Chapter 1: INTRODUCTION

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1.1 Cities Project Perth

Cities Project Perth is a natural hazard risk assessment study of the city of Perth by Geoscience Australia (GA) and its Federal, State and Local collaborators. Cities Project Perth has produced authoritative knowledge on the risks from sudden-onset natural hazards in Australia's fourth largest city and the capital of the state of Western Australia (WA).

Cities Project Perth is the most recent multi-hazard risk assessment undertaken by GA and collaborating agencies (notably the Bureau of Meteorology (BOM) and local governments), following earlier studies of the Queensland cities of Cairns (Granger et al., 1999), Mackay (Middelmann and Granger, editors, 2000), Gladstone (Granger and Michael-Leiba, editors, 2001) and South-East Queensland (Granger and Hayne, editors, 2001). GA also published the single-hazard report *Earthquake Risk in Newcastle and Lake Macquarie*, New South Wales (Dhu and Jones, editors, 2002).

This study is aimed at estimating the impact on the Perth community of several sudden-onset natural hazards. The natural hazards considered are both meteorological and terrestrial in origin. The hazards investigated most comprehensively are riverine floods in the Swan and Canning Rivers, severe winds in metropolitan Perth, and earthquakes in the Perth region. Some socioeconomic factors affecting the capacity of the citizens of Perth to recover from natural disaster events have been analysed and the WA data compared with data from other Australian states. Additionally, new estimates of earthquake hazard have been made in a zone of radius around 200 km from Perth, extending east into the central Wheatbelt. The susceptibility of the southwest WA coastline to sea level rise from climate change has also been investigated. A commentary on the tsunami risk to WA coastline communities is also included.

1.2 Aims of Cities Project Perth

The aims of Cities Project Perth were stated in the Project Agreement in 2001:

> *The goal of [the] Cities Project is to ascertain the vulnerability of Australian urban communities to the effects of geological and meteorological hazards (collectively referred to as geohazards), thereby providing emergency managers and planners with information and decision support tools that will aid in the mitigation of geohazards. The objective of the WA Cities Project is to improve the methodology, develop decision support tools and generate information to assist in the mitigation of geohazards.*

This statement of aims has remained relevant throughout the project. However, we can be more specific about these aims, and also broaden our original expectations from the project, reflecting the development of the project over time and developments in natural disaster risk assessment and mitigation nationally.

The historic cost of natural hazard events in WA has been approximately $62 million per year, according to the Bureau of Transport Economics (BTE, 2001). See Table 1.1. These estimates of cost by BTE are based on an analysis of historical data largely in the period 1967-1999, with prices in 1999 dollars.

Table 1.1: Average annual cost of natural disasters (drawn from Table 3.1, BTE, 2001)

	Average annual cost ($ million)						
	Flood	**Severe storms**	**Cyclones**	**Earthquakes**	**Bushfires**	**Landslide**	**Total**
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 1.1 represent the true costs of natural disasters for WA. BTE (2001) described at length the limitations of the data that were available to estimate the cost of natural disasters across Australia. It is thought that the costs of natural hazards in WA have not been fully recorded, for example through the Natural Disaster Relief Arrangements and preceding arrangements, and therefore the costs to WA have been underestimated (Jo Harrison-Ward, verbal communication, 2004).

This report aims to improve our understanding of the future costs to Perth for 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 provide quantitative information on the costs of these two hazards also.

Such new information on natural hazard risk to Perth provides input into the decision making processes by WA and local government community, planning and emergency management agencies with regard to setting priorities in:

- prevention, planning response and recovery (PPRR);
- risk management of the natural hazards against each other, for example floods against severe winds;
- applying resources in the most cost effective way in Perth to reduce the impacts of natural hazards, prioritised against other parts of WA; and
- applying resources to risk management of natural hazards, against applying resources to other 'all hazard' events that affect communities.

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. BTE's estimates of the costs of natural disasters are largely based on the events that occurred in a short, historic 'snapshot' of time (1967–1999). Few rare disaster events (those with long return periods and major consequences) are likely to have occurred in this 33-year period. Some rare events did occur in the period considered by BTE, such as cyclone *Tracy*, the 1989 Newcastle earthquake, and the 1999 Sydney hailstorm. These three events dominated the costs of disasters considered by BTE, contributing 31% of the total costs of all events in Australia in that period.

We illustrate the limitations of a short historical catalogue with a couple of examples. Consider a natural hazard event that has an annual probability of occurrence of 1% (that is, a return period of 100 years). The probability that this event would occur at least once in any 33-year period is about

28%, under certain assumptions[1]. An event with an annual probability of 0.2% (that is, a return period of 500 years), has only a 6% probability of occurring at least once in any 33-year period.

This report aims to overcome some of the limitations of the relatively short historic record by predicting, through computational modelling, the intensity, likelihood and variability of rare earthquakes, floods and severe winds that could impact on Perth, thus extending our understanding of possible future events.

Nationally, after the commencement of Cities Project Perth, a High Level Group reporting to the Council of Australian Governments (COAG) identified a 'lack of independent and comprehensive and systematic natural disaster risk assessments' and made recommendations to COAG to improve this situation, including 'develop and implement a five-year national programme of systematic and rigorous disaster risk assessments' (Reform Commitment 1, High Level Group, 2002). Cities Project Perth partners are active in pursuing this goal. The needs of government and non-government emergency managers and planners for improved information on natural hazard risk to Perth have much in common with these needs expressed at a national level.

More pointedly then, the aims of Cities Project Perth are to:

- produce authoritative information on the risk to greater metropolitan Perth from important sudden-onset natural hazards;
- improve the evidence base for implementation of emergency management and planning policy and practice for the benefit of government and non-government sectors;
- provide databases and datasets on hazard, exposure and vulnerability to be incorporated in databases for emergency management and planning policy and practice in WA;
- produce foundation information on flood, coastal erosion and wind hazard for further risk assessment studies by the WA, local or federal governments;
- develop methodologies, databases and models that can be applied to estimating hazard, vulnerability or risk from other types of hazards in Perth, for example human-caused hazards, or that can be applied elsewhere in Australia to estimate hazard, vulnerability or risk from any natural or human-caused hazard;
- produce estimates of hazard and risk that add to systematic and rigorous knowledge of natural hazard risk from a national perspective.

1.3 Participating Agencies

Full partners in Cities Project Perth are the WA Fire and Emergency Services Authority (FESA), the WA Department for Planning and Infrastructure (DPI, formerly the WA Ministry for Planning), the BOM through its WA Regional Office, and GA. A Project Agreement was signed by these agencies in June and July 2001. The WA Department of Environment (DOE, formerly the Water and Rivers Commission) also participated fully in this study throughout its duration although the department was not a signatory to the agreement.

