

# Chapter 8: CONCLUSIONS

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## 8.1 Key Results

In the Introduction to this report, we posed a series of Key Questions that the essential research in Cities Project Perth aimed to answer. This chapter summarises the main results of Cities Project Perth. Most of these results are integrated from the individual chapters in the report.

One overriding feature of Cities Project Perth is its use of predictive computational 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 never before recorded. The flood modelling also indicates higher water levels for scenarios much rarer than the 1% AEP scenarios that have been experienced in the past and that are used in planning guidelines. In this way, Cities Project Perth has provided important new information for emergency risk management.

**We emphasise that this report should be regarded as the best and most recent hazard and risk assessment for the natural hazards covered in this report for metropolitan Perth. However, we acknowledge that there are limitations in the models and data we have used, and that we have an incomplete understanding of the natural variability inherent in atmospheric, marine and terrestrial systems, building response and human behaviour. The results, interpretations and conclusions could change with the incorporation of new data and with different model assumptions. Therefore, the reader should not take action based on information in this report alone.**

### Severe wind hazard

The key results from Chapter 3 follow.

- The severe wind hazard calculated in this report for Perth Airport is in close agreement with the wind hazard described for Perth in the Australian wind loadings standard (Standards Australia, 2002). The Standard places Perth in Region A, the lowest hazard region of four in Australia. However, the historical record from the weather station at Perth Airport was the sole dataset used in calculations for the wind loadings standard. This airport is some 20 km inland and winds from the western quadrant, the strongest in Perth, are reduced in intensity in their path from the coast inland. 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.
- Across metropolitan Perth, severe wind hazard varies considerably. Localised areas of Perth with measurably higher hazard than the wind loadings standard lie:
  - in a band several kilometres wide along the coastline, with a nearshore coastal strip a few hundred metres wide having the greatest hazard;

- in a north–south band several kilometres wide running along the top of the Darling Scarp; and
- on exposed shores of the lower reaches of the Swan River, extending inland approximately as far as the Kwinana Freeway.
- The reader needs to be aware that variability in wind speed, wind turbulence, incoming wind direction, and the ability of the models themselves to describe accurately the physical characteristics of the wind, all add variability to the wind hazard at any place and for any particular wind event. The variability in the behaviour of buildings and other structures, due to variability in construction strength and orientation to the wind, will also add variability to damage for any specific event.

### **Flood hazard**

Chapter 4 incorporated hydrologic estimates and previously surveyed cross-sections into a single study and modelled the interactions of the tributaries with the Swan River. The geometry of the model was significantly enhanced by the addition of many cross-sections derived using a detailed DEM that was developed specifically for the modelling of flood flows.

- There are six major catchments in the study area that contribute flow to the Swan River, of which the Avon catchment is by far the largest. Not surprisingly, the hydrologic estimation of flows showed that the Avon River was the dominant flow contributor to the Swan River. Simulations showed that another significant source of flow is from the tributaries, particularly the Canning and Southern Rivers.
- The season of the tidal cycle was found to influence flood flows marginally, with water levels slightly higher in winter. As expected, the variation in water levels decreased with distance upstream from the Port of Fremantle.
- Perth has experienced a lengthy dry period in the past 40 years. Only two major flows have occurred, in 1983 and 1987, since all the streamflow gauging stations at the outer boundaries of the model became operational. The new model better models the hydraulic system and, being an unsteady flow model, is capable of reproducing non-linear behaviour such as tidal influence better than the earlier DOE model. Therefore when more data become available, the unsteady flow model should be recalibrated as far as possible.
- Water levels in this study were found to be lower than those modelled previously for the 1% AEP flood event. The variation in water levels can be explained by the differing methodology of this model and the earlier model. The model differences are best explained by the inclusion of the tributaries, followed by the use of an unsteady flow model rather than a steady flow model, in the Cities Project Perth model. The current lack of data has resulted in the model results being inconclusive and, therefore, the availability of the new model, on its own, does not warrant a complete replacement of current procedures on 1% floodplain mapping. This report provides recommendations that will help reconcile the two models and reduce uncertainties in flood hazard estimates.
- Eight flood scenarios were modelled for the Swan River and its tributaries ranging from AEPs of 10% to 0.05%. Previously, only the 1% AEP scenario had been mapped using a less complex steady flow model. The new model provides emergency managers and planners with important new hazard information for scenarios with a large range of return periods. The unsteady flow model and the stream levels predicted by the modelled events are now held by government agencies in WA, including DOE and BOM.

