



Australian Government

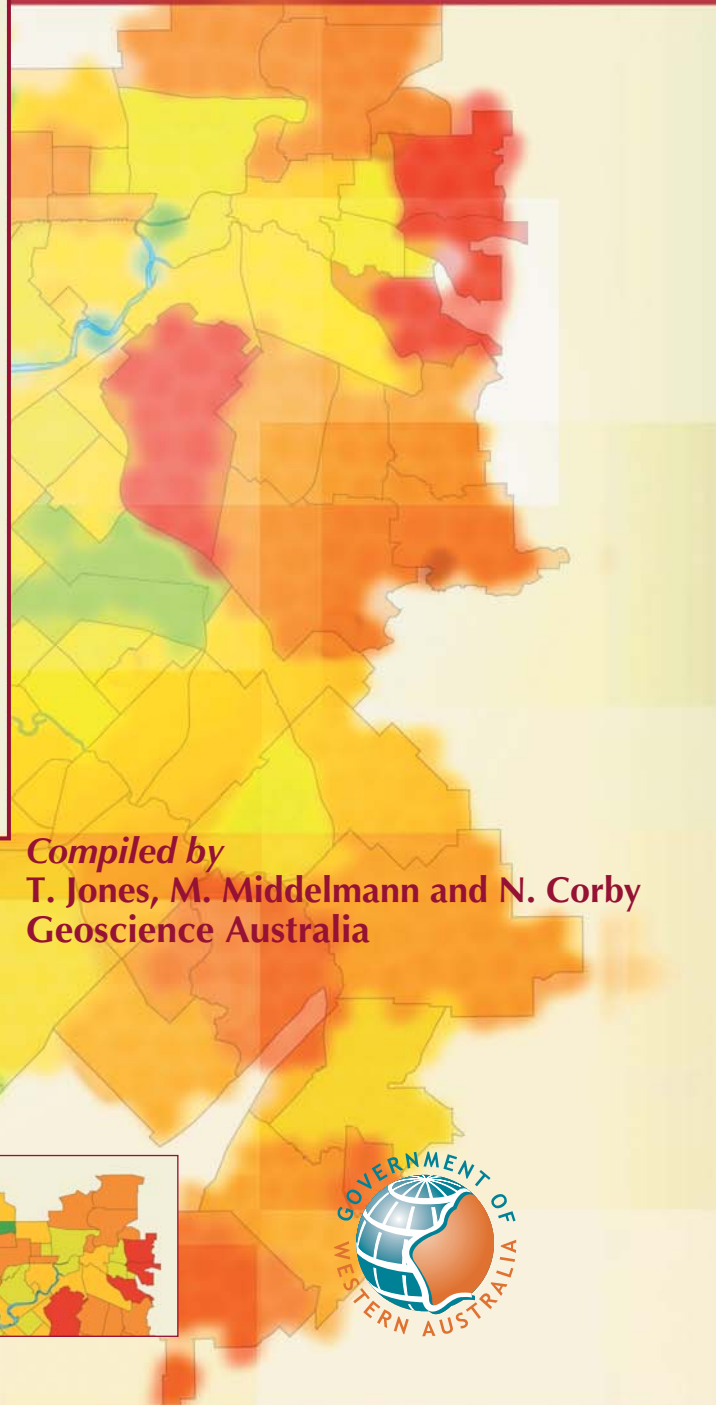
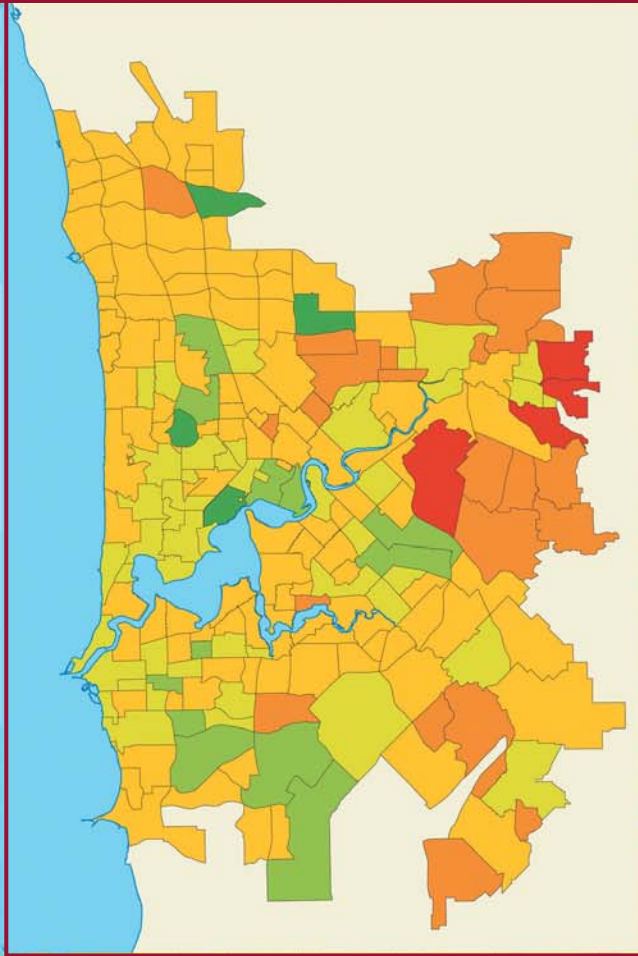


Natural hazard risk

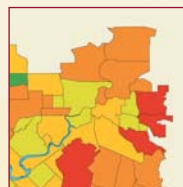
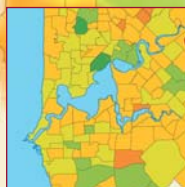
in

PERTH

Western Australia



Compiled by
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Geoscience Australia



Department of Industry, Tourism and Resources

Minister for Industry, Tourism and Resources:

The Hon Ian Macfarlane MP

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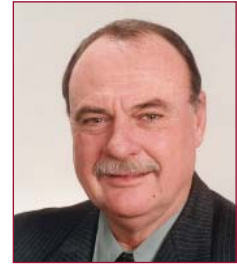
Bureau of Meteorology



Department for Planning and Infrastructure
Department of Environment
Western Australian Land Information System
Department of Land Information



Foreword



As a nation whose population is concentrated along its coastal fringe, it is critical that planners, emergency managers, advisors and the community are aware of the potential impact of natural hazards, such as earthquakes, cyclones, cool-season storms, floods and coastal erosion, and have confidence in the appropriateness of associated risk-management strategies.

This booklet summarises the findings of a collaborative research program into natural hazards that Australia's fourth largest city, Perth, could face in the future, and the risks arising from them.

To make informed decisions related to natural hazards risks, you need an appreciation of both our hazard-related history and the geosciences. For example, cool-season storms and tropical cyclones, often with associated bushfires, account for the highest natural hazard insurance losses in southwest Western Australia. This study demonstrates that communities exposed to wind, such as coastal communities, face a measurably higher wind hazard than the building code describes and that wheat-belt communities included in an enlarged earthquake source zone east of Perth face a higher hazard than described in the current earthquake loadings standard.

The study also reveals that, while many households can draw on their economic resources to assist their recovery after a natural disaster, some areas may experience difficulties in the recovery process due to limited financial capacity.

For the past four years, the Australian Government, Western Australian Government and local agencies have worked together to produce these and many other findings, building on research that Geoscience Australia undertook previously with some of its other partners in Queensland and New South Wales.

A full report detailing information about natural hazards, and the risks they pose to Perth, is provided in the attached compact disc.

We all want our communities to be safe places. Accordingly, I urge you to explore this important work and act on its recommended actions.

A handwritten signature in black ink, appearing to read 'Warren Entsch'.

The Hon Warren Entsch MP

Parliamentary Secretary to the Minister
for Industry, Tourism and Resources

Parliament House
Canberra ACT 2600

Foreword by WA Ministers



The Pickering Brook fire that started on 16 January 2005 is still very much in our minds.

It was the worst fire in Western Australia in the past 40 years, burning over 27,000 hectares of bush and taking nine days to bring under control. The fire continued to burn for several weeks.

However, fires are only one hazard that we potentially have to face, either as an emergency or in terms of planning to reduce risks.

This Cities Project Perth report that has been produced by Geoscience Australia in collaboration with several of our State Government Departments and the Bureau of Meteorology provides a comprehensive natural hazard risk assessment for the greater Perth area.

This information, which includes details of flood and earthquake risk, wind speeds and frequency and potential coastal erosion problems, will promote community awareness and understanding of these natural hazards and their risk in Perth region. It will be particularly useful in future urban and peri-urban planning and in the mitigation of, preparation for, and response to natural hazard events such as the Pickering Brook fires.

The Western Australian Government, in particular the Fire and Emergency Services Authority, the Department for Planning and Infrastructure, the Department of Environment and the Western Australian Land Information System (WALIS), has been pleased to work with the Federal Government and local government in this important project.

We urge all local governments in Perth, communities, organisations, businesses and individuals to benefit from the information provided in this report.