The Local Governments that are partly or wholly contained in Greater Metropolitan Perth comprise a key client group for the project outputs. Their participation in the project was largely coordinated by FESA. Several Local Governments directly contributed data or advice on hazards and community vulnerability. These included the Cities of Perth, Wanneroo, Joondalup and Swan.

[1] The stated probability of exceedance applies for events that follow a Poisson distribution. That is, events occur randomly, with no 'memory' of the time, size or location of any preceding events (Kramer, 1996).

The WA State Emergency Management Committee (SEMC) and the WA State Mitigation Committee also played an advisory and guiding role through the duration of the project. The Lifelines Services Group and the Lifeline Services Operational Group, both subcommittees of the SEMC, also provided expert advice to the project.

The valuable contributions of many other agencies and individuals are accredited in the Acknowledgements section.

1.4 Historical Events in Southwest WA

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 in early years caused many deaths.

> *There have been several historical Western Australian cyclones causing a significant loss of lives at sea. In March 1912 over 150 lives were claimed at sea. The coastal passenger vessel the* Koombana *was lost after setting out from Port Hedland to Broome with about 140 people on board. At least another 15 people died as other vessels went down in the same event…*
>
> *There have been two events in WA when about 140 men perished in pearling fleet disasters:*
> *- 22 April 1887 off Ninety Mile Beach*
> *- 26-27 March 1935 near the Lacepede Islands off Broome*
>
> (BOM, 2005).

Cyclones causing major economic losses in WA since around 1970 have included *Madge* (1973), *Joan* (1975), *Alby* (1978), *Hazel* (1979) and *Vance* (1999). Their cost in WA in the years 1967-1999 was estimated by BTE to be almost two-thirds of the total costs of natural disasters in WA (Table 1.1). Other natural hazards have had significant impacts on WA including severe storms, bushfires, earthquakes and floods.

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. The most significant historical events in the Perth region are listed in Table 1.2. Most of the events in the table, and many others, are described more fully in the following chapters.

The criteria for including events in Table 1.2 were:

- events caused impacts on communities within about 200 km of Perth, and may also have had a significant impact on metropolitan Perth; and
- the estimated losses from individual events totalled more than $5 million in 1998 prices; or
- the estimated number of deaths from individual events totalled five or more.

Table 1.2: Significant natural disaster events in Perth region WA

Local Date Start	Event	Location	Original loss ($M)	Loss (1998 $M)	Deaths
1862 Jul	The 1862 Swan River flood, estimated to have an ARI of 60 years, was said to be unprecedented by some sources. The *Perth Gazette* reported that much property was destroyed, with gardens backing onto the river between the Causeway and Mt Eliza largely underwater. [1 2 3]	Perth	£30,000		5
1872 Jul	Largest Swan River flood on record with an estimated ARI of 100 years. The flood reportedly caused considerable property damage along the Swan-Avon River. [4]	Perth	NA	NA	
1878 Jul 20	Cool season storm. *James Service* shipwrecked offshore from Rockingham–Mandurah with loss of all crew and passengers. [5]	Perth region			20
1899 Jul 12	Cool season storm. *Carlisle Castle* shipwrecked off Rockingham with loss of all hands (est. 24–26 persons) and cargo (est. £40,000–£50,000). *City of York* wrecked off Rottnest Island with loss of 11 crew. [5]	Perth region	> £40,000	NA	35
1926 Jul	The 1926 Swan River flood, although having an estimated ARI of only 30 years, resulted in the collapse of the Fremantle Railway Bridge and the Upper Swan Bridge. It also caused significant flooding of property in South Perth and in the Upper Swan–Guildford areas.	Perth	NA	NA	
1937 Feb 9	Cyclone and bushfire. A 'cyclone lashed the lower west coast on the 9th and 10th' Widespread property damage occurred, particularly south of Perth. Many boats damaged at Rockingham and further south. Severe bushfires in Denmark and Walpole. Hundreds of acres of forest, pasture and fruit trees were destroyed by the fires and stock losses were great. Widespread severe duststorms over the Wheatbelt. [6 7]	Southwest WA	NA	NA	
1961 Jan 19	'Dwellingup' bushfires. Several fires ignited by extreme fire weather, and more by lightning on 20 January, from Mundaring to Manjimup. On 24 January, the fires flared, driven by hot, gusty northwesterly winds influenced by a tropical cyclone in the Pilbara. Over 40,000 ha of forest burnt. Dwellingup destroyed, with 132 homes, 74 motor vehicles and other buildings lost, including the hospital. [8 9]	Southwest WA		35	
1968 Oct 14	Earthquake magnitude 6.8 Ms wrecked Meckering, damaged central Wheatbelt towns including York and Northam, and ruptured the Goldfields water supply pipeline. More than 6,400 insurance claims received for damage in metropolitan Perth. [10 11 12]	Meckering	1.5	12	
1978 Apr 4	Tropical cyclone *Alby*. Gale-force winds and widespread damage to property. Storm surge and large waves caused coastal inundation and erosion. Widespread fires and severe dust storms. [8 13 14]	Southwest WA (Perth to Albany)	13	39	5
1979 Jun 2	Earthquake magnitude 6.0 Ms wrecked buildings and infrastructure centred on Cadoux township 180 km northeast of Perth. More than 2,800 insurance claims for minor damage in Perth. [15 16]	Cadoux	3.5	12	

Local Date Start	Event	Location	Original loss ($M)	Loss (1998 $M)	Deaths
1988 Sep 22	Cool season storm. The storm caused extensive damage from Perth to Albany. Hundreds of roofs were damaged and several ripped off entirely, trees were downed, and power was lost to over 100,000 homes in the metropolitan area. [17]	Southwest WA (Perth to Albany)	8	12	1
1994 May 23	Cool season storm. Windstorm was one of the most destructive weather events to affect Perth. Majority of property damage minor, most claims being for fence damage. Downed powerlines, mostly due to fallen trees and branches, caused widespread blackouts, leaving up to one-third of Perth without power at the height of the storm. [8 17]	Perth	37		2
1997 Jan 8	Bushfires at Wooroloo and Wundowie (believed deliberately lit) destroyed 16 homes, part of the Wooroloo Prison Farm, sheds, fencing, livestock, vehicles and stored fodder. Total losses in excess of $12 million. [8 18]	Perth region	12		
2005 Jan 15	Largest bushfire in Perth Hills in 40 years. The fire was believed deliberately lit and burnt 27,000 ha of state forest, national park and bushland in Mundaring, Pickering Brook, Karagullen and Barton's Mill. [19]	Perth rural interface	NA	NA	

Notes: Estimated contemporary losses and losses in 1998 dollars are insured losses from Insurance Disaster Response Organisation unless otherwise stated.

