Foresight for risk – using scenarios for strategic risk assessment and management of emergent disaster risk

by

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Contents

Abstract

Disaster impacts around the world are increasing with 2011 and 2017 the largest on record in terms of total losses from disasters in recorded history (USD 444billion and USD 341billion, respectively). The reasons for the increase in losses are multiple. Climate change is increasing the likelihood and intensity of several natural hazard types, and as the world's population and economy grow, and humans increasingly develop in areas exposed to natural hazard (e.g. along rivers, and coastal areas), the values exposed are also rapidly increasing. These multiple factors contribute to the complex nature of disaster risk, which is considered to be the combination of natural hazard intensity and extent, exposure (assets, people, other values), and vulnerabilities of the exposed values to the characteristics of the hazards. This can be considered the risk triangle – hazard, exposure and vulnerability – and each of these factors change into the future impacted by a range of drivers; population and economic change, technology, urbanisation rates, political actions etc.

To reduce the impacts of disasters, risk management and reduction activities are designed and implemented, and are typically underpinned by risk assessments. Risk assessments use qualitative and/or quantitative approaches to attempt to characterise the likelihood and impact of disaster types for a region or organisation. Currently, risk assessments do not capture future changes across all dimensions of risk in a manner that provides insight into the strategic threats and opportunities of emergent disaster risks. Therefore, there is a need for approaches to consider realistic degrees of complexity within the disaster risk system and account for the uncertainty in emergent risk. By capturing this within disaster risk assessments, treatment options can be developed and tested that strategically manage these risks over time.

This research has developed these approaches and provides three key contributions through the use of foresight, primarily scenarios within disaster risk assessment processes, to support effective policy and investment decision making to reduce future impacts. The thesis is organised around three publications, all contributing to the development of a generic framework which integrates foresight into disaster risk management and specific approaches to develop and use scenarios for strategic risk assessment and management of emergent disaster risk. The first paper (Chapter 2) proposes and demonstrates this generic framework for the incorporation of the principles of foresight into risk assessment and management processes. The second paper (Chapter 3) focuses on the design of scenarios

to support policy making for disaster risk reduction through several improvements to the methodological approach for constructing relevant and challenging scenarios using an "outcomes of interest" framing. The third paper (Chapter 4) outlines and applies an approach for the use of exploratory scenarios within quantitative disaster risk assessment through the development of alternative pathways of disaster risk using scenarios and integrated risk models.

Statement of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Signed:……………………………………………...… Date: 07/11/2019

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AAL	Average Annual Loss
DRA	Disaster Risk Assessment
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
ISO	International Organization for Standardization
NERAG	National Emergency Risk Assessment Guidelines
NGO	Non-Government Organisation
RCP	Representative Concentration Pathway
SAS	Storyline and Simulation
SRES	Special Report on Emissions Scenarios
SSP	Shared Socio-economic Pathway
STEEP	Society, Technology, Environment, Economy, Politics
TCFD	Taskforce on Climate-related Financial Disclosures
TSNDRA	Tasmanian State Natural Disaster Risk Assessment
UN	United Nations
UNHaRMED	Unified Natural Hazard Risk Management Exploratory Decision support system
UNISDR	United Nations International Strategy for Disaster Reduction
USD	United States Dollar

CHAPTER 1

Introduction

Disaster risk is a complex, evolving and significant threat to the livelihoods and prosperity of people and economies around the world. It is however not merely due to the natural hazards – floods, wildfires, earthquakes and tropical cyclones – that cause disruptions. It is also the role of human societies' that expose vulnerable assets to the impact of these hazards. Without the combination of hazards, exposure and vulnerability, risk is not present and as such no disaster is natural. These elements of disaster risk – hazard, exposure, and vulnerability – interact in a complex and uncertain way to create risks to societies, and to better understand how risk is changing and how to best reduce the impacts, we must better understand the relationship between these elements and what drives them into the future.

Disaster impacts globally are increasing. Figure 1-1 shows the rise in number and financial impacts around the world from Swiss Re, a reinsurance company. The impacts are clearly rising, along with the number of disasters both weather-related and geological. The drivers of these increased losses are complex. Climate change is known to increase the likelihood and intensity of several natural hazards such as flooding (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013; Murnane et al., 2017; Ward et al., 2017); tropical cyclones / hurricanes (Cui & Caracoglia, 2016; Estrada, Botzen, & Tol, 2015); and wildfires (Bryant & Westerling, 2012; Flannigan, Logan, Amiro, Skinner, & Stocks, 2005; Krawchuk, Moritz, Parisien, Van Dorn, & Hayhoe, 2009; Westerling & Bryant, 2008). However, humankind's influence on climatic events is not the only driver for changing disaster impacts. As outlined previously disaster risk is an interaction between hazards, exposure and vulnerability and changes in these factors have a significant role in the increased impacts of disasters. Aon Benfield (2014) showed in their analysis of insured losses that 85% of the increase from 1980 to 2014 could be attributed to increase in urbanisation and economic value. It is also recognised in Australia that the interaction between socio-economic factors will significantly influence future risks. As outlined in the National Climate Resilience and Adaptation Strategy, "Population trends, urbanisation and residential shifts to high risk areas will intersect with climate change to increase Australia's exposure to natural hazards as a whole" (Commonwealth of Australia, 2015).

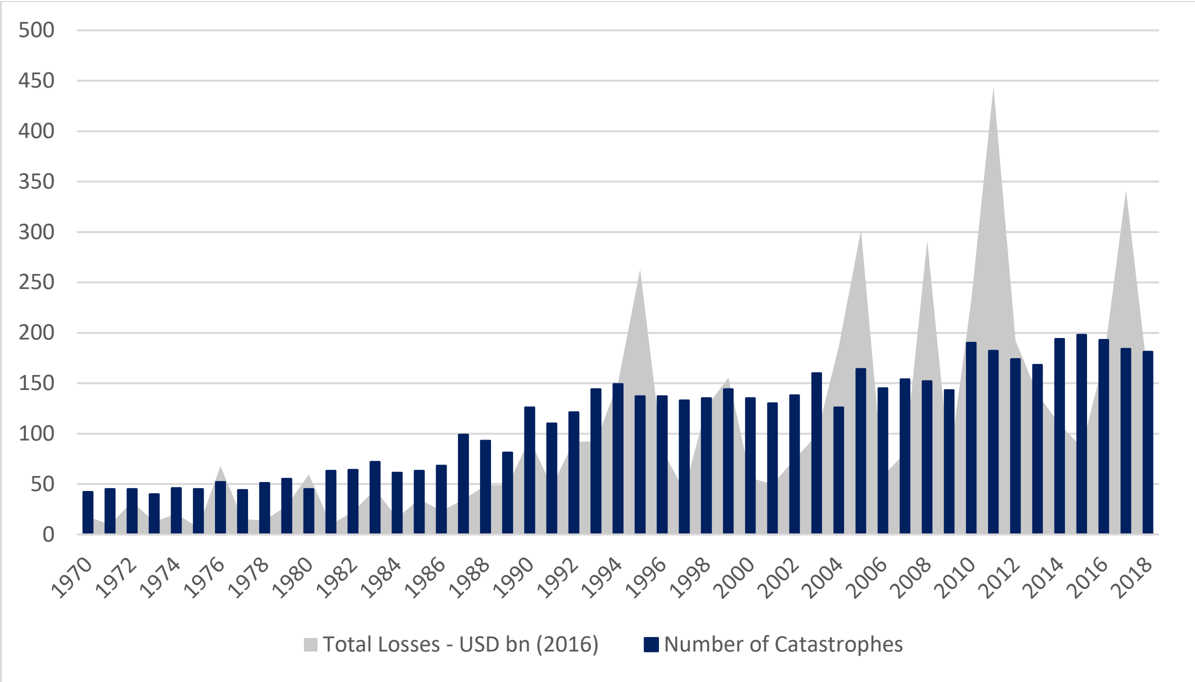

Figure 1-1: Overview of number of catastrophes and total losses from them from 1970 to 2018 (Swiss Re, 2018)

These drivers, which describe the historical increase in disaster impacts must also be considered when we look forward to see potential impacts from future disasters and plan to reduce them. The emergence of disaster risk[1] occurs due to increasing and new relationships between the hazards, exposure and vulnerabilities of a society or region, along with their changing capacity to deal with the risks. A variety of drivers including technological change, economic development, demographic shifts, migration and urbanisation rates, among many others, can all influence tomorrow's disaster risk.

