2022-23, https://insurancecouncil.com.au/wp-content/uploads/2023/09/20897_ICA_Cat-Report_Print-2023_RGB_Final_Spreads.pdf.

13. McPherson, A. A., 2017, A revised seismic site conditions map for Australia, Geoscience Australia, http://dx.doi.org/10.11636/Record.2017.012

14. Salmon, M., S. Mousavi, and M. Sambridge, 2022, 10 years of Australian Seismometers in Schools – education, outreach and research, Australian Earthquake Engineering Society 2022 National Conference, Mount Macedon, Victoria.

15. Raspberry Pi Foundation, 2024, Howit works, https://raspberryshake.org/about/technology/.

16. Geoscience Australia, 2019, The Australian Neotectonics Database: factsheet, Australian Government, https://pid.geoscience.gov.au/dataset/ga/71856

17. Johnston, A.C., 1994, Seismotectonic interpretations and conclusions from the stable continental region seismicity database, in The Earthquakes of Stable Continental Regions, Electric Power Research Institute, Report TR-102261-1, 4-1-4-102.

18. Hillis, R.R., Sandiford, M., Reynolds, S.D. and Quigley, M.C., 2008, Present-day stresses, seismicity and Neogene-to-Recent tectonics of Australia's 'passive' margins: intraplate deformation controlled by plate boundary forces, in The Nature and Origins of Compression in Passive Margins, Geological Society, London, Special Publications 306, 71-90.

19. With thanks to the Kuku-Yalanji clan of Wujal Wujal for sharing their oral history for the purposes of this assessment.

20. Rynn, J.M.W., 1981, A reappraisal of Queensland's largest known earthquake - The "Queensland" earthquake of 7 June 1918 (magnitude about 6). Papers of the Department of Geology of The University of Queensland, Brisbane.

21. Global Earthquake Model, 2024, Global Seismic Hazard Map, https://www.globalquakemodel.org/product/global-seismic-hazard-map

22. Stephenson, J., T. Allen, D. Clark, K. Wilson, and R. Spry, 2020, An atlas of earthquake scenarios for Australian localities, Australian Earthquake Engineering Society 2020 Virtual Conference.

23. Caldwell, R., 2010, Effects of the Newcastle Earthquake of 1989 on the New South Wales High Voltage Transmission System. Australian Journal of Structural Engineering.

24. Hoult, R., T. Allen, E. Borleis, W. Peck, and A. Amirsardari, 2021, Source and attenuation properties of the 2012 Moe, southeastern Australia, earthquake sequence, Seismol. Res. Lett. 92, 1112–1128, doi: 10.1785/0220200234.

25. Australian Energy Market Operator, 2012, Multiple Contingency Event Following an Earthquake in Victoria on 19 June 2012, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2012/Victoria_Earthquake_19_June_2012_v3.pdf accessed 27 Mar 2017

26. Ritschel, U., Warnke, I., Kirchner, J., and Meussen, B., 2003, Wind Turbines and Earthquakes, Windrad Simulation & engineering, http://www.windrad-online.de/wp-content/uploads/2014/07/windrad_wwec2003_windturbines_and_earthquakes_03.pdf

27. Frum, L., 2021, How Do Wind Turbines Respond to Winds, Ground Motion During Earthquakes?, AIP Publishing, https://publishing.aip.org/publications/latest-content/how-do-wind-turbines-respond-to-winds-ground-motion-during-earthquakes/

28. Khaled, Z. E., and Mcheick, H., 2019, Case studies of communications systems during harsh environments: A review of approaches, weaknesses, and limitations to improve quality of service, Sage Journals, https://journals.sagepub.com/doi/full/10.1177/1550147719829960

29. Bendimerad, F., 2013, Earthquake Risk Considerations of Mobile Communication Systems, Earthquakes and Megacities Initiative (EMI).

30. World Health Organization, 2003. Asbestos in Drinking Water - WHO Guidelines for Drinking-Water Quality.

31. Seismology Research Centre, Dams & Earthquakes, ESS Earth Sciences, https://www.src.com.au/earthquakes/seismology-101/dams-earthquakes/

32. Australian Institute for Disaster Resilience, 2014, Earthquake – Tennant Creek, https://knowledge.aidr.org.au/resources/earthquake-tennant-creek/.