[1] Loss estimate in 1862 pounds from the *West Australian,* March 12, 1934.
[2] *Perth Gazette*, 11 July, 1862, including estimate of 5 deaths.
[3] EMA Disaster Database cites 12 deaths.
[4] BOM, 1995.
[5] Western Australian Museum, 2005.
[6] BOM, 2005.
[7] Hanstrum, 1992.
[8] EMA Disaster Database.
[9] *West Australian*, 24 January, 1981.
[10] Everingham and Gregson, 1970.
[11] Gordon and Lewis, 1980
[12] Everingham *et al*., 1982.
[13] Estimate of deaths from Hanstrum, 1992.
[14] EMA Disaster Database estimates $50 million damage to property alone in 1978 prices.
[15] Lewis *et al*., 1981.
[16] Gregson, 1980, estimated costs at $3.8 million in 1979 dollars.
[17] Estimate of deaths from EMA Disaster Database.
[18] Loss estimate from Bushfires Board of Western Australia, 1997.
[19] FESA, 2005.

The radius from Perth of exposed communities was extended to about 200 km in Table 1.2 to ensure that many significant events that have had widespread impacts, such as cyclone *Alby* in 1978, the 1968 Meckering earthquake, thunderstorms in southwest WA, and cool season storms, would be included in the table. Events such as these had significant aggregated losses, even though their maximum impact may not have been in Perth itself.

The estimated losses in Table 1.2 are, with only three exceptions, estimates of insured losses published by the Insurance Disaster Response Organisation (IDRO, 2005) post-dating 1967. IDRO has maintained a Major Disaster Event List for events from June 1967. Events included in their list had disaster costs likely to have cost $10 million or more or, alternatively, had been declared a disaster by an appropriate government authority.

For all events, total losses must at least equal the insured losses and, therefore, the estimated cost of the events in Table 1.2 must be considered a minimum. Total losses include direct losses due to building and infrastructure damage and business disruption, tangible indirect losses due to impacts on businesses not directly impacted by the event and additional costs of post-disaster services, and intangible, indirect losses from death and injury, loss of personal effects, psychological, social and environmental effects. Total costs are probably several times higher than aggregated insured losses but are not known currently.

The proportion of total losses to insured losses has been estimated by Joy (1991), and BTE (2001) used factors derived from these proportions to estimate the costs of natural disasters nationally (Table 1.3). However, BTE (2001) more thoroughly costed a small sample of natural hazard events and produced ratios of uninsured to insured losses quite different from those of Joy. Their limited analysis indicated wide variability in these proportions and therefore, while we need to employ some scheme such as that of Joy, better means of estimating non-insured losses are essential to improve our understanding of the total costs of disasters and therefore improve decision-making for allocating resources to reduce these costs.

Table 1.3: Proportion of insured loss to total loss (Joy, 1991; after BTE, Table 2.2, 2001)

	Proportion of insured loss to total loss	**Factor**
Severe storm	35%	3
Tropical cyclone	20%	5
Flood	10%	10
Earthquake	25%	4
Bushfire (Wildfire)	35%	3

An analysis of the limited data on insured losses since 1967 in Table 1.2 indicates that tropical cyclones, combined with bushfires associated with them, have been the most costly natural hazards in southwest WA in recent times. Cool season storms rank second, earthquakes third, and there are no data in the table for floods. These rankings are similar to those of BTE (2001) for WA as a whole (Table 1.1), except that BTE estimated that annualised losses from floods in WA were similar to those from earthquakes.

Using the insured losses in Table 1.2 and the proportions of insured losses to uninsured losses of Joy (Table 1.3), we obtain annualised losses of approximately $15 million per year from the most costly natural hazard events in southwest WA in the period 1967 to 2004. These annualised losses are approximately one-quarter of those listed by BTE (2001) for WA as a whole (Table 1.1).

Floods

The author has included several historic events in Table 1.2 for which no estimate of cost was available. For example, the 1926 floods brought down the Fremantle Railway Bridge and the Upper

Swan Bridge and, as a consequence of the collapse of the Fremantle Railway Bridge, freight costs rose because goods traffic between Perth and Fremantle had to be diverted through Armadale. The costs from this event would probably have exceeded the criterion for Table 1.2.

The 1862 flood is also considered to meet the cost criterion for Table 1.2, even though Perth and the surrounding communities were then much smaller. Considerable infrastructure and buildings have been constructed on the floodplain and we estimate that, if a similar major event were to occur at the present time, significant losses would ensue. Chapter 4 presents graphic accounts of the impacts of the 1862 floods.

In other cases, significant floods have been excluded from the table because no evidence of damage or loss could be located in contemporary accounts or in the EMA or IDRO databases. Flood events been omitted from the table for this reason include events in August 1945 ('Approached 1926 flooding'), February 1955, and August 1963 (in which Guildford/Bassendean area flooding was 'almost as bad as 1926') (comments in parentheses by Richard Bretnall, WA DOE, written comm., 2005).

Tropical Cyclones

Although most WA tropical cyclones have wreaked their major havoc in the northwest of the state, a significant number also have made rapid, damaging transitions to the southwest. Cyclone *Alby* in 1978 (Table 1.2) is probably the most damaging of these events in the Perth region in terms of financial and economic impact, if not in loss of life. Chapter 2 of this report provides descriptions of the cyclones since 1830 that have made this transition to affect Perth and southwest WA.

Earthquakes

Perhaps surprisingly, Wheatbelt earthquakes, with epicentres more than 100 km distant from Perth, have caused significant losses to Perth. A total of 3,668 insurance claims arose from the 1979 Cadoux earthquake and, of these, 2,850 claims comprising 46% of the total value were from the metropolitan area (Lewis et al., 1981). The epicentre of this earthquake was approximately 180 km from Perth.

For the 1968 Meckering earthquake, with an epicentre 130 km distant from Perth, the ratio of the value of claims in metropolitan Perth to the total value of claims was much higher. Of a total of 7,706 insurance claims for both Houseowners and Fire (Commercial), 6,483 were received from metropolitan Perth (defined as within a radius of 48 km from Perth GPO). Total value of claims from the metropolitan area was $907,848, or 67% of the total value of $1,346,763 for all claims (1968 dollars; Gordon and Lewis, 1980). Claims for dwellings comprised about 78% of the total value of claims.

Other Hazards

Other types of natural hazard events have caused damage, financial and economic losses, deaths and other effects. These events include severe local wind storms (SLWS). SLWS can be divided into tornadoes and downbursts. The winds generated from tornadoes are the strongest that have occurred in Perth and southwest WA, and tornadoes have caused localised intense damage. For example, a tornado through Kings Park and South Perth on 15 July 1996 led to 35 insurance claims totalling $447,963 (Joe Courtney, written communication, 2005). A severe wind squall likely to have been a tornado destroyed 40 caravans and extensively damaged 24 cottages at Naval Base, south of Fremantle on 8 June 1968.