There is also the significant influence that policy, planning and investment decision can have on tomorrow's risks and these need to also be considered to 1) ensure assessment of disaster risk incorporates the full suite of influences and 2) to utilise these policies and investments to reduce future disaster risks. A publication by the Global Facility for Disaster Reduction and Recovery (GFDRR) outlined succinctly, "tomorrow's risk is being built today" (Global Facility for Disaster Reduction and Recovery, 2016). This not only means that we must incorporate

[1] Definition of emergent risk used is, "new risks or familiar risks that become apparent in new or unfamiliar conditions" and that can be categorised as one of three types, "1) high uncertainty and a lack of knowledge about potential impacts and interactions with risk absorbing systems; 2) increasing complexity, emerging interactions and system dependencies that can lead to non-linear impacts and surprises; and 3) changes in context (for example social and behavioural trends, organisational settings, regulations, natural environments) that may alter the nature, probability and magnitude of expected impacts" (IRGC, 2015)

future changes of risk into our understanding of disaster risk, but that we can use also these policy, planning and investment decisions to reduce disaster risk into the future.

The following sub-sections will provide background to disaster risk management (DRM) and assessment (DRA), as well as foresight approaches that can be incorporated into risk management to account for changes in disaster risk. Chapter 1.2 provides an integrated perspective on the opportunities for foresight in disaster risk, before Chapter 1.3 outlines the research objectives of this thesis and how they are linked to subsequent chapters.

1.1 Background

This thesis provides insight, approaches and benefits of the integration of disaster risk management and assessment and foresight - primarily scenario-based approaches – for enhanced strategic management of emergent risks. As such, background is provided on both these concepts outlining where they have originated from and providing critical analysis as to their current appropriateness to support management of emergent disaster risk. Chapter 1.1.1 begins with identifying the disaster risk management cycle and how it is understood both in public policy and international humanitarian forums along with research literature. It then provides a summary of approaches to disaster risk assessment and the principles underpinning DRM and DRA. Chapter 1.1.2 provides similar information on foresight and the general principles that underpin it before focussing on scenarios and how they have been applied in a variety of fields, as well as their advantages and limitations.

1.1.1 Disaster Risk Management and Assessment

As described previously this research will use the definition of disaster risk as the integration of hazards, exposures and vulnerabilities, which has been characterised as the risk triangle (Crichton, 1999). This definition allows for each component of risk to be treated individually, with a focus on risk management approaches that influence either hazard, exposure or vulnerability (or a combination of them). This is in comparison to definitions of risk that focus on concepts of likelihood and consequence, which makes the link between mitigating actions and the conceptualisation of risk less clear.

Following this definition of disaster risk, DRM is seen as the process to implement risk reduction policies and strategies to prevent new risks, and reduce existing and manage the residual risks (UNGA, 2016). This is often characterised around a cycle of prevention, preparedness, response and recovery, with DRM being the implementation of actions throughout the cycle. Figure 1-2 provides an overview of the DRM cycle and examples of actions on preventing new risks, reducing existing and managing the residual.

Figure 1-2: Overview of the disaster risk management (DRM) cycle - prevention, preparedness, response, recovery - and example of actions for each element adapted from Baas, Ramasamy, DePryck, and Battista (2008).

DRM has been discussed extensively throughout literature as well with critical contributions from Alexander (2002); Cardona et al. (2012); Birkmann et al. (2013), amongst many others who define the discipline, its actions, processes, actors and range of governance structures. A variety of themes are also apparent particularly in balancing global and national efforts – from a top-down perspective to managing disaster impacts (Coppola, 2011; G. O'Brien, O'Keefe, Rose, & Wisner, 2006), to bottom-up and community focussed DRM which sees the emphasis on local actions and community vulnerabilities (Paton & Johnston, 2001; van Aalst, Cannon, & Burton, 2008). This balance between scales is a clear signal regarding the complexity of DRM as is the extensive literature that focuses on societal vulnerability across scales from systemic societal vulnerabilities through to built-form vulnerability (Helfgott, 2017; Wisner, Gaillard, & Kelman, 2011). Particular research has also focussed on how distinct disciplines and global goals work together such as climate mitigation and adaptation, DRM, sustainable development and poverty reduction (Jones & Preston, 2011; Mercer, 2010; Rivera, Tehler, & Wamsler, 2015; Thomalla, Downing, Spanger-Siegfried, Han, & Rockström, 2006; Wamsler, 2006). Strategies utilised within DRM can also be considered proactive or prospective – which address and seek to avoid the development of new or increased disaster risk – or reactive or corrective – which address and attempt to reduce / remove already present disaster risk (UNGA, 2016). The temporal scales that each of these strategies operates at brings inherent uncertainty with DRM actions implemented and having effectiveness into the future under uncertain conditions – this is particularly true for proactive strategies (Bloemen, Reeder, Zevenbergen, Rijke, & Kingsborough, 2017; Simpson et al., 2016).

To support the planning, prioritisation and design of DRM actions, disaster risk assessments are often undertaken, underpinning the decision process in an understanding of the risks and what is contributing to their potential impact. Again, following UN terminology (although shortcomings of this definition will be explored more explicitly in Chapter 2), disaster risk assessment is defined as:

> *A qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend. (UNGA, 2016)*

As stated in the above definition qualitative and quantitative approaches exist to assess disaster risk. These typically involve the collection and presentation of data regarding the components of risk (hazard, exposure, vulnerability) in a specified region based on particular specifications such as identified hazards of interest, and the characteristics of the region (i.e. predominately urban or rural) (Murnane, Simpson, & Jongman, 2016). Quantitative assessments typically focus on producing estimates of damage from a range of hazards scenarios (particular return period and magnitude) and produce metrics such as average annual loss (AAL). This is done through the use of stage-damage curves or other functions which provide estimates of damage based on the exposed asset, its characteristics and the magnitude of the event (de Moel & Aerts, 2011; Stone, 2018). The results are then typically displayed graphically with maps of loss for the region. Similar results are show for non-quantitative or semi-quantitative DRAs which can classify risk through a matrix of likelihood and consequence to signify whether a region, or sub-region is at extreme, high, moderate or low risk from a particular hazard (Santos, Tavares, & Zêzere, 2014; Saunders & Kilvington, 2016). There are however challenges in how well static representations of risk presented in limited dimensions can capture the degree of complexity and uncertainty embedded within DRM (Birkmann et al., 2013; Flage & Aven, 2015).

All of these actions – the DRM cycle, underpinned by DRAs – are in support of disaster risk reduction (DRR) – the effort to reduce the impacts of disasters on societies. This aim, globally, is surmised with the 2015 Sendai Agreement and includes goals of significant reductions in fatalities, economic impacts and people impacted by disaster events (UNISDR, 2015). The planning and implementation of strategies for DRR however can prove challenging for a variety of reasons. Outlined throughout literature are examples and descriptions for the potential issues with investments in risk reduction prior to an event occurring, which include:

1. Investment in mitigation or proactive DRM strategies are challenging to justify based on uncertainty in effectiveness and accounting practices which discourage large long-term investments in comparison to unquantified contingent liabilities (Frazier, Walker, Kumari, & Thompson, 2013; Productivity Commission, 2014; Shreve & Kelman, 2014).
2. Financial support for DRM is limited globally and there will always remain a need to maintain capacity to finance response and recovery activities (Bouwer & Aerts, 2006; Pelling, 2011; Telford & Cosgrave, 2007).
3. DRAs typically don't show dynamics and future conditions and therefore providing ex-ante assessment of a strategy's effectiveness is challenging – the impact of decisions and developments on disaster risk need to be shown with DRA processes and decision making (Global Facility for Disaster Reduction and Recovery, 2016; Heazle et al., 2013; Pelling et al., 2004).

Often these challenges are summarised into the level of uncertainty involved in the conceptualisation and implementation of risk reduction activities, along with the complexity of their implementation working across agencies, and scales. However, changing the balance in investments to reduce impacts prior to them occurring is critical given the rising level of impacts, as shown at the beginning of this Chapter, along with global goals to reduce them outlined within the Sendai Agreement. This research therefore looks for opportunities to develop and demonstrate, approaches that can support investment and decision making in disaster risk reduction activities prior to disaster events.

1.1.2 Foresight and Scenario Planning

Given the degree of uncertainty and complexity that exists when developing and implementing DRM approaches, there is a significant need to incorporate this into their design and assessment. Foresight approaches have been considered a valuable way for incorporating such factors into long-term planning and strategic decision making in many fields (Fink, Marr, Siebe, & Kuhle, 2005; Godet, 2000; F. A. O'Brien & Meadows, 2013; van der Heijden, 2011).

Foresight as a process can use a variety of approaches to imagine the future and enables drivers of change such as globalisation, environmental degradation, and technological advances to be considered in terms of how they impact on the system of interest. There is an emphasis on foresight not being predictive, but instead to be used as a process to understand features or drivers that can impact on the effectiveness of a strategy, particularly in the long-term. The key purpose of embedding foresight principles into strategy development for an organisation and region looking to understand and manage disaster risk is the conscious effort to enhance and enrich the context of the disaster risk assessment and subsequent management strategy. There is significant literature on the use of foresight in supporting organisations and companies to better position themselves to deal with externalities – see Bradfield, Wright, Burt, Cairns, and Van Der Heijden (2005); and (Ramirez & Wilkinson, 2016).

