School of Public Health

Health Impacts of Climate Change in Urban Areas: A Pathway to Adaptation

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: ………………………………………….

Date: ………………………...

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Abstract

Health impacts of climate change are already being experienced around the world. These impacts range from the dramatic effects of extreme events to the less conspicuous, but equally important, impacts on food, water, air and disease. The way that societies react to these risks today will influence the extent to which current and future generations are affected.

While climate change is a global phenomenon, adaptation is a local affair. The complexity and size of the task presents an incredible challenge to all societies. This thesis presents a pathway for that challenge. The pathway is laid out within a Health Impact Assessment (HIA) framework, augmented by purpose-built risk assessment scales, and the system dynamics approach of Collaborative Conceptual Modelling (CCM).

The HIA of climate change in Perth, Western Australia, determined that the highest level of risk to human health in 2050 was associated with exposure to high ambient temperatures. The second phase of the research addressed this risk through the application of CCM to the risk management and decision-making steps of HIA. The development of a conceptual model representing the interaction between the urban environment, climate and health led to a focus on the issue of tree canopy in areas targeted for urban infill.

The loss of tree canopy is a significant contributor to the creation of urban-heat islands, which increase exposure to high ambient temperatures in urban areas. The research concluded that current paradigms and policies are contributing to tree canopy losses and that these losses will continue to occur without appropriate intervention.

In light of ongoing climate change and urbanisation, addressing the prospect of extreme heat in urban areas is critical. Despite this need, the results of this research indicate that current actions in Perth may well result in a more climate-sensitive city. The series of recommendations that emerged from this research provide an opportunity to move towards a more climate-resilient city. Whether or not these recommendations are implemented will influence the health and well-being of Perth residents for many years to come.

Table of Contents

Tables

Figures

Chapter 1 - Introduction

1.1 Introduction

Human health and well-being are inextricably linked to the climate in which people live. These links are demonstrated in many ways – from the devastating effects of extreme climatic events to changes in the quality of our environment, the spread of diseases and our way of life. Efforts to manage the effects of climate on health and well-being date back to the Stone Age, when humans first constructed shelters to provide protection from the elements. Over time, understanding of the links between climate and health has expanded to include a multitude of effects that occur via a large number of environmental, social and economic variables.

With strong scientific evidence for anthropogenic climate change, humans are faced with the reality that as the climate changes, so too will the links between climate and health. Current strategies, developed on the basis of our previous experiences, may prove ineffective. Without appropriate adaptation, risks to the health and well-being of billions of people will increase (Costello et al., 2009).

There are many challenges in developing adaptation strategies to address potential health impacts of climate change. The long-time frames, the uncertainties of projections, limitations in our understanding of the complex relationships between climate and health, and a lack of data all add to the difficulty of the task (Fussel & Klein, 2006; Fussel, 2009). In the last decade, these challenges have been met by studies that have assessed climate change impacts, vulnerabilities and/or adaptations (Carter et al., 2007; United Nations Framework Convention on Climate Change, 2006; World Health Organisation, 2003). Early assessments of vulnerability or adaptation tended to focus on identification of potential impacts and a range of potential adaptation strategies (Fussel & Klein, 2006). While this is a valuable starting point, it provides inadequate information as to where policies and adaptation measures should be targeted (Preston & Stafford-Smith, 2009). The need to progress, from identification of potential adaptation strategies to a greater understanding of how they will act out in complex systems, is paramount to successful adaptation planning (Adger et al., 2007).

The scope and extent of climate-related health impacts will be strongly influenced by location. Strategies to adapt to climate change will therefore need to be developed in the context of local environments. For example, the relationship between climate and health in urban areas is strongly influenced by the nature of the built environment and the high concentration of human activities. As one of the most urbanised countries in the world, the future health of Australia's population in the face of climate change will require adaptation responses designed for urban areas. The focus of this research is on the urban area of Perth, the capital city of Western Australia (WA).

In addition to the challenges of climate change, Australian cities will experience the additional pressures of population growth and ageing over the coming decades. The population in Perth is projected to double by the year 2050, and the proportion of the population aged over 65 is estimated to increase from 12% to just over 20% (Australian Bureau of Statistics, 2008). Responses to these changes introduce additional complexities to the urban climate-health system that must be factored into adaptation planning.

The development of effective adaptation strategies requires an understanding of the complex relationship between climate and health in urban areas. Developing such an understanding is no simple task – the links between climate and health encompass a multitude of variables that are strongly influenced by the fabric of the urban environment. Mechanisms to grapple with the complexities of the urban climate-health nexus are critical. Management approaches to such complexity often entail retreat into silos, where experts look at the 'parts' of the system and design solutions or policies to address problems that they see in their area of interest. Such solutions rarely have the impact intended in the whole system, and in the long-run many are ineffective or counterproductive (Checkland & Scholes, 1999; Senge, 2006).

1.2 Aim and scope of the thesis

The aim of the thesis is to develop and test a process that is designed to increase the effectiveness of climate change adaptation plans for health in urban areas. The proposed process is based on the introduction of systems approaches to a Health Impact Assessment (HIA) framework and will be applied to research conducted in Perth.

The research is conducted in distinct parts using an exploratory sequential mixed-methods design, with each part addressing exploratory questions with different methods. The first part utilises a Health Impact Assessment (HIA) framework that identifies and assesses health impacts in Perth. This assessment draws on collaborations with local government stakeholders. The HIA results guide the selection of a specific climate-related health issue that is then developed as a case study to test the application of systems approaches in the second part of the research.

The case study, which emerged from the first phase of the research, is focused on developing adaptation strategies to reduce exposure to high temperatures in Perth.

1.3 Structure of the thesis

The thesis is structured in 3 main parts as described in Figure 1.

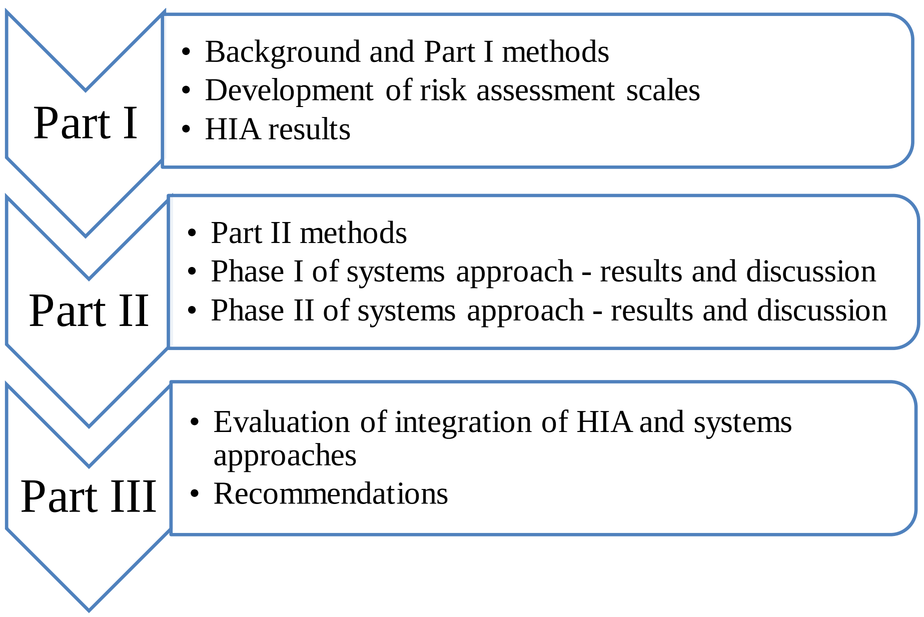

Figure 1 - Structure of the thesis

1.3.1 Part I – Background and HIA phase

Part I introduces the main concepts and methods used in the research and presents the outcomes of the HIA process. These outcomes are used as a rationale to justify the selection of an appropriate case study for the next phase of the research.

- Chapter 2 reviews the literature on links between climate change and health, with a particular focus on urban areas in developed countries. Key concepts of adaptation and vulnerability to the health impacts of climate change, health impact assessment, risk assessment and systems thinking are explained.

- Chapter 3 describes the overall design of the research and outlines the HIA process. It also identifies the need for quantitative health consequence scales which are suitable for climate change assessments.
- Chapter 4 describes the development of the risk assessment scales and presents the final scales that were ultimately deployed as part of the HIA.
- Chapter 5 tests the application of the risk assessment scales and reports the results from each step of the HIA. The results of the risk assessment step of the HIA were used to determine the focus for Part II of the research.

1.3.2 Part II – Case study of systems approaches

Part II provides the background to the case study, explains the methods used and presents the case study results.

- Chapter 6 introduces fundamental concepts and tools of systems approaches. It outlines Collaborative Conceptual Modelling (CCM) that is applied in Part II of the research.
- Chapter 7 reports and discusses the results from Phase I of CCM. This phase includes the first three activities of the CCM process.
- Chapter 8 presents and discusses the results from the three activities of Phase II of CCM. The outcomes result in a series of recommendations to improve adaptation to the potential health impacts of higher temperatures in Perth.

1.3.3 Part III – Assessment of HIA and systems approach

Part III concludes the research by evaluating the combination of HIA and systems approaches used in Parts I and II. The evaluation leads to a proposal for the integration of CCM activities to a HIA framework. The thesis concludes with a summary of the evidence collected throughout the research that was used to develop the final recommendations.

1.4 Climate and Health Cluster

This research was conducted under the umbrella of the CSIRO Urbanism, Climate Adaptation and Health Research Cluster, otherwise known as the ‘Climate and Health

Cluster'. The Cluster was divided into seven key projects, with this research forming part of Project 7 – 'Urbanism climate adaptation and health: Accounting for the links'. A key objective of Project 7 was the application of HIA and system dynamics, to increase the capacity to develop effective adaptation strategies, targeting health impacts of climate change in urban areas of Australia

1.5 Conclusion

This introductory chapter has outlined the links between climate and health and discussed the challenges of developing effective strategies that address the potential health impacts of climate change.

The aim of the thesis clarified that these challenges would be met using a combination of HIA and systems approaches in research conducted in Perth. The organisation of the thesis and a brief outline of each Part and Chapter were provided.

The following chapter reviews the literature on the potential health impacts of climate and the approaches that have been used to assess and adapt to such impacts.

Part I –Health impacts of climate change

Part I (Chapters 2 to 5) reviews the relationships between human health and climate and presents the methods and results used to assess the potential health impacts of climate change in Perth, Australia.

- Chapter 2 reviews the literature on the potential health impacts of climate change in urban areas in developed countries. It introduces fundamental concepts of mitigation, adaptation and vulnerability. Methods to assess and manage health impacts of climate change are discussed.
- Chapter 3 discusses the overall research design and the methods used in Part I of the thesis.
- Chapter 4 presents the risk assessment scales which were developed to provide a more quantitative assessment of health impacts of climate change.
- Chapter 5 reports and discusses the results from the scoping, profiling and risk assessment steps of the HIA. The application of the quantitative scales developed as part of the earlier research is discussed. The chapter concludes by selecting a specific focus for Part II of the research.

Chapter 2 - Health and Climate Change in Urban Areas

2.1 Introduction

It is clear that without appropriate adaptation, climate change is likely to result in significant health impacts in Perth over the coming decades. This chapter reviews the evidence for links between climate change and health and outlines current approaches to assess potential health impacts of climate change.

Direct and indirect links between climate and determinants of health will be considered primarily in the context of urban environments in Australia. A review of key assessments of health impacts of climate change will incorporate the concepts of vulnerability and risk. The role of mitigation and adaptation in addressing these issues will be discussed.

The challenges in developing effective adaptation strategies for health impacts of climate change in urban areas are significant. The complexity of the urban climate-health system, evidence gaps and the long time frames associated with climate change assessments all contribute to this challenge. This chapter will outline the need for methods that address the complexities of the system in which adaptation strategies will be implemented.

2.2 Determinants of health and links to climate

Health and climate are linked by multiple pathways, from relatively direct and well understood relationships to more complex relationships encompassing a large number of health determinants (McMichael & Haines, 1997). Understanding the associations between these determinants, climate and a particular health outcome is a crucial starting point in developing appropriate strategies to manage health (McMichael, Woodruff, & Hales, 2006).

A suitable starting point to consider the potential health impacts of climate change is a clear definition of health as “a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity” (World Health Organisaton, 1948, p. 100). Determinants of health include a vast array of socio-economic, cultural and environmental variables that traverse influences from the individual to the global level (Dahlgren, 1991).

Figure 2 (Australian Institute Health and Welfare, 2011) illustrates these determinants in a series of layers from the broad outer layer of global ecosystems to the inner set of individual determinants and behaviours. The global ecosystem is the ultimate provider of the environmental services critical for human life. In an analysis of global ecosystems, Rockström and colleagues (2009) proposed nine 'planetary boundaries' considered critical in providing a safe environment for humanity. They concluded that the boundary for climate change, based on 350 parts per million of atmospheric carbon dioxide, has already been transgressed.

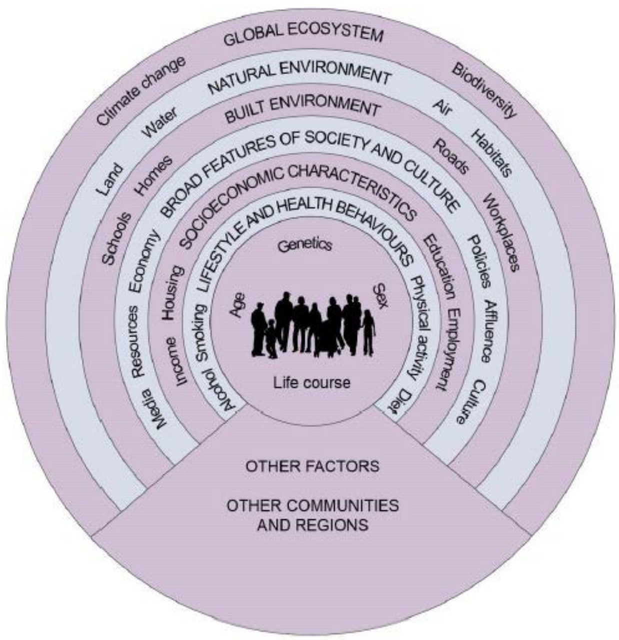

Figure 2 - Determinants of health and well-being

There are strong interactions between and within each of the layers (Australian Institute Health and Welfare, 2011; Rockström et al., 2009). For example, the activities undertaken in the built environment can impact on health via effects on the global ecosystem (emission of greenhouse gases), the natural environment (emission of local pollutants) and societal features (economy, housing and physical activity). In turn, the built environment can be affected by climate change, environmental conditions, policies, the economy and the demand for provision of services. These examples serve to demonstrate that solutions must take into account the individual elements within the broad 'list' of determinants and the connections between them. An understanding of the interactions between and within layers is clearly influenced by location. For example, the role and impact of the built environment layer tends to be more dominant in urban areas than in rural areas.

The rationale for a connection between climate change and health is based on our current understanding of the relationship between climate and health determinants. Where evidence for an existing relationship exists, it follows that a change to climate has the potential to influence health. Identifying and understanding these relationships is the first critical step in planned responses to address health impacts of climate change. Studying the pathways that link climate to health can identify multiple proximal and distal causes of a range of health impacts. Figure 3 categorises the exposures leading to health impacts into three main areas: direct exposures, indirect exposures and social and economic disruption (Confalonieri et al., 2007).

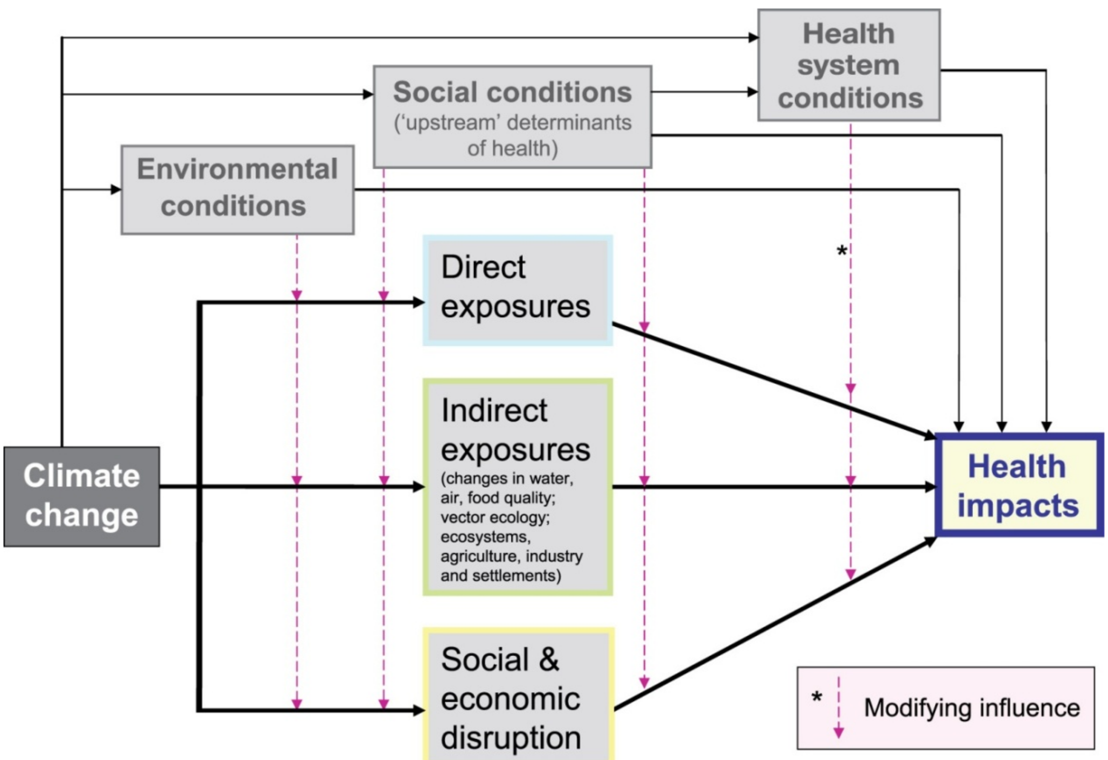

Figure 3 - Health impact pathways of climate change

Direct exposures refer to the relatively immediate and proximal health impacts that occur as a result of exposure to extreme events such as heatwaves, bushfires, floods and cyclones. The pathway between climate and health in such cases is clear and will often consist of one simple step, where exposure to a climate hazard results in injury or death. Examples include fatalities or injuries from floods, fires and heatwaves.

A far wider range of climate-related health impacts occur via indirect exposures from environmental determinants such as air, water and food quality, vector ecology and impacts on human systems, such as the built environment, agriculture and industry. Finally, climate can also result in social and economic disruption, from the global to the individual level, with flow-on effects to human health (Confalonieri et al., 2007). A single climatic variable or event may impact on human health by a combination of each of these exposure types. For example, widespread flooding may initially result in direct exposure to flood waters that lead to drowning or injury. In the period following the immediate event, flood waters can lead to disruptions in the adequate supply of safe water, food and shelter to humans, as well as disruptions to essential infrastructure services such as transport, power and medical treatment. Loss of property, including family homes, businesses or community facilities, can result in significant economic and social disruption that leads to reductions in quality of life and effects on physical and mental health (Brown, Proust, Spickett, & Capon, 2011).

Identifying the potential pathways from climate change to health impacts provides a mechanism to improve our understanding of the relationship between climate change and health. As part of this understanding, management strategies, that aim to minimise adverse health impacts (or maximise health benefits), can then be developed. The opportunities for such management strategies are represented in Figure 3 as the 'Modifying Influence' of environmental, social and health system conditions.

2.3 Climate change scenarios

Assessing health impacts of climate change is clearly dependant on the extent of the change, which will be determined by greenhouse gas emissions over time. The Special Report on Emission Scenarios (SRES) (IPCC, 2000) was based on four main scenario families, as shown in Figure 4. These scenarios incorporate the main driving forces of future emissions, including demographic, technological and economic factors. These factors include different future developments that might influence greenhouse gas sources and sinks, such as alternative structures of energy systems and land-use changes. The scenarios are aligned around two axes; one ranging from strong economic to strong environmental values; the other from increasing globalisation to regionalisation. No probabilities are assigned to the scenarios, and no one scenario is considered the 'most likely' (Nakicenovic, 2000). There are three scenarios within the A1 family based on alternative energy development; A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel).

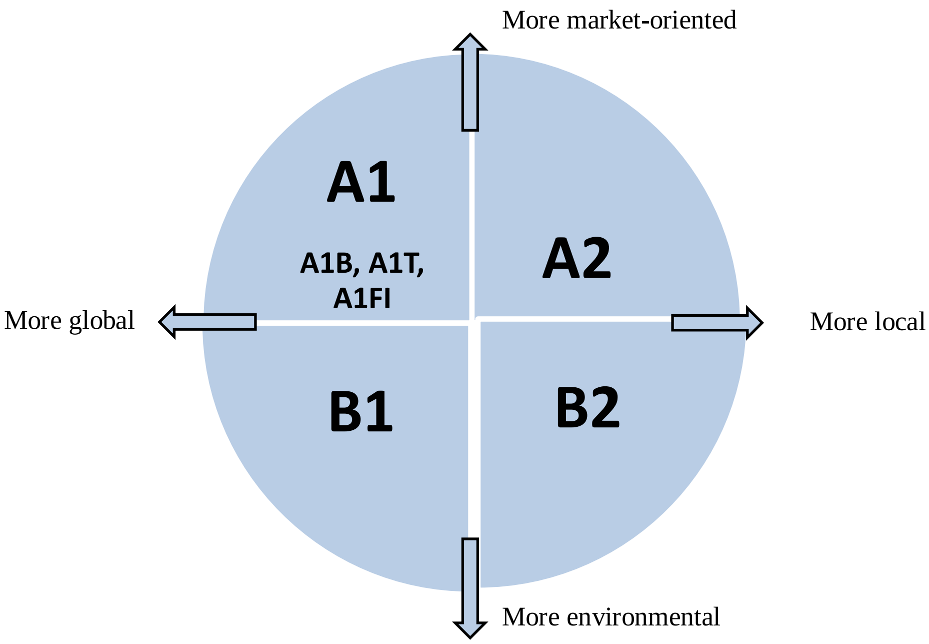

Figure 4 - SRES scenarios

Table 1 provides a more detailed description of each of the scenario storylines.

Table 1- Scenario characteristics

Storyline	Descriptions (adapted from IPCC, 2000)
A1	Very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
A2	Very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
B1	Convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in materials intensity, and the introduction of clean and resource efficient technologies.
B2	World with emphasis on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

Figure 5 (IPCC, 2007b) shows the projections for global surface warming based on each of these scenarios. The grey bars on the right indicate the likely range of surface warming in the year 2100, for each of the scenarios. The solid lines in the grey bars are the best estimates for each scenario. Figure 5 highlights that differences between the scenarios become much more apparent in the second half of the 21st century.

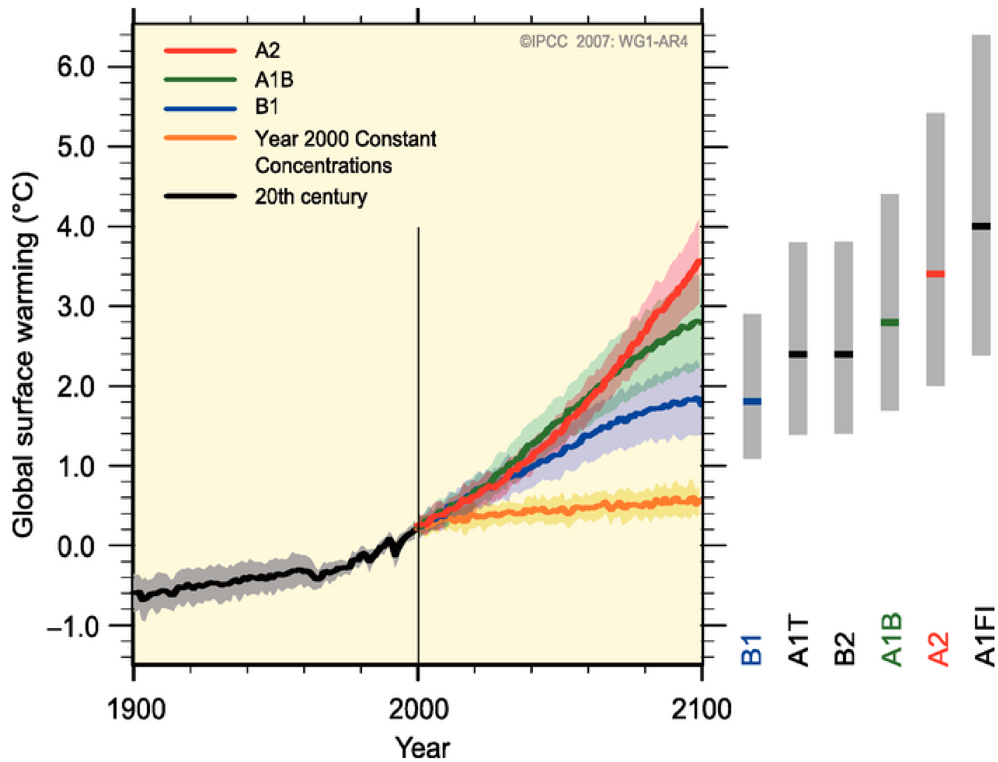

Figure 5 - Projected temperature increases for scenarios

The 5th Assessment Report of the IPCC, which is being released in stages during 2013 and 2014, is based on a set of Representative Concentration Pathways (RCPs) rather than emission scenarios (IPCC, 2013). While future assessments are likely to employ RCPs, the vast majority of published health assessments at the time of this research refer to the SRES scenarios.

2.4 Climate change action and management

Management of climate change is considered under a two-pronged approach of mitigation and adaptation. While mitigation is focused on the reduction of greenhouse gas emissions to limit the magnitude of climate change, adaptation focuses on managing the effects of unavoidable climate change. Adaptation planning can be considered on a broad scale that cuts across a range of impacts, or within a specific context. For example, in the context of this research, the focus is the potential health impacts of climate change in urban Perth.

The key objective of climate change adaptation is to reduce vulnerability to the adverse impacts of climate change. Vulnerability to climate change is defined as “the degree to which a system is susceptible to and unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes” (IPCC, 2007a, p. 883).

As depicted in Figure 6, vulnerability is a function of the extent and type of exposure to climate change and the level of adaptive capacity (IPCC, 2007a).

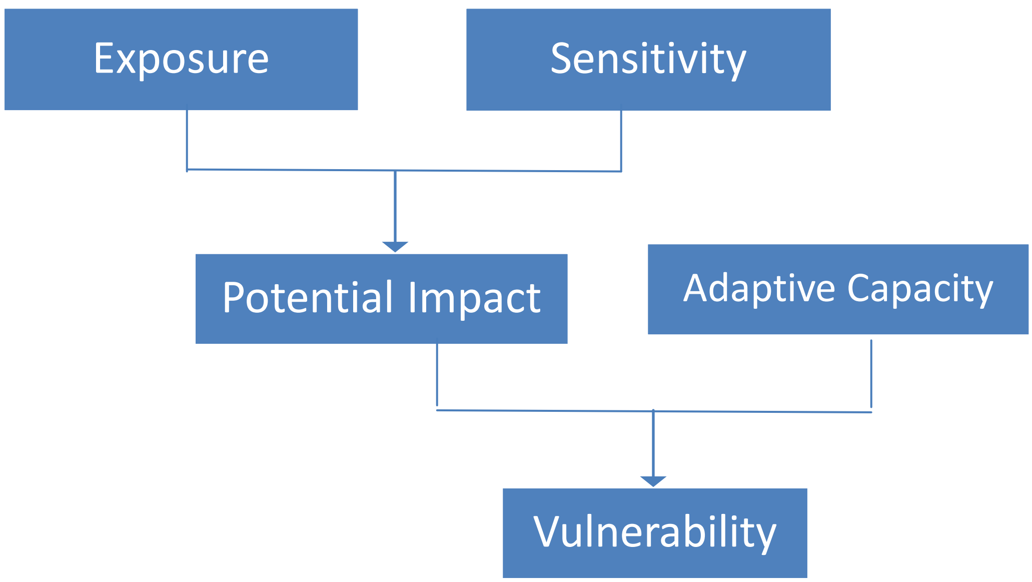

Figure 6 – Dimensions of vulnerability

In the first instance, initial exposure will be determined by the extent and nature of climate change that occurs in any particular location. To that end, the most fundamental way of managing exposure is mitigation of climate change. However, in terms of health impacts, exposure to certain climate-related risks will not be determined by climate change alone. For example, while vector-borne diseases may be influenced by climate change, other factors such as land-use planning will also play a significant role in determining exposure (Tong, 2008). These factors provide additional opportunities to manage exposures to hazards influenced by climate change.

Sensitivity is “the degree to which a system is affected, either adversely or beneficially, by climate variability or change (IPCC, 2007a, p. 881). In terms of human health, sensitivity can be considered in two ways. The first is the extent to which a given health outcome responds to changes in climate variables. The second relates to certain population groups that may experience more severe health effects or experience adverse effects at a lower threshold than the general population. Age and existing health status are two of the most important determinants of sensitivity. The elderly and very young are sensitive to a wide range of climate-related hazards, such as extreme events, air pollutants and food-borne pathogens. Existing health conditions such as cardiovascular or respiratory conditions or diabetes can also increase sensitivity to a range of environmental stressors, including exposure to heat and air pollutants (O’Neill et al., 2005).

The combination of exposure and sensitivity determines the potential impact that exists prior to the application of any adaptation strategies. Strategies targeted at reducing the level of risk at this point, particularly at a population level, have the advantage that they are more preventive in nature than strategies targeted at increasing adaptive capacity. If possible, reductions in the level of potential impact can reduce the need to adapt, improve the effectiveness of adaptation strategies, and potentially avoid thresholds, beyond which adaptation may become exceedingly difficult or expensive.

The extent to which the potential impact is translated into adverse health impacts will depend largely on the adaptive capacity of government, communities and individuals. Adaptive capacity is defined as “the ability of a system to adjust to *climate change* (including *climate variability* and extremes), to moderate potential damages, take advantage of opportunities, or to cope with the consequences” (IPCC, 2007a, p. 869). There is considerable variation in adaptive capacity between and within countries. Countries such as Australia, with well-developed economies, extensive scientific and technical capabilities, and robust health-care systems and disaster management strategies have considerably higher adaptive capacity than those with fewer resources. Nevertheless, even within countries such as Australia, certain groups, individuals or communities are likely to have significantly lower adaptive capacity than the general population and therefore be more vulnerable (Hennessy et al., 2007). For example, while a severe heatwave may have a high potential impact for elderly people with existing heart conditions, differences in social support networks and financial resources can result in considerable variation in vulnerability.

An assessment of each of these elements of vulnerability is critical in ascertaining which populations are vulnerable to which hazards and enabling adaptation measures to be targeted accordingly.

2.5 Assessing potential health impacts of climate change

The United Nations Framework Convention on Climate Change (United Nations, 1992) deems that national governments have a responsibility to carry out formal assessments of the risk to their population's health posed by global climate change. There are many challenges in assessing health impacts of climate change. The scale and uncertainties associated with climate change, the complex relationships in the climate-health system, a lack of relevant data and the long time horizon, all add to the difficulties of assessing impacts (Fussel & Klein, 2006; Fussel, 2009). Despite these difficulties, estimates of impacts are required to inform policy discussion on both climate change mitigation and adaptation (World Health Organisation, 2003).

2.5.1 Health Impact Assessment (HIA) and climate change

Health impact assessment is a "combination of procedures, methods and tools by which a policy, program or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population" (World Health Organisaton, 1999, p. 4).

The development of HIA has arisen from a growing awareness that health considerations need to be factored into a range of decision-making processes (National Academy of Sciences, 2011). HIA considers both positive and negative impacts on health and identifies population groups more likely to suffer some form of health disparity or inequity (Harris, Harris-Roxas, Harris, & Kemp, 2007; National Academy of Sciences, 2011).

HIA has been identified as a valuable tool for systematically identifying, and where possible, quantifying the multiple pathways that link climate change to human health (Patz, Campbell-Lendrum, Gibbs, & Woodruff, 2008; Spickett, Brown, & Katscherian, 2011; World Health Organisation, 2003). HIAs related to climate change have been conducted as part of multi-sectoral projects or as stand-alone assessments for selected health impacts (Confalonieri et al., 2007). The characteristics of a HIA are influenced by the subject and scope of the assessment and the availability of evidence and resources. The simplest of assessments identify the type of impacts, but do not provide information regarding the magnitude of impacts. Quantitative assessments that provide an indication of the magnitude of impacts are particularly useful for conducting a comparative risk assessment within HIA, but they are limited to impacts for which some measure of health outcome is available (Patz et al., 2008).

Despite differences in the form of HIAs, a general consensus has emerged regarding the procedural steps, although differences in terminology still exist (Harris-Roxas & Harris, 2011). The terminology and steps outlined in Figure 7 are those published by the Department of Health in Western Australia (2006). While this research does not fit into the traditional application of HIA to 'project, plan or policy', the steps provide a suitable framework that can be interpreted with respect to health impacts of climate change. More detail on each of these steps will be provided in the next chapter.

Screening	• Is a HIA necessary?
Scoping	• Defines boundaries and objectives of HIA
Profiling	• Collects background data
Risk Assessment	• Assesses the extent & distribution of health impacts
Risk Management	• Compare risks and benefits • Identify management options
Decision-Making	• Determine and implement management actions
Evaluation	• Has the HIA resulted in beneficial health outcomes?

Figure 7–The HIA process

Published assessments of health impacts of climate change have utilised some aspects of HIA, but few have undertaken a systematic approach that allows a comparison of risks using predetermined criteria. For example, "Human Health in a Changing Climate: A

Canadian Assessment of Vulnerabilities and Adaptive Capacity" (Health Canada, 2008), identifies and describes variables that contribute to vulnerability for a range of health impacts, but does not provide estimates of future risks using clearly defined criteria. The US National Assessment of the Potential Consequences of Climate Variability and Change describes health consequences with a simple scale that indicates whether the change for a particular health impact is likely to increase, decrease or change in either direction (Patz et al., 2000). Various risk assessments in Australia have provided estimates of climate change health impacts related to increased temperature and heatwaves, flooding, food poisoning and Dengue Fever (Bambrick, Dear, Woodruff, Hanigan, & McMichael, 2008; McMichael et al., 2003), however the lack of a common scale for risk makes comparison of results difficult.

Several assessments have developed more detailed criteria for the health impacts of climate change. A HIA of climate change in Western Australia provided qualitative criteria for assessing health impacts that enabled a ranking of health impacts based on risk (Spickett, Brown, & Katscherian, 2007). The UK Climate Change Risk Assessment (CCRA) group developed a comprehensive set of quantitative and qualitative metrics and scales that allowed a comparative measure of risk. The measures and scales were related to economic, environmental and health impacts (Department for Environment Food and Rural Affairs, 2010; Hames & Vardoulakis, 2012).

There are important differences between climate change and the typical application of HIA to a project, plan or policy. Firstly, the range of health effects of climate change is likely to be far larger, span longer time frames and affect a greater proportion of the population than a discrete project or activity. Secondly, the determination and implementation of appropriate decisions will relate to a wide range of impacts and cut across almost every facet and level of society. These fundamental differences in scope and complexity are likely to require methods and tools that have not typically been incorporated into HIAs.

This in itself is not a barrier. HIA is a flexible framework and there is a diverse range of procedures, methods and tools that have evolved over several decades (Harris & Spickett, 2011). The document 'Health Impact Assessment: A Practical Guide' states that "those undertaking a HIA are likely to pick and choose from a range of strategies and approaches" (Harris et al., 2007p. 3). The selection of tools will depend on the typology of the HIA and the activity being assessed (Harris-Roxas & Harris, 2011; National Academy of Sciences, 2011).

2.6 Systems approaches

There is a growing recognition of the need for methods that deal with the complexity of adapting to climate change impacts. In the 4th Assessment Report of the IPCC, Adger et al. (2007, p. 737) highlighted the "significant outstanding research challenges in understanding the processes by which adaptation is occurring and will occur in the future, and in identifying areas for leverage and action by government". The call for integrated approaches that provide more robust information about where adaptation measures should be targeted has also been made in Australia (Preston & Stafford-Smith, 2009).

System dynamics is a method that facilitates understanding and decision-making in complex systems (Sterman, 2000). Such systems are characterised by behaviour that emerges from the interaction of its parts, so that a study of the parts alone does not lead to an understanding of how the system behaves (Checkland & Scholes, 1999). Understanding the range of potential outcomes of actions in complex systems, such as the urban climate-health system, is generally beyond the limit of an individual's cognitive ability (Forrester, 2007; Meadows, 2008; Senge, 2006; Sterman, 2000). Because of this, complex problems are often managed through a silo approach where various experts look at the 'parts' of the system and design solutions or policies to address problems that they see in their area of interest. However policies designed in this manner typically fail.

Recognition of policy failures in complex issues has led to an increase in the use of system dynamics to tackle complex problems - sometimes referred to as 'messy' or 'wicked' problems (Australian Public Service Commission, 2007; Capon, Synnott, & Holliday, 2009; Homer & Hirsch, 2006; Vennix, 1999). The use of system dynamics has been applied to the issue of climate change impacts in Australia, with a focus on local government and urban settlements (Li, 2010; Smith et al., 2008) and is recognised as an appropriate approach to climate change adaptation (Australian Public Service Commission, 2007).

Interactions in complex systems typically include a network of circular feedback effects, so as one variable in the system is changed a range of outcomes, both intended and unintended, will occur (Meadows, 2008; Sterman, 2000). There is a range of techniques used in system dynamics, from simple qualitative models to fully developed computer simulations. Given the importance of collaboration and integration in understanding complex systems, systems approaches invariably demand model building (qualitative and/or quantitative) in group situations. The model building typically progresses through cycles of elicitation, integration, representation and reflection (Andersen & Richardson, 1997; Kim, 2009; Newell & Proust, 2012; Vennix, 1999).

The identification and analysis of system structure, particularly feedback loops, can help to facilitate the identification of leverage points (Goh, Love, Brown, & Spickett, 2010; Meadows, 2008; Senge, 2006; Wolstenholme, 1992). Leverage points are places in complex systems where intervention is most likely to be effective (Meadows, 2008). Simple models to identify leverage points have been utilised to develop hypotheses and/or interventions on a wide range of complex issues such as major accidents (Goh, Love, et al., 2010; Goh, Brown, & Spickett, 2010), obesity (Newell, Proust, Dyball, & McManus, 2007), chronic disease prevention (Homer & Hirsch, 2006), public health reform (Cavana & Maani, 2000), water and energy management (Proust et al., 2007) and climate change (Li, 2010).

The diversity of situations and circumstances under which systems approaches are applied, means that the selection of specific approaches and system tools will vary significantly from project to project.

2.6.1 Collaborative Conceptual Modelling

The specific systems approach employed in Project 7 was Collaborative Conceptual Modelling (CCM) developed by Newell and Proust (2012). CCM provides a set of flexible guidelines for groups wishing to develop a shared understanding of the dynamics of a complex system. The following description draws heavily on Newell & Proust (2012) with their permission.

An introduction to the key principles of CCM can be framed by a discussion of its title. The term ‘collaborative’ highlights the need for a team approach, with experts from a wide range of backgrounds and experiences working together to improve the group understanding of the system-of-interest. The collaboration in CCM extends beyond acknowledging different points-of-view to actually *using* everyone’s point of-view.

The term 'conceptual' refers to the focus on developing relatively simple models based on generic feedback structures that have the potential to dominate system behaviour. These conceptual models represent 'dynamic hypotheses' of the behaviour of the system. Evidence that relatively simple models can be used to describe the dominant dynamics of complex system is supported by the existence of system archetypes, discussed earlier in the chapter. Ecologists have discovered that even complex social-ecological systems with large numbers of variables can be understood by analysing the interactions between just three and five variables at any given scale (Walker et al., 2006). The process of working together to develop relatively simple conceptual models is the key to increasing systemic understanding of the challenge at hand.

The modelling component of CCM ranges from mental models, influence diagrams, CLDs, stock-and-flow maps to computer-based dynamical models and will be discussed in greater detail in Chapter 6.

2.7 Climate change in Western Australia

Climate projections in WA include increases in temperature, sea-level and extreme weather events such as bushfire, drought, cyclones and heatwaves. Changes to rainfall are more variable, but the Perth region is expected to experience reductions in rainfall (CSIRO, 2006)

Human health is most affected by extremes of temperature. Given the relatively mild winters in Perth, most temperature-related health effects in Perth occur as a result of extreme hot, rather than cold, temperatures (Bambrick et al., 2008). The 4th IPCC assessment (2007a) stated that hotter days and nights and more frequent heatwaves are already occurring around the world. In terms of projections for the 21st century, the IPCC has concluded that there is a greater than 99% probability that warmer and more frequent hot days and nights will be experienced over most land areas. In addition, projections indicate a greater than 90% probability that the frequency of heatwaves will increase over most land areas in the 21st century (IPCC, 2007a). Modelling in Australian supports these projections (CSIRO, 2012).

Current climate models suggest that relative to the period 1980 to 1999, the average temperature in Perth in 2050 will increase from 0.8 °C to 1.8 °C for a low emissions scenario, or from 1.5 °C to 2.8 °C for a high emissions scenario (CSIRO, 2007a). Impacts on health are most affected by extremes in temperature rather than changes to average. Table 2 summarises the projections for the number of hot days (>35°C and >40°C) in Perth, by the year 2050, under three emissions scenarios. The projections are determined by the application of 24 models, which enables an indication of the 'most likely' and the 'worst case' estimates for each estimate.

The most likely outcome of an A1FI scenario is an additional 11 days over 35°C and four more days over 40°C. The worst-case for A1FI indicated an additional 21 days over 35°C, 7.5 more days over 40°C and an extra five occurrences of more than 3 days in a row exceeding 35°C (CSIRO, 2007b).

Table 2–Temperature-related projections for Perth 2050

Scenario for 2050		Days >35^{0}C	3-5 day runs >35^{0}C	Days >40^{0}C
Current		28.1	4.3	4.1
A1FI	Most Likely Worst Case	39.5 49.1	7.1 9.2	8.1 11.7
A1B	Most Likely Worst Case	37.9 45.5	6.6 8.3	7.2 10.1
B1	Most Likely Worst Case	35.3 40.2	6.1 7.2	6.3 7.8

2.8 Potential health effects of climate change in Western Australia

The priority areas for climate change adaptation research in Australia were identified in the National Adaptation Research Plan (NARP) for human health as: heat, extreme weather events, vector-borne disease, food, air and water quality, mental health, community and indigenous health, health services and infrastructure (McMichael et al., 2009).

A HIA focused on Western Australia was undertaken in 2007 (Spickett et al., 2007; Spickett, Brown, & Katscherian, 2011). This project combined key concepts of climate change adaptation within a HIA framework. Approximately seventy stakeholders from a wide range of sectors took part in a series of workshops which:

- identified potential direct and indirect health impacts of climate change
- identified vulnerable groups
- assessed the adequacy of current responses in a changed climate
- assessed the level of risk of each impact
- identified a range of potential adaptation measures and assessed current capacity
- identified which sectors were responsible for each of these measures.

A group of 15 experts who attended the first workshop attended a risk assessment workshop to assess each of the health impacts previously identified. Each health impact was assessed in terms of a set of defined consequences and likelihood. Results were then entered into a risk matrix to determine the final level of risk. The highest ranked health impacts included those related to tropical cyclones, heat events, reduced air quality and inadequate infrastructure. The outcomes stressed that the impacts would not be felt uniformly across WA and recommended that future assessments take into account differences in vulnerability based on location (Spickett et al., 2007; Spickett, Brown, & Katscherian, 2011).

The latest census indicated that 77% of WA's population was located in the Perth region (Australian Bureau of Statistics, 2013). Population projections for the year 2056 indicate that this percentage will increase over the coming decades and that Perth will experience the highest percentage growth (116%) of all capital cities in Australia (Australian Bureau of Statistics, 2008). Given these figures and the fact that residents of urban environments are likely to experience and adapt to impacts of climate change in significantly different ways to those in non-urban environments (Younger, Morrow-Almeida, Vindigni, & Dannenberg, 2008), it is critical that appropriate adaptation strategies are developed for Perth.

The importance of adaptation planning in urban centres has been recognised in other countries with the development of extensive climate change adaptation plans in cities such as London and New York. Most city-wide assessments address a wide range of impacts and are not designed specifically to address health impacts (Greater London Authority, 2010; Rosenzweig & Solecki, 2010).

The discussion thus far has highlighted a number of potential health impacts of climate change that will be summarised in brief below. The review of the literature will focus on providing evidence for the links between climate change and human health, with a particular focus on Perth. This will provide the necessary information to inform the HIA phase of the project. A more detailed review for those impacts that are identified of most concern in the study area will be conducted during the course of the HIA.

2.8.1 Extreme events

Extreme events related to climate include heatwaves, floods, cyclones, droughts and bushfires. Direct and immediate health effects include death or injuries. Indirect health effects include impacts on essential environmental health services such as water and waste-water treatment and mental health effects. The type and extent of impacts experienced in cities is strongly influenced by the built environment. The high concentration of infrastructure and services can both exacerbate and alleviate potential health impacts of climate change. For example, heatwaves can be exacerbated by urban heat island effects and physical injuries from floods can be exacerbated by structural damage to buildings. On the other hand, the concentration of services in cities can provide significant opportunities to respond to extreme events that may not be available in rural areas.

Perth does not have a history of flooding (Jones, Middelmann, & Corby, 2005) and with projections for reductions in rainfall, flooding is not considered a major health risk in Perth. Tropical cyclones rarely extend to the Perth region and climate change projections have not highlighted tropical cyclones as a threat to Perth. The previous HIA concluded that the greatest vulnerability to health impacts of droughts was in rural areas. While city residents may be affected indirectly via impacts on food prices, they are less vulnerable to mental health impacts associated with drought than rural populations (Berry et al., 2008; Spickett et al., 2007).

The previous HIA concluded that the highest level of risk associated with climate change in WA was associated with heatwaves and this impact is reviewed in greater detail below.

2.8.1.1 Heatwaves and heat-related health effects

Evidence for an association between extreme heat and increased mortality is strong with a large number of international and Australian studies reporting significant excess mortality during heatwaves. A significant proportion of deaths associated with heatwaves occur as a result of the exacerbation of existing conditions such as cardiovascular disease or respiratory illnesses (Basu, 2009; Basu & Samet, 2002, Bi et al. 2009). For this reason analysis of the mortality effects of heatwaves usually uses the measure 'excess deaths' which estimates the number of additional deaths above that which would be expected during the heatwave period (World Health Organisation, 2003). Figure 7 (McMichael et al., 2006) provides a schematic representation of the relationship between temperature and mortality. The typical u-shaped curve indicates that health is most affected by extremes of temperature. Perth has relatively mild winters and does not experience significant cold-related fatalities (Bambrick et al., 2008).

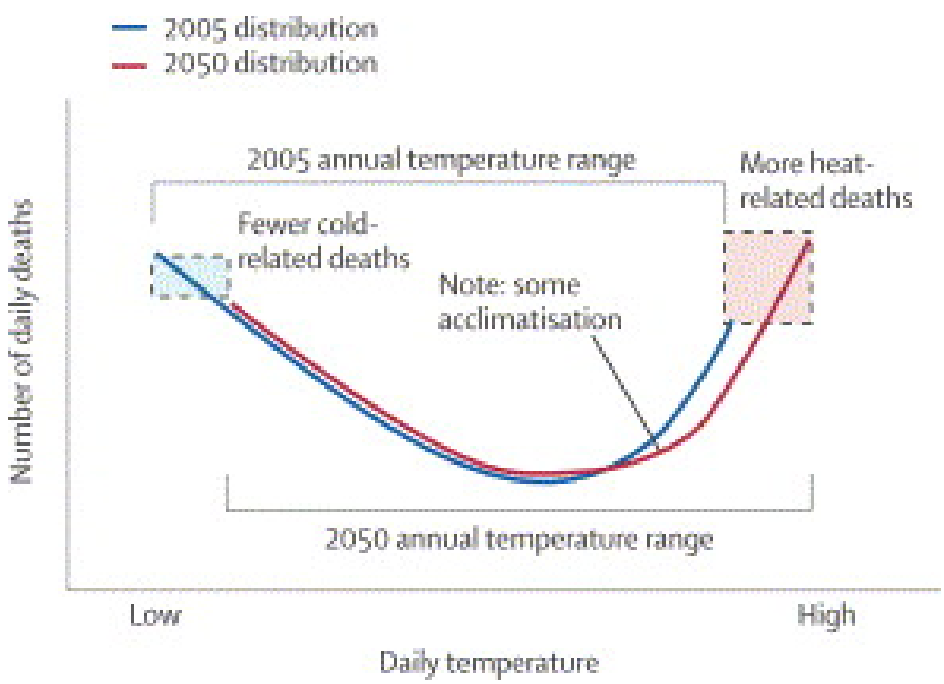

Figure 8 - Effect of increase in temperature on heat-related mortality

One of the most significant heatwaves in terms of mortality effects was the European heatwave of 2003 that resulted in an excess mortality of up to 45 000 deaths in a range of European countries (Fouillet et al., 2006). In France, around 60% of the heatwave deaths occurred in persons aged 75 and over (Confalonieri et al., 2007). Other harmful exposures were also caused or exacerbated by the extreme weather, such as ozone and particulate levels (European Environment Agency, 2003).

Groups that are considered vulnerable to heatwaves include the very young, the aged (particular those living alone) and people with chronic health conditions particularly cardiovascular or respiratory disease, diabetes, obesity and psychiatric illness. Other socioeconomic factors such as income and housing can also influence vulnerability (Department of Human Services, 2009; Westphal et al., 2010).

2.8.1.1.1 Mortality effects

Most Australian studies quantifying heat-related mortality have reported an association between temperature and mortality. The 2009 heatwave in the South East of Australia resulted in 374 excess deaths in Melbourne with the greatest number in those aged 75 years or older, but also significant increases in the 65 to 74 year age group (46% increase) and the 5- to 64- year age group (55% increase) (Bi et al., 2011). Other studies in Brisbane and Sydney reported 75 and 110 excess deaths respectively during heatwaves (Gosling, McGregor, & Páldy, 2007; Tong, Wang, & Barnett, 2010), Associations were found with all-cause mortality, but also circulatory and cerebrovascular mortality in Sydney (Vaneckova, Beggs, de Dear, & McCracken, 2008) and stroke, heart attack and respiratory failure in Brisbane (Auliciems & Skinner, 1989). In a study of two heatwaves in Adelaide Nitschke and colleagues (2011), reported considerable increase in total mortality for the 12-64 year age group during one of the heatwaves. No published data on mortality resulting from previous heatwaves in Perth was found.

The Oceania Risk Assessment on Climate Change (McMichael et al., 2003) estimated the temperature-attributable death rates in Perth for the 65+ age group at 199/100,000 over the period of 1997-1999. These deaths were all associated with high temperatures. An assessment of heat-related mortality in Perth was included in the Garnaut Climate Change Review using all causes of death from the Australian National Mortality Database from 1990 to 2005. This assessment estimated 292 heat-related deaths in WA for the year 1990 (Bambrick et al., 2008).

In a retrospective study of mortality and temperature data from 1979 to 1990 in Melbourne, Sydney, Brisbane, Canberra and Perth, Guest et al (1999) estimated a combined annual excess of deaths of 175 in association with days over the threshold of 28^{o}C for all cities combined. However, in contrast to other studies, none of these deaths was reported in Perth and the authors concluded that “Perth appears free of climate-related deaths”. Significant differences in estimates of heat-related mortality were also reported for other cities in these two studies, but the differences were larger for Perth. Other authors have suggested these differences may be explained by the use of different climate models and in adjustments for air pollution (Bi et al., 2011).

2.8.1.1.2 Morbidity effects

Reports of morbidity effects of heatwaves include hospitalisation for a range of conditions, presentations at emergency departments and impact on health services such as ambulances. The 2009 heatwave in South East Australia resulted in more than 3000 reports of heat-related illnesses (Queensland University of Technology, 2010). In a study of admissions for acute myocardial infarction (AMI) in Melbourne hospitals over a six year period, Loughnan and colleagues (2010) reported that an average daily temperature of 30°C or higher resulted in a 10.8% increase in admissions for AMI. Average temperature is calculated from the average of the daily maximum and daily minimum between 9am on one day and the next day, incorporating the effect of a hot day followed by a hot night. Over the 6 year period, there was a total of 9 days with an average temperature of over 30°C, resulting in an excess of 13 AMI admissions. In addition, a 3-day moving average temperature of 27^{0}C or higher was associated with a 38 % increase in AMI admissions or 208 excess admissions. These 208 admissions were spread over 42 days of elevated temperature, with an average of 69 excess AMI admissions for each 3 day period.

The utilisation of ambulance and emergency department presentations in Melbourne during a one-week heatwave was compared with the same period in the preceding year (Department of Human Services, 2009). Total emergency ambulance dispatches increased by 25% over the week, and by 46% over the three hottest days. Heat-related conditions accounted for approximately half of the reported increase in ambulance dispatches. The same study reported Emergency Department presentations increased by 12% overall and by 37% for people greater than 75 years of age. Almost 20% of the additional cases were classified as direct heat-related conditions and of these 46% were reported in persons aged greater than 75 years. Increases in ambulance call-outs have also been reported in Adelaide where the heatwaves of 2008 and 2009 resulted in call-out increases of 10 and 16% respectively (Nitschke et al., 2011).

Other links between heatwaves and increased hospitalisations have been reported for mental health or behavioural disorders and for renal conditions (Hansen et al., 2008; Nitschke et al., 2007). While no published data on these effects could be found in Perth, the following excerpt from the West Australian newspaper (21 February, 1995) provides anecdotal evidence of similar impacts of heatwaves in Perth:

> *"Perth's heatwave caused record power consumption and overstretched the ambulance service yesterday. A spokesman said the demand was caused by elderly people collapsing and having heart problems in the stifling heat. There were also many more assaults and brawls than normal in the early hours of Sunday when Perth sweltered through the hottest February night for ten years. Ambulances were called out 70 times, compared with an average of 30. Royal Perth and Sir Charles Gairdner hospitals reported treating people for dehydration, severe sunburn & heat exhaustion. Many people who came in with other illnesses also complained that the heat was making their problems worse" (Downloaded www.bom.gov.au October 12th, 2011).*

2.8.2 Air quality

The formation, transportation, dispersion and deposition of air pollutants is influenced by a complex set of meteorological variables that are likely to be affected by climate change (IPCC, 2007b). The national State of the Environment report (Department of the Environment, 2011, p. 67) concluded that "the combination of higher temperatures, more frequent bushfires and more raised dust associated with climate change can be expected to impact adversely on ambient air quality". The possibility of increases in concurrent exposure to extreme heat and air pollutants is particularly critical, as studies have indicated that air pollution may enhance the temperature-mortality relationship (Basu, 2009; Basu & Samet, 2002).

In general, air quality tends to be worse in urban areas due to the higher concentration of air pollutant sources, particularly motor vehicles. In Australia, approximately 1% of the burden of disease has been attributed to urban air pollution, with more than 3000 premature deaths annually (Beggs & Bennett, 2011). As shown in Figure 9, most of these deaths are associated with heart disease, lung cancer or circulatory diseases. Increases in urban air pollutants clearly pose a significant risk to public health and an increase in air pollutants at an air shed scale is a significant public health concern.

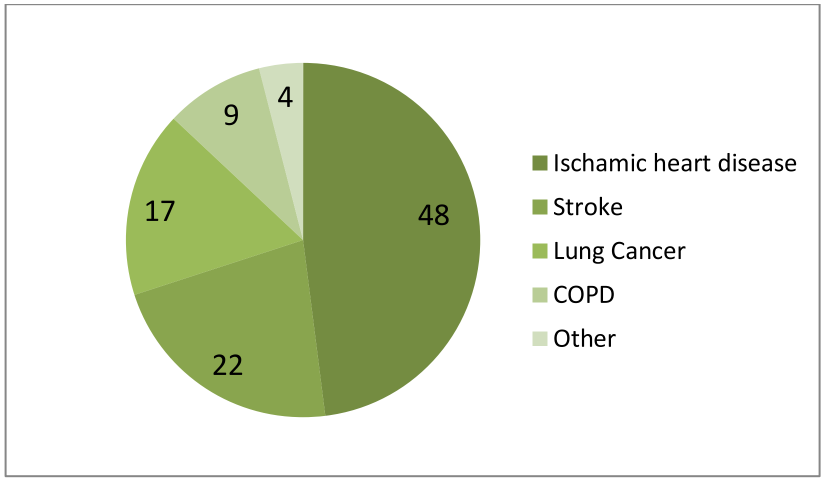

Figure 9 - Cause of premature deaths due to air pollution (Beggs and Bennett, 2011)

Figure 10 shows the range of other health effects associated with exposure to air pollution. The pyramid (adapted from AIRNET, 2004) indicates that the less severe the health impact, the larger the number of people affected. Therefore, while many assessments select premature mortality as the health outcome of interest, awareness of less severe health effects is important.

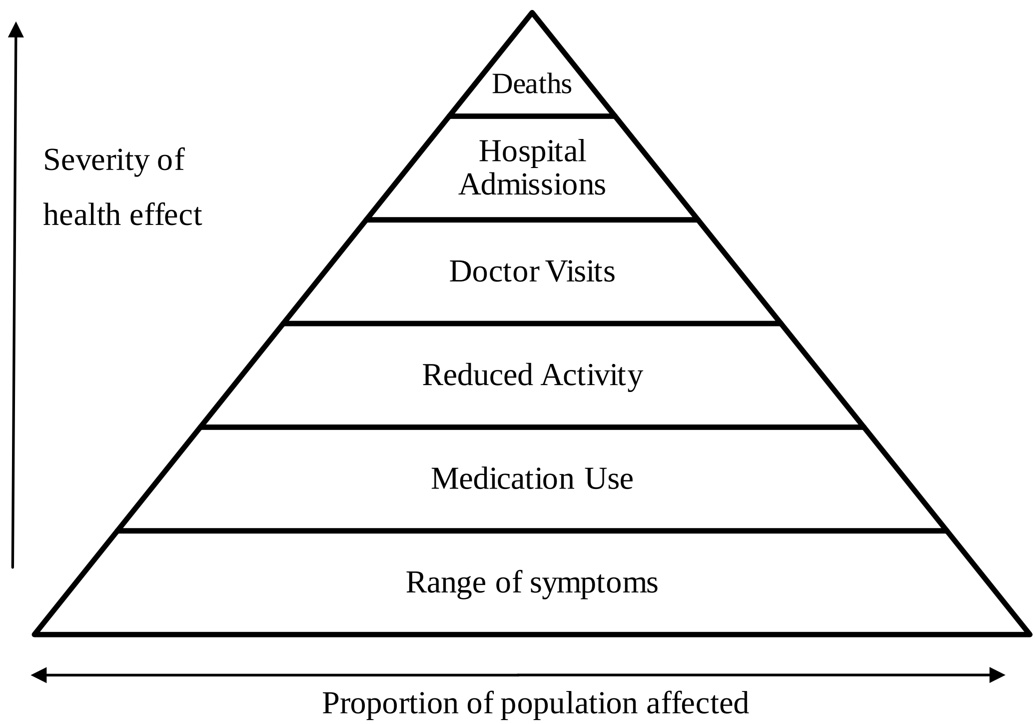

Figure 10 - Pyramid of health effects associated with air pollution

In Australia, air quality standards are set by the National Environment Protection Measure (NEPM) for Ambient Air Quality. The six pollutants covered by this NEPM are carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide, lead and particles (PM_{10}). As well as reporting individual pollutant levels, most cities also report an Air Quality Index. This index is linked to health advice and is an aggregate measure determined on the basis of comparison to the NEPMs for each criteria pollutant.

To date, the strongest evidence for links between climate change and increases in air pollutants is for ground-level ozone. Weaker evidence is available for particles (Ebi & McGregor, 2008; Spickett, Brown, & Rumchev, 2011)

2.8.2.1 Ozone

Ozone is formed from volatile organic compounds (VOCs) and nitrous oxides in the presence of sunlight. Higher temperatures cause higher emissions of VOCs and increases in ambient ozone levels. This effect is consistently demonstrated by the higher levels of ozone in summer months. Climate change projections for increases in average temperature and heatwaves have been linked to projected increases in ambient ozone levels (IPCC, 2007a).

Extensive reviews by the World Health Organisation (2006) and the United States Environmental Protection Agency (USEPA) (2006) have provided strong evidence for an association between short-term exposure to ozone and adverse health effects. These effects include: increases in mortality, increases in hospital admissions and emergency department visits for respiratory diseases, decreases in lung function, increases in respiratory symptoms, pain on inspiration, broncho-constriction, increased air responsiveness, epithelial injury, immune system activation and host defence impairment.

Studies indicate that the threshold for adverse health effects of ozone occurs at levels significantly lower than air quality standards. In a study of ozone levels and mortality in America, Bell and colleagues (2007) reported that the association between ozone and mortality was essentially linear above a threshold of approximately 15ppb.

Evidence for a small but significant association between short-term exposure to ozone and mortality is strong. Large multi-city time-series studies have been conducted in the US, Europe and Australia and several meta-analyses of data have been conducted by key agencies such as the WHO, the USEPA and the National Environment Protection Council (NEPC) in Australia. In a review of 31 studies (including Australian studies) the WHO (World Health Organisation, 2006) concluded that a 10ppb increase in 8-hour ozone levels resulted in an increase in daily mortality between 0.6 to 1.0%, above an estimated baseline of 0.035ppm. In another review of 3 meta-analyses, Bates (2005) concluded that a 10ppb increase in ozone is associated with a minimum increase of 0.86% in total mortality. The National Mortality, Morbidity and Air Pollution Study of 95 cities in the USA (Bell, Dominici, & Samet, 2005) reported that a 0.01ppm increase in ozone levels was associated with a 0.52% increase in daily mortality and a 0.64% increase in cardiovascular and respiratory mortality.

In Australia, the Environment Protection and Heritage Council (EPHC) reviewed multi-city air pollution studies conducted in five Australian and two New Zealand cities. This study used virtually all available data for daily mortality, daily hospital admissions and ambient air quality over the period 1998 to 2001 (Environment Protection and Heritage Council 2010). Pooling for estimates of mortality and morbidity showed positive associations between exposure to ozone and a range of mortality and morbidity effects. The percentage increase in health effects that were significantly associated with a 1ppb increase in 1-hour and 4-hour ozone levels were:

- 0.1% increase in total all-cause mortality for all ages
- 0.2% increase in cardiovascular and respiratory mortality for all ages.

The effects tended to be more significant during the warm part of the year (November to April). The multi-city study also reported that a 1ppb increase in 1-hour and 4-hour ozone levels was associated with a 0.2% increase in respiratory hospital admissions for ages one to four (EPHC, 2010).

2.8.2.2 Particulate matter

Particulate matter (PM) is composed of tiny particles of solid or liquid suspended in a gas or liquid. Particles are classified according to size as this is the critical determinant of the site of deposition within the respiratory tract. PM_{10} refers to particles less than 10 microns in diameter, and $PM_{2.5}$ to particles less than 2.5 microns in diameter.

The relationship between climate and air-borne particulates is very complex and the potential impact of climate change on particulate levels remains uncertain at this stage. The Climate Commission report on climate change and health in Australia (McMichael & Hughes, 2011) reported that particulate levels in Australia are likely to increase as a result of climate change. Bushfire smoke is a significant source of fine particles in Australia and projections for increased risk of bushfires is accompanied by an increased risk of higher particulate levels. In addition, the policy of prescribed burning, designed to mitigate major bushfire risks, is also likely to increase particulate levels. Increases in the incidence and severity of droughts may also result in higher levels of coarse particles from dust (McMichael & Hughes, 2011).

The health effects of air-borne particulate matter (PM) have been widely studied in humans and animals and the evidence for an association with adverse health effects is strong. Evidence supports that there is no ‘safe’ threshold for particulates (World Health Organisation, 2006). As with ozone, this indicates that adverse health effects due to particulate exposure occur below air quality standards.

Exposure to PM has been associated with cardiovascular diseases and respiratory illnesses including asthma and lung cancer in international and Australian studies (Erbas, Kelly, Physick, Code, & Edwards, 2005; Simpson et al., 2005). A review of air quality standards in Australia (National Environment Protection Council, 2010) concluded that there is substantial evidence for short- and long-term effects of exposure to PM_{10} and $PM_{2.5}$ and no evidence for a threshold. The review concluded that Australian air pollution studies showed a 0.2% increase in all-cause mortality for every 1ug/m^3 increase in PM_{10}. Associations were also shown with cardiovascular and respiratory hospital admissions.