Because tornadoes and downbursts are very localised and frequently short lived, individually and collectively they have not contributed significantly to total historical economic losses and casualties, so none are listed in Table 1.2. Chapter 2 provides further accounts of these events and their historical occurrence.

Numerous other natural hazard events that did not cause at least $5 million dollars in damage losses, or did not cause five fatalities or more, have occurred in southwest WA including Perth. It is notable that these events appear more often in event listings since about 1990. This increase in the numbers of events is probably due to two factors. First, reporting through the EMA Disaster Database and through the IDRO Disaster Event List has probably improved since that time. Also, like most major cities around the world, Perth is probably increasingly vulnerable to the impacts of natural disaster events because of its increasing population, urban expansion and its sensitivity to the availability of effective transport, communications and energy supply.

Several recent examples taken from the EMA Disaster Database illustrate the apparent increase in frequency of 'significant' albeit second-order events. It is noteworthy that all of these examples occurred in the summer months and nearly all were related to thunderstorm activity. Examples of recent events include:

- 8 February 1992, thunderstorm. Slow-moving storms caused Perth's wettest day on record, with falls over 100 mm. Strong winds and golf-ball sized hail damaged apartment blocks in Glendalough in the morning. Estimated $5 million losses in 1998 dollars;
- 23 February 1995, warm season thunderstorm downburst. Caused damage of over $4 million in the eastern suburbs of Perth;
- 15 January 2000, severe storms. Thousands of people were caught up in lightning, rain and hail which sparked fires and floods, jammed traffic and cut power to about 4,000 homes and businesses. Crop losses in Swan Valley. Estimated $5 million losses;
- 22 January 2000, flash flood. Second-highest Perth rainfall. While the event did not cause a major flood of the Swan River, it did considerable damage and disrupted activities in the city;
- 14 January 2002, thunderstorm. A supercell formed north of Perth causing hail at Regans Ford, before moving offshore and striking Kwinana, shifting an oil tanker from its moorings, and causing millions of dollars damage to the refinery. Estimated $5 million losses.

In preparing Table 1.2, discrepancies, omissions and inconsistencies for cost data and other information were noted among sources such as the IDRO database and the EMA Disasters Database. We do not underestimate the difficulty of obtaining accurate information, or in preparing and maintaining databases of rigorous and systematic information on costs of natural disasters. The estimates of loss that are available are almost exclusively estimates of total insurance claims. Almost any estimates of other losses, apart from casualty estimates, are rare and have not been systematically presented. BTE (2001) also described the many difficulties in obtaining cost information including, but not confined to, the relationship between insured and uninsured losses, cost of intangibles and indirect costs.

The costs of natural hazards in Perth must be considered against the costs of other, human caused hazards in priority setting for whole of government expenditure on risk reduction. Transport accidents are one source of comparison. Transport accidents feature strongly in the catalogue of disasters that have occurred in the Perth region, apart from natural disasters. In the 19th Century, scores of shipwrecks occurred in the shallow waters off the southwest WA coastline, many caused by navigation errors. Some of the most disastrous, however, were brought about by winter gales, and these wind events are described in Table 1.2. In the 20th Century, aircraft crashes have caused significant loss of life. In July 1949, a DC-3 aircraft crashed near Guildford Airport, metropolitan Perth, with the loss of 18 lives. In June 1950, an Australian National Airlines DC-4 aircraft crashed near York, approximately 90 km east of Perth, killing all 29 people aboard (EMA, 2005). BTE (2000) estimated the cost of road crashes in Australia in 1996 as $15 billion.

The types of impacts on the community from historic disaster events in southwest WA reflect the changing nature over time of community vulnerability. 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 and technological hazards. Nonetheless, we cannot dismiss the threat of multiple loss of life from bushfires, gales, floods, earthquakes (and transport accidents) in southwest WA. In future events, however, losses may be highest from environmental impacts and economic losses apart from casualties.

The reader will note from Table 1.2 that, despite the wide range of natural hazards that have occurred in Perth and southwest WA, no event has been truly catastrophic. No event for more than 100 years has caused more than five fatalities, and no event has caused more than $100 million insured losses, for example. This is a fortunate position indeed when Perth is compared with other cities and regions such as Brisbane (1985 storms), Newcastle (1989 earthquake), Sydney (1999 hailstorm), Canberra (2003 fires), Hobart (1967 fires), South Australia and Victoria (1983 Ash Wednesday fires), Darwin (1974 cyclone *Tracy*), and so on.

Are the citizens of Perth and its hinterland fortunate to live in a benign natural environment? What is the likelihood of future natural disaster events of a ferocity not experienced in Perth's relatively short continuous written history (since 1829)? This report provides answers to many key questions that lay the foundation for addressing current risk to Perth. Cities Project Perth has also developed many databases on hazard, exposure and vulnerability that will facilitate further investigations on natural hazard risk in Perth in the future.

1.5 Key Questions for this Report

There are a number of key questions regarding natural hazards and natural hazard risk that this report addresses. The answers to these key questions form the basis of the research work for this report. The key questions are listed below.

What is the severe wind hazard to Perth?

- How does the wind hazard, calculated in this report, compare with the hazard that is defined for Perth in the Australian/New Zealand wind loadings standard?

What is the flood hazard to Perth in the Swan River and its tributaries?

- What do improvements to the flood hazard model of the DOE add to our understanding of flood hazard for these rivers?

What is the earthquake risk to Perth?

To analyse the earthquake risk to Perth, we seek solutions to the following questions in Chapter 5:

- What is the earthquake risk to Perth when aggregated across the metropolitan area?
- What is the estimated annualised loss to Perth, expressed for example as a percentage of the total value of the building stock?
- Is the earthquake risk to Perth significantly higher in some local areas than others, and are particular building types at higher risk than other types?
- Where do the earthquakes occur that generate most risk to Perth, and how often are they likely to occur?
- What is the earthquake hazard in Perth?
- What is the earthquake hazard in the Perth region, that is, in a radius of about 200 km from Perth CBD? How does the earthquake hazard in Wheatbelt areas compare with the hazard in metropolitan Perth?
- How does the earthquake hazard, calculated in this report for Perth and southwest WA, compare with that defined in the Australia/New Zealand earthquake loadings standard?

How can socio-economic models and information improve our understanding of how well the Perth community will cope with recovery following significant natural hazard events?

What is the potential impact on the southwest WA coast from sea level rise due to climate change?

- Which areas of coastline near Perth are the most susceptible to coastal erosion due to sea level rise?

For each of the hazards considered, what are the most important risk management actions to reduce the risks from these hazards?

1.6 Study Area

The study area covers the places of work, sleep and play for most of the population of greater metropolitan Perth at the current time. The study area for social vulnerability research is identical to the ABS Perth Statistical Division that had a population of approximately 1.3 million people in 2001[2]. The study area for wind hazard contains a total of approximately 544,000 rateable buildings of all types[3], compared to approximately 550,000 residences in the broader ABS Perth Statistical Division. The study area for earthquake risk contains a building stock of approximately 355,000 buildings of all rateable types (Figure 1.1).