Scenario planning has been a prominent technique for foresight approaches, and it is this method this thesis will primarily focus on. A multitude of definitions for scenarios, scenario planning and all manner of derivatives exist, but for this research the definition from Van Notten (2005) will be adopted, that scenarios are:

> *Coherent descriptions of alternative hypothetical futures that reflect different perspectives in past, present and future developments which can serve as a basis for action. Van Notten (2005)*

Scenario planning is the methodology in which these coherent descriptions are developed and integrated within an organisation's strategic planning process – this uses our inherent capacity to imagine futures to both better understand the present situation and identify possibilities for new strategies or approaches (Ramirez & Wilkinson, 2016). Scenario development, thinking and planning can be traced back centuries to the writing of Plato in *The Republic,* Thomas More's *Utopia* and more modern writing with the work of Orwell, and Huxley in dystopian fiction of the 1930s and 40s. Approaches and methodologies began to be formalised in the 1950s through work at various research organisations, along with the ground-breaking work at Shell where a scenarios team was formed in the 1960s (Amer, Daim, & Jetter, 2013; Bradfield et al., 2005; Wack, 1985b). The work of this team is often credited with the survival and significant growth of the company following the Arab Oil Crisis in 1970 that the team had developed a scenario for earlier. With knowledge of the scenario, executives were able to identify some of the underlying factors and dynamics leading to the implementation of the embargo and begin acting in response to this far sooner than any other company at the time (van der Heijden, 2011; Wack, 1985a, 1985b).

Scenarios as defined above also have had a multitude of typologies applied to them, and for this research the classification shown in Figure 1-3, which is adapted from Börjeson, Höjer, Dreborg, Ekvall, and Finnveden (2006) and presented in Maier et al. (2016), will be used. Identified here are three key distinctions based on the type of question the scenario is trying to answer. For the rest of this research emphasis will be placed on *exploratory scenarios,* which question, 'what could happen?". This type of scenario is the focus due to their emphasis on capturing uncertain drivers and exploring what they could do to a system of interest rather than on what will happen (*trend scenarios* which focus on shorter time frames and less complex domains), and how to achieve an outcome (*normative scenarios* designed for meeting a specific future outcome).

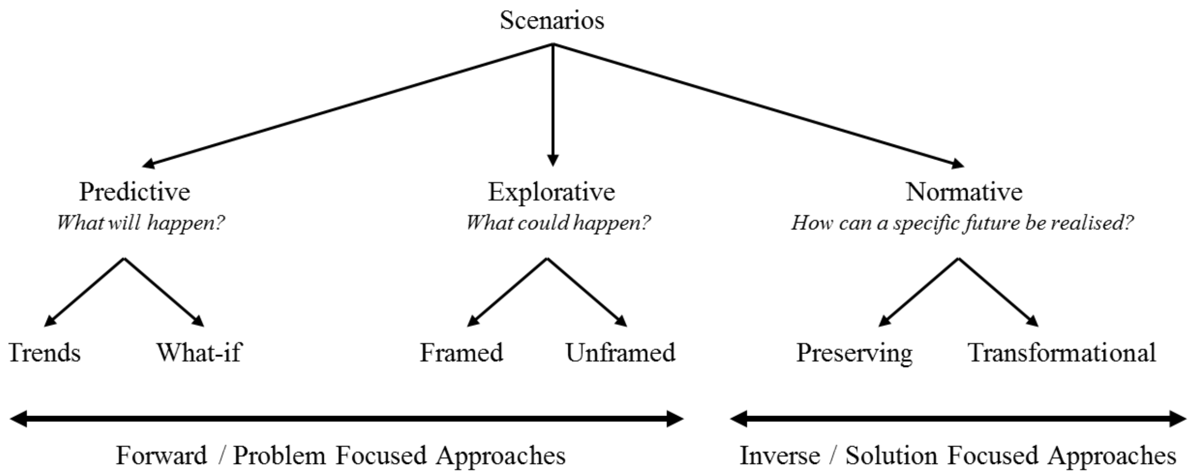

Figure 1-3: Overview of scenario typology and characterisation sourced from (Maier et al., 2016)

Approaches to develop exploratory scenarios range from fully quantitative to fully qualitative – driven by stakeholder and expert knowledge/opinion. Typically, however, there is a balance required to achieve the true value of scenario planning as engagement with stakeholders and buy-in to the process is critical, as is a grounding in plausibility and the ability for scenarios to be translated into business planning processes (or risk assessment approaches), which are greatly supported by quantitative insight. Participative scenario development has progressed from an expert driven approach shown by Morita and Robinson (2001) and Millennium Ecosystem Assessment (2005) to include diverse stakeholders in the decision making process

- see MedAction (van Delden, Luja, & Engelen, 2007; van Delden, Seppelt, White, & Jakeman, 2011). Some of the collected benefits of stakeholder engagement in scenario development from across literature are as follows:

- It acts as a way of building adaptive capacity and social learning (Barreteau, Bots, & Daniell, 2010; Pahl-Wostl et al., 2007);
- Stakeholder engagement may empower those involved through the cogeneration of knowledge (Kok, Patel, Rothman, & Quaranta, 2006; Reed et al., 2013);
- The inherent subjectivity and value-laden nature of decision-making requires a wide range of perspectives to adequately elaborate on the scenarios which can be satisfied by diverse stakeholder engagement (Berkhout, Hertin, & Jordan, 2002);
- It can provide local knowledge, possibly missed by external experts, leading to more pragmatic benefits (Reed et al., 2013);
- It can ensure the relevance to local decision making (Walz et al., 2007);
- It builds trust and can increase acceptance of planning decisions (Luz, 2000; Tress & Tress, 2003);
- The use of local knowledge to validate and deepen understanding can enhance internal consistency, logic and overall scenario validity (Walz et al., 2007).

Exploratory scenarios used to support public policy and organisational strategic planning now commonly use a combination of data sources, both qualitative and quantitative. This allows for the benefits of both, however, it also poses challenges such as translation of qualitative information into quantitative insight and the degree of subjectivity and reproducibility of the process (Alcamo, 2008; Kok, 2009). Approaches to deal with this focus mostly on iterating between stakeholders and modellers, with a high degree of transparency and traceability in parameterisation of the models (or translation of qualitative information into quantitative values). Storyline-And-Simulation (SAS) is one such common approach, and this approach will be revisited in Chapter 4 of this research as key to allowing appropriate degrees of uncertainty and complexity be integrated into quantitative risk assessments (Alcamo, 2008).

Scenarios, however, have also been challenged in their appropriateness and value across a number of dimensions in both academic and public policy spheres. These challenges commonly centre around three key issues:

1. Effectiveness in capturing decision and policy-relevant information;

2. The ability to be used in trade-off assessments and to be integrated into decision-making processes;
3. A high degree of subjectivity and resource requirement.

The above three points are discussed in greater detail in Bryson, Piper, and Rounsevell (2010); van Vuuren, Kok, Girod, Lucas, and de Vries (2012); and Parker, Srinivasan, Lempert, and Berry (2015), which provide examples of successes and challenges of scenarios integrated within planning processes. These challenges therefore need to be addressed and overcome for scenarios to be continued to be of interest and value to policy and decision makers, and this is especially true within the DRM context, where the challenge over resource allocation is high, with many competing priorities and needs.

1.2 Foresight for Disaster Risk: Challenges and Opportunities

Despite the clear benefits, there are challenges supporting investment in pre-event risk reduction activities and taking proactive, and strategic DRM actions. As outlined in Chapter 1.1.1, there is a litany of challenges in taking these types of actions, which can be characterised around the degree of complexity and uncertainty associated with them.

Van Asselt (2000) defines a complex decision making process as multi-problem, multi-dimensional and multi-scale. This can clearly be linked to disaster risk reduction policies with the problem covering sustainable development, climate adaptation and DRM priorities; multiple-dimensions in regard to the mix of disciplines involved in the design and implementation of actions, such as engineers, economists, community development experts, and financing and insurance expertise. Uncertainty also has a significant impact on the design and subsequent effectiveness of proactive risk management strategies, with knowledge uncertainty or uncertainty about the future having the potential to greatly influence the effectiveness of the implemented strategies (Maier et al., 2016; UKCIP, 2003). This type of uncertainty relates to different trends in the drivers of disaster risk, such as economic, population and climate change, along with the rate of urbanisation, as well as the influence of new technological and political policy on the future risk profile. Each of these drivers has the potential to produce a vastly different future condition and as such, these uncertainties need to be incorporated into the design of risk reduction actions.