Michelle Roberts, BA DipED MLA
Minister for Police and Emergency
Services; Community Safety

Alannah MacTiernan, BA LLB BJuris JP MLA
Minister for Planning and Infrastructure

John Bowler, MLA
Minister for Local Government
and Regional Development; Land
Information; Goldfields-Esperance
and Great Southern

Dr Judy Edwards, MB BS MLA
Minister for the Environment; Science

Background

Cities Project Perth is the most recent in a series of natural hazard risk assessment studies of major Australian cities undertaken by Geoscience Australia (GA) and its collaborative research partners.

Building on earlier multi-hazard studies of Cairns, Mackay, Gladstone and southeast Queensland, as well as single-hazard (earthquake-risk) assessments of Newcastle and Lake Macquarie, Cities Project Perth has produced new knowledge on the risks of sudden-onset natural hazards to Australia's fourth-largest city, Perth.

This booklet is primarily targeted at emergency managers, risk managers and land use planners who are responsible for reducing natural hazard risk in Western Australia (WA). However, the booklet will also appeal to a wide range of others who have interests in natural hazards, risk assessment and risk management. The booklet provides an overview of the methods, key results and recommendations of Cities Project Perth that are explored fully in the main report included on CD with this booklet.

Introduction

This study is aimed at estimating the impact on the Perth community of several, sudden onset natural hazards. Major elements of the study included an assessment of:

- flood hazard in the Swan River and its tributaries;
- severe wind hazard in metropolitan Perth;
- earthquake risk in metropolitan Perth, with reference to the earthquake hazard in the wheat-belt (up to 200 km from Perth);
- coastline susceptibility to sea level rise from climate change in southwest WA, including Perth beach suburbs;
- socio-economic attributes that influence the capacity of the citizens of Perth to recover from natural disaster events; and
- potential tsunami impacts on the WA coastline.

This report aims to improve our understanding of the future costs to Perth as a result of earthquakes through direct calculation of earthquake risk. The report also provides estimates of hazard for floods and severe winds that, with additional work on loss estimation, would also provide quantitative information on the costs of these two hazards to WA's capital city.

The study also developed more than a dozen major spatial databases and risk assessment models, including the flood hazard model and comprehensive building and building footprint databases, digital elevation models (DEM) and hazard maps. These databases and models will facilitate further investigations on natural hazard risk in Perth in the future.

Natural hazard events in WA have caused much economic impact, personal hardship and loss of life. Dominant among these events has been a long succession of tropical cyclones that have caused many deaths. In early events, loss of life was significant. Improved warning systems, emergency management response capability, land management planning and building codes have reduced the risk of loss of life from natural hazards. In future events, losses may be highest from environmental impacts and economic losses apart from casualties.

The historic cost of natural hazard events in WA has been approximately \$62 million per year, according to the Bureau of Transport Economics (BTE, see Table 1). BTE's estimates of cost are based on an analysis of historical data largely in the period 1967–1999, with prices in 1999 dollars.

Table 1: Average annual cost of natural disasters (drawn from BTE, 2001).

	Average Annual Cost (\$ Million)						Total
	Flood	Severe Storms	Cyclones	Earth-quakes	Bushfires	Landslide	
WA	2.6	11.1	41.6	3.0	4.5	0.0	62.7
Australia	314.0	284.4	266.2	144.5	77.2	1.2	1087.5

The question arises as to how well the costs in Table 1 represent the true long term costs of natural disasters for WA. In their report BTE (2001) described at length the limitations of the data that were available to estimate the cost of natural disasters across Australia.

One of the difficulties of estimating accurate costs from a short history is that only a small sample of all of the events that could possibly occur have in fact been observed. Cities Project Perth has overcome some of the limitations of the relatively short historic record in assessing hazard and risk for Perth. The project has predicted, through computational modelling, the intensity, likelihood and variability of rare earthquakes, floods and severe winds that could impact on Perth. This approach extends our understanding of possible future events — information that is critical for improving emergency risk management.

Perth's natural hazard history includes damaging earthquakes, tropical cyclones, cool-season storms, thunderstorms, bushfires, riverine and flash floods, often accompanied by related phenomena such as storm surge, tornadoes, hail, lightning and dust storms.

Despite the wide range of natural hazards that have impacted on Perth and southwest WA, no single event in this region in the past 100 years has caused more than five fatalities, nor caused more than \$100 million in insured losses. This contrasts with many examples elsewhere in Australia's major urban regions, many of which have experienced significant losses from natural hazards. Examples are: 1967 Hobart fires, \$101 million; 1983 Ash Wednesday fires, South Australia and Victoria, \$255 million; 1985 Brisbane storms, \$299 million; 1974 Brisbane floods, \$328 million; 2003 Canberra bushfires, \$342 million; 1974 Cyclone Tracy, Darwin, \$837 million; 1989 Newcastle earthquake, \$1.1 billion; 1999 Sydney hail storm, \$1.7 billion. The loss figures quoted are insurance losses in 1999 dollars, except for the 2003 Canberra bushfires for which the losses are in 2003 dollars (IDRO, 2005).

The citizens of Perth and its hinterland would appear to live in a comparatively benign environment. Given this history of comparative stability in Perth, the question that begs to be asked is: What is the likelihood of Perth suffering higher losses in the future as a result of a major natural disaster?

This report provides answers to many key questions — answers that lay the foundation for addressing the current risk to Perth. The study area in metropolitan Perth is shown in Figure 1.

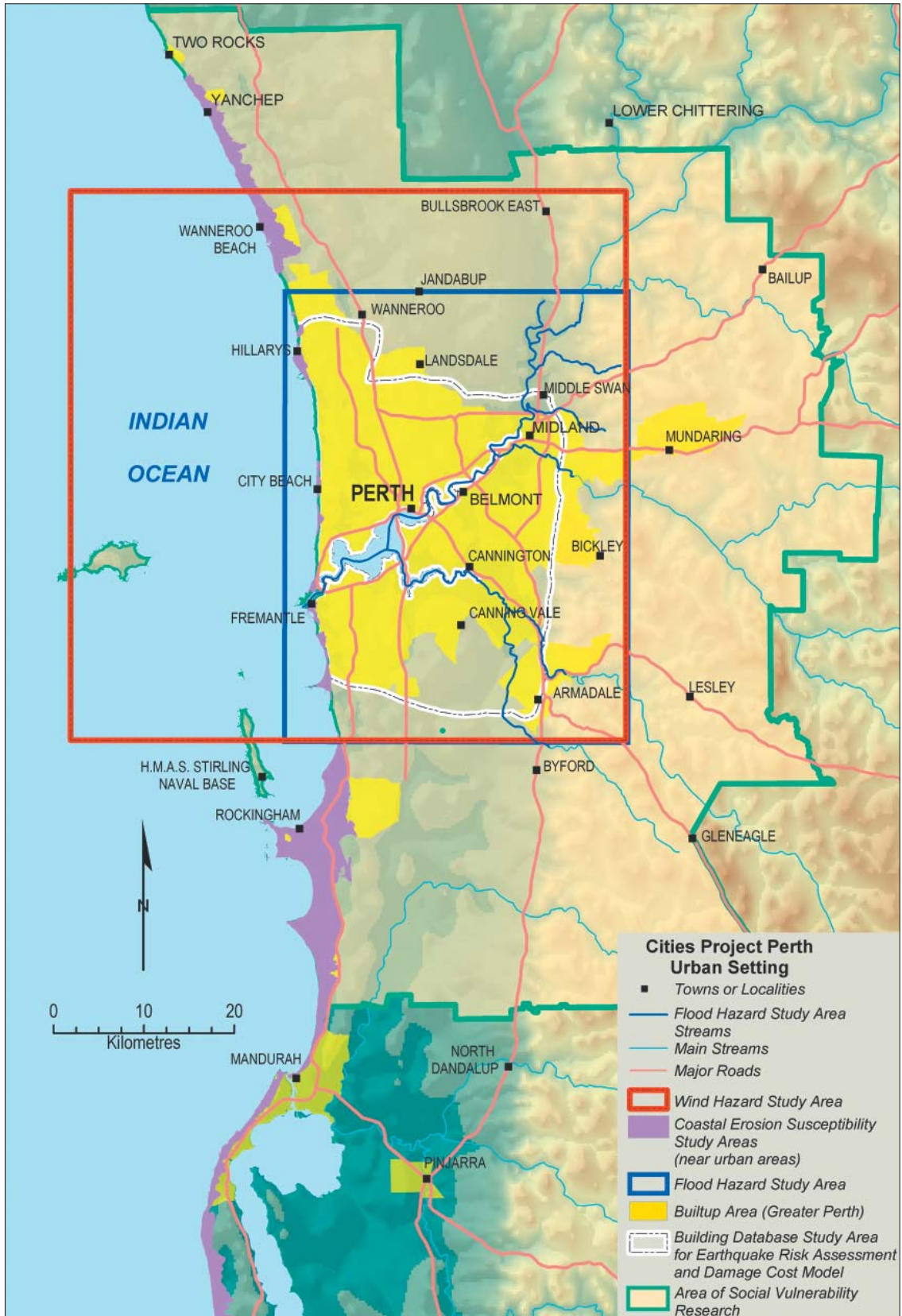


Figure 1: Study area — greater metropolitan Perth.