In general, the borders of the study area for Cities Project Perth are those of greater metropolitan Perth. However, the study area differs somewhat for the various investigations of hazard, vulnerability and risk in the report. For example, our investigations into factors that affect community recovery span the entire metropolitan area, whereas our assessment of flood hazard focuses on the floodplains of the Swan River and tributaries. Our choices in study area for the various hazard and risk assessments were driven by the need to cover as much area as possible, in two ways: first, to include those areas of the Perth community that could be affected by the individual hazards, and second to consider the region in which hazard events are generated, or traverse on their path towards Perth. On the other hand, the study area was restricted by the availability of data, usually hazard-related data such as Automatic Weather Station (AWS) data, or to where we could generate new data, using methods such as such as Seismic Cone Penetrometer Testing.

A core area covering the greater part of metropolitan Perth was used for the most of the hazard and risk assessments in this report, enabling us to report across a range of hazard events that could strike common areas of the city. This core area extends about 25 km east from the Perth CBD to the Darling Range, and to the Indian Ocean in the west. In the south, the core area extends about 60 km north–south, from Wanneroo and Joondalup in the northwest to Kwinana and Armadale. (See Figure 1.1.)

Our study area extends far beyond Perth for our assessment of the potential coastal erosion due to long-term sea level rise from climate change and for earthquake hazard. (See Figure 1.2.) For coastal erosion due to long-term sea level rise, we have considered a 300 km-long coastal strip from Cape Naturaliste, in the state's southwest, to Yanchep, at the northwest margin of greater metropolitan Perth. However, the area of greatest attention is along the coast of greater Perth.

[2] ABS figures from 2001 Census.
[3] Rateable building data from WA Valuer-General's Office building database, 2002.