Higher temperatures may increase the impact of health effects associated with particles. In a study in Brisbane the association between PM_{10} and a range of health effects including mortality, respiratory hospital admissions and emergency visits and cardiovascular emergency, was modified by the maximum temperature. PM_{10} exhibited more adverse health effects on warm days than cold days (Ren & Tong, 2006). Evidence for this relationship is uncertain, with some studies reporting temperature effects (Roberts, 2004; Stafoggia, Schwartz, Forastiere, & Perucci, 2008) and others not (Hales, Salmond, Town, Kjellstrom, & Woodward, 2000; Samet, Zeger, Kelsall, Xu, & Kalkstein, 1998). In addition, to cardiovascular effects of particulate levels may be greater in people with high blood pressure (Dubowsky, Suh, Schwartz, Coull, & Gold, 2006).

2.8.2.3 Allergens

In addition to effects on air pollutants, climate change may also influence the production of allergens such as pollen that have been linked to respiratory allergic diseases (Beggs & Bennett, 2011; D'Amato & Cecchi, 2008). Sensitivity to pollen allergens has been reported in 80 to 90% of children with asthma and 40 to 50% of adults with asthma (Beggs, 2010). Production of pollen is sensitive to temperature, rainfall and CO_2 levels, all of which will be affected by climate change (Beggs & Bennett, 2011; D'Amato & Cecchi, 2008). Evidence suggests climate change may already be having an impact on atmospheric pollen concentrations with reports of shifts in the geographical ranges of plant species, as well as changes in the timing and length of the pollen season (IPCC, 2000; Ziska, Epstein, & Schlesinger, 2009).

2.8.3 Food production and food quality

Access to adequate supplies of safe, nutritious food is an essential requirement for good health. Projected increases in extreme weather events, such as droughts, heatwaves and floods, as wells as changes in temperature, rainfall and CO_2 levels, will affect food production (Stokes & Howden, 2010). The impacts experienced will be spatially diverse, with projections indicating losers and winners. Agriculture in the south-west of WA has been identified as particularly at risk to adverse effects of climate change (Howden & Jones, 2004; Kingwell, 2006) The extent of flow-on effects to health will be highly dependent on location and socio-economic factors. In Australian urban communities, diet-related health impacts are more likely to occur in low-income groups who are vulnerable to increases in the price of healthy food alternatives (Friel, 2010). In addition to potential impacts on diet, communities or households who are reliant on food production for their livelihood may face additional stresses and mental health effects.

The incidence of food-borne diseases is affected by ambient temperature and extreme weather events, particularly flooding and heatwaves. There are multiple sources of food-borne illnesses, each affected by climatic variables in a unique way. While evidence is far from complete, a number of significant sources of food-borne illnesses show strong seasonal trends, indicating that climate is an important factor. The influence of climate is influenced directly by temperature and exposure to floodwaters, and indirectly via the influence that climate has on human behaviour. For example, there is a strong seasonal trend for *Salmonella* notifications, with cases peaking in summer in most countries (Hall, D' Souza, & Kirk, 2002). This increase occurs as a result of the higher proliferation of *Salmonella* at higher ambient temperature, but also as a result of behavioural risk factors such as consuming food at outdoor events where food storage may be inadequate. A strong correlation between ambient temperature and notifications of salmonellosis has been reported in Perth (D'Souza, Becker, Hall, & Moodie, 2003).

As with food production, the health consequences of these changes will be strongly influenced by adaptive capacity. For example, developing countries, with weaker food safety regulatory programs, are more likely to experience significant increases in fatalities (Campbell-Lendrum & Corvalan, 2007). However, food-borne illnesses in Australia do have a significant health and economic cost that should be considered in light of climate change projections (Bambrick et al., 2008).

2.8.4 Water quality

The quality of drinking and recreational water can be affected by extreme events, changes to rainfall patterns and increases in water temperature. There is a large number of water-borne pathogens including protozoa, viruses and bacteria, and our understanding of the influence of climate variables on specific pathogens is incomplete. While water-borne diseases are a significant contributor to the global burden of disease, these impacts occur predominantly in children in developing countries. Well established prevention and treatment strategies in developed countries result in relatively low water-borne disease burdens (Portier et al., 2010). Other water qualities that may be affected by climate change include the production of toxins by algal blooms and the proliferation of *Legionella* in air-conditioning systems. Exposure to water-borne diseases in recreational waters and air-conditioning systems is strongly seasonal with most exposures occurring in summer (Spickett et al., 2007).

2.8.5 Vector-borne Diseases

Vector-borne diseases (VBDs) are carried by organisms or vectors, such as mosquitoes and ticks that transmit pathogens from one host to another. Because vectors and hosts can be sensitive to climatic variables such as temperature and rainfall, VBDs are likely to be affected by climate change (Confalonieri et al., 2007). Changes in the geographic distribution of VBDs are possible under a changing climate, but because of the complexity of vector ecology, projections are highly uncertain (Hames & Vardoulakis, 2012).

The VBD that has received most attention in terms of climate change in Australia is Dengue Fever. However, transmission of Dengue Fever does not occur in the south-west of WA and the VBDs of most concern in the Perth region are Ross River Virus (RRV) and Barmah Forest Virus (BFV) (Lindsay, 2009). Temperature and rainfall can influence the number of available breeding sites and the life-cycle of mosquitoes and the distribution of hosts, so both RRV and BFV may be affected by climate change.

2.8.6 Mental health effects

Mental health conditions constitute a significant proportion of the burden of disease in many countries, including Australia. The causes of mental health conditions are complex and difficult to quantify, but a number of assessments have provided rationale and supporting evidence for links between climate change and mental health. Extreme events can lead to significant personal and financial loss and social disruption. An increase in the frequency and severity of extreme events may result in repeated exposures which makes recovery difficult. Groups that are more vulnerable to these impacts include those whose livelihoods are most affected by extreme events, such as farmers, low income groups who face greater financial strain during recovery and people with pre-existing mental health disorders (Berry et al., 2008; Greenough et al., 2001). Links have also been drawn between mental health and levels of stress associated with individual and community concern regarding climate change (Doherty & Clayton, 2011). Other links, previously discussed, include an increase in hospital admissions for mental health and behavioural disorders during heatwaves (Nitschke et al., 2007).

2.8.7 Social & economic disruption

There are strong associations between socio-economic characteristics and health status, with lower socio-economic groups bearing a disproportionate share of the burden of disease. Areas of higher socioeconomic disadvantage in Australia have higher rates of mortality and morbidity for a significant number of chronic health conditions and higher rates of adverse risk factors such as smoking, obesity, inadequate physical activity and insufficient serves of fruit and vegetables (Australian Bureau of Statistics, 2010a).In addition, people in areas of disadvantage are also more likely to have nutrient-poor, energydense diets (Friel, 2009). In general, people with low income, poor housing and low levels of education are considered vulnerable to health impacts of climate change (Haines et al, 2006, Spickett, Brown & Katscherian, 2011).

Impacts of climate change on social and economic determinants of health will occur indirectly and involve a significant number of variables. Social and economic disruption can occur at a community or individual level and refer to changes in lifestyle, recreational patterns, provision of services and increased costs of adapting to climate change (such as increased energy and insurance costs) (Confalonieri et al., 2007; Adger 2010).

The table below provides a summary of the main health impacts of climate change that have been identified. Given the global nature of climate change and the complex relationships between climate and health, it is unlikely that this table represents an exhaustive coverage of all potential health impacts of climate change. It nevertheless provides a brief summary of the health impacts that the current literature has highlighted as impacts of concern in Perth.

Table 3 - Summary of evidence for potential health impacts of climate change

Health Impact	Link to climate
Cardiovascular (CV) conditions • Ischaemic heart disease • Cerebrovascular disease • Angina	Mortality and morbidity effects of heatwaves are strongly associated with a range of CV conditions. Particulate levels, which may increase as a result of climate change, are associated with cardiovascular mortality and morbidity.
Respiratory conditions • COPD • Asthma	Mortality and morbidity effects of heatwaves are associated with respiratory conditions. Ozone & particulate levels are associated with respiratory mortality and morbidity and affected by climate.
Heat-related conditions • Heat rash • Heat cramps • Heat exhaustion	Occur during periods of high temperature, particularly heatwaves.

• Heat stroke	
Food-poisoning • Gastroenteritis	Caused by a range of viruses, bacteria and parasites, some of which are affected by climatic variables such as temperature and rainfall. Strong correlation between ambient temperature and notifications of Salmonellosis.
Water-borne diseases • Gastroenteritis • Respiratory infections	Outbreaks of water-borne pathogens such as *Cryptosporidiosis* are linked to extreme rainfall and temperature. Water shortages can also result in reductions in water quality. Most result in gastrointestinal health effects, but respiratory infections also occur from *Legionella* which may increase as a result of climate change.
Vector-borne diseases (VBD)	Transmission cycles of VBDs are influenced by climatic variables such as temperature and rainfall. Given the complex ecology of VBDs, the direction and magnitude of these influences as related to climate will vary between diseases and locations.
Diet-related impacts	Agriculture is influenced by extreme events, particularly drought and floods. This can have flow-on effects on the cost of food, thereby influencing the quality of the diet. Effects are likely to be most significant in developing countries or vulnerable groups in developed countries.
Colorectal cancer	Consumption of fruit and vegetables is a protective factor against colorectal cancer. Cost and availability of fruit and vegetables may increase as a result of climate change, leading to reduced consumption.
Diabetes	Diabetics are vulnerable to adverse health effects of heatwaves and increased air pollutants. Climate change may also influence a number of risk factors associated with diabetes, such diet and physical activity.
Renal Conditions	Higher temperatures can lead to exacerbation of renal symptoms.
Melanoma	Changes in temperature may affect behaviour that influences

	exposure to sun.
Mental-health	Complex and multiple links between climate and mental health. Can occur via a range of social, economic and physical determinants of health. Examples include mental health impacts of repeated exposure to extreme events such as floods, fires and droughts. Increased hospitalisations for mental health conditions have been linked to heatwaves.

2.9 Conclusion

This chapter has provided an outline of the numerous connections between climate and determinants of health. An explanation of climate change scenarios and examples of projections for Perth provided an indication of the extent of possible changes to our climate. The key determinants of vulnerability were discussed in relation to climate change adaptation – a major focus of this research. The challenges of assessing and responding to the health impacts of climate change were discussed, with an overview of the potential role of HIA and systems approaches.

The range of potential health impacts of climate change in Perth was then discussed. Evidence of the connections with climate and a summary of the type of potential health outcomes were provided for each impact.

The following chapter will present the overall research design and a detailed explanation of the methods used in Part I of the research.

Chapter 3 - Research Design and Part I Methods

3.1 Introduction

The previous chapter highlighted some of the challenges associated with assessing and managing the potential health impacts of climate change. Chapter 3 provides an overview of the research design and the methods used in Part I of the thesis. The Part I methods are centred on the application of a HIA framework. The need for specific tools that are suited to the high levels of uncertainty and long time frames associated with climate change is addressed by the development of semi-quantitative health consequence scales.

3.2 Research design

The project employed an exploratory sequential mixed-method design. Mixed methods research uses multiple approaches in answering research questions, rather than restricting or constraining researchers' choices (Johnson & Ongwuegbuzie, 2004). Exploratory sequential design conducts research in distinct phases, with each phase addressing exploratory questions with different methods. The analysis of each phase informs the formulation of the next phase and provides further explanation of the issue under study (Teddlie & Tashakkori, 2009).

The research has been designed in three main parts as follows:

- Part I (Chapters1 to 5): Health Impact Assessment
- Part II (Chapters 6 to 8): Case Study of Systems Approaches
- Part III(Chapter 9): Evaluation of Process and Recommendations

Part I applies the scoping, profiling and risk assessment steps of HIA to the issue of climate change in urban areas of Perth. The opening chapter provided a brief background to the research with respect to assessing and adapting to health impacts of climate change, particularly in urban areas. Chapters 3 to 5 summarise the methods and tools utilised in the HIA, report on the development of health consequence scales to be used in the research and present the results of the HIA. Part I concludes with a critical evaluation of the HIA results that will inform the focus of Part II.

Part II is a case study to test the introduction of system dynamics tools to the risk management and decision-making steps of HIA process. The objective of introducing these tools is to improve the ability to develop effective adaptation strategies within the complex urban health-climate system. Part II begins with a review of the selected impact, outlines the methods used and presents the results of the case study.

Part III evaluates the outcomes of the HIA and the case study. The key findings of the research are presented as a series of recommendations related to climate change adaptation in Perth. The thesis concludes with a final consideration of the value of systems approaches to a HIA framework.

3.2.1 Ethics

An application for 'Approval of Research with Low Risk (Ethical Requirements)' was made and approved by the Human Research Ethics Committee at Curtin University (SPH-08-2011).

3.3 Part I: HIA methods

This section will outline the major steps within the HIA and provide a summary of the methods used within each step. As discussed in Chapter Two, there is a broad range of methods and tools that can be used within a HIA framework. The heterogeneity of multiple health impacts does not allow a standardised approach to data collection and analysis across all stages of the HIA. In the case of climate change, data collection will often be limited by the extent of available evidence and may require significant assumptions to provide at least tentative assessments. In such cases, a clear statement of assumptions and limitations of evidence must be provided.

3.3.1 Screening

The screening step makes a decision as to whether a HIA is necessary and will be beneficial (Harris et al., 2007). This decision is made on the basis of a preliminary assessment of the extent of health impacts and whether an assessment will add to the existing knowledge regarding the likely health impacts (enHealth, 2001; Harris et al., 2007). The use of HIA in this research was pre-determined during the planning phases of the Urbanism Health

Climate Cluster. In addition, the literature review provided further evidence of the suitability of a HIA framework in addressing health impacts of climate change.

3.3.2 Scoping

Scoping sets the basic parameters of the HIA, including the timescale, geographical and population group boundaries, the list of health effects to be evaluated, the methods to be used and identification of key stakeholders (Department of Health, 2006; enHealth, 2001; Harris et al., 2007). Another key parameter, related specifically to climate change, is the selection of GHG emission scenarios.

3.3.2.1 Timescale and emission scenarios

Selection of the time period for which health impacts are assessed and the assumed emissions scenario will clearly influence the HIA results. Climate change projections and assessments in the literature are typically based on the years 2030, 2050, 2070 or 2100. Climate change is expected to increase over the course of this century and the selection of earlier time periods such as 2030 is unlikely to reflect the extent of long-term impacts. On the other hand, end of the century projections are too uncertain and distant to result in meaningful results for most stakeholders. The year 2050 provides a medium-term consideration of a future that is only one or two generations away (Cocks, 1999). This time is also an important symbolic date for Perth, as population projections suggest that Perth's population will double between 2010 and sometime in the 2050s (Department of Planning, 2010). A number of scenario-based studies such as; Australia to 2050: future challenges (Swan, 2010), Future Makers, Future Takers: Life in Australia 2050 (Cocks, 1999) and Boomtown 2050 (Weller, 2009) have also focused on this date.

Selection of emission scenarios is not straightforward. Most, but not all assessments, refer to the IPCC SRES scenarios outlined in Chapter 2, but the specific scenario(s) used vary widely. At the present time, each of these scenarios is considered equally likely. There is justification, in terms of risk assessment, in considering the 'worst-case' scenario. Emergency management and planning for '1 in 100 year' events are examples of this approach. As highlighted in Chapter 2, the differences in temperature projections between emission scenarios becomes most apparent toward the end of the 21st century, so to some extent the selection of 2050 helps to reduce the influence of different emission scenarios.

The decision was made not to select a specific emission scenario, primarily because the selection of a specific scenario would severely restrict the evidence available to the HIA. The risk assessment will take into consideration the effect that different emission scenarios may have.

3.3.2.2 Selection of study area

Vulnerability to climate change, across health and non-health sectors, is considered to be a function of exposure, sensitivity and adaptive capacity. Each of these factors will be influenced by location, such that the scale and nature of health impacts will not be uniform across an area the size of Perth. Given these differences and resource limitations, it was determined during the planning phases of the research that a HIA of the whole Perth area was not feasible. The selection of an appropriate study area was made on the basis of two selection criteria:

- predominantly urban within the Perth Metropolitan region
- demonstrates a significant level of vulnerability to health impacts of climate change.

The first criterion was determined by an analysis of information available through the Australian Bureau of Statistics (ABS). The Perth Statistical Division and the five Statistical Subdivisions (SSDs) were set in the early 1970s and designed to accommodate several decades of urban growth. SSDs are defined by the Australian Bureau of Statistics (ABS) as "socially and economically homogeneous regions characterised by identifiable links between the inhabitants." (Australian Bureau of Statistics, 2001). Each SSD consists of a number of Local Government Areas (LGAs) which are then further divided into smaller areas or suburbs.

The ABS considers population density of Collection Districts (CDs) at each census and defines areas as either 'Urban Centre' or 'Rural Remaining'. The urban Perth areas were identified from the 2006 census. Analysis was conducted for each of the local government areas located with the five major Statistical Subdivisions (SSDs) of Perth.

The second criterion for study selection was the selection of an area that contained a sufficient representation of population groups that may be vulnerable to health impacts of climate change. There are a number of key factors that are likely to contribute to sensitivity and adaptive capacity to health impacts of climate change. The elderly are sensitive to numerous health impacts of climate change. With an ageing population projected across Perth, the percentage of elderly was selected as an indicator of vulnerability. Projections for each LGA were collected from the Australian Bureau of Statistics.

Adaptive capacity is strongly linked to social determinants such as income, housing conditions and education levels (McMichael et al., 2009). The Socio-economic Indexes for Areas (SEIFA) of disadvantage combines variables such as income, education, employment, occupation and housing (Australian Bureau of Statistics, 2006) and was considered a good approximation of adaptive capacity. SEIFA scores are collected at a suburb level, providing an indication of the spread of disadvantage across each urban LGA.

3.3.2.3 Identification and recruitment of key stakeholders

The key stakeholders were determined on the basis of the selected study area. Given that a broad range of stakeholders had already informed the state-wide HIA, the local area perspective was provided by local government authorities. Recruitment was undertaken by direct contact with local government authorities within the selected study area. A presentation that explained the background and the objective of the project was the second stage in the recruitment process.

3.3.2.4 Prioritisation of health impacts

It is typically not practical to consider all of the potential health impacts in any given HIA. Impacts that seem most important from a public health perspective or have been identified by key stakeholders are typically selected (National Academy of Sciences, 2011). The previous state-wide HIA of climate change, developed over a 10 month period in consultation with a wide range of stakeholders, provided a suitable source to begin the process of short-listing impacts (Spickett et al., 2007).

Impacts identified for the state were considered in the context of Perth and preliminary adjustment of risk levels were made where evidence suggested this was appropriate. For example, the risk associated with hazards specific to the north of the state or rural areas were downgraded for the Perth region. The resulting list of impacts was provided to each of the local government stakeholders who then considered the following:

- Are the preliminary assessments of risk appropriate?
- What is the rationale or evidence for amending or retaining the level of risk determined in the state HIA?

The resulting risk levels were then used to determine a final short-list of health impacts likely to have the largest impact on health in the study area.

3.3.3 Profiling

Profiling of the population in the study area provides critical background data on any variables considered to have a significant effect on health. Baseline health status provides an indication of the range and extent of health impacts that are prevalent in the study area; it highlights any groups that may be vulnerable to particular health impacts; and it provides a reference point against which to measure future impacts (National Academy of Sciences, 2011). A consideration of social, economic and environmental determinants of health that may be relevant to the HIA was also undertaken (Department of Health, 2006; enHealth, 2001; Harris et al., 2007). Information was collected from sources such as census data and health statistics collected by government. In the case of climate change, additional profiling on the future characteristics of the population is required.

Baseline health data appropriate to the short-list of health impacts was collected from a range of sources. Demographic data, including population size, population projections and age distribution was collected from the ABS. Socio-economic characteristics were profiled by the Index of Relative Socioeconomic Disadvantage. Information for these variables is collected every 5 years for the Australian census and provides a convenient measure of demographic and socioeconomic variables that can be updated if future HIAs of this type are conducted.

Health data was collected from the Health Tracks Reporting system at the Epidemiology Branch of the Public Health Division of the Department of Health (WA). This system utilises population health and demographic data from the Department of Health data that is linked to spatial data from other state agencies. Available data sets were reviewed and selected on the basis of potential links to climate – a summary of selected data sets is provided below. Where possible, data was collected for each of the three local government areas and the Perth metropolitan region..

- **Burden of Disease – Disability Adjusted Life Years (1998-2007)**

Burden of disease is a measure of the impact of illness or disability on a population's life expectancy and quality of life. It is measured in Disability Adjusted Life Years (DALYs) which includes effect on mortality (Years of Life Lost, YLL) and disability (Years Lost due to Disability, YLD). Burden of disease has the advantage of providing a comparable measure of health impacts across a wide range of conditions (Murray & Lopez, 1996).

- **Avoidable mortality (1998-2007)**

Avoidable mortality is defined as deaths before the age of 75 years from conditions which are potentially avoidable given the present health system, available knowledge about social and economic policy impacts and health behaviours (Department of Health,2011a).

- **Potentially Preventable Hospitalisations (2005 – 2009)**

Potentially preventable hospitalisations (PPH) are defined as "conditions where hospitalisation is thought to be avoidable if timely and adequate non-hospital care had been provided" (Department of Health,2011a, p. 39).

- **Communicable diseases**

Communicable diseases in WA are recorded in the WA Notifiable Infectious Diseases Database. As a significant proportion of these notifications is unlikely to be captured in mortality or PPH data, the database provides another measure of potential morbidity effects that may be linked to by climate change.

- **Existing health conditions - vulnerable groups**

Additional information on the presence of existing health conditions was obtained from the WA Health and Wellbeing Surveillance System (Department of Health, 2011b). This system collects data on the prevalence of self-reported conditions for National Health Priority Areas for Health Conditions and Injury. This is relevant to the HIA because people with diabetes, cardiovascular or respiratory conditions and mental health problems are vulnerable to a range of hazards associated with climate change.

- **Risk factors**

  Climate change may also affect physiological and behavioural risk factors known to influence health. Additionally, these factors may also affect vulnerability to the health impacts of climate change. Examples include high blood pressure, level of physical activity and diet. Data on these factors is collected from the WA Health and Well-being Surveillance System. This data was accessed via the Health Tracks at the metropolitan regional level.

3.3.4 Risk Assessment

Risk assessment considers the extent of beneficial and detrimental effects on health and determines who will be affected (Department of Health, 2006). The available evidence is typically a mix of qualitative and quantitative data and highly dependent on the specific scope of the HIA. Information will range from published literature, data collected from routine monitoring and input from key stakeholders. There is a large range of tools that can be used at this stage including focus groups, workshops, health hazard identification, surveys, environmental monitoring and multi-criteria analysis (Harris et al., 2007).

The state-wide HIA did not identify any significant health benefits associated with climate change, so effects were limited to the short-list of adverse health effects identified during the scoping phase. Most reports of health benefits of climate change are linked to reductions in cold-related deaths which are virtually absent in Perth (Bambrick et al., 2008).

This step incorporates measures of the severity and likelihood of impacts. In some cases assessments will be limited to qualitative judgements such as large, medium, small or negligible (for severity) or definite, probable or speculative (for likelihood) (Harris et al., 2007). In other cases, there will be sufficient data and knowledge to enable a quantitative assessment of severity and/or likelihood.

A review of other assessments of health impacts of climate change (Chapter 2) highlighted that while some aspects of the risk assessment framework were utilised, few employed predetermined criteria that allowed a comparison of risks associated with different impacts. Comparison of risks can inform decision-making in the risk management phase and risk assessment is considered one of the most policy relevant tools in the realm of environmental health (Kovats, Campbell-Lendrum & Matthies, 2005).

It was determined at this stage of the research that the HIA would benefit from the development of quantitative risk assessment scales to assess potential health impacts of climate change in Perth. This would build upon the previous qualitative assessment conducted during the state-wide HIA (Spickett et al, 2007). As a result of this decision, an additional step was added to Part I of the research. This step will be explained in full in Section 3.4.

Once the risk assessment scales were developed, the risk assessment phase continued. Given the range of health impacts being assessed, a diverse range of sources was used to assess the level of risk associated with each impact. Sources included peer-reviewed journals, the IPCC assessment reports, other climate change assessments, government reports and the Health Tracks system. Preference was given to data from Perth, followed by Australia and where appropriate, international data. Evidence was collated and judgements made according to the risk assessment scales developed for the research.

3.3.5 Risk Management

The risk management phase of HIA utilises the information and judgements made in the previous stages to consider a range of management options. In general, higher levels of risk will result in a higher level of priority to reduce that level of risk to an acceptable level.

In the context of this research, the risk management step evaluated the information collected during the course of the profiling and assessment steps to select an impact that led into Part II of the research. The selected impact was the basis of the case study to test the introduction of systems approaches to HIA.

3.3.6 Implementation and decision making

The traditional application of HIA considers the capacity of the assessment to inform the decision-making process. This includes the ability to impose specific conditions or requirements, such as monitoring on relevant stakeholders. This step was also conducted as part of the case study – the exact form of the outcomes ultimately depended on the nature of the case study and included a set of potential adaptation strategies.

3.3.7 Evaluation

Evaluation typically considers whether the HIA process has resulted in beneficial outcomes with regard to health and whether specific conditions placed on activities have been met.

This type of evaluation is generally applied to the specific 'project, plan or proposal' that was considered during the HIA. In contrast, this HIA evaluated the process that was developed as part of this research, with a specific focus on the:

- Risk assessment scales
- Integration of system thinking tools into a HIA framework
- Usefulness of the final recommendations
- Potential of the process for future HIAs of climate change or other complex health issues.

The evaluation step will be reported in Part III of the thesis.

3.4 Development of risk assessment scales

Traditional risk assessment combines a measure of likelihood and consequences of a particular outcome to estimate a level of risk that is compared to a set of predetermined criteria. The use of predetermined criteria enables a comparison of risk associated with dissimilar effects (Standards Australia, 2006). Depending on the type of assessment and the availability of data, this process employed a mix of quantitative, semi-quantitative or qualitative methods. While quantifying outcomes, particularly in situations with high levels of complexity, can be difficult, efforts to quantify will typically lead to new insights that progress knowledge in the area.

It was therefore determined that the development of quantitative risk assessment scales, suitable for application to Perth, would make a valuable to contribution to the research. Such scales are more amenable to an objective judgement of risk than qualitative scales. As well as reviewing and collecting new information this process also identified key gaps in current knowledge. The development of the scales began with a review of four key sources:

- Health impacts of climate change in WA (Spickett, Brown & Katscherian, 2007)
- HRA (Scoping) Guidelines (Spickett, Goh, Katscherian, & Ellies, 2010)
- UK Climate Change Risk Assessment (Hames & Vardoulakis, 2012)
- IPCC 4th Assessment Report (IPCC, 2007a)

The first two sources provide an important local context as both were developed and published in WA with input from a range of health experts. As a result, these scales are likely to incorporate judgements that are an appropriate reflection of broader societal values in WA.

The first source, already discussed in previous chapters, assessed health impacts of climate change using qualitative scales (Appendix A). The Health Risk Assessment (Scoping) Guidelines were selected primarily because they included quantitative scales for health consequences that were considered suitable for assessing health impacts in WA (Appendix B). These guidelines were developed primarily for application to potential health impacts of planned developments and activities in WA (Spickett, Goh, Katscherian, & Ellies, 2010).

The UKCCRA Health Sector and Evidence Reports (Department for Environment Food and Rural Affairs, 2012a; Hames & Vardoulakis, 2012) provided a comprehensive set of semi-quantitative and qualitative scales developed for assessing impacts of climate change. The scales addressed economic, environmental and health impacts (Appendix C). The semi-quantitative measures were also developed in consultation with a range of experts. While the metrics were developed for a population of 62 million in the UK, they provide a useful starting point for scales in other locations.

The first three sources were chosen primarily for their respective health consequence scales. The IPCC has not published scales that are specific to health impacts, but has developed scales for likelihood and uncertainty. Given the pivotal role of the IPCC in the field of climate change, these scales were also reviewed. The first three sources also included measures of likelihood and/or uncertainty which were reviewed.

The scales were reviewed and considered with respect to application to a HIA of climate change in Perth. The review of these four key sources was used to develop a set of semi-quantitative scales for use in the risk assessment phase. The proposed scales were distributed to professionals with expertise in the field of health risk assessment. Experts included authors of the first three sources, staff from the Health Department of WA, Curtin University, other Australian and overseas universities and private risk assessment consultants.

Comments were received from a total of 12 experts. All comments were analysed and used to inform further adjustment of the scales. The scales were then utilised as part of the risk assessment step of the HIA.

3.5 Conclusion

This chapter has described the overall design of the research project and detailed the methods that were utilised in Part I of the research. This information is summarised in Figure 11.

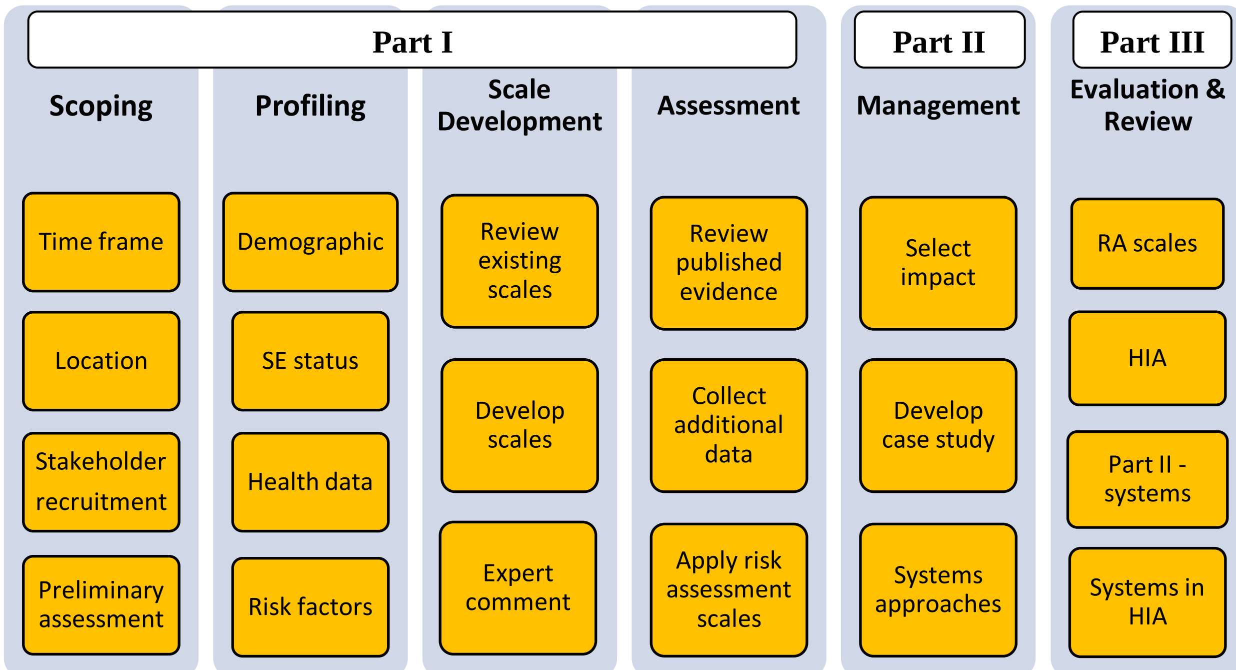

Figure 11 - Summary of proposed HIA process

The following chapter will discuss the development of the health consequence, likelihood and certainty scales that were applied during the risk assessment step of the HIA.

Chapter 4 – Development of Risk Assessment Scales

4.1 Introduction

This chapter presents the review of existing risk assessment scales and explains the subsequent development of scales used in the HIA. It includes a discussion of experts' comments on the scales. The scales that have been developed enable a more detailed and robust assessment of risk associated with health impacts of climate change. They could also be applied to assessments in other locations.

Given the unique challenges of climate change and the relative infancy of research in the area the process of developing scales is highly iterative. Utilisation of these scales in the risk assessment stage was used to consider potential improvements to the scales for future applications.

4.2 Review of health consequence scales for climate change

The HIA of climate change in WA provided a "starting position for future assessments" (Spickett et al., 2007, p. 1). The health consequence scale consists of five levels from insignificant to catastrophic. Each level includes a description of outcomes, related to severity and scale, as shown in Table 4, but no numerical estimates are provided. The top ranking is shown below. The full scale is provided in Appendix A.

Table 4 - Excerpt from HIA of climate change in WA

Catastrophic Consequences
Large numbers serious injuries, illnesses or loss of life
Severe & widespread disruption to communities
Long term inability to deliver essential goods and services
Severe long-term reductions in quality of life
Huge economic costs

4.2.1 HRA (Scoping) Guidelines

In an attempt to address the limitation of the above scales, a review of the HRA (Scoping) Guidelines was undertaken (Spickett et al., 2010). These guidelines were developed to enable an initial appraisal of potential health impacts of projects within other approval processes, such as Environmental Impact Assessments (EIA). As shown in Figure 12, a health risk assessment is conducted at the early scoping phase of an HIA.

The guidelines included a number of quantitative measures of health consequences developed for application to planned developments and activities in WA.

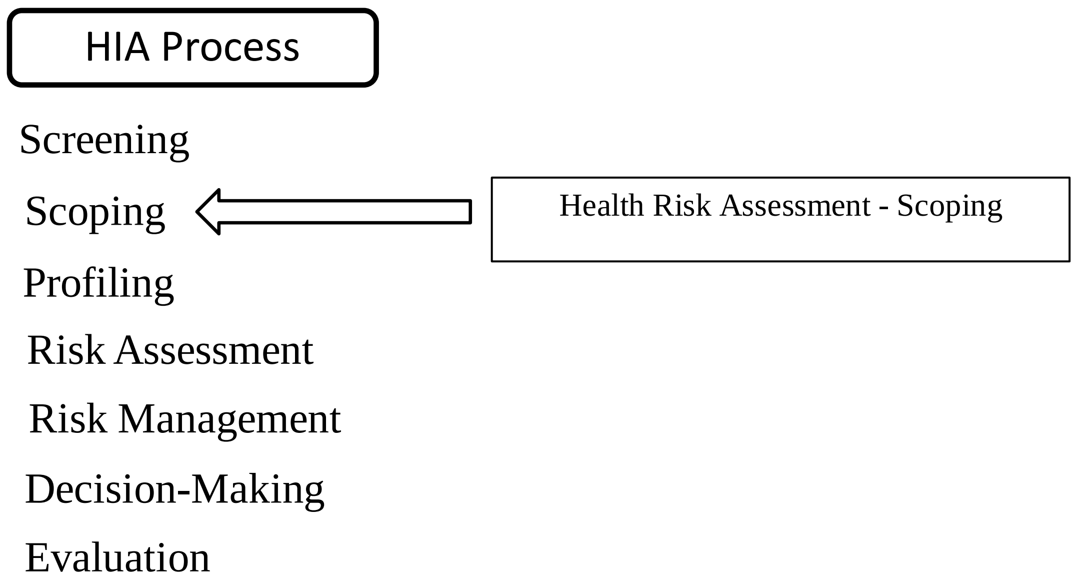

Figure 12 – Introduction of HRA at Scoping Phase of HIA

These measures are applied to the population that is considered at risk from the activity or proposal being assessed. In contrast, the entire population will be exposed to climate change. The differences in terms of scale and time-frame represent a significant departure from the original intent of the scales. Despite these key differences in intended application, it was considered that the quantitative health metrics could provide useful information for the development of scales in this research. The full set of health consequence scales from the HRA (Scoping) Guidelines are provided in Appendix B.

The health metrics include fatalities, injuries or health effects requiring hospitalisation, and chronic health effects requiring hospitalisation. Because of the pervasive nature of climate change, it was assumed that the entire population will be exposed and the quantitative metrics were therefore applied to the current Perth population of 1.7 million. To put these estimates in context, the resulting number of fatalities and hospitalisations were compared to the expected number of deaths and potentially preventable hospitalisations (PPH) for a population of 1.7 million. Crude estimates (Table 5) were determined by applying the PPH and mortality rates from the profiling phase (Section 5.3).

Table 5- PPH and mortality estimates

PPH and Mortality Estimates	Figure
PPH[1] (PPH/1000 population)	26.9
PPH Estimate for population of 1.7 million	45 696
Mortality Rate [2](deaths/1000)	5.7
Mortality Estimate for population of 1.7 million	9690

1- Health Tracks System, downloaded September 11th, 2011

2- ABS. Demography, Western Australia 3311.5.55.001

Table 6 displays the results from the two highest consequence levels. Results for all consequence levels are included in Appendix B. The results, as applied to a population of 1.7 million, are highlighted in grey. The results of applying each measure were then compared to the expected number of PPH and deaths per annum.

Table 6 – Health consequence scale applied to 1.7 million

Ranking: Catastrophic		
Description	**Measure (% of population at risk)**	**Applied to population of 1.7 million (% increases per annum)**
More than 1 fatality	1	More than 1 fatality >0.01% increase total mortality
Non-permanent injuries requiring hospitalisation	5-10	Increase of 85 000 to 170 000 = PPH increase of 186 to 371%
Acute health effect requiring hospitalisation	5-10%	Increase of 85 000 to 170 000 = PPH increase of 186 to 371%

Chronic health effect requiring medical treatment for:	10-15%	Medical treatment for 170 000 to 255 000
Ranking: Massive		
1 fatality	1	1 fatality 0.01% increase total mortality
Non-permanent injuries requiring hospitalisation for:	2-5%	Increase of 34 000 to 85 000 = PPH increase 74 to 186%
Acute health effect that needs hospitalisation for:	2-5%	Increase of 34000 to 85000 = PPH increase 74 to 186%
Chronic health effect requiring medical treatment for:	5-10%	Medical treatment for 85 000 to 170 000

This exercise identified several problems. The first is that the fatality metric is given as an absolute figure, while the hospitalisation metrics are expressed as a percentage of the population at risk. Having hospitalisations but not fatalities linked to population size, distorts the relative weighting between the two and overestimates the weighting given to fatalities. For example, according to Table 6, two fatalities per annum for a population of 1.7 million is regarded as catastrophic.

In contrast the hospitalisation estimates appear excessively high. The estimated number of hospitalisations at the catastrophic level is between 85 000 and 170 000 hospitalisations. This represents an increase of between 186 to 371% on the expected number of annual PPH. Even a moderate consequence equates to an additional 17 000 hospitalisations per annum, or an increase of up to 37%. Current evidence suggests that consequences of this magnitude are extremely unlikely and would certainly result in a demand for health services that far outstrips capacity.

While the numerical estimates in the HRA (Scoping) Guidelines are not suited to the direct application to an assessment of climate change, they provide important guidance on the type of indicators deemed appropriate by health experts in WA. The review has also highlighted the importance of linking data to population size – this is particularly relevant for climate change as assessments are likely to consider large populations and occur over long time-frames in which significant changes to population size will occur.

4.2.2 UK Climate Change Risk Assessment scales

The final scales reviewed were from the UKCCRA Health Sector and Evidence Reports (DEFRA, 2012, 2012a; Hames & Vardoulakis, 2012). These reports provide a comprehensive set of quantitative and qualitative scales developed specifically for the issue of climate change. The scale consisted of three consequence levels (low, medium and high). They were developed for application across economic, environmental and social impacts. Health impacts were considered within the social category and are reproduced in Table 7. The complete scale is provided in Appendix C. Each ranking includes a description of the impacts and quantitative measures, highlighted below in bold italics. The quantitative measures were developed in consultation with a range of experts and described in order of magnitude terms such as ‘hundreds’ or ‘thousands’.

Table 7 -UKCCRA health metrics from consequence scales

Consequence Ranking	Social Impacts
High =3	Potential for many fatalities or serious harm Loss or major disruption to utilities Major consequences on vulnerable groups Increase in national health burden Major role for emergency services ~ ***million affected*** ~ ***1000s harmed*** ~ ***100 fatalities***
Medium = 2	Significant numbers affected Loss or major disruption to utilities Increased inequality Consequence on health burden Moderate increased role for emergency services ***~ 100s thousands affected*** ***~ 100s harmed*** ***~ 10 fatalities***
Low =1	Small numbers affected/within coping range Small reduction in community services Within 'coping range' ***~ 10s thousand affected*** ***~ 10s harmed*** ***~ 1 fatality***

The three quantitative health metrics were 'fatalities, harmed and affected.' The ratio of each health metric *between consequence levels* increased by a factor of ten from low to medium to high as shown in Figure 12. In other words the number of fatalities at the high level is ten times higher than fatalities at the medium level, which is ten times higher than at the low level. The same pattern is followed for the harmed and affected metrics.

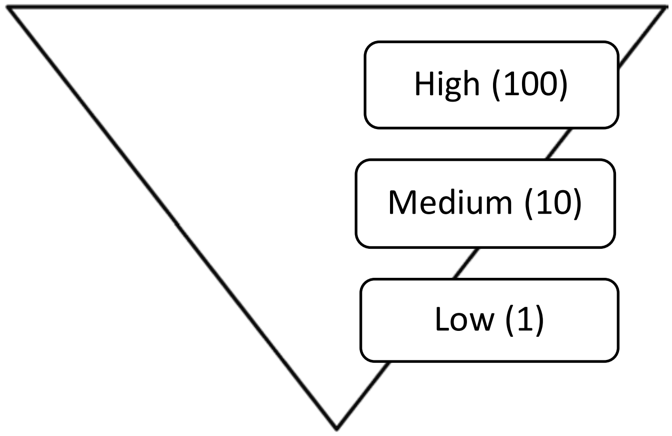

Figure 13 - Ratio of health metrics between each consequence level

The ratio *between metrics* also remained constant across all levels and is shown in Figure 13. This gives an indication of the relative weighting given to each type of health metric. For example, the scale judges that the following outcomes are all considered as a 'Medium' consequence: tens of fatalities, hundreds harmed and hundreds of thousands affected.

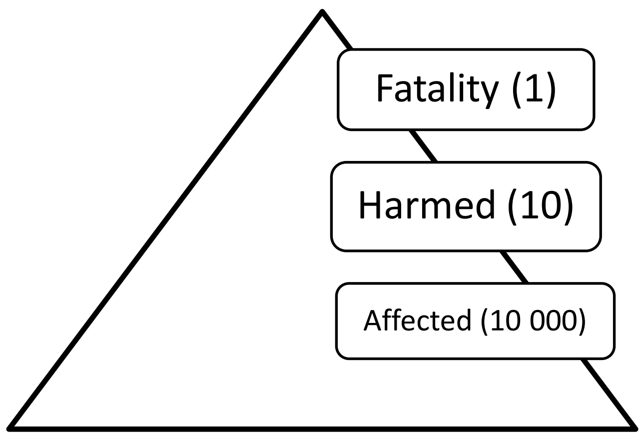

Figure 14 - Fatality: Harmed: Affected

The health assessment applied the scales to three climate-related hazards: flooding, temperature extremes and ground-level ozone. In each of these cases, the specific measure used for the harmed metric was hospitalisation.

While the metrics were developed for a population of 62 million in the UK, they provided a useful starting point to develop scales appropriate for Perth.

4.2.3 Proposed consequence scales

The review of existing scales highlighted strengths and weaknesses of each for application to the issue of climate change in Perth. The proposed scale incorporated strengths from each to develop a consequence scale that:

- Provides quantitative and qualitative measures of consequences
- Is responsive to population size and baseline health data
- Includes appropriate health metrics that can be readily measured
- Is relatively simple and easy to communicate.

The first step was to determine appropriate health metrics to use in the scale. The three metrics chosen were:

- Percentage increase in total mortality
- Percentage increase in potentially preventable hospitalisations (PPH)
- Percentage of population affected.

All three metrics are linked to population size enabling application to different populations across time and space. This addresses a short-coming of each of the reviewed scales which ultimately precluded them from direct application to this HIA.

Existing data sources can be used for mortality and hospitalisation and both of these metrics are commonly used in health risk assessments, including scales reviewed here. The PPH measure was selected because it was considered reasonable to assume that the majority of hospitalisations occurring as a result of climate change would fall under the definition of 'potentially preventable'. In addition, the ratio between PPH and total mortality in Perth is similar to the fatality: harmed ratio used in the UKCCRA scales. As mentioned previously, the 'harmed' measure used in each application of the scales was hospitalisations. The third metric of 'percentage population affected' is a composite of measures which will be discussed in greater detail below.

The second step was to determine the quantitative measures for each metric. It was considered that order of magnitude estimates, such as those used in the UKCCRA, were more appropriate than simple linear scales. Order of magnitude scales lack the precision of typical linear scales, but are more appropriate in situations where the level of risk for different hazards is not well understood and likely to span more than one order of magnitude (Levine, 2011). There is little doubt that climate change fits into this category and it was therefore decided that the 1:10 ratio between each level was appropriate. It was also decided to continue with the five levels of consequence, as per both of the WA scales. The three levels from the UKCCRA scale were extended by the application of the 1:10 ratio as shown in Figure 15. This figure also defines the relative magnitude of consequences between each level. For example, the 'Very High' level contains fatalities, hospitalisations and/or 'affected' outcomes that are 100 times greater than the 'Medium' level.

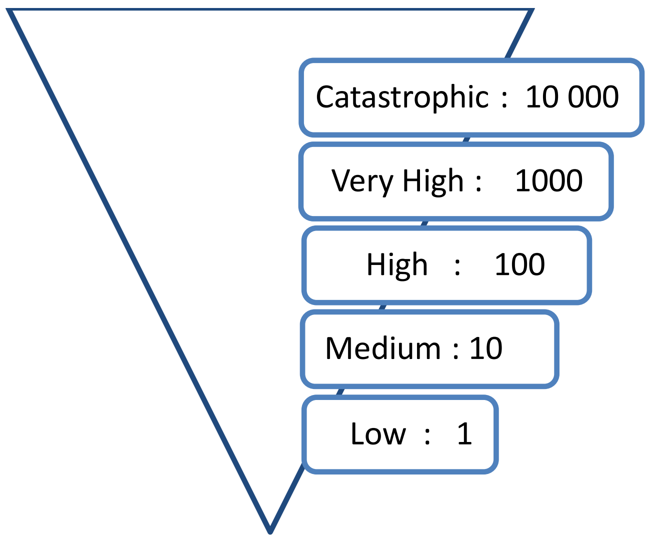

Figure 15 - Ratio for all health metrics across consequence levels

The next step was to determine the numerical ranges of each step. Given that the UKCCRA provided the only quantitative measures designed specifically for climate change impacts, they were considered an appropriate starting point. Adjustments for population size and mortality rates were achieved by converting the original figures into percentage increases in total mortality.

There are approximately 500 000 deaths per annum in the UK (Hames & Vardoulakis, 2012), so an increase of 100 fatalities, defined as a 'High' level of consequence, represents an increase of approximately 0.02% in total mortality. This definition of a High health consequence provided the starting point to populate the remainder of the scale. The first step was to apply the 1:10 ratios shown in Figure 15 to determine the percentage increases in mortality across all levels.

With the fatality levels determined, the next step was to determine the hospitalisation metric. The UKCCRA scale applied a simple factor of ten to determine the harmed metric (measured as hospitalisations). While the simplicity of this approach is attractive, the short-coming is that a fixed ratio between fatalities and hospitalisations can only be maintained if the scale is expressed in raw numbers. As this scale is linked to population size and baseline health data, the exact proportion of 'deaths, PPH or affected' can change as underlying health and demographic factors change. As a result, the relationship between the three health metrics in the proposed scale will not be characterised by a fixed ratio.

While the fixed ratio of 1:10 between health metrics will not be used in this scale, it was nevertheless considered a suitable starting point to determine an appropriate hospitalisation metric. Analysis of Perth metropolitan health data collected during the profiling phase of the HIA indicated that potentially preventable hospitalisations (PPH) are approximately five times greater than the total mortality. For example, when the 2% increase in mortality (catastrophic level) was applied to a Perth population of 1.7 million, this equated to 194 deaths. A 4% increase in PPH for the same population equates to 1828 deaths. This represents a ratio of 9.4 which was considered suitable for the proposed scale. It was therefore determined that each consequence level would include a percentage increase of 'y' in mortality (for example 2%) and a percentage increase of '2y' in PPH (for example 4%).

The final 'affected' metric is a composite measure of health-related outcomes selected from the reviewed scales. The components of the affected metric are shown in full in Table 8. Standard data sets are not readily available for these metrics and expert judgement was required to make appropriate estimates of the affected metric. The starting point to develop a semi-quantitative measure for the 'affected' metric was a PPH to affected ratio of 1:1000 (as per Figure 13). Using this ratio, the minimum number of affected people in Perth in 2011 at the 'very high' level was 182 800. This figure represents approximately 10.8% of the population. Bearing in mind, the requirement for a scale that is relatively simple to communicate it is proposed that this figure be amended to 10% as shown in Table 8.

The final step was to apply the proposed scales to a Perth population of 1.7 million. The percentage increases in mortality and PPH were based on the expected number of PPH (45,696) and expected number of deaths (9690) as calculated in §4.2.1.

Given that the HIA planned to assess health impacts in the year 2050, the scales were also applied to an estimated population of 3.1 million - the mid-range population estimate for Perth in that year (Australian Bureau of Statistics, 2008). The full set of results for both populations is shown in Table 8.

The proposed scale defines a ‘Very High’ consequence in Perth (2011) as between 20 and 195 deaths, between 183 and 1830 PPH, or more than 170 000 people affected. To provide context, the number of deaths due to road accidents in the five SSDs of Perth in 2011 was 65 (WA Police, 2012) while the number of hospitalisations due to road traffic injuries in Perth (2010) was approximately 1400 (Hill, Thompson, Yano & Smith, 2012). Both of these figures fall within the ‘Very High’ consequence level of Table 8. The number of deaths that lead to a catastrophic ranking in the proposed scales is equivalent to at least 3 times the annual road toll deaths recorded in metropolitan Perth in 2011.

Table 8 - Proposed consequence scales applied to Perth in 2011 and 2050

Consequence Level	Mortality Increase (%)	PPH Increase (%)	Population Affected (%)	Results as applied to Perth in the year:	
				2011	2050
Catastrophic	>2	>4	100% population affected as below: • Health effects not requiring hospitalisation • Significant decline in delivery of essential goods & services • Significant long-term reductions in quality of life	>195 deaths >1830 PPH 1.7 million affected	>356 deaths >3340 PPH 3.1 million affected
Very High	0.2 to <2	0.4 to < 4	10 to <100% population affected as above.	20 - 195 deaths 183 -1830 PPH >170 000 affected	36 -356 deaths 334 -3340 PPH >310 000 affected
High	0.02 to <0.2	0.04 to <0.4	1 to <10% population affected as above.	2 - 20 deaths 18 -183 PPH >17000 affected	4 -36 deaths 34 -340 PPH >31000 affected
Medium	0.002 to <0.02	0.004 to <0.04	0.1 to <1% population affected as above.	<2 deaths 2 -18 PPH >1700 affected	<4 deaths 3 - 34 PPH >3100 affected
Low	<0.002	<0.004	<0.1% population affected as above.	0 deaths <2 PPH <1700 affected	0 deaths <3 PPH <3100 affected

By the year 2050, the ‘Very High’ consequence level would equate to between 36 and 356 deaths, between 334 and 3340 PPH or more than 310 000 people affected.

Although health consequences are ranked according to numerical estimates of adverse health outcomes, it must be acknowledged that perception and acceptance of risk is influenced by many other factors. For example, although people are aware of the fatalities and injuries associated with road accidents, most people are willing to accept the level of risk associated with driving. If the same number of deaths and injuries occurred as a result of a less familiar event, such as a series of industrial accidents, community acceptance will be far lower.

4.3 Review of likelihood scales

An assessment of health consequences is only one part of the risk assessment equation. The next step is to consider the likelihood or probability that the consequence will occur. It has been recommended that scientists conducting health assessments of climate change provide probability distributions for specific estimates, as this is preferable to determinations being made by users with less expertise (Kovats et al., 2005).

The Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties (Mastrandrea et al., 2010) provides a thorough coverage of measures of likelihood and uncertainty as related to climate change. The IPCC defines likelihood with a set of ‘fuzzy’ boundaries as shown in Table 9. For example a statement that an outcome is ‘likely’ means the outcome has a probability between 66% and 100%. The level of likelihood is determined on the basis of quantitative analyses or an elicitation of expert views that the *well-defined outcome* will occur (Mastrandrea et al., 2010).

The HRA (Scoping) Guidelines developed descriptions and numerical estimates for both acute and chronic health effects. As shown in Table 9, the scale for chronic health effects is similar to the IPCC likelihood scale. The likelihood scale used in the previous HIA of climate change in WA used similar terminology but did not incorporate numerical estimates. The UKCCRA utilised a different approach where likelihood was assessed on a scale of 1 to 3 (low, medium and high) and interpreted as “likelihood that consequences will occur within the next century”. Given the central role and expertise of the IPCC, and the similarity to scales developed in WA, it was determined that the IPCC scale provided the best foundation for likelihood scales in this project.

Table 9 - Comparison of likelihood scales

IPCC Likelihood Scale		HRA (Scoping) Guidelines	
Terminology	**Likelihood of the outcome**	**Terminology**	**% chance chronic health effect**
Exceptionally unlikely	< 1%	–	–
Very Unlikely	<10%	Rare/remote	Up to 5
Unlikely	<33%	Unlikely	6-30
About as likely as not	33 – 66%	Possible/occasionally	31-60
Likely	>66%	Likely	61-90
Very Likely	>90%	Almost Certain	Over 90
Virtually certain	>99%	–	–

4.3.1 Proposed likelihood scale

The proposed likelihood scale for this project is shown in Table 10. The scale is a slight adjustment of the IPCC likelihood scale (Mastrandrea et al., 2010) with the two extreme levels of <1% and >99% removed. Given that a five level consequence scale has been proposed, a five level likelihood scale will be easier to accommodate in a risk assessment matrix. In addition, it is considered highly unlikely that health-related outcomes included in risk assessments will have likelihoods of <1% or >99%.

Table 10 - Proposed likelihood scale

Level	Likelihood of the occurrence/outcome
Very Unlikely	< 10%
Unlikely	< 33%
About as likely as not	33 – 66%
Likely	>66%
Very Likely	>90%

Climate change assessments typically occur over long time periods and are based on particular emission scenarios. At this point in time, probabilities have not been assigned to any of these scenarios – they simply represent different possibilities for the future. As a result of this an absolute measure of likelihood is not possible with the current level of knowledge. Instead, assessments are conditional upon the particular emissions scenario and time period. The likelihood of whether that particular set of conditions will lead to the ‘well-defined’ health outcome is then assessed. It does not include an assessment of how likely that particular emission scenario is. The level of precision, with which the ‘well-defined’ outcome is expressed, will also depend on the available evidence.

In the application of these scales, the outcome will be defined in terms of the consequence scale of Table 8. For example, a possible ‘High’ consequence using the proposed scales is ‘heat-related hospitalisations that result in a 0.04 to <0.4 % increase in PPH’.

4.4 Proposed confidence scale

Health risk assessments of climate change incorporate uncertainties regarding emission scenarios, changes in regional climate, impact on a complex set of health determinants and realisation of health effects, resulting in what has been termed a cascade of uncertainty (Schneider, 1983).

A measure of confidence in the consequences and likelihood levels assigned to each health impact being assessed can assist in identifying key shortcomings in current knowledge and help to inform future research. The guidance notes for the IPCC 5th Assessment report (Mastrandrea et al., 2010) describe confidence on the level of agreement and evidence as shown in Figure 11. Evidence is considered in terms of the type, amount, quality and consistency. This scale moves away from the scoring system out of ten used in the 4th Assessment report.

Table 11 - Proposed confidence scale

Confidence Legend	Very Low	Low	Medium	High	Very High

Agreement →			
	High Agreement Limited Evidence	High Agreement Medium Evidence	**High Agreement** **Robust Evidence**
	Medium Agreement Limited Evidence	Medium Agreement Medium Evidence	Medium Agreement Robust Evidence
	Low Agreement Limited Evidence	Low Agreement Medium Evidence	Low Agreement Robust Evidence
	Evidence (type, amount, quality, consistency) →		

4.5 Risk levels

Results from consequence and likelihood assessments are combined to give a measure of risk. Risk assessment matrices combine these two measures and describe risk in descriptive or numerical values. The two WA scales reviewed both used a traditional 5 x 5 risk assessment matrix. The UKCCRA developed a risk score (out of 100) based on magnitude, likelihood and urgency (see Appendix 3). The decision was made to apply a standard risk assessment matrix as shown in Table 12. This format is widely accepted across a range of settings, is familiar to people with knowledge of risk assessment and is relatively simple to communicate.

Table 12 – Proposed risk assessment matrix

Likelihood	Consequences				
	Low	**Medium**	**High**	**Very High**	**Catastrophic**
Very Unlikely	Very Low	Very Low	Low	Low	Medium
Unlikely	Very Low	Low	Low	Medium	High
About as likely as not	Low	Low	Medium	High	Very High
Likely	Low	Medium	High	Very High	Extreme
Very Likely	Medium	High	Very High	Extreme	Extreme

4.6 Expert feedback

The proposed risk assessment scales were distributed to a range of people and organisations with expertise in assessments of health impacts. Experts included authors of reports on the two WA scales reviewed and an author of the UK CCRA Health Report. Requests were made to the Department of Health (WA), the Australasian College of Toxicology and Risk Assessment and academic staff of Australian Universities with at least ten years experience in the field of health risk assessment or health impact assessment. A total of 12 experts agreed to review the scales.

The experts were provided with the background and rationale for the scales (similar to that presented in this chapter) and asked the following questions:

- Are the health metrics reasonable?
- Is the scaling factor of 10 between consequence levels reasonable?
- Are the quantitative ranges used for each health metric reasonable?
- Is the proposed likelihood scale reasonable?
- Does the risk assessment matrix provide a reasonable measure of risk?
- Is the confidence scale appropriate?

To assist in the final consideration of the suitability of the proposed risk levels one set of configurations for each risk level was highlighted (Table 13) and then described in full (Table 14).

Table 13 – Possible outcomes from risk assessment process

Likelihood	Consequences				
	Low	**Medium**	**High**	**Very High**	**Catastrophic**
Very Unlikely	Very Low	Very Low	Low	Low	Medium
Unlikely	Very Low	Low	Low	Medium	High
About as likely as not	Low	Low	Medium	High	Very High
Likely	Low	Medium	High	Very High	Extreme
Very Likely	Medium	High	Very High	Extreme	Extreme

This provided experts with the opportunity to consider whether the measure of risk associated with specific outcomes appeared reasonable in today's terms. For example, with reference to the 'Very High' risk highlighted in Table 13, experts could consider if a likely outcome (66%) of between 20 and 195 deaths, or 183 and 1830 extra PPHs, or more than 170,000 people affected would be considered as 'very high'. A total of 12 experts provided feedback on the scales. Comments and responses are provided in the following section.

Table 14 - Explanation of highlighted cells from RA matrix

Risk	**Consequence (per annum, Perth 2011)**	**Likelihood**
Extreme	>195 deaths or >1830 PPH or 1.7 million affected	>66%
Very High	20-195 deaths or 183-1830 PPH or >170 000 affected	>66%
High	2-20 deaths or 18-183 PPH or >17 000 affected	>66%
Medium	<2 deaths or 2-18 PPH or >1700 affected	>66%
Low	0 deaths or <2 PPH or <1700 affected	>66%
Very Low	0 deaths or <2 PPH or <1700 affected	<33%

4.6.1 Health metrics

- ***Do you think the general health metrics are reasonable?***

All experts expressed general agreement with the health metrics, with comments highlighted in Table 15. Responses are provided below each comment in Table 15.

Table 15 - Expert comments on health metrics

Yes metrics are appropriate. However, it won't really pick up on the gradual impacts as the question would be an increase compared to what? Last year or last decade?
The question of comparison with a particular time period will be addressed by each assessment. For example, this assessment will compare health data from the most recent decade to specified emission scenarios in the year 2050. The issue of incremental changes to baseline health data is a valid one. The idea of a specific baseline period such as the 1990-1999 baseline period often used in climate change projections is problematic for health data. Health outcomes are influenced by a large number of demographic and economic factors, as well as changes in medical technology and treatment. Untwining the influence that each of these variables have on health over the

coming decades is beyond the scope of the assessment process. It is possible that as research in this area advances, consideration of these aspects may be possible in the future. As long as the evidence exists for a relationship between a climatic variable and a health outcome, an assessment of the potential consequences, even for gradual impacts, is possible. For example, there is a clear relationship between ambient temperature and cases of Salmonellosis that can be used to estimate the level of consequences associated with defined increases in temperature. Although the effect may occur gradually and may be difficult to detect, this does not remove the capacity to make an **assessment** of the potential impact and compare to an appropriate baseline period.
It is generally easier to quantify mortality than the other metrics mentioned above. How can health effects not requiring hospitalisation be quantified, by expert elicitation? It is not clear what the 'essential goods and services' are. Could you provide some examples? Does quality of life mean living without disability?
While it is clearly easier to quantify mortality, it is important that non-fatal health impacts are not overlooked. Sources used for assessment will depend on the nature of the impact and the availability of data or evidence. In some cases, data such as notifications of disease or visits to GPs may be available. In other cases, particularly where data is not readily available, expert elicitation will be an important part of assessments. The intent of the term 'essential goods and services' refers to provision of utilities such as water, gas and electricity, community and health services and emergency management services. Quality of life is a broader term than 'living without disability'. It is a multi-dimensional term that encompasses physical, mental and social aspects that contribute to a person's overall health and well-being (Juniper et al., 2004).
The use of % increase should be substantiated with consideration of the size of the base. E.g. a base of 1 fatality and a 100% increase versus a base of 100 fatalities and a 100% increase might be perceived very differently, but the scale seems to indicate that they are equivalent?
Yes, this example is correct and highlights that population size will be a limiting factor for the use of the scale. For example, if the scale was applied to a population of 100 000 the high consequence would equate to a very small number of deaths (0.1 to 1) which presents practical limitations. It is suggested that application of the scale is best suited to populations of at least 1 million. A 'high' consequence for a population of this size,

assuming the same mortality and PPH rates, would be between 1 and 12 deaths or an additional 11-108 PPH.
What about financial or economic impacts?
Financial and economic impacts are important however assessment of these is beyond the resources of the project. It is feasible that additional criteria could be developed to cover these impacts. Both the UKCCRA and the HRA (Scoping) Guidelines included economic impacts that could provide some guidance.
Emergency Room attendance might be more relevant for flooding and winds - patching up injuries etc. Is there some way to express the outcomes in DALYs, because the death of an older person isn't the same as death of a young person in health economic terms?
Yes, this is true, particularly for extreme events. In the proposed scale, emergency room attendance would be incorporated in the % Affected scale, which could be considered an under-valuation of this outcome. It may therefore be preferable to expand the hospitalisation metric to include some measure of emergency room attendance. However, emergency room attendance is not a critical metric for the evidence collated as part of this HIA, so the decision was made not to develop this metric. Nevertheless it is acknowledged that future scales could incorporate such a measure. The HIA will rely primarily on published studies of health impacts of climate change or other climate-related studies. Most of these studies present health outcomes in terms of increased mortality, hospitalisations or other discrete outcomes. While normalising health outcomes through the use of DALYs could assist in comparison of outcomes, current limitations in data exclude this option.

4.6.2 The 1:10 ratio between consequence levels

- ***Do you think a scaling factor of 10 between consequence levels is reasonable?***

All experts expressed general agreement with the ratio between consequence levels, with additional comments and responses included in Table 16.

Table 16 - Expert comments on ratio between consequence levels

Seems fine to me. It is common in quantitative risk analysis to use log-log scale, e.g. Frequency – number of fatality curves, because the order of magnitude is more critical.
I agree that given the uncertainties, the order of magnitude estimates are appropriate. Any more precise ranges are unlikely with the current state of knowledge. However, presentation of the scale would be improved by simplifying to a series of 'less than' ranges. For example, just present 0.02<x< 0.2 as <0.2. This should tidy up the scale and make it easier to interpret
It is agreed that the simplifying of ranges makes the scales easier to interpret and this change will be made.
Yes. The ranges are a more accurate reflection of the limited accuracy associated with assessing impacts of climate change – especially future impacts.

4.6.3 Ranges of each health metric

- ***Do you think the quantitative ranges used for each health metric are reasonable?***

All experts expressed general agreement with the range of metrics, with comments and responses included in Table 17.