Chapter 1.1.2 outlined the background to foresight and scenario planning, along with the benefits that it can bring to strategic planning processes. Figure 1-4 shows that scenarios can be effective in contexts characterised as highly uncertain and complex in comparison to traditional planning processes, which are less capable of dealing with such wicked problems. Evidence from literature points to the fact that foresight practices, implemented via scenario planning, could enable the encapsulation of complexity and uncertainty into DRM actions supporting proactive risk reductions. This is because scenario planning can support:

1. Identifying and describing key drivers of change, which is critical to understanding future risks to support reducing them;
2. The testing of the effectiveness of strategies / actions against a range of futures and thus characterising avoided loss / reduced risk under different scenarios (ex-ante assessment of options to provide the evidence base for action);
3. The drawing together of a variety of relevant actors (through the scenario development process) to capture a range of views and develop a shared vision and strategy forward for DRM.

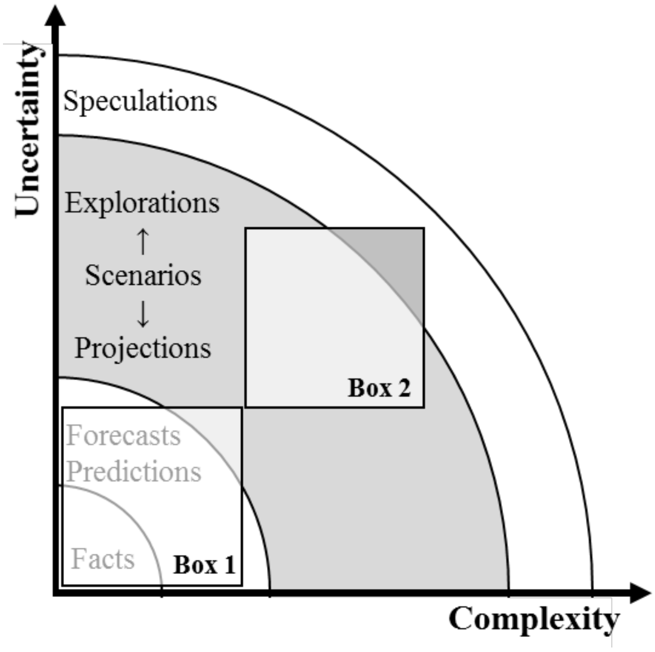

Figure 1-4: Highlighting methods to handle uncertainty and complexity, showing how scenarios differ from facts, forecasts, predictions and speculation – text on the left hand side denotes methods to capture the degree of uncertainty and complexity captured by the axes. Box 1 represents the uncertainty and complexity space where 'optimal control' management strategies are effective, Box 2 represents the space where 'scenario planning' management strategies are effective. Adapted from Zurek and Henrichs (2007) and Biggs et al. (2007).

However, Chapter 1.1.2 also outlined challenges with scenario development and use / planning processes, specifically related to how well they can be integrated into existing decision processes and be of higher relevance to policy-making and planning. These challenges need to be tackled to allow for the above benefits of scenario planning to be integrated into DRM processes. Therefore, improvements to the scenario process in consideration of the requirements and context of DRM is necessary to support strategic management of disaster risk. This is particularly true for emergent risks that can only be captured within the DRA (and subsequently treated) through exploring the degree of future uncertainty and complexity that is present in the region / system under assessment. These identified gaps will form the basis of this research, as further described in Chapter 1.3, which outlines the research objectives in more detail.

1.3 Research Objectives

In order to address the problems outlined above, this research develops a generic framework to support the integration of futures thinking and scenarios into disaster risk assessment and management processes. This is along with developing specific approaches and methodological improvements to particular aspects of scenario development, and disaster risk modelling, to support the framework's effectiveness. These specific improvements are demonstrated within the framework, and described in detail in respective Chapters of this research.

Distilling the challenges described in Chapter 1.2, the research looks to meet three particular research objectives, as outlined and described below. Table 1-1 highlights how each of the subsequent chapters (and included research articles) supports the fulfilment of the objectives and sub-objectives.

Objective 1: Highlight and demonstrate the value of foresight processes being integrated into disaster risk management and assessment processes:

1.1 Using existing definitions and established practices, establish gaps within disaster risk assessment processes that foresight can assist with.

1.2 With case-study applications, show how foresight provides insights and support for strategic disaster risk management of emergent risks.

Objective 2: Provide specific improvements to scenario development and use processes so that they can support effective and insightful disaster risk assessment and subsequent strategic disaster risk management.

2.1 Improve the relevance of scenarios for DRM through changing the framing and development of qualitative scenarios.

2.2 Improve the value of scenarios for DRM through quantitative modelling approaches supporting use in DRAs.

Objective 3: Provide a generic framework and specific approaches on how scenarios, as foresight processes, can be used within disaster risk assessments.

3.1 Develop a generic framework that integrates the development and application of scenarios into existing assessment processes and international standards.

3.2 Develop and demonstrate subsequent, more tailored and specific, guiding integrative approaches for particular risk assessment methodologies.

Table 1-1: Overview of research objectives and how each paper / Chapter relates to them.

		Paper 1 (Chpt. 2)	**Paper 2 (Chpt. 3)**	**Paper 3 (Chpt. 4)**
1	**Highlight and demonstrate value of foresight processes**	**X**		**X**
1.1	Use existing definitions and practise establish gaps DRA processes foresight can assist with	X		
1.2	Case-study applications showing foresight can support strategic DRM	X		X
2	**Specific methodological approaches for scenario development and use for strategic DRM**		**X**	**X**
2.1	Qualitative scenario development		X	
2.2	Quantitative scenario development and use			X
3	**Framework and approaches for using scenarios within DRA**	**X**		**X**
3.1	Generic framework development	X		
3.2	Develop and demonstrate integrated approaches for specific risk assessment methodologies	X		X

CHAPTER 2

Paper 1: Tomorrow’s disasters – embedding foresight principles into disaster risk assessment and treatment (Published paper)

Statement of Authorship

Statement of Authorship

Title of Paper	Tomorrow's disasters – embedding foresight principles into disaster risk assessment and treatment
Publication Status	☐ Published ☐ Accepted for Publication ☑ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Submitted to 'Disasters'

Principal Author

Name of Principal Author (Candidate)	Graeme A Riddell		
Contribution to the Paper	Conceptualisation of approach, implementation and stakeholder engagement design and practice. Lead role in drafting manuscript.		
Overall percentage (%)	70		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	15/04/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Hedwig van Delden		
Contribution to the Paper	Input to conceptual approach, stakeholder engagement and drafting of manuscript.		
Signature		Date	16/04/'19

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Abstract

Disaster risk is a complex, uncertain and evolving threat to society which changes based on broad drivers of hazard, exposure and vulnerability such as population, economic and climatic change, along with new technologies and social preferences. It also evolves as a function of decisions of public policy and public / private investment which alters future risk profiles. These factors however are often not captured within disaster risk assessments and explicitly excluded from the UN General Assembly definition of a disaster risk assessment which focuses on the current state of risk. This means that 1) we cannot adequately capture changes in risk and risk assessments are out of date as soon as published but also 2) we cannot show the benefit of proactive risk treatments in our risk assessments. This paper therefore outlines a generic, scale-neutral, framework for integrating foresight – thinking about the future – into risk assessment methodologies. This is demonstrated by its application to a disaster risk assessment of heatwave risk in Tasmania, Australia, and shows how risk changes across three future scenarios and what proactive treatments could be possible mitigating the identified drivers of future risk.

Keywords: Disaster risk management; risk assessment; foresight; scenarios; risk treatment

2.1 Introduction

Disasters are complex in their nature, based on the interaction between three elements, 1) natural events - potentially cascading and compounding in their behaviour, hazards; 2) the area in which they impact and the assets that exist there, such as people, buildings, hospitals, areas of cultural and historical significance, exposure; and 3) the degree to which these assets are susceptible to the hazard events, vulnerability; (Crichton, 1999; Global Facility for Disaster Reduction and Recovery, 2016; Peduzzi, Dao, Herold, & Mouton, 2009).

Each of these elements is also continuously in flux. The nature of hazards is changing with climate change, which alters the frequency and intensity of events (Hallegatte et al., 2013; van Aalst, 2006). Exposure similarly is changing in its nature due to technological change and urbanisation rates, which are some of the many drivers of exposure. Vulnerability which can act as the relationship between hazard and exposure, also changes with time. For example, vulnerability changes as infrastructure deteriorates with weathering and usage (Cui & Caracoglia, 2016; Stewart, Wang, & Nguyen, 2011), along with the increasing connectedness of society, creating new dependencies and vulnerabilities (Pescaroli & Alexander, 2016).