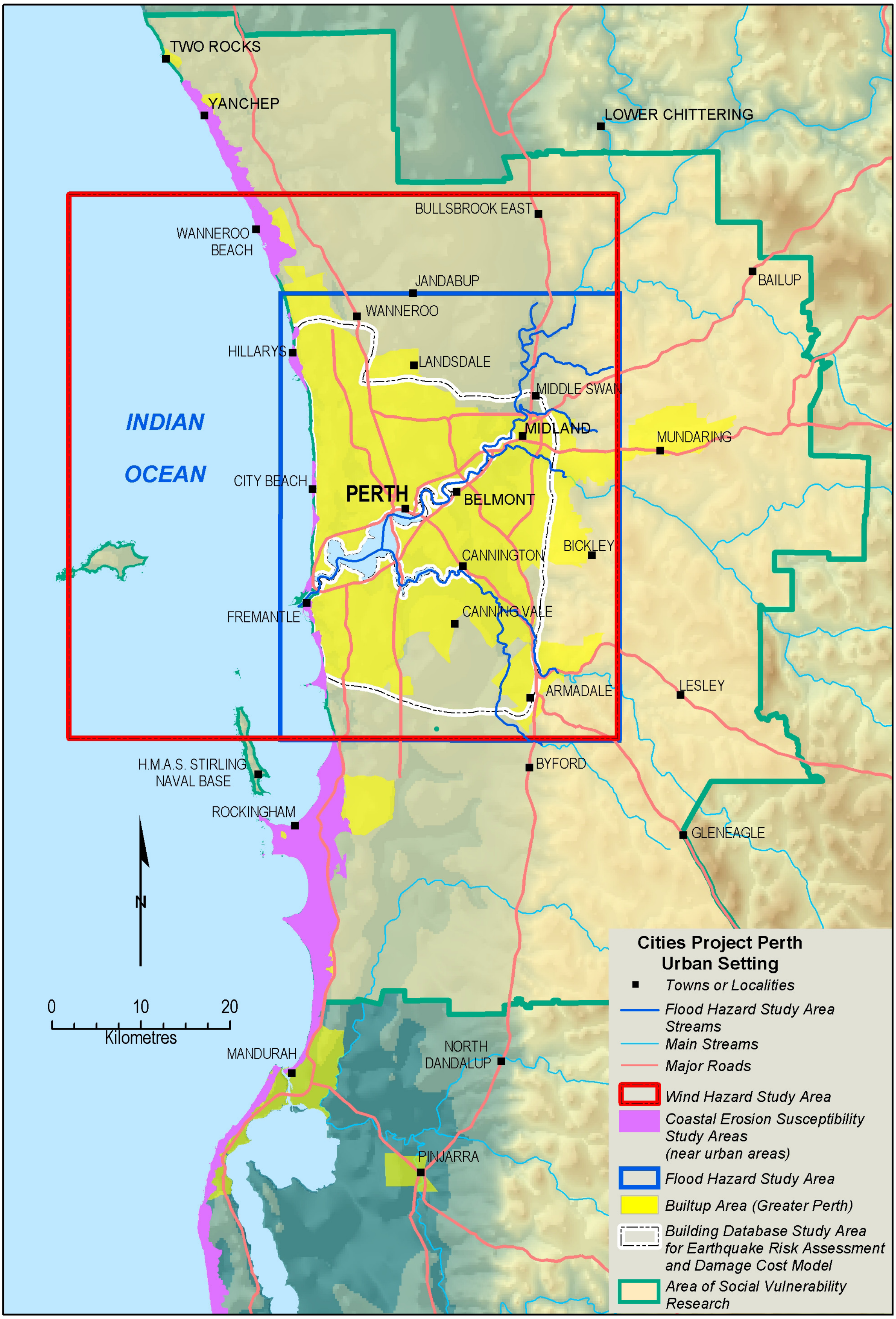


Figure 1.1: Study area – greater metropolitan Perth

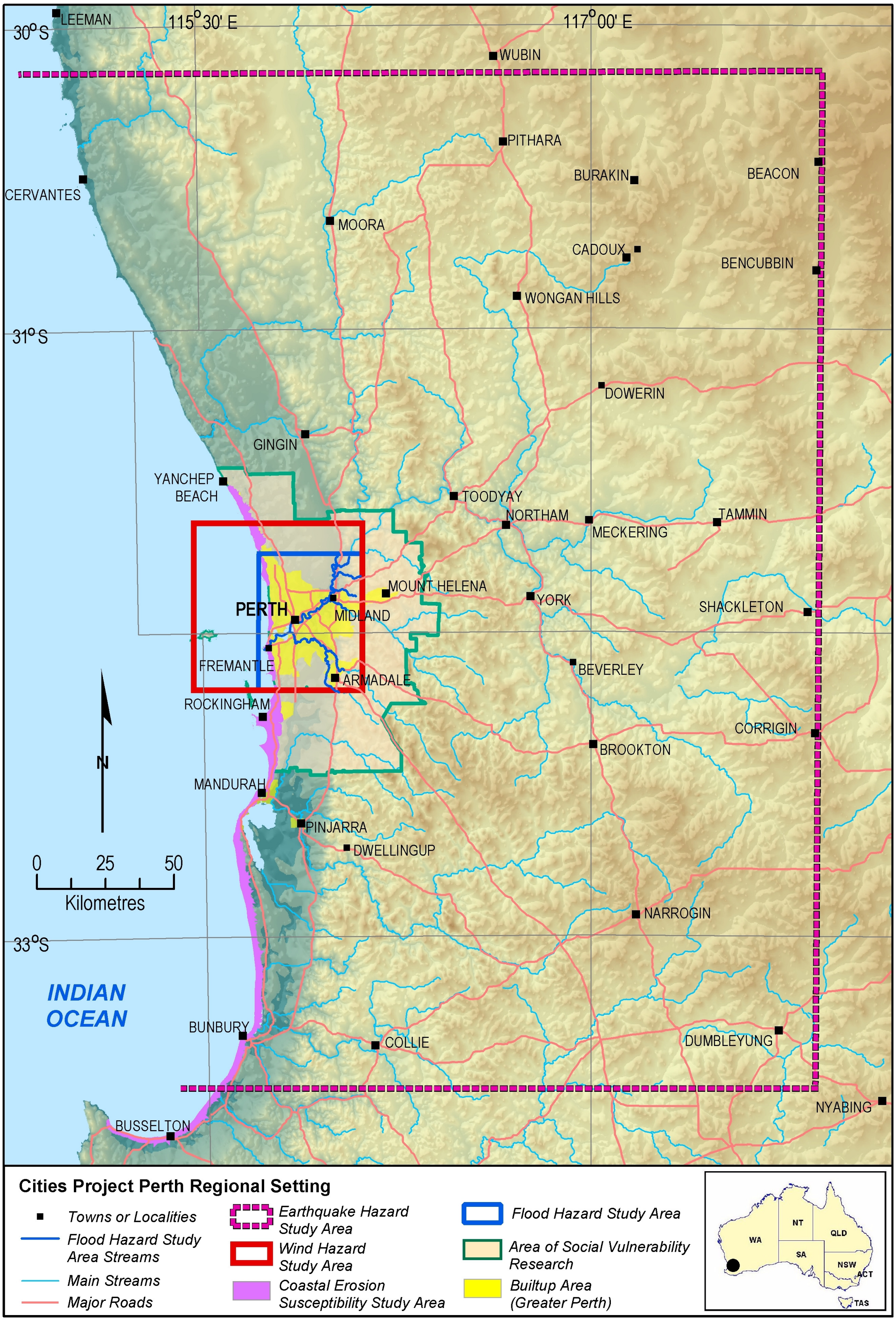


Figure 1.2: Study area in southwest WA

For assessing earthquake hazard, we chose a zone with a radius of around 200 km from Perth CBD. Earthquakes occurring within this radius, such as strong earthquakes originating at the western margin of the Wheatbelt, have the potential to cause widespread damage and disruption across metropolitan Perth. Also, in the Wheatbelt itself the earthquake hazard is significantly higher than in metropolitan Perth and WA emergency risk managers have a direct interest in managing the earthquake threat to their communities. For earthquake *risk* assessments, as against earthquake *hazard* assessments, the study area comprises the major part of metropolitan Perth (Figure 1.2).

The study area for severe wind hazard was influenced by the locations of the AWS operated by the BOM in the Perth region (Chapter 3).

1.7 Study Area and Future Growth in Perth

Cities Project Perth focuses on assessing hazard, vulnerability and risk to the current population of Perth and its built infrastructure. However, the databases and assessment methods developed for this report provide an excellent foundation for assessing hazard and risk to the city in its future form. The study area in this report extends across much of the city in its planned expansion to 2030. Also, the most comprehensive assessments of hazard and risk have been conducted on the central core of the city that is planned to undergo major urban infill in future decades.

The WA Planning Commission's (WAPC) community consultation document *Network City* contains a comprehensive and well-defined set of strategies, options and objectives for the future development of Perth and Peel to the year 2030 (WAPC, 2004). The study area of Cities Project Perth is largely consistent with the WAPC area, except that we have excluded Mandurah City and Murray Shire, collectively called Peel, immediately south of metropolitan Perth, from our investigations.

Perth is one of the fastest growing capital cities in Australia, in both population and area. Urban spread and population growth was consistently high through the 20th Century (see Table 1.4).

Table 1.4: Population change in selected capital cities, 1921–2001 (adapted from Troy, Table 1(i), 1995)

		1 Metropolitan/urban population (000)	2 Ratio of population to 1921 population	3[1] Population in 1921, metro boundary (000)	4 % of total living in 1921 boundary
Perth	1921	155		127	82
	1971	731	4.7	228	31
	1991	1019	6.5	205	20
Sydney	1921	899		899	100
	1971	2725	3.0	1513	56
	1991	3098	3.4	1351	44
Melbourne	1921	718		718	100
	1971	2408	3.3	1199	50
	1991	2762	3.8	977	35
Adelaide	1921	255		249	98
	1971	809	3.1	575	71
	1991	957	3.7	544	57

Note: *1* 'The metropolitan area boundary was used for column [3] except where it could not be traced in later years because of boundary changes. In the case of Perth some additional areas were omitted because the 1921 boundary was very wide. In all cases the area used for column [4] is constant… Source: Australian Census of Population and Housing 1921, 1971, 1991.
(Troy, 1995, p.3).