### **Earthquake risk**

The earthquake risk to Perth discussed in Chapter 5 can be summarised by the following results.

- 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 loading standards. These results have come from a comprehensive update of the earthquake hazard in Perth and in

southwest WA. The reader is referred to Chapter 5 for a comparison of the earthquake hazard calculated in this report and the hazard described in the current and draft earthquake loadings standards.

- The earthquake risk to Perth has been aggregated across the metropolitan area and illustrated by a risk curve or probable maximum loss (PML) curve in Chapter 5. Loss is expressed as a percentage of the total value of all buildings and their contents in the study region.
- The results of this study suggest that, on average, greater metropolitan Perth will suffer an estimated economic loss of around 0.04% per year.
- 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 indicates that the risk is likely to be realised very rarely. These earthquake events will have relatively high consequences. This provides a motivational challenge for emergency managers to remain vigilant and for appropriate risk treatments, such as adequate insurance, to remain in place.
- Impact events with annual probabilities of occurrence up to 0.004 (return periods up to 250 years) contribute an additional one-quarter of the risk. While these relatively frequent events will have low impacts, total losses could be significant when individual losses are aggregated.
- The earthquake risk to Perth varies spatially across the study region. A gradual reduction in risk occurs across metropolitan Perth in a southwesterly direction as distance from the southwest seismic zone (SWSZ) increases. The effect of the higher earthquake hazard in the Wheatbelt region can thereby be discerned.
- Most of the annualised risk for building usage type is for residential types (almost 90%) with the next most common being commercial. This is mainly because residential buildings make up the overwhelming majority of buildings in the study area, and comprise the majority of the total estimated value of all buildings in the study area.
- The unique capital city profile of Perth has also influenced the results in that the residential building stock is predominantly unreinforced double brick construction, with a much smaller proportion of framed timber construction. Unreinforced masonry is significantly more vulnerable than framed timber construction.
- The locations of earthquakes that create most of the risk to metropolitan Perth show a split distribution. About half of the earthquake risk in metropolitan Perth is due to moderate to strong earthquakes (magnitudes in the range about 5 to 6.5) that could occur with epicentres at distances of less than 30 km from Perth. Estimates of earthquake risk in Perth are sensitive to model assumptions of the rate of occurrence of earthquakes for these close-in earthquakes, because historic seismicity has been low in and around Perth.

The second significant contribution to earthquake risk in Perth comes from large earthquakes that could occur at the western margin of the SWSZ (60–90 km from Perth), where the earthquake activity is higher than it is in Perth.

- The area of elevated hazard in the Wheatbelt is considerably more extensive than identified in the current earthquake loadings standard. This area is wider in an east-west direction, extends further northward and is generally located closer to Perth.

### **Indicators of social resilience for recovery**

The indicators ‘household financial capacity’, ‘community and social networks’ and ‘distance to services’, explored in Chapter 6, show that Perth households and the broader community have many characteristics 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 LGAs in the Perth Statistical Division rank in the top 50% of Australian LGAs in the ABS Index for Economic Resources (ABS, 2004a). 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 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 strong community network in WA is indicated by results from the General Social Survey (ABS, 2004b). This strong network 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. Almost all WA participants in the GSS indicated that they could ask someone outside of their home for assistance in times of need, including a health, legal or financial professional, charity or religious organisation. This information may assist recovery managers in tailoring programs and services for people in the Perth community.
- 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 are medical, welfare, social or cultural, can be important factors in influencing the recovery of the 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**

Key findings from Chapter 7 follow.