33. Johnston, J.F., and White, S.R., 2024, Understanding the Meckering earthquake, Western Australia, 14 October 1968, Government of Western Australia (Department of Energy, Mines, Industry Regulation & Safety Bookshop), https://dmpbookshop.eruditetechnologies.com.au/product/understanding-the-meckering-earthquake-western-australia-14-october-1968.do

34. Beheshtian, B., and Sommerville, P., 2023, Seismic Risk Evaluation of Transportation Networks in Australia, Risk Frontiers, https://riskfrontiers.com/insights/seismic-risk-evaluation-of-transportation-networks-in-australia/

35. Clark, D.J., and Edwards, M., 2018, 50th anniversary of the 14th October 1968 Mw 6.5 (Ms 6.8) Mechering earthquake: Australian Earthquake Engineering Society Pre-conference Field Trip, Mechering, 15 November 2018, Geoscience Australia, https://ecat.ga.gov.au/geonetwork/srv/api/records/fbaeb10f-f50a-450d-bb6a-8cc1a80619df

36. Rafferty, J. P., and Murray, L., 2011, Christchurch earthquake of 2010-11, Britannica, https://www.britannica.com/event/Christchurch-earthquakes-of-2010-2011

37. Rattue, P., 2011, Earthquakes Have Devastating Health Effects, Medical News Today, https://www.medicalnewstoday.com/articles/237093#1

38. Coates, L., Haynes, K., Radford, D., D'Arcy, R., Smith, C., van den Honert, R., and Gissing, A., 2017, An Analysis of Human Fatalities from Cyclones, Earthquakes and Severe Storms in Australia, Risk Frontiers, https://www.bnhcrc.com.au/sites/default/files/managed/downloads/cyclone_earthquake_and_storm_-_fatalities_report_28-12-2016.pdf

39. Australian Standard 3826-1998 is available from https://www.standards.org.au/

40. Goldsworthy, H., McBean, P. and Somerville, P., 2015, Mitigation of seismic hazard in Australia by improving the robustness of buildings. In Tenth Pacific Conference on Earthquake Engineering. Sydney.

41. National Building Specification Design Strategies, 2014, Seismic Design Actions on Non-Structural Components. TECHnotes.

42. V.J.Carr et al, 1995, Psychosocial sequelae of the 1989 Newcastle earthquake: Community disaster experiences and psychological morbidity 6 months post-disaster.

43. King, T. R., M. Quigley, and D. Clark, 2019, Surface-rupturing historical earthquakes in Australia and their environmental effects: new insights from re-analyses of observational data, Geosciences 9, 408, doi: 10.3390/geosciences9100408.

44. Clark, D. J., S. Brennand, G. Brenn, M. C. Garthwaite, J. Dimech, T. I. Allen, and S. Standen, 2020, Surface deformation relating to the 2018 Lake Muir earthquake sequence, southwest Western Australia: new insight into stable continental region earthquakes, Solid Earth 11, 691–717, doi: 10.5194/se-11-691-2020.

45. King, T. R., M. Quigley, D. Clark, A. Zondervan, J. H. May, and A. Alimanovic, 2021, Paleoseismology of the 2016 MW 6.1 Petermann earthquake source: implications for intraplate earthquake behaviour and the geomorphic longevity of bedrock fault scarps in a low strain-rate cratonic region, Earth Surf. Processes Landforms 46, 1238-1256, doi: 10.1002/esp.5090.

46. Clark, D., A. McPherson, M. Cupper, C. D. N. Collins, and G. Nelson, 2017, The Cadell Fault, southeastern Australia: a record of temporally clustered morphogenic seismicity in a low-strain intraplate region; In Landgraf, A., Kübler, S., Hintersberger, E., and Stein, S., Eds., Seismicity, fault rupture and earthquake hazards in slowly deforming regions, Geological Society, London, Special Publications. 432, 163-185, doi: 10.1144/SP432.2.

47. Aronson, R. B., Precht, W., Macintyre, I. G., and Toth, L., 2011, Catastrophe and the Lifespan of Coral Reefs, Ecology.