Meteorological hazards

The Perth region is subject to a range of meteorologically related hazards — winter storms, summer storms, floods, tropical cyclones, heatwaves and bushfires. Of these, cool-season storms are the most frequent hazard and, on average, they have had the greatest economic impact. Strong fronts cause winds of gale-force intensity near the coastal fringe of the southwest and produce mostly minor damage over a wide area. The more significant events also produce an increase in tidal levels known as a storm surge and can combine with large waves to cause coastal erosion. Wind damage, such as fallen power lines, typically occurs over a wide area, with the potential to cause significant power outages and traffic disruption. Fallen trees and branches often cause much of the property damage. Strong fronts may also spawn severe localised winds including tornadoes (Figure 2). Winds may be strong enough to unroof houses although such damage is typically confined to small areas. Historically, strong fronts posed a major threat to shipping activities. The loss of the Marquess of Anglesea and damage to other vessels during a gale in 1830 was described at the time as almost a ‘death blow to the infant colony’. During the May 1994 event almost one-third of Perth was without power at one stage and it took almost a week to fully restore power to Perth homes. The 16 May 2005 event is the most recent damaging example of these storms.

Floods and tropical cyclone hazards have impacted Perth in the past. If Perth were to again experience floods of the magnitude of those in 1862, 1872, 1917, 1926 and 1945, then the economic impact could be of the order of many tens of millions of dollars. However, Perth’s average annual rainfall has decreased in the past 40 years, which reduces the likelihood of such floods. Possibly Perth’s single greatest meteorological impact was cyclone Alby in 1978 when damage was estimated at \$39 million (1999 dollars). Strong winds damaged properties and fanned bushfires, while a storm surge and large waves caused massive coastal erosion and flooding in low-lying areas.

The fact that Perth has not experienced a major flood or cyclone impact in recent times has led to an increased level of complacency and lack of risk awareness. This highlights the need for describing and communicating the level of risk so people can be informed and prepared for the next major event when it occurs.

Although summer thunderstorms are much less common in Perth than in most other Australian cities, they have potential to be as severe as the Sydney hailstorm in 1999 that caused \$1.7 billion insured losses in 1999 dollars (IDRO, 2005).

Heatwaves, although viewed as a ‘passive’ hazard, have historically killed more people than any other meteorological phenomenon. However, the impact of heatwaves has reduced in recent years, particularly because of factors such as better housing design and greater awareness of the risk.

For people living in the hill-suburbs, and in semi-rural areas, bushfires are a major threat, particularly on hot and windy days from January to March. *The West Australian* described how a fire front burned through the hills town of Dwellingup:

“About 8.30 pm on Tuesday January 24, 1961, hundreds of terrified people watched helplessly as fire engulfed and destroyed most of Dwellingup, a timber milling town 100 km south of Perth. A short time before they had hurriedly abandoned their homes with only the clothes they wore. They watched a petrol station blow up, houses and motor vehicles explode into flames seconds after being abandoned and flames jump hundreds of metres ahead of the main front, fanned by 120 km/h winds. Some people jumped into a well to escape the inferno and workers trapped at a forestry mill lay face down on the ground and took turns spraying water on each other...”



Figure 2: Tornado damage at Naval Base, 8 June 1968 (Courtesy of The West Australian).

Severe winds

Extreme wind is one of the major natural hazards experienced in Perth, and cool-season storms have been the cause of the highest insurance losses in southwest WA in the past 40 years or so.

The recent cool season storm of 16 May 2005 is probably the most costly of these events since the May 1994 storm which caused insurance losses at the time of \$37 million (IDRO, 2005). Early estimates of the insured losses from the 2005 event are at least \$24 million (IDRO, 2005). *The West Australian* (17 May 2005) reported:

“Hundreds of insurance claims poured in from homes and business owners counting the costs of damage to fences and gates, roofs and walls caused by cyclonic winds and heavy rain from 6 am when the biggest cold front in years crossed the WA coast from Geraldton to Bunbury ... A Western Power spokesman said at the peak of the storm about 100,000 homes were without power ...”

Prior to this study, the understanding of future severe wind impacts on Perth was inadequate for emergency managers, planners and others who need an improved knowledge of the intensity, possible locations and potential impacts of future events. Many of the Perth localities that suffered damage in the 16 May 2005 storm are in exposed areas that this report has highlighted as having a higher wind hazard than other areas in Perth.

The Australian wind loadings standard (Standards Australia, 2002) places Perth in Region A — the lowest hazard region of four in Australia. The historical record from the weather station at Perth Airport was the sole dataset used in calculations for the wind loadings standard. However, the airport is some 20 km inland, and the windspeed conditions at this location are not wholly typical of conditions closer to the coast. This is important because the strongest regional winds in Perth, on average, arrive from the western quadrant, and they reduce in intensity as they travel inland across metropolitan Perth. This project has produced a simplistic ‘decay’ model to illustrate how these westerly winds reduce in intensity onshore

This report used a variety of tools to develop a series of comprehensive wind hazard maps that cover the major part of the metropolitan area. The tools included a statistical analysis of historical wind gust data from eight automatic weather stations across Perth, remote sensing and GIS techniques, and the new decay model. The project also developed terrain roughness, shielding and topography multipliers for eight wind directions using these techniques and models provided in the Australian wind loadings standard.

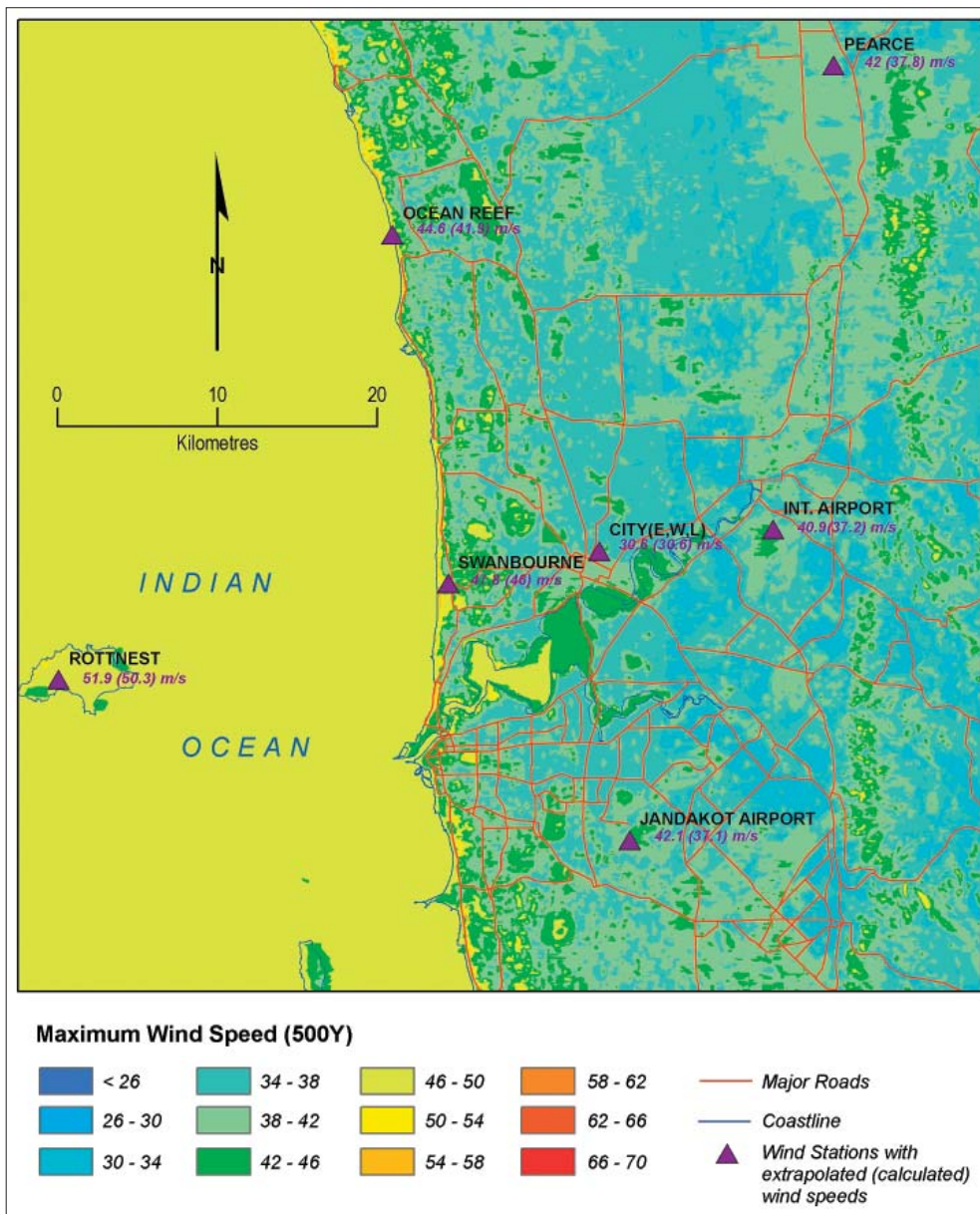


Figure 3: Maximum non-directional wind speeds with a 1 in 500 likelihood of being exceeded in any one year at any particular location (return period of 500 years). Wind speeds are expressed as 3-second maximum gusts in units of metres per second.