- 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, Swanbourne beach is likely to erode approximately 40–50 m and 100–130 m respectively.
- The impact of modelled coastal recession at Swanbourne Beach is not significant due to a lack of overlying 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 (1) the Tamala Limestone is preserved below sea level, (2) this sector is poorly sheltered from offshore swell, and (3) this location is at the southern end of the net northward littoral conveyor that operates along the Swan Coast.
- 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 major part of the area. This is due to the fact that this sector has been the primary depositional province for the Swan coast over the last 8,000 years.
- The Hillarys to Yanchep coastline does not appear to be 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. With an increasing development of coastal urban infrastructure, this sector is an important focus for quantitative coastal erosion modelling in southern Western Australia.

**A great deal of variability was included in the models used to generate these results. To some degree this variability was incorporated to account for our lack of knowledge about the various models used in the study. The effect of high levels of variability is to increase the estimates of risk. Future studies 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.**

## 8.2 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 reach many other public and private sector users of the information.

The risk management options include the following.

### Severe wind hazard

#### Use the wind hazard maps:

- to review, improve and complement the design and construction guidelines for severe winds set by state and local governments;
- as a source of information for response planning and response;
- 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.

This report shows that the severe wind hazard values in the Australian wind loadings standard for Perth are most applicable to sites some kilometres inland, and that the wind hazard in exposed localities in Perth is measurably higher than the hazard in the standard. The wind hazard maps for return periods of 50, 100, 500 and 1,000 years for metropolitan Perth provide a rich new source of information on localised wind hazard to complement the wind loadings standard.

#### Use the wind hazard multipliers for topography, terrain roughness and shielding:

- to review, improve and complement the design and construction guidelines for severe winds set by state and local governments;
- as a reference for design engineers and the construction industry;
- 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.

Values of multipliers that modify the free field wind speeds for the effects of localised topography, terrain roughness, and shielding of buildings by other structures have been prepared across much of the metropolitan area. These values have been calculated on a grid with spacing of 25 m intervals for eight directions of the compass.

**Note:** the wind hazard values and the multipliers have been calculated for a grid across metropolitan Perth. The values provide a guide for low rise structures such as residential buildings in local areas. They are not suitable for application to individual properties and they should not be used for site-specific design purposes.

### **Flood hazard**

The flood hazard model developed in this study is the most recent, rigorous and comprehensive model prepared for the Swan River and its tributaries. It estimates time-dependent inundation depths and lateral extents of flooding for AEPs as rare as 0.05%.

However, Perth has experienced a 40-year dry period, and only two major flows have occurred since all the streamflow gauging stations became operational at the outer boundaries of this model. These two factors have made validation of the model difficult.

Therefore, the following recommendations apply.

**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 flow 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.**

### **Earthquake risk**

The earthquake risk assessment in this report included a comprehensive review of earthquake hazard, not only in Perth, but in a region extending approximately 200 km from Perth. This hazard assessment is currently the best available for southwest WA.

The earthquake hazard maps (on rock foundation) for the Wheatbelt within 200 km of Perth are especially valuable. They indicate that the region associated with the seismically-active SWSZ has significantly higher earthquake hazard than metropolitan Perth. This result was previously known, and a zone of elevated hazard is shown in the current Australian earthquake loadings standard. However, the newly-mapped zone of elevated earthquake hazard has a much greater geographic extent, and is located closer to Perth, than the zone mapped in the earthquake loadings standard (Standards Australia, 1993). The new results place more Wheatbelt communities at higher risk than the earthquake loading standard may indicate.

The following recommendations are made to reduce earthquake risk.