These factors highlight the changing and complex nature of disasters. They are not simply 'natural events' but a function of interactions between changing environmental threats and societal developments and decisions. Disaster risk, when considered in this manner, is an inherently complex system displaying characteristics of emergence, and wickedness (Cutter, 2013; Jones & Preston, 2011; G. O'Brien, O'Keefe, Gadema, & Swords, 2010). This complexity, and uncertainty, must be incorporated into the thinking and conceptualisation of disaster risk, pushing past a probabilistic understanding of risk, which is inherently a past-oriented paradigm, and instead conceptualising risk as a dynamic system. This paper proposes a framework to enable this conceptual definition to be incorporated into the planning for the assessment and treatment of disaster risks.

Efforts to minimise disasters or manage their impacts are traditionally facilitated by disaster risk assessment processes (Marzocchi, Garcia-Aristizabal, Gasparini, Mastellone, & Di Ruocco, 2012; UNISDR, 2017). Risk assessment is an effort to understand the uncertain factors and influences that may impact on an organisation's ability to achieve its objectives (International Organization for International Organization for Standardization, 2009) (ISO). Under the ISO principles, risk is focussed on uncertainty and defined as the "consequence of an organisation setting and pursuing objectives against an uncertain environment"

(International Organization for International Organization for Standardization, 2009). With this definition, risk is not inherently negative, but instead includes events that could have an effect on an organisation's objectives, either positive or negative, that are uncertain.

In the disaster / natural hazards and emergency management spheres, there is, however, a difference in how risk is generally defined and considered, as well as how risk assessments and subsequent management activities are developed and implemented. Terminology of the United Nations International Strategy on Disaster Reduction (UNISDR) defines disaster risk as the "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a *specific period of time*, determined probabilistically as a function of hazard, exposure, vulnerability and capacity" (UNGA, 2016). Similarly, disaster risk assessment is defined as "a qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating *existing conditions* of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend" (UNGA, 2016).

Consequently, while the ISO definition of risk includes reference to uncertain environments, the definitions of risk used in the disaster / natural hazard management sphere focus on current conditions while omitting the consideration of uncertainties, especially those resulting from future changes. This is a significant shortcoming, as the impact of uncertain future conditions impacts on our understanding of disaster risk and how to effectively treat it. This focus on the current risk, and probabilistic understanding from UNISDR likely originates from a historical emphasis on response and recovery in comparison to prevention along with the significant role quantitative risk modelling plays in insurance markets following the rise of catastrophe modelling since the late 1980s. Therefore quantitative risk assessments have mostly been designed for a detailed current understanding of disaster risk to more accurately price risk within insurance markets for a 1-3 year policy horizon.

Risk assessments within the literature follow this UNGA definition and focus on capturing data on the current situation, using census, economic and land use information to inform the development of exposure information such as in Gunasekera et al. (2015), Aubrecht, Özceylan, Steinnocher, and Freire (2013), and Santa María, Hube, Rivera, Yepes-Estrada, and Valcárcel (2017). Similarly, information regarding vulnerabilities is described based on either socio-economic indicators of societal resilience and vulnerability to hazards (Brooks, Adger, & Kelly, 2005; Cutter et al., 2008; Cutter, Boruff, & Shirley, 2003; Khazai, Anhorn, & Burton, 2018; Khazai, Merz, Schulz, & Borst, 2013), or the physical characteristics of assets that make them more or less susceptible to hazard events, such as construction types, ages and floor heights (de Moel & Aerts, 2011; Jongman, Kreibich, et al., 2012). This results in risk assessments focussed on the current risk, based on latest information, with little consideration of how this is changing, and what emergence is occurring within the exposure and vulnerability elements of risk.

For hazards, although some consideration is given to future conditions via the impacts of future projections of climate change (when relevant) on the frequency and intensity of hazard events (Alfieri, Feyen, Dottori, & Bianchi, 2015; Hallegatte et al., 2013), little consideration is given to 1) emergence between the risks associated with multiple hazards (e.g. compounding events of coastal storms and riverine flooding, the occurrence of wildfire leading to increased likelihood of flooding due to loss of vegetation and top-soil); or 2) the influence of future exposure changes on the nature of the hazard (e.g. changing amount of permeability on flood risks, and road and electricity infrastructure on wildfire ignition probability). This lack of consideration of dynamics, emergence (newly created, identified or increasing (Flage & Aven, 2015)) and wickedness (variety of stakeholders, conflicting views and diverging perspective of solutions (Churchman, 1967)) of disaster risk is shown in multiple recent disaster / natural hazard risk assessments, including Depietri, Dahal, and McPhearson (2018), who consider multiple hazards across New York city. They assess the region's relative exposure and vulnerability is to heatwaves, inland and coastal flooding based on socio-economic factors. However, there is little consideration of how these factors change in time and in relation to each other. This is also the case in Bernal et al. (2017), which assesses multi-hazard risks in taking a probabilistic modelling approach to earthquakes and landslides while considering only existing housing inventories; and similarly in Feroz Islam, Bhattacharya, and Popescu (2019) and Novelo-Casanova et al. (2019), both of which present innovative studies on risk assessment and include discussion on the role of urban planning as risk mitigation strategy but do not include drivers of future risk.

As evidenced above, there is therefore an absence of risk assessment processes within disaster risk management that capture the degree of wickedness within the disaster risk system. This means that changes in disaster risk, and therefore the risks to organisations and communities, are not adequately captured. There are also broader implications for disaster risk assessment and management considering the principles of risk management. Considering ISO31000, risk treatments are determined based on risk identification, analysis and evaluation, and are then reviewed against these components through monitoring and review phases. Therefore, as risk treatments identified and subsequently evaluated cannot be tested against reduction of future or emergent risks, treatments will only have reactive functions (treating existing risk), not proactively treating emergent risk in a strategic manner. This represents a fundamental blind-spot, and a significant loss in the ability of risk assessments to inform risk reduction actions for tomorrow's disasters. This is substantial given 85% of the increase in insured losses from 1980 to 2014 could be attributed to increase in urbanisation and economic value (Aon Benfield, 2014).

Additional to disaster risk assessments not being able to inform risk reduction actions for tomorrow adequately, by not doing this, treatments implemented, or decisions made in other domains of public and private entities, may result in maladaptation and negative risk outcomes over the long-term. These include environmental degradation and displacement, even in the case of implementing structural risk reduction activities (dams etc.), which can exacerbate vulnerabilities in communities impacted (Lewis, 2012). Short-term reactions to disaster events, not considering future implications, often leads to either decreased resilience locally or misuse of limited resources. This is shown in the case of excessive fire suppression in the USA post the 1910 wildfires in the western United States, which has led to many forests becoming more flammable and less controllable as the natural fire regime has been removed (Anderson et al., 2018). The "levee-effect" where the provision of flood defences leads to increased risk is another example of how the lack of consideration and exploration of interactions and dynamics of risk into the future has led to negative outcomes (Ferdous, Wesselink, Brandimarte, Di Baldassarre, & Rahman, 2019; Hutton, Tobin, & Montz, 2019). These are just a few examples of how future considerations not being accounted for within disaster risk assessment and management can lead to adverse outcomes. There are many others including coping mechanisms leading to longer term vulnerability (Ncube-Phiri, Mudavanhu, & Mucherera, 2014); increased fuel management in areas with recent fire experience leading to reduce fuel management efforts in other similar regions; and a focus on short-term actions and a lack of focus on systemic changes through land use planning (Anderson et al., 2018).

In other applications of risk management there is growing use of the principles of foresight to inform strategic risk management – "a process for identifying, assessing and managing risks and uncertainties, affected by internal and external events or scenarios, that could inhibit an organization's ability to achieve its strategy and strategic objectives with the ultimate goal of creating and protecting shareholder and stakeholder value" (Frigo & Anderson, 2009, 2010). Foresight can be considered as a process of strategic thinking that looks to challenge common perceptions of what will happen, and allow for an expanded range of strategic options to be considered in a planning process (Voros, 2003). In an organisational setting, foresight can enable decision makers to see the future with different perspectives, and improve understanding of the implications of various trends in society (Fink et al., 2005; Glenn, Gordon, & Dator, 2001; Inayatullah, 2018; Rijkens-Klomp & Van Der Duin, 2014).

There have been few examples of concepts that fall under the banner of foresight linked with disaster risk assessments. These include Kwadijk et al. (2010), who look at future climate scenarios and coastal risks in the Netherlands; Lempert et al. (2013), who use exploratory simulation models to test flood risk management strategies against future uncertainties; and Riddell, van Delden, Maier, and Zecchin (2019), who develop exploratory scenarios to assist disaster risk planning for a metropolitan region. However, these represent disparate examples, and are lacking in an overarching framework to incorporate the benefits of foresight with a disaster risk assessment to enable proactive and strategic risk treatments.