Table 17 - Expert comments on ranges

Yes with a proviso that there may be movement between the different levels (ie not fixed in stone). Difference between single events (100 deaths at one time) v gradual onset. Could miss if comparison is just with last year.
Agreed - development of the scales will be an on-going process. Application of the scales is likely to highlight aspects of the health metric ranges that require adjustment. In addition, as more evidence becomes available, it should be possible to provide narrower ranges. The scales are based on per annum figures, so do not distinguish between 100 deaths at one time or 100 deaths over the period of one year. The differences between these two scenarios will be dealt with at the risk management phase, where the particular adaptation response for each impact will be considered. Differentiation between single and gradual onset events, with respect to financial and health services impacts, could be achieved by the development of additional metrics for these impacts.
Could consider doing age-adjusted rates for longer time frames

Yes, this will be essential for an ageing population. There will be other parameters, such as changes in medical treatment, lifestyle or behavioural changes that also influence the baseline mortality and PPH rates. While these are important considerations, factoring them into the risk assessment process introduces an additional layer of complexity. In addition, given that the health consequence ranges are based on order of magnitude estimates, it is likely that this range will accommodate a significant proportion of the changes to mortality or PPH rates based on age and other factors.
"Catastrophic" level: 100% population affected sounds extreme. I would think that if >90% of the population is affected the level should be catastrophic. The "Very High" level of 10-100% population affected is an extremely wide range. It means that if a consequence affects 10% or 99% of the population the level will be the same. In my opinion, the % values in the "population affected" column are not very helpful.
Better to have a range than a fixed number for catastrophic level of 'affected' Eg 90-100% instead of 100%.
The '100% affected' figure will be changed, so the catastrophic level is >90% of the population and the very high level is between 10 and 90%. The 'population affected' variable is similar to the 'affected' variable in the UKCCRA scales, but is expressed in percentage of population rather than a fixed figure. It is acknowledged that this variable incorporates a large number of disparate indicators of health that may be difficult to measure and to compare. Nevertheless, the inclusion of this metric will encourage assessments to consider a range of health effects other than mortality and hospitalisations. A focus on these measures alone overlooks a large number of health effects which may not result in death or hospitalisation, but can nevertheless have a significant impact on overall health and well-being.
The "coping" aspect could be titrated against remoteness and the potential need for national intervention.
It is considered that these aspects would be considered either in the specific assumptions of the assessment or during the risk management phase.

4.6.4 Likelihood

- ***Do you think the proposed likelihood scale is reasonable?***

Expert reviewers agreed with the use of likelihood scales based on the IPCC scales, with additional comments as per Table 18.

Table 18 - Expert comments on likelihood scale

Why not couple with frequency (number of times per year)? Percentage might be hard to comprehend in some situations.
The percentage refers to the likelihood of a specific health outcome occurring, assuming a given emission scenarios and year. It does not refer to the likelihood of the specific emission scenario or a particular climatic event (such as 2 heatwaves per year). The specific outcome can be defined in terms of extreme events, such as "the likelihood that between 20 and 200 deaths per annum are likely to occur as a result of heatwaves, based on A1FI emissions scenario in the year 2050". If you include a frequency (such as 2 heatwaves per year), this does not provide an indication of the **likelihood** that the particular health outcome will occur.

4.6.5 Risk Assessment matrix

- ***Do you think the risk assessment matrix provides a reasonable measure of risk?***

There was general agreement with the proposed use of a risk assessment matrix as recorded in Table 19.

Table 19 - Expert comments on risk assessment matrix

I would suggest adding an "urgency" dimension (similar to the UKCCRA). Using the proposed matrix, there will be no differentiation between consequences of the same magnitude and likelihood occurring in the next decade or in the next century. The RA matrix would also benefit from a "timeline", i.e. when are these deaths per annum occurring, this decade, in mid-21st century, later?
The urgency dimension would be suitable if consequences from different time periods were being considered. However, in the context of this research, a single time-frame is being selected, so a direct comparison of consequences (or risks) will reflect the relative degree of urgency, at that particular time. If the scales were applied across multiple time frames, it would be critical to clarify which time periods were being considered and an

urgency dimension introduced.. For example, a ‘very high’ risk in 2030 would imply a higher level of urgency than a ‘very high’ risk in 2070. If comparisons between different dates were considered necessary, then an ‘urgency’ dimension could prove useful, but it is not considered necessary for this research. The intent of these scales is to apply them to a clearly defined time frame. The deaths per annum would therefore be referring to the number of deaths in the specified year.
A table specifying the actions (e.g. if extreme, population affected has to be evacuated within 1 week) to be taken for each category of risk is needed to assess if the risk matrix is suitable.
Yes, a response table could be developed as part of risk management. However, the focus of this work is developing scales for the assessment, rather than the management of impacts.
The range is the perceived risk - the consequence-likelihood approach may not have much street credibility.
The consequence-likelihood approach is well accepted in risk assessment and risk management practices. Any consequence scale includes a judgement regarding the level of risk. In this respect, there is no ‘right or wrong’ regarding the scales and the details of the scales will always be influenced by judgements surrounding particular outcomes. The perceived risk is also likely to be relative to baseline health data – which is why the metrics have been linked to current health outcomes. While assessed levels of risk may not always match perceived levels of risk (for example 100 deaths in a single-event compared to 100 deaths spread over a year), the scales provide an important tool to compare risk based on evidence of health outcomes, rather than public perception or political factors. The HIA process recognises that these factors will influence decisions made during the risk management and implementation stages.

4.6.6 Confidence

- ***Do you think the confidence scale is appropriate?***

Refer to Table 20 for comments on the confidence scale.

Table 20 - Expert comments on confidence scale

How will this be used? *It is not clear how the confidence measure will influence level of risk?*
Confidence levels do not directly influence the level of risk but can be used to allocate resources appropriately. For example, if confidence levels are low but the potential risk is significant, resources are best allocated to further research or monitoring that can improve the level of confidence. Alternatively, if confidence levels are high, resources are best allocated to management strategies to reduce the level of risk.

4.7 Conclusion

All expert reviewers agreed with the basic characteristics of the proposed scales. The expert comments resulted in a number of minor adjustments to the scales. The 'Population Affected' metric for the health consequence scale was changed to >90% (rather than 100%) for the catastrophic level. The presentation of the range values was simplified for each health metric as shown in Table 21. The resulting health consequence scale was used to provide estimates for each consequence level as applied to a projected Perth population of 3.1 million in 2050.

The advantage of this scale is that, unlike the scales reviewed, it can be applied across both time and space by taking into account differences in population size and current mortality and morbidity rates

Table 21 – Final health consequence scales

Level	Mortality Increase (%)	PPH Increase (%)	Population Affected (%)	Perth 2050
Catastrophic	>2	>4	>90% population affected as below: • Health effects not requiring hospitalisation • Significant decline in delivery of essential goods & services • Significant long-term reductions in quality of life	>356 deaths >3 340 PPH >2.8 million affected
Very High	>0.2	>0.4	>10% population affected as above	>36 deaths >334 PPH >310 000 affected
High	>0.02	>0.04	>1% population affected as above	>4 deaths >33 PPH >31 000 affected
Medium	>0.002	>0.004	>0.1% population affected as above	>0 deaths >3 PPH >3100 affected
Low	<0.002	<0.004	<0.1% population affected as above	0 deaths <3PPH <3100 affected

The advantage of this scale is that it can be applied across temporal and spatial scales, while taking into account differences in population size and current mortality and morbidity rates. Likelihood, confidence and risk assessment measures will be applied according to Tables 10 to 12 respectively.

The scales will be applied to the risk assessment phase of the HIA of climate change in Perth (2050). The results of this application will be discussed in the following chapter.

Chapter 5 – HIA Results and Discussion

5.1 Introduction

The final chapter of Part I reports and discusses the results from the scoping, profiling and risk assessment steps of the HIA. In addition, the use of the risk assessment scales, which were developed as part of this research, is reviewed. Suggestions are made for further development of these scales and their potential application to other settings. Finally, the results of the risk assessment step are used to determine the focus of Part II of the research.

5.2 Scoping

As outlined in Chapter 3, the study area was chosen on the basis of two criteria – an urban classification and an indication of a significant level of vulnerability to health impacts of climate change. Of the 31 LGAs in Perth, eight did not meet the urban selection criteria. These LGAs were therefore excluded from the list of potential study areas. Table 22 groups the LGAs into SSDs and classifies each LGA as either urban or non-urban.

Table 22- Urban and non-urban LGAs of each SSD

Included: LGAs with at least 90% of collection districts classified as Perth urban				
Central SSD	**North SSD**	**South West SSD**	**South East SSD**	**East SSD**
All ten LGAs	Stirling Joondalup	Cockburn East Fremantle Fremantle Melville	Belmont Canning Gosnells South Perth Victoria Park	Bassendean Bayswater
Excluded: LGAs with less than 90% of collection districts classified as Perth urban				
Central	**North**	**South West**	**South East**	**East**
	Wanneroo	Kwinana	Armadale	Kalamunda

		Rockingham	Serpentine-Jarrahdale	Mundaring Swan

The indicators of vulnerability used were the percentage of residents aged over 65, and areas with high levels of socioeconomic disadvantage. Table 23 summarises the percentage of people aged more than 65 and the deciles of disadvantage in each SSD. The first decile indicates the most disadvantage. The results indicate that the Central SSD has minimal socioeconomic disadvantage and is therefore likely to have significantly higher levels of adaptive capacity than other areas. On the basis of this indicator of vulnerability, the central metropolitan region was the only SSD discounted as an appropriate study area.

Table 23 - SEIFA disadvantage deciles and age distribution

SSD (urban)	Population	Range of suburb deciles	% age>65
Central	139935	8 to 10	13.4
North	268363	1 to 10	11.5
South West	218707	2 to 10	13.2
South East	292727	3 to 10	11.6
East	74322	3 to 10	14.1

The basic profile of the remaining SSDs was relatively similar and any one of these was considered suitable for the study. The East area was removed due to its comparatively small population. Although each of the remaining SSDs was considered a suitable study area, the South West area, with the highest percentage of residents older than 65, was selected.

Recruitment was undertaken as explained in Section 3.3.2.3. Representatives of the three largest urban LGAs in the South West SSD - the cities of Cockburn, Fremantle and Melville – all agreed to take part in the study. The potential health impacts identified during the state-wide HIA were considered in the context of the study area. The rationale for either retaining or amending the original level of risk and the responses received from each of the local government stakeholders are included in full in Appendix D. The level of risk for the majority of health impacts remained unchanged from the state assessment. Table 24 summarises the impacts that were amended, with the rationale for the adjustment and the response from each local government.

Table 24 - Preliminary amendment of risk level

Impact	Risk Amend-ment	Rationale for adjustment	LGA Responses C- Cockburn; F- Fremantle; M- Melville
Direct impact from tropical cyclones	Extreme → low	Rarely reach study area. If tail-end of cyclone reach Perth, most impacts are likely to be on infrastructure and services.	**F:** Risk may increase as warming is evidence that cyclones can reach to lower latitudes. Evidence that severe pre/post cyclone storms over 24 hours can result in damage.
Direct impact from storms	High →Medium	Direct physical injury from flooding was considered unlikely in study area. Impacts likely to be limited to damage to infrastructure (regional council report). Recorded storm events for last 10 years in the South Metropolitan region resulted mostly in property damage, with one reported injury and one fatality.	**C:** No reported health effects relating to storm damage. All damage recorded has been structural. Mental health concerned with rehousing has not been addressed. **F:**Medium is a reasonable rating **M:** More emergency for infrastructure. Power supply – food health and vulnerable medically.
Direct health impacts from flooding	High →Medium	Vulnerable populations were those residing in flood zones. The Natural Hazard Risk in Perth report (2005) stated that the reduction in Perth's average annual rainfall over the past 40 years is likely to reduce the likelihood of floods. Previous floods in Perth have resulted in infrastructure and property damage, but no record of direct health impacts of flooding in the Perth region has been reported.	**C:** We have increased our requirements for development sites to accommodate increased rainfall events. From a 1 in 20 year storm to a 1 in 100 year storm. The City has carried out a basic topographical risk assessment of the impact of a 1m rise in sea level and ensured that areas at risk of inundation or damage have been identified. **F:** Localised flooding has been noted from significant rain events and storm sumps are in place.

			M: Compounding effects from pumping outlets and sewage discharge points. Appropriate controls are in place.
Direct impacts from bushfires	Extreme→ Medium	The Natural Hazard in Perth report highlighted bushfires as a major threat for people living in the hill-suburbs, and in semi-rural areas. The study area is predominantly urban and fire-prone areas are limited to sections of remnant bush-land that are not likely to pose a significant threat to human health. There is no record of injuries or fatalities from bushfires in the area.	**C:** Large number of regional parks and semi-rural areas. May be premature to downgrade this risk rating in Cockburn. A specific project aimed at identifying bush fire risk in these areas is planned for 2011/12 **F:** Risk can be reduced further. There are two very small natural bushland patches, which are surrounded by a roads & residential areas. **M:** Compounding effect of lack of water and increasing temperature – heatwaves. Needs ongoing evaluation. The Community has ranked this risk as high, but mainly around loss of biodiversity and impact on soil. May pose mental health risks?
Reduced access to health care, food & water	Extreme→ medium	Increase in number and severity of extreme events may place additional pressure on health services, however a reduction in access to key services is more likely to be an issue in regional or remote areas of the state. The possibility of reduced access to health care is possible in urban areas, with occurrence of extreme events and growing demands on health care system due to ageing population.	**M:** High – Medium. Competing with surrounding populations from storm events etc.
Water-borne	High	Vulnerable groups in state HIA were remote Aboriginal and	**F:** There is an opportunity for more people to use

diseases from contamination of drinking water in extreme events	→low	rural communities. Water-borne diseases from drinking water are not likely to occur in communities with highly regulated supply and treatment of drinking water and the good sanitation	off-grid water supplies as an adaptive response. The City demonstrates how to do this at a community centre. **M:** Medium – Low. Reliant on Water Corporation. There is a good supply of bottled water at present.
Dislocation	High → medium	Risk of permanent dislocation due to economic stresses via increase in drought is not applicable to study area. Risk of permanent dislocation in study area due to sea-level increase is not considered high.	**F:** This reminded me of the Tim Flannery quote, "I think there is a fair chance Perth will be the 21st century's first ghost metropolis"
Population reduction and loss of goods and services	High→ low	Reductions in population most likely in rural and drought affected areas. ABS forecasts indicate that each of LGAs will experience continued population growth. Potential loss of goods and services due to higher demand in the study area are covered in infrastructure section.	**F:**If the regional population all migrates at the same time as a result of climate change to metro areas then the pressure on metropolitan housing, water, power & waste services is likely to increase- this is a low to medium risk
Neglect physical health during times of crisis	Medium→ low	Referred predominantly to rural populations facing drought. Not considered as relevant in urban setting.	

Compilation of all risk rankings after the preliminary risk assessment resulted in seven impacts with a risk level of high or greater (Table 25). One of the risks – the inability to meet demand for energy – is associated with periods of peak energy demand during heatwaves. For this reason, this impact was considered as part of the heatwave impact. While the level of risk associated with reductions in biodiversity remained unchanged at high, a meaningful assessment of the health impacts of biodiversity loss in the study area is unlikely with the current knowledge. It was therefore decided that the first five impacts outlined in Table 25 would be assessed in greater detail in the HIA.

Table 25 - Short-list of hazards with risk level of high or greater

Impact	Level of Risk
Heatwaves	Extreme
Air pollutants	High/Extreme
Air-borne allergens	High
Food-borne diseases	High
Ross-River Virus, Barmah Forest Virus	High
Inability to meet demand for energy	Extreme
Reductions in biodiversity	High

5.3 Profiling

Where possible, profiling data was collected for each local government area and the entire Perth metropolitan region.

5.3.1 Demographic Data

The study area covers a total of 239km^2 and has a total population of approximately 218, 000, representing 12.5% of the total population of the Perth Metropolitan region (Australian Bureau of Statistics, 2007).

Table 26 summarises the basic demographic data (Australian Bureau of Statistics, 2007). Cockburn is the largest of the three LGAs and has a significantly lower population density and proportion of elderly residents than Fremantle and Melville. Fremantle and Melville have relatively high densities (for Perth) and two of the highest proportions of elderly.

Table 26 - Population and age>65

	Cockburn	Fremantle	Melville	Study Area
Area (km^2)	167	19	53	239
Density (people/ km^2)	532	1478	1908	911
Population (2006)	88 702	28 105	101 052	217 859
Age >65 (%)	9.9	15.2	15.4	13.1
Age > 65 (#)	8781	4272	15 562	28 539

Population projections indicate that Perth will experience the highest percentage growth (116%) of Australia's capital cities over the next 40 to 50 years (Australian Bureau of Statistics, 2008). Table 27 provides population projections for Perth and each LGA (Department for Planning and Infrastructure, 2005). Significant changes in population structure are likely, with the number of elderly projected to increase from the current average of 13% to 19.6% in 2031in the study area. While the projections for the proportion of elderly do not extend to 2050 at the LGA level, projections are available for Perth. These projections indicate that the proportion of elderly in Perth is likely to increase further from 17.6% in 2031 to 20.9% by 2050 (ABS, 2008). Assuming a similar increase in the percentage of elderly in the study area, between 2031 and 2050, the overall percentage of elderly in the study area will be approximately 23% by 2050. These increases in the number of elderly will increase vulnerability to a number of health impacts of climate change.

Table 27 - Projected population and age>65

	Cockburn 2031	Fremantle 2031	Melville 2031	Total 2031	Perth Metro	
					2031	2050
Population	123 416	29 991	103 567	256 974	2,419,205	3,109,990
Age>65 (%)	16.8	23.5	21.8	19.6	17.6	20.9
Age >65	20 760	7047	22536	50 343	425 780	631328

Preliminary assessment of socioeconomic status conducted in the scoping phase was expanded to give an indication of the percentage of residents within each LGA who may have a low adaptive capacity in relation to climate change. Figure 16 shows the percentage of residents in each LGA living in suburbs with SEIFA Disadvantage quintiles of 1 to 5, with 1 being the most disadvantaged. The City of Melville clearly has the least proportion of disadvantage, with 79% of residents living in the highest quintile and only 5% living in areas of most disadvantage. It is important to note that the SIEFA scores are a suburb average, and a high score does not suggest an absence of disadvantage within that suburb.

Cockburn had the largest range of results, with similar percentages of the population in the bottom (48%) and top (40%) SEIFA quintiles. Over 80% of residents in Fremantle lived in suburbs that were in the bottom three quintiles.

Analysis of minimum SEIFA scores at the smaller collection district level highlighted the fact that areas of disadvantage can still exist within high quintile areas. For example, while the suburb Bibra Lake recorded an average decile of 8, there were collection districts in the suburb that fell within the bottom decile.

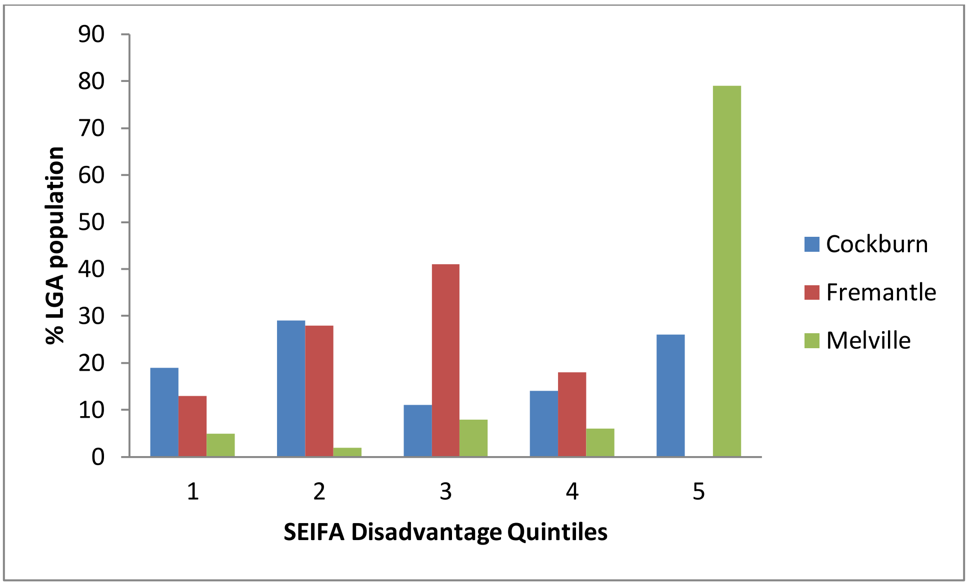

Figure 16 - Distribution of population according to suburb SEIFA quintiles

Projections for SEIFA indexes are not available, however 5-yearly Census data will enable regular updating of figures. In addition, information from local governments such as planned development projects will also be available to consider the impact on variables affecting disadvantage.

5.3.2 Baseline health status

Tables 28 to 36 provide a summary of baseline health data collected from a range of sources. Complete data sets have been retained to provide an overall picture of the proportion of health impacts that may be affected by climate change. Data considered relevant to the health impacts being considered as part of this study have been highlighted in each table. If links between climate and other health impacts exist, these were acknowledged but an in-depth analysis of these impacts was not pursued.

5.3.2.1 Burden of Disease – Disability Adjusted Life Years

The top ten burden of disease conditions were obtained from a data request to the Epidemiology Public Health Division of Department of Health WA (2011). In the absence of data at the local government level, data from the South Metropolitan Area, in which the study area is located was utilised. As shown in Table 28, cardiovascular (ischaemic heart disease and cardiovascular stroke) and respiratory (chronic obstructive pulmonary disease (COPD) and asthma) conditions accounted for 17.2% of the total burden of disease. Exposure to heat and air pollutants, both identified as priority issues, have established links to cardiovascular and respiratory conditions. While there is no evidence that climate change will influence the incidence of diabetes, evidence indicates that diabetics are more sensitive to a range of climate-related health impacts, including heat-related impacts and air quality effects (O'Neill et al., 2005).

Evidence for links between mental health and climate change have been reported (Berry, Bowen & Kjellstrom, 2010), but as this impact was not included in the priority list, the mental health conditions have not been highlighted. No evidence was found to link the remainder of the top ten burden of disease conditions with climate change.

Table 28- Top ten disease conditions in South Metropolitan Area (2006)

Age	Rank	Disease condition	YLD	YLL	DALY	Total burden(%)
All ages	1	Ischaemic heart disease	1417	6093	7510	8.2
	2	Anxiety and depression	7397	16	7413	8.1
	3	Type 2 diabetes	4251	1069	5320	5.8
	4	Dementia	3411	1273	4684	5.1
	5	Sense organ disorders	4053	<5	4053	4.5
	6	Cardiovascular stroke	1059	2382	3441	3.8
	7	Lung cancer	219	3175	3394	3.7
	8	Asthma	2293	146	2439	2.7
	9	COPD*	1054	1259	2313	2.5
	10	Breast cancer	710	1332	2042	2.2
		Total Burden	49837		91031	

*Chronic obstructive pulmonary disease

Asthma was the leading burden of disease condition for ages 0 to 14, accounting for 20% of the total burden, primarily as years lost to disability. None of the remaining top ten conditions in this age group had probable links to climate change.

5.3.2.2 Avoidable mortality (1998-2007)

The top ten causes of avoidable mortality from 1998 to 2007 for each LGA and the Perth Metropolitan area are shown in Table 29. Data was obtained from the Health Track Reporting System. As with burden of disease, the prioritised health effects with well characterised links to climate variables were cardiovascular and respiratory conditions, which accounted for between 25 and 30% of avoidable mortality. The remainder of the conditions have no established climate-links to the health impacts being considered.

Other health impacts in Table 29 that may be influenced by climate change but will not be assessed in detail are colo-rectal cancer and melanoma of the skin. Inadequate consumption of fruit and vegetables is a risk factor for colo-rectal cancer (Australian Institute Health and Welfare, 2011). Since climate change may result in higher prices for fresh fruit and vegetables, reduced affordability may result in lower consumption of fruit and vegetables. Melanoma of the skin is closely linked to UV exposure and time spent outdoors, which may be affected by changes in ambient temperature.

Table 29 - Ten leading causes of avoidable mortality for each LGA and Perth (1998-2007)

Condition	Cockburn		Melville		Fremantle		Perth Metropolitan	
	#	%	#	%	#	%	#	%
Ischaemic heart disease	184	19.6	191	17.6	106	20.7	3906	19.8
Lung Cancer	132	14.1	150	13.8	56	10.9	2629	13.4
Suicide	72	7.7	106	9.8	38	7.4	1496	7.6
Colo-rectal cancer	61	6.5	86	7.9	45	8.8	1444	7.3
Breast Cancer	47	5.0	78	7.2	27	5.3	1102	5.6
CV Disease	45	4.8	44	4.1	33	6.4	1080	5.5
COPD	-	-	40	3.7	18	3.5	781	4.0
Diabetes	42	4.5	40	3.7	-	-	712	3.6

Alcohol-related	34	3.6	36	3.3	28	5.5	521	2.6
Accidental poisonings	30	3.2	34	3.1	20	3.9	-	-
Stomach cancer	26	2.8	-	-	-	-	-	-
Bacterial/Protozoal infection	-	-	-	-	17	3.3	-	-
Melanoma of skin	-	-	-	-	-	-	474	2.4
Total	690	75.1	1279	76.6	388	75.7	14 145	71.8

Cell with no data (-) indicates that the condition is not in the top ten causes of mortality for that area.

5.3.2.3 Potentially Preventable Hospitalisations (2005 – 2009)

A search for the top causes of PPH for the LGAs of Cockburn, Melville and Fremantle and the Perth Metropolitan area was conducted using the Health Tracks Reporting System. Results showed that each LGA and the Perth Metropolitan area had the same top 14 causes of PPH with some differences in ranking. These accounted for 96.6% of all PPH in the study area. In addition to diabetes and cardiovascular and respiratory conditions, Table 30 includes dehydration and gastroenteritis, both conditions likely to be affected by climate change.

Table 30 - Leading causes of PPH (2005 to 2009)

Condition	Study Area		Perth	
	Cases	% PPH	Cases	%PPH
Diabetes complications	5995	24.9	51,454	24.5
Dental conditions	3733	15.5	28,176	13.4
Pyelonephritis	1979	8.2	17,089	8.1
COPD	1686	7.0	10,838	5.2
Congestive cardiac failure	1669	6.9	17,633	8.4
Dehydration & gastroenteritis	1478	6.1	14,008	6.7
ENT infections	1294	5.4	12,686	6.0
Iron deficiency anaemia	1235	5.1	10,331	4.9
Asthma	1044	4.3	11,358	5.4
Convulsions & epilepsy	1032	4.3	8,984	4.3
Angina	809	3.4	8,025	3.8
Cellulitis	553	2.3	6,297	3.0
Influenza & pneumonia	437	1.8	3,634	1.7
Perforated ulcer	287	1.2	2,183	1.0

5.3.2.4 Communicable diseases – enteric and vector-borne diseases

Results from the Health Tracks Reporting System on notifiable communicable diseases are shown in Table 31. The major diseases groups with climate-related links are enteric and vector-borne diseases, which accounted for 21.3 and 5.6% of communicable diseases in the study area respectively.

Table 31 - Notification of communicable diseases (2005 to 2009)

Major Disease Category	Study Area		Perth Metropolitan	
	Number	**%**	**Number**	**%**
Sexually transmitted diseases	3247	40.8	28,510	42.4
Enteric diseases	1700	21.3	13,696	20.4
Vaccine preventable diseases	1796	22.6	12,592	18.7
Blood-borne diseases	677	8.5	6,945	10.3
Vector-borne diseases	445	5.6	4,623	6.9
Zoonotic diseases	N/A	-	38	0.1
Other notifiable diseases	94	1.2	819	1.2
Total			67,223	100.0

The proportion of specific enteric diseases in the South Metropolitan region (South Metropolitan Public Health Unit, 2011) was used to estimate the number of specific diseases over the 2005 to 2009 period. The top two causes of enteric diseases were *Campylobacter* and *Salmonella*, accounting for 84% of all cases (Table 32). This equated to an annual average of 1745 cases in Perth and 646 cases in the study area. Food-borne sources are the major cause of these bacterial infections and previous studies in Australia have reported that approximately one third of gastroenteritis cases in Australia are caused by food-borne sources (Abelson, Potter, Forbes & Hall, 2006). Salmonellosis has a strong association with temperature, peaking in summer months, with a summer excess of 105% (Bambrick et al., 2008). A study of the effect of temperature on notifications of Salmonellosis in major Australian cities reported significant associations in all cities. Results from Perth indicated a 4.1% increase in notifications with every 1^{o}C rise (D'Souza, Becker, Hall & Moodie, 2004). Links between *Campylobacter* notifications and temperature is less clear, with cases peaking in spring and a small summer excess of 12.3%.

Table 32 – Notifications of enteric cases (2005 -2009) and links to climate

Condition	% of enteric notifications	Cases(2005-2009)		Links to climate
		Study Area	Perth	
Campylobacteriosis	60.8	1034	8327	Affected by temperature. Small summer excess (12.3%) reported in Australia.
Salmonellosis	23.5	400	3219	Strong seasonal trend with 104.8% summer excess in Australia. 1°C increase associated with 4.1% increase in notifications in Perth
Rotavirus	8.7	148	1192	Winter peak. 1°C increase associated with 2-5% decrease in hospital admissions.
Cryptosporidiosis	3.5	60	480	Strong seasonal trend with 187.4% summer excess.

Cryptosporidiosis is caused by a parasite and has a strong seasonal trend with a summer notification excess of 187.4% (Bambrick et al, 2008). There are multiple sources of the infection including recreational waters, food, soil and animals. The seasonal difference of notifications has been attributed predominantly to behavioural factors, such as an increase in contact with recreational water bodies during summer, rather than a direct relationship with ambient temperature (Bambrick et al., 2008).

Another health impact in Table 32 that may be influenced by climate change is Rotovirus infections, which accounted for 8.7% of enteric notifications. Higher temperatures in winter have been associated with a reduction in hospital admissions. Evidence suggests that colder winters result in greater time spent indoors which facilitates virus transmission (Bambrick et al., 2008).

There were 5 vector-borne diseases included in the top 15 causes of communicable diseases in the study area (Table 33). Given the current transmission range of these, Ross River Virus and Barmah Forest Virus are the only VBDs acquired in the vicinity of Perth that are expected to be affected by climate change. Notifications of malaria and Dengue Fever may be affected as a result of cases acquired elsewhere.

Table 33 - Notification of vector-borne diseases (2005-2009)

Condition	Study Area		Perth Metropolitan	
	N	% of communicable diseases	N	% of communicable diseases
Ross River Virus	234	2.9	1906	2.8
Schistosomiasis/Bilhariasis	75	0.9	1580	2.4
Barmah Forest Virus	45	0.6	420	0.6
Dengue Fever	35	0.4	Not in top 15	-
Malaria	13	0.2	405	0.6

Ross River Virus was the most prevalent vector-borne disease and accounted for 2.9% of total communicable diseases in the study area. This amounted to an annual average of 381 cases in Perth and 47 cases in the study area respectively. Reports from the Department of Health indicate that in most years the majority of these cases were acquired outside the study area, although locally acquired cases have been reported during years with major outbreaks in the south west of WA (Lindsay, 2009). Notifications of Barmah Forest Virus were considerably lower, with an annual average of 84 and 9 cases in the Perth metropolitan and study areas respectively.

5.3.2.5 Existing health conditions - vulnerable groups

The prevalence of existing health conditions that may increase vulnerability to adverse health effects of climate change is summarised in Table 34. Results were collected from the Health and Wellbeing Surveillance System (Department of Health, 2011b). Highlighted cells show the prevalence of conditions with links to the list of prioritised health impacts. While not under consideration in this assessment, the potential link between mental health and climate change, especially given the high prevalence rate, should be noted.

Table 34 - Self-reported prevalence of major conditions (2010)

Conditions	South Metropolitan		Perth Metropolitan	
	%	N	%	N
Diabetes	6.9	45237	6.4	89780
Heart disease	6.4	41823	6.0	84034
Cancer	6.0	38952	5.3	74166
Current asthma	8.4	54485	8.3	115065
Current respiratory problems[(a)]	1.6	10682	1.7	23245
Stroke	1.7	11275	1.7	23557
Arthritis	20.9	136187	19.9	277036
Osteoporosis	5.3	34799	5.0	69436
Injury[(b)]	22.7	147812	23.0	319859
Current mental health problems[(c)]	15.6	101900	14.9	206894

(a) Respiratory problem other than asthma that has lasted 6 months or more

(b) Injury in the last 12 months requiring treatment from a health professional

(c) Diagnosed with depression, anxiety, stress-related or other mental health problem in past 12 months.

5.3.3 Risk factors

Prevalence rates for behavioural and physiological risk factors with possible links to climate are shown in Table 35. Prevalence estimates for the South West Metropolitan Region were obtained from Health Tracks and based on results from the WA Health and Wellbeing Surveillance System (2009). The attributable contribution to Burden of Disease (BoD) figures was derived from national figures (Australian Institute Health and Welfare, 2003).

Table 35 - Prevalence of risk factors influencing health and links to climate

Health Behaviour	Attributable Percentage of BoD	Prevalence Estimate (%)	Evidence for Links to Climate
Currently smokes	7.8% total 9.7% CVD	15.9	Smoking is a significant risk factor for cardiovascular and respiratory diseases which increase vulnerability to health impacts of extreme heat and reduced air quality.
Does not eat 2 or more serves of fruit daily	2.1% total 9.6% CVD 2.0% cancer	46	Possible impact of climate change on quality, availability and price of food.
Does not eat 5 or more serves of vegetables daily		86.5	
Insufficient physical activity	6.6% total 23.7% CVD 23.7% diabetes 5.6% cancer	45.8	Weather can affect physical activity patterns. Higher pollutant levels and temperatures can increase health risks associated with physical activity. Mitigation/adaptation measures also have the potential to influence physical activity levels.
Physiological and Psychological Risk Factors			
Current high blood pressure	7.6% total 42.1% CVD	18.9	People with high blood pressure are more susceptible to cardiovascular effects of particulate exposure.
Current high cholesterol	6.2% total 34.5% CVD	21.1	Possible impact of climate change on quality, availability and price of food with flow-on effects on diet.
Overweight	7.5% total 54.7%	38.6	Obese individuals are vulnerable to adverse health effects of

	diabetes		heatwaves. Obesity is a risk factor for cardiovascular disease and diabetes, which both increase vulnerability to some climate-related health impacts. Climate change may also affect quality, availability and price of food.
Obese	19.5% CVD 3.9% cancer	26.8	
High or very high psychological distress	Not available	10.8	Multiple indirect links between weather and mental health. Increased frequency and occurrence of extreme weather events is likely to affect stress associated with such events. Hospital admissions for behavioural disorders increase during heatwaves.
Lack of control over life in general	Not available	3.9	

5.3.4 Summary of the profiling step

The profiling step has provided evidence that a significant proportion of the current burden of disease in Perth is caused by conditions that have established links to climate. In addition it provides evidence that factors affecting vulnerability to some health impacts of climate change will increase significantly between now and 2050. The extent of these influences will be assessed during the risk assessment phase. The profiling step has demonstrated that health effects of climate change are likely to occur as a result of multiple influences. For example, in addition to increased exposure to heat and air pollutants, cardiovascular disease may also be influenced by climate-related changes to physical activity and diet.

A summary of the baseline health data is provided in Table 36.

Table 36 Summary table of data from profiling step

Condition	Link to climate	Burden of Disease Rank, % total	Avoidable Mortality Rank, % total	Preventable Hospitalisations Rank, % total	Notifiable Infectious Diseases Rank, % total	Vulnerable Groups
Ischaemic heart disease	Cardiovascular (CV) related mortality and morbidity is affected by exposure to heat. Association between CV conditions and exposure to air pollutants, particularly particulates and weaker evidence for ozone.	1st 8.2%	1st 19.8%	5th, 6.9%[1] 11th, 3.4% [2]		Elderly, Existing illnesses, Diabetics, Obese
Cardiovascular stroke		6th 3.8%	6th 5.6%			
Asthma	Respiratory related mortality and morbidity affected by exposure to heat. Risk of respiratory death due to heat stress is greater than that of CV effects. Association between respiratory mortality and morbidity and ozone, particulate and allergen levels. People with existing respiratory diseases vulnerable to these impacts and to heatwaves.	8th 2.7% Age 0-14: 1st 20%		9th 3.4%		Children, Asthmatics
COPD		9th 2.5%	7th 4.3%	4th 7%		Elderly, Existing respiratory diseases
Dehydration	Caused by a range of viruses, bacteria and	-	-	6th		Very young,

&Gastroenteritis	parasites, some of which are likely to be			6.1%		elderly
Enteric Diseases	affected by climate change, particularly temperature increases. Strongest association shown for *Salmonella* and *Cryptosporidium*.				2nd 21.3%[3]	
Type 2 diabetes	People with type-2 diabetes are more vulnerable to heatwaves and air pollutants.	3rd 5.8%				Obese
Vector-borne Diseases	Vectors can be sensitive to a range of climatic variables. RRV and BFV are the main vector-borne diseases endemic in areas in close proximity to Perth.				5th, 5.6%	

Risk Factors	Links to Climate	Prevalence (%)
Low fruit and vegetable consumption	Possible impact of climate change on quality, availability and price of food. Associated with 2.1% total BoD.	44% < 2 serves fruit per day 87% < 5 serves vegetables per day
Insufficient physical activity	Climate, pollutant levels and range of mitigation/adaptation measures can affect physical activity patterns. Associated with 6.6% total BoD, predominantly CV disease and diabetes.	45.3%
High body mass	Obese individuals are vulnerable to adverse health effects of heatwaves. Indirect effects of climate change may impact on diet and physical activity. Associated with 7.5% total BoD –the majority from diabetes and CVD.	38.6% overweight 26.8% obese

High blood pressure	Evidence that people with high blood pressure are more susceptible to CV effects of particulate exposure. Associated with 7.6% total BoD, majority from CV disease.	18.9%
High blood cholesterol	Possible impact of climate change on quality, availability and price of fresh fruit and vegetables. Associated with 6.2% total BoD, majority from CV disease.	21.1%
Indicators of existing mental health	Multiple indirect links between climate and mental health. Anxiety and depression are second highest cause of BOD in study area	15.6% - current mental health problem 10.8% - high level psychological distress 3.9% - lack of control over life in general

[1]Classified as congestive heart failure; [2]Classified as angina; [3]Specific categories: *Campylobacter* 12.8%, *Salmonella* 4.2%, *Cryptosporidium* 1.4%; [4]Specific categories: Ross River Virus 2.9%, Barmah Forest Virus 0.6%, Dengue Fever 0.4%; [5] Does not include Influenza as direction of this impact is likely to be positive

5.4 Risk Assessment

The aim of this section is to assess the level of risk for each priority health impact. In addition to the evidence collected during the scoping and profiling steps, evidence from other sources, such as the peer-reviewed literature, were used to inform the assessment. The priority health impacts, as identified during the scoping phase, are those associated with:

- Heatwaves
- Air quality, in particular ozone, particulates and allergens
- Food-borne diseases
- Vector-borne diseases

The risk assessment scales developed in Chapter 4 were used to determine the consequence, likelihood and confidence levels. As determined during the scoping phase, the selected time-frame for the assessment is the year 2050. Key assumptions, such as the selection of SRES scenarios, and any other assumptions that may affect the assessment are clearly stated.

5.4.1 Heatwaves and heat-related health effects

The effects of heatwaves are difficult to model, and as a result most assessments are based on the health effects of temperatures above well-defined thresholds. The risk assessment prepared for the Garnaut Climate Change Review (Bambrick et al., 2008) assessed a range of scenarios. The first climate change scenario was based on the A1F1 storyline, and the second on a strong mitigation storyline. The assessment took into account projections for population growth and ageing. Figure 17 shows that the number of heat-related mortalities in Perth, without climate change, is estimated to double by the year 2050 and then plateau – this increase is attributable to population increases and an ageing population. The A1F1 scenario results estimated an additional 29 deaths in 2050, 121 in 2070 and 320 by the year 2100. The strong mitigation scenario had a small impact with fewer than 5 additional heat-related deaths projected for each of the time periods modelled (Bambrick et al., 2008). However, since this assessment, evidence suggests that the strong mitigation scenario of 1.5^{o}C by 2100 is increasingly unlikely (The World Bank, 2013).

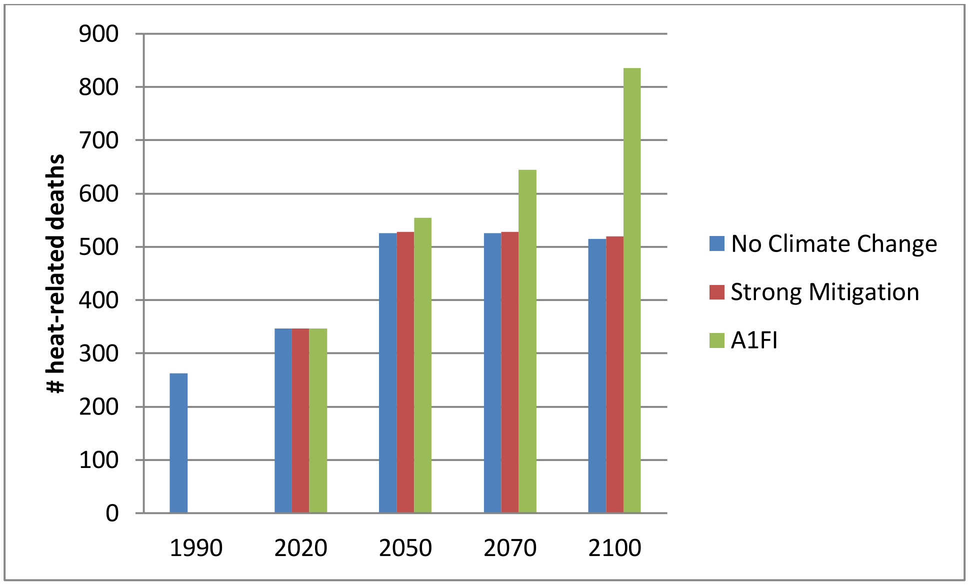

Figure 17 - Projected heat-related deaths in Perth

Applying the same scenarios, the assessment also modelled the effect of maximum temperature on daily emergency hospital admissions using historical data from Sydney, Melbourne and Brisbane, and then applying to all capital cities. Figure 18 shows that as for mortality the largest increases in emergency admissions were linked to demographic rather than climatic changes. The A1F1 scenario resulted in additional 50, 94 and 184 emergency admissions in Perth in 2050, 2070 and 2100 respectively. A strong mitigation scenario reduced the number of additional heat-related admissions attributable to climate change to 23, 24 and 31 respectively.

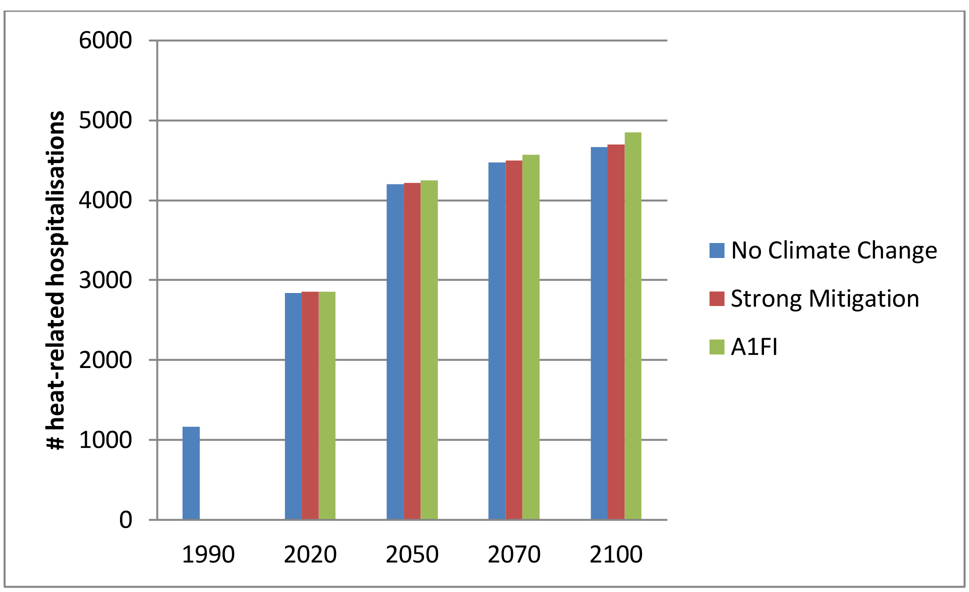

Figure 18 - Projected heat-related hospitalisations in Perth

An assessment of health impacts of climate change in Oceania (McMichael et al., 2003) applied low, mid and high-range emission scenarios to capital cities. Figure 19 (McMichael et al, 2003) shows the number of heat-related deaths estimated for the mid-range emission scenario for five capital cities. Perth recorded the highest number of temperature-related deaths. This was related to the high number of days with maximum temperatures over 40°C compared to other cities.

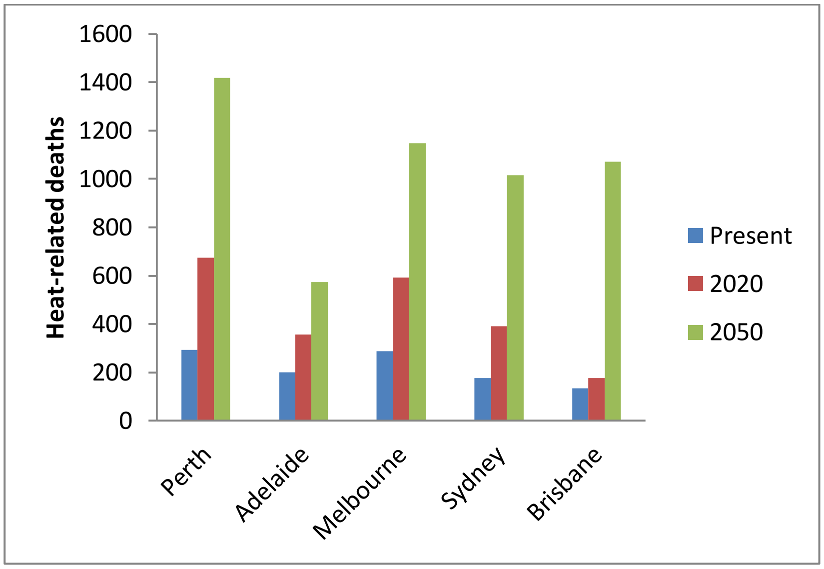

Figure 19 - Heat-related deaths under a mid-range emissions scenario

Figure 20 shows the break-down of deaths in Perth in 2050, estimated by McMichael and colleagues (2003) under mid- and high-range emissions scenarios. The figure also shows that a significant increase in the number of heat-related deaths is likely to occur as a result of population ageing alone. The estimated increase in the number of deaths attributable to climate change in 2050 was 79 and 188 for mid- and high-range scenarios respectively.

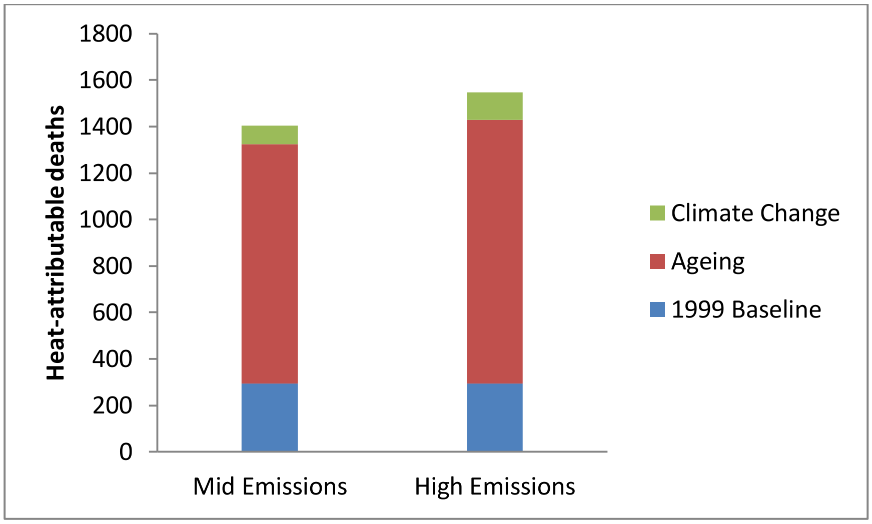

Figure 20–Cause of projected temperature-related deaths in Perth, 2050

In addition to studies that focus on health effects above specific temperature thresholds, an Excessive Heat Factor has been developed to model the potential health effects of heatwaves in Australia (Department of Climate Change and Energy Efficiency, 2011). Heat-related deaths were reported as an annual average or those that would occur during a top heat event. Top-heat events were defined as "infrequent, extreme events with significant impacts on a community" (p. 6). The model estimated a fivefold increase in annual average heat-related deaths in Melbourne, 2050, under a mid-range emissions scenario. Although the report did not undertake an assessment for Perth in 2050, the authors concluded that there was, "no reason to suppose that other susceptible cities would not also be exposed to significantly higher risks as a result of climate change" (p. 6). If the model results of a fivefold increase in deaths in Melbourne are applied to the baseline Perth data provided in the report, an additional 104 deaths per annum are estimated in Perth by the year 2050.

In addition to impacts on mortality and morbidity an increase in extreme temperatures is likely to impact on leisure and work activities. In a Perth study, modelling projected significant increases in the number of days that people would not be able to undertake outdoor activity due to inadequate thermoregulation (Maloney & Forbes, 2011). The effect was greatest in unacclimatised people where the annual number of days increased from the present 4-6 days per year to 33-45 days by 2070. Effects on acclimatised people performing moderate activity predicted an increase in the number of days where heat stroke was a real possibility from 1 day every 5 years to 10 days per year by 2070. The number of days where manual labour was considered dangerous was predicted to increase from the current 1 day per year to 21 days per year. While these figures indicate the potential for impacts on health and leisure and work patterns, the modelling assumed a 6°C increase in average temperature by 2070. Published estimates indicate that the probability of an increase of this size, even under a high emissions scenario, is very low (CSIRO, 2007b).

The evidence presented in section 5.4.1 is summarised in Table 37. The evidence is assessed in accordance with the scales developed in Chapter 4.

Table 37 - Risk assessment table for heat-related impacts of climate change in Perth 2050

Vulnerable	Aged, existing CV or respiratory conditions, diabetics, obese, isolated	
Current Data	Current heat-related deaths: 260-300p.a. Vulnerable groups: 13% elderly; 6.9% type-2 diabetes; 25.6% obese, 17% of BoD attributed to CV or respiratory conditions	
Future trends affecting vulnerability	Ageing population: 23% elderly by 2050 ~ 25% increase respiratory and CV conditions by 2030 (Goss, 2008) Significant increases projected for diabetes and obesity → Significant increase in vulnerable population	
Health Consequences	**Health Effect**	**Magnitude**
	Mortality	29 deaths p.a.(A1FI) 79 - 118 deaths p.a. (mid to high emissions) 104 deaths pa for heatwave events
	Hospitalisations	Additional 23-50 hospitalisations p.a. by 2050 (Bambrick et al., 2008)
	Affected	Limited data available on less severe impacts. Some data available on loss of productivity but insufficient to assess.
	VERY HIGH (Between 36 and 360 deaths in the year 2050)	
Likelihood of between 36 and 356 deaths pa by 2050	Very likely (>90%) that heatwaves occur more frequently (IPCC, 2007b). Causal link between heatwaves and health effects is well-established. High baseline of respiratory and CV conditions. Key indicators of vulnerability (elderly, obesity and diabetes) are all projected to increase significantly by 2050.	
	VERY LIKELY (> 90%)	
RISK	**VERY HIGH**	
CONFIDENCE	**HIGH:** Robust evidence. Medium agreement for modelling results.	

5.4.2 Increases in ozone levels and related health effects

There is clear evidence linking ambient temperature with ozone levels in Perth. Figure 21, from the Perth Vehicle Emissions Inventory (Department of Environment and Conservation, 2010a), shows the relationship between temperature and emission of evaporative volatile organic compounds from vehicles in Perth. The highest emissions occur on the hottest days (termed high-oxidant days). These are days when the average of the maximum and minimum temperatures is over 27°C. Other summer days, when average temperature is below 27°C, result in approximately double the evaporative VOC emissions of winter days.

Given the relationship between temperature and ozone levels in Perth, projected increases in average and maximum temperatures and in the number of days over 35°C is likely to result in increases in ozone levels compared to a no climate change scenario. This conclusion is supported by the national State of the Environment report which concluded that climate change was likely to lead to the formation of more ozone (Department of the Environment, 2011).

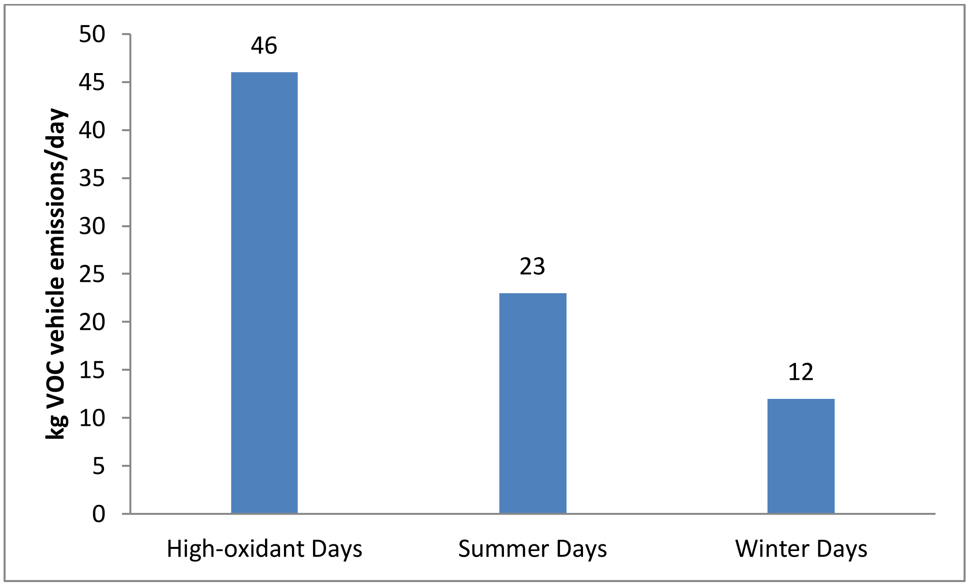

Figure 21 – Variation in VOC emissions in Perth (2006-2007)

While this data focuses on vehicle emissions, it is important to note that biogenic emissions of VOCs are also higher during summer. Elevated ozone levels can also occur in conjunction with large bushfires, as reported in the Victorian fires of 2003 and 2006 (Office of the Commissioner for Environmental Sustainability, 2008).

While there may be strong evidence that higher temperatures will lead to increases in VOC emissions and ozone levels, the magnitude of that change is difficult to determine. Modelling of future ozone levels is highly complex and subject to significant variations associated with methodological choices and modelling assumptions (Selin et al., 2009). For example, assumptions regarding future air pollution emissions, the climatic variables to include in modelling, and the selection of ozone measurement (1-, 4- or 8-hour) all impact on results. The majority of assessments for ozone assume the A2 SRES emission scenario, but fix local emissions of ozone precursors at current levels. While future ozone levels will clearly be influenced by parameters such as the number of vehicle-kilometres travelled and improved emission performance (Department of Transport and Regional Services, 2005), the objective of these models is to isolate the effect of climate change on future ozone levels.

At the time of this HIA, there were no published models of the impact of climate change on ozone levels in Perth. In the absence of such a model, consideration of modelling in other urban locations provides a useful starting point for an assessment of health impacts in Perth.

In Australia, modelling has been conducted in both Sydney and Melbourne. Cope and colleagues (2008) modelled future ozone levels in Sydney in the decades 2020-2030 and 2050-2060 and compared these levels to recorded levels from 1996-2005. Results showed a variation of -5 to +10 ppb for 1-hour ozone in 2020-2030, with the majority of changes being positive. Mostly positive increases of up to 15ppb were modelled for the decade 2050-2060. Similar results were recorded for 4-hour ozone levels. Modelling in the Port Philip region in Melbourne, indicated an increase in daily maximum 1-hour ozone levels of 4% (1.9ppm) in the decade 2025 to 2035 and a 10% (4.7ppm) increase by 2065 to 2074, compared to the baseline period of 1996 to 2005.

A modelling study of the impact of climate change on ozone levels in 50 US cities for the year 2050 reported an average increase in summertime 1-hour maximum ozone levels of 4.8ppb. The average number of days that exceeded ozone standards increased by 68% (Bell et al., 2007). Increases in 1-hour ozone, of between 0.3 and 4.3ppb, were reported across 31 urban counties in New York by the 2050s. Other US studies have reported modelled increases of up to 10ppb by 2030 in US cities (Ebi & McGregor, 2008). Despite the differences in ozone modelling results, Table 38 shows that the majority of studies have indicated small increases in ozone levels due to climate change, particularly from 2050 onwards.

Table 38 - Summary of ozone and climate change modelling

Location	SRES	Ozone Change	Source
Sydney	A2	1 hr O_3 2020-30: -5 to +10ppb (mostly +ve) 1 hr O_3 2050-60: Up to 15ppb (mostly +ve)	Cope et al. (2008)
Melbourne	A2	1 hr O_3 2025-35: 4% increase (1.9ppb) 1 hr O_3 2065-75: 10% increase (4.7ppb)	Cope et al. (2008)
50 US cities	A2	1 hrO_3 2050: +5ppb Daily Average O_3: +2.9ppb	Bell et al.(2007)
New York	A2	2050: +5ppb (average of 30 locations)	Knowlton et al. (2004)
US cities	A2	1 hrO_3 2030: +10ppb	Ebi & McGregor (2008)

Monitoring of ozone levels in the study area is undertaken at the South Lake monitoring station in Cockburn. Figure 22 shows the current National Environmental Protection Measure (NEPM) for 4-hour ozone and historical levels from 2000 to 2009. In addition, the effect of three hypothetical increases in ozone, ranging from 5 to 15 ppb, has been added. With historical levels ranging from 72 to 95% of the NEPM, adherence to standards may be threatened by climate-related increases in ozone. With no clear evidence for a health effect threshold (World Health Organisation, 2005), even increases below the NEPM will result in adverse health outcomes.

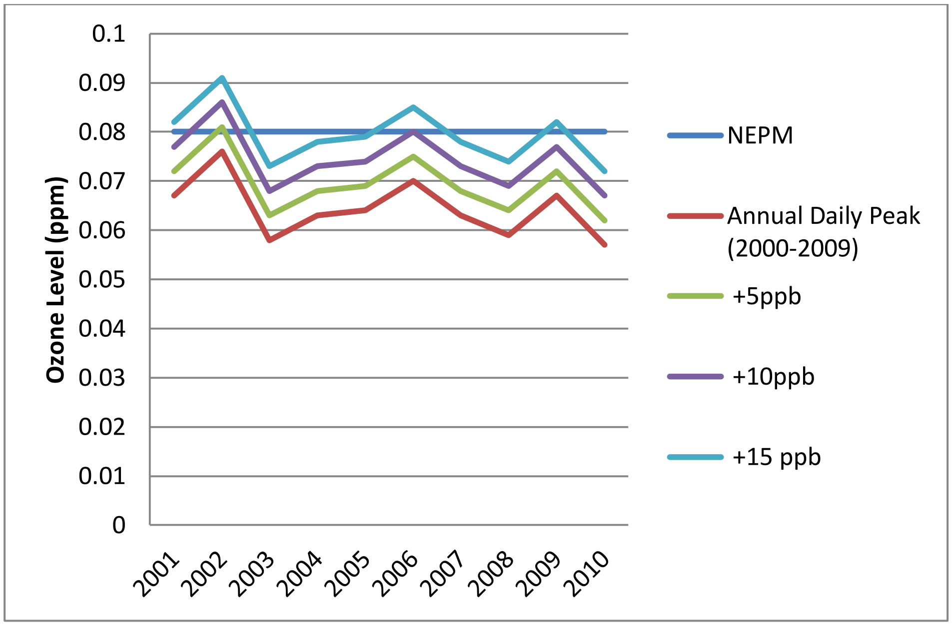

Figure 22–Potential ozone increase in comparison to NEPM at South Lake

5.4.2.1 Estimate of ozone-related health impacts

Health impacts of potential increases in ozone levels in Perth associated with climate change have been estimated using the standard approach for HIA of air pollution as developed by WHO (2006). As shown in Figure 23, information on air pollution data is combined with concentration-response functions, exposure estimates and existing health data to provide estimates of impacts associated with changes in pollutant levels. Selection of the health endpoint will depend primarily on the availability and strength of evidence, particularly concentration-response functions. If available, total-cause mortality figures are used in preference to specific cause mortality, as errors due to misclassification of death are avoided (World Health Organisation, 2006).

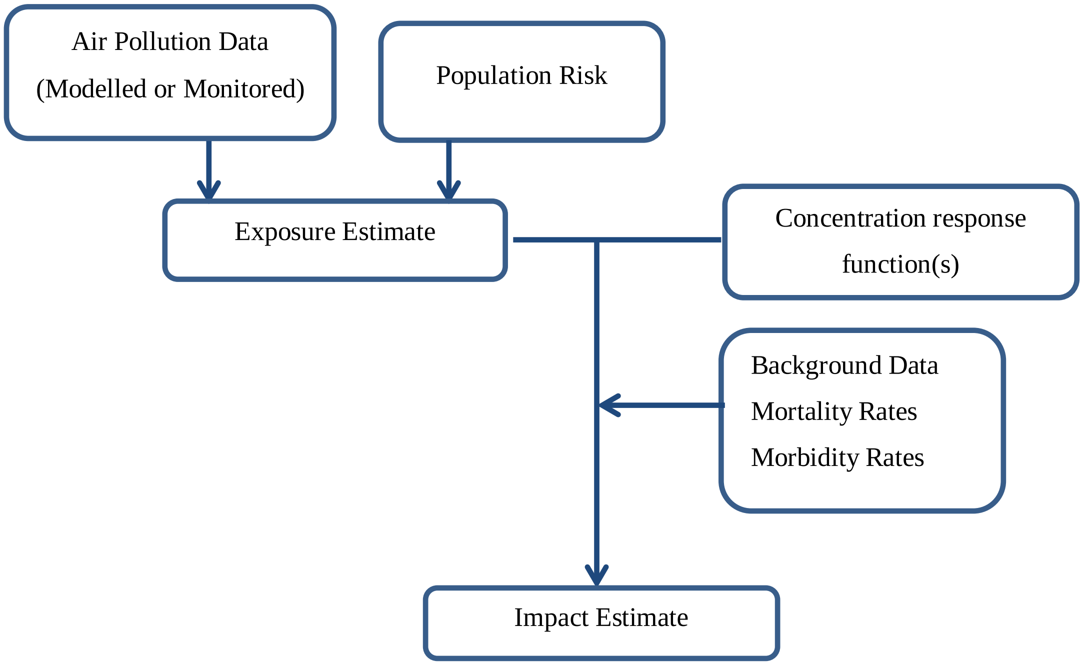

Figure 23 – Main steps of HIA for air pollutants (WHO, 2006)

The assessment assumed no threshold and a linear concentration-response relationship. This is consistent with other health assessments of ozone (Selin et al., 2009) and findings from Bell et al. (2007, p. 532), which concluded that "any mortality threshold would exit at very low concentrations, far below international ozone standards and nearing background levels." The review of Ambient Air Quality measures in Australia also reported there was insufficient evidence to define a threshold for ozone-related mortality (National Environment Protection Council, 2010).

The increase in the number of deaths is calculated according to the following equation from the WHO air quality guidelines (2006, p. 164):

E = beta × **B** × **P** × **C**, where:

- E = expected number of premature deaths due to short-term exposure (p.a.)
- beta = percentage change in mortality per 1ppb change in ozone
- B = recorded number of deaths (p.a.)
- C = change in ozone concentration (ppb)

Concentration response functions (beta) were taken from the "Expansion of the Multi-city Mortality and Morbidity" study as outlined in Chapter 2. The beta value for total-all cause mortality for all ages was a 0.1% increase in total all-cause mortality (all ages) for every 1ppb increase in 4-hour ozone (Environment Protection and Heritage Council 2010).