**Use the earthquake hazard maps for metropolitan Perth and the Perth region:**

- **to review, improve and complement the design and construction guidelines for earthquakes set by state and local governments;**
- **as a source of information for response planning and response.**

**Enforce the compliance of all new structures with current earthquake loadings standards.**

**Promote the importance of adequate insurance against earthquakes for householders, small business operators and corporations.**

**Structurally retrofit where necessary facilities such as police, SES, fire and ambulance stations and hospitals, which 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 expected performance under earthquake loadings. This recommendation is pertinent for Wheatbelt communities in or near the SWSZ.**

The earthquake risk results are sensitive to the models used and to the data that were incorporated in the models. The sources of uncertainty are many. Two of the most important sources of uncertainty are the attenuation models, used to describe the decay of earthquake energy with distance from the

earthquake source, and the magnitude–recurrence relationships that describe the rate of earthquake occurrence in the various earthquake source zones. The most effective way to improve our understanding of these critical parts of the earthquake risk models is to collect instrumental data in the field.

Therefore, it is recommended that state and local government:

**Support long-term earthquake monitoring, and recording of earthquake strong ground motion, in Perth and its surrounding region.**

This support could take the form of direct financial support, provision of staff to assist station operations, use of government sites for establishing monitoring stations, and/or logistic support of field activities such as aftershock recording surveys.

### **Socioeconomic factors in community recovery**

There is considerable scope to develop the social vulnerability model framework based around the elements of household financial resilience, community relationships and access to services. Application of this framework will improve risk assessments by broadening the concepts of risk. An understanding of how the framework applies to metropolitan Perth can also improve community recovery through focussed preparation by government agencies.

**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 all sudden-onset hazards.**

We further recommend that government agencies collect, integrate and analyse socioeconomic data that will improve their understanding of community vulnerability to natural hazards.

There are more factors that influence recovery not explored in this report that need to be researched and addressed in order to gain a better understanding of recovery. There are also many structural issues that need to be addressed on how socio-economic and environmental models and impacts can be incorporated into risk assessments. The following points highlight some of the key recommendations for the improved development of comprehensive risk assessments:

- Local community development agencies and state recovery managers have a valuable role and must be involved in risk assessment development and strategic risk management decisions. Only then can government begin to better reduce the impact that natural disasters have on Australian communities;
- We need to further understand emotional and psychological factors associated with accessing services during recovery.

### **Potential impact on the southwest WA coast from sea level rise due to climate change**

Two recommendations related to future research and data collection that will assist coastal planning are taken from Chapter 7.

**To improve decision making and reduce uncertainties about the potential for future coastal erosion due to sea level rise:**

- **Undertake a Bruun Rule calculation as a preliminary methodology in planning for coastal recession due to sea level rise.**
- **Focus future research on the Bunbury to Mandurah coastline, the Cape Naturaliste to Bunbury coastline, and the Port/South beach area of Fremantle.**
- **Improve data availability, particularly sector specific wave data and more detailed subsurface data.**

- **Improve the sophistication of current models to allow for calculation in areas where the nearshore/offshore includes competent substrate.**

### **Spatial databases and risk assessment models**

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 and GIS hazard maps, were developed for use in Cities Project Perth.

**WALIS and DLI have played leading coordination roles in ensuring that the Cities Project Perth databases will be added to, maintained and made available by the appropriate WA government agencies. These databases will be reviewed for possible inclusion in the WA Shared Land Information Platform (SLIP).**

### **Risk assessment for floods and severe winds**

The hazard assessments for severe wind and flood in this report provide an excellent basis for extension of the hazard assessments to risk assessments that estimate physical impacts on the built environment and socio-economic losses. Comprehensive data for exposure and vulnerability are available to extend the hazard assessments in this way. Building databases are available through the WA Valuer-General's Office, and GA researchers have acquired additional important information such as building and contents cost models, building floor area, and building floor height for structures in the Swan floodplain. Demographic and household financial and socioeconomic information for metropolitan Perth that can be used for socio-economic vulnerability and loss analysis is available from ABS, for example through the census.

**Undertake probabilistic risk assessments for flood and severe wind in metropolitan Perth using the hazard assessments from this report as a basis.**

The development of a flood risk assessment for Perth, and/or a severe wind risk assessment, provides an excellent opportunity to compare and contrast risks from important sudden-onset natural hazards in Perth. Other risk assessment studies already developed or under development include the WA government initiative on bushfire threat analysis for the Perth urban/rural interface and the probabilistic earthquake risk assessment in Cities Project Perth. GA has also commissioned a study by Risk Frontiers on average annualised damage for metropolitan Perth as a single entity. The annualised losses from these risk assessments could be compared against the annualised historic losses estimated by BTE (2001) for WA as a whole, in order to obtain information on the costs of forecast rare events, the likes of which have not occurred in the historic record.