48. Nepal, S. M., n.d., Impact of Earthquake on Ecosystem & Biodiversity, WWF, https://www.ajne.org/sites/default/files/event/9/session-materials/02-mr.-santosh-mani-nepal-wwf_web.pdf

49. Elsevier B.V., 2024, Journal of constructional Steel Research, ScienceDirect, https://www.sciencedirect.com/journal/journal-of-constructional-steel-research

50. Potter, S.H., Becker, J.S., Johnston, D.M., and Rossiter, K.P., 2014, An overview of the impacts of the 2010-2011 Canterbury earthquakes, ScienceDirect, https://www.sciencedirect.com/science/article/pii/S221242091500031X

51. Massey, C., Townsend, D., Villeneuve, M., Dellow, S., and McColl, S., 2017, Landslides Caused By The 14 November 2016 Kaikoura Earthquake, South Island, New Zealand, https://www.nzgs.org/libraries/nzgs20_dellow2/

52. Institute of Geological & Nuclear Sciences, 2024, Landslide Planning guidance; Reducing Landslide Risk through Land-Use Planning, https://www.gns.cri.nz/assets/Data-and-Resources/Download-files/MS-144-Landslide-Planning-Guidance_FINAL_25Jan2024.pdf

53. The State of Queensland (Queensland Fire and Emergency Services), 2019, Tsunami Guide for Queensland, Queensland Government, https://www.disaster.qld.gov.au/__data/assets/pdf_file/0019/339301/Tsunami-Guide-For-Queensland.pdf.

54. Edwards, M., Vaculik, J., and Wehner, M., 2022, Earthquake retrofit for Older Masonry Buildings, Geoscience Australia, https://pid.geoscience.gov.au/dataset/ga/146599

55. Becker, J. S., Vinnell, L.J., Doyle, E. E. H., Paton, D., McBride, S. K., and Johnston, D. M., 2023, Earthquake perceptions, beliefs, and preparedness in the Canterbury Region: A comparison before, during and after the Canterbury Earthquake Sequence in Aotearoa New Zealand, Australian Earthquake Engineering Society, https://aees.org.au/wp-content/uploads/2023/11/38.-J-BeckerLauren-Vinnell.pdf

56. Statewide California Earthquake Centre, 2024, Great ShakeOut Earthquake Drills, https://www.shakeout.org.

57. The State of Queensland, 2024, Get Ready Queensland, Queensland Government, https://getready.qld.gov.au.

58. Allen, T., A. Carapetis, J. Bathgate, H. Ghasemi, T. Peji▪, and A. Moseley, 2019, Real-time community internet intensity maps and ShakeMaps for Australian earthquakes, Australian Earthquake Engineering Society 2019 Conference, Newcastle, New South Wales.