The all-cause mortality figures for Perth for the period 2003 to 2007 were collected during the profiling step of the HIA. The number of all-cause deaths other than accidental or external causes from 2003 to 2007 was 41,758 (8352 per annum) for the Perth metropolitan area, and 5464 (1092 per annum) for the study area. In the absence of specific ozone modelling for Perth, information from models in other locations (Table 38) was used to guide the selection of 4 possible scenarios of climate-related increases in ozone levels in Perth. Table 39 presents the expected number of annual deaths over 2003-2007 for each scenario as calculated from the above equation.

Table 39- Estimated increases in ozone-related mortality

Scenario: Ozone Increase	**Increase in total mortality (%)**	**Additional deaths (pa)**	
		Perth	**Study Area**
1ppb	0.1	8.3	1.1
5ppb	0.5	41.7	5.4
10ppb	1.0	83.5	10.9
15ppb	1.5	125.3	16.3

Calculations indicate that between 2003 and 2007 an increase of 5ppb of 1-hour ozone would be expected to result in 42 deaths per annum in Perth. The concentration-response function in the EPHC study was higher in the warmer period of November to April, so it can be assumed that the majority of these deaths will take place during those months.

The multi-city study also reported that respiratory hospital admissions for 1-4 year olds increased by 0.2% for every 1ppb increase in 4-hour ozone. The effect of a 5ppb increase in 4-hour ozone was estimated using national hospital admission data and 2006 census results (Australian Bureau of Statistics, 2010b). The average respiratory hospital admission rate for 1-4 year olds in Australian cities is 0.405 cases per day per 100 000 (Environment Protection and Heritage Council, 2010). The number of 1-4 year olds in Perth was estimated by multiplying the 0-4 year age group in the 2006 census by 0.75, for an estimate of 71,450 children aged from 1 to 4 years.

The expected number of admissions for respiratory cases in Perth for the 1-4 year age group was then estimated by applying the national admission rate. The number of expected respiratory hospital admissions in Perth during the 2003 to 2007 period was 106 admissions per year. Applying the function-response of a 0.2% increase in respiratory hospital admissions for every 1ppb, an average 5ppb increase in ozone would be expected to result in a 1% increase, or one hospital admission per year.

While the multi-city study did not report significant associations in other age groups, a number of single-city studies in Australia and international studies have reported an association between respiratory hospital admissions and other age groups. For example, a Perth study estimated a 0.3% increase in asthma hospitalisation for children aged between 0 and 14 years for every 1ppb increase in 1-hour ozone (Department of Environment, 2003).

As well as the aged, other susceptible groups include those with pre-existing respiratory conditions such as asthma and COPD. These conditions accounted for 11.3% of PPH in the study area over the period 2005 to 2009, equating to 2730 hospitalisations. Results from the Health and Wellbeing Surveillance System indicate that the current prevalence rate of asthma in the study area for people aged over 16 is 8.4% and for respiratory problems is 1.6%.

5.4.2.2 Estimated impact in 2050

The results presented in Table 39 and an adjustment for population size was used to estimate the impacts of ozone levels in Perth in 2050. Although other influences, such as an ageing population and changes in disease rates, are likely to influence future impacts, these were not considered.

As outlined in the profiling phase, the population in Perth is projected to increase to approximately 3.1 million by year 2050, while the results in Table 39 were based on a Perth population of approximately 1.5 million. Adjusting for population size, an additional 17.1 deaths is estimated for the Perth metropolitan area for every 1ppb increase in ozone in the year 2050.

Working backwards from the health consequence scales used in this research, an estimate of the increase in ozone levels expected to cause a particular level of health impact can be made. For example, the catastrophic health consequence level in 2050 is defined as more than 356 deaths per annum. At an estimated 17.1 deaths for every 1ppb increase in ozone in the year 2050, this equates to an increase in ozone of at least 20.8 ppb. Table 40 displays the increases in ozone levels that correspond to the top three health consequence levels used in this assessment.

Table 40 - Ozone scenarios and resulting consequence level (2050)

Ozone Scenario – ppb increase	Consequence Level	Number of Deaths
>20.8	Catastrophic	>356
2.1 – 20.8	Very High	>36
0.2 – 2.1	High	>4

As shown in Table 40, an increase in ozone levels of between 2.1 and 20.8 ppb would be expected to result in a consequence level of Very High. On the basis of modelling results in other cities and the clear relationship between ambient temperatures and ozone levels in Perth, the ‘Very High’ consequence level was selected as the most likely for Perth in 2050.

Table 41 summarises the risk assessment of ozone-related impacts of climate change in Perth in 2050.

Table 41- Risk assessment for ozone-related impacts of climate change in Perth 2050

Vulnerable	Aged, existing CV or respiratory conditions, diabetics, outdoor workers	
Current Data	Vulnerable groups: 13% elderly; 6.9% type 2 diabetes; 25.6% obese, 17% of BoD attributed to CV or respiratory conditions	
Future trends	Ageing population: 23% elderly by 2050 ~25% increase respiratory and CV conditions by 2030 (Goss, 2008).	
Health Consequences	**Type of Health Effect**	**Magnitude**
	Mortality	Estimate of 17.1 deaths pa/1ppb increase in O_3 →2ppb increase: 34 deaths pa →5ppb increase: 85 deaths pa →10ppb increase: 171 deaths pa
	Hospitalisations	5ppb increase: 5 asthma hospitalisations (1-4 yr)
	Affected	Limited data is available on less severe impacts. Potential impacts include asthma attacks, reduction in lung function and reduced ability to work outdoors during high ozone episodes.
	VERY HIGH (Between 36 and 360 deaths)	
Likelihood of between 36 and 356 deaths pa by 2050 → ***Equates to an increase in ozone of 2.1 - 21 ppb.***	Strong evidence for links between ozone exposure and health effects, and temperature and ozone level in Perth. No ozone modelling available for Perth, but modelling elsewhere supports that an increase of at least 2.1 ppb by 2050 is a reasonable estimate. IPCC (2007a) - high confidence in an increase in cardio-respiratory morbidity and mortality associated with ground-level ozone due to climate change.	
	LIKELY (>66%)	
RISK	**VERY HIGH**	
Confidence	**MEDIUM:** Medium agreement, medium evidence	

5.4.3 Increases in Particulate Levels and Related Health Effects

A review of information on particulate levels at South Lake indicated that all exceedances of the current NEPM for PM_{10} occurred in summer months and were associated with bushfires, controlled forestry burns or use of heavy machinery close to the monitoring site (Department of Environment and Conservation, 2010b). This information supports the link between projections for drier and hotter conditions and particulate levels in Perth. The current NEPM for PM_{10} is $50ug/m^3$ averaged over 24 hours with no more than 5 exceedances allowed per year. Although exceedances have occurred, Table 42 highlights that no year has reported more than the allowable number of five.

Table 42 - Annual daily peak PM_{10} (24 hours) at South Lake Station

Peak Measures ug/m^3	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
PM_{10}(24-hr)*	56.7	82.6	44.5	50.5	98.8	45.3	56.7	55.0	49.0	61.0
# exceedances (days)	1	2	0	1	3	0	1	1	0	4

*Exceedance of $50ug/m^3$

A monitoring and advisory reporting standard for 24-hour and annual $PM_{2.5}$ concentrations was introduced in 2003. As this is currently an advisory measure, the number of allowable exceedances has not been set. The advisory standards for $PM_{2.5}$ are:

- $25ug/m^3$ averaged over 24 hours
- $8ug/m^3$ averaged over 1 year

Monitoring data for $PM_{2.5}$ is shown in Table 43 and shows a similar pattern to PM_{10} with most years reporting a small number of exceedances. Annual average figures for $PM_{2.5}$ either exceed or are close to exceeding the advisory standard.

Table 43 - Annual $PM_{2.5}$ at South Lake Station

Measures	**2006**	**2007**	**2008**	**2009**	**2010**
$PM_{2.5}$(24-hr)	30.5	21.2	45.2	32.0	40.0
# exceedances (days)	1	0	1	3	2
$PM_{2.5}$(annual average)	8.7	7.6	7.7	8.2	8.7

*Exceedance of advisory measures

The composition of bushfire smoke is distinctly different from typical urban sources of particulates and questions remain whether this alters the relationship between exposure and health outcomes. Establishing this is particularly difficult due to the relatively short duration of exposure to particulates from bushfires that is available for analysis (Dennekamp & Abramson, 2011). Studies in Darwin, Brisbane and Sydney that investigated the health outcomes of particulates associated with bushfires reported mixed results – of six studies, half reported a significant association between bushfire smoke and health outcomes (Chen, Verrall, & Tong, 2006). The study in Brisbane by Chen and colleagues (2006) reported higher increases in respiratory hospitalisation due to particles from bushfires than non-bushfire sources.

In the absence of specific concentration-response relationships for particulates from bushfire smoke, data from urban air studies were employed. The multi-city mortality and morbidity study (Environment Protection and Heritage Council, 2010) concluded that there is substantial evidence for short- and long-term effects of exposure to PM_{10} and $PM_{2.5}$, with no evidence of a threshold. Meta-analysis of the multiple city studies showed significant increases in total mortality, cardiovascular and respiratory mortality, and hospital admissions associated with particulate levels (Table 44). The majority of increases were reported for $PM_{2.5}$ with evidence for cardiovascular outcomes particularly strong.

Table 44 -Significant concentration-response functions

Health Outcome / 1ug/m^3 PM	**PM_{10} (%)**	**$PM_{2.5}$ (%)**
Total all-cause mortality	-	0.2
Cardiovascular mortality	0.2	0.4
Respiratory mortality	-	0.6 (75+)
Cardiovascular hospital admissions	-	0.3 (65+)
Respiratory hospital admissions	0.2 (1-4) 0.3 (5-14)	0.6 (<1), 0.4 (1-4) 0.3 (15-64), 0.4 (65+)

(EPHC Multicity Study Results: specific age group in brackets)

Given the preference for all-cause mortality data (World Health Organisation, 2006), the concentration-response function of a 0.2% increase in total all-cause mortality for every 1 ug/m^3 $PM_{2.5}$ was used to estimate the impact of increased particulate levels. Because increases in particulate levels are likely to be episodic, the estimates were calculated at the daily, rather than annual level as for ozone.

The average daily number of all-cause deaths other than accidental or external causes in Perth from 2003 to 2007 was 22.9. An increase of 1ug/m^3 $PM_{2.5}$ is therefore estimated to result in an increase of 0.046 deaths per day. Applying this crude rate, the effect of increases in $PM_{2.5}$ levels on deaths per day in Perth over the 2003 -2007 period is shown in Table 45. For example an increase of 10ug/m^{3}in the 24-hour $PM_{2.5}$ level (across the entire Perth region) would be expected to result in approximately 0.5 deaths per day in Perth.

As with the ozone assessment, an adjustment for population size was made to estimate the number of additional deaths in the year 2050 due to increases in $PM_{2.5.}$ The result was that an estimated 0.95 deaths would occur per day per 10ug/m^3 increases in $PM_{2.5}$.

Table 45 - Estimated number deaths in Perth associated with increases in $PM_{2.5}$

Increase $PM_{2.5}$ (ug/m^3)	Deaths per day 2003 to 2007	Deaths per day 2050
10	0.5	0.95
20	0.9	1.9
50	2.3	4.7
100	4.6	7.1

5.4.3.1 Future particulate levels and estimated impacts

The chemistry of particulate formation is very complex and the effect of climate change on particulate levels remains uncertain (IPCC, 2012). The Australian State of the Environment report (2011, p. 143) reported that hotter, drier conditions and more extreme weather events "can be expected to increase bushfires and dust storms, leading to short-lived, very high levels of particulate pollution, which, depending on location, may affect large urban populations." Given that recent exceedances of particulates in Perth have occurred in summer months and been associated with bushfires or controlled burns, the increased risk of bushfires and continued policy of controlled burning highlight this as an area of concern.

Evidence presented to the Perth Hills Bushfire Review (Keelty, 2011) stated that the conditions suitable for prescribed burning in the south-west of WA are conducive to the formation of temperature inversions that trap smoke in and around Perth. The review acknowledged that the effects of climate change would further limit the opportunities to undertake prescribed burns, which could affect future bushfire risks. At a national level, the inquiry into Bushfire Mitigation and Management (Ellis, Kanowski, & Whelan, 2004) reported that the frequency, intensity and size of bushfires are likely to increase in Australia as a result of climate change. This inquiry concluded that more intense fires and longer prescribed burning season were likely to result in increases in smoke-related respiratory illness.

Exposure to increased levels of particulates associated with bushfires will be limited to summer when the risk of bushfires is highest or to spring and autumn when the majority of prescribed burning is conducted. Increases in particulate levels of $10ug/m^3$ are common during bushfire periods (Chen et al., 2006) and far larger increases have occurred in

Australian cities. For example, PM_{10} levels higher than 150 µg/m^3 were recorded in Sydney for a period of 10 days in 2001 (Jalaludin, Smith, O'Toole, & Leeder, 2000). Melbourne recorded 15 days with PM_{10} levels exceeding the NEPM during the 2006 bushfires, resulting in the release of health alerts (Environmental Protection Agency Victoria, 2007). Reports of specific particulate levels resulting from prescribed burns are limited, although peak concentrations of 120 and 90ug/m^3 were reported in the Perth metropolitan in 1995 as a result of prescribed burns (Leslie & Speer, 1998). Potential health impacts of prescribed burns need to be balanced against the reduced risk of major bushfires.

In the absence of any published particulate modelling, two scenarios based on $PM_{2.5}$ levels recorded during bushfires have been used to provide a crude estimate of the number of deaths that could occur as a result of higher particulate levels. In each case, the assumption has been made that the increased levels occur across the entire Perth air-shed. The first scenario is based on $PM_{2.5}$ levels shown in Figure 24, recorded at South Lake station during a bushfire that broke out in the south-west of WA on the 9th February, 2012. The graph was downloaded from the Department of Environment and Conservation (DEC) air quality site (http://www.dec.wa.gov.au/pollution-prevention/air-quality.html). Each horizontal line represents an increase of 5ug/m^3 and the black dotted line represents a background level of 10ug/m^3.

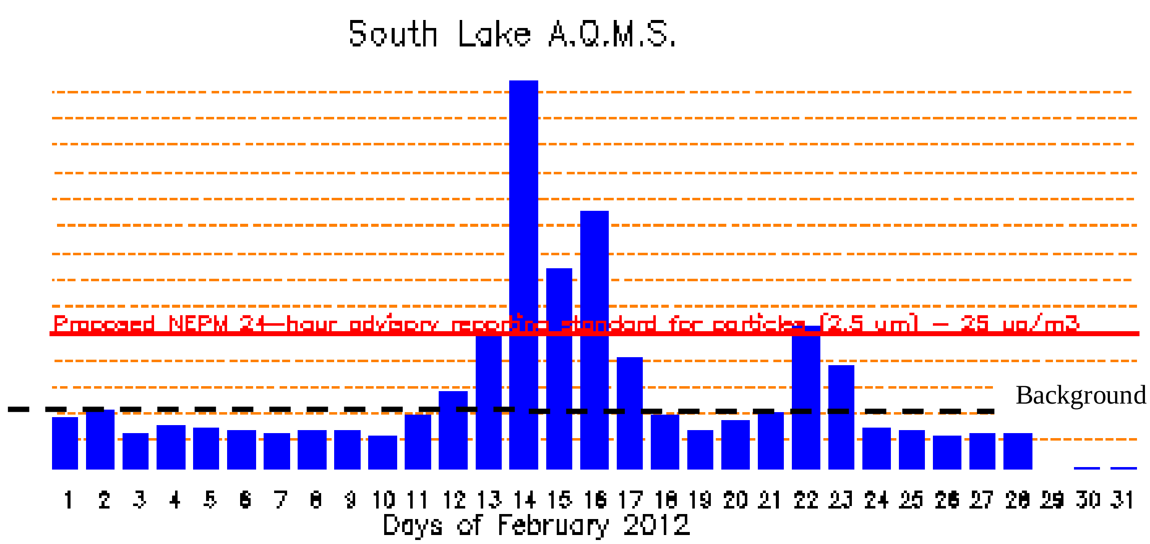

Figure 24– $PM_{2.5}$ levels during a bushfire in the South West of WA

The increase in $PM_{2.5}$ levels during February and the figures from Table 43 were used to provide an estimate for the number of deaths that would be expected in Perth in 2050 under this scenario. As shown in Table 46, approximately 17 deaths would be expected to occur in Perth as a result of this exposure.

Table 46 - Scenario 1: Based on particulate levels shown in Figure 24

$PM_{2.5}$ above baseline	Days	Deaths (2050)
5	1	0.5
10	2	1.9
15	2	2.8
25	1	2.4
35	1	3.3
60	1	5.7
Total	8	16.6

The second scenario assumes $PM_{2.5}$ levels similar to those recorded in Melbourne during the 2006/2007 bushfires. These levels are significantly higher than Scenario 1, but are nevertheless feasible, and may be considered as a worst-case scenario in the future. Figure 25 (Dennekamp, 2011), highlights PM_{10} and $PM_{2.5}$ levels recorded at the EPA monitoring station in Alphington.

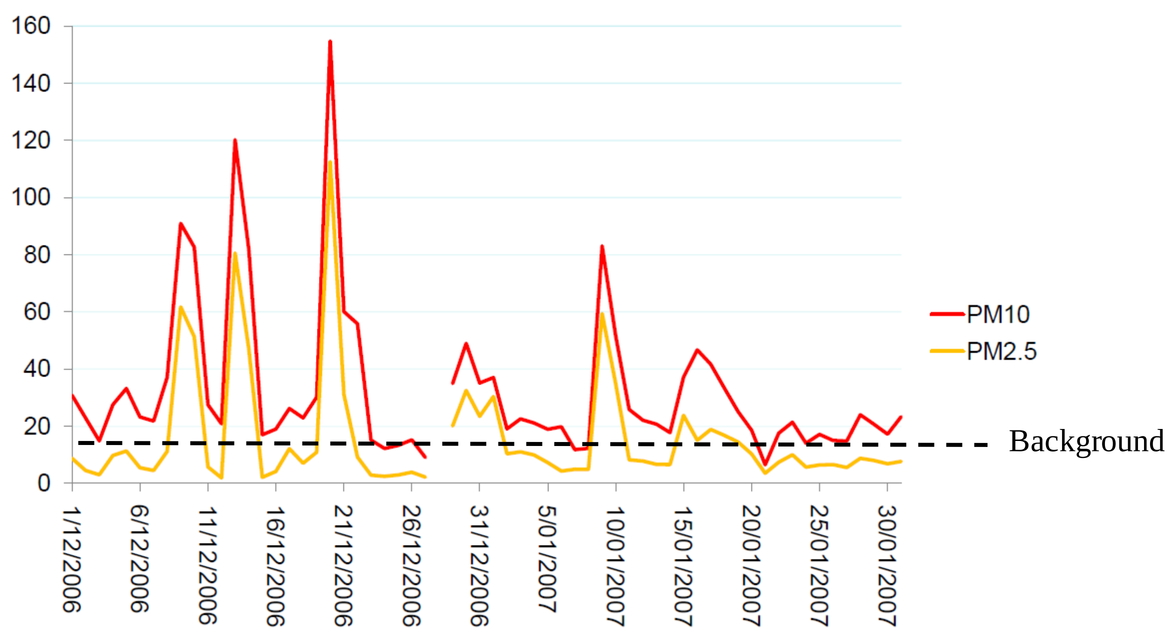

Figure 25 - PM levels associated with bushfire smoke in Melbourne

An estimate of the $PM_{2.5}$ levels was taken directly from Figure 25. The period from the 1st of December to the 30th of January included a total of 16 days over the background figure of 10ug/m^3. These increases are recorded in Table 47 and were used to calculate the number of expected deaths in Perth 2050 if the entire population were exposed. As with first scenario, the number of deaths was estimated using the figures from Table 45. Under this scenario, an additional 43 deaths are expected in 2050 (Table 47).

Table 47 - Scenario 2– Based on particulate levels shown in Figure 25

Increase $PM_{2.5}$ (ug/m^3)	**# Days**	**# deaths**
5 to 10	6	4.3
11 to 50	7	17.7
51 to 100	2	11.6
>100	1	9.6
Total	**16 days**	**43 deaths**

In addition to possible increases in particulates due to bushfires, the literature suggests that increases in dust particles may occur as a result of a hotter and drier climate (Department of Environment, 2011). The extent of this potential increase is highly uncertain and no published evidence could be found to support any reasonable estimate. This potential impact has therefore not been considered in the risk assessment in Table 48.

Table 48 - Risk assessment for particulate effects related to climate change in Perth 2050

Vulnerable	Aged, Existing CV or respiratory conditions, diabetics, outdoor workers	
Current Data	Vulnerable groups: 13% elderly; 6.9% type-2 diabetes; 25.6% obese. 17% of BoD attributed to CV or respiratory conditions	
Future trends	Ageing population: 23% elderly by 2050 Increase respiratory and CV conditions projected by 2030 (Goss, 2008).	
Health Consequences	**Health Effect**	**Magnitude**
	Mortality	12 deaths for 1 additional instance of Scenario 1 32 deaths for 1 additional instances of Scenario 2
	Hospitalisations	Increase in respiratory hospital admission for most age groups. Limitations in access to age-specific rates precluded a quantitative assessment.
	Affected	Limited data available. Health alerts recommend that people avoid physical activity outdoors, particularly people with heart or lung conditions, children and older adults.
	HIGH (Between 4 and 36 deaths in the year 2050)	
Likelihood of between 4 and 36 deaths pa in 2050	Increased risk of bushfires is acknowledged. High particulate levels in Perth are typically associated with bushfires or prescribed burns. Evidence for mortality and morbidity effects of particulate exposure is strong, with no evidence of a threshold. There is no modelling to translate increased risk of fires to future particulate levels. Using the above scenarios, the likelihood of between 4 and 36 deaths pa in 2050, translates to: One additional instance of Scenario 1 every 3rd year or; One additional instance of Scenario 2 every 8th year.	
	ABOUT AS LIKELY AS NOT (>33%)	
RISK	**MEDIUM**	
Confidence	**MEDIUM** - Medium evidence, low agreement	

5.4.4 Aero-allergens

Australia has high rates of asthma that contribute substantially to the burden of disease. The impact is particularly high in children under the age of 14, where asthma is the top contributor to the burden of disease in Perth. Deaths are relatively uncommon, with latest figures indicating 1.4 deaths per 100 000 people in WA (Australian Centre for Asthma Monitoring, 2011). This is reflected by the burden of disease data that indicates 94% of the asthma burden is due to disability. Research in Australia has indicated that a relatively high percentage of adult asthmatics report poor life satisfaction, poor health status, high psychological distress, and reduced activity days (Ampon, Williamson, Correll, & Marks, 2005). While hospitalisation rates among asthmatics are relatively low, they account for 0.45% of all hospital separations in Australia (Australian Centre for Asthma Monitoring, 2011).

While the rationale that changes in temperature, rainfall and carbon dioxide levels will affect pollen and other aero-allergens is sound, there is currently a lack of evidence regarding the nature and extent of this influence. Researchers in the field have highlighted the need for improvements in monitoring and forecasting of aeroallergens. As indicated in Table 49, the current level of knowledge does not enable a quantitative estimate of the health consequences that may occur as a result of climate change.

Table 49 -Risk assessment for aero-allergens related to climate change in Perth 2050

Vulnerable	Asthmatics, Existing respiratory conditions Significant vulnerable population with approximately 10% of the population reported as asthmatic.	
Current Data	Asthma – 8th highest cause of BoD for all ages and highest cause of BoD for 0-14 years. 9th highest cause of PPH in study area (4.3%) 8.4% of population (aged>16) reported current asthma	
Future trends	Future air pollutant levels, which also have an impact on asthma, will be influenced by increasing urbanisation and possible improvements in emissions technology.	
Health Consequences	**Health Effect**	**Magnitude**
	Mortality	No estimate possible, but deaths are relatively uncommon.
	Hospitalisations	No estimate possible, but asthma accounts for 0.4% of all hospitalisations in Australia (AIHW, 2013).
	Affected	No estimate possible. Asthma is associated with poorer quality of life, increased days of work or school and significant financial expense (AIHW, 2013).
	Insufficient evidence to estimate magnitude of any health consequences.	
Likelihood	No consequence rating on which to base likelihood.	
RISK	**Insufficient Evidence to Determine**	
Confidence	**LOW** - Limited Evidence, Medium Agreement	

5.4.5 Food-Borne Diseases

Gastroenteritis and dehydration is the 7th highest cause of PPH in the study area and accounts for 6.1% of all hospitalisations. It has been estimated that approximately one third of gastroenteritis cases in Australia are associated with food-borne gastroenteritis (Hall et al. 2005). Some of these cases are likely to be affected by increases in temperature and extreme weather events. Quantitative assessments of the effect of climate change on food quality have focused on the effect on *Salmonella*, as notifications have a well-established relationship with temperature. The relationship in Perth is a 4.1% increase in notifications of Salmonellosis for every 1°C increase in ambient temperature (D'Souza et al., 2004).

Enteric disease notifications in the study area report that 23% of notifications are due to *Salmonella*. Using notifications of Salmonellosis from 2005 to 2009, the estimated increase in the number of notifications in Perth for temperature increases between 1 and 4^{o}C is shown in Table 50. For every 1°C increase in temperature, an additional 26 notifications per annum of Salmonella gastroenteritis would have been likely to occur in Perth over the years 2005 to 2009.

Table 50 - Estimated temperature-related increases in Salmonellosis

Temperature Increase (°C)	Perth (2005-2009)		Study area (2005-2009)	
	# notifications	pa	# notifications	pa
1	132.0	26.4	16	3.3
2	263.9	52.8	33	6.6
3	395.9	79.2	49	9.8
4	527.9	105.6	66	13.1

Under-reporting of enteric diseases is common and it is estimated that the number of cases of gastroenteritis in Australia is approximately seven times higher than the number of notified cases (Hall et al., 2002, 2005). Taking into account an under-reporting factor of seven, an increase of approximately 185 cases per annum of *Salmonella* gastroenteritis would be expected to occur in Perth for every 1°C increase in temperature.

Table 51 shows that on the basis of population changes alone (no climate change), notifications of Salmonellosis are expected to increase by 687 cases per annum in Perth by the year 2050. Applying the temperature-notification relationship described by D'Souza et al. (2004), every 1°C increase in temperature is estimated to result in an additional 54 notified cases of Salmonellosis in Perth in 2050. The final column of Table 51 shows the number of additional cases assuming an under-reporting factor of seven. These results indicate that, without further adaptation strategies, a 2°C increase in ambient temperature in Perth in 2050 would be expected to result in an additional 109 reported cases or 763 total cases of Salmonellosis. This represents a 16% increase in the estimated baseline figure.

Table 51 - Estimated increases in Salmonellosis in Perth 2050 compared to 2007

Temp Increase (°C)	**2050**	
0	**Baseline: 687**	
	Extra Notifications	**Under-reporting Factor**
1	54	378
2	109	763
3	164	1148

Previous projections of the impact of climate change on Salmonellosis in Australian states have been published by Bambrick et al (2008) using similar methods. The number of additional cases in WA in 2050 ranged from 41 to 70 additional cases per annum, depending on the climate change scenario. The assessment also undertook crude estimates of the possible impact of climate change on bacterial gastroenteritis in WA. Estimates were based on the excess of summer notifications and population increases (Bambrick et al., 2008). The additional number of cases of all bacterial gastroenteritis in WA for 2050 ranged from 15,000 to 25,000 cases per annum.

The reported consequences of food-borne cases of gastroenteritis in Australia (Abelson, Forbes & Hall, 2006) have been applied to two possible outcomes, as described previously. The first is based on the total number of extra cases of Salmonellosis estimated for 2°C increase in ambient temperature and described in Table 50. The second is a mid-range estimate of 20,000 additional cases of bacterial gastroenteritis in WA, taken from the previously published assessment by Bambrick et al (2008).

Table 52 indicates that an additional 763 cases of Salmonellosis would result in zero deaths, two hospitalisations per year, approximately two hundred GP visits and over 800 days of lost work. The significantly higher estimate of 20,000 cases of bacterial gastroenteritis resulted in an estimate of zero deaths, 56 hospitalisations and over 21,000 days of lost work. Assuming the 20,000 cases are reported in different individuals, it is estimated that 0.65% of the population in 2050 will be adversely affected by bacterial gastroenteritis as a consequence of climate change.

Table 52 – Estimate of gastroenteritis effects of climate change in Perth 2050

Baseline data	Annual cases	# deaths	Hospital Admissions	GP visits	Days lost work
Food-borne gastroenteritis	5.4 million	80	15000	1.4 million	5.8 million
Perth Projections 2050					
Salmonellosis	763	nil	2.0	198	819
Bacterial gastroenteritis	20,000	0.3	56	5185	21,480

These risk assessment results for food-borne diseases are summarised in Table 53.

Table 53 - Risk assessment for food-borne diseases related to climate change in Perth 2050

Vulnerable Groups	Very young, elderly	
Perth Data (current)	Gastroenteritis is the 6th highest cause of PPH (6.1%) –one third of these cases are related to food-borne diseases. 23.5% of enteric disease notifications caused by *Salmonella*	
Future Trends	Proportion of elderly group projected to increase.	
Health Consequences	**Health Effect**	**Magnitude**
	Mortality	Deaths in Australia are rare
	Hospitalisations	Salmonellosis - increase of two PPH Bacterial gastroenteritis - increase of 56 PPH
	Affected	Vomiting, diarrhoea and abdominal cramps with typical recovery within 2-5 days. Salmonellosis: 763 additional cases, 198 GP visits and 820 days work lost. Bacterial gastroenteritis: 20,000 cases, 5000 GP visits and 21,500 days work lost
	Salmonellosis: <3 hospitalisations and <3100 affected = **LOW** Bacterial Gastroenteritis: >34 hospitalisations and >3100 affected = **MEDIUM**	
Likelihood	Relationship between ambient temperature and notification of Salmonellosis is well-established. Consistent evidence for relationship between temperature and excess notifications for bacterial pathogens, but relationship is more complex	
	Salmonellosis: **VERY LIKELY**: >90% Bacterial Gastroenteritis: **LIKELY** >66%	
RISK	Salmonellosis: **MEDIUM** Bacterial Gastroenteritis: **MEDIUM**	
CONFIDENCE	**HIGH** - High Evidence and Agreement (for Salmonellosis) **LOW** - Medium Evidence and Low Agreement (Bacterial)	

5.4.6 Ross River Virus and Barmah Forest Virus

The previous HIA of climate change in WA concluded that changes to extreme events, ambient temperature, rainfall and sea-level increase would affect the ecological cycles of vector borne diseases in WA. Given the range of climate-related variables that can influence transmission cycles of VBDs, it was concluded that changes to these variables are likely to result in a combination of increases and decreases to the activity of VBDs (Spickett, Brown & Katscherian, 2007).

The health effects of RRV and BFV are similar and include painful and/or swollen joints, sore muscles, aching tendons, skin rashes, fever, tiredness, headaches and swollen lymph nodes. Symptoms typically persist for two to six weeks, but can persist for three months or longer, particularly for RRV. In these cases the effects on quality of life can be quite debilitating.

The environmental conditions that influence RRV and BFV activity are discussed in the WA Department of Health Mosquito Management Manual (Lindsay, 2009) and are summarised below:

- Rainfall - the biggest threat of RRV activity in WA follows heavy rains. This is in line with a national review of environmental precursors of outbreaks of RRV around Australia between 1896 and 1998 that found rainfall to be the single most important risk factor (Kelly-Hope, Purdie & Kay, 2004).
- Temperature – high temperatures can shorten the life span of mosquitoes and increase evaporation of water in potential breeding sites, thereby reducing activity. Temperature can also play a role by influencing patterns of human activity and therefore exposure to infected mosquitoes. Temperature also influences the rate of replication (extrinsic incubation) of arboviruses in the mosquito vector.
- Tides – high tides can lead to increases in breeding sites on saltmarshes or wetlands.
- Extreme weather events – each of the three variables above can be influenced by extreme weather events. Evidence also suggests that while drought conditions lead to reduced RRV activity, the period following a drought can lead to dramatic increases in activity due to increases in the level of non-immune vertebrate hosts.

With respect to the RRV cases reported in Perth, investigations show that many of these were acquired from infected mosquitoes outside Perth. Nevertheless, significant outbreaks of RRV have occurred in Perth, demonstrating the potential for similar occurrences in the future. BFV has also been isolated from mosquitoes in southern suburbs of Perth.

In addition to changes in climatic variables over the coming decades, human activities are also likely to play a major role in determining the level of RRV and BFV activity in Perth. The projected doubling of the population by the 2050s will undoubtedly result in significant changes to land-use that affect the proximity of people to mosquito breeding sites and the creation of new breeding sites in built environments.

In summary, the conclusion reached is that there is insufficient evidence to make a quantitative estimate of the health consequences associated with the effect of climate change on RRV or BFV, in Perth for the year 2050. However, it is apparent that a changing climate and human adaptation to such change will impact on transmission of mosquito-borne diseases such as RRV and BFV. Therefore it will be important that surveillance and management strategies for these arboviruses are maintained.

Table 54 - Risk assessment for vector-borne diseases related to climate change in Perth 2050

Risk Assessment for Vector-Borne Diseases in Perth, 2050		
Vulnerable Groups	No particular age group. Those more likely to be exposed.	
Perth Data (current)	RRV – 2.9% of communicable diseases, average 381 cases pa in Perth. Large outbreaks of RRV in South-West occur every few years, with transmission spreading to mostly outer metropolitan areas (including City of Cockburn) BFV – 0.6% of communicable diseases, with 84 cases pa in Perth.	
Future Trends	Complex ecology makes estimate of future trends difficult. RRV and BFV activity can be affected multiple climatic variables. In addition to climate change, changes to land-use patterns, particularly proximity of residential developments to breeding sites, are likely to influence future activity.	
Health Consequences	**Health Effect**	**Magnitude**
	Mortality	Nil. RRV and BFV are non-fatal.
	Hospitalisations	No reports of hospitalisation due to RRV or BFV were found.
	Affected	Painful swollen joints, sore muscles, skin rashes, fever, tiredness, headaches and swollen lymph nodes. Persistent symptoms can result in significant reductions in quality of life.
	Insufficient evidence to estimate magnitude of health consequences.	
Likelihood	The likelihood of any particular health consequence is unable to be determined at this stage.	
RISK	**Insufficient Evidence to Determine**	
Confidence	**VERY LOW** - Limited Evidence, Low Agreement	

5.4.7 Summary of Risk Assessment Results

The risk assessment step of the HIA scrutinised the available evidence with respect to the scales presented in Chapter 4. The results of this process are summarised in Table 55. As a result of the risk assessment findings, an additional risk category 'insufficient evidence for assessment' has been added.

The risk assessment concluded that the highest level of health risk to the residents of Perth in 2050 associated with climate change was 'Extreme' for heat-related impacts, followed by 'Very High' for ozone. The level of risk for particulates and food-borne diseases (Salmonellosis and bacterial gastroenteritis) was medium. It was not possible, on the basis of current evidence, to estimate the level of risk associated with changes in aero-allergens or RRV and BFV activity.

Table 55 - Summary of Risk Assessment Results

Risk Level Legend						
Very Low	Low	Medium	**High**	Very High	**Extreme**	**Unknown**

Likelihood	***Consequences***				
	Low	***Medium***	***High***	***Very High***	***Catastrophic***
Very Unlikely					
Unlikely					
About as likely as not			Particulates		
Likely		Bacterial Gastroenteritis		Ozone	
Very Likely	Salmonellosis			**Heat-related**	
Insufficient Evidence	RRV, BFV Aero-Allergens				

5.5 Discussion of risk assessment scales

The scales developed as part of this research provided a useful framework to assess the range of potential effects of climate change on health and well-being. In addition, the introduction of a quantitative health consequence scale, highlighted several important points which will be discussed below.

5.5.1 Health consequences

The clear set of numerical guidelines used in this HIA reduced the ambiguity that can result from descriptive scales. When quantitative estimates are available, the scales will enhance the ability of assessors to rank consequences according to well-defined criteria. The application of these scales suggests that at this time, order of magnitude scales are more appropriate than more precise, linear scales. For several health impacts even an order of magnitude estimate was not possible with current evidence. This finding can help to inform a consideration of future research needs.

Assessment of health impacts of climate change are clearly influenced by the climate change scenario(s) applied. The advantage of the order of magnitude scales is that differences in estimates of health impacts due to different scenarios are often significantly less than an order of magnitude. In effect, the order of magnitude scales help to 'capture' some of the inherent uncertainties that exist in any climate change assessment. This is particularly so for assessments that are aimed at time periods around the middle of the century, when the divergence between different emission scenarios is less pronounced. If confidence in data improves over time, the order of magnitude scales can be amended to give a more precise measure of risk that can distinguish between health impacts of different scenarios.

The ability to interpret and compile this data with reference to the health consequence scales was particularly useful. In addition, the three levels of health metrics encouraged a range of health effects to be considered. The results highlighted that most assessments focus on measures of mortality and hospitalisations. While this is understandable in terms of data collection, the three metrics serve as a reminder that impacts should be considered across all levels. This may prove particularly important in countries such as Australia, where high adaptive capacity and strong health-care systems may lead to relatively few severe impacts such as death and hospitalisations. If risk assessments focus primarily on these metrics, other less severe impacts that nevertheless have the potential to impact significantly on health and well-being may be overlooked, and ultimately risks underestimated.

The issue of interpretation also extends to the definitions of health consequences used in this assessment. In reality, there is no ‘right or wrong’ boundary, as any assessment of risk requires value judgements regarding the acceptability of outcomes. If the scales provide a reasonable judgement of risk, they are a valuable tool to assess, compare and combine risk across time and space. In terms of risk management, this information is critical. Because the health consequence scales are normalised against population and health data, they can be applied to other locations and time periods. For example, if background demographic and health data are available, the scales can be applied to other Australian cities, and combined to form a national assessment or expanded to other countries.

Figure 26 demonstrates how the health consequence scales can be used to direct future HIAs of climate change. Three climate-related health hazards in Perth and Brisbane have been provided as examples – the complete framework would address other impacts and could be applied to other populations of at least 1 million. The health consequence rankings provided are hypothetical but help to demonstrate the principle of the framework. For example, the pyramid referring to flooding in Brisbane indicates that a HIA of climate change assessed the number of fatalities as a moderate consequence, the estimated number of hospitalisations as a very high consequence and the less severe consequences as a high consequence.

The framework provides a simple visual method of aggregating information, identifying gaps in current knowledge and communicating potential health consequences. The framework can also be used to develop systematic research programs that address knowledge gaps and prioritise adaptation efforts.

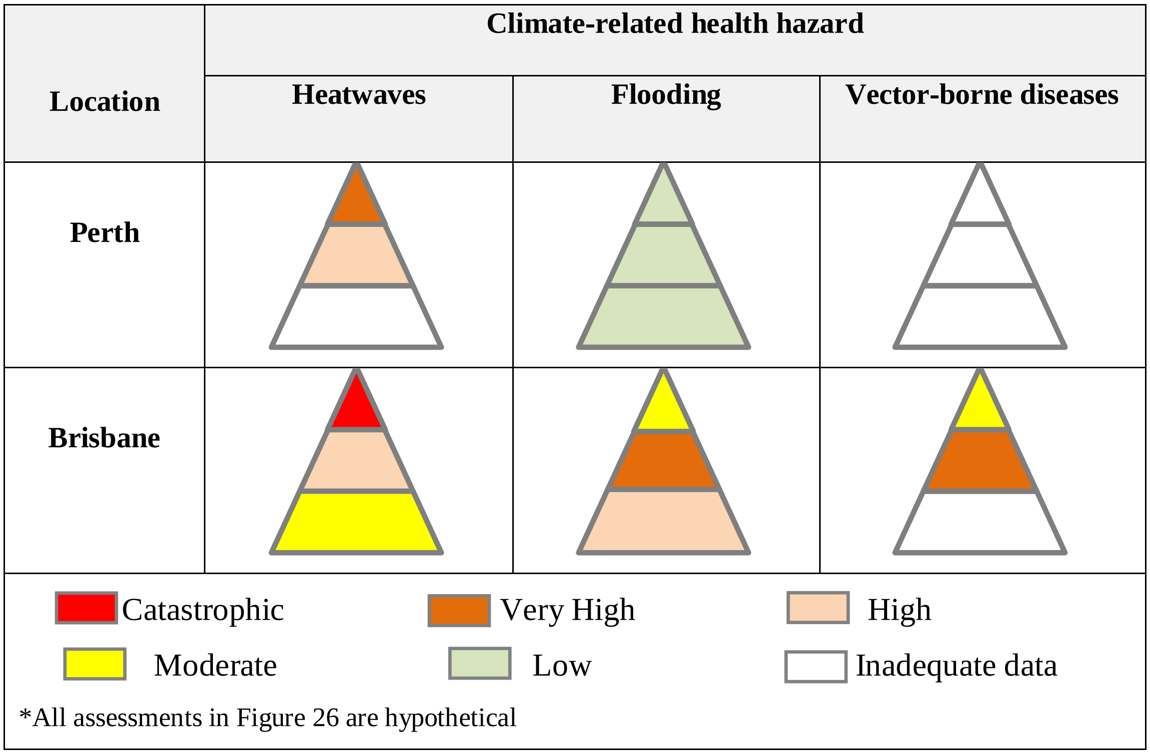

Figure 26 - Framework for assessing health consequences of climate change

In summary, it was concluded that order of magnitude health consequence scales achieve an appropriate balance between the current status of knowledge and providing useful information to key decision-makers.

5.5.2 Likelihood of health outcome

Given the intrinsic level of uncertainty associated with estimating health impacts well into the future, determining the likelihood of specific climate change impacts is particularly challenging. The use of order of magnitude health consequences helped to address this challenge. For example, the likelihood decision for the ozone assessment was centred on the question 'what is the likelihood that in the year 2050, increases in ozone levels caused by climate change, will be between 2.1ppb and 21ppb?' Although the answer to this question was considered by assessing modelling in other locations, the majority of assessments fell within this range. If health consequences had been defined in narrow terms a judgement of likelihood would be difficult. On the contrary, likelihoods that are based on very broad health-related outcomes such as 'ozone levels are likely to increase' have limited usefulness.

5.5.3 Further development of scales

Further development of the scales will be influenced by the quality and reliability of the data used to assess health consequences and likelihoods. At this stage the order of magnitude estimates for health consequences and the likelihood scales developed by the IPCC are considered commensurate with the current level of knowledge.

The process highlighted that the current scales may tend to underestimate some health effects, particularly those not requiring hospitalisation. For example, while RRV can be a ‘debilitating illness’ it is not fatal and results in very few hospitalisations. The current scale equates one hospitalisation with approximately 1000 cases of RRV. On face value, this appears to be an underestimation of the true health impacts of RRV. It may therefore be appropriate to develop an additional health metric by dividing the ‘affected’ variable into two broad categories of health outcomes, based on level of severity.

Effective scales need to provide a balance between accuracy, practicality and the ability to provide information that can communicate risk and inform decision-making. It is proposed that the scales developed and trialled in this research provide a solid foundation for future assessments of health impacts of climate change.

5.6 Conclusion - Progression to Part II

The completion of Part I of the study has provided important new information regarding the potential health impacts of climate change in Perth. The scoping phase highlighted key differences between the anticipated health impacts in Perth compared to the state. Evidence collected during the profiling step indicated that a significant proportion of health outcomes in Perth have links to climate. The assessment of potential impacts of climate change was assisted by the development of quantitative risk assessment scales. The conclusion of the assessment was that heat-related health impacts pose the highest level of risk associated with climate change for Perth in 2050. This was followed by ozone-related health impacts.

Figure 27 summarises the health impact pathways considered during Part I of the research. The dotted links highlight the high level of uncertainty regarding the impact of climate change on allergens and VBDs that precluded an assessment of risk. The timeline identifies important factors that are likely to influence health outcomes in Perth between now and

2050. Finally, the two highest levels of risk, health impacts associated with heat and ozone, are highlighted in yellow. As explained in Chapter 2, exposure to high temperatures and high ozone levels often occur concurrently and share similarities, both in terms of health outcomes and sensitive groups.

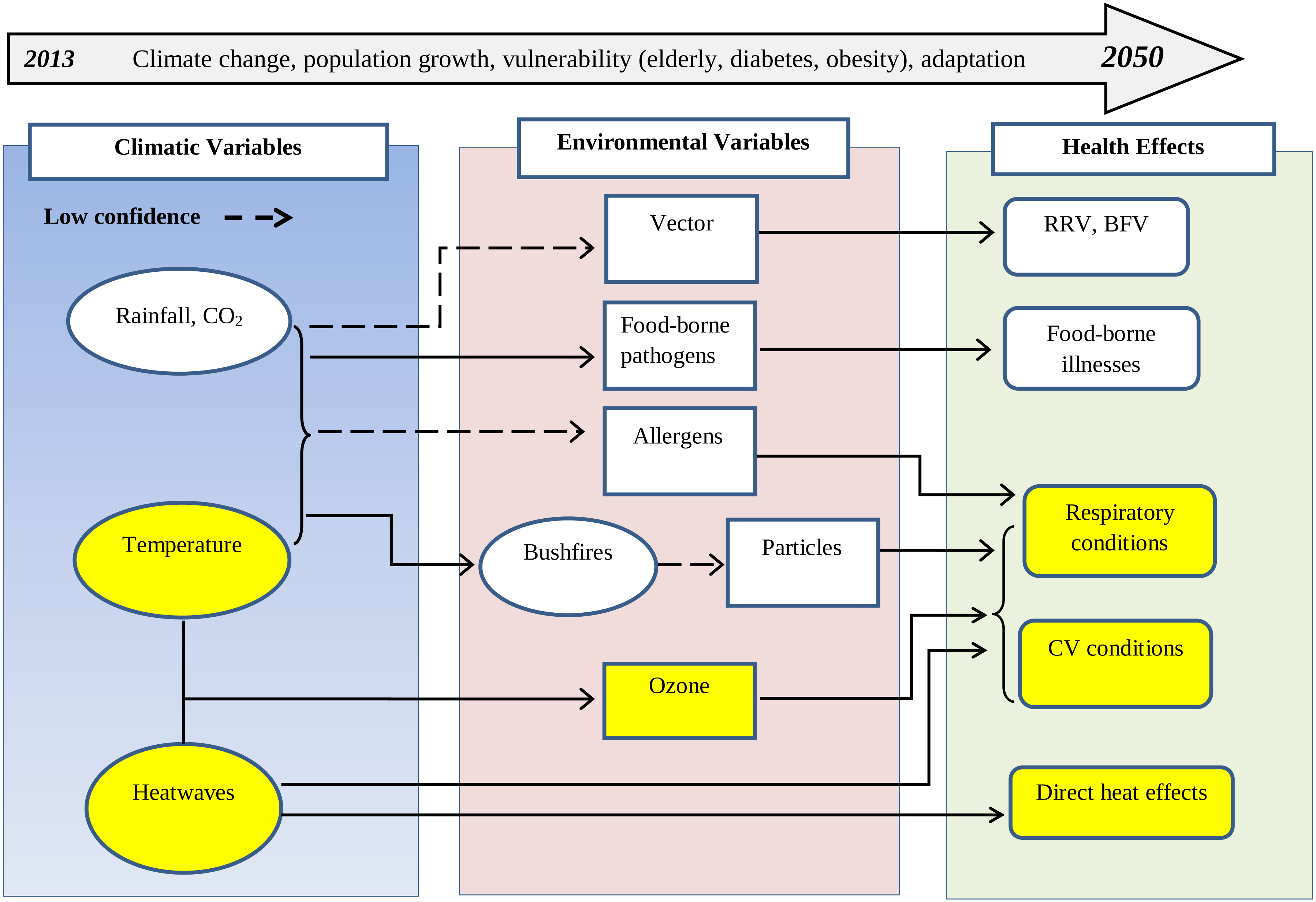

Figure 27 –Summary of health impact pathways

The immediate focus for Part II of the research was narrowed to the direct health impacts related to heatwaves and high ambient temperature. This was undertaken as part of the progression from the risk assessment step of HIA to the subsequent steps of risk management and decision-making. In a diversion from traditional HIAs, a systems approach, specifically Collaborative Conceptual Modelling, was implemented.

Part II – A Case Study of Systems Approaches in HIA

Preface

The risk assessment step of the HIA concluded that the highest level of risk to public health associated with climate change in the year 2050 in Perth will be impacts associated with exposure to heat, followed by ozone.

Vulnerability to the effects of climate change is a function of three main elements - exposure, sensitivity and adaptive capacity (IPCC, 2001). A combination of strategies that addresses each of these elements is likely to be more effective than strategies that do not encompass all three. Reducing vulnerability to heatwaves in Perth has focused primarily on increasing adaptive capacity via the development of the emergency response plan entitled “WESTPLAN heatwave” (Department of Health, 2012).

Part II complements these measures by focusing on the element of exposure. Exposure to heat and ozone at levels injurious to health often occurs concurrently, and is strongly influenced by ambient temperature. This highlights that, while assessments may be conducted separately, the impacts related to different hazards often result in simultaneous and sometimes synergistic effects that, in reality, are difficult to separate.

For the purposes of this study, exposure will be defined as summer ambient temperatures across the Perth urban area. Any subsequent alteration of temperature, such as air-conditioning, is a response to the primary exposure and is therefore considered as part of adaptive capacity.

In the long run, climate change mitigation will clearly be an important determinant of exposure to higher ambient temperatures. However, exposure in both the short and long term will also be influenced by local factors. The ability to manipulate these local factors provides an opportunity to reduce the adverse health effects associated with higher temperatures. An adaptive response that focuses on reducing ambient temperatures has several advantages. It is clearly preventive in nature and the benefits are not limited to heatwaves as is the case for emergency response plans. As discussed in Part I, health impacts associated with heat are typically estimated on the basis of increases in temperature above a certain threshold, and are not limited to heatwave periods. Evidently, any adverse health impact that is associated with higher ambient temperatures, such as ozone-related health effects or food-borne diseases, may benefit from measures that result in reductions in summer temperature.

While the issue of exposure to heat in urban environments has clear implications for the health sector, the opportunity to affect exposure, particularly at a city-wide level, is likely to fall within the jurisdiction of other sectors such as planning, development and the environment. The perspective and understanding of the issue will vary significantly between and within each sector. If policy and management decisions are made without awareness and understanding of these perceptions, the intended outcomes of those decisions are unlikely to be achieved.

This will be addressed in Part II by the introduction of systems approaches to the risk management step of HIA. The aim of Part II is to develop a case study that utilizes systems approaches to develop adaptation strategies that reduce the risk to health associated with exposure to high ambient temperatures in Perth.

Part II consists of the following chapters:

- Chapter 6 introduces fundamental concepts and tools of systems approaches. It outlines Collaborative Conceptual Modelling that is applied in Part II of the research.
- Chapter7 presents and discusses the results from Phase I of CCM
- Chapter 8 – presents and discusses the results from Phase II of CCM.

Chapter 6 - Part II Methods

6.1 Introduction

Addressing the issue of exposure to heat in urban environments demands a study of how cities function. The interaction between the physical, economic and social components of cities, and the resulting outcomes, is a classic example of a complex system. Well-known studies on the complexity of cities include Forrester's study of urban dynamics (1969) and Boyden's human ecology study of Hong Kong (1981).

The most fundamental requirement of managing complex systems is an understanding of the dynamic behaviour of the system. This chapter will introduce systems approaches that are designed to do just that. An overview of the overarching principles of systems approaches will be followed by a discussion of the commonly used system tools. The chapter will conclude with an outline of Collaborative Conceptual Modelling (CCM) which is the systems approach used in this study (Newell & Proust, 2012).

6.2 Systems concepts

The key characteristic of complex systems is that the behaviour of the system is determined by a network of circular feedback effects between individual components of the system (Checkland & Scholes, 1999). This network of feedback effects means that if one variable in the system is changed a range of outcomes, both intended and unintended, will occur (Meadows, 2008; Sterman, 2000). In particular, some of these changes can amplify or dampen the original change, and so lead to unwanted practices and policy effects (Meadows, 2008; Sterman, 2000).

Understanding the range of potential outcomes of actions in complex systems is generally beyond the limit of an individual's cognitive ability (Forrester, 2007; Meadows, 2008; Senge, 2006; Sterman, 2000). Because of this, complex problems are often managed through a silo approach where various experts look at the 'parts' of the system and design solutions or policies to address problems that they see in their area of interest. While short-term success may be achieved, the failure to take into account the feedback effects can ultimately lead to ineffective or counterproductive outcomes (Checkland & Scholes, 1999; Senge, 2006).

Systems approaches aim to support understanding and decision-making in complex systems. Systems thinking (Checkland, 1994; Senge, 2006), and system dynamics (Forrester, 1969; Sterman, 2000) are approaches that use a range of conceptual and analytical methods designed to increase understanding of the dynamic behaviour of complex systems.

6.2.1 Causal links

The first step in understanding the behaviour of any complex system is an understanding of the links between different variables. Figure 28 contains four models, each containing variables represented by X and Y, that can increase or decrease. The direction of the arrow indicates the direction of the effect, so in each of these cases X is affecting Y. Figure 28(1), the simplest of the models, indicates only that X influences Y in some way. The next two models introduce the concept of polarity, which refers to the direction of influence that one variable has on another. There are two types of polarity – positive and negative. Positive polarity is represented by a plus sign, as shown in Figure 28(2), and indicates that as the value of X changes, this causes a change in the value of Y in the *same* direction. In other words, if X increases, Y increases or alternatively, if X decreases, then Y also decreases.

Negative polarity is represented by a minus sign, as shown in Figure 28(3), and indicates that as the value of X changes, this causes a change in the value of Y in the *opposite* direction. In other words, if X increases, Y decreases or *vice versa*. The final example, Figure 28(4) introduces a second important concept – that of delay. If the effect of X on the level of Y occurs with a significant delay, this is represented by double, parallel lines as shown in Figure 28(4). The example shown below is a delay on a link with negative polarity, but delays can also occur on links with positive polarity. This nomenclature is used throughout a variety of systems tools.

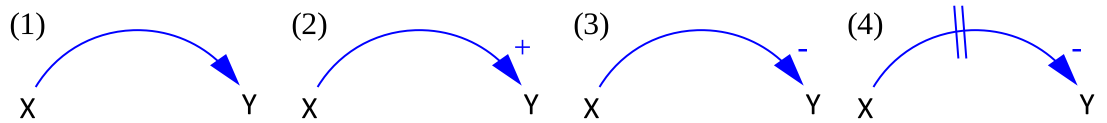

Figure 28 - Polarity and delays of causal links

6.2.2 Causal loops

The concept of feedback is central to understanding behaviour in complex systems. Figure 29 shows two simple models with the variables X and Y. The first is a duplicate of Figure 28(1) – as well as showing that X influences Y in some way, it also indicates that Y does not influence X. Figure 29(2) introduces the concept of feedback – the variables remain the same, but an additional link, from Y back to X has been added. This model indicates that a change in X will lead to a change in Y that will 'feedback' to cause a change in X and so on around the feedback loop.

If feedback structures are present in systems, but they are managed assuming a linear structure as in Figure 29(1), the expected outcome may occur in the short term, but as feedback effects come into play, these outcomes are unlikely to be sustained.

Figure 29(2) is an example of an influence diagram – the simplest type of qualitative systems model. Influence diagrams capture the feedback structure of a system, but they do not give an indication of the polarity of the links between variables. They can however, include delay marks.

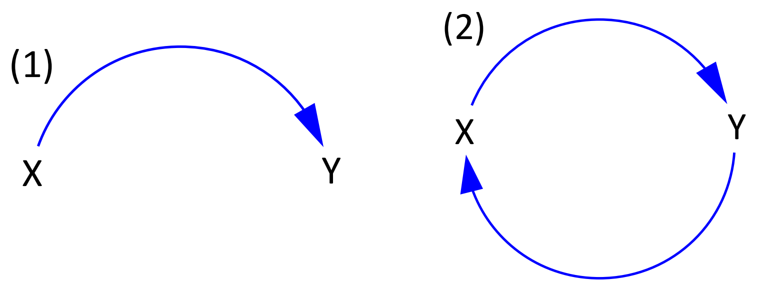

Figure 29- Basic linear and feedback models

The nomenclature for assigning polarity to causal links can be used to assign polarity to the links within influence diagrams. This results in another type of qualitative systems model – Causal Loop Diagrams (CLDs). Figure 30, discussed below, contains 3 examples of CLDs. Influence diagrams and CLDs will be discussed in greater detail in §6.3.1.

Figure 30(1) consists of two links with positive polarity – following the set of rules explained earlier, as X changes direction, this will cause Y to change in the *same* direction, and that change in Y will cause X to change in the *same* direction and so on, around the loop. The initial change in X can be either an increase or a decrease – the critical point is that the structure of the system will reinforce or amplify the initial change in X. Feedback loops that demonstrate this type of behaviour are referred to by two names – positive or reinforcing loops. This type of loop is represented by the letter R in the middle of the feedback symbol, as shown in Figure 30.

Both links in Figure 30(2) have a negative polarity. A change in X (e.g. an increase) will result in a change in Y in the *opposite* direction (a decrease). The change to Y will result in a change in the *opposite* direction to X (an increase). As with Figure 30(1), this feedback structure also reinforces the original change in X, hence the R notation in the feedback symbol.

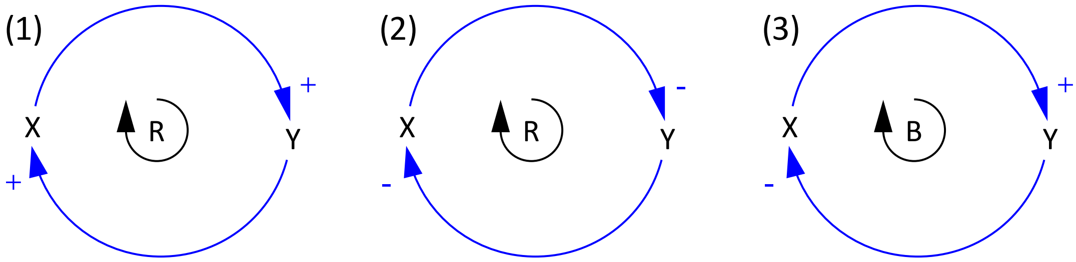

Figure 30 - Reinforcing and balancing loops

The second type of feedback loop is depicted by Figure 30(3). This example consists of a positive and a negative causal link. As X changes direction, this will cause Y to change in the *same* direction and that change in Y will cause X to change in the *opposite* direction and so on, around the loop. As with the previous examples, the original change in X can be either an increase or a decrease – the key point is that the original change in X will be countered by the influence of Y. Feedback loops that demonstrate this type of behaviour are referred to by two names – negative or balancing loops. This type of loop is represented by the letter B in the middle of the feedback symbol.

The type of behaviour generated by reinforcing and balancing loops is very different. Reinforcing (positive) feedback structures characteristically exhibit exponential growth and balancing (negative) feedback structures exhibit exponential decay, goal-seeking, and oscillatory behaviours. The typical shape of the time series generated by these behaviours is shown in Figure 31, from Sterman (2000).

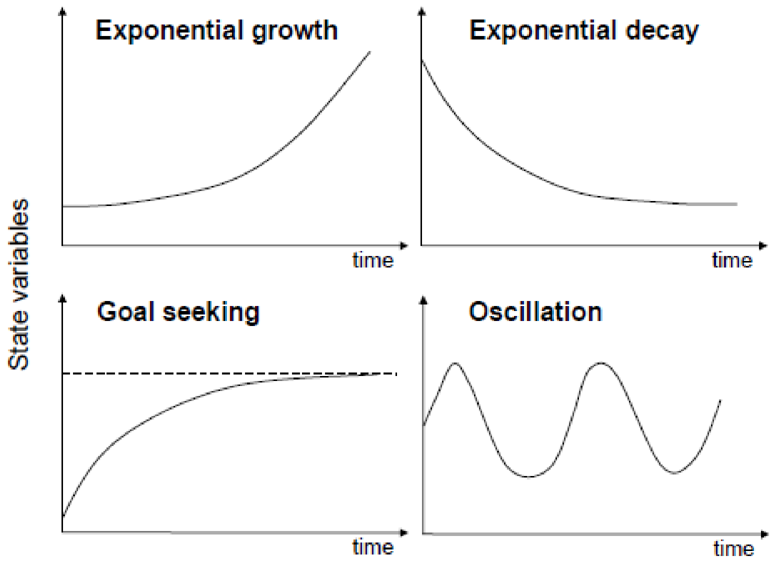

Figure 31 - The fundamental modes of dynamic behaviour

The influence of feedback structures on system behaviour serves to demonstrate the key role of internally generated or endogenous behaviour of complex systems (Richardson, 2011; Proust et al, 2012). While variables external to the system will often exert an influence on the system, it is the endogenous feedback interactions between the variables within the system that ultimately determine the system's response to these exogenous forcings. Once set in motion, this endogenous behaviour will continue to drive the system even if the external force is removed (Newell & Proust, 2012). System approaches are designed to help policy makers and managers to understand and manage the critically important and counterintuitive endogenous behaviour of systems.
The complexity of these problems requires us to divide them into manageable components. The key point here is the setting of boundaries. A silo approach will typically divide the complex problem along lines of traditional disciplines or jurisdictions, but overlook interactions with other silos. In contrast, systems approaches are particularly mindful of capturing such interactions within the study boundary.
In reality, complex systems consist of interconnected feedback loops with multiple links. Over time, dominance can shift from one feedback loop to another, resulting in shifts between different modes of dynamic behaviour (Sterman 2000; Vennix, 1999). These effects are fully reviewed by Sterman (2000).

An understanding of the fundamental systems concepts of polarity, feedback and delay is the foundation for a greater understanding of dynamic behaviour in complex systems.

Indeed, each of the concepts discussed in the remainder of this section, is built upon these fundamental concepts.

6.2.3 System archetypes

Senge (2006) has described a series of generic feedback structures known as system archetypes. These archetypes are recurring systemic structures that are found in a wide range of situations. Each system archetype has a characteristic behaviour over time that can be used to identify its probable influence in a real-world system. An understanding of these structures and their behaviour can facilitate the identification of leverage points (Wolstenholme 1992; Sterman 2000; Senge 2006), which will be discussed in greater detail in §6.2.4.

Each of the archetypes has a range of tested management strategies that can be used to plan interventions suited to the system under study (Senge 2006).The potential use of system archetypes to investigate system behaviour and inform effective decision-making is demonstrated by an explanation of the 'Fixes that Fail' archetype (Figure 32). The dynamic hypothesis of this archetype is that management solutions that focus on the problem symptom are likely to reduce the symptoms in the short-term. However, in the long run, the fix leads to unintended consequences that make the problem worse.

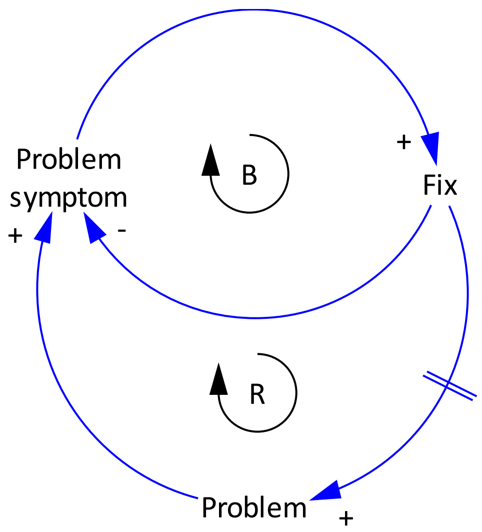

Figure 32 - Fixes that Fail archetype

The typical dynamic behaviour of the 'Fixes that Fail' archetype is shown in Figure 33 (Braun, 2002). The initial reduction in the problem symptom convinces decision-makers that the fix has been a success. After a delay, the underlying problem begins to escalate. Given the previous evidence that the fix 'works' the escalation of the problem is often blamed on another cause, and the initial fix is reapplied with increased vigour. The initial reduction in the symptom serves to reinforce the belief that the fix is effective.

This sets up the pattern of behaviour in Figure 33, where the problem symptom and the unintended consequence increase over time.