### **Bushfire risk assessment**

The historic record (see Chapters 1 and 2) indicates that bushfires have caused major damage in southwest WA. Climate change may modify the frequency and intensity of these events in future decades. The work of government agencies such as FESA and the WA Department of Conservation and Land Management (DCLM) in bushfire threat analysis would benefit from aligning their methods of research with that of Cities Project Perth, so that bushfire hazard and risk can be compared more systematically with other natural hazard risks. Therefore, it is recommended that the department's bushfire threat analysis methodology and the methodologies in Cities Project Perth are drawn together.

**Align the bushfire threat analysis currently being undertaken by WA government agencies with the hazard, exposure, vulnerability and loss assessment methodologies and databases of Cities Project Perth in order to develop a systematic and consistent set of information on the risks from the major sudden-onset natural hazards in Perth.**

### Cost of disasters

Chapter 1 mentioned the difficulties in obtaining accurate and complete information on the costs of natural disasters. Improved information on the total costs, and the breakdown of costs into who pays and who benefits, will improve risk assessment models and decisions on cost effective mitigation, as recognised in the report to COAG (High Level Group, 2002). Recommendation 11 from that report is repeated here.

*that jurisdictions jointly and progressively develop processes and systems that capture costs for all areas of disaster management, so that the cost of natural disasters, government expenditures, and costs and benefits of disaster mitigation are increasingly accurate and understood.*

In the case of future natural hazard events that cause significant losses, efforts should be made to capture systematic loss information. This action is necessary to obtain a full understanding of the event with the aim of introducing measures to mitigate similar future events. Also, the loss information, combined with information on the physical intensity of the event itself, provides extremely valuable ‘calibration’ data to improve risk models, and therefore our understanding of future risk from natural hazards. Recommendation 40 in the report to COAG is repeated here (High Level Group, 2002).

*‘that post-disaster assessments be undertaken routinely after every event of significance and the findings incorporated into improved disaster management processes to deal with future events.’*

### 8.3 Where to from here?

In this chapter we have suggested mitigation options that could reduce natural hazard risks in Perth based on the results of the research in Cities Project Perth. Most of the suggested options are aimed at the key public and private sector agencies who are responsible for emergency management, land use planning and information management in WA. Some of these mitigation options include recommendations for additional research and additional data gathering to make the risk management more effective again.

It is now largely the task of the WA partners in Cities Project Perth, and the people and organisations with whom they work, to implement decisions based on the new information herein made available.

### 8.4 References

- Australian Bureau of Statistics (2004a) *SEIFA 2001 Standalone (CD-ROM)*, Release 2 2004, Australian Bureau of Statistics, Canberra.
- Australian Bureau of Statistics (2004b) *2002 General Social Survey (CD-ROM)*, Australian Bureau of Statistics, Canberra.
- Bureau of Transport Economics (2001) *Economic Costs of Natural Disasters in Australia*, Report 103, Bureau of Transport Economics, Canberra.
- Bureau of Transport Economics (2000) *Road Crashes in Australia*, Report 102, Bureau of Transport Economics, Canberra.
- High Level Group (2002) *Natural Disasters in Australia: Reforming mitigation, relief and recovery arrangements, a report to the Council of Australian Governments*, Australian Department of Transport and Regional Services, Canberra.
- Standards Australia (2004) *DR 04303 : Structural design actions – Part 4 : Earthquake actions in Australia*, Standards Australia, Homebush, Sydney.
- Standards Australia (2002) *Structural Design Actions, Part 2: Wind actions*, AS/NZS 1170.2:2002.
- Standards Australia (1993) *Minimum Design Loads on Structures, Part 4: Earthquake loads*, AS 1170.4-1993.