Wind speeds were estimated for annual likelihoods of exceedance of 1 in 50, 1 in 100, 1 in 500 and 1 in 1,000 at any one location. This means, for example, that the 1 in 50 scenario wind speed has a likelihood of 2% (or 1 in 50) of being exceeded in any one year. These annual likelihoods correspond approximately to return periods of 50, 100, 500 and 1,000 years respectively. These estimates were then interpolated to the entire study area in metropolitan Perth on a 25 by 25 m grid.

This analysis demonstrates that estimated wind speeds in several exposed areas exceed those set out in the Australian wind loadings standard.

The new maps provide valuable new information that can be applied to planning guidelines for building design and construction. The maps are also valuable for emergency managers because they highlight exposed areas that may be damaged in future severe-wind events. An example of these maps is shown in Figure 3. This example shows the wind gust speeds that have a 1 in 500 likelihood of occurring in any one year at any particular location.

Floods

Historically floods in the Swan River and its main tributaries have caused considerable damage in Perth, yet there is little information available on the economic costs of these events. Cities Project Perth has examined a range of river flood scenarios, including rare events, and improved the understanding of potential impacts from this significant hazard.

Previous studies of the flood potential in the Swan-Canning catchment utilised a relatively simple steady flow model to estimate the magnitudes of floods that could occur comparatively frequently. The rarest flood scenario that previously had been modelled and mapped had an annual exceedance probability (AEP) of 1%. That is, this scenario flood level had a likelihood of 1 in 100 (or 1%) of being exceeded in any one year.

Initial investigations by Cities Project Perth suggested that a more sophisticated unsteady flow model might reveal more information on flood hazard, particularly regarding the duration of inundation and water levels for more extreme events. An unsteady flow model was developed for the lower portion of the Swan-Canning catchment, encompassing the outer metropolitan Perth region. Modelling the river flows required the development of a 3-D image of the river channel, formed by generating a series of cross sections of the stream network, and detailed DEMs. Historical river flows and flood levels were used to calibrate the model. The model was validated by comparing the results with the Swan River flood plain modelling conducted by the Department of Environment (Water Authority of Western Australia, 1985).

In this study, predicted water levels for the 1% AEP flood event were found to be lower than those modelled previously. The variation in water levels can be explained in the differing methodology of this model and the earlier model. This report provides recommendations that will help reconcile the two models and reduce uncertainties in flood hazard estimates. Figure 6 illustrates the 1% AEP flood scenario model from this study.

This study modelled eight flood scenarios for AEPs ranging from 10% to 0.05%. That is, the most probable scenario event modelled had flood levels with a likelihood of 1 in 10 (or 10%) of being exceeded in any one year. The rarest scenario modelled had flood levels with a likelihood of 1 in 2,000 (or 0.05%) of being exceeded in any one year.

These results are valuable for establishing floodprone areas, land use planning, development controls for future development and for emergency response and recovery planning purposes.

Although Perth is currently experiencing a 40-year dry period, documented accounts of past floods demonstrate the potential impacts that this region could experience. Historical records of floods for Perth date back to July 1830 when the Swan River rose 6 m above its usual water level (Bureau of Meteorology, 1995). In July 1862, the Swan River rose to ‘unprecedented’ levels.

This ‘unprecedented’ flood was surpassed in July 1872 with Perth’s largest flood on record. Its estimated AEP was 1% and considerable property damage occurred along the Swan-Avon River (Bureau of Meteorology, 1995). *The Perth Gazette* and *WA Times* (26 July, 1872) described the flood as follows:

“In and about Perth, the water owing to the force of the incoming seas at the mouth of the river presented a scene of a great lake, all the jetties were submerged, the high roads to Fremantle covered, and passage traffic rendered impossible, quantities of sandalwood lying along the banks of river were washed away, and the inhabitants of the suburban villas on the slopes of Mt Eliza obliged to scramble up the hill sides to get into Perth ... The rise in the Helena was two feet three inches higher than in the great flood of 1862.”



Figure 4: Mill Point, South Perth in flood, July 1926 (Courtesy of the Batty Library 225145P).



Figure 5: Fremantle Railway Bridge destroyed by the July 1926 floods (Courtesy of the Batty Library 54902P).

The flood of July 1926 is perhaps the best-documented case of flooding of the Swan River (Figure 4 and Figure 5).

“The North Fremantle railway bridge was sagging yesterday as a train passed over it. Shortly afterwards, when it was only by a miraculous piece of good fortune that there was no passenger train on it, the structure began to collapse, and the effect of the swirling flood waters soon put it hopelessly out of commission. This is by far the most serious result of the recent floods, as it means that the ordinary Fremantle train service will be disorganised for at least a month ... the disaster will have far reaching effects on the shipping and commerce of the Port ... the southern side of the harbour was practically isolated as far as cargoes coming from Perth were concerned, at any rate, until the railways in the country districts were reorganised and goods trains could be frequently sent to Fremantle via Armadale (The West Australian, July 23, 1926).”

Although the destructive nature of flooding has not been seen for some time, significant infrastructure has been constructed in the Swan-Canning catchment in recent decades. Therefore, the impacts of any future floods in this catchment should not be underestimated.

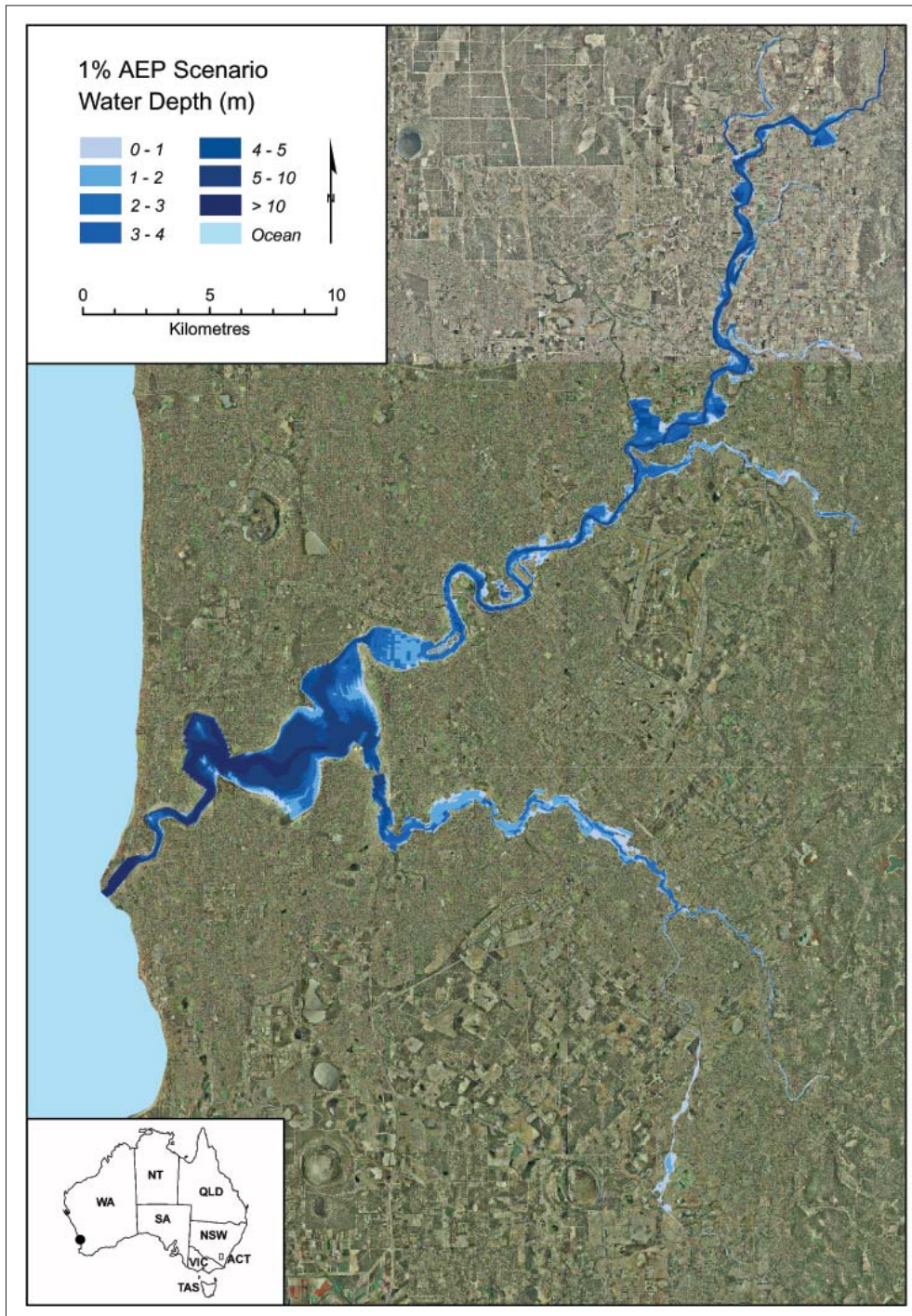


Figure 6: Flood inundation map for the 1% AEP scenario showing maximum water depth contours. These scenario flood levels have a likelihood of 1% (or 1 in 100) of being exceeded in any one year.