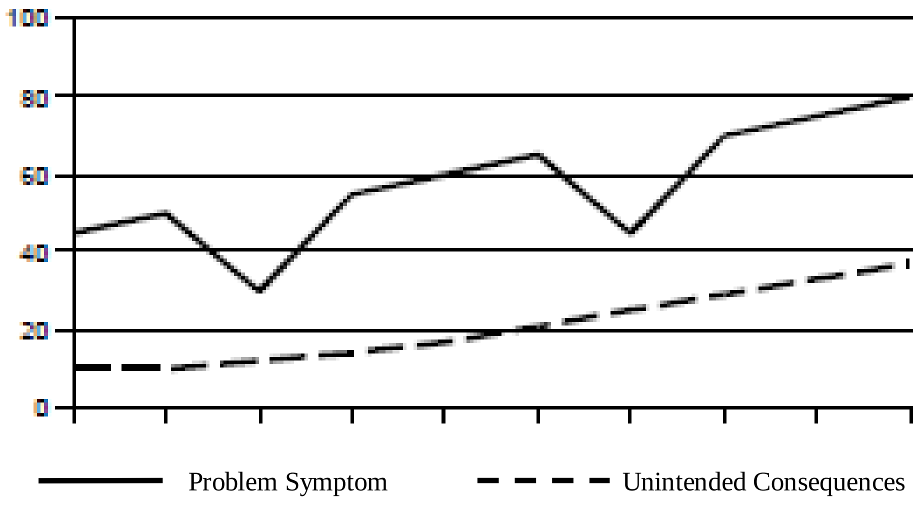

Figure 33 - Behaviour over time for Fixes that Fail

The solution to situations that display this type of archetypical behaviour is to identify and manage the problem – the underlying *cause* of the symptom. If the effect of these fundamental solutions is likely to exhibit significant delays, a short-term solution can be introduced that manages the symptoms until the fundamental solution takes effect (Senge, 1992).

6.2.4 Leverage points

Leverage points are “places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything” (Meadows, 1999; p. 1). Identifying the leverage point (and which direction to push it in) must be accompanied by an ability and willingness to make the required change (Forrester, 1969; Meadows, 2008; Newell & Proust, 2012). Systems approaches have led to an understanding of typical behaviour in complex systems. Recognition of these patterns has led to an increased awareness of how and where to intervene in the system to produce effective long-term solutions.

Meadows (Meadows, 1999) provides an overview discussion of the nature of leverage points. She includes a useful classification of types of leverage points that are ranked in order of their effectiveness. Table 56 summarises the leverage-points from weakest to strongest (Meadows, 2008).

Table 56 -Leverage points

Leverage Point	Description
Numbers	Constants and parameters such as subsidies, taxes, and standards.
Buffers	The size of stabilising stocks and inventories relative to their flows.
Stock-and-flow Structures	Physical systems and the way that they interact.
Delays	The length of time delays relative to the rates of system change.
Balancing feedback loops	The strength of stabilising loops relative to the changes that they oppose.
Reinforcing feedback loops	The strength (gain) of the driving loops.
Information flows	The structure of who does and does not have access to information.
Rules	Policies and laws, including incentives, punishments, and constraints.
Self-Organisation	The ability of the system to change its own structure.
Goals	The purpose or function of the system.
Paradigms	The mind-set out of which the system arises. This mind-set determines the system's goals, structures, rules, delays, and parameters.

6.2.5 Stocks and flows

Stocks and flows are fundamental to the dynamics of systems (Forrester , 1969). A stock is an accumulation of material or non-material things. For example, the volume of water in a dam, the population of a city, the number of people who own a computer and the level of trust in a workplace are all examples of stocks that can increase or decrease over time. Figure 34 uses the bathtub metaphor (Sterman, 2000) to explain the relationship between stocks and flows. The stock in this instance is the level of water in the bathtub. With the plug in the bath, the outflow is zero and when the tap is turned on, the level in bathtub beings to rise (water begins to accumulate).

If the tap is turned off and the drain opened, the water level in the bathtub will begin to drop. If we consider both flows occurring simultaneously, the water level will depend on the difference between the inflow and outflow. If the inflow and outflow of water are equal, the system is in dynamic equilibrium and the level in the bathtub will remain unchanged until one of the flows is changed. If the drain is opened just a little more, the level in the bath will drop, but only very slowly. Achieving the desired level of water in the bathtub is very difficult if the tap and the drain are managed in isolation. The delay between removing the plug and an empty bathtub will depend on the difference between the inflow and outflow rates. While the example appears relatively simple, understanding the implications of stock and flow relationships and time delays demonstrated by the bathtub metaphor is generally poor (Sterman, 2000, Meadows, 1999)

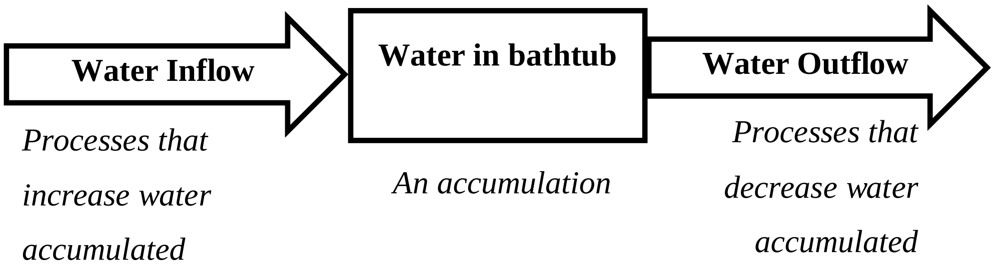

Figure 34 - Stock and flows

6.2.6 Mental models

Mental models are deeply ingrained assumptions, generalisations, or ways of thinking that influence not only how we understand the world, but also how we act (Senge, 1990). Given the overwhelming complexity of the world, it is inevitable that mental models are simplifications of reality that are based on personal experiences (Sterman, 2006).In addition to narrow mental models that overlook interactions between variables in the system, most mental models are dominated by short time horizons (Sterman, 2006).

All systems approaches recognise the limitations that mental models can place on an understanding of the dynamic behaviour of systems. A key to overcoming this limitation are integrated processes that ensure expertise is incorporated from across conventional boundaries (Newell & Proust, 2012). Effective collaboration and integration can not only affect immediate decision-making but also result in changes to our mental models that will result in a new framework for future decisions. This is represented in Figure 35 by Sterman's model of double-loop learning. This model reflects the iterative nature of systems thinking, where real world experiences of integration result in an expansion of the temporal and spatial boundaries of existing mental models.

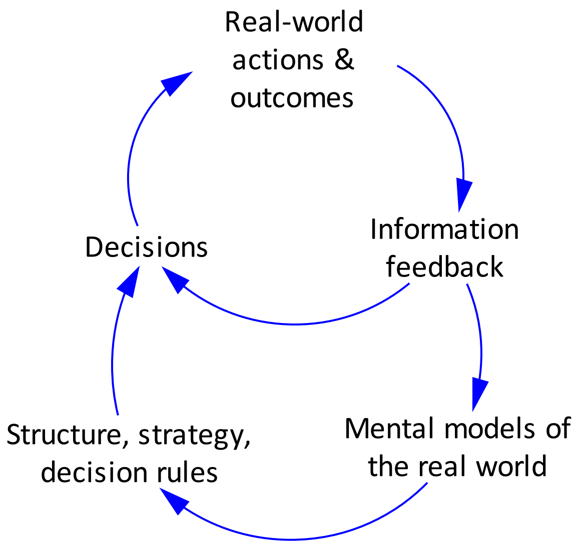

Figure 35 - Model of double-loop learning (Sterman, 1984)

6.3 Systems tools

Systems tools utilise the concepts of stocks, flows, delays and feedback to develop models that are simplified representations of a real-world system. Such models are designed to help practitioners develop deeper insight into the behaviour of the system, and can provide a hypothesis of how the structure of the system drives that behaviour.

In complex situations, where a myriad of inter-related decisions take place, models provide an invaluable tool for making more informed and robust decisions (Burns & Musa, 2001; Lagergren, 1998). There is a range of modelling tools used in systems approaches, from simple qualitative models to working computer simulations. The selection of appropriate tools will depend on the context and aims of the specific exercise. Each step in the modelling process aims to develop new insights into the behaviour of the system - insights that can be used for more effective management strategies. In many instances the construction and study of qualitative models will provide sufficient insights into system behaviour to enhance decision-making, without the construction of quantified models (Coyle, 1999).

Whichever type of model is used, evidence is required to support the fundamental structure of the model. In the first instance, evidence is provided by the model builders and confirmed by evidence from the literature or elsewhere. Data are likely to include a consideration of historical patterns of behaviour ((Nguyen, Bosch & Maani, 2011; Proust, 2004). Analysis of relevant data can lead to necessary adjustments, resulting in more accurate and authentic models (Burns & Musa, 2001; Sterman, 2000).

6.3.1 Influence diagrams and Causal Loop Diagrams

Influence diagrams and causal loop diagrams (CLDs) were introduced briefly in §6.2.2. Both are qualitative models that aim to capture the basic feedback structure of the system of interest. Influence and causal loop diagrams are good starting points for collaborative efforts to develop initial dynamic hypotheses and construct stock-and-flow models (Proust 2004). Both are constructed using a simple set of rules and provide a visual representation of the key variables and links between them (Sterman 2000). Variables represent stocks that are capable of a change of level and are expressed as nouns or noun phrases (Vennix, 1996, Newell & Proust, 2012). The variables range from readily measured physical variables (such as temperature) to more intangible measures (such as level of community support for a particular legislation).

Compared to CLDs, influence diagrams are easier to produce and enable the creator(s) to quickly capture their perspective of a complex issue in a form that can be readily communicated. The diagrams can then be converted to a CLD at a later time (Li, 2010; Newell et al., 2007). Influence diagrams are also useful during the development of conceptual models when the variables in the system represent broad groups of variables and the links between them represent multiple processes (Proust et al, 2012). Some authors refer to CLDs without polarity assigned as ‘conceptual’ CLDs (Maani & Cavana, 2007), but the term ‘influence diagram’ will be used in this thesis.

Figure 36 represents a high-level dynamic hypothesis concerning technology-dependence in urban settings and is an example of an influence diagram where the variables are still too abstract to enable polarity to be assigned to the links and the feedback loops (Proust et al, 2012). Depending on the specific example being analysed the feedback loops could be either reinforcing or balancing loops – hence the “R/B” text within the feedback symbols. The hypothesis or concept depicted by Figure 36 can guide the construction of CLDs that focus on a specific technology dependence. Polarities can then be assigned to the links, and the feedback loops classified as reinforcing or balancing, enabling greater insight into the dynamics of that particular system.

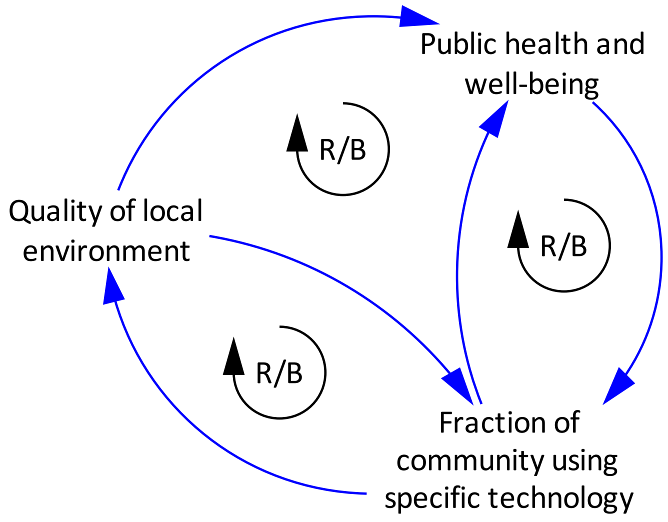

Figure 36 - Example of a high-level influence diagram

Compared to typical linear thinking, influence diagrams and CLDs can provide tremendous insight to the connections and feedback processes that affect system behaviour. They also provide a way to capture and communicate the mental models of different stakeholders. Comparison with system archetypes can help to develop hypotheses and/or interventions on a wide range of complex issues such as major accidents (Goh, Love, et al., 2010; Goh, Brown, et al., 2010), obesity (Newell et al., 2007), chronic disease prevention (Homer & Hirsch, 2006), public health reform (Cavana & Maani, 2000), water and energy management (Proust et al., 2007), climate change vulnerability (Li, 2010) and technology dependence (Proust et al., 2012).

6.3.2 Stock-and-flow diagrams

Influence diagrams and CLDs are qualitative representations of the interactions between stocks and flows within the system of interest. Progression to quantitative models requires CLDs to be converted to stock and flow maps. Figure 37 demonstrates the labelling conventions used in stock and flow diagrams. The state of a system at any time can be specified by the level of its stocks (or state variables) at that moment. Stocks are represented by rectangles. The process flows are represented by the double-lined arrows. The rates of state-change processes (flows) are represented by 'tap' symbols. The clouds represent 'infinite' sources or sinks that are outside the boundary of the study.

Figure 37 has an inflow and an outflow. The single blue lines represent influence links where stocks influence or control rates of processes. In this particular example, changes in the state variable have the potential to influence the rate of both the inflow and outflow processes.

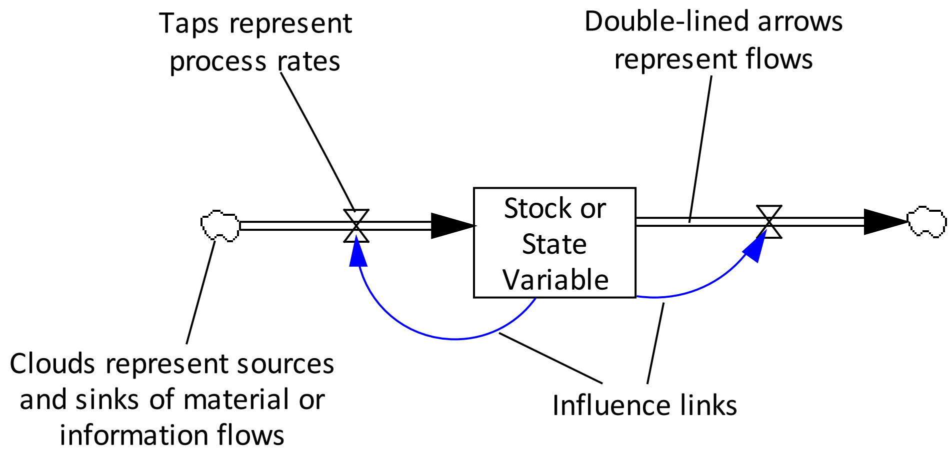

Figure 37 – Stock-and-flow diagram

Work with stock-and-flow diagrams provides the basis for the construction of simple stock-and-flow models that can lead to the construction of computer models that assist in investigations of system behaviour. The ability to progress to quantitative models will depend on whether quantification of key variables is possible.

6.3.3 Dynamical computer models

Computer models are used in system dynamics to explore the behaviour of complex systems over time. Software packages, such as Stella, Powersim and Vensim, have been designed to support system dynamics modelling. Flow rates are expressed as differential equations and initial levels of stock are estimated from existing information and knowledge. The computer model integrates the differential equations, using small time increments, to simulate the behaviour of the system over time (Sterman, 2000). The ability to see the behaviour of their imagined system unfold over an extended time period enables users to consider the long-term implications of decisions that are often difficult to envisage. This experience leads to a greater systemic understanding of the system and can help to develop strategies that are more likely to succeed in the long run.

6.4 Application of Collaborative Conceptual Modelling (CCM)

In addition to the systems concepts and tools already introduced in this chapter, CCM incorporates new protocols based on insights from cognitive science and the practice of applied history (Newell & Proust, 2012; Proust, 2004)

Figure 38 shows the *CCM Poster* which summarises the main activities of the process. The approach provides a strong, but flexible set of guidelines that can be tailor-made to suit the individual characteristics of each study. While there is a natural progression from activities one to six, the results at each step often lead to new understandings that cause the group to re-examine previous activities. These activities are therefore referred to as “co-evolving” and will be represented throughout this thesis by the abbreviation CA followed by the appropriate number.

CCM is divided into two main phases. Phase I comprises CA1 to CA3 and strives to develop new, shared understandings of the system. The focus in Phase I is on collaborative systems thinking. In Phase II (CA4 to CA6) the focus is on collaborative system analysis. The activities include developing an understanding of the dominant dynamics of the system, the identification of leverage points, and the construction of scenarios. Phase II requires significantly more resources and expertise than Phase I.

CCM does not require the completion of all six activities. In many cases Phase 1 will be sufficient to increase understanding of system behaviour to such an extent that significant improvements in management result (Newell and Proust, 2012). This research will utilise aspects of CA1 to CA6.

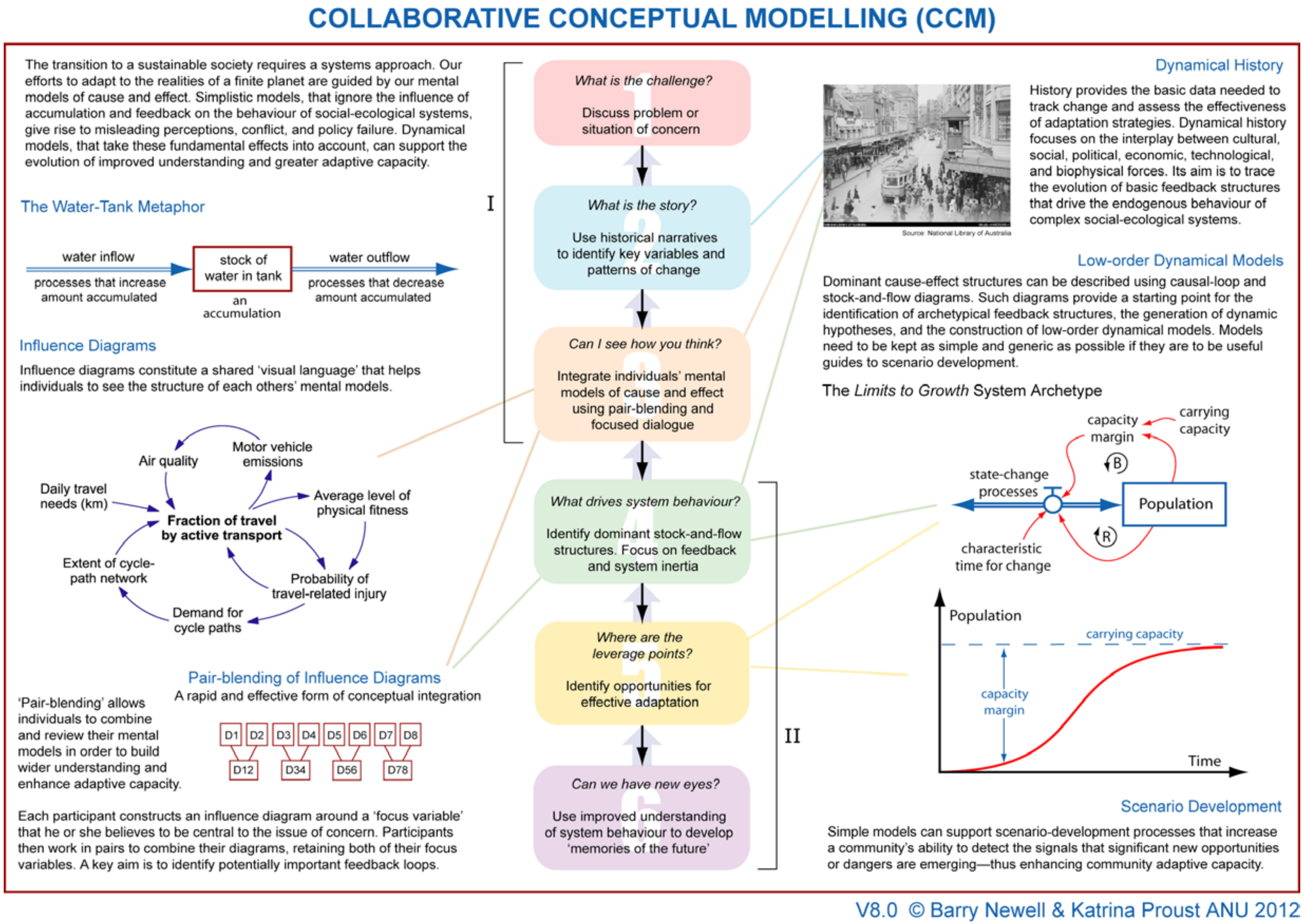

Figure 38 - CCM Poster

6.4.1 CCM co-evolving activities

This section provides an overview of the main activities conducted within a CCM framework. The CCM process of building understanding and models is highly iterative. As demonstrated by the circular nature of Figure 39 and the internal links between activities, the understanding of the problem tends to co-evolve from the process rather than emerge in distinct steps.

Figure 39 - Summary of the main iterative pathways in CCM

(This diagram was kindly provided by Barry Newell and Katrina Proust)

6.4.1.1 CA 1 –What is the challenge?

Members of the group discuss the challenges they face. Care is taken not to focus on a specific issue too early in the process. Concepts of stocks and flows are introduced to the group as early as possible to encourage participants to frame their ideas and expertise in a format that is conducive to system dynamics.

6.4.1.2 CA 2 – What is the story?

Historical studies are used to help identify key stock-and-flow feedback structures that have influenced system behaviour in the past. The term 'Dynamical History' is used to convey the focus on system dynamics. The historical aspects of complex problems will invariably extend well beyond the memory or experience of current decision-makers (Proust, 2004). Developing a historical account can help decision-makers and communities learn from past experiences. This type of history is gathered from a wide range of sources including oral histories, ‘cause-and-effect’ stories, photographs and written historical documents.

6.4.1.3 CA3 - Can I see how you think?

This activity helps individuals to mesh their mental models of the challenge being addressed. The step is typically conducted in a group setting, such as a workshop, using influence diagrams and focused dialogue. Participants, who have already been introduced to the concepts of stocks and flows, are asked to construct an influence diagram that describes what they believe is a dominant causal structure of the system (or challenge) being addressed. Eliciting individual mental models prior to group work avoids the possibility of ‘group-think’ (Janis, 1972). Participants are given approximately 15 minutes to construct a diagram and are provided with a simple set of instructions as follows:

Step 1 (Figure 40)

- Identify a specific focus variable that is central to the challenge
- Identify 3 to 4 key driver variables that influence the focus variable
- Express variable names clearly, using nouns or noun phrases so that they are capable of a change of level (increase or decrease)
- Represent the processes or flows by an arrow

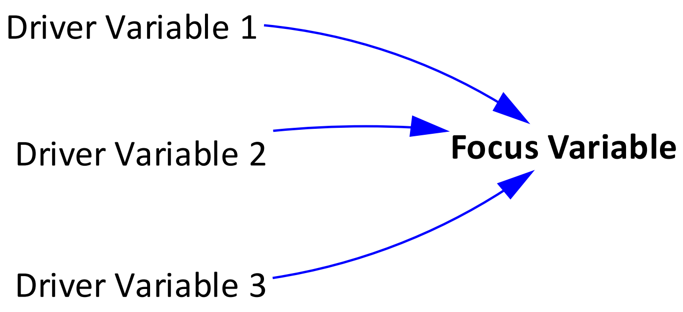

Figure 40 - Step 1 of influence diagram

Step 2 (Figure 41)

- Identify 3 to 4 key variables that are affected by the focus variable

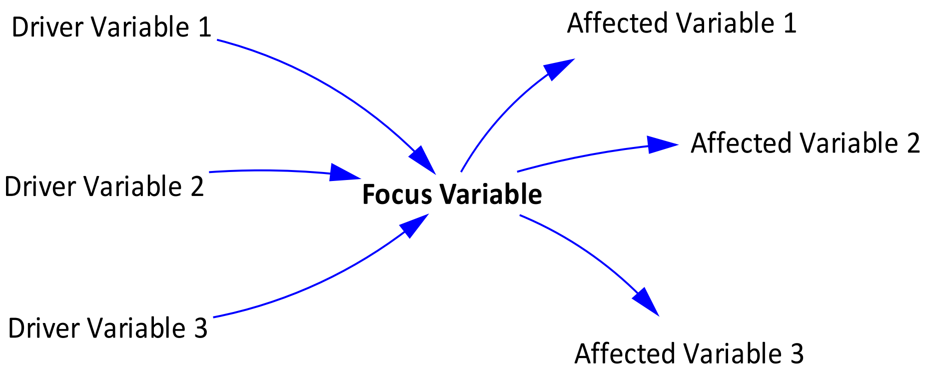

Figure 41 - Step 2 of influence diagram

Step 3 (Figure 42)

- Identify possible feedback loops between the 'driver', 'affected' variables and focus variable. If necessary, add 'linking variables' that are a critical part of the feedback process.
- Limit the number of variables to approximately ten.

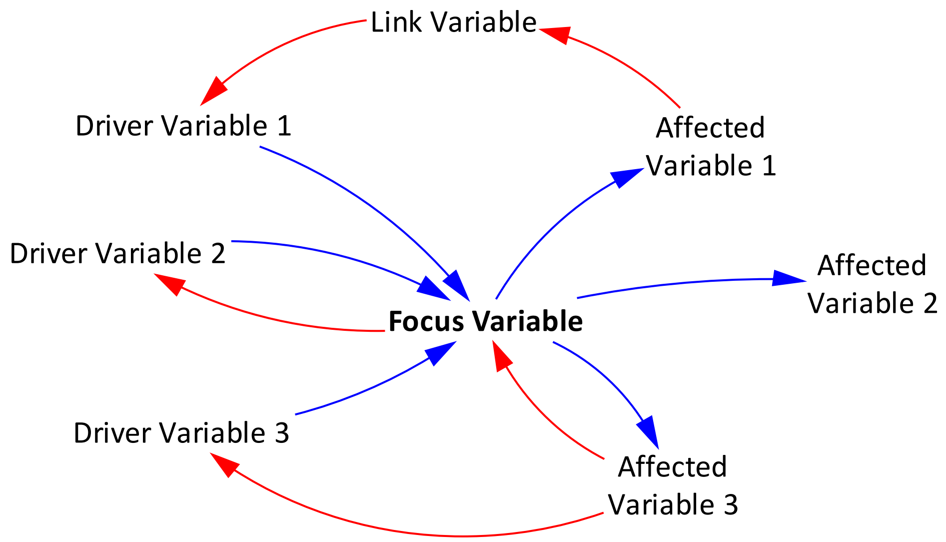

Figure 42 - Step 3 of influence diagrams

After the completion of the individual diagrams, pairs are formed. Ideally, individuals with clearly different views of the system are paired. The pair then works together for approximately 30 minutes to construct a 'pair-blended' diagram that integrates both viewpoints. The resulting diagrams are then shared with the wider group for discussion. Depending on the size of the group, this step can take several hours. This group discussion helps to identify and potentially resolve conflicts between people with different experiences and view-points of the challenge under study. A mixture of individual, small group and plenary tasks, developed prior to the day is similar to that reported by Andersen and Richardson (1997) who advocate an approach entailing a series of small group processes called 'scripts'.

Figure 43 is an example of an influence diagram (from the *CCM Poster*), with *Fraction of travel by active transport* as the focus variable. The outcome of this activity can trigger collection of more data and lead to a reconsideration of the original challenge.

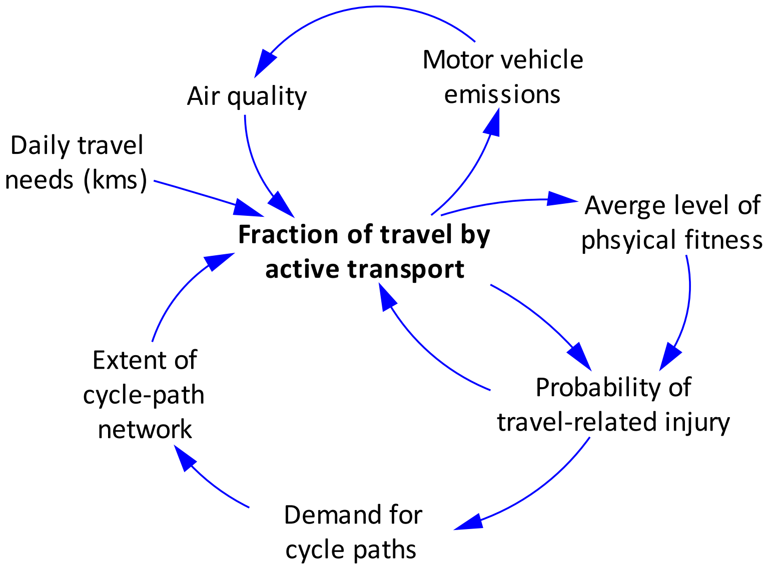

Figure 43 - Example of influence diagram from a CCM workshop

6.4.1.4 CA4 – What drives system behaviour?

CA4 is the first activity in Phase II of CCM and aims to identify dominant stock-and-flow structures. The information and shared understanding from Phase I is used as a basis for analysing the dynamic behaviour of the system. This and the other activities in Phase II require a greater level of expertise in system dynamics than Phase I.

Comparison with system archetypes (§6.2.3) is used to reflect on the underlying structure of the system being studied. System archetypes are generic in nature and must be interpreted (and often elaborated) in light of the real variables of the system. The interpretation of system structure in terms of system archetypes leads to a dynamic hypothesis that is intended to explain the behaviour of the system.

This hypothesis can be elaborated using a process of 'Feedback-Guided Analysis' (B. Newell, personal communication, 2013) that has been developed as part of CCM. Feedback-Guided Analysis involves the following steps (see Figure 44, Newell & Proust, 2012):

- Develop an 'overview template' – an influence diagram is developed that considers the major sub-systems of the human-environment (HE) complex considered relevant to the study. The main feedback links between them are identified. This represents a 'high-level' view of the system.
- Develop one or more 'problem-space diagrams' – the overview template is used to structure an approach to the type of management problems that have been identified during Phase I. As shown in Figure 44, there is likely to be more than one type of Problem Space that is captured by the broader, overview template
- Develop one or more 'system-of-interest' diagrams for each problem space – the problem-space diagrams are used as the basis for the development of diagrams, each of which is tightly focused on specific system-of-interest or management problem

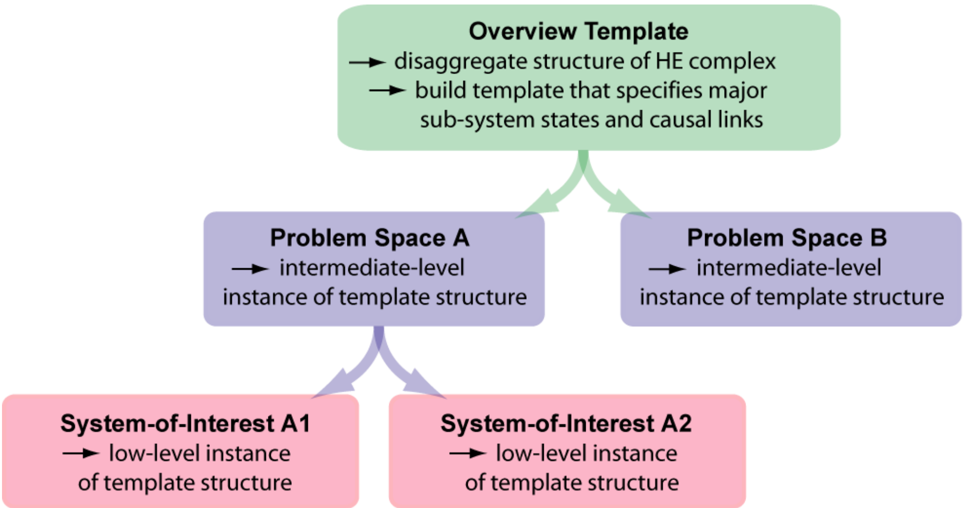

Figure 44 - The CCM feedback-guided analysis procedure

The conceptual models can be presented as influence diagrams, CLDs, stock-and-flow maps or low-order system-dynamic models. The selection of model type and specific Problem Spaces and Systems-of-Interest will depend on the discussions of the group and the understanding gained throughout the CCM process. The Feedback-Guided Analysis process can be used to create a series of CCM studies that share fundamental patterns of behaviour, but are projected down to a level that is useful for decision-making in a variety of specific situations. This provides a framework for shared understanding between studies developed under the one overview template.

Application of CCM within the Urban Climate-Health cluster resulted in the development of an overview template depicting the relationships between climate and health in urban areas (Proust et al 2012). The template, entitled the ‘Co-Effects Template’ and the application of feedback-guided analysis, will be discussed in greater detail in §6.5.2.

6.4.1.5 CA5 – What are the leverage points?

The system behaviour captured by the system archetypes and models constructed in CA4 is used to identify potential leverage points. The management solutions suggested by system archetypes (6.2.3) and the Meadows leverage-point scale (6.2.4, Table 50) are used to identify opportunities for effective adaptation.

6.4.1.6 CA6 – Can we have new eyes?

This activity is designed to explore the policy implications of the dynamic hypothesis about system behaviour. The increased understanding of the system that emerges from the CCM process will alter the perception of the initial ‘what is the challenge?’ activity (CA1). This is indicated in the circular CCM diagram (Figure 39) by the dotted link between CA6 and CA1.

The implications for policy can be explored further by the construction of ‘systemic scenarios’. Just as the historical analysis in CCM is considered in terms of dynamic behaviour, the scenarios place particular emphasis on the dynamics of the system. Scenarios are typically constructed by asking key stakeholder which variables they believe will have the greatest influence on the situation of interest in the future. The scenarios are built around the two variables that are considered the most important and the most uncertain (Van der Heijden, 1996, Schwartz, 1991). As shown in Figure 45 this leads to four potential scenarios based on the two selected variables (X and Y).

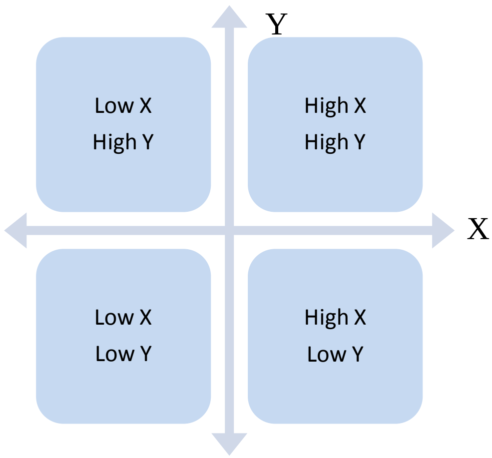

Figure 45 - 2x2 scenario matrix

These scenarios are elaborated by imagining the possible future suggested by each combination – This process creates what Ingvar (1985) has called “memories of the future”—memories of previously imagined future outcomes that surface as the actual future unfolds. Such memories increase people’s sensitivity to the critical variables. The construction of each scenario typically involves narratives that focus on opportunities, barriers and critical success factors. In the case of CCM, the construction is guided by the dynamic hypotheses of the models developed in earlier CCM activities. Progression from dynamic hypothesis to CA6 can be undertaken directly from CA3, CA4 or CA5. While maximum benefit will be achieved by progressing through all steps, bypassing CA4 or CA5 may be necessary if resources are limited.

6.4.2 Co-effects template

Four CCM workshops, attended by members from all project groups within the Urban Climate-Health cluster, culminated in the development of a conceptual template that depicts the relationships between climate and health in urban areas (Proust et al 2012). The process, described in full by Proust and colleagues (2012), resulted in the ‘Co-Effects Template’ (Figure 46).

This template captures the underlying patterns of feedback behaviour between the urban environment, the biosphere and human health. The template can be used to guide discussions on a range of adaptation challenges that will be faced in urban areas as a result of climate change.

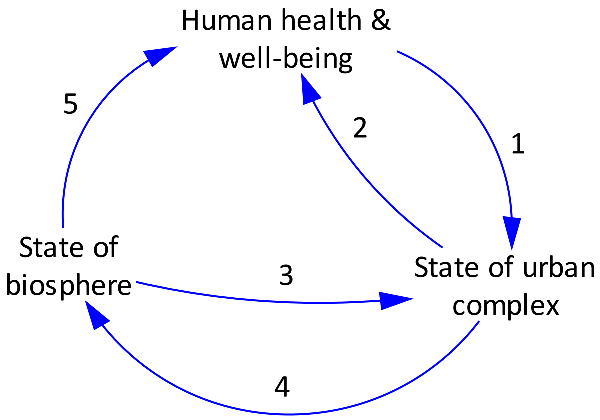

Figure 46 - The Co-Effects template

The links in this influence diagram represent the multiple interactions that occur between the state of the urban environment, the biosphere and human health and well-being. The Co-Effects Template has three feedback loops. The ‘health effects’ loop operates through Links 1 and 2. The ‘environmental effects’ loop operates through Links 3 and 4. The final loop is the ‘co-effects’ loop that operates through Links 1, 4, and 5.

The Co-Effects Template can be used to guide develop an influence diagram that is focused on the urban environment-health issue of interest. Following the process of feedback-guided analysis, the fundamental structure of the Co-Effects template is maintained and the broad variables are replaced by variables specific to the issue. The example given by Proust et al (2012) in Figure 36 is an example that focuses on the co-effects of technology dependence in urban areas. At this level the state variables and the cause-effect processes are still too abstract to allow dynamical analysis, and so the nature of the feedback loops cannot yet be determined.

The next step is to consider specific systems-of-interest that exemplify the feedback structure of the diagram. For example, in the case of the co-effects of technology dependence, specific examples include dependence on private motor vehicles or air-conditioning. Examples can be developed as case studies within the broader challenge. The variables at this level are tightly specified which enables polarities to be assigned to the cause-effect links. This progression enables a more detailed analysis of the system behaviour. .

The step-wise reduction, from the broad level of the Co-Effects Template to the urban environment-health issue of interest to a more specific example of the issue of interest, helps to create boundaries around issues while ensuring that the interactions between urban environment, the biosphere and people are taken into account. The disciplined nature of the reduction also enables the development of a coherent set of system-of-interest-based case studies within different challenges. In much the same way that systems archetypes can provide effective management solutions for similar situations, the lessons gained from each case study can be extended to others developed under the same problem-space diagram.

Tables 57 and 58 are excerpts from Proust et al (2012) and describe the variable sets and links in the Co-Effects Template.

Table 57 - Co-Effect variables

Variable Set	Description
State of Urban Complex	A set of variables that specifies the state of a city and its inhabitants. Both physical and social state variables are required. Examples include area of city, area of green space, kilometres of roads, dominant transport modes, quality of infrastructure, extent of infrastructure, street permeability, energy consumption, albedo of urban region, size of population, population density, security of food supply, affluence, social cohesion, alienation, equality, and visual amenity.
State of Biosphere	A set of variables that specifies the physical and ecological state of the planet. The set must include variables measuring the physical state of the planet and those measuring the health of ecosystems at all scales from local to global. Examples include atmospheric energy content, greenhouse gas concentrations, ocean acidity, biodiversity, species abundance, extent of native vegetation, condition of soils, and condition of fresh water.
Human Health & Well-being	A set of variables that specifies the physical and psychological state of an urban community. Examples include incidence of specific diseases, extent of obesity, physical fitness, stress levels, level of mental health, acclimatisation to weather extremes, sense of purpose, sense of comradeship, and sense of security.

Table 58 - Co-Effect process

Link	Cause-effect processes
1	Process of designing and implementing formal and informal social and public health policies that affect the state of the urban complex.
2	Processes whereby the state of urban physical and social systems affects individuals' physiological and psychological functioning.
3	Process of designing and implementing formal and informal environment protection policies that affect the state of the urban complex.
4	Processes involving extraction of natural resources and pollution (dumping of wastes). Conservation and restoration processes.
5	Processes whereby environmental conditions affect human physiological and psychological states.

6.5 Conclusion

Effective adaptation to the potential health impacts of climate change in urban areas must be designed on the basis of the dynamic behaviour of the system. Policies and decisions based on linear thinking are likely to fail. While it is challenging to tackle the complexity of these systems, there are concepts and tools, introduced throughout this chapter that are specifically designed to deal with such complexities.

The genesis of effective adaptation must stem from a greater level of systemic understanding by key decision-makers. Part II of the thesis aims to achieve this by applying the CCM activities outlined in this chapter to the challenge identified in Part I. To recall, that challenge is how to address the exposure to the higher ambient temperatures projected for Perth.

Chapter 7 – CCM Phase I: Results & Discussion

7.1 Introduction

Phase I of CCM comprises CA1 to CA3. The objective of this phase is to construct the foundations of a shared understanding of the determinants of exposure to heat in Perth and the resulting impacts on health. The first activity described in Chapter 7 builds upon the Co-Effects Template, developed as part of the Cluster. The answer to the question 'what is the challenge?' provided the focal point for the remainder of the research. The second activity considered the challenge from a historical and policy context. The third and final activity of Phase I, a half-day workshop attended by stakeholders from health, environment, planning and development sectors, captured and integrated viewpoints from across traditional silos. The new and shared understanding gained from each of these activities provided critical support for Phase II of CCM.

7.2 CA1 – What is the challenge?

The fundamental question of 'What is the challenge?' was guided by the Co-Effects Template. In this challenge, the 'State of Biosphere' variable of interest is ambient temperature in urban areas of Perth during summer (Figure 47). Other than the specific focus on Perth, the 'State of Urban Complex' and 'Human health and well-being' variables remain unchanged from the definitions provided in Chapter 6 (§6.5.2). When considered in the context of the HIA undertaken, the immediate revelation is that Figure 47 does not incorporate the influence of global climate change on ambient temperatures in Perth.

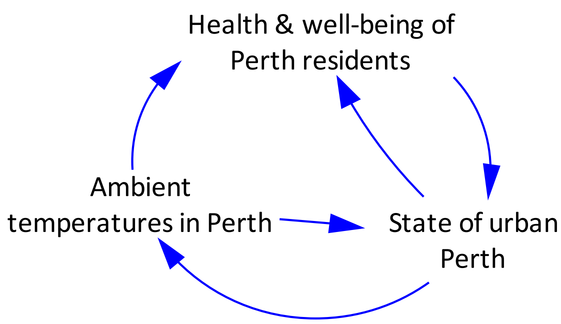

Figure 47 - The Challenge

Given the key place of climate change in this research, the 'Co-Effects Template' was adjusted to include influences on temperature at both the local and global level. The resulting template was named the Global Local Model.

7.2.1 The Global Local model

The Global Local Model (Figure 48) is divided into two sections – the 'Global Loop' and the 'Local Loop'. The numbering system is the same as the 'Co-Effects Template' with the letters G and L used to differentiate between links in the global and local loops respectively. The template consists of a single 'Health Effects' loop (in blue), two 'Environmental Effect' loops (in green) and two 'Co-Effects' loops (1→4G→5G and 1→4L→5L).

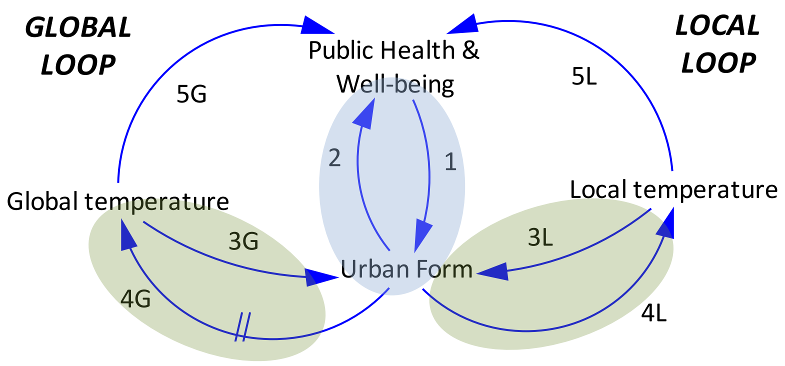

Figure 48 - The Global Local model

In practice, the ambient temperature in Perth will be measured as a single stock with no distinction between 'global temperature' and 'local temperature'. Likewise, separation of health effects that occur via links 5G and 5L is unlikely. Nevertheless, the conceptual differentiation is important in terms of understanding the dynamics of the system. In particular, the separate loops effectively communicate the vast difference in spatial and temporal scales between the global and local loops. A greater understanding of these different scales will assist in developing strategies to address increasing ambient temperatures in Perth and other cities.

Each of the links in the Global-Local Model is defined in Table 59. Links 1 and 2 remain unchanged from the original 'Co-Effects Template' links (Table 57).

Table 59 - Global Local model links

Link	Cause-effect processes
1	Process of designing and implementing formal and informal social and public health policies. Processes whereby policies affect the state of the urban complex.
2	Processes whereby the state of urban physical and social systems affects individuals' physiological and psychological functioning.
3L	Process of designing and implementing formal and informal policies designed to control ambient temperatures in urban environments. Processes whereby these policies affect human activities.
4L	Processes whereby the physical characteristics and activities of the city influence local temperatures by the retention, production and removal of heat from the urban environment. Usually referred to as the Urban Heat Island (UHI) effect.
5L	Processes whereby changes to 'local' temperature affect human physiological and psychological states.
3G	Process of designing and implementing formal and informal policies in response to global climate change. Includes policies to reduce GHG emissions. Processes whereby these policies affect human activities.
4G	Processes where the physical characteristics and activities of the city influence the temperature at a global scale via the emission of GHGs. Note that due to the inertia of the climate system, this link is characterized by a significant delay.
5G	Processes whereby changes to 'global' temperature affect human physiological and psychological states.

There are several characteristics of the 'Global Loop' that make it insensitive to changes to urban form in Perth. Firstly, although per capita GHG emissions in Perth are very high, the total emissions represented by link 4G constitute a fraction of 1% of global GHG emissions (Garnaut, 2008). The physical influence of link 4G on global temperatures will therefore be negligible for this study. Secondly, as discussed in

Chapter 2, the inertia of climate systems results in a lag of at least several decades between greenhouse gas emissions and global climate change.

7.2.1.1 The Local Loop

The Global Local Model highlights that while the Global Loop is critical in terms of mitigation efforts, adaptation must target strategies that operate predominantly in the Local Loop. In effect, the link between temperature and health in the Global Loop (link 5G) will be treated as exogenous to the system. The question of 'What is the Challenge?' therefore begins with a more detailed examination of the link between urban form and climate within the 'Local Loop' (link 4L).

The typical characteristics of cities often result in UHI effects where higher temperatures occur in cities than surrounding areas (Chandler, 1962; Oke, 1982; Taha, 1997). The three parameters of most relevance to UHIs are surface albedo, evapotranspiration from vegetation and anthropogenic heating from mobile and stationary sources (Taha, 1997). Albedo is a measure of a material's ability to reflect solar energy. The materials used in roads, pavements and buildings have a low albedo – that is they tend to absorb rather than reflect solar energy. As a result of the high proportion of materials with low albedo, city areas absorb and store up to twice the amount of heat compared to rural areas (United States EPA, 2008). The geometry of buildings can also impede the release of stored heat into the atmosphere. The large volume of land area that is covered by impervious surfaces also results in less moisture being retained in cities, which in turn reduces evapotranspiration.

Urbanisation typically involves the continuous loss of vegetation (Elmqvist, Alfsen, & Colding, 2008). Vegetation reduces urban temperature in two ways. Firstly, tree canopy provides shade that reduces the amount of solar energy reaching built surfaces and can reduce peak surface temperatures by up to 20°C (Greater London Authority, 2006). In a study of surface temperatures in urban neighbourhoods of Phoenix, Arizona, Jenerette et al (2007) reported that vegetation cover explained 78% of the temperature variation between neighbourhoods, with the highest temperatures recorded in areas with the least vegetation. Secondly, the evapotranspiration of water from leaves, results in a reduction in the surrounding air temperature. The combination of shading and evapotranspiration can reduce air temperatures by between 1 and 5°C (Huang, Akbari & Taha, 1990; Kleerekoper, van Esch & Salcedo, 2012; Williams, Shoo, Isaac, Hoffmann & Langham, 2008).

The final component of urban environments that contributes to the UHI effect is the release of anthropogenic heat. Waste heat from vehicles, industry and air-conditioners are the main sources of anthropogenic heat in cities (Sailor & Lu, 2004; United States EPA, 2008).

Urban heat island effects have been reported in many cities around the world (Coutts, Beringer & Tapper, 2008; Greater London Authority, 2006; Stone, 2005; Yamamoto, 2006). While the magnitude of the UHI effect varies according to the particular characteristics of a city, the effect has been measured at between 2 and 12^{o}C (Oke, 1995). In a study of 50 US cities, urban temperatures in cities experiencing growth increased at double the rate of background global increases (Stone, 2012). The only cities that did not experience temperature increases above background levels were those that had not undergone significant urbanisation over the study period. Figure 49 shows a night-time UHI effect in Melbourne of 4^{o}C in the central business district and 2°C in surrounding urban areas (Coutts, Beringer & Tapper, 2010). While the profile depicts temperature differences at a relatively large spatial scale, these outcomes occur as a result of a vast number of microclimates that vary within a distance of several meters (Kleerekoper, van Esch, & Salcedo, 2012).

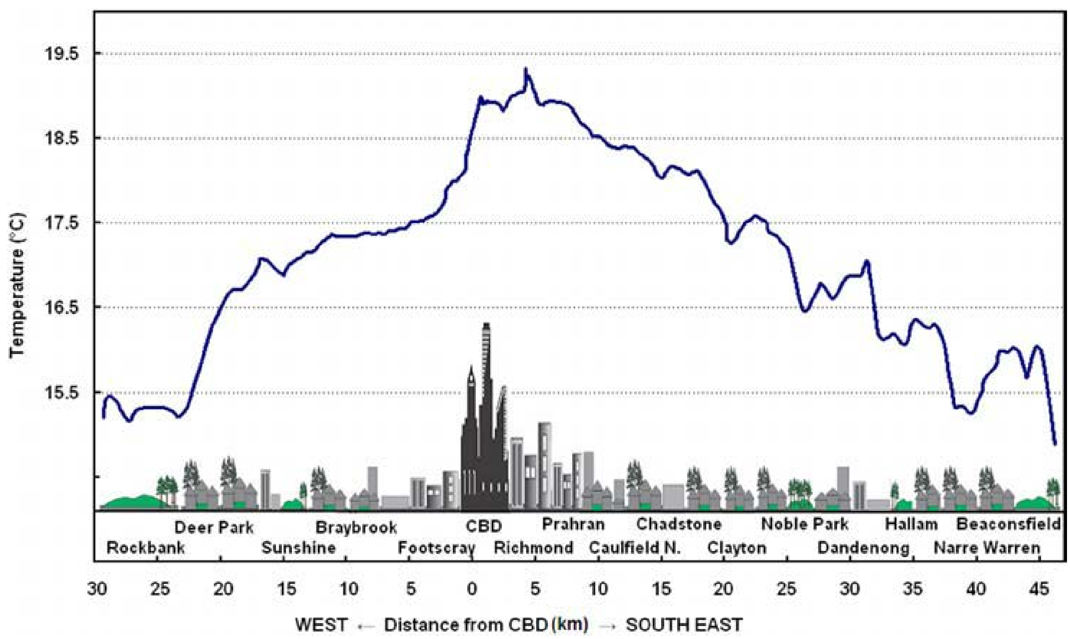

Figure 49 - Urban heat profile in Melbourne

Staff from the Bureau of Meteorology and the Department of Environment and Conservation were contacted as part of this research and were unaware of any UHI studies in Perth and no reports were found in the peer-reviewed literature.

UHI mitigation strategies use a combination of increasing urban vegetation, increasing albedo of built surfaces and reduction of waste heat emissions. Reported reductions in city-wide air temperatures of between 1 and 7°C have been reported as a result of UHI mitigation (Stone, Vargo, & Habeeb, 2012). Of these, vegetative strategies, particularly tree planting, are generally found to be one of the most effective in reducing the UHI effect (Hart & Sailor, 2009; Lynn et al., 2009; Zhou & Shepherd, 2010). Because the physical characteristics that influence urban climate range from the individual building to the design of the entire city, the policy scale of UHI mitigation strategies is very broad (Greater London Authority, 2006).

While the occurrence of UHI is well documented, factors relating to management of climate within urban areas tend to be afforded little consideration within planning frameworks and development policy (Coutts et al., 2008; Fehrenbach, Scherer, & Parlow, 2001).

7.2.1.2 Urban form in Perth

As discussed in the HIA profiling step, the population of Perth is projected to double in the 2050s. Given this increase, changes in the characteristics of Perth's urban form are inevitable. An indication of the nature of that change can be considered via the key strategic planning policy *Directions 2031 and Beyond* (WA Planning Commission, 2010). This policy intends to guide the planning and delivery of housing, infrastructure and services for Perth during the coming decades. The vision of *Directions 2031* (p2) is:

> "By 2031, Perth and Peel people will have created a world class liveable city: green, vibrant, more compact and accessible with a unique sense of place."

The move toward more compact cities is a world-wide phenomenon, driven by an awareness of the high economic, environmental and social costs of urban sprawl (Rydin et al., 2012). Compact cities enable more efficient delivery of essential infrastructure and goods and services. The environmental cost of land-clearing and long commute times can be alleviated by higher densities. In terms of health, compact cities are considered more 'walkable' thereby encouraging active transport and physical activity in general (Lopez, 2004).

A key platform of *Directions 2031* is to increase the volume of infill residential development. The target is a 50% increase on current infill residential development, which translates to an additional 154 000 dwellings as infill development by 2031. Eighty percent of this infill is expected to occur in the central sub-region of Perth.

The projected population growth and anticipated changes to urban form in Perth clearly have the potential to contribute to the formation of UHIs. In the context of record-breaking heatwaves around the globe and projections for more extremes of hot weather in the future, other cities have recognised the need to address this issue. The Tokyo Metropolitan Government has referred to the UHI phenomena and climate change as the 'twin warmings' facing cities in the future (Yamamoto, 2006). In a review of climate action plans of US cities, Stone (2012, p263) concluded that plans that do not include UHI mitigation strategies may "fail to adequately protect human health and welfare from rapidly rising temperatures".

The concerns reflected in the above statements are captured in Figure 50. Panel (a) shows the 'Former Climate' and the 'New Climate'. The probability of hot weather is significantly increased in the New Climate scenario. In addition, record hot weather is more likely to occur. Similar figures to Panel (a) have been published by the IPCC (Folland et al., 2001) and the Australian Climate Commission (Steffan, 2013).

Panel (b) introduces a second increase in average temperature that occurs as a result of the UHI effect. The impact on temperature extremes is evident – the hot weather and record hot weather increase even further and a new category, 'extreme hot weather', has been introduced. The need for 'new categories' of weather was demonstrated in Australia in early 2013 by the widely reported need to introduce a new colour (purple) to cater for temperatures of between 50 and 54^{o}C on the Bureau of Meteorology forecast maps.

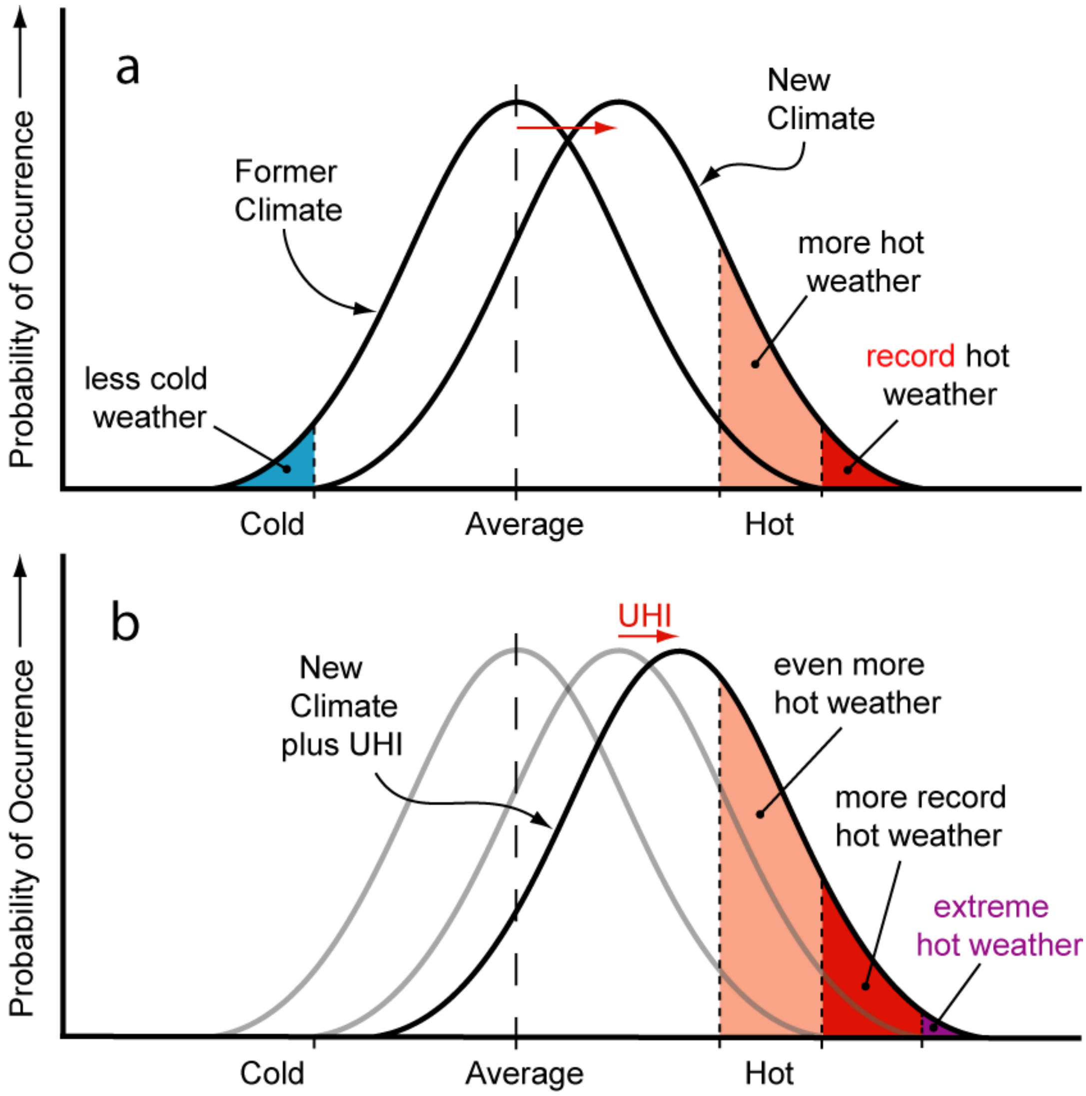

Figure 50 - The effect of climate change and UHI on extreme temperatures

The extent, to which the climate curve will move to the right, will clearly depend on the time-frame and mitigation efforts targeting climate change and the UHI effect. It must also be noted that Figure 50 only represents the impact that increases in average temperature will have – increased variations in temperature, which are also expected as part of climate change, will exacerbate this effect even further (Folland et al., 2001).

7.2.2 What is the challenge?

The background research on the Local Loop has identified a number of issues of interest related to the interaction between the urban development and heat exposure in Perth. These issues can be divided along the lines of the three main elements of UHI mitigation. Further collaboration with key stakeholders and some preliminary analysis, were used to determine the specific issue that the CCM process would address.

Presentations on the potential creation of UHI effects in Perth were delivered to the local government stakeholders from Part I, as well as staff from the Department of Planning and the Department of Environment and Conservation. Discussions at these presentations and a review of policies (§7.3) revealed that no explicit UHI mitigation policies or plans currently exist in Perth.

However, stakeholders highlighted that policies to improve the energy efficiency of buildings incorporated measures that increase the albedo of building materials and reduce waste heat. Examples include the Building Code of Australia and a number of rating systems designed to measure the energy efficiency of buildings. These measures are supported by strong economic incentives to reduce energy costs and environmental incentives to reduce GHG emissions. In contrast, responses from stakeholders highlighted that the situation with regard to urban vegetation, particularly tree canopy, was less encouraging. The following excerpt from the *Capital City Planning Framework* supported this outlook (WA Planning Commission, 2013p. 27):

> *"Evidence suggests that the urban tree canopy is under threat from lack of protection, removal, damage, disease and a changing climate. Expected increases in the density of urban form will increasingly affect mature trees in yards and verges. Loss of tree canopy is an incremental process which often goes unnoticed until it is too late to undertake preventative actions."*

These findings suggest a possible divergence between efforts to encourage 'green construction' and the natural 'green' components of urban environments. As a result, the challenge selected for the CCM study was the management of tree canopy in areas targeted for urban infill. The interaction between tree canopy in areas targeted for urban infill, ambient temperatures and health and well-being is depicted in Figure 51.

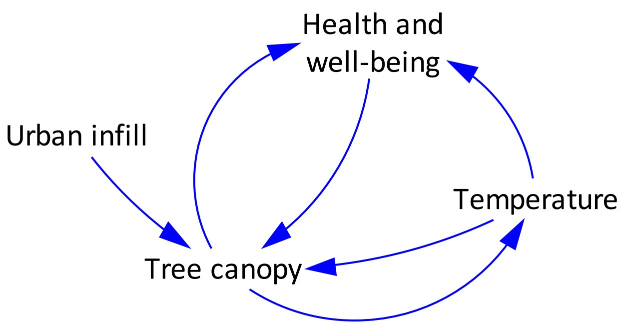

Figure 51 - The tree canopy and urban infill challenge

7.3 CA2 - What is the story?

The direct links between temperature and health and well-being were addressed during Part I of the research. The historical aspects of the relationship between urban development and tree canopy in Perth were gathered from the literature, policy documents and conversations with key stakeholders. Background information was collected on the physical, environmental and cultural variables affecting tree canopy in urban areas, and implications for the environment and human health. The challenge was also considered within the context of current planning policies. The information collected during CA2 was used to inform the objectives and format of the CCM workshop (CA3).

7.3.1 Historical development of Perth and planning policy

The Swan River Colony was established in 1829, but it was not until the discovery of gold in the 1890s in regional WA that the urban characteristics of Perth emerged. The population grew from 16 000 to 61 000 in a decade and limited transportation infrastructure meant that the majority of the population was forced to live near the urban centres of Fremantle and Perth (Weller, 2009). Development was largely uncontrolled with very few services and the result was unhealthy and over-crowded settlements. As wealth from the gold rush flowed into the government coffers, major public works such as roads, railways and provision of water services expanded. People took the opportunity to move away from the unhealthy city into newly created suburbs (Weller, 2009).

Health concerns regarding the contamination of ground-water supplies with sewage from septic tanks led to the creation of a minimum block size of a quarter of an acre ($1012m^2$) (Hedgcock & Hibbs, 1992). Conditions placed on the development and sub-division of land, including connection to mains water and the sewerage system, were implemented by the Town Planning and Development Act (1928). Gradually, as more sewered areas were developed, block sizes reduced to $600m^2$ by the 1960s (Weller, 2012). Further reductions in the minimum block size occurred as a result of the Strata Titles Act (1975) and the Residential R- Codes in 1982 (WA Planning Commission, 2003).

A historical review of the impact of planning policy and legislation on trees in Perth has been conducted by Brunner and Cozens (2012). The review, indicated that regulation and protection of trees in urban areas has been given limited attention in planning policy. Given that the Town Planning and Development Act (1928) was enacted at a time when Perth had a population of 400,000 and featured quarter-acre blocks with ample room for trees, it is perhaps unsurprising that the Act did not include any reference to trees. In reality, little value was placed on trees. Front gardens were typically English in design and shade trees were rarely planted as they interfered with the neat, ordered street facade (Weller 2012).

Clearing of land during the first half of the century was labour-intensive and tended to retain the natural contours of the land and some vegetation. This changed in the post-World War II period with the advent of heavy earth-moving machinery that flattened natural contours and clear-felled bushland (Weller, 2012). No limitations were placed on land clearance (Brunner and Cozens, 2012).

From the mid-1950s, as Perth's population increased, greater emphasis was placed on the density of dwellings, but mention of trees was restricted to multi-residential development. "Green" references were primarily with respect to the protection of bushland and provision of public open-space for recreational purposes, but urban trees were not considered as a separate entity (Brunner and Cozens, 2012). By the 1990s concerns emerged regarding the continued expansion of the coastal sprawl which was encouraged by the Corridor Plan of the 1970s. Metroplan (1990) called for more consolidated urban development and this continued with Network City and Directions 2031 (2010). City-wide targets or control for urban trees were not mentioned as part of these policies. Brunner and Cozens (2012, p1) concluded that under current policies "the protection of mature vegetation and trees in WA has been afforded little time or consequence."

7.3.2 Evidence of tree canopy changes in Perth

Evidence in Australia indicates that decreases in urban tree canopy are occurring primarily on private land (Coutts et al., 2010; Department of Sustainability and Environment Victoria, 2011; Hall, 2010). Previous studies in Perth also support the premise that tree canopy levels are being affected by urban infill patterns. Figure 52 shows the change in vegetation levels and hard surfaces in Como – an inner city suburb of Perth (Brunner & Cozens, 2012).