Challenges do exist in the integration of foresight into disaster risk management including the lack of resources currently to support risk assessment and reduction activities (Lavell & Maskrey, 2014); quantification challenges of future changes into disaster risk models (Riddell et al., 2019); and challenges associated with foresight studies in general including lack of focus on policy and planning and decision-making, subjectivity of findings and true representativeness (Alcamo, 2008; Parson, 2008; G. A. Riddell, H. Van Delden, G. C. Dandy, A. C. Zecchin, & H. R. Maier, 2018). The benefits however if integration is performed well can be substantial.

Therefore, the objectives of this paper are to 1) introduce and describe a framework for using the principles of foresight for proactive, strategic disaster risk management, 2) provide greater insight into the role that foresight can provide to disaster risk assessment and management, and 3) highlight the utility of foresight through applying the framework to a disaster risk assessment (the Tasmanian State Natural Disaster Risk Assessment 2016). The paper aims to achieve these objectives by, in Chapter 2.2, outlining a proposed framework for the integration of foresight with risk assessment and risk treatment, and then in Chapter 2.3, applying this framework to an existing disaster risk assessment via engagement with representatives in the case study region to explore drivers of risk. Chapter 2.4 provides discussion of the framework, its applications and future directions for research. Conclusions are offered in Chapter 2.5.

2.2 Embedding Foresight into Disaster Risk Management: a Framework for Managing Tomorrow's Disasters

Foresight can be integrated into risk management procedures by allowing a broader consideration of the 'context' pertinent to the risk assessment. It can also allow for the consideration of treatment effectiveness under future, uncertain conditions. Figure 2-1 shows the outline of the proposed framework to enable foresight to be used to inform dynamic risk assessments and risk treatments, and how each of these components relate, inform and update each other. It is thought this framework can support any disaster risk assessment process at any scale and hazard. For example, the framework could be used to assessing multiple natural hazards impacting on a growing urban area / city. Alternatively, the framework could be used to inform and assess national level disaster risk management policies in a non-spatial manner developing futures of national change.

The three key components 1) risk foresight, 2) dynamic risk assessment and 3) risk treatment (labelled a, b, and c, respectively – Figure 2-1) allow for disaster risk management processes to draw on insights from each component, along with the information they provide other components, resulting in an iterative framework. Each component of the framework provides critical insight into the disaster risk management processes, these key roles of the components are described in Figure 2-2. Also important to the framework is the interactions between components – these are labelled 1-6 in Figure 2-1. The following sections provide further details on each of the framework's main components (Chapter 2.2.1 - 2.2.3) and their interaction processes (Chapter 2.2.4).

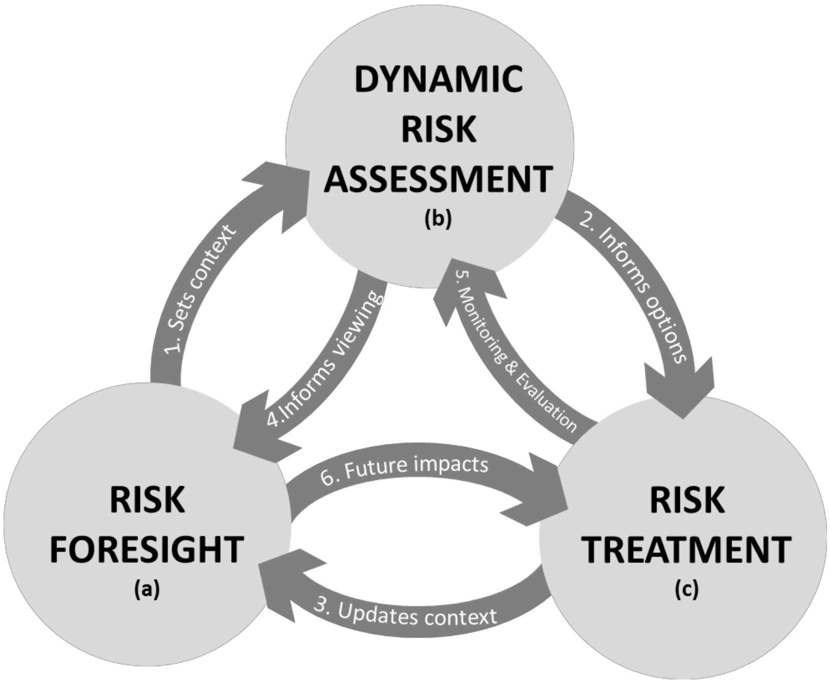

Figure 2-1: Overview of framework, its three key components (a-c), and six interaction process (1-6).

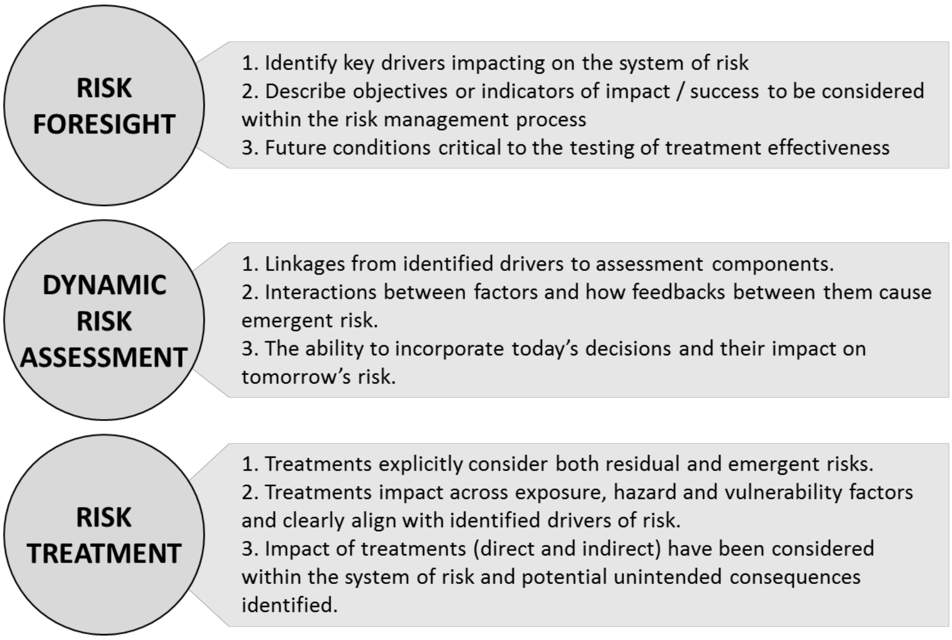

Figure 2-2: Three key roles of each of the framework's components.

2.2.1 Risk foresight

Foresight allows for the strategic and transparent consideration of driving forces impacting on disaster risk, and the system of values in a region undergoing a risk assessment and management processes. Foresight is a process that enables drivers of change – globalisation, urbanisation, technological development, changing societies and work patterns etc. – to be considered and how they impact on the system moving into the future. Importantly, there is an emphasis on foresight not being a predictive process, but an approach to understand features or drivers that can have an impact on the long-term effectiveness of a strategy.

There is significant literature on the role of foresight approaches within organisations and companies, allowing them to better position themselves to deal with external factors - see Bradfield et al. (2005), Wright, van der Heijden, Burt, Bradfield, and Cairns (2008), and Ramirez and Wilkinson (2016). However, the key purpose of foresight exercises, and the embedding of foresight approaches into strategy development and decision making, is in the conscious effort to enhance and enrich the context within which the planning, implementation and execution of a strategy are undertaken. It is under this concept of defining the context that foresight can also assist significantly in the risk assessment and treatment process. Foresight allows for a broader context to be considered when assessing risks and allowing an expanded range of strategic risk treatments to be considered by challenging assumptions and perceptions.

Multiple techniques can be used to challenge assumptions/perceptions in a foresight process. Such techniques generally involve the creation of a working group and participatory processes, along with scanning of current trends to assess possible future directions (Bishop, Hines, & Collins, 2007; Reimers-Hild, 2018). Other methods take a more quantitative approach and exploit existing modelling systems to determine vulnerabilities and interesting cases for strategy development (Bryant & Lempert, 2010; Kwakkel & Pruyt, 2013). Regardless of the process, foresight should provide insight into the impact of drivers on risk, for example, the density of residential developments and agricultural decline causing migration to urban areas.

Arguably the most common approach used in foresight studies is the development of scenarios and the integration of these scenarios into planning processes. Scenarios are typically defined as "coherent descriptions of alternative hypothetical futures that reflect different perspectives in past, present and future developments which can serve as a basis for action" (Van Notten, 2005), and often in the context of foresight studies portray future plausible states, and pathways that led to their development. They can be considered, from Börjeson et al. (2006) and Maier et al. (2016), as either predictive - questioning what will happen (although still posing multiple results), exploratory - designed to question what could happen, and normative - which considers how a specific future can be realised. This is different to how scenarios are often considered in disaster risk assessment, which focus on a specific series of events in an emergency or disaster situation and often do not include any forward-looking perspectives on future conditions as contained within the above definition from Van Notten (2005).