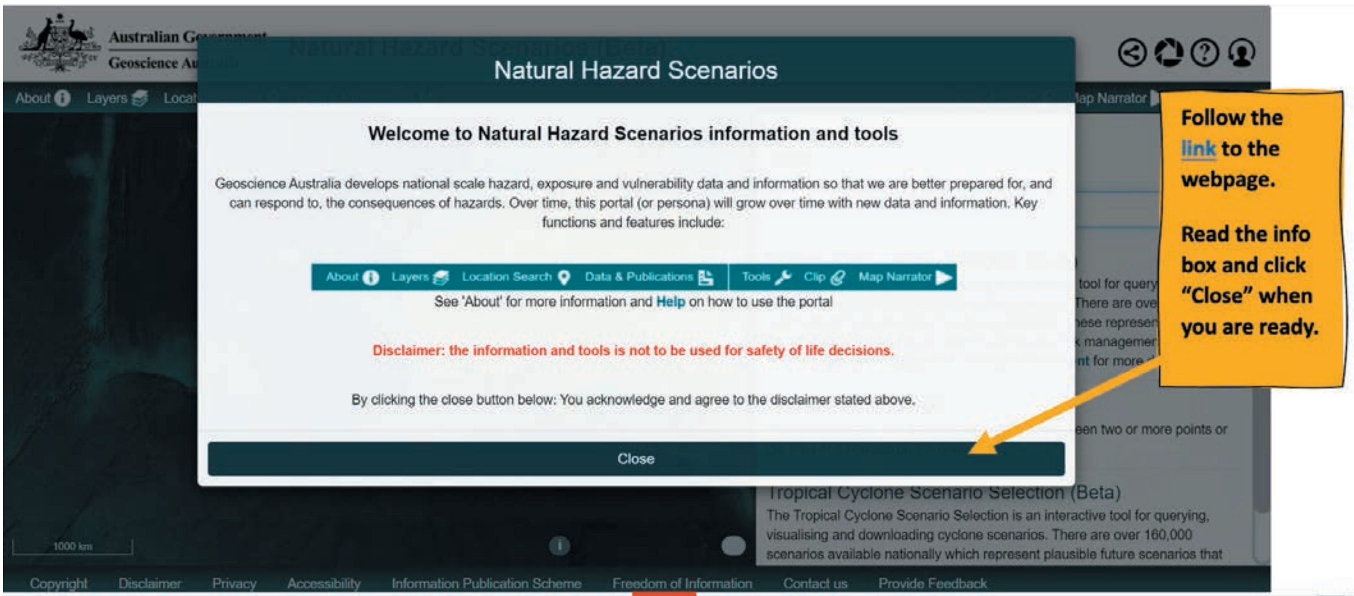
59. Clark, D. J., S. Brennand, G. Brenn, M. C. Garthwaite, J. Dimech, T. I. Allen, and S. Standen, 2020, Surface deformation relating to the 2018 Lake Muir earthquake sequence, southwest Western Australia: new insight into stable continental region earthquakes, Solid Earth 11, 691–717, doi: 10.5194/se-11-691-2020.

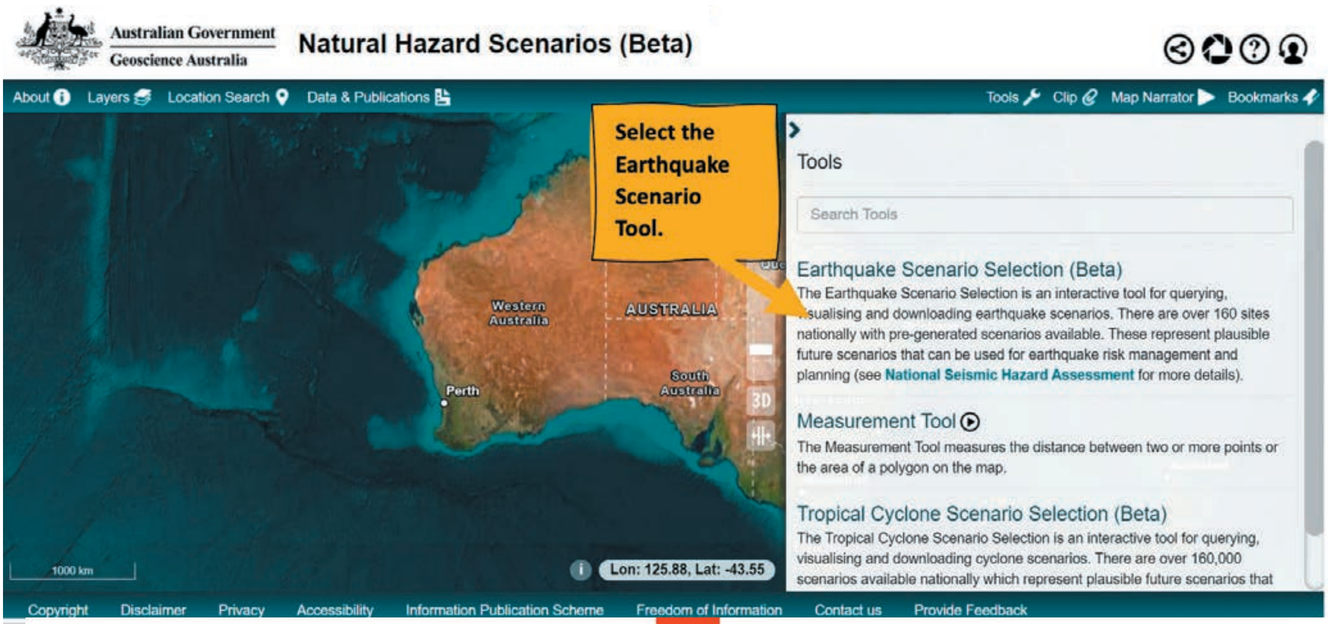
60. Mathews, E., J. Bathgate, T. Allen, C. Collins, M. Lissogourski, K. Bevan, L. Saikal, and R. Herrmann, 2011, Evaluation of the April 2011 Bowen ML 5.3 earthquake and aftershock sequence, Australian Earthquake Engineering Society 2011 Conference, Barossa Valley, South Australia.