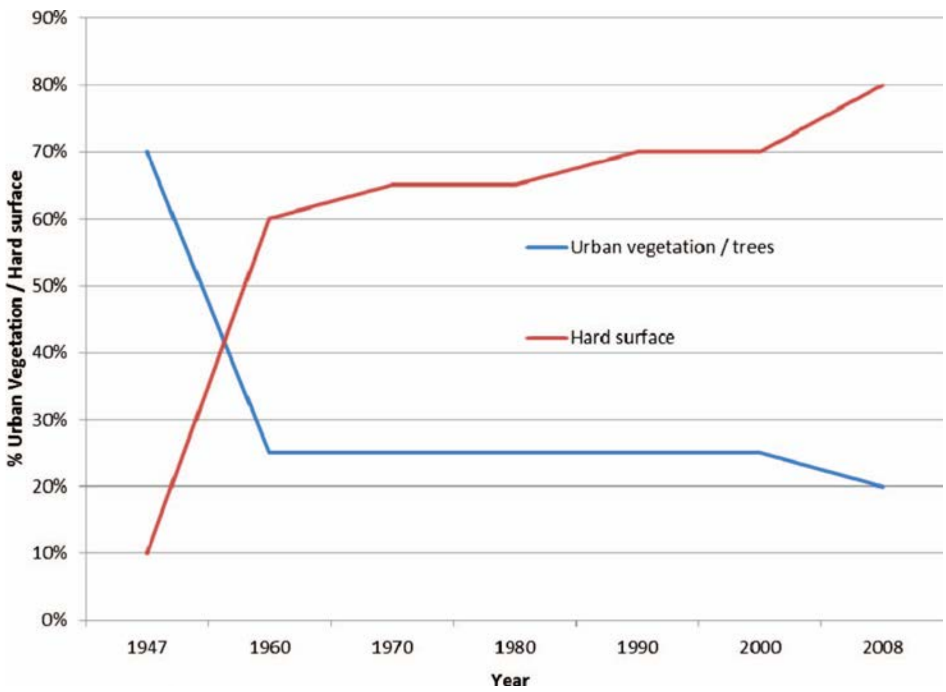

Figure 52 - Changes in vegetation and hard surfaces in Como

The hypothesis of the authors is that after the large loss of vegetation that occurred during initial development (1947 to 1960) vegetation remained relatively stable for a period of approximately 40 years. This period represented a period of dynamic equilibrium where the rate of tree canopy removal that occurred as a result of ongoing development was balanced by the growth of trees planted as part of earlier development. The reduction in vegetation that became apparent around the year 2000 coincided with a change in the type of infill development. The previous pattern of building new houses at the rear of a block was replaced with demolition of the original house and sub-division into two long, narrow blocks, both with a street frontage. Typically, all vegetation, including mature trees was removed. Coupled with the trend to larger houses, opportunities to plant trees with significant canopy were reduced. This suggests that rather than entering a new cycle of dynamic equilibrium, where growth from new plantings contributes to canopy, the limited opportunities to plant trees will result in a continual decline of canopy levels.

Figure 53 provides additional photographic information on tree canopy loss in the City of Melville. The original image, selected by staff at the planning department of the City of Melville as an area with significant urban infill activity, was analysed for vegetation cover and height by staff at the CSIRO Urban Monitor group (Peter Caccetta, personal communication, 2013). The green represents vegetation and the brightness indicates height. Urban infill is concentrated in the area adjacent to the major road running from left to right on Figure 49. These areas can be readily identified by the close proximity of roofs and the lower levels of bright green, compared to areas further away from the main road where levels of infill are lower. Two examples of such areas are highlighted by the white rectangles in Figure 53.

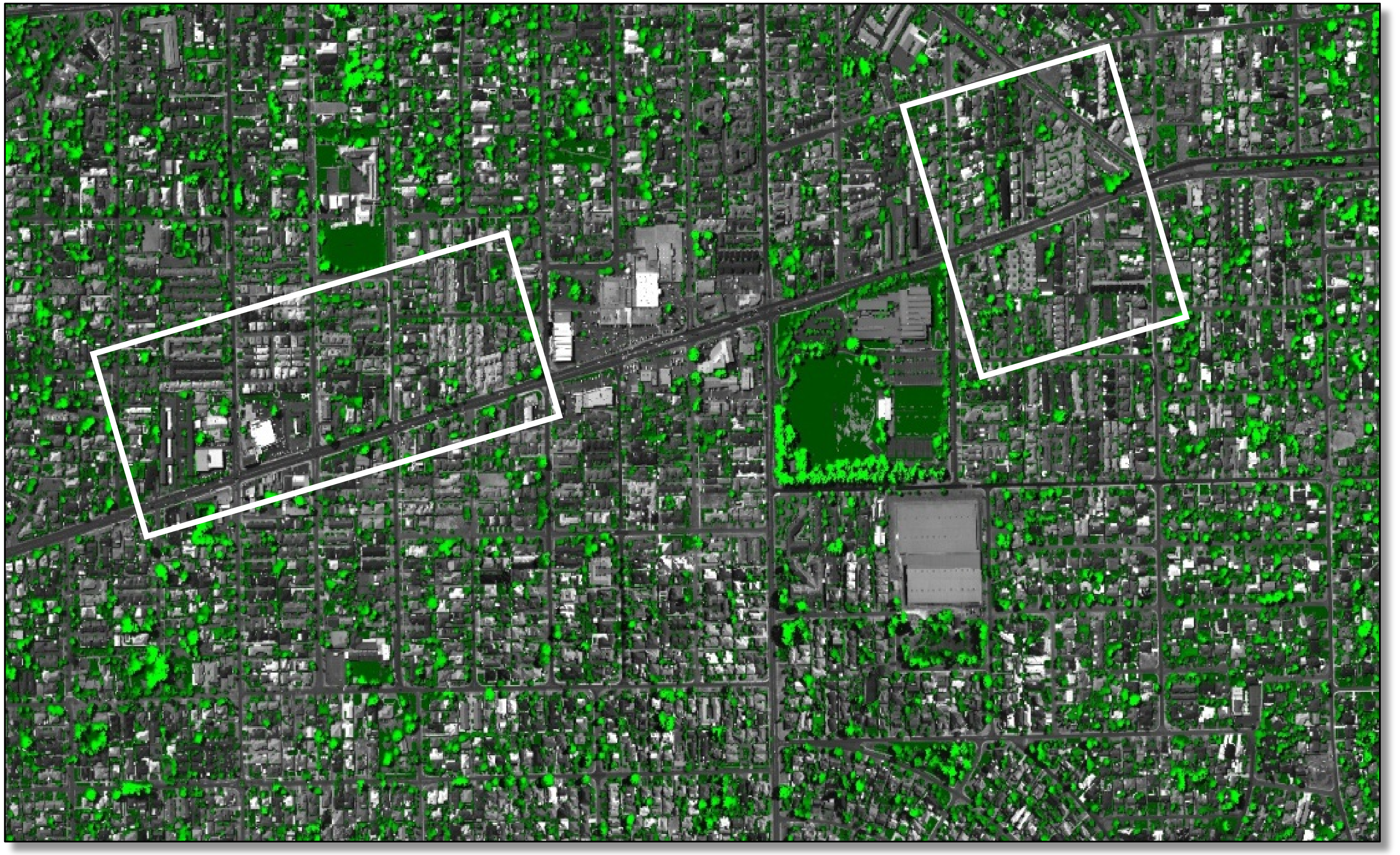

Figure 53 - Vegetation height in Melville, 2007

An example of typical urban infill is demonstrated at a finer scale in Figure 54. The completed development highlights the limited opportunities for replacing the trees that were removed during site preparation. The lack of natural shade and vegetation and the increase in hard surfaces are likely to result in a significantly hotter microclimate for these dwellings.

Figure 54 - Example of urban infill in Perth

(http://www.nearmap.com/Accessed Oct 2011)

7.3.3 Content analysis of current policy

This section reviews a range of current planning policies to investigate the extent to which interactions between the urban environment (particularly vegetation), climate and health are considered. The focus is on state and city-wide planning policies, as these direct the general aims and planning directions of the various local planning strategies.

The policies reviewed were:

- Directions 2031 (D2031)
- State Planning Policy (SPP) 3 – Urban Growth and Settlement.
- SPP 3.1 – Residential Design Codes and Explanatory Guidelines
- Liveable Neighbourhoods
- Capital City Planning Framework

The review was undertaken by applying a coding scheme to each of the selected documents. The coding scheme was based on the interactions between vegetation, climate and health and incorporated key words as shown in Figure 55. Similar approaches have been used in textual analysis of the extent to which health is incorporated into planning strategies of major Australian cities (Wheeler, 2011). The full results of the initial textual search are provided in Appendix E. The following paragraphs summarise the main findings of the search.

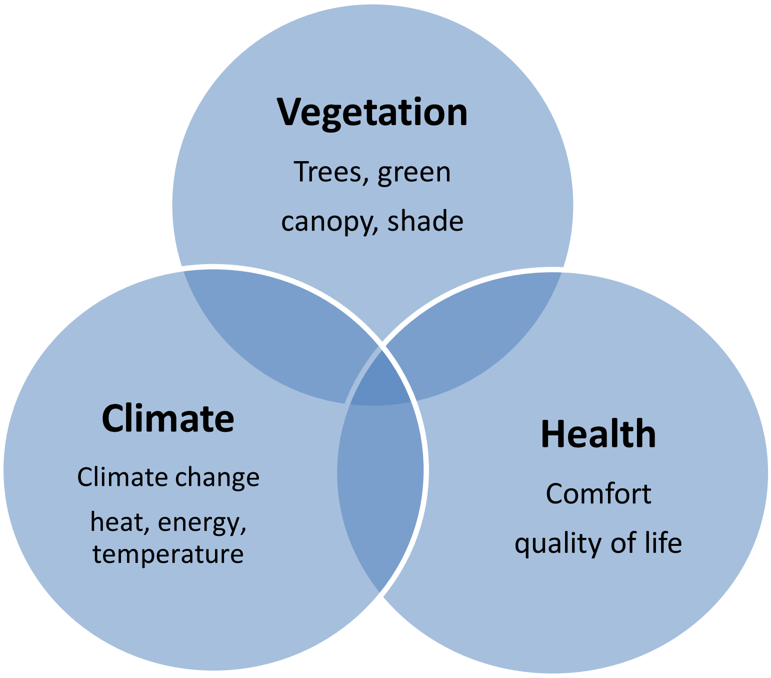

Figure 55 - Coding scheme for textual analysis

Directions 2031 and Beyond (2010) – D2031 is the highest level of strategic metropolitan planning to guide the development of more detailed polices, strategies and plans. The vegetation code returned a total of four matches. The focus was on the importance of a green network and a green city, but there were no entries for trees, canopy or shade. The need to mitigate and adapt to climate change was mentioned five times throughout the document, however no mention of climate change was made in the Executive Summary. Incorporating sea-level increases into land-use planning policies was the only specific physical aspect of climate change mentioned. Heat and temperature were not mentioned. The references to energy were focused on issues of sustainability, particularly the transportation energy savings achieved by more compact cities. Health was focused on access to health services and greater use of more active transport. While no specific mention of the health impacts of climate change was made, expectations related to 'personal comfort' were mentioned.

SPP 3 Urban Growth and Settlement (2006) – this policy does not include specific reference to vegetation, green, shade, trees, canopy, climate change, heat or temperature. The need to manage urban development in recognition of relevant climatic constraints is stated. As with *D2031*, the importance of energy efficiency with respect to sustainability and more efficient land use is noted. The role of the planning system to 'influence quality of life of communities by integrating the social, economic and environmental consequences of land use and development' is stated.

SPP 3.1 Residential Design Codes and Explanatory Guidelines (2010) – The 'R-Codes' contain the 'rules' that apply to residential development. Requirements for landscaping are limited to group or multiple dwellings, but no specific mention is made of a requirement for trees. The protection of existing trees is 'desirable' and the use of trees for screening is mentioned. The importance of shade for energy efficiency is noted, but the focus is on built structures such as verandahs and pergolas. The R-Codes state the need for climate-sensitive design, but no specific mention is made of climate change or high temperatures. The objective of climate-sensitive design is "to optimise comfortable living and facilitate sustainable development". The stated aims under this objective are reduced energy consumption and optimising and protecting solar access. There is no mention of the role of vegetation in affecting microclimates. Mention of health is limited to the general need for comfortable living and pedestrian comfort.

Liveable Neighbourhoods, 3rd Edition (2007) – the impact of this non-statutory policy is limited to large urban infill projects and greenfield sites. It will therefore have limited relevance for smaller urban infill developments, but it nevertheless provides an indication of urban elements relevant to the topic. It is stated that lot shape and orientation should "provide space for appropriate planting for microclimate management and energy conservation." The connection between street trees, canopy, pedestrian comfort and amenity is a dominant feature, with trees mentioned 39 times. No specific mention is made of climate change, heat or temperature. Health considerations are an important facet of 'Community Design' and refer predominantly to urban environments that support physical activity, safety and a sense of place.

Capital City Planning Framework (2013) – released in early 2013, the Framework provides a key planning strategy for Central Perth. It targets an area of 12km x 12km around the central business district – an area where a substantial proportion of urban infill is planned. The search indicates a significant escalation of the inclusion of tree canopy and an awareness of the link between urban design and planning for a more climate-resilient city. The framework defines 10 key objectives derived from the *Directions 2031* vision, including "Build robustness against climate change". Unlike the previous policies reviewed, there is specific mention of the role of the built environment and landscape in providing protection against increasing temperatures in Perth. The links between climate change and health are also explicit and includes a healthier city where ‘the city’s climate is ameliorated by natural spaces, a tree canopy and innovative building design’ (p. 28). The importance of urban tree canopy is recognised in encouraging pedestrian movement, reducing heat and providing protection from the sun and visually appealing streetscapes.

With respect to energy, the Framework has multiple references to the need for greater energy efficiency, including transportation and solutions that integrate infrastructure, open space, vegetation and buildings. Key excerpts from the Framework are provided below.

Urban Tree Canopy (p. 10)
Trees are located in streets, verges, yards and on other private land, and collectively they are referred to as an urban tree canopy. They are a hallmark of central Perth’s character and the most evident aspect of our green fabric outside of parks, open spaces and reserves. The tree canopy varies considerably across Perth.

Urban trees (p. 27)
Urban trees have been shown to add value to properties, and provide other tangible economic benefits such as reduced building heating and cooling costs. A well-treed environment is good for human health, providing contact with the natural environment and filtering and deflecting urban noise. The shade provided by trees is important for safe outdoor activity, protecting people from extreme temperatures and ultra-violet light. Trees help to clean the air by absorbing pollutants, ameliorate the extremes of temperature, surface water run-off and erosion

Where the relationship between trees and buildings is well designed, this enhances places for people and wildlife and limits the environmental footprint of the city. Indigenous street trees, and some non-native trees, support local biodiversity by providing roosting and nesting sites, and act as important stepping stones for birdlife between parks and reserves.

Urban trees (continued) (p. 27)
Evidence suggests that the urban tree canopy is under threat from lack of protection, removal, damage, disease and a changing climate. Expected increases in the density of urban form will increasingly affect mature trees in yards and verges. Even in areas where density is unchanged, the practice of clearing entire lots prior to redevelopment can result in the unnecessary loss of significant trees. Loss of tree canopy is an incremental process which often goes unnoticed until it is too late to undertake preventative actions. Efforts to counteract these changes are hampered by a lack of data and of a strategic, linked approach guided by common principles. Some advances are being made, for example some local governments have adopted tree strategies and the undergrounding of power lines provides an excellent opportunity to retain and plant trees.

In addition, the inclusion of heatwaves was reviewed in three documents related to planning for natural hazards or climate change:

- WESTPLAN Heatwave
- SPP 3.4 – Natural Hazards and Disasters
- WA Local Government Association (WALGA) Climate Change Management

WESTPLAN Heatwave (2012) – the State Emergency Response Plan for heatwaves acknowledges that extreme heat events are likely to become increasingly common as a result of climate change. It highlights that heatwaves have resulted in more deaths in Australia than any other natural hazard. The potential for UHI effects to increase vulnerability to health effects of heatwaves is recognised. The potential for significant economic losses by impacts on infrastructure (roads, railways and bridges), power supply and industry is also noted.

SPP 3.4 – Natural Hazards and Disasters (2006) – the objective of this State Planning Policy is to include planning for natural disasters as a fundamental element of all planning documents. Floods, cyclones, storm surge, severe storms, landslide, bush fires and earthquakes are mentioned. However, there is no specific mention of heatwaves. Section 5.1 states that planning strategies should take into account the possibility of hazards which result from a combination of elements, such as climate, the built environment and “long-term changes to risk such as climate and land-use changes” (p. 1534).

WALGA Climate Change Management (Draft) (2012) **–** these draft guidelines focus on local government responsibilities with respect to climate change. The guidelines refer to the Commonwealth Position Paper, ‘Adapting to Climate Change in Australia’, that determines local government must take future climate change into account with respect to "decisions about land use, infrastructure design, location and management of parks and reserves and rules about water management." They provide a rationale for the responsibility via interpretation of a range of current policies including the Planning and Development Act (2005) and the Natural Hazards and Disasters State Planning Policy. The draft guidelines include a discussion of heatwaves as a “naturally occurring event which poses a threat to human health, life and the built or natural environment” (p. 17). Suggested requirements include the retention of trees and vegetation as an integral component of climate-responsive design across all levels of planning. Examples include clearing controls on sub-divisions, ‘green buildings’ and the provision of green space to aid cooling, although the latter is confined to high density and commercial areas. The guidelines recommend that planning proposals require information regarding solar efficiency and breezeway design, but make no specific reference to the role of canopy.

7.3.3.1 Summary of current policy review

The majority of references to climate change in the reviewed documents focus on mitigation and the need for increased energy efficiency. Particular emphasis is placed on the transport efficiencies of compact cities. References to building efficiencies are generally focused on issues of siting, access to solar radiation, and “green buildings.” The potential loss of tree canopy as a result of urban consolidation is only mentioned in two non-statutory documents – the *Capital City Planning Framework* and the *WALGA Climate Change Management Draft Guidelines.* Both acknowledge the importance of urban tree canopy in controlling microclimates and the threats facing tree canopy in Perth.

Climate change mitigation in the reviewed documents was focused primarily on reducing transportation emissions and promoting more “green buildings”. Although ambient temperatures are a critical determinant of energy use, the effect of urbanisation on ambient temperatures is largely overlooked. Peak energy-demand in Perth occurs during heatwaves and is driven primarily by the use of air-conditioners, which account for almost one third of peak power consumption (Western Power, 2012a). The impact on peak energy-demand has significant implications for electricity generation, transmission and distribution. The Productivity Commission (2013) estimates that providing the necessary infrastructure to meet the top hours of peak demand (less than 1% of time) accounts for around 25% of electricity charges. The potential for power cuts during peak demand poses significant increases in health risks, particularly for those reliant on air-conditioning (Broome & Smith, 2012). Figure 56 shows that a 20% increase in average summer energy load per household has occurred in Perth between 2001 and 2010 (Western Power, 2012b). Expectations are that projections for more days over 35°C and more frequent and extreme heatwaves will result in more pressure on peak demand. The increase in peak energy-demand in Perth is forecast to grow 25% faster than the increase in average demand (Weller, 2009). These figures highlight the need to consider interactions between urban planning and ambient temperature, for economic as well as health and environmental reasons. Among the planning documents reviewed only the *Capital City Planning Framework* and the WALGA *Climate Change Management Draft Guidelines* (both non-statutory) specifically mentioned the issue of UHI effects. No explicit UHI mitigation policy currently exists in the statutory planning policies reviewed.

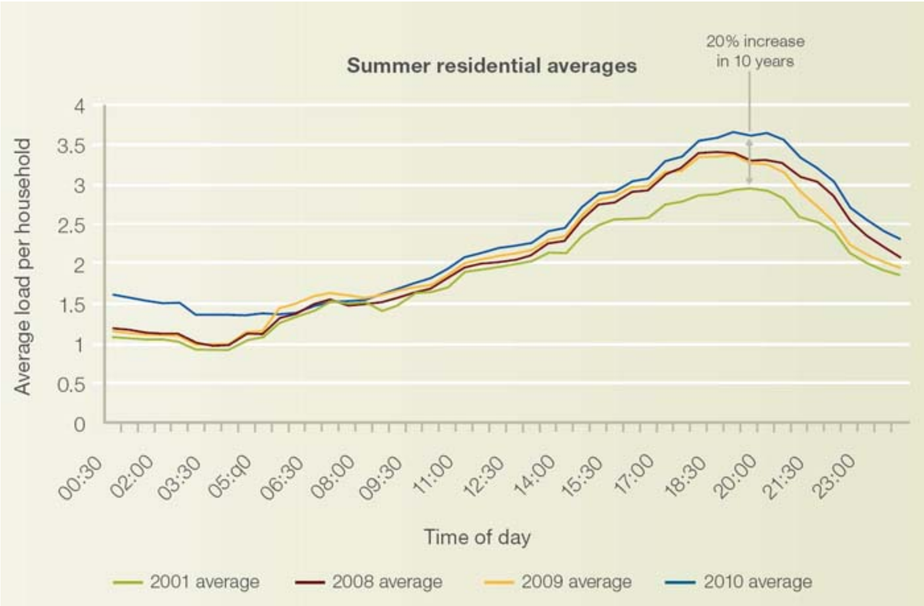

Figure 56 - Perth summer energy use per household

The exclusion of heatwaves from the *Natural Hazards and Disaster Policy* suggests that the link between urban form and urban heat is not afforded a high priority by the planning sector. This is despite the recognition of strong links between heatwaves and infrastructure in *WESTPLAN Heatwave*. The tendency to downplay the risk associated with heatwaves was acknowledged in the Natural Hazard Risk in Perth study which stated "heatwaves are probably the most under-rated weather hazard in Australia" (Department of Industry Tourism and Resources, 2005, p. 51). This is linked to the fact that heatwaves, in contrast to other hazards such as flooding and bushfires, are viewed as a 'passive' hazard. Other Australian reports on heatwaves have stated that ensuring buildings and infrastructure in cities are more resilient to heat events is an important public policy issue, particularly with regard to protecting vulnerable members of the community (Commonwealth Government, 2011). In light of this evidence, the omission of heatwaves from the SPP for Natural Hazards and Disasters is a significant concern.

7.3.4 CA2 conclusion

In terms of policy history, climate change is a relatively new issue. Previous planning for climatic variables has been made on the assumption of a relatively stable climate, where historical records were relied upon for future planning. Even relatively recent planning policies such *as Liveable Neighbourhoods* (2007) and the R-Codes (2010) make no specific mention of climate change. Given that current policies are based on assumptions and experiences that are not indicative of future climate, this review suggests that planning policy and practices need to incorporate more explicit consideration of a hotter future.

The evidence is that tree canopy levels in Perth are decreasing and current policies are not adequate to prevent further loss. Studies of the urban energy balance indicate that this will lead to urban heat island effects, which have the potential to increase human exposure to extreme heat in Perth (United States EPA, 2008). This outcome suggests that current policies may contribute to a city that, in the future, is more sensitive, rather than more resilient, to climate change.

As an aside from the above findings, background discussions with stakeholders indicated that there was a level of political sensitivity due to the possibility that the research be construed as 'anti-consolidation'. Awareness of this possibility was an important revelation and care was taken throughout the research to ensure that participants understood the research was focused on understanding the interactions between urban consolidation, tree canopy, climate and health in Perth. Furthermore it was clarified that the intent of this improved understanding was to inform more effective *adaptation to climate change and better public health outcomes for urban development, not to advance either a 'pro' or 'anti' consolidation sentiment.*

7.4 CA3 – Can I see how you think?

This activity, which is designed to help individuals to mesh their mental models of the challenge being addressed, was conducted in a workshop setting. The workshop was held at the head office of the Department of Planning. The support of this major stakeholder was pivotal in establishing credibility and attracting stakeholders from other sectors. The target workshop number was 36 – consisting of six tables of six. Care was taken to ensure that workshop participants represented interests from the health, planning, development and environment sectors. In addition, a mix of representation from state and local government, organisations and the private sector was achieved. Five local governments, including the three that took part in the HIA, were represented at the workshop. The full list of participants and their affiliations are listed in Appendix G. A selection of the workshop results was compiled in a report entitled 'Cool communities: Urban trees, climate and health' (Brown, Katscherian, & Carter, 2013). The workshop will be referred to from this point forth as the 'Tree Canopy Workshop'.

The Tree Canopy Workshop was conducted over 4 hours on March 17th, 2013. The full list of participants is included in Appendix G. A pre-workshop package that contained background information and a survey was developed and distributed to each participant the week prior to the workshop (Appendix H).

The aims of the workshop were to:

- Identify key variables linked to tree canopy and the relationships between them
- Establish an integrated view of the issues surrounding tree canopy
- Increase understanding of system behaviour to inform effective management of trees as part of the vision for a compact, green and liveable city.

Participants were organized into tables of six, with at least one representative from each sector per table. A presentation provided a brief background to the day and a summary of the activities.

7.4.1 Individual influence diagrams

Participants were given an explanation of how to construct influence diagrams, as outlined in Chapter 6. All participants were instructed that 'Tree Canopy' (in areas targeted for urban infill) was the focus variable. In addition, participants were told to assume that over the next 50 years Perth would experience climate change, significant population growth and a policy environment geared toward urban consolidation.

A summary of instructions was visible to participants throughout the activity. Diagrams were recorded post-workshop using the Vensim™ software package. The main purpose of these diagrams is to capture the mental model of each individual before proceeding to the pair-blending exercise. As such, detailed analysis of influence diagrams in CCM is generally undertaken at the pair-blended stage rather than individual diagrams. Nevertheless the individual influence diagrams did raise several issues worth mentioning.

The first observation was that a significant number of participants struggled to identify links between the 'driver' and 'affected' variables. Many participants were clearly more knowledgeable on one 'side' of the diagram. For example, Figure 57 is an individual influence diagram of a representative from the planning sector. This diagram is focused on the 'driver' variables and does not include any explicit mention of 'affected' variables – as a result no feedback between tree canopy and 'driver' variables was identified. A mix of environmental, social and economic drivers with feedback loops (shown in red) was identified. This participant's mental model of the system is focused on his/her experience of the variables that influence tree canopy levels with minimal consideration of the effects of tree canopy.

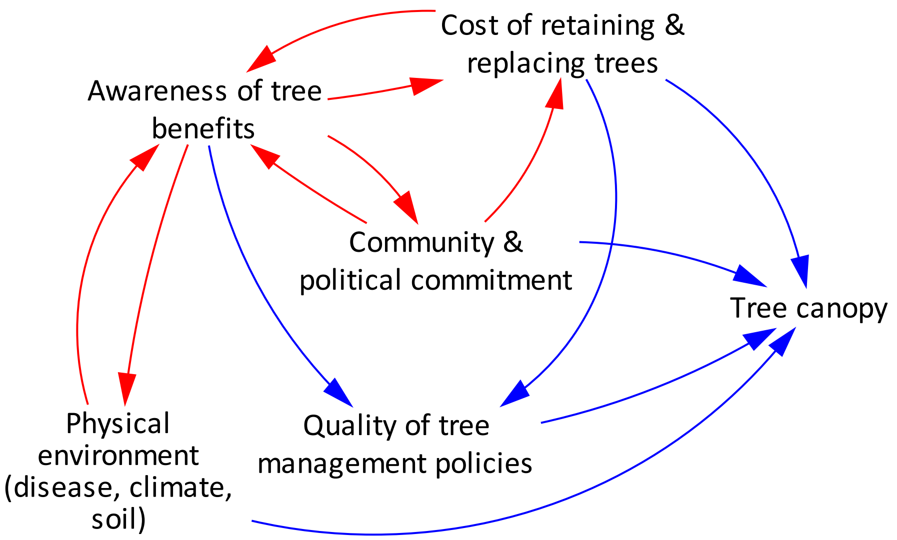

Figure 57 - Individual influence diagram: planning participant

In contrast, the emphasis of Figure 58, from a health sector representative, is clearly on the 'affected' variables. This participant's mental model of the system is focused on his/her experience of the impacts of tree canopy on health. The only feedback link to tree canopy is via the physical variables of water quality and biodiversity. In general this viewpoint is focused on the physical aspects of tree canopy, with no consideration of policy variables.

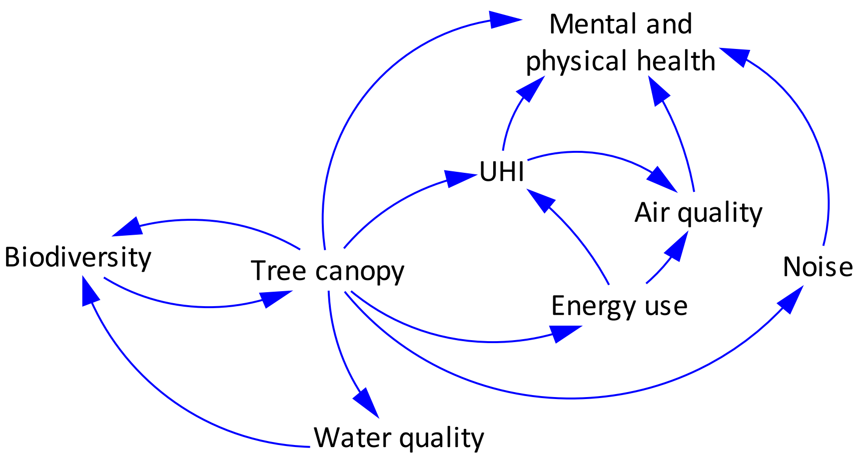

Figure 58 - Individual influence diagram: health participant

The final example shows the viewpoint of a participant representing the development sector (Figure 59). This diagram is more 'balanced' than the previous examples and has identified the feedback between tree canopy effects and policies influencing tree canopy.

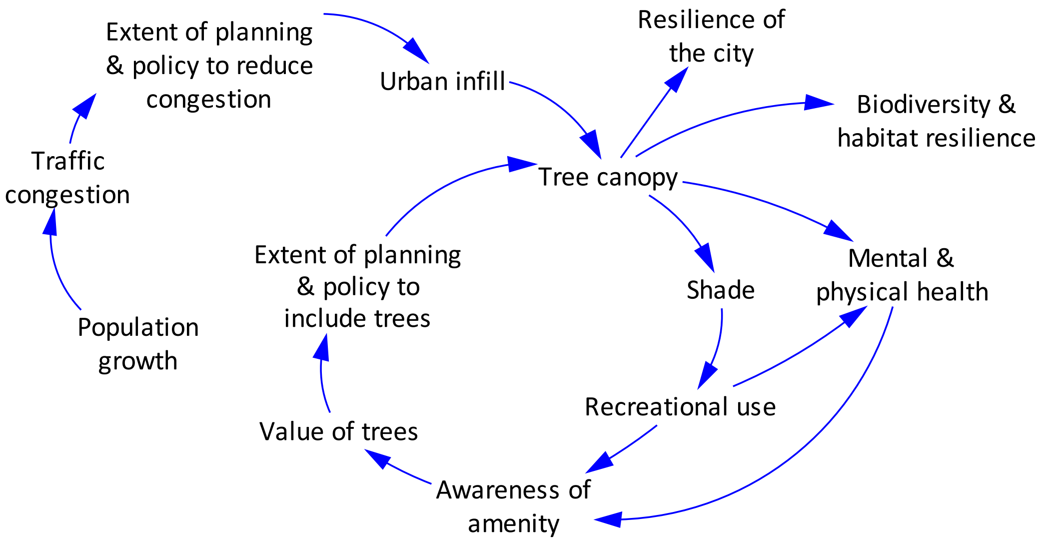

Figure 59 - Individual influence diagram: development participant

There was significant variation between individual diagrams and the above examples are not representative of a particular sector. Rather, the examples serve to demonstrate the significant variation and limitations of individuals' mental models.

7.4.2 Pair-blended influence diagrams

People were assigned a partner from a different sector and asked to explain their view of the issue as captured by their individual influence diagram. Instructions were provided on how to construct the pair-blended diagrams. A total of 16 pair-blended diagrams were constructed. A selection of diagrams is presented and discussed below. These diagrams were considered to represent the range of views captured by the 16 diagrams.

Minor adjustments were made to the diagrams post-workshop – these included grouping of similar variables and rephrasing variables in terms of neutral stocks. If a variable was expressed as ‘reduction in shade’ it was rephrased as ‘extent of shade’ (in keeping with CCM guidelines). In situations where the meaning of variables was unclear, participants were contacted for clarification. The diagrams have been labeled and grouped according to sectors. The description of variables and links between them was informed by discussions at the workshop or from the literature.

- **Health and Planning**

Figure 60 expresses a dynamic hypothesis developed by participants from the health and planning sectors. The effects of tree canopy have been disaggregated into a number of physical and social effects that each influences the public perception of tree benefits. This leads to a change in the community demand for trees, which ultimately feeds back to influence tree canopy levels via policy and market mechanisms. Pressures from the market place and policies will influence the extent to which the design and practices of development incorporate trees into the urban landscape.

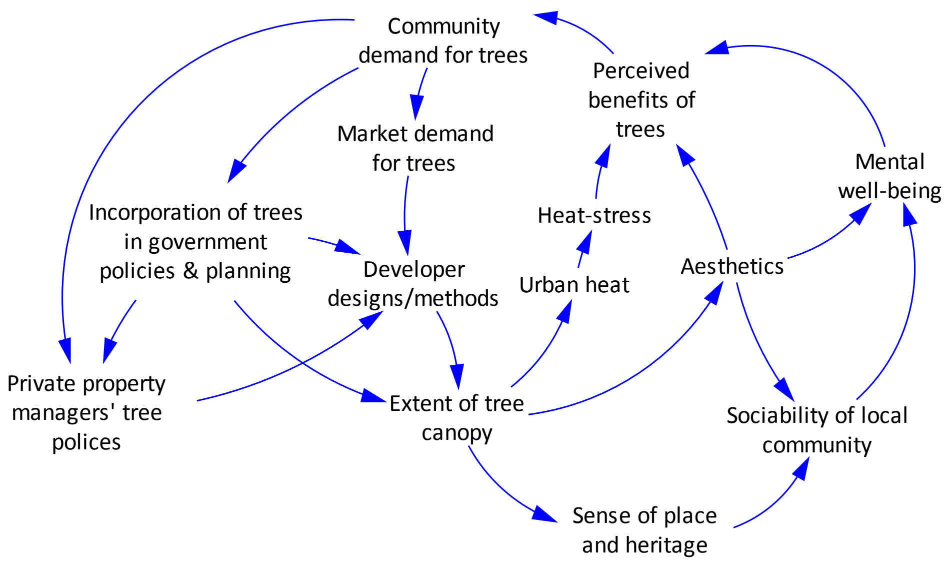

Figure 60 - Health and Planning influence diagram

The intent of this diagram was to convey that a reduction in tree canopy levels will lead to a greater awareness of the benefits that tree canopy provides. This is an example of a balancing feedback loop, where tree canopy reductions will ultimately be countered by the feedback from the ‘community demand’ variable.

- **Health and Development**

The dynamic hypothesis developed by a pair from the health and development sectors is shown in Figure 61. The health and well-being effects of tree canopy were expressed as a single broad variable. The participants provided examples of this as ‘provision of shade that increases thermal comfort, reduces UV exposure and influences physical activity and; the provision of visual amenity that contributes to sense of place’. As with the previous example, a feedback loop was depicted via community expectations of trees in urban environments.

The priority assigned to trees during planning was considered as a comparative measure against other planning/design elements. For example, the expectation for other design elements such as car parking spaces or size of houses will also influence the priority given to trees.

The issue of control of privately owned land was included in this diagram. Private ownership of land and the development of single rather than grouped lots of land, reduce the ability to coordinate the type of built form. This includes the opportunity to incorporate trees into the design of urban infill. This is supported by the evidence gathered in CA1 and CA2. This hypothesis provides an additional balancing feedback loop, whereas the priority assigned to trees during planning processes increases, some form of public control of trees in private ownership is introduced. These processes could include changes to regulations such as tree protection ordinances. This control could also extend to planning elements that impact on the ability to retain or plant trees such as restrictions on building height or placement of built structures.

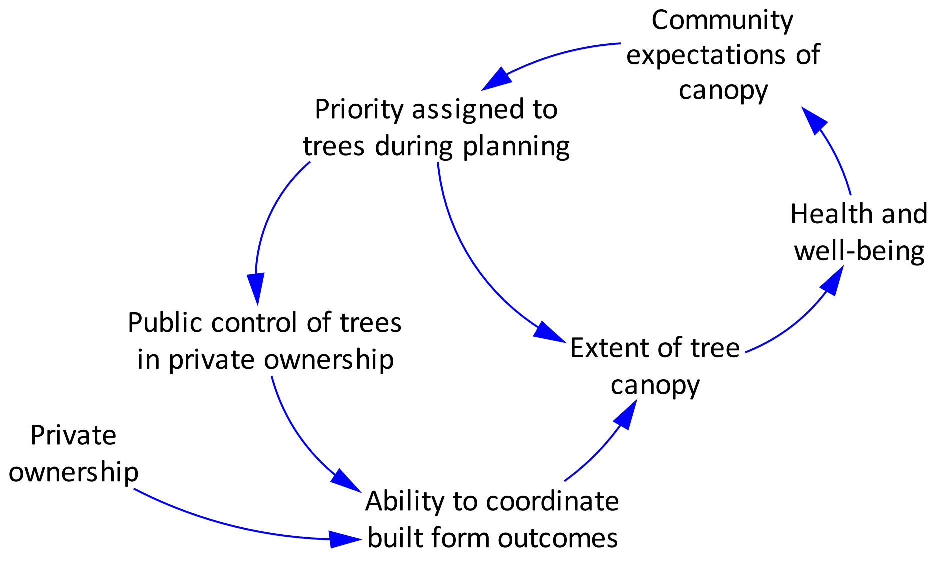

Figure 61 - Health and Development influence diagram

- **Development and Environment**

A shared viewpoint of participants from the development and environment sectors is shown in Figure 62. As urbanisation increases, there are more space demands for services and infrastructure such as housing, roads, driveways and utilities. This leads to competition for space. As the availability of space is reduced, policies and practices will affect tree canopy either directly (such as street tree policy) or indirectly (drainage, essential services). The extent of tree canopy will influence the available space for other services. This 'loop' is essentially about a number of variables that in some circumstances are viewed as 'competing interests'. A related workshop comment is that protection or provision of trees is down the 'pecking order' in terms of infrastructure requirements.

There is another feedback loop, where the extent of tree canopy influences temperature, which in itself can influence the extent of tree canopy. For example, if an UHI effect of 2-3°C occurs this may affect the health of trees, and therefore the extent of canopy, which in turn affects temperature. The change in temperature then has flow-on effects to *Quality of life* which includes social and health variables. It was also recognised that the extent of tree canopy will have other influences on *Quality of life.*

Once again, the participants saw the community value of trees as a key variable in influencing tree canopy via a combination of resources for tree management and changes in the extent to which other policies impact on trees.

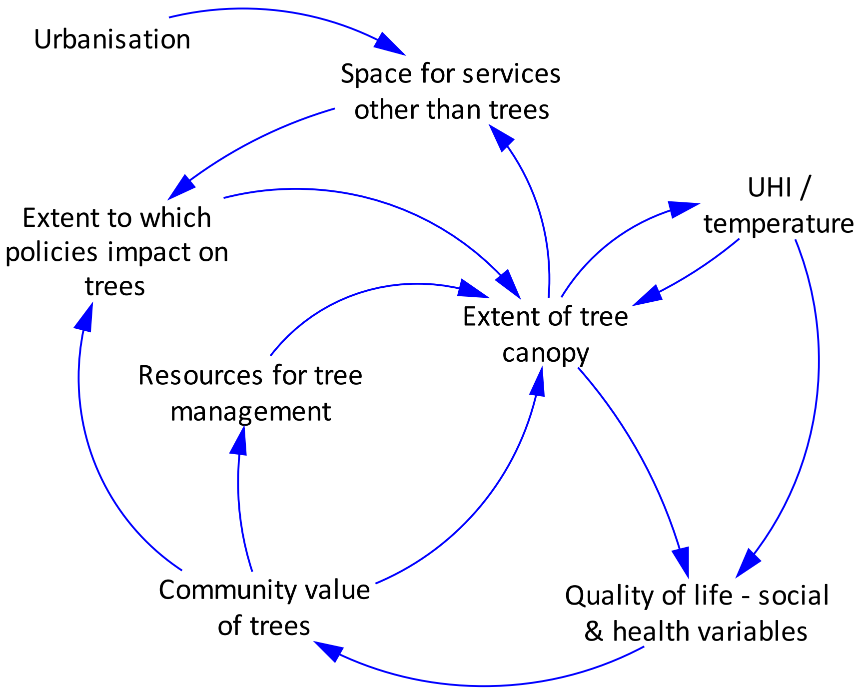

Figure 62 - Development and Environment influence diagram

- **Planning and Environment**

Figure 63 depicts how management practices can be influenced by different factors over time. Urban infill and development has a direct influence on the extent of tree canopy. Tree canopy loss leads to reductions in shade and higher temperatures, which both have detrimental effects on liveability. Liveability is defined in the *Capital City Framework* as 'the capacity of a place to deliver the everyday qualities of life to which most of us aspire'. This includes qualities such as accessibility to amenities; a safe and healthy living environment; a sense of community; vibrancy; and choice (Department of Planning, 2013).Urban character, which could be included as part of liveability, was selected by the pair as a separate variable. Increases in heat can escalate as higher energy use (air-conditioning) releases more waste heat into the environment. This section of the diagram represents important aspects of the UHI effect and also recognises the impact on the *Global Loop* where higher energy use results in increases in greenhouse gas emissions that contribute to climate change. Over time, the extent of tree canopy will be influenced by climate change.

As these effects are realised, public pressure is exerted on management practices to counter the original reductions in tree canopy. The types of processes include members of the community lobbying local government or local politicians to retain trees in their community; formation of community groups that increase awareness of the issue through direct involvement in the community, and consumer pressure for property in areas with good tree cover.

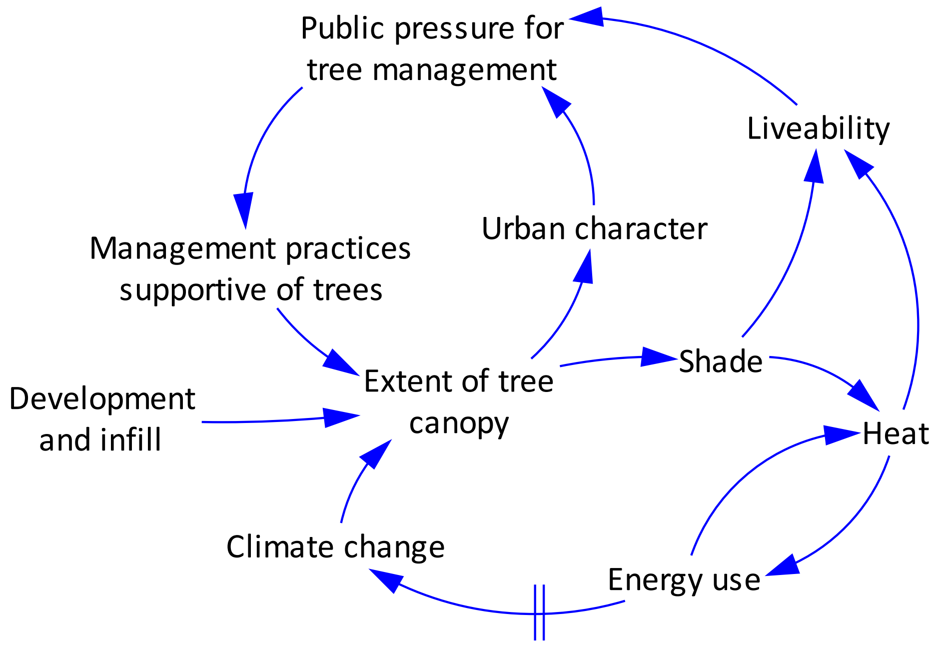

Figure 63 - Planning and Environment influence diagram

Another influence diagram for a 'planning and environment' pair is shown in Figure 64. This viewpoint highlighted the effect of tree canopy on the heat-island effect and public health in general, but did not identify any feedback loops from health. Visual amenity was seen as the key link between tree canopy and the value given to trees. The level of importance given to trees as an element of urban design will be influenced by the overall value given to trees.

This diagram also illustrates that while greater public demand for trees can lead to increases in tree canopy, the financial costs associated with tree inclusion in the urban environment will also influence the extent of tree canopy. As with earlier examples from other sectors, these participants also identified that urban consolidation impacts on the availability of natural resources such as land and water.

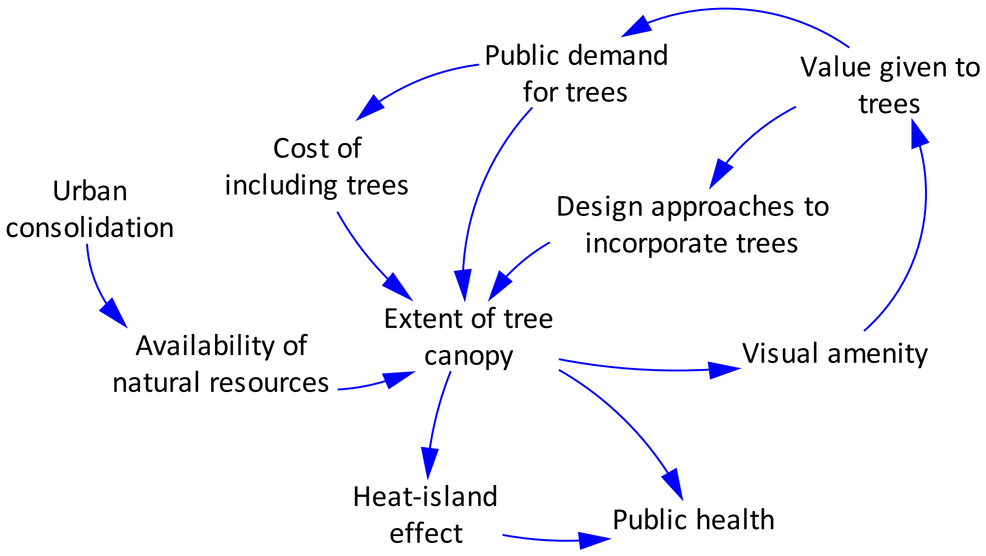

Figure 64 - Environment and Planning influence diagram (2)

- **Health and Environment**

The hypothesis represented in this influence diagram (Figure 65) is that the extent of tree canopy affects a range of ecological services (including shade, visual amenity and reduction in heat and air pollutants) that has flow-on effects to health and well-being. As these effects are realised, this leads to greater awareness of the benefits of trees on quality of life, which affects the status given to trees by the community.

As with previous diagrams, Figure 65 highlights that the community status afforded to trees acts to influence canopy levels via both policy and market mechanisms.

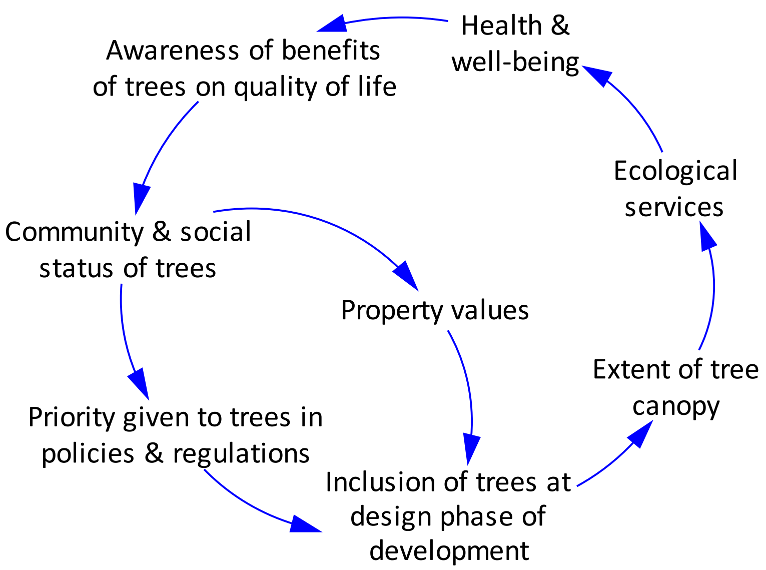

Figure 65 - Health and Environment influence diagram

7.4.2.1 Summary of pair-blended diagrams

The pair-blended influence diagrams from the workshop share common themes. All diagrams include an indicator of community awareness of the importance of trees. Whether labeled as awareness, demand or expectations, this variable fed back to affect tree canopy levels via policy or market mechanisms.

Secondly the intent of most diagrams was to show that a decrease in tree canopy would lead to a decrease in some benefit. The selection of benefit varied significantly between stakeholders. The effect on health and well-being occurred via a large number of pathways such as visual amenity and 'ecological services' such as regulation of microclimate, air quality, water quality and shade. All of the diagrams assumed that a decrease in health and well-being or environmental quality would lead to a greater awareness of the benefits of tree canopy that would eventually slow down tree loss.

The limitations of the individual diagrams were largely overcome by the pair-blending process. The shared understanding of policy and market variables features strongly in the pair-blended diagrams. A more detailed analysis of the feedback mechanisms captured by these diagrams was undertaken in CA5.

7.4.3 Focused dialogue

The pair-blended diagrams were presented and discussed at table groups. The diagrams were also displayed around the room during morning tea, enabling participants to view a selection of diagrams from other tables. After viewing and discussing the pair-blended diagrams participants returned to their original tables to agree upon eight key variables that they believed played a critical role in tree canopy management in urban infill areas. Each person was then provided with three coloured stickers, representing a range from most important (3 points) to 2nd most important (2 points) and 3rd most important (1 point)..

Table 60 summarises the variables and points from each table. Post-workshop, the variables were classified according to four main categories: Health/Social, Economic, Environment and Planning, which are colour-coded as shown at the bottom of Table 60.

Table 60 - Total score for all variables

Variable	1	2	3	4	5	6	Sum
Social & community values/expectations	10	4		5	4	10	33
Health and well-being		4	8	11	5		28
Policy, standards, guidelines, regulations		7	3		10	3	23
Urban design - sufficient space, urban character		15					15
Urbanisation- the processes and practices	10			2			12
Market drivers - buyers, finance for end users/developers			4		8		12
Economic valuation of trees						8	8
Protection of biodiversity			2	2		4	8
Understanding of co-benefits by key agencies			7				7
Developer/building practices: subdivision, clearing			6				6
UHI				5			5
Outdoor limitations on activity and liveability						5	5
Public space tree management	4						4
Private open space & tree management	3						3
Desired quality of life - shade, aesthetics, health	3						3
Energy efficiency/cooling effects			3				3
Air Quality				3			3
Ecological Services - air quality, temp, biodiversity, water					3		3
Water Availability/water cycle				2			2
Changing demographics						2	2
Total of Major Categories							
Social/Health 73	**Planning 57**		**Environment 31**		**Economic 26**		

Figure 66 shows the mix of key scoring variables at each table. The groups at Tables 1 and 2 focused predominantly on social and planning variables, while Tables 3-6 introduced environmental and economic variables.

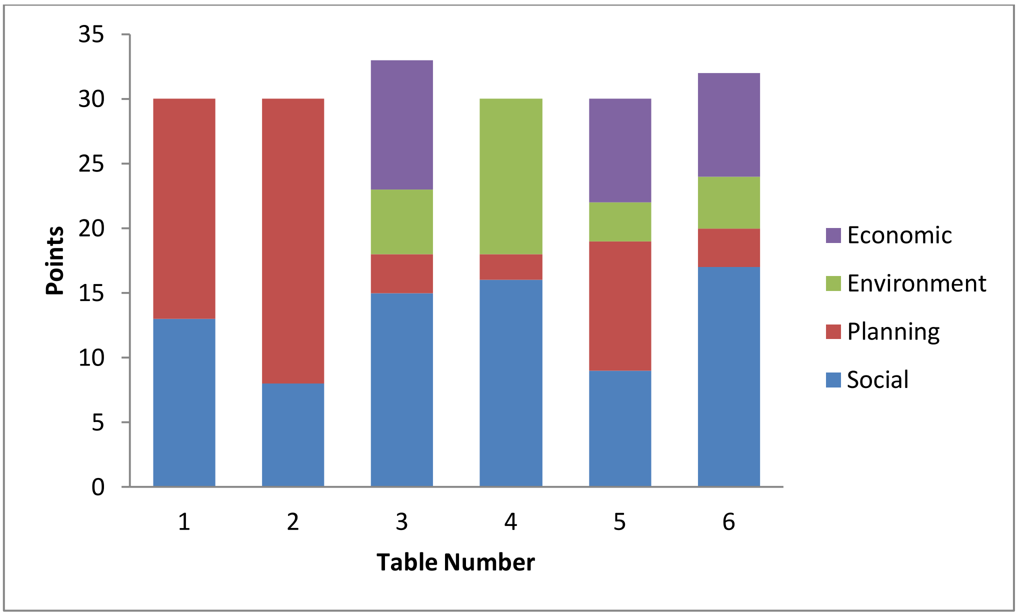

Figure 66 - Classification of key variables by table group

Once the scoring activity was complete, each table disclosed their three highest scoring variables. A plenary discussion agreed that the variables "Policies and regulations" and "Urbanisation - processes and practices" were similar and they were combined. The top seven variables are shown in Table 61. Each group was then invited to select one of the seven variables to discuss in greater detail for the next workshop activity.

Table 61 - Top scoring variables

Top Seven Variables	Score
Urbanisation policies, regulations and practices	35
Social & community values/expectations	33
Health and well-being	28
Urban design - sufficient space, urban character	15
Market drivers - buyers, financers for end users and developers	12
Economic valuation of trees	8
Protection of biodiversity	8

Discussion for each group was guided by a list of suggested topics (shown below). The summary of outcomes is provided in the following section.

- Focal points
- Opportunities
- Barriers

- Potential conflict or complementary current activities
- Identification of stakeholders groups.

7.4.3.1 Variable 1: Urbanisation policies, regulations and practices

The focal points identified by this group included tree protection policies, asset management and service provision, local planning guidelines and the requirements for infrastructure management and development. Accounting for the benefits that tree canopy provides, and the costs of tree canopy reduction were identified as important opportunities to influence urbanisation policies. The need to address potential conflict with other infrastructure requirements was also identified.

Table 62 - Variable 1 group discussion

OPPORTUNITIES	**Stakeholders**
Develop state based framework for tree management. Develop incentives for development sector to retain trees	State/Local Governments Private Developers Community
Recognise the value of the asset Recognise the externalised costs of removing trees	
Develop collaborative approach between disciplines	
Introduce appropriate controls on the removal of mature trees from urban environments	
BARRIERS	
Economic circumstances Different perceptions about the value of trees Politics and short-term electoral cycles Difficulties in implementing policies	Potential conflict with other policies/needs such as: • Infrastructure requirements • Water management • Storm-water drainage

7.4.3.2 Variable 2 - Social/community values and expectations

The focal points were community attachment (or lack of) to trees and changing fashions and community pressure with respect to trees. For example, the desire for larger homes can be a higher priority than leaving sufficient space for trees.

Opportunities, including education and community engagement, involved stakeholders across planning, environment, education, health and the media. Potential barriers were focused on the issue of competing community values, market forces and potential conflict with other policies.

Table 63 - Variable 2 group discussion

OPPORTUNITIES	Stakeholders	Connections
Education and awareness raising regarding the benefits of trees	LG, Schools NRM groups Community groups Media Dept. of Health State Gov't	Arbour Day Heritage Act Town Planning Current Education Curriculum DIY TV
Community engagement in protection/policy		
Expectation management with regard to size of homes and services that trees can provide		
Managing outcomes to ensure common goals are met		
BARRIERS		
Competing community values – e.g. desire for larger homes Market-forces that encourage large homes Conflict with other polices – e.g. increasing density, protection of services (e.g. water, power)		

7.4.3.3 Variable 3 - Health and well-being

The focal points identified were those related to mental health, community well-being and social capital, changes in crime rates (potentially decreased) and decreases in heat-related illness and stress.

The need for collaboration across a wide range of sectors was also identified as was the need to consider the benefits of tree canopy in economic terms.

Table 64 - Variable 3 group discussion

OPPORTUNITIES	**Stakeholders**
Increase recognition of health and well-being benefits with key state and local government agencies. This can result in: • Incorporation of health into policies to protect trees • Cross-sector collaboration to address common issue of trees (though agencies may have different drivers) • Development of cross sectoral business cases to drive work in this area (saving trees)	Departments: DEC Planning Transport Main Roads Health Sport & Rec
Investigate potential for liability claims if nothing is done	
To build a case for economic benefit when presenting the idea to Dept. of Premier and Cabinet. E.g. the cost of retaining/maintaining trees versus health care cost savings.	Mental Health Commission WALGA
Further research (either through literature review and consolidation of existing research findings or conducting new research where there are gaps): To provide an evidence base to underpin strong supporters of tree canopy policies To demonstrate causal pathways to be addressed For example: • Plant trees → area looks nice → people out and about more → increase physical activity → increase physical and mental health and well-being. • People out and about more →increases in passive surveillance → decrease crime-rates.	Cancer Council Heart Foundation Community Universities
Lots of groups and political parties (and big ones) which are interested in health issues → could be strong backers of tree canopy policies.	
Health, especially mental health, is an issue that the community often responds to, so there is the potential to use this response to influence tree canopy management.	
For multiple reasons, health costs will continue to increase into the future, but there are insufficient funds to sustain this. Therefore, we must start focusing on preventing health issues -	

with retention/increase in canopy being one example.	
BARRIERS	
The benefits are recognised but are spread across many interests/sectors, with no single 'ownership' of the issue.	

7.4.3.4 Variable 4 - Urban design

The focal points identified included (a) sufficient space for trees to grow effectively and (b) the need for more information and evidence on the influence of design on policy and health and well-being. Stakeholders were primarily from the planning and development sectors, as well as financial organisations. The need to incorporate trees in urban design and collect evidence about the benefits of this design was noted as an important influence on both policy and market drivers.

The poor level of community knowledge, which was identified as a key variable in the influence diagrams, was seen as a barrier to the inclusion of trees in urban design.

Table 65 - Variable 4 group discussion

OPPORTUNITIES	**Stakeholders**	**Connections**
To include trees as integral part of overall design Retain existing trees, but must consider diversity of species and age of trees Develop case-studies of urban design that focus on the use of trees - the results of case-studies may be used to inform decision-making with respect to policy and the market place.	Local & state government Developers Builders Public/buyers Financial organisations	Street tree policies LGAs Tree registers Develop control policies
BARRIERS		
Lack of community knowledge Lack of communication between all stakeholders Lack of understanding of tree biology Lack of regulation – too much policy!	LGAs	Conflict between agencies: With regulation With levels of gov't

7.4.3.5 Variable 5 - Market value and drivers

The focal points identified were (a) the influences on developers, end users and regulators, (b) the importance of a central management plan that enables a coordinated and objective approach to tree management, and (c) barriers in addressing financial responsibilities and control on private land.

Table 66 - Variable 5 group discussion

OPPORTUNITIES	Stakeholders	Connections
Implement urban forest management plan to: • allow an objective overview of issue • apply a value to individual trees • provide for development actions	Property owners & tenants. Elected member	Development & management branches of government and private sector need to collaborate
Establish a site-specific requirement for green plot ratio (GPR), as in Singapore. (The GPR is a measure of leaf area per unit ground area (Pomeroy, 2012)).	Industry Government	R codes, Liveable Neighbourhoods
Community education and incentives		
Identify economic value of the tree as it relates to the services it provides (CO_2 capture, cooling, power and water conservation etc.)	Government Community	
Transfer of money from illness management to improved health outcomes	Government Community	
Reward the owners of trees financially	Tenants, owners, wider community	Owners may come into conflict with tenants. Authority may become embroiled in private disputes.
BARRIERS		
Who pays? There is likely to be strong resistance to control on private land		

7.4.3.6 Variable 6 – Economic value of trees

The focal points identified were the potential to drive decision-making and value of trees in the public realm. Collaboration was viewed as a significant opportunity, with multiple sectors being called upon to assess and disseminate the benefits of trees.

Table 67 - Variable 6 group discussion

OPPORTUNITIES	Stakeholders	Connections
Build on work/research/evidence of other cities		Not on state agenda Research translation
Agencies that would benefit from increased tree cover should assess and disseminate the benefits for a whole of government approach	Health Transport (cycle/walk) Community Development Local Government Water Energy Environment	
Greater recognition of the potential to increase property values	Householder Developer	
BARRIERS		
Limited understanding of benefits in economic terms The challenge of how to evaluate existing mature trees		

7.4.4 Pre-workshop information and surveys

Pre-workshop information was compiled from evidence collected during CA1 and CA2. Key sources included tree management and urban forest management plans from Australian and overseas cities (City of Melbourne, 2012; Department of Sustainability and Environment Victoria, 2011; Locke et al., 2011; Trees & Design Action Group, 2012).

Pre-workshop information was distributed to invitees the week prior to the workshop. The information informed the participants of the purpose of the workshop and provided basic background information on key aspects of the issue. Attendees were asked to complete a pre-workshop survey to provide expert opinion on a series of issues associated with areas targeted for urban infill, which considered:

- The benefits of tree canopy
- The barriers to retaining or replacing trees
- Potential strategies to be adopted

The answers from the survey provided an important insight into the range of opinions from key stakeholders to assist in Phase II of CCM.

7.4.4.1 Benefits of tree canopy

Participants were provided with a list of known benefits of tree canopy and asked to rank the level of importance as: 1 – Low; 2 – Medium; 3 – High; 4 – Very High; or 5 – Essential. Participants were asked to give a personal ranking, based on their own expertise, and a 'sector' ranking based on the level of importance implied by **current** practices in the participant's own sector or profession.

A total of 25 pre-workshop surveys were collected. The level of perceived importance for all benefits fell between high (3) and essential (5). The current level of importance given to each of these benefits fell between medium (2) and high (3). Figure 67 shows the average scores from all responses and indicates a significant gap between perceived levels of importance and current level of importance given to each of the benefits.

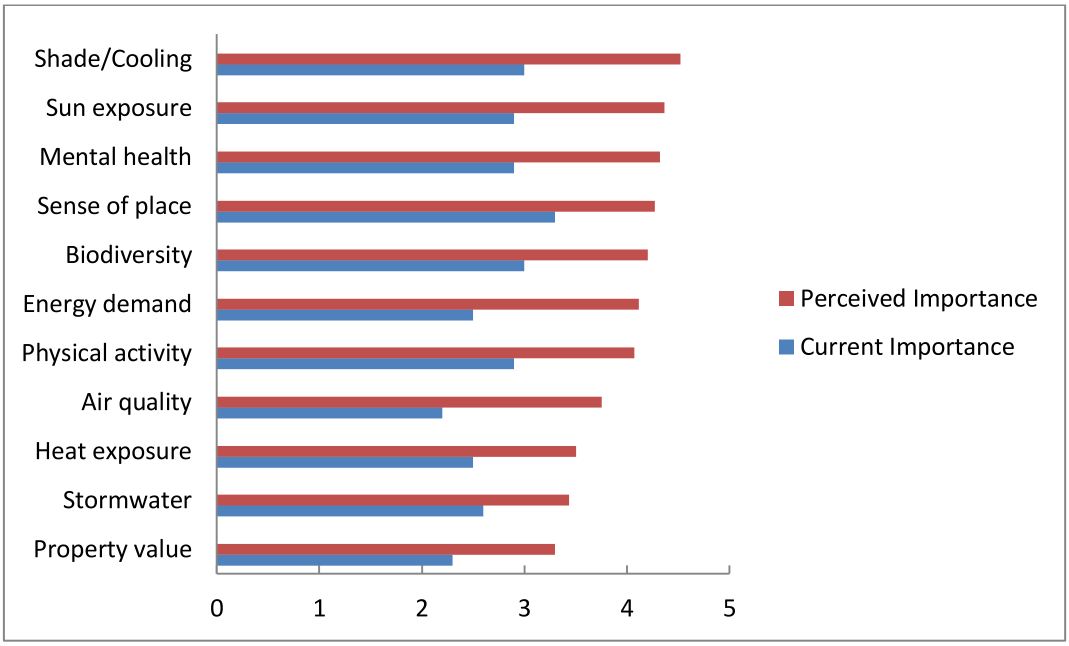

Figure 67 - Average scores for tree canopy benefits

7.4.4.2 Barriers to planting or retaining trees

Identification of the most significant barriers to planting or retaining trees in areas targeted for urban infill in Perth is an important consideration for policy makers. Participants were provided with the following list of potential barriers and asked to rank these in order from 1 to 8 (from most to least significant).