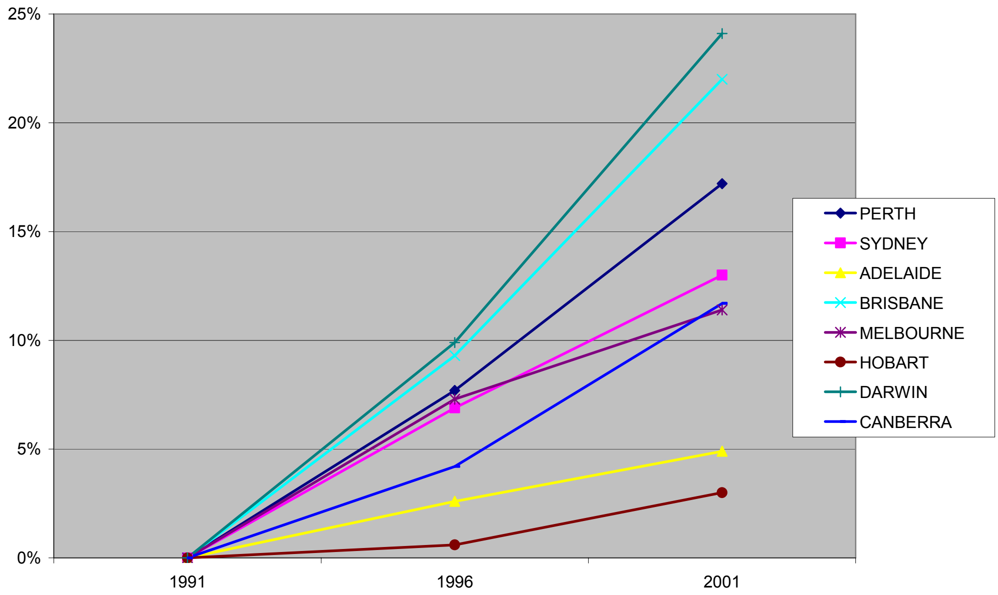


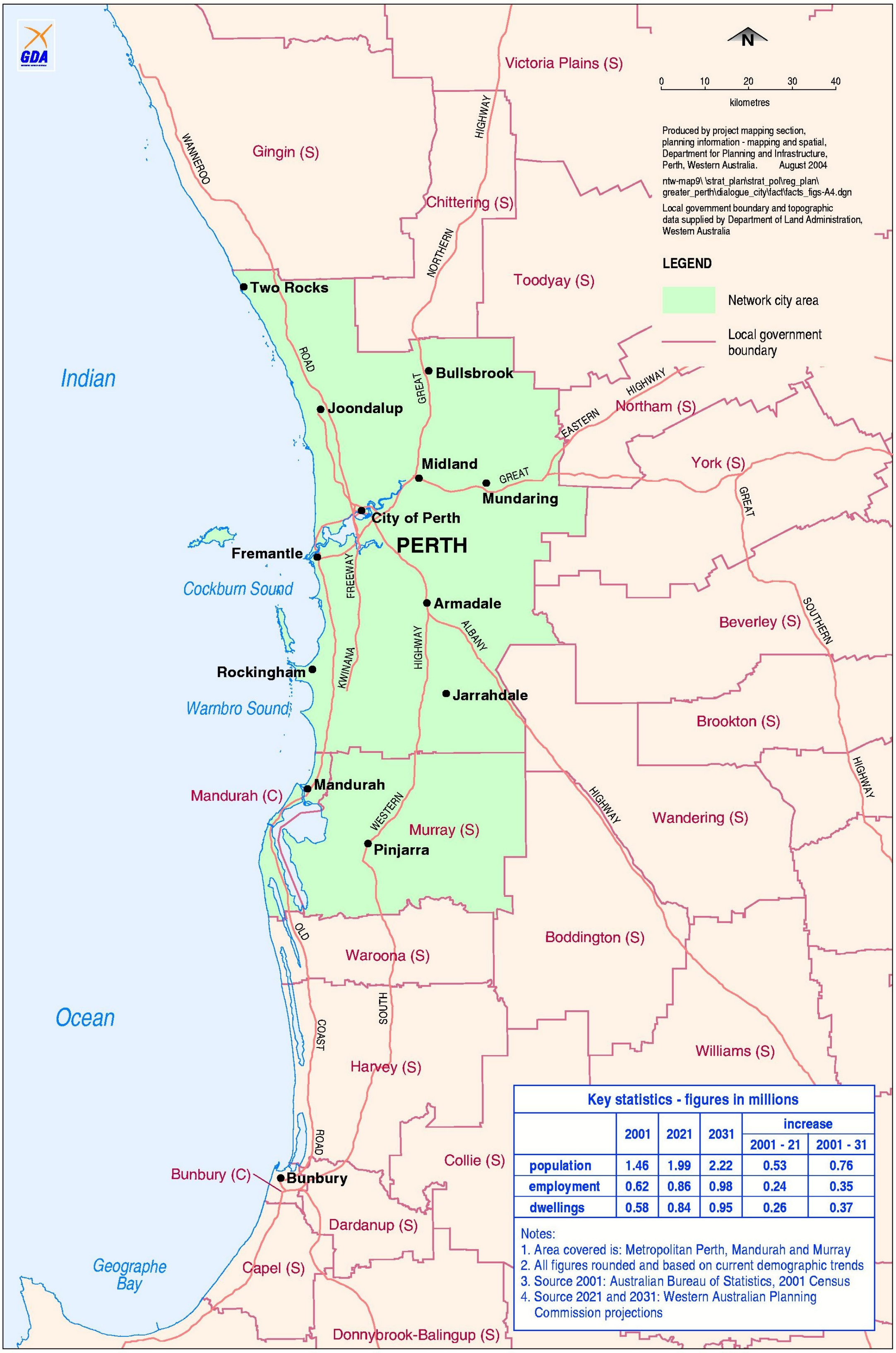
Figure 1.3. Population growth for Australian capital cities in the 1996 and 2001 Census as a percentage of population in the 1991 Census (source of data: ABS, 2005)

Recent population growth in metropolitan Perth has continued strongly (Figure 1.3).

It is worth quoting in part from the WAPC strategy because it sets out priority areas for growth in population, dwellings and employment to 2030. Growth in these areas indicate areas where community exposure to natural hazard risk will increase in future, and indicate increases in the aggregated risk for the future city (Figure 1.4).

> *'WAPC has developed a comprehensive planning strategy through extensive public consultation leading, to several well defined options for future growth. Faced with a population that will grow by about 760,000t in the next 25 years, Perth and Peel require an additional 375,000 homes and 350,000 new jobs.*

One of the priority strategies proposed in Network City is to achieve 60% of future dwelling growth within already developed urban areas, with only 40% being provided in "greenfield" sites on the fringe of the city. This represents a significant change from previous patterns of growth, where the majority of dwellings have usually been provided in fringe locations.



	2001	2021	2031	increase 2001 - 21	increase 2001 - 31
population	1.46	1.99	2.22	0.53	0.76
employment	0.62	0.86	0.98	0.24	0.35
dwellings	0.58	0.84	0.95	0.26	0.37

Figure 1.4: Network City – key facts and figures (from *Network City: Community planning strategy for Perth and Peel, for public comment*, September 2004. Figure reproduced courtesy WAPC)

1.8 Overview of this Report

Chapter 2: Meteorological Hazards, provides an overview of meteorological phenomena in the southwest of WA that affect Perth. The chapter was prepared primarily by Joe Courtney from the BOM, WA Regional Office, as a part of the contribution by the Bureau to the Cities Project Perth. The chapter provides descriptions of the origins and physical development of cool season storms including severe local wind storms, thunderstorms, heavy rain and flooding, tropical cyclones, heatwaves and bushfires. The chapter also provides a record of major historical events and their impacts in Perth and in southwest WA.

Chapters 3, 4 and 5 report the essential findings of hazard and risk assessments for severe winds, floods and earthquakes respectively. They are the core of the risk assessment in Cities Project Perth. They report the results of major computational investigations into these hazards by researchers from GA, the WA DOE, BOM, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other institutions.