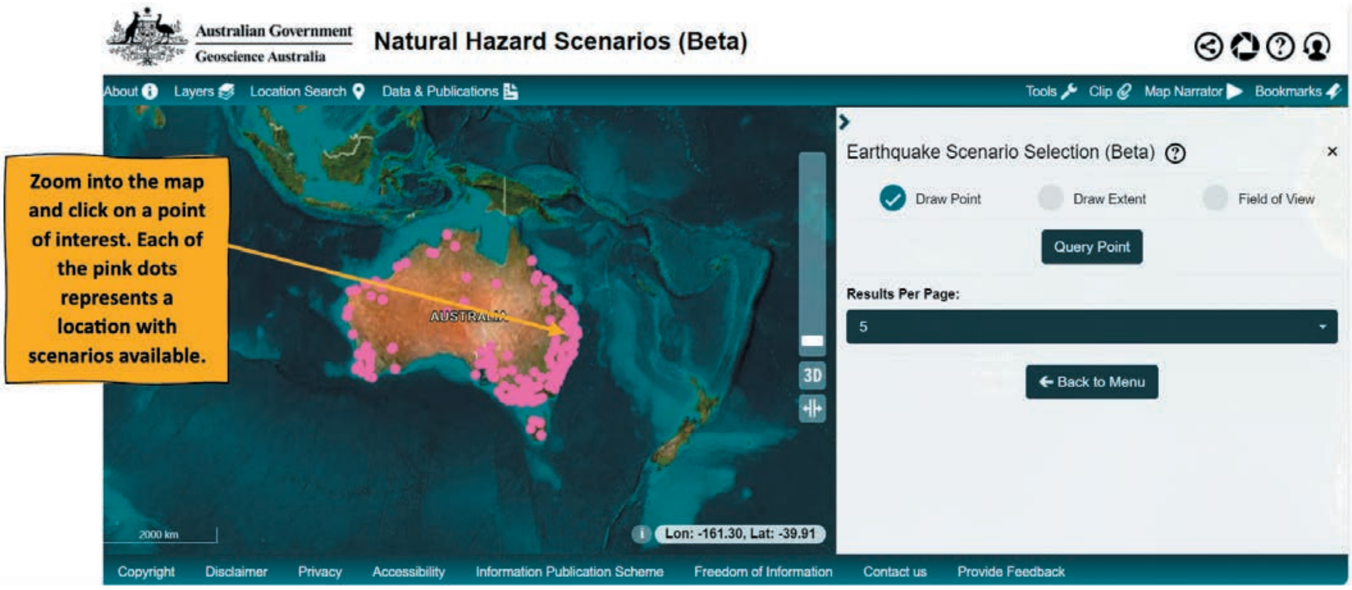
Appendices

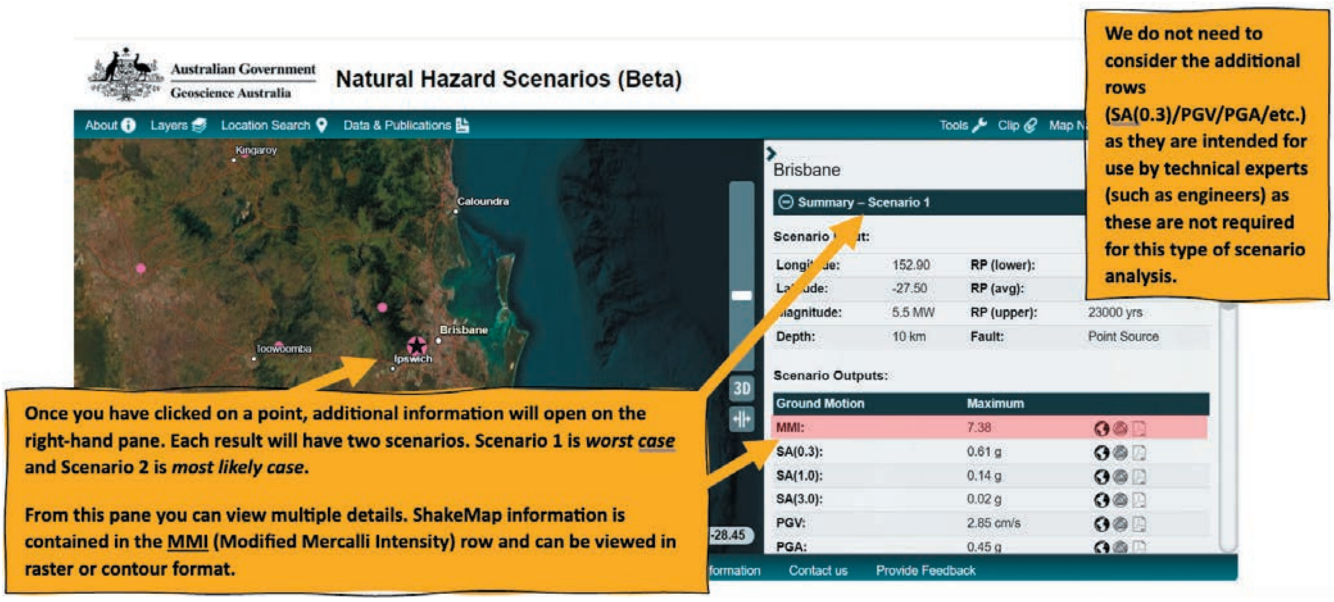
Appendix A: Earthquake