The potential barriers to tree canopy specified were:

- Provision of adequate space for trees
- Demand for water
- Cost of retaining trees during development
- Conflict with utilities such as power, telecommunications
- Lack of awareness and formal accounting of tree benefits
- Lack of clear policies, standards or regulations regarding tree management
- Inadequate resources allocated to planning and implementing tree management
- Lack of tangible incentives to retain trees

The average rankings of the barriers are shown in Table 68. The overall column represents the average of all respondents, while the subsequent columns have been divided into the planning, environment, health and development sectors respectively. The top three rankings (highlighted by bolded italics) were similar across planning, health and development sectors. However some key differences were apparent in the responses from those in the environment sector. For example, the provision of adequate space for trees, ranked number one by respondents from the environment sector, was ranked 7th and 8th by the planning and development sectors respectively. The top two barriers of the planning representatives were “Lack of awareness and formal accounting of trees” and “Cost of retaining trees during development.” These barriers were given a relatively low ranking of 5 and 6 respectively by representatives from the environment sector.

Table 68 - Average ranking of barriers by whole group and by sector

Barrier	Overall	Plan.	Env.	Health	Devp't
Lack clear policies & regulations	***1***	***3***	***2***	***1***	***1***
Lack of awareness & formal accounting of trees	***2***	***1***	6	***2***	4
Cost of retaining trees during development	***3***	***2***	5	***3***	***2***
Lack of tangible incentives to retain trees	4	4	***3***	5	***3***
Provision of adequate space for trees	5	7	***1***	4	8
Inadequate resources for tree management	6	6	4	5	6
Conflict with services (power etc)	7	5	7	7	7
Demand for water	8	8	8	8	5

These results support the findings from the individual influence diagrams that considerable differences in viewpoint exist on the issue.

7.4.4.3 Strategies

A list of potential strategies to ensure trees are part of urban landscapes was provided to participants (Table 69). The strategies were arranged into four broad categories of 'plan, design, plant and manage' that represent a natural hierarchy of management, from overarching plans and policies down to more detailed aspects such as tree planting

Table 69 - Potential strategies for urban tree management

Planning Strategies
1. Record of existing trees including nature, condition and canopy cover
2. Comprehensive tree strategy and canopy target
3. Clear standards for protection, care & planting of trees in strategic plans & policies
Design Strategies
1. Design trees into places – includes consideration of utilities & provision of space
2. Appropriate tree selection
3. Recognise and seek multiple benefits
Planting Strategies
1. Plant healthy, vigorous trees conditioned for selected environment
2. Improve soil moisture & water quality
3. Broad stakeholder & community engagement and involvement in decision-making
Management Strategies
1. Asset Management – inclusion of tree benefits and costs
2. Balanced approach to tree safety management
3. Adjust management to local needs

The level of importance that participants believed should be placed on each strategy within their sector was then ranked from 1 (low) to 5 (essential). Figure 68 shows the average level of importance given to each of three strategies within each category. The numbers represent the average workshop score for the plan, design, plant and manage categories. Almost all strategies fell between an importance level of high and very high.

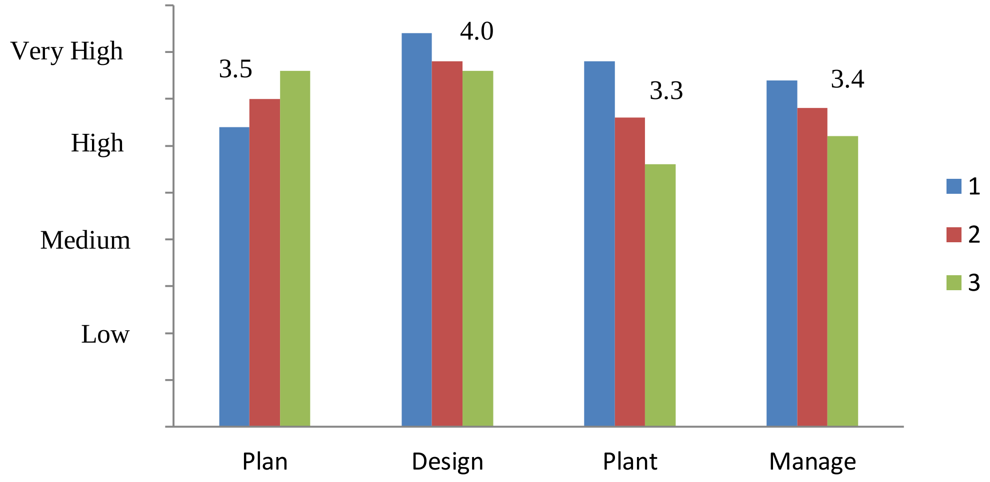

Figure 68 - Importance of strategies

Participants were requested to rank the current status of each strategy in their own sector from 1 (absent) to 4 (well developed) or 5 (not known). The 'Not Known' responses were primarily associated with respondents from the health sector and these responses were removed from the calculation of average status scores. Figure 69 shows the average response for each strategy, and the average score for each of the four categories. The current status of the group of 'plan' strategies was lower than the other categories.

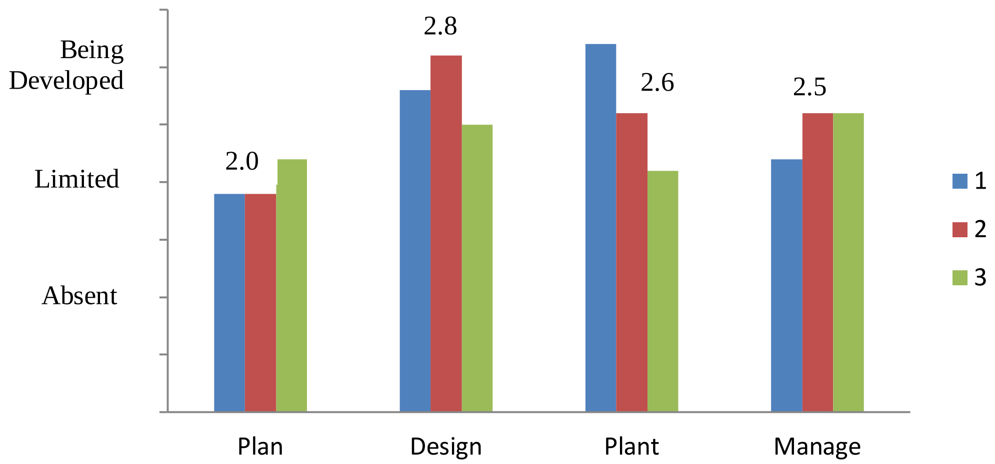

Figure 69 - Current status of strategies

These results indicate that the gap between the perceived level of importance and the current status of each strategy is the highest for the group of planning strategies, followed by the design strategies.

7.5 Conclusion: Phase I CCM

The Global Local Model proved a useful tool to consider and communicate the spectrum of spatial and distal influences on heat in urban environments. This led to a decision to focus on strategies within the 'Local Loop' that can influence population exposure to heat. The issue of tree canopy, particularly in the light of expected population growth and urban consolidation, emerged as the specific issue of interest for the CCM study.

Analysis of historical and current policy pointed to a general lack of protection and recognition of the importance of tree-canopy with respect to urban environments in Perth. In addition, the evidence suggests that current planning policy does not fully reflect the implications of exposure to extreme heat; the increased risk that climate change poses in this regard; or the need for UHI mitigation strategies as an integral part of urban consolidation.

This finding was supported by the outputs of the Tree Canopy Workshop which identified urbanisation policies and regulations as one of the key variables in the system, but at the same time recognised the "lack of clear policies and regulations" as one of the most significant barriers to effective tree management. Likewise, while community awareness of the importance of tree canopy was identified as a key variable, the 'lack of awareness' was identified as a barrier.

Economic considerations featured strongly throughout the workshop – in relation to (a) the cost of incorporating trees in the urban environment, (b) how to capture the external costs associated with tree canopy loss and (c) the role of market forces in driving change in urban design.

While heat exposure was the primary trigger for the Tree Canopy Workshop, the systems approach clearly established that tree canopy levels have the potential to impact on numerous environmental, social and economic variables. The large number of stakeholders identified in the focused dialogue exercise of CA3 is testament to that view.

Finally, while difficult to assess, the learning and communication component of the Tree Canopy Workshop is an important outcome. The breadth of expertise and knowledge of workshop participants cut across multiple disciplines, sectors and levels of government. The interaction between these participants resulted in new, shared perspectives of the issue. While conflicts emerged, everyone endorsed the need for collaborative approaches to develop effective management of urban trees. It is hoped that the Tree Canopy Workshop will be instrumental in achieving that end.

Phase II of CCM will build upon these results to develop a better understanding of the dynamic behaviour of the system. This information was used to consider effective adaptation strategies to address the issue of tree canopy management in Perth.

Chapter 8 – Part II CCM Results & Discussion

8.1 Introduction

The application of CCM Part I highlighted that while the extent of urban tree canopy is an important component of a healthy city, it is under increasing pressure from urbanisation. Managing tree canopy will require a better understanding of the features that drive system behaviour. An analysis of the information gathered in Part I of CCM will be used in CA4 to develop this understanding. CA5 will assess the information and identify leverage points to ensure a healthy and sustainable tree canopy during a period of expected urban consolidation in Perth. The chapter concludes by considering how improvements in systemic understanding have led to new insights on the issue.

8.2 CA4 – What drives system behaviour?

The information from Phase I was analysed to answer the critical question of 'what drives system behaviour?' The conceptual models and workshop outputs from Phase I were analysed to identify key feedback structures and to consider which elements of the system currently dominate behaviour.

8.2.1 Key variables and themes

Evidence of cross-sector feedback structures was identified from the pair-blended influence diagrams and focused dialogue of CA3. The key variables and themes identified were: community awareness; urban consolidation policies; economic considerations; private and public ownership; and urban design.

8.2.1.1 Community awareness

Community awareness of the benefits provided by tree canopy was identified as one of the main influences on the extent of tree canopy. The perceived nature of the benefit was influenced by participants' mental models and included a range of health, social, environmental and economic variables. The extent of community awareness was considered to influence the extent of tree canopy via pressure on policy makers and the market place to incorporate trees into urban environments. The strength of this balancing feedback is a critical determinant of the system's behaviour.

Outputs from CA1 to CA3 suggest that this feedback loop is relatively weak. As stated in the *Capital City Planning Framework* the incremental nature of tree canopy loss often means that it 'goes unnoticed until it is too late to undertake preventative actions'.

In effect, as levels gradually decline, lower tree canopy levels become the new 'norm'. In addition, the feedback loop relies on an awareness of the causal connections between tree canopy effects and changes in tree canopy levels. While some effects may be self-evident (such as loss of visual amenity), perception and knowledge regarding the links between tree canopy and other impacts such as air quality, water quality, microclimate and mental health will be limited.

The combination of these factors suggests that the influence of community awareness on policy makers or the market place is likely to be limited and delayed. This is depicted in Figure 70 by the dashed line.

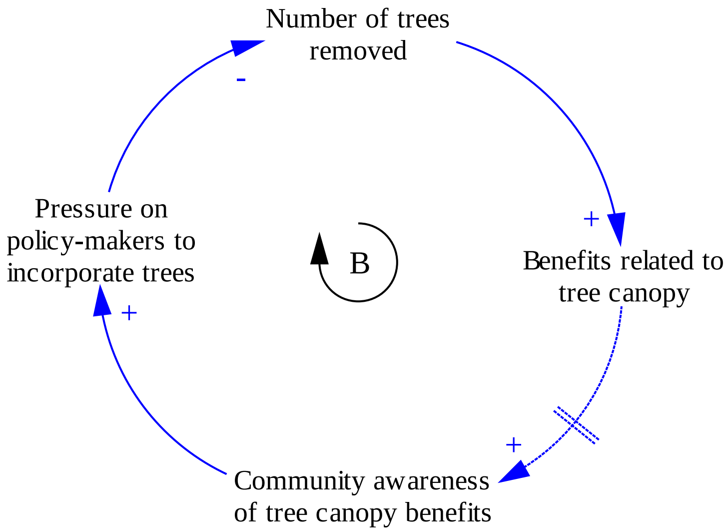

Figure 70 - Weak community feedback

Weak or missing balancing loops are often a cause of system imbalance (Meadows, 1998, Sterman 2000). In the case of tree canopy, the repercussions of delayed and relatively weak feedback are substantial. As evidenced in CA2 and CA3, urban infill often results in landscapes that do not have sufficient space for trees. As these outcomes are likely to persist over extended periods of time, opportunities to re-incorporate trees will be progressively reduced.

8.2.1.2 Urban consolidation policies

Urban consolidation policies were a clear focus of the workshop discussions. The ‘more compact’ element of the D2031 vision is supported by a target of 47% of the required 328,000 dwellings as infill development by 2031. Longer-term estimates by Weller (2009) indicate that an additional 376,000 free-standing homes or 445,000 apartments will be required as infill development by the year 2050. The implementation of these targets is supported by the Urban Growth Monitor which reports on construction of dwellings in urban areas and is a ‘cornerstone for the implementation of Directions 2031’ (WA Planning Commission, 2011, p. iv) The gap between the current level of density and the urban-density target helps to drive actions to increase urban density. As urban density approaches the target level, the gap between the two will reduce, the rate of infill development will slow down, and ideally the target level is achieved. This ‘Compact Mechanism’ is depicted in the stock and flow map of Figure 71.

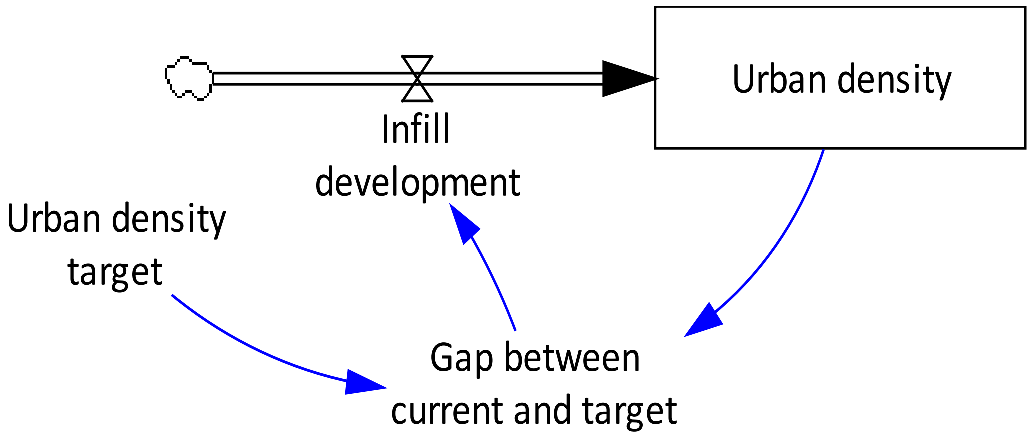

Figure 71–The compact mechanism

The red dashed links in Figure 72 depict the influence that the ‘compact mechanism’ has on the tree canopy stock. The evidence collected in Phase I of CCM indicated that current urban infill practices typically reduce opportunities to plant trees and increase the rate of removal of trees, leading to a decline in tree canopy. These effects have been expressed as ‘unintended consequences’ in Figure 72.

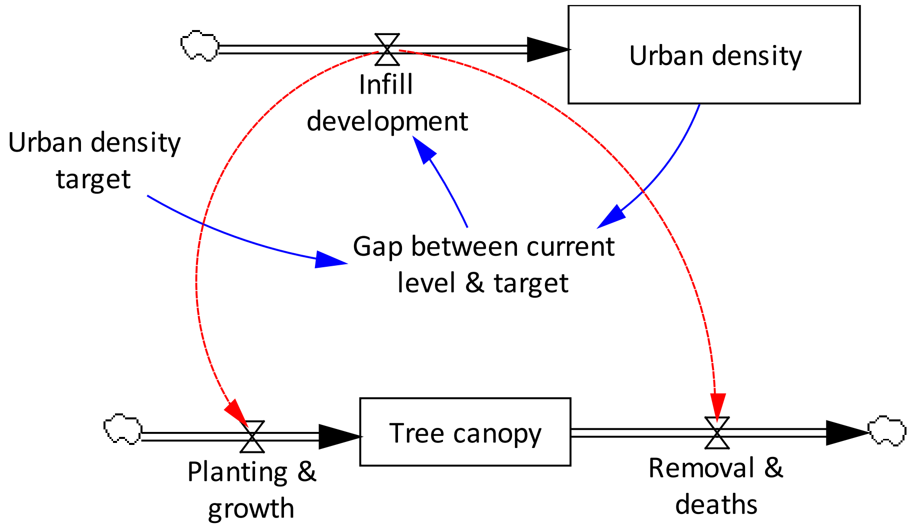

Figure 72 - Unintended consequences of urban infill

It is clear that this system assists progress toward the ‘more compact’ element of Perth’s vision. However, the unintended consequences illustrated in Figure 89 may also have an impact on this vision. Tree canopy clearly contributes to a visually greener environment. In addition, the participants at the workshop identified a significant number of tree canopy effects that contribute to a more environmentally sustainable city. These included impacts on energy use, water quality, air quality and biodiversity. The extent of tree canopy was also identified as an important contributor to the final element of the vision, ‘a unique sense of place’.

The importance of tree canopy with respect to health and well-being was a key theme that emerged from the Tree Canopy Workshop and was discussed in Chapter 7. While the Perth D2031 vision does not explicitly mention health, it is evident that health and well-being are at the forefront of any considered definition of liveability.

In summary, while urban infill targets are an effective mechanism to achieve a more compact city, they also have the potential to significantly reduce tree canopy levels and undermine progress toward the complete vision of a world-class liveable city.

8.2.1.3 Economic considerations

Economic variables featured strongly across all elements of CA4. The first, discussed earlier in the chapter, was the market pressures that come to bear through increased community awareness of tree canopy benefits. This was captured by the increased demand for trees in urban landscapes and the willingness to pay a premium for greener areas. This response can be viewed as the ‘invisible hand’ of market forces, but as indicated previously, this feedback effect is likely to experience significant delays. In contrast, competing market forces, such as the demand for larger houses, provide immediate financial benefits to developers (higher sales prices) and purchasers (larger capital asset).

The focused dialogue at the Tree Canopy Workshop indicated that the ability to pay a premium for tree canopy will be influenced by the income level of buyers. This was captured by mention of the 'green leafy suburbs' – a reference to expensive, well-established Perth neighbourhoods with mature canopy trees. Nevertheless, the character (and value) of these suburbs may be eroded as urban infill reduces tree canopy levels. Studies in other cities have shown a strong correlation between income and vegetation level. For example, the highest temperatures in Phoenix (Arizona) were recorded in low income, poorly vegetated areas (Jenerette, 2007).

The failure of the current system to account for the value of trees and the external costs associated with tree removal was identified as a significant barrier to tree canopy management in urban infill areas. Addressing this shortcoming was seen as a significant opportunity for progress. Specific comments on this issue from the Tree Canopy Workshop included:

- It is important to recognise the asset value of trees and the costs associated with their removal.
- It is necessary to build an economic case for the benefits from trees, appropriated to present to the Department of Premier and Cabinet; e.g. the cost of retaining/maintaining trees versus health care cost savings
- It is important to identify the economic value of trees related to ecosystem services (CO_2 capture, cooling, energy and water conservation)
- There is limited understanding in government agencies of the benefits in economic terms
- The benefits are spread across many areas. Agencies that benefit from increased tree cover should assess and disseminate the benefits to enhance understanding across all government agencies.

The comments relate primarily to increasing information flows regarding the value of trees and the social, environmental and economic costs of tree canopy reduction. The "natural capital" provided by trees can be interpreted as both a resource (shade, aesthetics and habitat) and a sink for pollutants (heat, air pollutants and water pollutants). The provision of these services is critical to the functioning of any city, yet the above comments indicate that accounting and responsibility for the provision of these services is largely lacking. The comments also captured the cross-sectoral nature of the problem and the need for a whole-of-government approach.

In contrast to these missing information flows, the immediate financial costs of retaining trees as part of urban development is effectively captured by market mechanisms. Increases in the cost of site-preparation and potential reductions in the building footprint can reduce profits to the developer. If these increased costs are passed onto the consumer, there are additional implications for housing affordability. These costs are immediate and discrete and are captured efficiently in dollar terms. In addition, these potential costs can be overcome simply and quickly by the removal of trees.

The short- and long-term market mechanisms are represented in Figure 73. The B1 feedback loop captures the immediate market cost to urban infill developers of retaining trees. Loop B2 represents the longer term picture, where reductions in tree canopy ultimately reduce the liveability of urban areas. In the context of this stock-and-flow map, liveability is intended to capture a broad range of variables that will influence all aspects of the D2031 vision. The range of adverse effects linked to tree canopy loss, which was discussed at the workshop, ultimately reduce the liveability of an area. The widening gap between expected 'liveability' and the actual level drives up community demand for trees. This community demand eventually translates to higher prices for areas with good tree canopy cover, increasing the income of developers. When developers become aware of this, the extent to which trees are incorporated into urban environments increases.

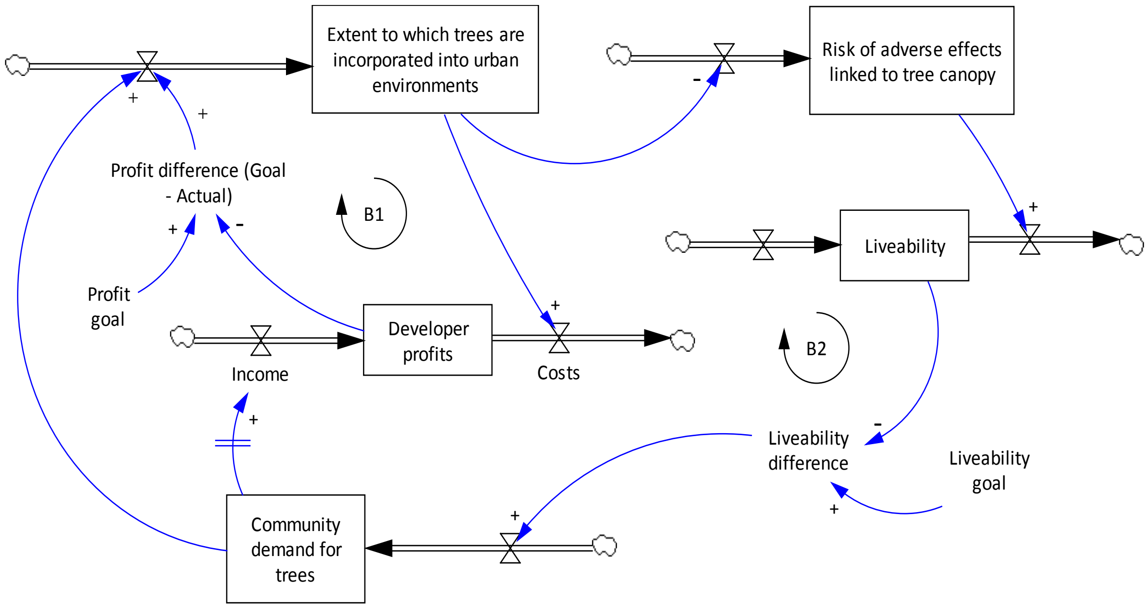

Figure 73 - Market Mechanisms and tree canopy

The hypothesis presented here is that in terms of market mechanisms, the pressure to include trees will only be effective when it is clear that the additional income for developers from increased community demand for trees (Loop B2) exceeds the added cost of incorporating trees into urban development (Loop B1). The evidence from Phase I suggests that the stocks and flows in Loop B1 are currently dominant. If the inclusion of trees in areas of urban infill is left entirely to market mechanisms, the shift to Loop B2 dominance will occur with significant delays and will be limited by personal income levels.

The direct link between ‘Community demand for trees’ and the influence on ‘Extent to which trees are incorporated into urban environments’ serves as a reminder that community demand can result in direct community action and pressure on decision-makers such as local government to incorporate trees into urban environments.

The final aspect of the economic theme, which is also captured by Figure 73, was expressed at the workshop as ‘who pays?’ If Loop B2 is dominant, the consumer pays. However, if Loop B1 is dominant, the developer is left to bear the additional cost of incorporating trees into the urban landscape. In a free-market system it is unlikely that the developer will decide to incur an additional cost that the community is not willing to pay for. This conundrum highlights the challenge of relying primarily on free-market mechanisms to determine the level of tree canopy in Perth.

The significant limitations of market mechanisms in capturing the social, environmental and economic value of tree canopy leaves the question of ‘who pays?’ unresolved. In a dominant Loop B1 system, the costs of tree canopy reduction are transferred to society and government. Table 70 provides a summary of the costs associated with tree canopy loss that were discussed as part of the HIA and CA1 to CA4.

Table 70 - Summary of costs associated with tree canopy loss

Environmental Impact	Health and Social Impacts	Economic Impact
Urban Heat Island effect	Heat-related health effects • Mortality • Heat stress • Cardiovascular and respiratory effects	Health costs Energy costs Infrastructure costs Lower productivity
Less shade	Skin cancer Less walkable neighbourhoods Lower amenity and physical activity	Health costs
Lower aesthetic value	Sense of place reduced Mental health impacts	Health costs Impact on business activity Lower property values
Reduction in biodiversity	Loss of contact with nature	
Reduction in water quality Increased storm-water		Increased storm-water costs Infrastructure costs
Air quality	Respiratory impacts Cardiovascular impacts	Health costs

8.2.1.4 Private and public land

The 'natural capital' provided by trees in urban environments does not distinguish between trees on privately or publically owned land. The services provided by trees, such as regulation of the microclimate, provision of habitat and effects on air, water and soil quality, benefit the entire community regardless of ownership. Nevertheless, management of tree canopy is strongly influenced by the issue of ownership. Assuming that the provision of adequate canopy levels is the desired outcome, the question of how to achieve that outcome, taking account of the differences between public and private land, must be considered.

The evidence from CCM Phase I suggests that removal of trees is an inevitable consequence of urban infill, particularly on private residential land. In the absence of regulations or incentives to incorporate trees, market forces and physical limitations are the main determinants of tree canopy levels on private land. In both cases, these influences tend to reduce tree canopy levels. While resistance to control over private land was identified as a barrier at the workshop, the possibility of greater controls was also identified as a significant opportunity. If the loss of trees on private land continues, the attainment of desired canopy levels will become increasingly reliant on trees on public land. The transfer of this provision to the public sector will also have associated costs.

While management of trees on public land is not as sensitive to market forces as on private land, the lack of accounting of the natural capital provided by trees does influence decision-making. While street trees and park trees are increasingly viewed as a critical component of the urban landscape, the evidence from CA2 and CA3 indicated that trees are considered to be well down the 'pecking order' in terms of infrastructure requirements. Where conflicts exist between trees and utilities such as power, telecommunications and water or other services such as drains, footpaths or roads the trees are often removed. While it was established at the workshop that several councils were trialling the use of software packages designed to account for tree costs and benefits, their use is not widespread.

In conclusion, although differences clearly exist between the management of trees on private and public land, both face similar obstacles that are rooted in the inability of the current system to fully account for the natural and social capital provided by tree canopy.

8.2.1.5 Urban design

Consideration of urban design was incorporated into each of the previous themes (community awareness; urban consolidation policies; economic considerations; and private and public land). Urban design was identified at the workshop as the process that translates community, policy and market drivers of tree canopy levels into urban form, both on private and public land. The importance of urban form in accommodating a doubling of Perth's population by 2050 was recognised by Weller (2009, p. 37) who stated that “simply accommodating such numbers is not the only issue. The urban form of that accommodation and the quality of life it generates is what ultimately matters.”

The limited ability of the current system to encourage the inclusion of trees into urban design was identified throughout the activities in CCM Phase I. First, the current system is strongly influenced by the inclusion of urban infill targets and the absence of tree canopy targets. Second, the inability of the current system to account for long-term costs of tree removal, mean that decisions about whether or not to include trees in urban design are dominated by short-term market influences that typically undervalue trees. Finally, current regulations and the *ad hoc* development of private land can restrict the opportunity to plant trees. For example, when density and height restrictions, setback rules and requirements for parking space are adhered to, there remains limited space to enable the retention or planting of trees. As discussed at the workshop, the ability to coordinate development and utilise space more efficiently is limited by the ‘block by block’ basis of most infill development.

In conclusion, the structure of the current system discourages the inclusion of trees in urban design. Without suitable intervention, it is likely that this structure will lead to continued tree-canopy loss.

8.2.2 System archetypes

The results from the CCM activities to date were used to help identify system archetypes that play an important role in determining tree canopy levels in Perth. As explained in Chapter 6 (§6.2.5), the identification of system archetypes can assist in developing management strategies appropriate for each particular archetype. The following activity will explain the two key system archetypes identified. Management strategies based on leverage points of each archetype will be considered in CA5.

8.2.2.1 Success to the Successful

The *Success to the Successful* archetype represents a situation where there is a competition between different stakeholders for limited resources (Meadows, 2008). When one party is successful at attaining the most resources, the success that this brings, leads to further success – often at the expense of those who have minimal resources. Resources can be considered in terms of knowledge, money, people, experience and access to decision-makers.

Figure 74 depicts a *Success to the Successful* structure relevant to urban development in Perth. As discussed during the previous section, there is substantial evidence that tree canopy levels in urban areas are predominantly determined by market forces. At present, those market mechanisms do not adequately account for the long-term social, environmental and economic costs of tree removal. The dominance of short-term market forces and a failure to account for the future costs results in behaviour that is the antithesis of sustainable development.

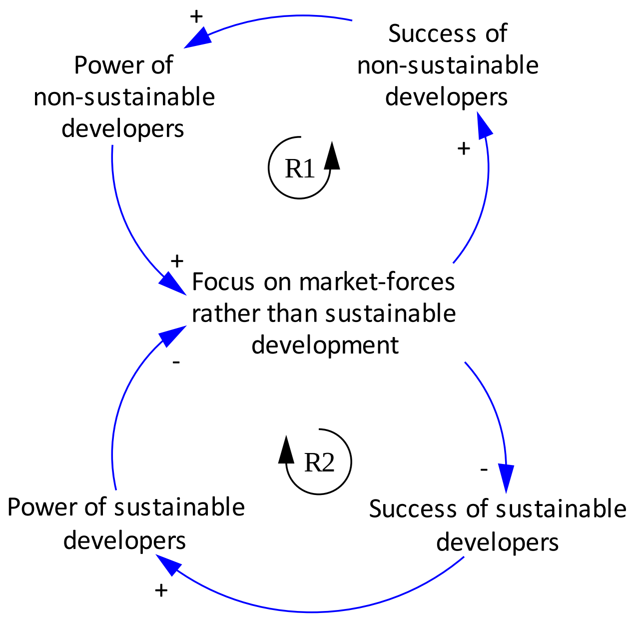

Figure 74 - Market versus sustainable development

A tendency to focus on market-forces rather than sustainable development leads to greater success for non-sustainable developers compared to sustainable developers. Recalling the previous stock-and-flow map (Figure 73), if developers choose to incorporate more trees into the urban landscape at a time when the market-place will not support a higher price, their success will be limited. This limitation means that in comparison to non-sustainable developers, they will have less power to shift the focus toward more sustainable development. In this system the sustainable developer may have limited success in niche markets, but the market will remain dominated by less-sustainable developers who are driven primarily by short-term pressures to reduce costs.

Another example of the *Success to the Successful* archetype is shown in Figure 75. This figure relates to the statement that trees are 'down the pecking order' when it comes to resources, data, decision-making and related policies and regulations. This view is supported by the workshop outcome that identified (a) a lack of awareness and formal accounting of tree benefits, and (b) a lack of clear policies, standards or regulations, as the top two barriers to effective tree management. This has been stated in Figure 75 as ‘Strength of accounting systems and policies for other infrastructure compared to trees’.

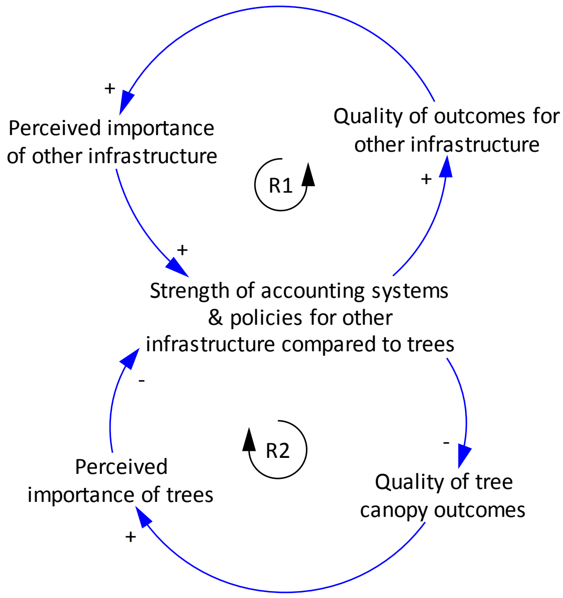

Figure 75 – The infrastructure 'pecking order'

8.2.2.2 Shifting the Burden

This archetype depicts a situation where the gap between the desired state and the current state of the system can be managed by two alternative solutions – a symptomatic solution or a fundamental solution. The fundamental solution, which focuses on attainment of a ‘high quality’ goal, often experiences a significant delay before the goal is attained. As a result, quicker, more expedient solutions are implemented in preference to the fundamental solution. However, rather than address the original ‘high quality’ goal, these solutions only appear effective because they have lowered the goal. The benefits of the symptomatic solution reduce the perceived need to pay attention to the fundamental problem and its solutions.

In addition, the application of the symptomatic solution, results in other effects that can reduce the opportunity to apply fundamental solutions. This system archetype results in a pattern of behaviour where the continued reliance on the symptomatic solution undermines the ability to implement the fundamental solution. The result is that, despite the benefits delivered by the symptomatic solution, the problem symptom persists and gradually increases over time. It is important to recognise that the symptomatic solution is often an important part of the fundamental solution – the *Shifting the Burden* behaviour sets in only when the symptomatic solution is applied as if it were the fundamental solution (Senge, 2006).

The *Shifting the Burden* archetype is presented in Figure 76 as the opportunity for two futures – the Compact City or the World-class Liveable City (the D2031 vision). The underlying problems that these 'futures' are addressing is the need to cater for a significantly larger population in a more sustainable manner, while still maintaining the desired quality of life. This is represented as the gap between the state of Perth and the D2031 vision. The ultimate aim of the system is to close this gap.

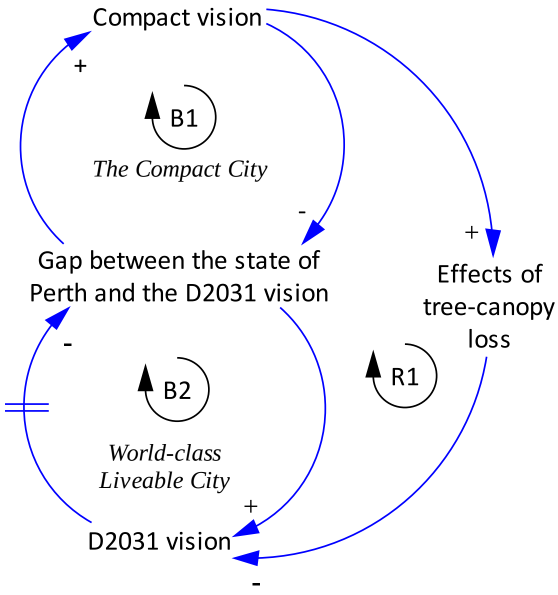

Figure 76 – The narrowing of Perth's vision

The Compact City represents the symptomatic solution to the gap, while the World-class Liveable City represents the fundamental solution. Loop B1 is measured in terms of dwellings per hectare, while Loop B2 includes many intangible aspects that contribute to quality of life.

The hypothesis presented in Figure 76 is that there has been a strong tendency to focus on the comparatively simple Compact City, rather than the 'high quality' goal of a World-class Liveable City. The focus on Loop B1 has also resulted in reductions in tree canopy (Loop R1), which ultimately undermines progress toward the *Directions 2031* vision. Further rationale and evidence for this hypothesis are presented below.

Symptomatic solutions are frequently applied because they do respond to a problem symptom and are often *part of* the fundamental solution. Both are true in this case. The problem symptom that the Compact City is responding to is urban sprawl. The economic, environmental and social costs of urban sprawl are well-recognised and the call for a more compact city is driven by the need to avoid more of these problems. This is reflected in the call for a more compact city as *part of* the D2031 vision.

Symptomatic solutions are also frequently applied because, compared to fundamental solutions, they are easier to implement and produce more immediate results. As evidenced by the research to date, the ‘Compact City’ is:

- Relatively simple to define and measure (number of dwellings per hectare)
- Relatively quick (time taken to construct more dwellings per hectare).

If these results are celebrated as unequivocal progress toward the ‘Compact vision’ rather than as *partial progress* toward the D2031 vision, a *Shifting the Burden* behaviour is at play. A fixation on the successes of the Compact City lowers the perceived need to introduce other, more fundamental solutions.

The fundamental solutions in Loop B2 require actions that ensure ***all*** aspects of the *Directions 2031* vision – green, vibrant, more compact and accessible with a unique sense of place – are met. A clear definition of each element of this vision, as well as targets, measurement and monitoring systems, and a plan of how to achieve each element is a daunting task. At the present time, none of these other elements is clearly articulated, let alone measured or monitored.

The ‘results’ of the World-class Liveable City will take considerably longer than those of the Compact City. Each additional dwelling constructed in a given area represents an immediate and discrete progression toward the Compact City. In contrast, fundamental solutions intended to meet the ‘greener and more vibrant’ aspects of the vision, will typically require more time to mature and develop – they cannot simply be constructed. In addition, as shown by the side-effect loop (R1) of Figure 76, the tendency to focus on higher densities can undermine the ability to apply fundamental solutions, such as the creation of cities with adequate tree canopy coverage.

Following the archetypical behaviour of the *Shifting the Burden* structure, Figure 76 shows that the original application of the compact solution initially results in a reduction in the gap between the state of the city and the D2031 vision. This is because a more compact city is an important part of the D2031 vision. However, if management is focused on the compact vision, other fundamental aspects of the D2031 vision are overlooked and the overall gap begins to widen. The longer that Loop B1 dominates, the greater the impact of the side-effect loop, which further widens the gap. A significant proportion of these effects involve changes to infrastructure that are difficult to reverse.

It is important to note that if the *Shifting the Burden* structure represented here continues to dominate, the Compact City may still offer a better alternative to a 'Business as Usual City' of continued urban sprawl. Nevertheless, the Compact City is likely to fall considerably short of attaining what is ultimately possible – a green, sustainable and healthy city.

If the focus on the Compact vision delivers short-term economic benefits to the development industry, these benefits will reinforce the *Success to the Successful* archetype discussed earlier. This is shown in Figure 77 – the 'Compact Trap'. It is assumed that developers who focus on density without consideration of the other elements of the vision are non-sustainable developers. The reinforcing Loop R4 indicates that a greater focus on the narrow Compact vision will increase the success of non-sustainable developers, which in turn will lead to a greater tendency to focus on the narrow compact vision and so on. If Loop R4 dominates, this reinforces the focus on market-forces rather than sustainable development (Loop R2).

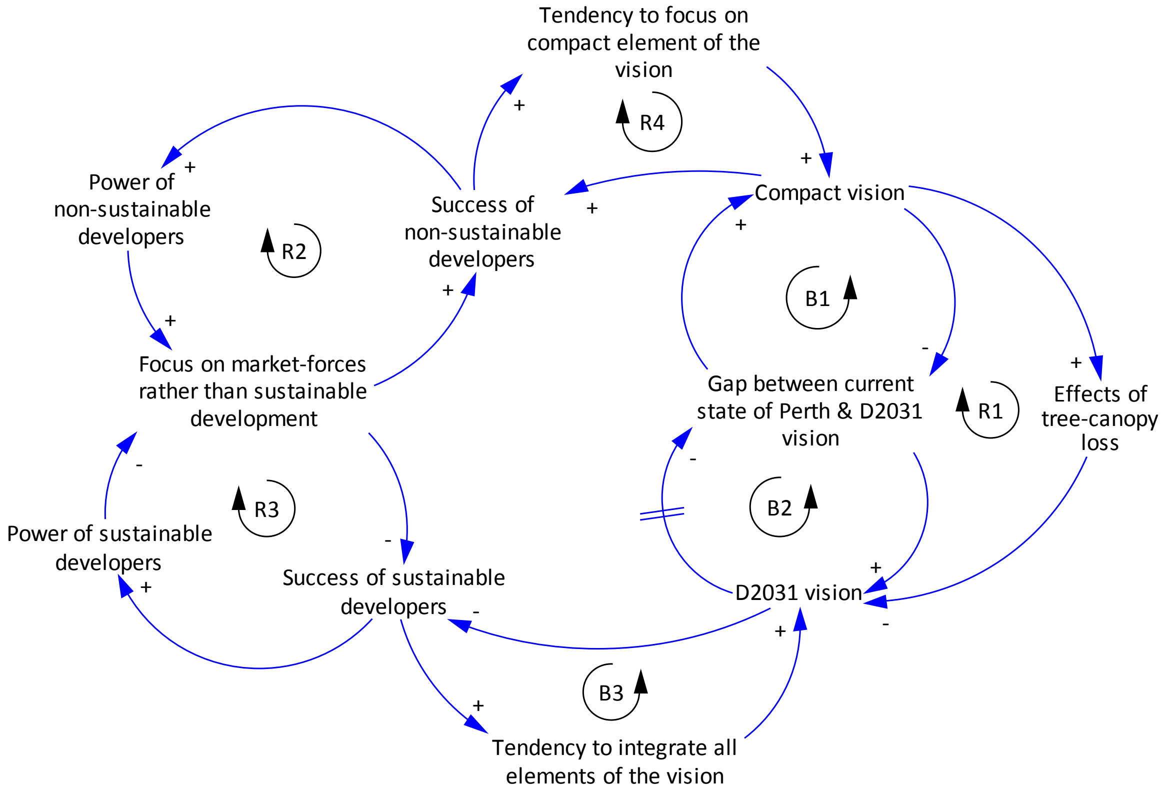

Figure 77 - The Compact Trap

Alternatively, developers who incorporate all aspects of the vision are assumed to be sustainable developers. In the Compact Trap the efforts of sustainable developers to focus on the higher quality D2031 vision leads to higher costs that are difficult to recover. These costs tend to reduce their success, which in turn reduces their tendency to plan developments that can attain the entire vision (Loop B3). This is a reflection of the current dominance of the short-term market forces discussed earlier in Chapter 4. The failure to reward sustainable developers serves once again to reinforce the *Success to the Successful* behaviour (Loop R2 and R3). The longer the 'Compact Trap' operates, the more progress toward the complete vision is undermined and the more difficult it is to reverse the trend.

8.2.3 CA4 conclusion

The findings of CA4 have provided significant insight into the factors currently dominating tree canopy levels in areas of urban infill in Perth. These factors include:

- A lack of awareness about the range of benefits provided by tree canopy and the long-term costs associated with their removal
- Planning policies and practices driven predominantly by the goal of a more compact city resulting in significant reductions in tree canopy
- Accounting processes with regard to urban infrastructure do not adequately capture the value of services provided by trees or the cost of their removal
- A lack of policies and regulations to support the inclusion and retention of trees in a more compact city

Despite broad in-principle support for sustainable development, the evidence suggests that at this time, management decisions are dominated by economic considerations. The current system does not have sufficient mechanisms in place to capture the long-term social and environmental costs of significant tree reductions. These costs are therefore being transferred to future generations – an outcome that is at direct odds with the objective of sustainable development. Potential solutions to overcome this situation are considered in the following section.

8.3 CA5 – What are the leverage points?

The influence diagrams, stock-and-flow maps and system archetypes discussed in CA4 were used to identify potential leverage points with respect to the effective management of tree canopy in areas of urban infill. Guidance was provided by the range of potential management solutions for each system archetype (Senge, 2006; Kim & Anderson, 2007; Novak & Levine, 2010; Braun, 2002) and from Meadow's list of leverage points (§6.2.4, Table 50).

The following discussion of the leverage points identified is organised from the least to the most powerful, as defined by Meadow's list.

8.3.1 Numbers

These are the three weakest leverage points according to Meadow's list. Numbers are considered to have the lowest leverage because they rarely change behaviour. The one exception is when the number represents the goal of the system. The numbers that have been identified as part of this research are related to the goal of the system and will therefore be discussed under that section.

8.3.2 Physical stock-and-flow structures

Physical stock-and-flow structures are also considered relatively weak leverage points because they are usually difficult to change once they are in place. This is the case in this system because once physical infrastructure such as buildings and roads are built they typically remain in place for a long time. The longevity of these decisions highlights that the leverage point in this system rests in high quality urban design in the first place.

8.3.3 Delays

Delays are also relatively low down on the leverage point list because they are often difficult to change. The reality is that it takes time for things to change. The key delays identified in this research were those associated with (a) community awareness of the effects of tree canopy loss, (b) the translation of awareness into market and policy decision-making processes and (c) the realisation of fundamental solutions to the D2031 vision. A critical point to make regarding each of these is that delays are likely to result in long-term physical changes to the urban environment that reduce opportunities to replenish tree canopy.

The greatest leverage point here is greater recognition of the delay and of the risks associated with it. Some delays, such as the time taken for trees to mature, are essentially fixed. Others, such as the delay between tree canopy loss and an awareness of the costs of that loss, can be reduced by the delivery of critical information. Such strategies are part of higher-level leverage points and will be discussed in greater detail in several sections below.

8.3.4 Balancing feedback loops

Balancing feedback loops act to keep a particular stock close to its goal – strengthening this feedback can therefore be an important leverage point. A critical point here is that strengthening balancing feedback loops is only desirable if the goal within the loop is desirable. The potential for balancing loops that direct the state of the system to a spurious goal was demonstrated by the Narrowing the Vision structure of Figure 76. The leverage point here is to shift the dominance of the system to the balancing loop that provides the desired outcome. As these balancing loops relate to the 'Goals of the System' – which are one of the most powerful leverage points – they will be discussed in greater detail in that section.

The Market Mechanism (Figure 73) also consisted of two balancing feedback loops. The dominant loop was considered to be the short-term 'developers' loop where immediate considerations of costs associated with inclusion of tree canopy were captured. The costs associated with the loss of tree canopy benefits were only captured via the longer-term impacts on liveability, which eventually flowed onto community awareness and increased demand for trees in urban environments. The leverage point here is to transfer some of the costs associated with tree-canopy loss (as outlined in Table 64) from the long term to the short term. This will be discussed in greater detail under the leverage points of 'Information Flows' and 'Rules'.

8.3.5 Reinforcing feedback loops

The Success to the Successful archetypes of 'Market versus Sustainable Development' (Figure 74) and 'Infrastructure Pecking Order' (Figure 75) each contain two reinforcing loops. The reinforcing feedback loops in Figure 74 relate to the most powerful leverage point of paradigms and will be discussed in that section.

The 'Infrastructure Pecking Order' is dominated by infrastructure other than trees. The key to this leverage point is captured by the central variable of 'Accounting systems and policies that support urban infrastructure other than trees'. The leverage points here are to (a) alter the system so the widespread benefits provided by trees are accounted for in some way and (b) introduce specific policies that require the inclusion and protection of trees in urban environments. The introduction of these strategies would help to 'level the playing field' and lead to the consideration of trees as a critical piece of infrastructure for a healthy urban environment. Each of these points will be discussed in greater detail in 'Information Flows' and 'Rules'.

Other reinforcing loops were identified during CA4. For example, Figure 78 shows some of the reinforcing feedback loops related to tree canopy reductions and ambient temperature in urban environments. Loop R1, the UHI loop, shows that as tree canopy is reduced, local temperatures rise which drives up air-conditioning use. As waste heat from air-conditioners is released, local temperatures are driven up and so on. In addition, the higher levels of air-conditioning use lead to higher GHG emissions which feed into the Global Loop. The increase in temperature from the UHI and global loops places greater stress on trees which can lead to further reductions in tree canopy (Loop R3). In addition, other long-term changes to climate, such as projections for further reductions in rainfall in Perth, create additional stresses on trees (Loop R4). The leverage points here are to minimise the loss of tree canopy, and to reduce the gain of the reinforcing loops, by the introduction of UHI mitigation strategies, and by reducing reliance on mechanical air-conditioning.

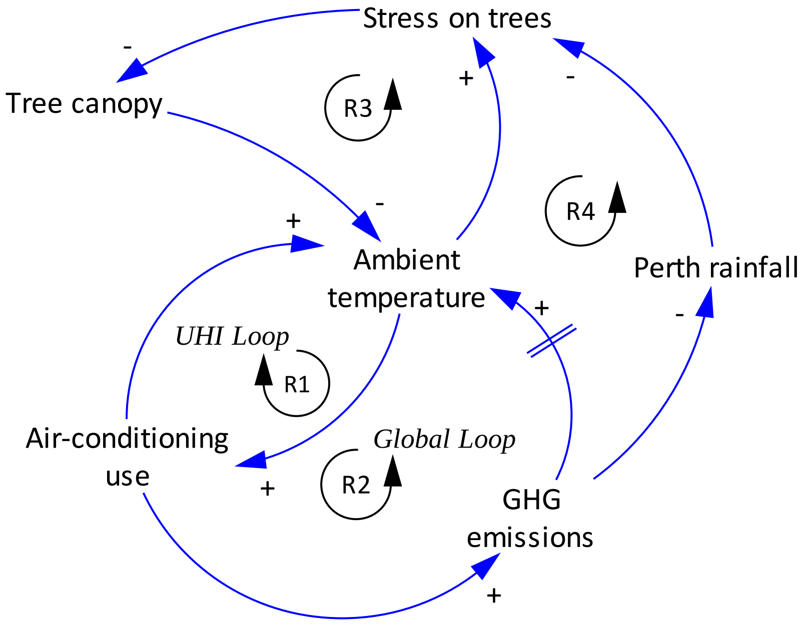

Figure 78 - Reinforcing loops affecting temperature and tree canopy

8.3.6 Information flows

Delivering information to new places in the system is a strong leverage point in changing system behaviour. Compared to changing physical flows or stocks, creating new information flows can be relatively inexpensive. The analysis of the current system has indicated that there are significant gaps and biases in the information flows of the system. Without information about developing problems there is little perceived need for action. In the absence of tree canopy monitoring and reporting, tree canopy levels will be largely overlooked. In contrast, if the community were informed that tree-canopy levels in their suburb had dropped by 30% over the last decade, and was currently sitting at half the desired canopy level, awareness and propensity for action would be increased. This type of information can also be used to direct management and resources to the most vulnerable areas. Such areas could include those with low levels of tree canopy, those with higher ambient temperatures or areas of low income where the capacity to adapt to higher temperatures may be limited.

The second area of missing information is a clearly communicated and shared accounting of all the costs and benefits associated with tree canopy in urban areas. This includes the need to undertake further research to understand the causal structures that link tree canopy with social, environmental and economic factors. The need for a whole-of-government approach to provide this information was a clear outcome of the workshop. Such a collaborative approach is required not only to ensure that different categories of information are included in the analysis, but also to ensure that different perceptions of the system are taken into account. It is therefore recommended that a cross-sector working group be established to address the issue of tree canopy in urban areas. In addition to key government agencies, industry, business, university and community representatives should be involved in the collaboration. Participants at the Tree Canopy Workshop identified the following opportunities for increasing information flows:

- Education and awareness-raising regarding the benefits of trees
- Incorporation of health issues into policies to protect trees
- Provision of evidence to underpin policy and practice
- Further research to into the causal structure of the urban-health system
- Studies of UHI effects in Perth
- Urban design case studies to demonstrate/test tree benefits
- Identification, consolidation and communication of the benefits/costs associated with trees.

8.3.7 Rules

Policies and laws, including incentives, constraints and punishments, are examples of system rules (Meadows, 2008). The real leverage with respect to rules is to ensure that they target the true goal of the system. If the goal of the system has been narrowed, the rules will tend to follow suit. The review of past and current policies (CA2) concluded that the current rules do not provide adequate protection of tree canopy levels in Perth. The finding was also supported by the workshop outcomes and by the 'Infrastructure Pecking Order' structure. In short, the current rules are a reflection of the current focus on higher urban densities.

Many cities in the world have developed and implemented urban forest strategies and a range of tree management policies and regulations. Such a policy would provide support for a range of specific rules to help promote trees in urban areas. Tree canopy targets are typically an important facet of urban forest policies. Rules pertaining to each of the processes affecting tree canopy stocks in Figure 72 (tree planting and removal) are critical. For example, the widespread practice of removing all vegetation during development, particularly mature canopy trees should be prevented wherever possible. Other cities in Australia have constraints on the removal of trees above a certain height. For example, Development Control Plans in the City of Sydney ensure that trees with a height of at least 5m or a canopy spread of over 5m are not removed or significantly pruned without permits or development consent. This Plan extends to trees both within and adjacent to development sites (City of Sydney, 2012).

Incentives or requirements to retain or plant trees on both private and public land can also be considered. Community tree planting programs have played a significant role in tree management plans of other cities and this type of incentive has the added advantage of increasing community awareness about the importance of trees in urban environments.

Rules that help to overcome the lack of accounting for the natural capital provided by tree canopy should be considered. Several local councils in Perth have implemented programs with the capacity to assess the full range of costs and benefits associated with trees. If programs of this nature were supported by rules, they would be powerful leverage points that ensure trees are considered as important aspects of green infrastructure.

In addition to the introduction of new rules, it is equally important to consider the impact of existing rules on behaviour that affect tree canopy. The physical limitations created by other policies, such as zoning limitations, setback and height limits and requirements for other infrastructure, may severely limit the physical opportunities to incorporate trees into the urban design. If the current rules discourage the inclusion of trees in urban design, these rules should be reconsidered.

8.3.8 Goals of the system

Goals capture the purpose or function of the system (Meadows, 2008). Goals are a powerful leverage point because they have a significant influence on other leverage points throughout the system. The discussion of Perth's vision, as expressed in *Directions 2031*, has been a focal point of this research to date. The *Shifting the Burden* archetype represented in the 'Narrowing of Perth's Vision' (Figure 76) hypothesised that a focus on the Compact vision, to the neglect of other aspects of the D2031 vision, will ultimately undermine progress toward a truly world-class liveable city.

There are numerous management solutions to overcome this archetypical behaviour. The first is to develop a vision that is clear, compelling and shared by everyone (Braun, 2002, Senge, 2006). If symptomatic solutions exist, it is important that they are recognised as such, and any unwanted effects are properly managed. While there is clearly awareness that urban consolidation is reducing tree canopy, there is little evidence that the effect is being properly managed. Also, the symptomatic solutions must be seen as only part of 'the solution' that provides time to develop more fundamental solutions.

One issue is that the clearest, most compelling and shared vision is reserved for the Compact vision. It remains the only aspect of the vision that is clearly defined, has a definite time-frame and is supported by a reporting system. Beyond generalisations, it is not clear what the 'green' aspect of the D2031 vision really means, or how 'sense of place' is to be interpreted, let alone how these elements will be monitored, reported and integrated into the vision.

The attainment of a clear and compelling goal is often undermined by other conflicting goals within the system (Senge 2006, Novak and Levine, 2010). In addition to the conflict between the two visions discussed above, a conflict also exists between the D2031 vision and the internal vision of developers. To survive in the market-place, the goal of developers is typically centred on the creation and growth of profit. Alignment with this goal is currently more likely to occur with the Compact vision than the D2031 vision. The lack of alignment between developer profits and elements of the D2031 vision undermines progress toward that vision.

Creating a shared high quality vision is only possible if the structure of the system supports the attainment of that vision for all the stakeholders. Senge (2006) discusses shared visions primarily in terms of organisational vision; however the D2031 vision extends well beyond organisational boundaries and encompasses a broad range of stakeholders with visions of their own. The evidence from this research suggests that while developers may aspire to the D2031 vision, in terms of tree canopy, the current system contains significant obstacles and few incentives or constraints that enable them to do so. A powerful leverage point would be to introduce elements to the system that support greater 'buy-in' to the D2031 vision. While this is a challenging task, the findings of the workshop suggest not only strong underlying support for the D2031 vision, but also a growing awareness that progress toward that vision is hampered by various aspects of the current system. This is a strong foundation for continued collaboration, which would be greatly enhanced by systems approaches.

The choice of appropriate indicators to measure goals is not only an important determinant of behaviour, but also an indicator of what we value most. In terms of leverage, changing indicators can be one of the most powerful and easiest ways of creating system change (Meadows, 2008). It is proposed that tree canopy levels should be used as an additional indicator of progress toward a more liveable city. Not only is there widespread agreement regarding the importance of trees in urban environments, there is also widespread agreement that they are facing immediate and long-term threats. This indicator would sit comfortably under a more sustainable approach, which will be discussed in greater detail in the next section.

Figure 79 shows how the gap between current canopy levels and an urban canopy target could be used to protect and encourage inclusion of trees in urban areas. The first step in the setting of the target is an explicit statement of what level of tree canopy we aspire to. This should be set in the light of a warming climate and guidance from targets in other Australian cities, such as Sydney and Melbourne. As with the urban density mechanism, the tree canopy mechanism must be accompanied by appropriate monitoring and reporting systems and supported by policies. There is a range of methods available for measuring tree canopy levels and recent developments in this area by the CSIRO Urban Monitor group provide significant potential. Policy support includes earlier suggestions discussed under 'Rules' of the system (§8.3.7). The extent of tree canopy over time will be determined by the relative strength of each process affecting inflows (planting and growth) and outflows (removals and deaths). Efforts to increase inflows and reduce outflows can target infill development and other facets such as tree management on public land.

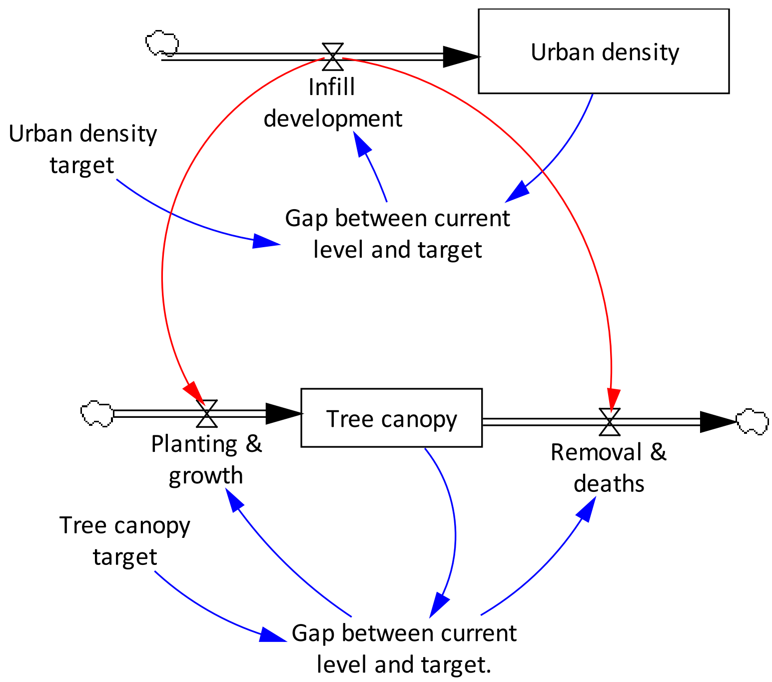

Figure 79 - Introduction of urban tree canopy target

8.3.9 Paradigms

Paradigms are defined by Meadows as "the mind-set out of which the system – its goals, structure, rules, delays, and parameters– arises" (2009, p. 162). This definition demonstrates why paradigms are considered the most powerful leverage point – they determine the system itself. This research supports the hypothesis that the market-forces paradigm currently dominates the system. While the need for sustainable development is widely recognised and promoted, this research has highlighted the tensions that exist between sustainable development and the current market-focused development. My application of the *Success to the Successful* archetype (Figure 74) led to the dynamic hypothesis that urban development in Perth is currently dominated by market considerations. Reflecting this market-based paradigm, the intent of the workshop question ‘who pays?’ was to ascertain who is responsible for the added cost of retaining trees in urban areas. However, if the question is asked from within a different paradigm –one of sustainable development – an entirely different response will be forthcoming. The exercise can be extended to ask the questions: when do we pay, and what are we paying for?

Figure 80 represents the answers to these questions using the two halves of the Yin and Yang symbol. The white half represents development from a market-focused viewpoint. The black half represents development from a sustainable-focused viewpoint. The Yin and Yang symbol serves to remind us that the system is made up of economic, environmental and social aspects that are part of a highly connected system and must be managed as a whole if the system is to function sustainably.

The question of when we pay is fundamental to the tensions between market-focused and sustainable-focused development paradigms. Market paradigms have a strong tendency to focus on the relatively short-term and ‘discount the future’. This was demonstrated by ‘Market Mechanisms and Tree Canopy’ (Figure 73) where the short-term consideration of increased costs dominated system behaviour because of the delays associated with consumer willingness to pay for the additional costs. The cornerstone of sustainable development is the protection of resources for future generations, so a sustainable paradigm would give far greater emphasis to the future costs and benefits of tree canopy. The clear evidence from the research was that these costs and benefits are not accounted for by our current system.

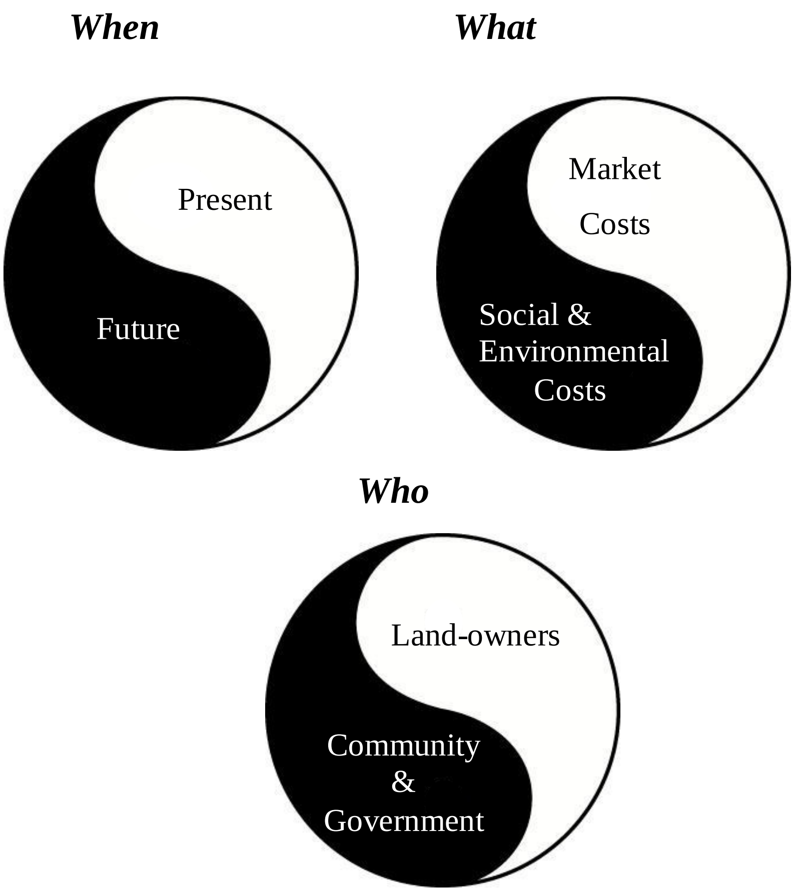

Figure 80 - The paradigm questions

Any question of payment leads to the obvious question of what are we actually paying for? With respect to the market paradigm, the payment is the market value attached to the inclusion of trees in urban environments. This can be interpreted from the perspective of both the private and public sector. The sustainable value would also encompass the external costs associated with the removal of tree canopy from urban environments. Again, these costs are not being accounted for in the current system.

Returning to the original question of 'who pays?' the market paradigm considers that the land-owner will ultimately pay for the inclusion of trees. The sustainable paradigm considers the long-term costs and benefits associated with tree canopy that have been discussed throughout this research. The costs of these impacts, many of which will be incurred in the future, will be borne primarily by members of the community and government.

In summary, the evidence presented in terms of tree canopy management in Perth suggests that the current development paradigm assumes the validity of the free-market model. This paradigm influences decision-making across all levels of the system - from the individual to private companies to all levels of government. Therefore, the most powerful leverage point is to develop a mindset that understands not only that the current system is in a state of imbalance, but also that the ability of a free-market model to achieve sustainable development is limited.