Scenario development can take many forms, including participatory processes with large stakeholder groups (Reed et al., 2013), trend analysis and extrapolation using forecasting models (Gordon, 1994), as well as a combination of simulation models and stakeholder/expert input (Kok & van Delden, 2009; Kok, van Vliet, Bärlund, Dubel, & Sendzimir, 2011). Purely quantitative methods can also be applied, such as scenario discovery (Bryant & Lempert, 2010) or decision-scaling (Brown, Ghile, Laverty, & Li, 2012), when quantitative system models exist, which is especially true for risk assessment processes at an asset or closed system level, such as water supply systems. Other mechanisms of foresight that provide value within the context of considering tomorrow's disasters include the use of mega-trends, Delphi studies and exploratory modelling approaches, of which more can be found out about in Hamarat, Kwakkel, Pruyt, and Loonen (2014); Kwakkel and Pruyt (2013); Liimatainen et al. (2014); Moallemi, de Haan, Kwakkel, and Aye (2017); Reimers-Hild (2018); Smeets-Kristkova, Achterbosch, and Kuiper (2019); and Toppinen, Röhr, Pätäri, Lähtinen, and Toivonen (2018).

Critical to the success of the process though, irrespective of mechanisms selected to provide foresight – which could be selected based on scale, resources, available time, are several key questions the exercise must answer. These are 1) what are the key drivers impacting on the system of interest, 2) what objectives or indicators of impact / success are to be considered within the risk management process and 3) what future conditions are critical to the testing of treatment effectiveness (these key questions are summarised in Figure 2-2 for each of the components). By responding to these, the foresight exercise provides: critical insight into drivers of risk that must be incorporated into the risk assessment process at an appropriate scale; future conditions or states of world for treatments to be tested against and a mechanism by which assumptions can be exposed, and challenged in a way that reduces unintended consequences that occur when influencing a wicked problem.

2.2.2 Dynamic risk assessment

Following Figure 2-1, after the risk foresight process, dynamic risk assessment processes occur. As outlined in the Introduction (Chapter 2-1), traditionally disaster risk assessments focus on the capture of accurate data related to the exposure of people, assets and other values to the attributes of a natural hazard that could cause them damage (e.g. water level from flooding, peak ground acceleration for earthquake). For quantitative risk assessments that produce damage estimates, such as average annual loss, effort is then concentrated on defining the relationship between the magnitude and likelihood of the natural event with the damage it produces against a chosen exposure class, which is defined as vulnerability, and is commonly expressed with stage-damage curves (de Moel & Aerts, 2011; Stone, 2018).

Non-quantitatively focused risk assessment processes may see results shown in a matrix format of likelihood vs consequence, such as Santos et al. (2014) and Saunders and Kilvington (2016), or visually map the intersection between exposure and hazard without quantifying the impact of the interaction and instead using representative indices for vulnerability such as Koks, Jongman, Husby, and Botzen (2015). There is significant description of these processes in EMA (2015) and UNISDR (2017). Depending on the exposure of interest, more sophisticated quantitative assessments may also take place that look at the broader economic impacts – such as Hallegatte (2008); and Koks and Thissen (2016).

For a foresight enabled dynamic risk assessment on tomorrow's disaster, the above components of a risk assessment procedure do not change, they are however framed in a dynamic context allowing for them to provide insight into how the risk is changing, and importantly why. Using the defined context from risk foresight, the disaster risk assessment processes must account for the identified drivers of risk for the context and scale of interest. For rapidly urbanising regions, this may see the modelling used within the risk assessment process requiring consideration of changing land use, and its subsequent influence on exposure (increased urban footprint), vulnerability (changed stage-damage curves for new construction), and hazard (increased urbanisation changing flood magnitude, flow paths and infiltration rates). For regions where there is economic decline, consideration should be given to how this influences risk components as well (e.g. in increased socio-economic vulnerability to recover from events, and capability to invest in risk reduction methods from central governments with a declining tax base).

Similar consideration also needs to be given to all potential drivers of risk including climate change. Incorporation of climate impacts within the hazard modelling may show increases in intensity, frequency and duration of certain events (Alfieri et al., 2015; Krawchuk et al., 2009). Extreme uncertainty that may arise from downscaling of climate parameters should also be tested from considering the effects which can cause the greatest uncertainty against the objectives of the region or organisation. Consideration of other climate impacts such as transition risks on economic activity may also be relevant (Taskforce on Climate-related Financial Disclosures, 2017). By connecting drivers of risks to the risk assessment process, insight can be gained on how to best inform the assessment process by including more relevant information related to exposure and vulnerability – such as the need to consider changing economic fortunes for vulnerability assessments. It also shows how to best treat risk and emergent risks based on mitigating the factors causing them to occur.

Similar to the foresight process, the mechanisms employed for the risk assessment process can be broad, depending on a variety of factors, scope, resources etc. However, key information must be included. Risk assessment processes that account for the wickedness of tomorrow's disaster must include 1) linkages from the identified drivers to assessment component; 2) interactions between factors and how feedbacks between them cause emergent risk; and 3) the ability to incorporate today's decisions and their impact on tomorrow's risk, providing a wind-tunnel for risk management actions. By ensuring the inclusion of these three factors and embedding them within the qualitative or quantitative process that is used to determine the nature of the disaster risk, dynamic risk assessments can be produced, which provide insight as to how disaster risk changes with uncertainty across its drivers and how treatments can be designed to manage this.

2.2.3 Risk treatment

Risk treatment is the final stage in the framework and utilises the risk assessment process to evaluate potential options to be implemented to avoid, remove, change or share the risk (or potentially accept it). Disaster risk treatments traditionally have focused on response capabilities as performed by civil protection and emergency management agencies. A growing focus has been on the mitigation of disaster risks, with a study showing cost-benefit analysis of mitigation efforts ranging from 1.3:1 to 1800:1 (Shreve & Kelman, 2014). Risk mitigation efforts see the design and construction of levees and dykes informed by risk modelling (Ward et al., 2017; Woodward, Kapelan, & Gouldby, 2014), as well as fuel load reduction burns to minimize the threat of wildfire (Bradstock et al., 2012) and retrofitting options to roof structures to mitigate the impact of extreme wind and cyclone hazards (Lee & Rosowsky, 2005).

There is also a broad group of treatment options that can influence across the elements of risk - exposure, vulnerability, and hazard. Bouwer, Papyrakis, Poussin, Pfurtscheller, and Thieken (2014) provide an overview of the range of risk reduction options that are possible, most of which focus on a traditional conceptualisation of disaster risk. Urban / spatial planning, included within Bouwer et al. (2014), is discussed as one of the most powerful but under-utilised risk reduction methodologies (Glavovic, Saunders, & Becker, 2010; Kim & Rowe, 2013; Lyles, Berke, & Smith, 2014). However, given risk assessment and treatments' emphasis on reactive actions on current risk, and that the influence of urban planning primarily is on future disaster risk, the under-utilisation of urban/spatial planning is not necessarily a surprise.

For foresight-informed risk treatments, portfolio approaches may need to be embraced to deal with both existing and emergent disaster risks. This is focused on managing and reducing existing risks through risk reduction methods, as previously outlined, but also integrating measures and treatments that influence the drivers of future risk and reduce the role of bad decisions made today, leaving tomorrow's risk behind for emergency management and civil protection agencies to respond to and recover from. Evaluation and prioritisation of treatment actions should consider performance against time, and how well individual treatments can be combined into portfolios. Therefore treatment's robustness, adaptability and long-term performance or deterioration become highly relevant.

Systemic and forward thinking risk assessment and treatment should see risk reduction measures being considered across a broad range of activities to act on the disaster risk system. This may encompass actions such as improving school education to increase the effectiveness of messaging and other child-orientated actions (Johnson, Ronan, Johnston, & Peace, 2016), reforestation (or slowing deforestation) of large areas reducing flood risk (Bradshaw, Sodhi, Peh, & Brook, 2007) or explicit incorporation of the systemic causes of vulnerability (societal dynamics and power structures, poverty etc.) to effectively address them (Cannon, 2008). It also enables a systematic understanding of the full potential impacts of intended risk reduction activities, or other actions that influence the disaster risk system, such as the provision of road infrastructure to improve accessibility of response vehicles and evacuation routes, which could also induce increased urban growth and subsequent exposed values, as well as change flood paths by decreasing infiltration and acting as channel (Semadeni-Davies, Hernebring, Svensson, & Gustafsson, 2008; Swan, 2010), and increasing the likelihood of ignition for wildfire disaster risk (Badia, Serra, & Modugno, 2011; Chas-Amil, Prestemon, McClean, & Touza, 2015).