Scenario Selection Tool User Guide

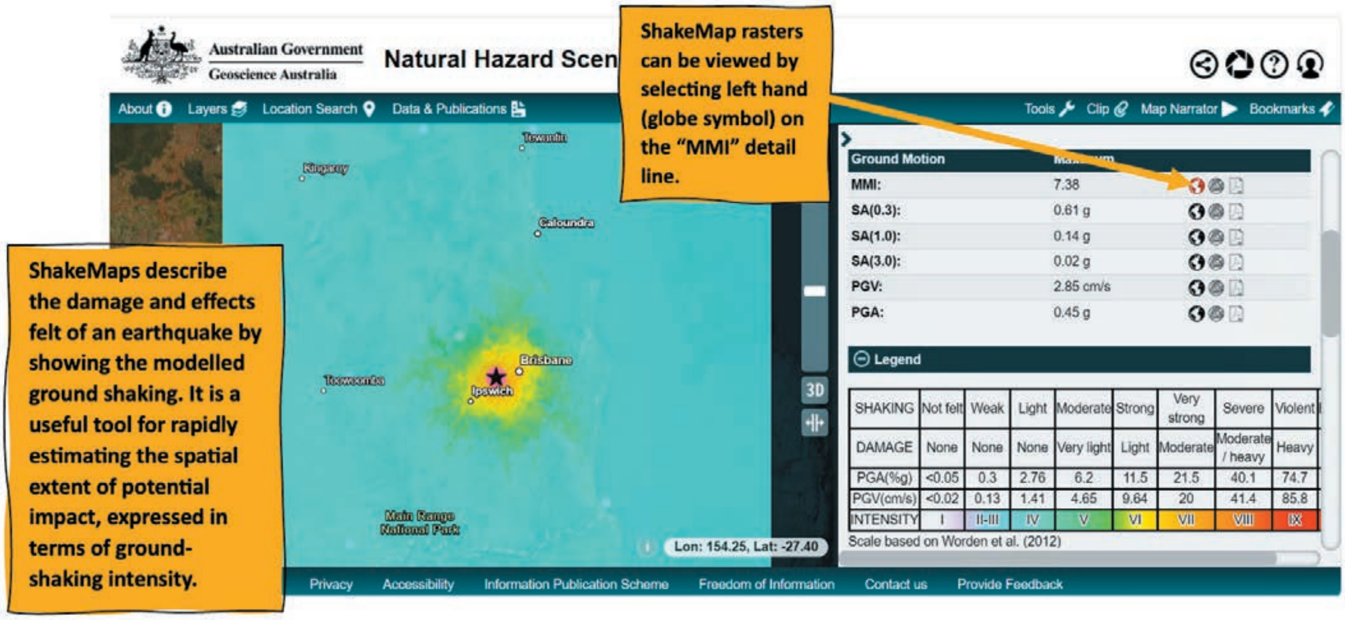
Earthquake Scenario Selection Tool User Guide