Chapter 3 investigates the wind hazard across metropolitan Perth. The estimates of wind hazard are based on an innovative extreme value analysis of data from AWS operated by BOM in and around metropolitan Perth. The AWS data have captured wind gusts from tropical cyclones, cool season storms, thunderstorm downdraughts and airflow from the east over the Darling Scarp. Estimates for wind speeds were calculated for return periods in the range 50 years to 1,000 years.

Ground surface topography, terrain roughness and shielding of buildings by other buildings all affect the incoming windfield upon its interaction with the urban environment. We have calculated terrain multipliers that take these three effects into account. These multipliers have been calculated at each point across metropolitan Perth at intervals of 25 m, with different multipliers for eight cardinal directions of the compass calculated at each point. These multipliers have been calculated in a GIS environment using a method consistent with the Australian/New Zealand wind loadings standard (Standards Australia, 2002).

We have developed a model that attenuates the windspeeds of westerly winds on their travel inland from the coastline. This model was developed to improve our interpretation of expected future wind speeds in Perth, because winds from the western and northern quadrants have historically been the strongest and are expected to be in the future. This model matches well with the historical data collected from the AWS.

The return period wind speeds calculated using these methods provide a guide to engineers and planners of return period wind speeds that can be expected in relation to design considerations, extending across metropolitan Perth.

In Chapter 4, we estimate flood hazard on the Swan and Canning Rivers. An unsteady state flow model has been developed that estimates flood levels for annual exceedance probabilities (AEPs) in the range 10% to 0.05% (corresponding to return periods approximately in the range 10 years to 2000 years). This model updates earlier models developed by the WA DOE and will be incorporated in the Department's hydraulic modelling program. A comprehensive field survey was also conducted to capture attributes of all buildings in the floodplains in metropolitan Perth, extending from the streams up to levels approximating those of flood events with AEP 0.2% (return periods of approximately 500 years). The attribute information collected in the field estimates of ground floor height for each building. The floor height and other building attribute information such as building age, construction type and occupancy type, will assist risk assessments that examine potential losses in the future, and also response plans in relation to the scale and location of potentially affected structures and their occupants.

Chapter 5 is a comprehensive study on earthquake risk in metropolitan Perth. A broad-based assessment of earthquake hazard was conducted for this part of the continent under Cities Project

Perth, and this assessment is considered to be the best available at the time of publication, significantly improving and refining the estimates of earthquake hazard in the Australian earthquake loading standard AS1170.4:1993 and the new version of the standard, currently in draft form and due for publication in 2005. The earthquake hazard assessment has also included the collection of ‘microtremor’ field information (ambient seismic noise) at Northam, in the Wheatbelt, to assist the assessment of earthquake site response and earthquake hazard there.

The earthquake hazard assessment thus provides new and important information, not only for Perth but also for regional communities from Burakin in the north to Collie in the south, including Northam, York, Meckering and Cadoux, where the earthquake hazard on rock foundation is higher than that of rock sites in Perth. The earthquake hazard in these Wheatbelt communities is a significant planning and emergency risk management consideration for protection of residents and for continuity of critical infrastructure such as electric power supply, water supply and emergency services.

Chapter 6: Community Recovery, expands the scope of this report beyond estimates of the likelihood of various hazard events and, in the case of earthquakes and floods, estimates of the impacts on the Perth community of a range of return period events. Chapter 6 provides insights into how Perth as a whole, and Perth citizens in local areas as small as Census Collectors Districts, may cope with future disaster events. A recovery framework with three factors of recovery – household financial capacity, community and social networks and distance to services – is established, and measures of these three attributes are analysed in the chapter utilising published data from the Australian Bureau of Statistics (ABS).

Chapter 7 investigates the potential coastal erosion of the Swan Coastal Plain due to long-term sea level rise. It is highly likely that coastal erosion due to long-term sea level rise associated with global warming will have a significant impact on Australia’s coastal systems and any associated infrastructure over the next century. Therefore, attempting to quantify this natural hazard is critical to future development and management of these localities. The potential impact of coastal erosion on the Western Australian built environment between Cape Naturaliste and Yanchep is assessed in this chapter.

Local wind-generated ocean waves are the dominant mechanism controlling net northward sand transport and determining the nearshore structure of sandy beaches. The subsurface distribution of the erosion-resistant limestone has been determined in order to assess the erosion potential of the coastline. An evaluation of potential erosion rates over the next century using a conventional two-dimensional coastal behaviour model is presented for one site within the Fremantle to Hillarys sector.

The final chapter, Chapter 8: Conclusions, draws together the major results from this study. It comments on the implications for the residents of Perth of the flood hazard, wind hazard, coastal erosion susceptibility earthquake risk, and community attributes of recovery. The chapter also integrates the recommendations for future work that were set out in individual chapters.

Five appendices also accompany the main body of the report. These appendices provide additional detail on models that were developed for the risk assessments. Appendix A provides details of the computational wind hazard assessment methodology.

Appendix B provides metadata for spatial databases that were developed in this project. These databases include GIS datasets for the Perth building database, approximately 600,000 building footprints, and other, smaller building databases developed from field surveys in the CBD area of Perth and in the Swan and Canning floodplains.

Appendix C describes the cost model that was developed for remediation or replacement of buildings and replacement of building contents. This cost model was used in the earthquake risk assessment and could be readily applied to risk assessments for flood and severe wind, among other possibilities.

Appendix D is a description of the Perth Basin that underlies Perth. The appendix features a comprehensive analysis of the Cainozoic geology and the development of geological Site Classes for earthquake hazard assessment. Ultimately, in this report, the site classification described in Appendix D was not used for the earthquake risk assessment because the original geophysical model of the Perth Basin did not describe adequately the damping of seismic wave energy travelling through the many kilometres of sediments. Instead, in this report, a simplified, empirically-based Perth Basin model was employed that did reflect the reduction in energy of seismic waves travelling through the Perth Basin (see Chapter 5). Nonetheless, the site class description in Appendix D is a robust work based on empirical data gathered from agencies such as DOE, and also collected by GA in the field. This classification is a valuable reference for design engineers and planners who employ the earthquake loading standard. The site class model could be incorporated in earthquake hazard assessment models for Perth in future with improved model parameters for the underlying Perth Basin sediments.

Appendix E is a commentary on the potential for tsunamis, generated by Indonesian earthquakes, to impact on southwest WA. The appendix is particularly timely, following the appalling Boxing Day 2004 Indonesian earthquake and tsunami which killed more than 200,000 people in southern Asia. The appendix refers to remarkably premonitory research by the author on the tsunamigenic effects of previous great Sumatran earthquakes in 1833 and 1861, and the potential for future great earthquakes to generate tsunami in the region.

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