Earthquakes

Regions of WA exhibit high levels of seismic activity compared with most other regions of Australia. Several damaging wheat-belt region earthquakes, such as the Meckering Earthquake of 1968 and the Cadoux Earthquake of 1979, have been evidence of this elevated seismic activity. These events have generated a local awareness of the need to consider earthquake hazard in the construction of infrastructure both in the wheat-belt itself and in the Perth metropolitan area. However, none of these historical events has caused significant damage in Perth.

Previous studies of earthquake hazard in Perth had only evaluated the shaking potential on bedrock. The local potential for significant modification (amplification or de-amplification) of ground shaking within the Perth Basin itself, and the potential for infrastructure damage and associated socio-economic losses, had not been assessed.

Cities Project Perth undertook a systematic re-appraisal of the seismicity of the greater Perth region and an assessment of the earthquake risk posed within a Perth metropolitan study region. This significant work utilised several key inputs, including updated earthquake event catalogues, a complete revision of earthquake hazard assessment in southwest WA, assembly of GA's most extensive building database, and the development of building and contents cost models. Collectively, they have contributed to the most rigorous assessment of the seismic risk posed to Perth ever undertaken.

Earthquake hazard at the level of bedrock is a key reference parameter for use in structural design. The bedrock hazard determined in this study is similar to that published in the current earthquake loadings standard (Standards Australia, 1993) and that in the draft revised standard (Standards Australia, 2004). Significantly though, the area of elevated hazard is more extensive than previously identified and is wider in an east-west direction, extending further northwards and located closer to Perth (see Figure 7). This hazard progressively reduces in a westerly direction towards Perth, which means that the level of hazard for Perth itself is similar to that for Adelaide, Melbourne and Sydney.

Cities Project Perth undertook an extensive analysis of the properties and spatial distribution of the overlying soils, geological sediments and weathered rock (regolith) that typically amplify vibrations and increase the demands on certain building types. A comparison of the resulting regolith amplification factors to the observed ground motions from several earthquakes demonstrated that the dominant contributor to local ground motions in the Perth Basin was in fact the deep basin sedimentary rocks, and not the shallow surface material. The combined model has predicted the typical regolith hazard for low-rise structures founded on stiff soil to be higher than that defined in the current loadings standard. In contrast, the draft standard defines a similar, though slightly higher hazard. The earthquake hazard posed to taller structures on stiff soil sites was shown by this study to be much lower than defined in both the current and draft standards suggesting that the current standards are conservative for these. These important observations require further study before any hazard adjustments can be recommended.

The Perth earthquake risk assessment takes into account the vulnerability of the building structures. The predominant construction type in the Perth building stock differs from all other state capital cities of similar size. Almost 90% of buildings are of unreinforced masonry construction, which has historically performed less well than timber-framed construction in Australian earthquakes.

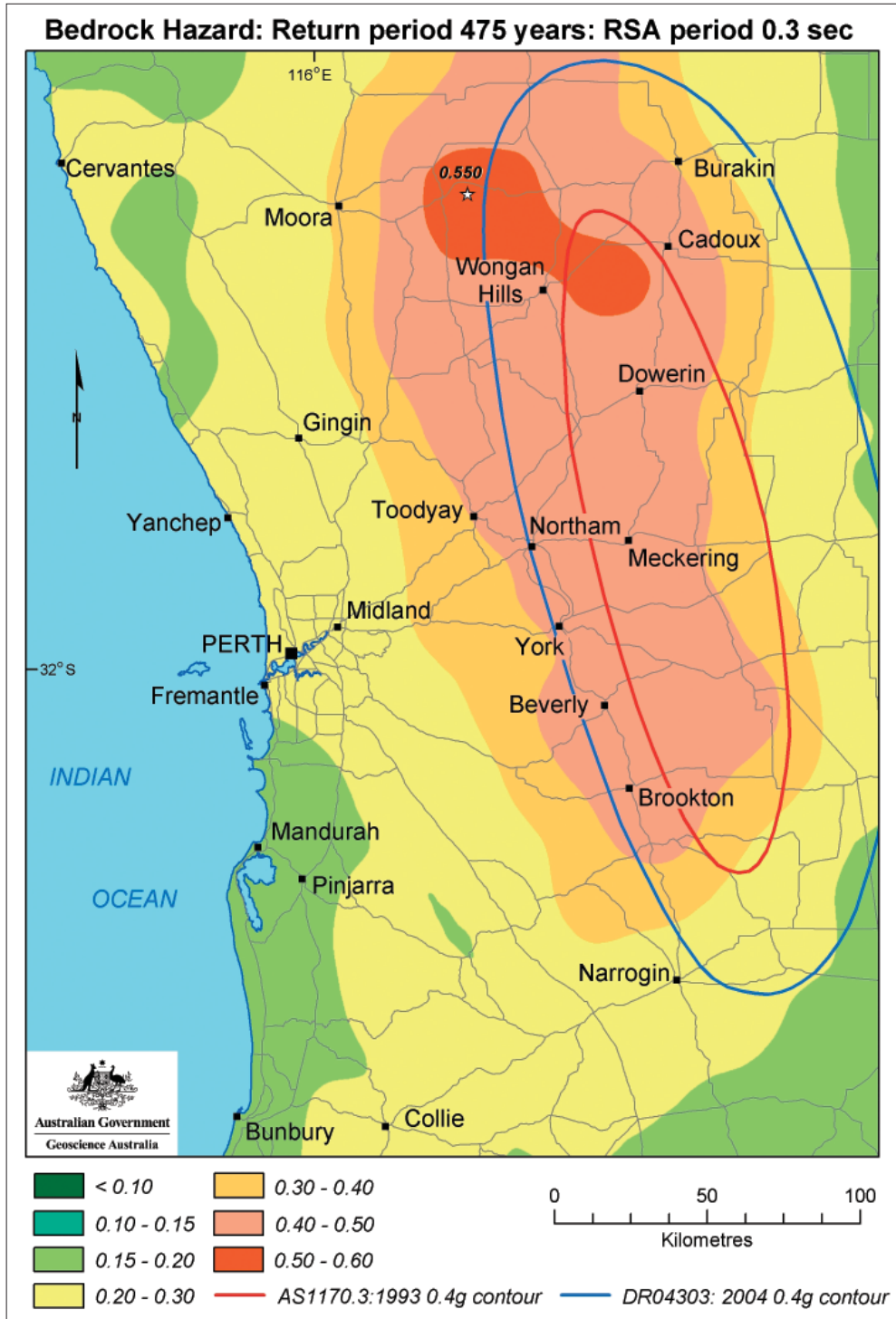


Figure 7: Bedrock level earthquake hazard (Response Spectral Acceleration at 0.3 s) for the Perth region having a likelihood of 1 in 475 of being exceeded in any one year (a return period of approximately 475 years). Units of acceleration are 'g', the acceleration due to gravity.

The earthquake risk calculated is presented at suburb level in Figure 8. It generally follows the variation in earthquake hazard, with the suburbs closest to the wheat-belt region in the east having the highest hazard due to their closer proximity to the region of higher seismic activity.

The Perth study region was assessed to suffer an average annual direct economic loss of 0.04%. That is, on average, an estimated loss of 0.04% of the total value of all buildings and

contents in the study area accumulates each year. This result does not mean that earthquakes will cause this level of damage and loss each year, but rather represents a long term average for the impact of earthquakes in the region. The accumulated losses are predicted to be realised some time in the future. While Perth has not historically experienced this level of annual average loss, the return periods for the larger events that represent the bulk of the loss potential would not typically have been experienced during Perth's period of settlement.