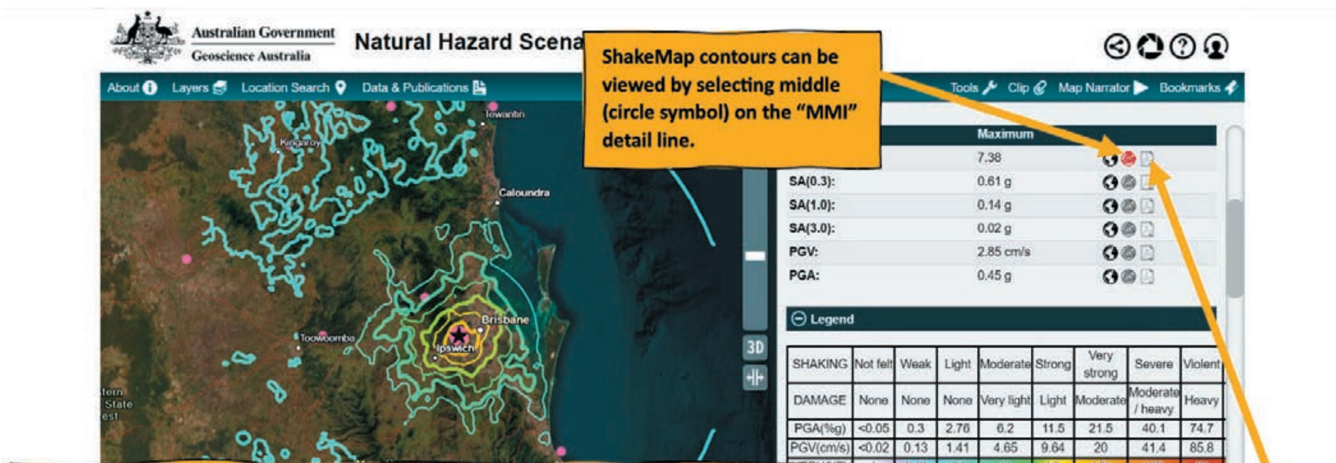





Australian Government
Geoscience Australia
Natural Hazard Scenarios (Beta)
About
Layers
Location Search
Data & Publications
Tools
Clip
Map Narrator
Bookmarks
Zoom into the map and click on a point of interest. Each of the pink dots represents a location with scenarios available.
AUSTRALIA
Earthquake Scenario Selection (Beta)
Draw Point
Draw Extent
Field of View
Query Point
Results Per Page:
5
Back to Menu
2000 km
Lon: -161.30, Lat: -39.91
Copyright
Disclaimer
Privacy
Accessibility
Information Publication Scheme
Freedom of Information
Contact us
Provide Feedback