Societies tend to strongly resist challenges to their current paradigm (Meadows, 2008). Although such a paradigm shift may be difficult to achieve, it is important to remember that if achieved the behaviour of the entire system will follow suit. There is no doubt that a change of paradigm at the societal level will not occur quickly – it is more likely to occur as a gradual transition to a more sustainable approach. Nevertheless, the widespread agreement on the need for sustainable development and the relative ease (and speed) with which individuals can alter their paradigms, provide an important starting point (Meadows, 2008).

The key to supporting paradigm change is to present evidence which highlights the shortcomings of the current paradigm and to provide a clear alternative. The effect of the dominant free-market paradigm on tree canopy in Perth and the ensuing recommendations of this research are a suitable case in point.

8.4 CA6 – Can we have new eyes?

The final activity of CCM reconsiders the original challenge defined by CA1. The understanding gained from the CCM process feeds into Sterman's model of double-loop learning (Figure 35, §6.2.3), creating new mental models or 'new eyes'. Recalling CA1, the original challenge, derived from the Global Local Model, was the challenge of managing tree canopy in parallel with urban consolidation.

Using the 'new eyes' developed by applying the CCM process, we see that this issue is a part of a larger challenge – the challenge of transitioning to a more sustainable development system, and the attainment of a world-class liveable city. While the CCM process began with the Global Local Model, the focus of the challenge was defined predominantly within the Local Loop. However, in this final step of the CCM process, the challenges at the local level must ultimately be viewed within the context of a changing global climate. This process of 'zooming in and out' is a reflection of the fundamental systems viewpoint of seeing wholes and patterns of change rather than static snapshots (Senge, 2006).

The undeniable link between urbanisation and the creation of urban heat-islands provides Perth with an opportunity to avoid, or at least reduce, the adverse effects of urbanisation that have been experienced in other cities. Given the health, economic and environmental effects that can result from extreme heat, it is proposed that in light of climate change, excess heat is considered as a pollutant in urban areas. This is the case in other cities where UHI mitigation plans are an important component of urban planning (Yamamoto, 2006; Greater London Authority, 2006) and air quality management plans (Gorsevski, Taha, Quattrochi, & Luvall 1998; United States EPA, 2008).

Despite the opportunity to learn from other cities, this research has indicated that the current planning system in Perth is largely overlooking the role of trees in climate-sensitive urban design. The conclusion is that current planning and development practices in this area are more likely to exacerbate than ameliorate the anticipated effects of climate change. The outcome of this will be to reduce the resilience of the Perth community to the impacts of future heatwaves and higher temperatures. This outcome is at direct odds with the need for effective climate change adaptation.

The *Capital City Planning Framework* (p. 27) called for a “strategic, linked approach guided by common principles” to address the issue of tree canopy loss in Perth. It is proposed that the leverage points identified in CA5 provide a framework from which to develop these principles.

Projections of land-supply needs for a city of 3.5 million were estimated in *Directions 2031* under three urban infill rates of low, medium and high. While this scenario planning was useful for estimating land supply and infrastructure needs, the exercise should be extended to include more qualitative aspects of Perth’s future. For example, the impact on the future quality of life in Perth could be considered in terms of tree canopy scenarios.

Although the application of the CCM process highlighted clear conflicts between the current drive for urban infill development and tree canopy, there was no evidence to suggest that a greener and more compact city is unrealistic. The outcome is achievable and the recommendations below are a suitable starting point.

The consideration of these issues within the context of the Global Local Model presents another paradigm challenge – the transition from a system based on our experience of past climate to one that must adapt to a new climate. This transition may prove the difference between a climate-resilient and a climate-sensitive city, and must be considered as a key to the progression to a more sustainable city.

8.5 Recommendations from Phase II CCM

The objective of Phase II was to develop strategies to support the effective management of tree canopy in areas targeted for urban infill in Perth. The foundation for these strategies was an increase in our understanding of the underlying system structure and behaviour that affects tree canopy levels in Perth. This improvement in understanding, which began with Phase I of CCM, was extended by the application of CA5 and CA6 in Phase II.

The discussion of leverage points provided the final key for recommendations to improve the management of tree canopy as part of urban infill processes in Perth over the next few decades. The recommendations listed below are seen as an intrinsic part of a more climate-resilient city:

- Review the extent to which current strategies, policies and actions effectively integrate the economic, social and environmental aspects required for sustainable development

This recommendation sits at the heart of the issue and is related to the two strongest leverage points – paradigms and goals. The appropriate balance between economic, social and environmental aspects is not currently being met with respect to tree canopy management. More broadly speaking, the balance is also lacking with respect to the *Directions 2031* vision, which is a central goal of the system. Questioning the extent to which current strategies achieve a suitable balance between economic, social and environmental outcomes is the basis for a shift toward a more sustainable paradigm which supports progress toward a healthier and more liveable city.

- Ensure that all elements of the *Directions 2031* vision are supported by appropriate targets and strategies

The evidence suggests that policies, targets and information flows that support the 'more compact' goal of the world-class liveable city are more prevalent than actions which support other elements of the vision. In the absence of specific targets and strategies to deliver other aspects of the vision, important elements of liveability such as tree canopy will largely be determined as a 'side-effect' of progress toward a more compact city. Effective strategies must acknowledge and address the interests of all stakeholders from community members to government to developers.

- Develop an urban forest management plan which includes:
    - A tree canopy target and associated monitoring and reporting procedures
    - A system to account for the long-term costs and benefits of tree canopy and other elements of the urban forest
    - Incentives and constraints to support inclusion of trees in urban areas

The goal of a more compact city is supported by strong information flows and rules regarding urban density. However, with respect to tree canopy, these information flows and rules are either weak or absent. This recommendation seeks to overcome this.

- Develop an urban heat-island mitigation plan

The findings of the HIA concluded that the highest health risk in Perth 2050 related to climate change will occur as a result of exposure to extreme heat. Given the extent of planned urban development in Perth, effective adaptation to health impacts of climate change must include an urban-heat island mitigation plan. While the focus of this study is health, this recommendation is also critical to climate change adaptation plans with respect to urban infrastructure.

- Establish a cross-sector working group to address gaps in understanding and awareness of the role of trees in Perth
- Develop educational and awareness-raising materials regarding the benefits of trees (for all stakeholders)
- Conduct further research into the causal structure of the urban-health system
- Collect evidence that demonstrates the influence of tree canopy on liveability.

The final four recommendations are critical to increasing understanding of the issue. As previously discussed, delivering information to new places in the system can be a highly effective way of changing system behaviour. Each of the above recommendations aims to increase knowledge regarding the role of tree canopy in influencing health in urban areas. The distribution of this knowledge across sectors and the community is critical because a better understanding of the system can only be achieved if the viewpoints and challenges of all stakeholders are considered.

The development and implementation of these recommendations will undoubtedly take time. However, an important outcome of this research was the recognition that current urban infill processes can result in virtually irreversible changes to the urban environment. If current infill practices are allowed to continue, the number of opportunities to incorporate trees will be reduced. Given this and the rapid rate of development in Perth, it is important that actions to address the issue are developed and implemented as soon as possible.

The application of CCM in this research was centred on the conclusion of the risk assessment step of the HIA - that the greatest health risk in Perth (2050) associated with climate change is increased exposure to heat. The introduction of CCM at this stage represents a significant deviation from the approaches typically used within HIA. A review of this process and the results it achieved will be discussed in greater detail in Chapter 9.

Chapter 9 – Systems Approaches in HIA

9.1 Introduction

This chapter is focused on the final element of the research – the evaluation and review of systems approaches in HIA (Figure 81). As mentioned in Chapter 1, successful adaptation planning for climate change requires an understanding of where measures must be targeted and how they will act out in a complex system (Adger et al., 2007; Preston & Stafford-Smith, 2009). In this chapter, I consider whether this requirement has been met by the application of CCM within the HIA framework. The chapter begins with an analysis of the lessons learnt from each of the CCM activities undertaken. The potential for wider application of systems approaches in HIA is discussed. Finally, some closing thoughts are provided on the transition to a healthier and more sustainable city, in the face of climate change, urbanisation and continued population growth.

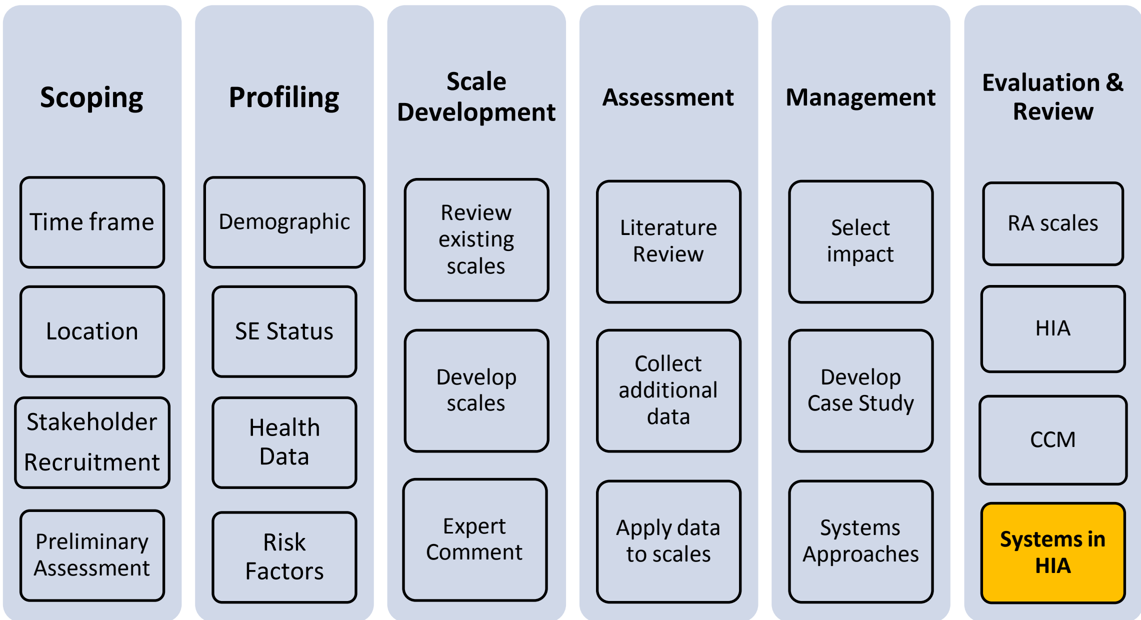

Figure 81 - The final element: evaluation of systems approaches in HIA

9.2 Application of CCM – lessons from the case study

Each of the CCM activities undertaken within the context of this research is interpreted with respect to how they relate to HIA.

9.2.1 CA1 - What is the challenge?

The findings of the scoping, profiling and risk assessment steps of the HIA were the foundation of this activity. The question of 'what is the challenge' was therefore centred on the issue of exposure to heat in Perth over the coming decades.

The development of the Global Local Model provided a relatively simple but effective way to communicate this issue. Most importantly, it communicated the issue in a way that encouraged stakeholders to think in terms of feedback and interactions across traditional disciplines. The illustration of the issue at the global and local scale enabled stakeholders to view the 'big picture', while presenting them with a clear path of action relevant to the local setting. This template was then used to consider one aspect of the issue – that of tree-canopy and urban consolidation. An obvious extension of the research is to consider other aspects of the issue, such as albedo and urban consolidation.

Comprehensive HIAs typically assess numerous impacts that are influenced by multiple, interacting factors. The development of a high-level conceptual model that can capture the essence of these interactions could prove a useful starting point to the management or decision-making phase of HIA. As with the example above, the conceptual template can be used to guide work on different 'parts' of the problem while still maintaining an awareness of the major links in the system.

9.2.2 CA2 - What is the story?

The historical analysis of urban planning and development with respect to tree canopy provided an understanding of how policy has affected tree canopy in Perth. In the absence of specific policies targeting tree canopy, levels have essentially been determined by the 'side-effects' of other policies and development practices. In addition, this step also highlighted the gradual emergence of climate change as a significant policy issue.

The stakeholders involved in a HIA represent a repository of knowledge regarding past decisions, actions and outcomes related to the issue at hand. A systems approach would combine this knowledge, with the evidence collected during the HIA, to enable an understanding of the dynamic behaviour of the system. This information can be transformed into a greater understanding of the consequences of past actions and an awareness of the multiple drivers of current and future situations (Newell & Proust, 2012).

9.2.3 CA3 - Can I see how you think?

This activity was undertaken as a CCM workshop and included the use of individual and pair-blended influences diagrams and focused dialogue. The challenge of incorporating multiple, competing stakeholder interests is a familiar one for HIA practitioners (Chadderton, Elliott, Hacking, Shepherd, & Williams, 2013). Decisions that are made both during and subsequent to HIAs are influenced by a range of political, economic, technical, and practical considerations (National Academy of Sciences, 2011). Within this context, the pair-blending process offers a tool purpose-made to address such challenges.

From the perspective of HIA, the pair-blending process offers several advantages. The first is that it encourages stakeholders to see the feedback nature of the system from a shared point of view. The second is that the diagrams provide a relatively simple representation of the system with a common 'language' that aids communication. Finally, the influence diagrams represent the system – in other words, they provide a picture not just of the problem, but also of how the problem emerges from the structure of the system. Within this picture lie both the causes of and solutions to the problem.

9.2.4 CA4 - What drives system behaviour?

Identification of systems archetypes and the construction of qualitative systems models resulted in a far greater understanding of, (a) the forces that determine tree canopy levels, and (b) how these levels will influence health and well-being in Perth. The analysis of feedback loops, delays and other features determined that the system is currently dominated by mechanisms that undermine progress toward a healthy tree canopy. In addition, it was concluded that these dominant mechanisms may undermine progress toward a healthier and more sustainable city.

The HIA process clearly requires an awareness of the connections between health outcomes and determinants of health. However, in the case of complex systems, awareness does not translate into an understanding of behaviour (Senge, 2006; Sterman, 2000). Designing effective interventions in complex systems without an understanding of system behaviour is unlikely.

The wider use of system archetypes could deliver significant advantages to HIA. For example the archetypes identified in this research, the *Success to the Successful* and *Shifting the Burden*, can be applied to situations or issues other than the management of tree canopy. As awareness regarding the archetypes increases, so too does the likelihood that more suitable interventions will be applied. In an example of double-loop learning, the identification of archetypes and the lessons learnt from the ensuing interventions, will inform future HIAs.

9.2.5 CA5- What are the leverage points?

The consideration of leverage points, as developed by Meadows (2008), resulted in the development of recommendations to ensure more effective management of tree canopy during a period of urban consolidation. In light of climate change projections, the opportunity to reduce exposure to heat at a population-wide level is a significant one.

The ability to consider the effectiveness of interventions, with respect to strength of leverage points, would be particularly useful for HIA. Decisions, which are often made in the face of resource or political constraints, would be aided by an understanding of the relative strengths of suggested interventions and their effect on system behaviour. In addition, even if current constraints prevent the application of a high leverage intervention, the awareness of the intervention (and the constraint) is an important outcome in itself. In such cases, a long-term approach would be to focus on an intervention that acts to overcome the constraint.

9.2.6 CA6- Can we have ‘new eyes’?

The trigger for Phase II of the research was the issue of exposure to heat in urban environments. The case study focused on the role of tree canopy in Perth and how that may be affected by urban consolidation. The application of the CCM activities led to a recognition that trees are a multi-functional asset of urban environments and their influence extends well beyond the issue of urban temperatures. In essence the ‘new eyes’ saw trees as part of the entire urban system, with connections to health, the environment, the community and the economy. Figure 82 provides examples of some of environmental, health and economic variables that are linked with tree canopy and health. The figure is intended to represent that the future liveability of Perth will be determined by many aspects, and can be used as a tool to help stakeholders consider future scenarios for Perth with respect to health and well-being. With respect to this research, scenarios of a compact city with or without a healthy tree canopy can be used to increase awareness and understanding of the issue and inform the decision-making process.

Figure 82 - Influence of tree canopy on liveability

The analysis of these connections was undertaken as part of the CCM activities. The conclusion was that fundamental tensions between the market forces of urban development and the driving forces of sustainable development were resulting in reductions in tree canopy.

Ultimately, the case study has provided a 'new way' of looking at HIA. This involves, particularly for HIAs of important strategic or policy directions, a greater emphasis on understanding behaviour in complex systems. It is believed that this new way of looking at HIA responds to calls for greater integration and better understanding of the complex interactions that ultimately determine the health and well-being of people (Chadderton et al., 2013; Adger et.al, 2007; National Academy of Sciences, 2011; Harris & Spickett, 2011).

9.3 Guidelines for the integration of CCM with HIA

The experience of this research has suggested a natural nexus between HIA and CCM as shown in Figure 83. Step 1 begins with the traditional application of the scoping, profiling and risk assessment steps of HIA. Scoping would determine if and how system approaches were to be introduced to the HIA. For example, a determination may be made that only CA1 to CA3 are utilised. The evidence and findings of the HIA steps then inform CA1 and CA2 of CCM. The outcome of the HIA steps may lead to a focus on a specific issue (as with this research) or on a number of issues. In this research, there was a clear separation between the early HIA steps (Part I of the thesis) and the introduction of CCM (Part II of the thesis). With the findings of this thesis and Figure 83 for guidance, that separation would become less distinct. For example if the evidence collected during the HIA steps was gathered with an awareness of the planned CCM activities, the degree of overlap and the efficiency of the process would be enhanced.

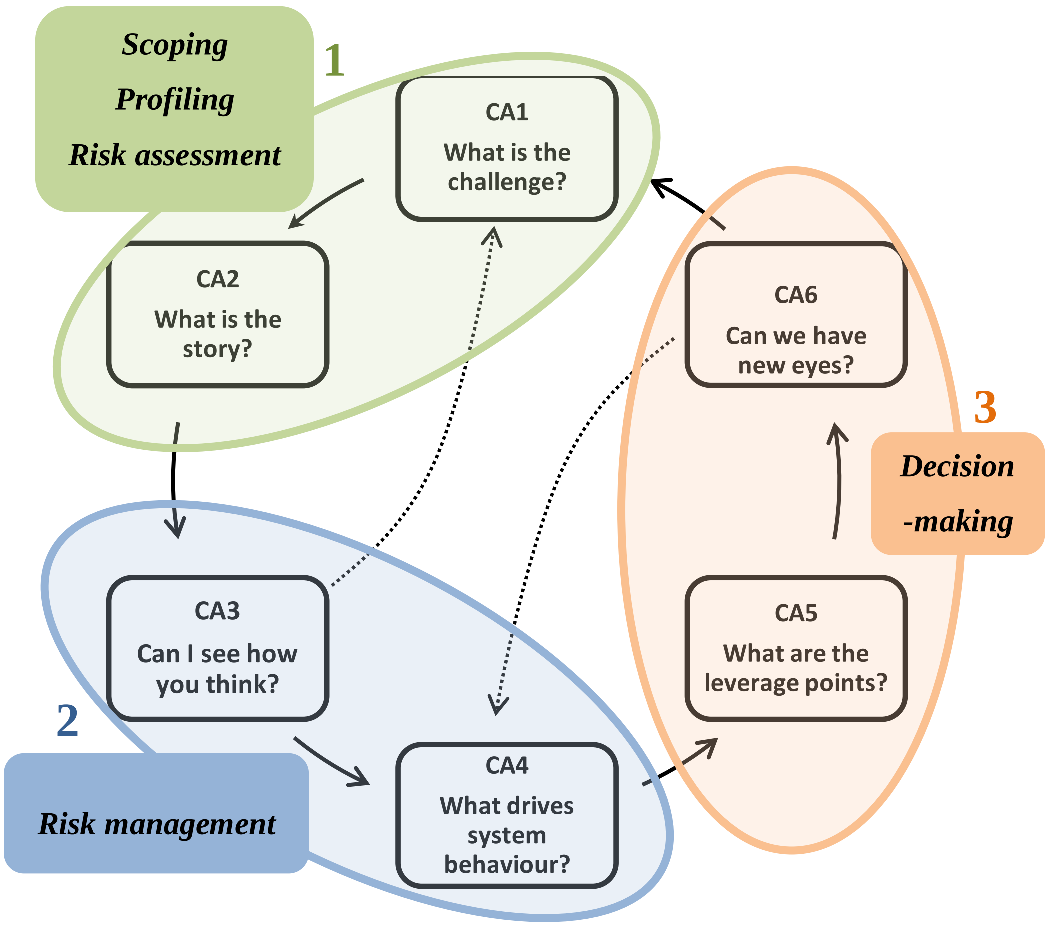

Figure 83 - Proposed integration of co-evolving CCM activities with HIA

The typical HIA progression from risk assessment to risk management and then decision-making is maintained in this process. CA3 and CA4 fit neatly into the risk management step of HIA. As discussed previously, these activities are designed to develop a shared understanding of complex issues faced by stakeholders from a range of disciplines – characteristics that are inherent in the risk management step of many HIAs.

The decision-making process in HIAs is fraught with difficulties. There is no certainty with regard to outcomes of decisions made in complex dynamic systems. And yet, decisions must be made. CA5 and CA6 of CCM are designed to address these difficulties – not to deliver any notion of certainty, but rather to provide a better understanding and rationale upon which to base decisions.

While Figure 83 provides guidance for the introduction of CCM activities to HIA, in practice the current approach where "those undertaking a HIA are likely to pick and choose from a range of strategies and approaches" (Harris et al., 2007, p. 3), is likely to continue. Indeed, this approach is supported by Newell and Proust (2012, p. 4), who state that "selected activities can be downplayed or augmented depending on the particular needs of a specific group." In many cases, the CCM activities can fit neatly alongside existing HIA activities. One obvious point of integration is the introduction of CA1 to CA3 (Phase I of CCM) to HIA workshops.

The introduction of CCM to HIA led to the development of recommendations that, if implemented, will deliver significant health benefits to Perth residents. In response to the findings of the risk assessment, the recommendations respond to the threat of increased exposure to heat posed by climate change. I conclude that it is unlikely that these recommendations would have emerged from a traditional HIA, without the use of systems tools. It is therefore proposed that, if HIAs are addressing issues of significant complexity, the introduction of system dynamics approaches such as CCM would be a valuable addition to the process.

9.4 A final note – the vision for a healthier city

The proof of commitment to visions lies not in words, but in the behaviour of the system (Meadows, 2008). Sustained tree canopy loss in Perth therefore questions the commitment to a greener and more sustainable city.

Health is considered both as an outcome and a precondition of the economic, social and environmental pillars of sustainable development (United Nations, 2012). A lack of progress toward sustainable development has been attributed to a lack of integration across these three pillars (Haines et al., 2007). This research suggests that the current failure of urban consolidation policies to actively manage the impact of these policies on tree canopy is indicative of the struggle to integrate economic, environmental and social considerations of development.

The recommendations below provide an opportunity to align the behaviour of the system with the words of the vision. The recommendations are organised into three broad areas of policy, collaboration and research.

1. **Policy - develop policy that is supportive of *all* aspects of the *Directions 2031* vision**

- Review the extent to which current planning strategies, policies and actions effectively integrate all aspects required for sustainable development, including the need for climate change adaptation
- Ensure that the 'non-compact' elements of the *Directions 2031* vision are supported by appropriate targets and strategies
- Develop an urban forest management plan which includes:
  - A tree canopy target and associated monitoring and reporting procedures
  - A system to account for the long-term costs and benefits of tree canopy and other elements of the urban forest
  - Policies to counter the loss of tree canopy associated with urban infill
- Develop an urban heat-island mitigation plan.

2. **Collaboration - increase collaboration between stakeholders connected to the issue of tree canopy**

- Establish a cross-sector working group to inform policy, address gaps in information and improve understanding and awareness of the role of trees in Perth
- Share information and evidence regarding programs that account for tree canopy costs and benefits
- Develop educational and awareness-raising materials regarding the benefits of trees (for all stakeholders).

3. **Research – conduct research into the interactions between the built environment, tree canopy, microclimates and health**
    - Develop future scenarios that incorporate all aspects of the D2031 vision, including tree canopy
    - Establish the extent of the UHI effect in Perth and potential mitigation strategies
    - Conduct research into the influence of tree canopy on microclimate and liveability in Perth

- Develop urban design case studies that consider the role of tree canopy in areas of urban infill and support climate-resilient cities.

The evidence for these recommendations is scattered throughout this thesis. The location of the evidence, organised into the three parts of the integrated HIA-CCM process, is provided below. In some cases evidence is located in more than one Part – if so, the statement is listed under the Part where the primary piece of evidence was gathered, but the location of supporting evidence is also noted.

Part 1- Risk Assessment, CA1 and CA2

- Exposure to heat poses the highest health risk related to climate change in Perth in the year 2050 (§5.4.7)
- Increases in ambient temperature in Perth will be influenced by global and local drivers (§7.2.1)
- Population increases and urban consolidation policies are likely to place increasing pressure on tree canopy and contribute to UHIs (§7.2.2, §7.4)
- Past and current policies have not provided adequate protection of trees in urban areas (§7.3.1, §7.3.3)
- Current policies largely overlook the impact of urbanisation on ambient temperatures and the prospect of a hotter climate (§7.3.3)
- There is no formal UHI mitigation policy in Perth (§7.3.3.1)

Part 2 – Risk Management, CA3 and CA4

- The range of environmental, social and economic benefits provided by trees is currently undervalued across a range of sectors (§7.4.3, §7.4.4)
- Community awareness is an important driver of decision-making in the marketplace and policy arena, but is weak with regard to tree canopy (§7.4.2, §8.2.1.1)
- The gap between current dwelling density and density targets is one of the main driving mechanisms of tree canopy loss (§ 8.2.1.2)
- Current policies to manage tree canopy in areas of urban infill are inadequate (§8.2.1.2, §7.4.4.2)
- The benefits provided by tree canopy are not adequately accounted for and this is a main reason for tree canopy reductions (§8.3.5)

- The behaviour of the current system is dominated by relatively short-term market-forces which are a barrier to sustainable development (§8.2.2.2)
- The current structure of the system is focused on attaining the goal of a more compact city at the expense of other aspects of Perth's vision (§8.2.2.2)

Part 3 – Decision-making, CA5 and CA6

- The lack of information on desired and existing tree canopy levels is a barrier to effective management of trees in urban areas (§8.3.6, §8.3.8, §7.4.4.2)
- The lack of an integrated Urban Forest management plan (and appropriate incentives and constraints) is a barrier to effective management of trees in urban areas (§8.3.7, §7.4.4.2)
- The current planning and development systems are driven by a paradigm based on market-forces rather than sustainable development (§8.3.9)
- Integration of systems approaches to HIA resulted in a greater understanding of system structure and behaviour which enabled the development of more robust recommendations (§9.2.6,§9.3)

The recommendations presented in this thesis provide an opportunity to develop and implement measures designed to achieve better health outcomes for current and future generations of Perth residents in the face of a warming climate. The evidence suggests that a failure to do so will exacerbate the health effects of climate change, and compromise progress toward a world-class liveable city.

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Appendix A: Health Impacts of Climate Change in WA Consequences

Consequence Level	Description
Catastrophic	Large numbers of serious injuries, illnesses or loss of life Severe and widespread disruption to communities Long term inability to deliver essential goods and services Severe long-term reductions in quality of life Huge economic costs
Major	Small numbers of serious injuries, illnesses or loss of life Significant and widespread disruption to communities Significant decline in delivery of essential goods and services Significant long-term decline in quality of life
Moderate	Small number of minor injuries or illnesses. Significant disruption to some communities. Significant decline in delivery of essential goods and services. Significant short-term or minor long-term reduction in quality of life.
Minor	Serious near misses or minor injuries. Isolated short-term disruption to some communities. Isolated but significant reductions in essential goods and services. Minor reductions in quality of life.
Insignificant	Appearance of a threat but no actual harm. Very minor disruption to small section of community. Isolated, minor reduction in delivery of essential goods and services. Insignificant impacts on quality of life.

From Spickett, Brown & Katscherian, 2007, p. 68

Appendix B: HRA (Scoping) scale applied to Perth 2011

HRA (Scoping) Consequence Scale		**Population at risk of 1.7 million**
Catastrophic		
Fatality	>1	>0.01% increase total mortality
OR Non-permanent injuries requiring hospitalisation for:	5-10% of population at risk	Increase of 85000 to 170000 hospitalisations = Increase in PPH of 186to 371%
OR Acute health effect requiring hospitalisation for:	>5-10% of population at risk	Increase of >85000 to 170000 hospitalisations = Increase in PPH of >186 to 371%
OR Chronic health effect requiring medical treatment	10-15% of population at risk	Medical treatment for 170000 to 255000
Massive		
Fatality	1	0.01% increase total mortality
OR permanent disabilities	2-5	
OR Non-permanent injuries requiring hospitalisation for:	>2-5% of population at risk	Increase of 34000 to 85000 hospitalisation = Increase in PPH of 74 to 186%
OR Acute health effect requiring hospitalisation for:	>2-5% of population at risk	Increase of 34000 to 85000 hospitalisation = Increase in PPH of 74 to 186%
OR Chronic health effect requiring medical treatment	5-10% of population at risk	Medical treatment for 85000 to 170000
Major		
Fatality	Nil	Nil
OR Non-permanent injuries requiring hospitalisation for:	>1-2% of population at risk	Increase of >17000 – 34000hospitalisations pa = Increase in PPH of 37 to 74%
OR Acute health effect requiring hospitalisation for:	>1-2% of population at risk	Increase of >17000 – 34000 hospitalisations pa = Increase in PPH of 37 to 74%
OR Chronic health effect requiring medical treatment	2-5% of population at risk	Medical treatment for 34000 to 85000 persons
OR Evacuation is necessary		
Moderate/Significant		
Fatality	Nil	Nil
AND Non-permanent injuries requiring hospitalisation for:	<1% of population at risk	Increase of < 17000 hospitalisations pa Increase in PPH of <37% or less
OR Acute health effect requiring hospitalisation for:	<1% of population at risk	Increase in PPH of <37% or less
OR Chronic health effect requiring medical treatment	1-2% of population at risk	Medical treatment for 17000 to 34000 persons
AND No evacuation		
Minor		
Fatality	Nil	Nil
AND Non-permanent injuries requiring hospitalisation for:	1-5 persons	1-5 persons hospitalised
OR no acute health effect requiring hospitalisation for:	Nil	Nil hospitalisations
OR Chronic health effect requiring medical treatment	0-1% of population at risk	Medical treatment for 0 to 17000 persons
AND No evacuation		

Appendix C: Consequence scale & risk score from the UKCCRA

Scale	Economic	Environmental	Social
High (=3)	• Major and recurrent damage to property and infrastructure • Major consequences on regional and national economy • Major cross-sector consequences o ~ £100 million for a single event or per year	• Widespread decline in land/water/air quality • Widespread failure of ecosystem function or services • Major cross-sector consequences o ~ 5000 ha lost/gained o 10 000 km river water quality affected	• Potential for many fatalities or serious harm • Loss or major disruption to utilities • Major consequences on vulnerable groups • Increase in national health burden • Major role for emergency services o ~ million affected o ~ 1000s harmed o ~ 100 fatalities
Medium (= 2)	• Widespread damage to property and infrastructure • Influence on regional economy • Moderate cross-sector consequences ~ £10 million per event or year	• Regional decline in land/water/air quality • Moderate cross-sector consequences ~ 500 ha lost/gained 1000 km river water quality affected	• Significant numbers affected • Loss or major disruption to utilities • Increased inequality • Consequence on health burden • Moderate increased role for emergency services ~ 100s thousands affected ~ 100s harmed ~ 10 fatalities
Low (=1)	• Minor or very local consequences • No consequence on national or regional economy o ~ £1 million per event or year	• Localised decline in land/water/air quality o ~ 50 ha damaged o 100 km river water quality affected	• Small numbers affected/within coping range • Small reduction in community services • Within 'coping range' ~ 10 thousands affected etc

Risk Score Calculation

$$100 \times \frac{(\text{Social} + \text{Environmental} + \text{Economic})}{9} \times \frac{\text{Likelihood}}{3} \times \frac{\text{Urgency}}{3}$$

The magnitude score consists of three equally weighted measures of social, environmental and economic metrics.

Final risk score is out of a possible 100 points, and scores >30 were considered for more detailed assessment.

Appendix D: Local Government responses for preliminary risk assessment

Impacts	Risk for State	Amendment to Risk Level for Study Area		Proposed amended risk in study area	Responses from stakeholders: C: Cockburn, F: Fremantle, M: Melville
		Yes/No	Rationale for amendment		
Direct physical impacts of extreme events					
Tropical Cyclones – direct physical injuries	Extreme	Yes	Vulnerable region was in North-West of state. Tropical cyclones rarely reach study area and current climate change projections do not indicate that the study area is likely to experience any increase in exposure to tropical cyclones.	Medium-Low	**F:** Risk may increase as warming is evidence that cyclones can reach to lower latitudes. Evidence that severe pre/post cyclone storms over 24 hours can result in damage.
Storms	(not assessed)	Yes	Increased frequency and intensity of storm events forecast for study area. Recorded storm events for last 10 years (taken from SMRC report) result mostly in property damage but also one injury and one fatality. SMRC reported this risk as high, but most likely due to infrastructure and property damage rather than health impacts.	Medium	**C:** No reported Health effects relating to Storm damage. All damage recorded has been structural. Mental health concerned with rehousing etc has not been addressed **F:** This is a reasonable rating. Some of the secondary effects from storms are captured below, so I wouldn't say that it was completely missed in the

					original study **M:** More emergency for infrastructure. Power supply – food health and vulnerable medically.
Flooding – physical injuries, drowning	High	Yes	Vulnerable populations were those residing in flood zones. The Natural Hazard Risk in Perth report (2005) stated that the reduction in Perth's average annual rainfall over the past 40 years is likely to reduce the likelihood of floods. Previous floods in Perth have resulted in infrastructure and property damage, but no record of direct health impacts of flooding in the Perth region could be found.	Medium	**C:** City has increased requirements for development sites to accommodate increased rainfall events. From a 1 in 20 year storm to a 1 in 100 year storm. The City has carried out a basic topographical risk assessment of the impact of a 1m rise in sea level and ensured that areas at risk of inundation or damage have been identified. **F:** BoM & Swan River Trust would have this detail for Perth metro area. Localised flooding has been noted from significant rain events and storm sumps are in place. **M:** Compounding effects from pumping outlets and sewage

					discharge points. Marmion Lakes overflow for sewage. Controls in place.
Fires – physical injuries	Extreme-High	Yes	The Natural Hazard in Perth report highlighted bushfires as a major threat for people living in the hill-suburbs, and in semi-rural areas. The study area is predominantly urban and fire-prone areas are limited to sections of remnant bush-land that are not likely to pose a significant threat to human health. The SMRC Climate Change Risk Management report assessed the impact of bushfires on public safety as high – given the study area included Kwinana and Rockingham, which have a higher occurrence of semi-rural, rural and bush, is this an over-estimation for the current study area?	Medium	**C:** The City of Cockburn has a large number of regional parks and semi-rural areas. May be premature to downgrade this risk rating in Cockburn. The City is in the process of identifying all existing and areas requiring a Fire Management Plan (FMP). No records of injuries or fatalities from bushfires. **F:** Risk can be reduced further. There are two very small natural bushland patches, which are surrounded by a roads & residential areas. **M:** Compounding effect of lack of water and increasing temperature – heatwaves. Needs ongoing evaluation. The Community have ranked this risk as High (mainly around loss of biodiversity and

					impact on soil. May pose mental health risks?
Heat Events	Extreme	No	Large sensitive population with higher than state average over the age of 65 in Melville and Fremantle. Also possibility of urban-heat island effect in some areas. Study area includes low SES areas that are likely to have lower than average adaptive capacity to deal with increased incidence and severity of heatwaves.	Extreme	**M:** Check likelihood and consequence for this. This may refer to a lack of volunteers to respond to heat events. High to Extreme..
Water-borne Diseases					
Water-borne diseases from contamination of drinking water in extreme events	High	Yes	Vulnerable groups were remote Aboriginal and rural communities. Centralised supply of treated drinking water in Perth reduces level of risk.	Medium	**F:** There is an opportunity for more people to use off-grid water supplies as an adaptive response. The City demonstrates how to do this at a community centre. **M:** Medium – Low Reliant on Water Corporation – also good supply of bottled water at present.

Exposure to pathogens in recreational waters	High	No	Study area contains significant recreational waters (ocean and river areas) used by large numbers from within and outside the study area	High	**C:** Recreational waters (ocean) within the City are regularly monitored and forms part of a program conducted by the DOH. The results are monitored and interpreted by the DOH and reports placed on their website. Blue Green Algae incidence sometimes results in the City erecting signs around recreational lakes reporting on the potential health effects **M:** Report on 95th percentile with DEC &Department of Health. 6 locations for sanitation reports. Have signage and high level of knowledge and recovery plans. Waste water overflow. Signage strategy in place.
Exposure to pathogens in grey-water and non-potable water	High/ medium	No	Vulnerable populations were rural/remote communities, but as water costs increase and water conservation is promoted, grey-water systems in study area are likely to increase.	High/medium	**C:** Record kept of all approved grey water systems installed in the City. We are not anticipating major problems with defective grey water systems because there are so few in the City. No recorded

					problems/complaints received. **F:** To encourage take up of GW the City has a policy to refund prescribed application and permit fees for approved grey water systems. The industry that sells and installs these apparatus guide the market price of the apparatus in a simple supply & demand model. **M:** Standards in place. Receive around 3 applications per year
Vector-borne Diseases					
Ross River Virus (RRV) Barmah Forest Virus (BFV) Dengue Fever Murray Valley Encephalitis (MVE)	High	No	Most cases of RRV are acquired outside Perth. However significant south-west outbreaks in 1999/00 and 2003/04, have led to locally acquired cases in Perth, predominantly in outer metropolitan local government areas. The 2003/04 outbreak recorded 485 cases occurring across more than 170 Perth suburbs. City of Cockburn recorded the third highest	High Ross River Virus Barmah Forest Virus	**C:** All RRV and BFV are meant to be reported to LG. Interviews are conducted and questionnaires returned to DoH. No statistics appear to be produced relating to where patients may have acquired disease. **C:** keep overall statistics but has also not broken down as to where the likely point of infection occurred. Information also published by DoH

			attack rate in Perth in that season. Activity of RRV is strongly influenced by temperature, rainfall and tides, which will be affected by climate change. Activity is also influenced by human influences such as location of residential areas in relation to known mosquito breeding site. Development of new residential areas, particularly in the south of the study area, may also alter future activity levels of RRV. The incidence of BFV cases is much lower than RRV and most cases are acquired outside the Perth area. However, *Cx. annulirostris* has been isolated in the southern suburbs of Perth, indicating that transmission cycles can occur in the metropolitan area (DoH, WA) Dengue Fever and Murray Valley encephalitis have not been recorded		on regular basis which identifies the occurrence by Public Health Area (South Metro) **F:** Personal observations of high river tides for long periods can lead to areas of standing river water in low lying areas or 'flood plain' patches in the Swan River Park catchment. This phenomenon can lead to increased mosquito breeding in summer which can lead to virus infection in the local human population. **M:** High – Extreme Increased mosquito numbers and transient human population along with tourism. Breeding potential for mosquitoes. Need State Wide controls in place. Already seeing changes in bird populations with increased "pest" species

			in the Perth region and are unlikely to pose a significant risk to the study area.		
Air Quality					
Respiratory Disease	High/Extreme	No	Urban areas contain a large number of ozone sources and levels of ozone tend to be higher in urban areas. Ozone levels in Perth are typically below the National Air Quality Standards for ozone, however exceedances have been recorded. Increased temperatures are associated with higher ozone levels, and this can also be exacerbated in urban areas. In combination with significant growth projections in Perth, ozone levels are likely to increase. Large sensitive population with higher than state average over the age of 65 in Melville and Fremantle.	High/Extreme	**F:** It is surprising that this is so significant.Is there any modelling to follow the causal chain from increased temperature to health impacts?
Asthma/Allergies	High	No	No significant difference from WA	High	**M:** Storms ->mould

			assessment		
VOC Exposure	Medium	No	No significant difference from WA assessment	Medium	
Food-borne Disease					
Food Poisoning	High	No	No significant difference from WA assessment	High	
Mycotoxins	Medium	No	No significant difference from WA assessment	Medium	
Sea-food poisoning	Medium	No	No significant difference from WA assessment	Medium	**M:** Potential from river
Bites/Stings	Medium	No	No significant difference from WA assessment	Medium	

Indirect health impacts with complex climate-health relationships

Impacts	**Risk for State**	**Amendment to Risk Level for Study Area**		**Proposed amended risk in study area**	**Responses from stakeholders as follows: C: Cockburn; F: Fremantle; M: Melville**
		Yes/No	Rationale		
Food Production					
Changes to availability/cost of food	Medium	No	No significant difference from WA assessment, but some groups in study area will be more vulnerable than others.	Medium	

Health Impacts from exposure to pesticides	Low	No	No significant difference from WA assessment	Low	
Higher levels of imported foods	Medium	No	No significant difference from WA assessment	Medium	**M:** Testing reliant. State need to increase sampling regime.
Infrastructure					
Reduced access to health care, food & water	Extreme	Yes	Increase in number and severity of extreme events may place additional pressure on health services, however a reduction in access to key services is more likely to be an issue in regional or remote areas of the state.	High	**M:** High – Medium. Competing with surrounding populations from storm events
Inability to meet demand for energy	Extreme	No	Energy-demand in Perth likely to increase and place additional pressure on supplies. Loss of power during high demand times such as heat-waves will reduce adaptive capacity, thereby increasing vulnerability.	Extreme	**M**: For vulnerable populations.
Social Impacts					
Dislocation	High	Yes	Risk of permanent dislocation due	Medium	**F:** This just reminded me of the Tim

			to economic stresses via increase in drought is not applicable to study area. Risk of permanent dislocation in study area due to sea-level increase is not considered high (see SMRC Climate Change risk management report, Coastal Vulnerability report)		Flannery quote, "I think there is a fair chance Perth will be the 21st century's first ghost metropolis" **C:** See previous comments on flood/sea-level increase
Mental Health Impacts	High	No	Mental health impacts associated with increased drought will not be felt as strongly in urban areas, but given the wide range of flow-on mental health impacts from extreme events and other climate-related hazards, that are relevant to urban areas, the risk level will not be amended.	High	**M:** Working together as a community facing adversity can be beneficial.
Lifestyle/behavioural					
Increase in crime	Medium	No	No significant difference from WA assessment	Medium	
Increase in	Medium	No	No significant difference from	Medium	

accidents			WA assessment		
Sleep deprivation	Medium/Low	No	No significant difference from WA assessment	Medium/Low	
Effects on recreation	Medium	No	Do the combined effects of increased temperature and loss of green space on recreation/physical activity warrant inclusion in the study? The risk management plan by the SMRC assessed the impact of reduced water availability for watering on community and lifestyle as Extreme.	Medium	**F:** Extreme does seem a little pessimistic. I think that Medium is probably more appropriate. It would be interesting to see if there's research done around City's that have had severe water restrictions such as Melbourne **M**: Sea Level Rise. Already reaching water allocations for public open space.
Increase alcohol consumption	Medium	No	No significant difference from WA assessment	Medium	
Neglect physical health during times of crisis	Medium	Yes	Referred predominantly to rural populations facing drought.	Low	
Loss of green space/gardens	Medium	No	Impact of watering restrictions and water costs of green spaces	Medium	
Community					
Population	High	Yes	Reductions in population most	Low	**F:** If the regional population all

reduction and loss of goods and services			likely in rural and drought affected areas. ABS forecasts indicate that each of LGAs will experience continued population growth. Potential loss of goods and services due to higher demand in the study area are covered in infrastructure section.		migrates at the same time as a result of climate change to metro areas then the pressure on metro housing, water, power & waste services is likely to increase- this is a low to medium risk
Miscellaneous					
Reductions in biodiversity	High	No	Links between health and reductions in biodiversity in urban areas is poorly understood and complex.	High	**C:** We would like to see this included in the scope of this study. There have been many journal articles published that detail the benefits that natural areas (aka biodiversity) provide to our health and well-being.
Increased chemical exposure	Low	No	No significant difference from WA assessment	Low	

Appendix E: Results of textual search of key documents

1. **Directions 2031**		
VEGETATION	Section, Page	**Entry with key words highlighted**
Vegetation	Part 3, 51	Existing sites that provide basic raw materials are in conflict with, and at risk from urban encroachment and are constrained by the presence of remnant vegetation.
Green	Part1, p 2	Directions 2031 is based on a vision: "By 2031, Perth and Peel people will have created a world class liveable city: green, vibrant, more compact and accessible with a unique sense of place."
	Part 1, p 3	Green Network - A network of parks, reserves and conservation areas that support biodiversity, preserve natural amenity and protect valuable natural resources.
	Part 2, 21	Our expectations vary depending on our particular situation but generally include a place that is clean, green, productive and distinctive
Trees, Canopy Shade	Nil	
CLIMATE		
Climate change	Part 1, 13	Australia faces significant challenges over the long term to accommodate population growth and ageing, as well as climate change, national productivity and other social, economic and environmental drivers of change.
	Part 2, 19	The criteria will ensure that cities have strong transparent and long-term plans in place to manage population and economic growth; plans that will address climate change and improve housing affordability and tackle urban congestion

	Part 2, 23	Strategy under Sustainable Theme: Mitigate and adapt to climate change.
	Part 4, 67	Mitigate and adapt to climate change: The economy and the physical environment will be impacted by climate change as governments move to reduce carbon emissions and as the changing climate affects food production, water provision and consumption, and infrastructure maintenance and operating costs. Prepare for sea-level rise along the WA coast, will inform the development and integration of adaptation responses to climate change into WAPC land-use planning policies.
	Part 4, 97	Develop a climate change planning policy (Under initiatives for a sustainable city) DPI, WAPC, DEC, WALGA
Energy	Part 1, 1	Provide direction on how we provide for a growing population whilst ensuring that we live within available land, water and energy resources;
	Part 1, 4	A connected city pattern of urban growth is characterised by: protecting and enhancing the natural environment, agricultural land, open spaces and our heritage and community wellbeing; reducing energy dependency and greenhouse gas emissions;
	Part 3, 39	A significant amount of time, money and energy is consumed in the movement of people and goods around the city, so it is important that the movement network be as efficient as possible.
	Part 3, 55	Whilst it is currently debatable whether the real cost of private car transport will increase due to higher energy costs ... there are a number of....... benefits associated with a shift away from private car travel
Temperature Heat	Nil	

HEALTH		
Health	Part 1, p 5	People living in areas with limited access to public transport or jobs will experience increased travel time to access work in other areas, traffic congestion and higher private transport costs to households as well as reduced leisure time, declining community health and increasing obesity as walking and riding become less practical.
	Part 2, 21	Expectation of city: provides high standards of affordable and diverse housing forms, education and health care;
	Part 2, 23 Part 4, 63	Protect our natural and built environments and scarce resources; respond to social change and optimise the land use and transport conditions that create vibrant, accessible**,** healthy and adaptable communities.
	Part 3, 36	These centres ..contribute to a decrease in daily car use and increase in **the health** of the community within the walkable catchment.
	Part 3, 45	Community health relies on the provision of appropriate public spaces for recreation to encourage walking, cycling and sports as part of the overall community health picture.
	Part 3, 55	Directions 2031 recognises the importance of walking and cycling as not only the most sustainable form of transport, but also a major contributor to the health of our communities
	Part 4	Multiple references to health services such as hospitals
	Part 4, 68	Air quality can adversely affect human health and the environment. Perth and Peel, like most urban areas in Australia, experience occasional episodes of poor air quality. The main issues affecting our city are photochemical smog in summer and particulate haze during winter.
Comfort	Part 2, 21	We all have expectations about the place in which we live. These often relate to our personal comfort, the neighbourhood we live in, the services and facilities we use and the impact that

		we have on the environment.
Quality of life	Forward, iii	Our challenge is to find room for this new growth while preserving our unique local environments and valued quality of life
	Part 4, 63	"Sustainable City" - Long-term sustainability is critical to maintain a high quality of life within the metropolitan area.
2. SPP 3 – Urban Growth and Settlement		
VEGETATION	**Section, Page**	**Entry**
Vegetation, Green, Shade, Trees, Canopy	Nil	
CLIMATE		
Energy	4. p 1066	Objectives of Policy: To promote the development of a sustainable and liveable neighbourhood form which reduces energy, water and travel demand whilst ensuring safe and convenient access to employment and services by all modes, provides choice and affordability of housing and creates an identifiable sense of place for each community.
	5.1 1067	The key requirements for sustainable communities are—making the most efficient use of land in existing urban areas through the use of vacant and under-utilised land and buildings, and higher densities where these can be achieved without detriment to neighbourhood character and heritage values;.. and promoting and encouraging urban development that is consistent with the efficient use of energy; to minimise development impacts on land, water, energy, minerals, basic raw materials, agriculture and other natural resources that help sustain urban economies and society;

Climate		To manage the growth and development of urban areas in response to the social and economic needs of the community and in recognition of relevant climatic, environmental, heritage and community values and constraints
Climate Change Temperature Heat	Nil	
HEALTH		
Health	Look up..	Mixed use urban development which provides for a wide range of living, employment and leisure opportunities capable of adapting over time as the community changes, and reflects appropriate community standards of health, safety and amenity;
Quality of life	5.0 1066	Objectives of the Policy - To build on existing communities with established local and regional economies, concentrate investment in the improvement of services and infrastructure and enhance the quality of life in those communities.
	5.1 p. 1066	Sustainability is central to the planning system in WA. Sustainability requires us to integrate the social, economic and environmental consequences of land use and development in order to deliver a better quality of life now and for future generations. The planning system is uniquely placed to influence the quality of life of communities because of its capacity to resolve conflicts and deliver solutions which balance social, economic and environmental objectives.
	1067	The key requirements for sustainable communities are: development, rather than overly focussing on regulation and controls, in ways which contribute to economic growth, support safe, sustainable and liveable communities, and improve the quality of life, and with

		community involvement appropriate to the level of planning
Comfort	Nil	
3. SPP 3.1 Residential Design Codes and Explanatory Guidelines		
VEGETATION	Section, Page	Entry
Vegetation		
Green		Multiple references to 'green title'
Shade	7.3.2** P8	Landscaping of open spaces: Landscaping between each 6 consecutive external parking spaces and to include shade trees.
	Guidelines 6.4., p16/17	Because of the importance of providing shade in summer, especially in conjunction with outdoor living, a part of such areas should be allowed to be permanently covered. The codes require the provision of landscaping as part of the development of communal open space and where required common property, but not of private open space. Landscaping for communal open space should be prepared with regard to: desirability of protecting existing trees where possible, and providing new trees for shade and to complement built form The need to provide for winter sun, that will influence the choice of trees and their placement The need for shade structures such as pergolas to complement trees.
	Guidelines, 6.9, p33	Design for climate: energy conservation and comfortable living Pergolas with removable awnings or deciduous vines can be designed to provide solar access for desired times in winter while excluding solar access for desired times in summer. The sun is most fierce in summer in the afternoon. As this time it comes from the west…. Protect the dwelling with trees or vines (preferably deciduous so as to allow in the sun in

		winter) pergolas or verandahs. Protecting solar access for neighbouring properties (relates to shadows cast by adjoining buildings but may becoming more relevant for trees because of photovoltaic cells)
Trees	3.4.1	Existing site plan shall include: the position, type and size of any tree exceeding 3 m in height street trees
	G-6.8,	Vegetation in the form of screen planting or selective placement of suitable trees or shrubs can provide effective screening and also can enhance the amenities of development.
	G: 7.3.2, p28	Minimise hard surfaces by allowing for sufficient room for trees to grow through maximising the amount of permeable surface for water penetration to the soil.
	3.5	Proposed Development Site Plan shall include: Structures and trees to be removed; Areas to be landscaped
	6.4.5	Landscaping Requirements All grouped and multiple dwelling common property areas are fully developed with appropriate planting, paving and other landscaping material that.. retains significant existing trees Landscaping of grouped and multiple dwelling common property and communal open space in accordance with: Retention in open space of existing trees which are greater in height than 3m.
	6.5.4	Vehicular access provided so as to minimise the number of crossovers and avoid street trees. Where this is unavoidable, the street trees replaced by the council
Canopy	Nil	
CLIMATE		
Energy	G: 6.9	Energy efficient design – see climate section below.

Climate	**G:6.9** 6.9.1	Design for climate requirements. Objective – to optimise comfortable living and facilitate sustainable development. Solar access for adjoining sites - development designed to protect solar access for neighbouring properties taking account the potential to overshadow: outdoor living areas, major openings, solar collectors or balconies or verandahs.
	G: 6.9, 32	In terms of residential development the 3 main aims of climate-sensitive design are to reduce energy consumption, optimise on-site solar access and protect solar access for neighbouring properties.
Heat	Guidelines	Comment on reflective roofs
Climate Change Temperature	Nil	
HEALTH		
Comfort	**6.9**	**Design for climate requirements**. Objective – to optimise comfortable living and facilitate sustainable development
	G- 7	Provide a high level of pedestrian comfort thereby promoting pedestrian friendly environments
Health, QoL	Nil	
4. Liveable Neighbourhoods (2010). Applied to large urban infill and greenfield		
VEGETATION	Section, Page	Entry
Vegetation	Element 1	..increased emphasis on planning for natural resource conservation and management.

		Protection of significant vegetation….
	Element 3	For subdivisions north of latitude 26 lots should be shaped and oriented to enable ..to take advantage of micro-climate benefits, particularly cooling breezes, shading and canopy vegetation.
	Element 5	Recognises need for integration of urban water management and vegetation
	Appendix 4	Cash in lieu for public open space – acceptable funding includes clearing of vegetation, seating, grass planting
Green	Nil	
Shade	Element 2	Require planting of shade trees next to footpaths
	Element 2	Street trees contribute to a pleasant walking environment, provide shade and accommodate fauna. They are an integral part of street types in LN.
	Element 2	R33 – footpaths should be designed and located taking into account pedestrian amenity, sun and shade
	Element 2	R47: Street trees that provide a generous canopy at maturity should be planted in most streets for pedestrian shade, shelter, streetscape amenity and traffic management.
	Element 7	Key factors for a potentially successful neighbourhood centre include: verandah for shade.
	Element 7	Centres should create a high quality street environment with shade, shelter, trees, landscaping
Trees (Selection of results: total of 39 hits)	Guide	Street verge to include street tree
	Element 2	Use of 7.2m streets – where street reservation needs to provide for larger scale street trees.
		Street trees contribute to pleasant walking environment, provide shade and accommodate fauna. They are an integral part of local streets.
	Element 2	Effect of trees on street lighting

	Element 2	Traffic-calming benefits of street trees relatively close to the pavement
	Element 6	To maximise efficient location of utilities while providing sufficient space to accommodate large canopy street trees in all road reservations
	Element 3 Table 9	Inclusion in detailed area plan – location of existing trees to be retained in the street or in lots (as agreed with local government)
	Element 4	Retention of significant trees in local park with adjacent medium density housing.
Canopy		See above in trees, vegetation
CLIMATE		
Energy	Guide	..underlying objective is to create Liveable Neighbourhoods that reduce dependency on private vehicles and are more energy and land efficient.
	Element 2	LN promotes several differences from conventional street systems including: high interconnected and is aimed at reducing local travel distances and related emissions and energy use
	Element 2	Design of street network can assist in energy conservation through reduced vehicle travel, facilitate climate-responsive house siting
	Element 3	Criteria for Evaluation of area plans…solar access for amenity and energy efficiency, usable private recreational open space
	Element 3	Creation of new streets - .along sunny outdoor space and to achieve passive energy efficiency through minimising the need for heating and cooling.
Climate	Element 3 R17	Lots should be shaped and oriented to enable dwelling built on them to be sited to: provide space for appropriate planting for microclimate management and energy conservation.
Heat	Nil	

C. Change Temperature		
HEALTH		
Comfort	Nil	
Health,	Element 1 Obj 08	
QoL	Nil	
5. **Capital City Planning Framework** (2013) (Selection of key results)		
VEGETATION	**Section, Page**	**Entry**
Vegetation	ix and p33	Encourage holistic solutions that integrate infrastructure, open space, vegetation and buildings to improve sustainability performance.
	p. 10 2.1.5	The diversity of flora across the central Perth region is evident in remnant vegetation assemblages,
Green	5 instances	Green, vibrant, compact, and accessible, with a unique sense of place.
	5 instances	Multi-functional green network
		These natural environments should be conceived and planned as a green infrastructure network, delivering a wide range of ecosystem services
	3 instances	Green spaces
Shade	p. 27	The shade provided by trees is important for safe outdoor activity, protecting people from extreme temperatures and ultra-violet light.
Trees	2.1.6 3.1.4	A total of 13 instances under headings of Urban Tree Canopy and Urban Trees. Excerpts provided in main body of thesis, p. 178 to 179..

Canopy	2.1.6 3.1.4	A total of 13 instances under headings of Urban Tree Canopy and Urban Trees. Excerpts provided in main body of thesis, p. 178 to 179..
CLIMATE		
Energy	22 instances	More efficient consumption of water and energy will become increasingly essential
		Reduce energy and water consumption in buildings, including through the incorporation of environmentally sustainable design principles
		Reduce energy and water consumption in buildings, including through the incorporation of environmentally sustainable design principles
		Human wellbeing relies on healthy, functioning natural systems for a wide range of services, including the provision of food, materials, clean water and air, energy and climate regulation.
Climate /	33 instances	Climate and climate change is a dominant feature throughout.
Heat		Reduced rainfall and increasing heat, storms and sea levels will challenge the liveability, economy and ecosystems of central Perth.
		Provide for greater protection from storms and increasing heat, including improved design of the built form and landscape.
Temperature	9 instances p. xiv 3.1.4, p. 27	Refer to section on urban trees. High temperatures and UV indices also often deter walking and other physical travel methods In this respect, a healthy urban tree canopy is valuable for reducing solar gain and temperatures and providing protection from the sun. Higher temperatures and lower rainfall, which may have an impact on our health, comfort, vulnerability to fires, and on water and food supplies, as well as impacting on the urban tree canopy, and the biodiversity and stability of ecological systems.
HEALTH		

Comfort	4 instances 2.1.4, p. 10	It helps improve human comfort and well-being by ameliorating the effects of climate extremes, and air, water and noise pollution. See above
Health	18 instances 3.1.3 p. 26	Open spaces encourage outdoor activity, improve wellbeing, moderate the climate, and so reduce public health costs With issues such as an ageing population, a changing climate and increasing concerns about poor physical and psychological health, and their personal and social impacts, we need to create a healthier urban environment. There is a correlation between urban structure, environmental quality and health patterns.
QoL	4.1.5, p. 33	Utilise the value of quality design in providing diversity, choice, dignity and quality of life.

Appendix F: List of Workshop Participants

Sector	Participant	Organisation
State Government	Teresa Ballestas	Department of Health
	Melanie Bradley	Department of Planning
	Tia Byrd	Department of Planning
	James Duggie	Department Environment and Conservation
	Dan Ellis-Jones	Building Commission
	Catherine Garlick	Environmental Protection Authority
	Deborah Munroe	Department of Planning
	Erin Tuckwell	Department of Water
	Peta Turner	Department of Health
	Lisl van Aarde	Department of Planning
Local Government	Chris Beaton	City of Cockburn
	Brad Bowden	City of Subiaco
	Greg Bowering	City of Cockburn
	Marcello Druck	City of Cockburn
	Marius Brand	City of Bayswater
	Jenni Harrison	City of Cockburn
	Andy Jarman	City of Cockburn
	Sue Judd	City of Cockburn
	Nicki Ledger	City of Melville
	Michael Leers	City of Fremantle
	William Schaefer	City of Melville
Industry Associations	Karen Barlow	WA Local Government Association
	Peter Ciemitis	Planning Institute of Australia (PIA)
	George Crisp	Doctors for Environment
	Debra Goostrey	Urban Development Institute of Australia (WA)
	Esther Ngang	Nursery and Garden Industry WA
Universities	Julie Brunner	Curtin University
	Dave Hedgecock	Curtin University
	Dianne Katscherian	Curtin University

	Jana Soderlund	Curtin University
Other	Marc Drexel	ARCeden
	Jane Elton	Stockland
	Sabrina Hahn	Gardens with Soul
	Bret Hart	Public Health Physician
	Francis Kotai	Place Laboratory
	Brendan Oversby	Town Management Engineering Pty Ltd
	May Carter (Facilitator)	PlaceScape

Appendix G: Pre-Workshop Information and Survey

Urban Consolidation and the Management of Tree Canopy

Management of trees in urban areas targeted for consolidation is a complex issue with implications for community, infrastructure and services.

This workshop aims to capture the knowledge and perspectives of different stakeholders on the role and management of tree canopy, in the context of urban infill in Perth. This understanding can contribute to effective management of the issue. Some important issues that have been identified include:

- Projected increases in temperature and heatwaves in Perth pose a significant risk to public health and liveability over the coming decades.
- Exposure to heat in urban areas can be exacerbated by the creation of urban heat islands.
- Loss of vegetation, particularly tree canopy is a significant contributor to urban heat islands.
- Tree canopy is linked to other variables that impact on public health, liveability & sustainability.
- Urban development, particularly urban infill, places significant pressure on tree canopy.

Useful Links *(For your interest)*

Health Impacts of Heatwaves, Urban Heat Island Effect

Melbourne Urban Forest Strategy, Urban Tree Management Principles

Pre-Workshop Activity

Please complete the following 3 tables prior to attending to the workshop. These tables ask your opinion about trees in urban environments. They will be collected at the workshop and be discussed in the first activity of the morning.

Given the differing backgrounds of workshop participants you may not be able to complete all sections of the activity. Please enter n/a for any incomplete sections.

BENEFITS

The following have been identified as benefits of tree canopy. In your opinion, what is the level of importance of each benefit, and what level of importance is placed on each benefit within your current practice or professional sector?

1: Low 2: Medium 3: High 4: Very High 5: Essential

Benefits of tree canopy in Perth	**Importance (Your opinion)**	**Importance placed on this benefit within your sector or current practice**
Provide shade and cooling		
Reduce air pollution		
Provide habitat and support biodiversity		
Reduce volume of storm-water		
Reduce heat-related illnesses		
Reduce sun exposure		
Provide sense of place & identity		
Improve mental well-being		
Encourage outdoor activity		
Increase property values		
Reduce demand for energy		

My Sector ______________________________________

For ease of identification, participants have been sorted into the following groups. Please use the term that most readily identifies you or your sector:

- Development (Government or private)
- Environment (includes parks and gardens)
- Health
- Planning (State or local government)
- Other (Please specify)

BARRIERS Assuming that retaining existing or planting new trees provides benefits, what, in your opinion, are the most significant barriers to planting or retaining trees in areas targeted for urban infill in Perth? Please rank the following items from 1-8 – with 1 indicating most significant and 8 least significant	
Potential Barriers	**Rank**
Provision of adequate space for trees	
Demand for water	
Cost of retaining trees during development	
Conflict with services (power etc.)	
Lack of awareness and formal accounting of tree benefits	
Lack of clear policies, standards or regulations regarding tree management	
Inadequate resources allocated to planning and implementing tree management	
Lack of tangible incentives to retain trees	

My Sector ______________________________________

For ease of identification, participants have been sorted into the following groups. Please use the term that most readily identifies you or your sector:

- Development (Government or private)
- Environment (includes parks and gardens)
- Health
- Planning (State or local government)
- Other (Please specify)

STRATEGIES

The following table includes descriptions of suggested strategies for ensuring trees are part of urban landscapes. Please consider each in terms of current status (is a similar strategy already in place) and importance (would this strategy make a positive contribution to your practice or decision-making in your sector?).

A. CURRENT STATUS

To your knowledge, what is the **current status** of each strategy in your area of practice or sector?

1: Absent *2: Limited* *3: Being developed* *4: Well-developed* *5: Don't know*

B. IMPORTANCE

From your perspective, what level of importance should be placed on developing this type of strategy within your practice or sector?

1: Low *2: Medium* *3: High* *4: Very high* *5: Essential*

STRATEGY	**A. Current Status**	**B. Importance**
PLAN		
Record of existing trees including nature, condition and canopy cover		
Comprehensive tree strategy and canopy target		
Clear standards for protection, care & planting of trees in strategic plans and policies		
DESIGN		
Design trees into places – includes consideration of utilities & provision of space		
Appropriate tree selection		
Recognise and seek multiple benefits		
PLANT/PROTECT		
Plant healthy, vigorous trees conditioned for environment		
Improve soil moisture & water quality		
Broad stakeholder and community engagement and involvement in decision-making		
MANAGE/MONITOR		
Asset Management – inclusion of tree benefits and costs		
Balanced approach to tree safety management		
Adjust management to local needs		

My Sector ____