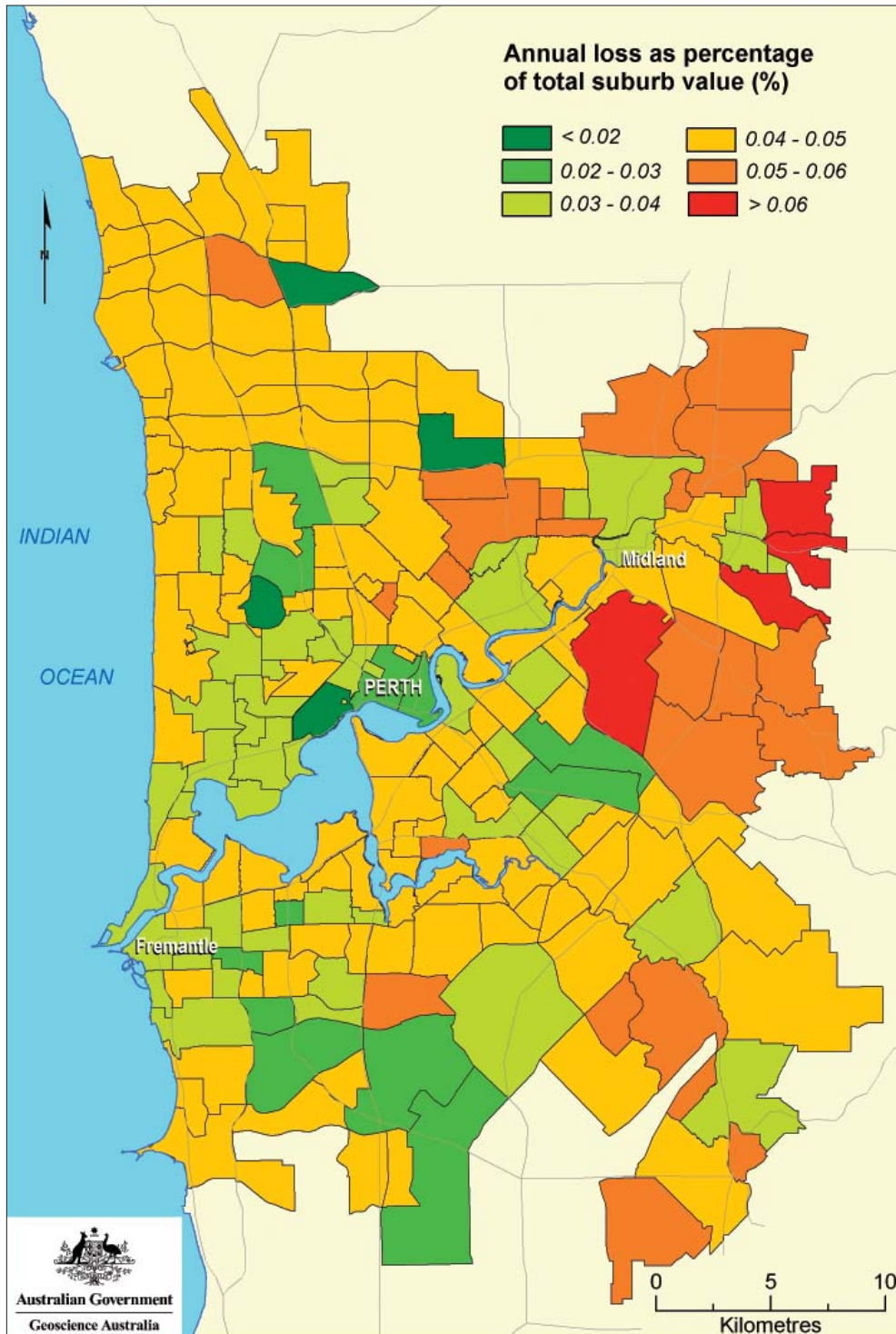


Figure 8: Annualised earthquake losses at suburb level in the Perth study region. Losses are expressed in terms of total value of buildings and their contents.

The rare, but high-impact nature of earthquake risk in the Perth region strongly indicates that the most effective means of mitigation are appropriate building design and construction standards, and adequate insurance levels.

Coastal erosion due to long-term sea level rise

The latest Intergovernmental Panel on Climate Change (IPCC) report indicates that global warming will cause sea levels to rise over the next 100 years (IPCC, 2001). This sea-level rise will cause extensive coastal erosion of many sandy beaches. Many of the world's sandy coastlines have retreated in the past few decades and this is likely to continue into the future. With extensive deposits of coastal sand, some of which host significant urban developments, Perth has already experienced coastal erosion events and will encounter the risk from sea level rise in future years (Figure 9).

Cities Project Perth investigated the susceptibility of the southwest WA coastline for erosion due to long-term sea level rise. An innovative technique was developed to assess potential erosion. This work was undertaken to improve information for planners and to provide recommendations for further research based on present techniques and data availability. In order to present meaningful results along a 300 km section of coast, the study area was divided into sectors that were defined primarily by the availability of data.

The analysis in this report is based on an integrated investigation of the Swan coastal system, comprising an examination of the geomorphology of the region in the context of coastal dynamics and sediment budgets. The key stage in this process involves a number of regional GIS datasets that are used to reconstruct the three-dimensional architecture of the shoreline geology, in order to comment on the potential erosivity of the underlying 'competent' limestone and shoreline.

The natural foundation of the Swan Coastal Plain is a series of submarine to emergent limestone ridges, upon which coastal dunes and beach sediments are deposited. The relative coastal erosion hazard varies considerably along the Swan coast. In some areas coastal erosion is likely to be considerable over the next century and, in other areas, minor erosion may occur, but will likely be balanced by input of sand through longshore drift. There are also some areas where coastal erosion is highly unlikely because the underlying limestone is situated well above sea level.

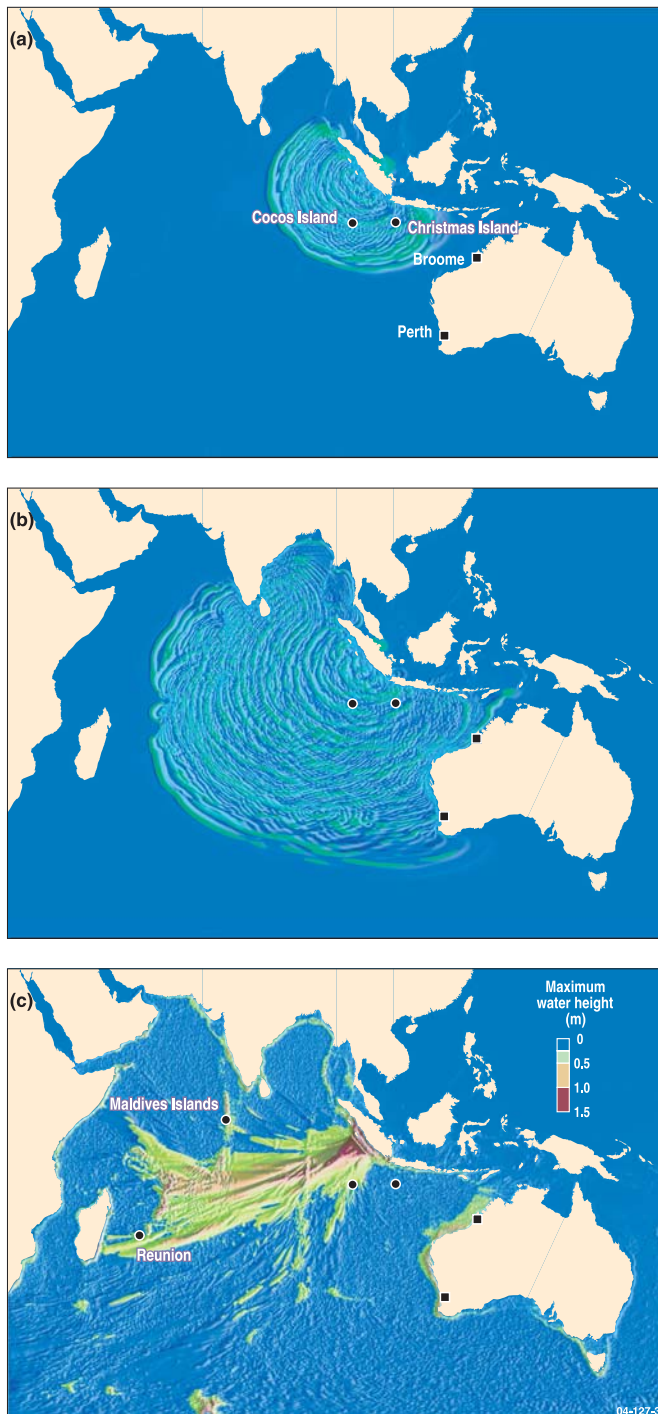


Figure 9: Coastal erosion on Perth's beaches as a result of Tropical Cyclone Alby in 1978 (Courtesy of The West Australian).

The Bunbury to Mandurah region of the Swan coast appears to be the region most susceptible to coastal erosion over the next century. This is because the limestone is preserved below sea level. This region is not well sheltered from offshore swell, and marine sediments from this region are transported north. In contrast, the shoreline to the north of Hillarys (see Figure 1) does not appear to be susceptible because limestone is preserved above sea level along the major part of the coast, and the beaches are well sheltered by three lines of offshore reefs.

Based on an IPCC (2001) estimate of median sea level rise of 48 cm over the next 100 years, a quantitative assessment of potential erosion in the Swanbourne Beach area (see Figure 3) suggests that the shoreline may recede by as much as 100 – 130 m over the next century. This would have little impact on existing infrastructure at the site, but is significantly greater than anticipated in the *Western Australian Planning Commission Statement of Planning Policy No. 2.6 — State Coastal Planning Policy*. Quantitative assessments should be undertaken throughout the Swan Coastal Plain, and improvements in data availability (e.g. site-specific wave and substrate data) would facilitate these.