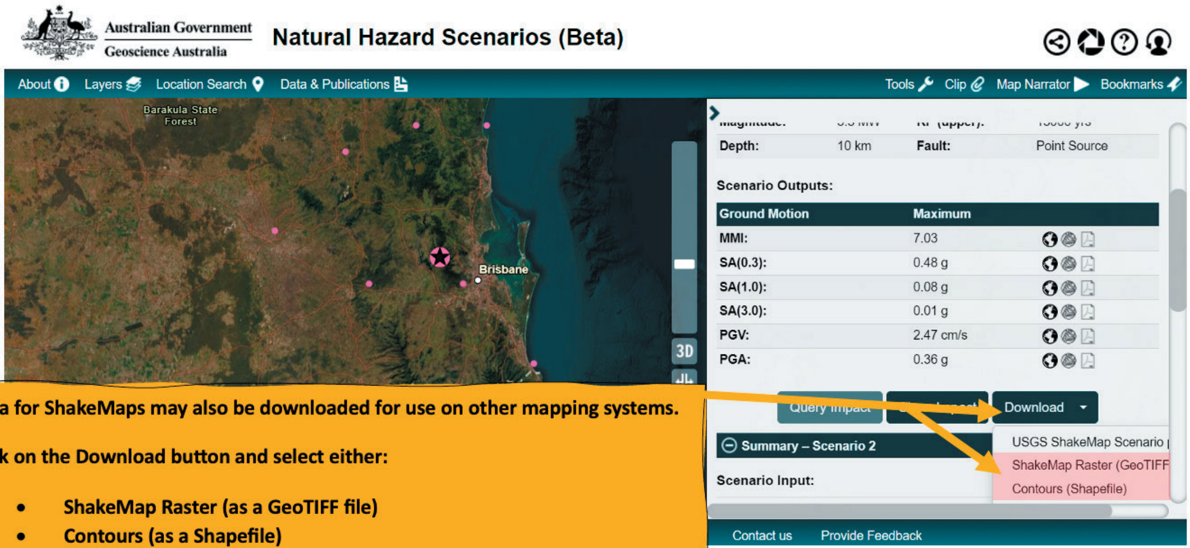

We do not need to consider the additional rows (SA(0.3)/PGV/PGA/etc.) as they are intended for use by technical experts (such as engineers) as these are not required for this type of scenario analysis.
Australian Government
Geoscience Australia
Natural Hazard Scenarios (Beta)
About
Layers
Location Search
Data & Publications
Tools
Clip
Kingaroy
Caloundra
Brisbane
Toowoomba
Ipswich
Brisbane
Summary – Scenario 1
152.90
-27.50
5.5 MW
RP (lower):
RP (avg):
RP (upper):
23000 yrs
Depth:
10 km
Fault:
Point Source
Scenario Outputs:
Ground Motion
Maximum
MMI:
7.38
SA(0.3):
0.61 g
SA(1.0):
0.14 g
SA(3.0):
0.02 g
PGV:
2.85 cm/s
PGA:
0.45 g
Once you have clicked on a point, additional information will open on the right-hand pane. Each result will have two scenarios. Scenario 1 is *worst case* and Scenario 2 is *most likely case*.
From this pane you can view multiple details. ShakeMap information is contained in the MMI (Modified Mercalli Intensity) row and can be viewed in raster or contour format.
Contact us
Provide Feedback





The raster view represents the map as a continuous visualisation, assigning a MMI value to each cell. Whilst the contour view connects points of equal MMI.

Both views visualise ground shaking intensity of an earthquake – the file you use will depend on your product, system, and audience.



Data for ShakeMaps may also be downloaded for use on other mapping systems.

Click on the Download button and select either:

- **ShakeMap Raster (as a GeoTIFF file)**
- **Contours (as a Shapefile)**

The option downloaded will depend on the requirements of your mapping system. Most programs will be compatible with both, after downloading you can simply upload the entire zip file to your system. Certain systems may allow you to upload individual files inside the zipped folder.

What's Next?

The Earthquake Scenario Selection Tool can be used by disaster managers to perform scenario analysis to inform risk assessments, exercises, and planning.

The ShakeMap data aids in understanding how an earthquake would impact an area of concern. Disaster managers can better approximate areas where the greatest ground shaking intensity is expected, where in the community the ground shaking is being reported, and to what intensity.

Disaster managers should consider how this data will be used to inform risk assessments, planning, and response. Some thoughts to consider:

- **Assessing earthquake hazard on exposed elements provides a clear understanding of vulnerabilities. What and where are these exposed elements? Consider those expanded on in the State Earthquake Risk Assessment: essential utilities, roads and transport, housing and community infrastructure, human and social, economy, and environment.**
- **Consider any secondary hazards that may arise from an earthquake event.**
- **Are there other stakeholders (within the QDMA) which could provide additional data to inform the assessment? Additional insights on critical infrastructure, terrain, vulnerable communities, etc. will be incredibly valuable in conducting a risk assessment or exercise.**
- **Can we reduce vulnerability or increase resilience of any vulnerable elements? Is there adequate planning in place, such as BCPs for critical infrastructure holders?**
- **How can the Local or District disaster management group improve resilience and be better prepared for an earthquake based on the information available from the scenarios?**

Queensland
Government