Tsunamis



Even before the great Sumatran earthquake and tsunami of December 2004, it was recognised in Cities Project Perth that Indonesian tsunamis could have significant impacts in WA, including the Perth coastal region. An appendix on tsunami hazard potential for WA was developed for the Cities Project report (included on CD with this booklet). This appendix provides an overview of the historical impacts of tsunamis in WA and comments on the potential for this hazard to impact on southwest WA coastal communities in future.

Tsunamis are usually generated by earthquakes in subduction zones, where one of the rigid, tectonic plates that comprise the Earth's surface dives beneath another. The subduction zone that presents the most direct tsunami hazard to WA lies offshore Indonesia, to the northwest of Australia.

Figure 10: Numerical modelling results of the propagation of the tsunami associated with the 1833 Sumatra earthquake throughout the Indian Ocean.

Recent massive earthquakes off the coast of Sumatra (December 2004 and March 2005) greatly heightened awareness of the tsunami hazard among the Australian public, especially in WA. While earthquakes off Java have caused large tsunamis that have reached heights of 4 to 6 m on Australia's northwest coast, the tsunami source zone that poses a greater hazard for the Perth area lies off the coast of Sumatra.

As pointed out by GA (2004), great thrust earthquakes that can generate massive tsunamis have occurred off Sumatra in historic times. The 2004 earthquake occurred to the northwest of these previous historical earthquakes and, unlike the earlier events, this led to a severe tsunami impact across the region. Although all the massive earthquakes off Sumatra have the potential to generate tsunamis that can devastate Sumatra, and impact upon the entire Indian Ocean basin, there is considerable variability in the degree to which these large earthquakes can generate tsunamis. This was demonstrated by the March 2005 earthquake which, despite being the seventh largest earthquake ever recorded, generated only a local tsunami with little impact outside Indonesia.

Although it is impossible to predict when the next large earthquake off Sumatra will occur, the risk of another major event occurring further southeast along the Sumatra subduction zone in our lifetime has been heightened following the occurrence of the 2004 and 2005 events. This heightened risk is due to a mechanism called 'stress triggering', in which the change in stress field due to a large earthquake adds to the stress already accumulated on adjacent faults, causing them to fail in a new earthquake. This explanation may account for the occurrence of the March 2005 earthquake only three months after the massive 2004 event.

Although there are other sources of tsunami hazard for the Perth area, the most likely source is earthquakes in the Indonesian region.

The Australian Government announced, in its 2005–06 budget, a measure to develop the Australian Tsunami Warning System that will provide tsunami warnings to Australia and the region.

The analysis undertaken so far of potential tsunami impacts in Australia indicates that the WA coastline may be one of the most exposed areas of the coastline. Therefore it is important that the risk to southwest WA communities from this natural hazard is investigated further as a part of this major, multi-agency initiative.

Community recovery

Researchers in Cities Project Perth have improved risk assessment results for Perth by developing and implementing models that incorporate socio-economic factors.

Technical risk assessments have not previously incorporated models for community recovery following a natural disaster event. Cities Project Perth has addressed this by incorporating an exploratory study of community recovery to emphasise the value of including social issues with any geological, engineering and economic assessment of natural hazards in Perth.

The factors influencing recovery are complex. However, key aspects of recovery are recognised by researchers, practitioners and the recent Council of Australian Governments (COAG) Review into Natural Disasters (High Level Group, 2002). These aspects can be incorporated into natural hazard risk assessments for communities. Many factors influence

community recovery, including local economic activity, business interruption, environmental impacts, infrastructure, household financial capacity, social networks and distance to services. Cities Project Perth undertook a study of the last three factors using national-level social data. This study of community recovery provides insights into some of the attributes that may influence the recovery of the Perth community from a natural hazard event.

The three factors show that the Perth community has many characteristics that will influence the recovery process following a natural hazard event. While the 'household financial capacity', 'social networks' and 'distance to services' only skim the surface of the many factors influencing recovery, the framework presented in this chapter shows that Perth has favourable attributes that will influence and assist the recovery process of many households.

HOUSEHOLD FINANCIAL CAPACITY

The capacity to buy house insurance, access temporary accommodation, build a new house, purchase new goods, and take time off work contributes to the recovery of a person or a household from a natural hazard event. Limited financial options can contribute to stress that, in turn, can adversely affect people. It is, therefore, important to know which households may require financial assistance in both the medium and long term.

The ABS data from the *Socio-Economic Index For Areas on Economic Resources* rank households according to their financial capacity. For metropolitan Perth, the areas of low household economic resources, and therefore the areas that may need financial assistance during the recovery process, are highlighted in this report.

SOCIAL NETWORKS

Social networks include interactions with neighbours, friends, family and the wider community and are an important part of social capital. The World Bank describes this as 'the relationships, the attitudes and values that govern interactions among people and contribute to economic and social development'. Social networks can be found in sport and cultural event participation, and through contacting family and friends, providing favours and volunteering. The strength of these networks may influence a community's capacity to recover after a natural hazard impact.

The General Social Survey (ABS) indicates that WA has strong informal networks, which suggests that, for many in Perth, recovery may involve a strong utilisation of friends, family, neighbours and informal organisations. Almost all residents in the General Social Survey indicated that they can ask someone outside of their home for assistance in an emergency, while 83% could access emergency money within a week if needed. These factors of strong social networks, combined with the 36% of Western Australians who indicated that they volunteer, are important during recovery from natural disaster (Figure 11). Such information can assist recovery managers in tailoring recovery programs and services for people in the Perth community.

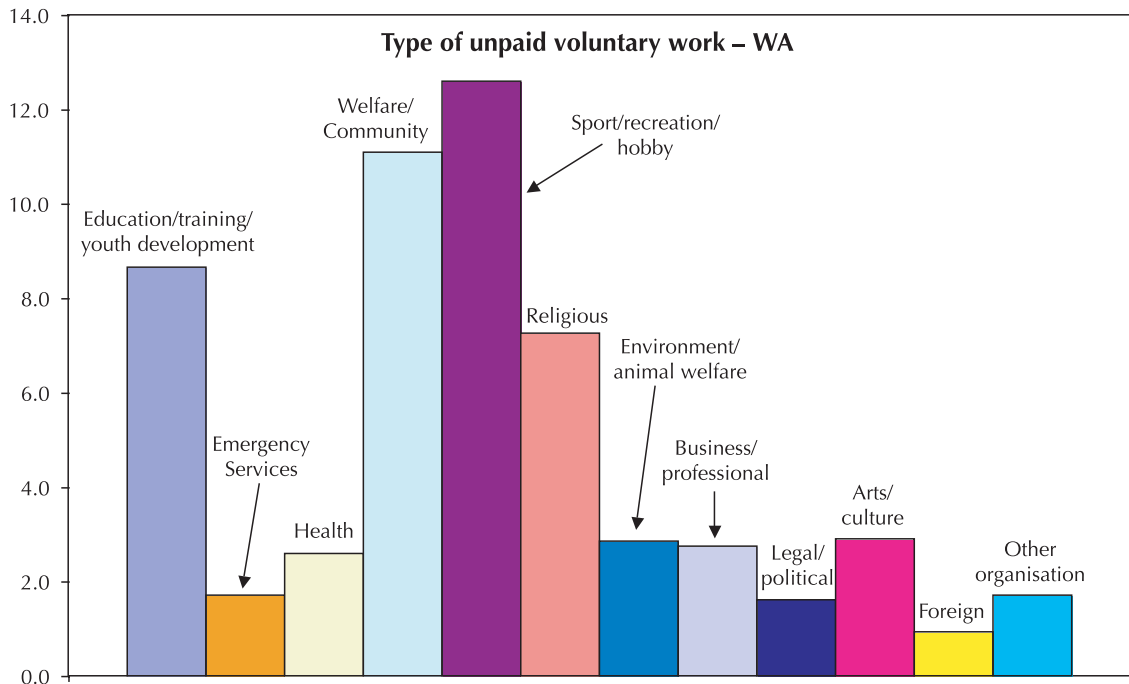


Figure 11: 36% of Western Australians surveyed in the General Social Survey undertook volunteer work in 2002. Of these, more were likely to be involved in a sport, recreation or hobby, or welfare or community activity. Volunteerism is an important social network and can be of great value to a community's recovery after a natural hazard impact.

DISTANCE TO SERVICES

Distance to services is an important factor in the recovery of many communities, particularly outside major cities. Following a natural disaster, people may need regular visits to medical and welfare services, so the ability to access these is an important factor in recovery. Reconstructing houses, rebuilding local playgrounds and reconnecting water, electricity and gas depends, among other factors, on the distance between the disaster and the available materials and workforce.

Perth communities are generally close to the major services that would be needed in the recovery process. Residents of the outer communities of Armadale, Kalamunda, Kwinana, Rockingham, Swan and Wanneroo are further from major services. If transport routes are affected by a natural disaster, people in these communities will be more physically isolated than those in central areas.

Key results

One innovative feature of Cities Project Perth is its use of predictive models to provide information on rare events with high impacts, not seen in the historic record, that could occur in the future.

The model results show that Perth could experience an extremely rare earthquake with high socio-economic losses. Similarly, the analysis of severe winds indicates that a damaging cool season storm could impact broadly on exposed areas of Perth with an intensity not recorded previously. The flood modelling also shows that higher water levels could occur for scenarios that are rarer than those observed in the past. In this way, Cities Project Perth has provided important new information for emergency risk management.

The key results of this works can be summarised as follows.

SEVERE WIND HAZARD

- The severe wind hazard calculated for Perth airport is in close agreement with the wind hazard for Perth in the Australian wind loadings standard (Standards Australia, 2002). However, Perth airport is well inland, and return-period wind speeds in the standard are most applicable to Perth sites some kilometres inland. This study has produced a richness of wind hazard estimates extending across metropolitan Perth, including exposed coastal and other areas.
- Across metropolitan Perth, severe wind hazard varies considerably. Areas exposed to wind face a measurably higher wind hazard than the Australian Standard describes. These areas lie along the coast and on exposed shores of the lower reaches of the Swan River.

FLOOD HAZARD

- Eight flood scenarios were modelled for the Swan River and its tributaries with AEPs ranging from 10% to 0.05%. That is, the modelled flood levels have likelihoods of 1 in 10 to 1 in 2,000 of being exceeded in any one year. These likelihoods correspond to return periods of approximately 10 years to 2,000 years. Previously, only the 1% AEP scenario had been developed using a less complex steady flow model. The new model provides emergency managers and planners with important new risk information for scenarios with a large range of return-periods.
- While there are six major catchments in the study area that contribute flow to the Swan River, the Avon catchment is by far the most dominant flow contributor. Flows from the Canning and Southern rivers also contribute significantly to flows in the Swan River.
- Due to Perth's lengthy dry period, it has been difficult to validate the model against observed events. Since all streamflow gauging stations at the outer boundaries of the model became operational, only two major flows (in 1983 and 1987) have occurred.

EARTHQUAKE RISK

- Overall, the estimates of earthquake hazard on rock foundation in Perth and in southwest WA are similar to those in the current and draft Australian earthquake loadings standards.
- The results of this study suggest that, on average, greater metropolitan Perth could suffer an estimated economic loss of around 0.04% per year, expressed in terms of the total value of all buildings and contents in the study area.

- About three-quarters of the earthquake risk in the study region is from events that have annual probabilities of occurrence of 0.004 or less (return periods of 250 years or more). This suggests that about three-quarters of the risk to metropolitan Perth is from rare events with major or, in extreme cases, catastrophic impacts. The long-term nature of earthquake risk to Perth and regional communities to the east is likely to be realised very rarely. However, on such occasions, consequences could be relatively high. This provides a motivational challenge for emergency managers to remain vigilant, and for appropriate risk treatments, such as adequate insurance, to remain in place.
- Perth's residential building stock is unusual because it is predominantly unreinforced double brick construction, with only a small proportion of framed timber construction. Unreinforced masonry is significantly more vulnerable than framed timber construction.
- The area of elevated hazard in the wheat-belt is considerably more extensive than identified in the current earthquake loadings standard. This area is wider in an east-west direction, extends further northwards and is generally located closer to Perth.

INDICATORS OF SOCIAL RESILIENCE FOR RECOVERY

- Perth households and the broader community have many characteristics related to 'household financial capacity', 'community and social networks' and 'distance to services' that will favourably influence the recovery process following a natural hazard event. However, these indicators are only three of many influencing recovery.
- The majority of households in metropolitan Perth have good economic resources, relative to the rest of Australia. Twenty-nine of 30 Local Government Areas (LGAs) in the Perth Statistical Division rank in the top 50% of Australian LGAs in the ABS *Index for Economic Resources*. Of these 29 LGAs, 22 rank in the top 25% nationally. Therefore, in the event of any natural disaster that has direct and widespread effects on residences, the community has many households that can draw on their economic resources to assist with their recovery. However, it must be noted that there are some areas, or clusters, of households within suburbs that may experience difficulties in the recovery process due to limited financial capacity.
- The ABS *General Social Survey* indicates a strong community network in WA. This suggests that, for many in Perth, recovery may involve a strong utilisation of friends, family, neighbours and informal organisations, such as community groups or sporting clubs.
- People in some outer suburban areas may have further to travel to access major services than those living more centrally. These major services, whether they be medical, welfare, social or cultural, can be important factors in influencing the recovery of these outer communities. This information may assist recovery managers in understanding some access/transport issues for people living in this part of the Perth metropolitan community.

POTENTIAL IMPACT ON THE SOUTHWEST WA COAST FROM SEA LEVEL RISE DUE TO CLIMATE CHANGE

- It is highly likely that coastal erosion will have a significant impact on coasts around the globe, including Australian coasts, over the next century.
- Three sections of the Fremantle to Hillarys coastline appear to be susceptible to coastal erosion: Port/South Beach; Swanbourne to Floreat Beach; and the Pinaroo Point area. The hazard decreases from south to north, primarily due to the northward net longshore drift.

- Given a sea level rise of 18 cm over the next 50 years and 48 cm over the next 100 years (IPCC, 2001), Swanbourne Beach is likely to erode approximately 40 – 50 m and 100 – 130 m respectively. However, the impact of modelled recession at Swanbourne Beach is not significant due to an absence of major urban infrastructure. Similar erosion at the other vulnerable localities would have a much greater impact.
- The Bunbury to Mandurah coastline is the section of Swan coast that appears to be most susceptible to coastal erosion over the next century. This is because: the Tamala Limestone is preserved below sea level; this sector is not well sheltered from offshore swell; and marine sediments from this region are transported north.
- The majority of the Mandurah to Fremantle coastline does not appear to be susceptible to coastal erosion over the next century, despite the fact that the Tamala Limestone is preserved below sea level across the majority of the area. This is due to the fact that this coastline is the primary Swan region where marine sediments are being deposited.
- The Hillarys to Yanchep coastline appears to be least susceptible to erosion over the next century as Tamala Limestone is preserved above sea level along the majority of the coast, and the beaches are well sheltered by three lines of offshore reefs.
- The Cape Naturaliste to Bunbury area may be impacted by coastal erosion associated with long-term sea level rise.

Risk management recommendations

The broad-ranging information developed in this study presents new opportunities to improve risk assessment and risk management in Perth and the surrounding region. The suggested risk management options are largely focussed toward State and Local Government action that will also involve many other public and private sector agencies.

Listed below are the main risk management options recommended by the study.

1. Use the **wind hazard maps**, the **wind hazard multipliers** for topography, terrain roughness and shielding, and the **earthquake hazard maps** for metropolitan Perth and the Perth region:
 - to review, improve and complement the design and construction guidelines set by state and local governments for severe winds and earthquakes; and
 - as a source of information for response planning and response.
2. Additionally, use the **wind hazard maps** and the **wind hazard multipliers**:
 - as a basis for further research on severe wind risk in Perth; and
 - as an aid to bushfire risk assessment at the Perth urban/rural interface.
3. With regard to the **flood model** developed for the Swan and Canning Rivers:
 - acquire and apply further data to refine, revise and recalibrate the model;
 - collect systematic data during future major flood events;
 - review the model for river flooding in the Swan and Canning Rivers after each major event; and
 - until adequate data are available to further refine and calibrate the new model, continue to use the Department of Environment's 1% AEP floodplain mapping as the basis for ensuring that future development has adequate flood protection.

4. To reduce **earthquake risk**:
 - enforce the compliance of all new structures with current earthquake loadings standards; and
 - promote the uptake and maintenance of adequate insurance against earthquakes.
5. An additional mitigation option for **earthquake risk** is to:
 - protect facilities such as police, SES, fire and ambulance stations and hospitals that provide essential services following any earthquake event. These facilities could be examined by suitably qualified engineers on a site-by-site basis to assess their performance under earthquake loadings. This recommendation is pertinent for wheat-belt communities in the southwest seismic zone.
6. To improve understanding of the socio-economic cost of natural hazards to the community, relevant WA Government agencies and Local Governments should:
 - participate in **national research in social vulnerability models** as they apply to the sudden impacts of ‘all hazards’.
7. To improve decision making and reduce uncertainties about the potential for future **coastal erosion due to sea level rise**:
 - focus future research on the Bunbury to Mandurah sector, the Cape Naturaliste to Bunbury sector, and the Port/South beach area of Fremantle;
 - improve data availability, particularly sector specific wave data and more detailed subsurface data; and
 - improve the sophistication of current models to allow for calculation in areas where the nearshore/offshore includes competent substrate.

Cities Project Perth developed more than a dozen major spatial databases on hazards and the vulnerability of the Perth built environment during this study. The WA Land Information System and the Department of Land Information are playing leading coordination roles in ensuring that, where appropriate, the Cities Project Perth databases will continue to be maintained, improved and made available to users through the WA Shared Land Information Platform (SLIP).

Future research could focus on improving the models that have been used. This will allow for the variability in the models to be decreased, which will most probably result in a decrease in the estimates of risk.

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