As with previous components, the procedures used to determine appropriate risk treatments and their form are not as significant as their key ability to deliver critical information. For risk treatments, key questions to respond to are 1) does the treatment (or portfolio of treatments) explicitly consider both existing and emergent risks, 2) do treatments impact across exposure, hazard and vulnerability factors and clearly align with the identified drivers of risk, and 3) have the impacts (direct and indirect) of treatments been considered across the system of risk - identifying potential unintended consequences and influence. Responses to these questions enable the risk treatments to strategically treat and proactively reduce risks, using the decisions of today to positively influence on tomorrow's risk profile.

2.2.4 Interaction processes

Outside of the three key components of the framework, the interactions and flow of information between them is critical for a foresight informed risk assessment and management approach. Previously Figure 2-1 and Chapter 2.2 provided high level details on the interactions and this section will provided further details. Table 2-1 summarises linkages between components in both forward and backward interaction processes.

Following the feedforward processes (items 1-3 in Figure 2-1), risk foresight provides information into the dynamic risk assessment (item 1), with dynamic risk assessment informing risk treatment (item 2) and finally completing the loop with treatment informing subsequent foresight activities (item 3). For risk foresight to have influence over the risk assessment process as outlined earlier, setting the context is critical. Within 'sets context' risk foresight needs to provide the risk assessment an outline of the disaster risk system of interest now and into the future including system elements and linkages, actors and drivers. With this understanding, the risk assessment process can look to assess the relative significance of each of the elements and how they can be included in each of the hazard, exposure, and vulnerability elements of disaster risk assessments.

Risk assessment informs options to be considered within the treatment component. This involves highlighting the risks that need to be treated, both emergent and existing, and the factor of risk contributing to or driving the change in risk profile. This is then used within the risk treatment component to identify, evaluate and subsequently implement treatments that can reduce, change, transfer or accept the assessed risks.

The final feedforward links risk treatment back to risk foresight and enables the context to be updated due to the design and implementation of risk treatment options. This iterative loop supports the effectiveness of foresight processes so that assumptions made within risk foresight can be tested against development, and re-occurring foresight supported risk assessment allows for drivers and assumptions to be greatly improved, as analysis on the dynamics of change can be undertaken and incorporated within the next iteration. Examples of this could include the implementation of urban planning strategy to restrict residential development in a region – this can be included within the refreshed foresight process along with any impacts this may have also had such as the increased density in areas surrounding the exclusion zone (causing potential emergent risk).

The backwards interaction processes are also critical between components, with the link between risk treatment and assessment providing the basis for monitoring and evaluation of implemented treatments. Risk assessment has the feedback to risk foresight by establishing the boundary conditions for the foresight exercise (e.g. defining hazards of interest) and outlining the types of relevant information the foresight exercise can provide to the risk assessment (e.g. specific exploration of known vulnerabilities in the current system and values to be included in the assessment). Risk foresight to risk treatment provides future conditions for risk treatments to be effective for managing emergence, which allows a mechanism for their effectiveness to be tested ex-ante by assessing against the same metrics of the risk assessment.

Table 2-1: Overview and description of the proposed framework's linkages.

Provider	**Receiver**	**Link**	**Description**
Feedforward processes			
Risk Foresight	Risk Assessment	Sets context	Provides the basis of risk assessment as to hazards considered, environmental and social setting, time horizon, stakeholders involved etc.
Risk Assessment	Risk Treatment	Informs options	Provides insight as to areas requiring treatment and information on appropriate treatments.
Risk Treatment	Risk Foresight	Updates context	The application of treatments will change the situation and as such may require updates to conditions providing the basis for foresight and assessment.
Feedback processes			
Risk Treatment	Risk Assessment	Monitoring & Evaluation	The application of treatments is measured and monitored against risk assessment to evaluate performance.
Risk Assessment	Risk Foresight	Informs viewing	Provides the conditions and influences the framing within which to undertake the foresight exercises and identifies specific information required.
Risk Foresight	Risk Treatment	Future impacts	Provides future conditions under which risk treatments can be assessed in relation to their impact on emergent risk.

2.3 Embedding Foresight into Disaster Risk Management in Tasmania: Case Study Application of Framework

2.3.1 Case study background

The above framework, its key components and interactions, are demonstrated by its application to a disaster risk assessment in the state of Tasmania, Australia This section demonstrates the application of the framework through detailing engagement processes for the risk foresight component of the framework, before highlighting how this can be used to inform a disaster risk assessment by showing how it can be integrated into the previously commissioned Tasmanian State Natural Disaster Risk Assessment (TSNDRA) (White, Remenyi, McEvoy, Trundle, & Corney, 2016). Engagement was undertaken following the disaster risk assessment process with various government representatives, developing alternate scenarios that were relevant to future disaster risk in the state. Following the disaster risk assessment process, engagement was undertaken with various government representatives, developing alternate scenarios that were relevant to future disaster risk in the state. The risk foresight process was designed for all hazards included within the TSNDRA however demonstration of risk assessment and risk treatment will focus on heatwave risks in Tasmania.

Figure 2-3 provides an overview of the following sections and results, as to how they represent the implemented framework for risk assessment in Tasmania. Each panel represents a component of the framework – risk foresight, assessment and treatment – and shows the types of information and methods used for each component in the application of the framework. Boxes in light grey – 'Tas. State Natural Disaster Risk Assessment', and 'Reactive risk treatments' summarise work done previously within the TSNDRA, dark grey boxes represent additional information and insight derived from the application of the framework. Each of the following sections provides insight into existing work done on the disaster risk assessment, subsequent insight derived from the application of the framework and its implications (interactions with other components of the framework).

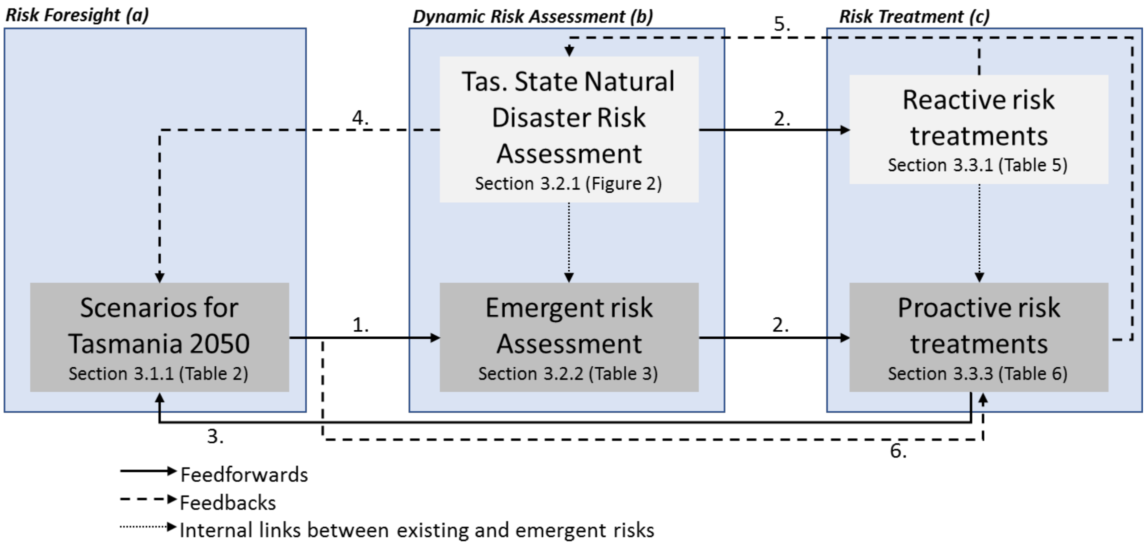

Figure 2-3: Overview of application of framework to Tasmanian case-study. Connectors describe the relationship between components of the framework with labelled numbers linked back to the interaction processes as described in Figure 2-1 and Table 2-1.

Tasmania is Australia's island state and has a population of approximately 522,000. It is subject to a range of natural hazards and has been severely impacted recently by both bushfires and floods. In the context of this application the framework was based on a previously performed risk assessment, the TSNDRA. Following this disaster risk assessment process, engagement was undertaken with various government representatives, developing alternate scenarios that were relevant to future disaster risk in the state. This engagement involved two workshops and semi-structured interviews with 13 state agencies over a year period.

The engagement process informed the risk foresight section of this demonstration. Stakeholders were subsequently not engaged in the other demonstrated elements of the case-study. Results shown for dynamic risk assessment (Chapter 2.3.3) and risk treatments (Chapter 2.3.4) were done by the authors and future research will consider further interaction with stakeholders. The risk foresight process was designed for all hazards included within the TSNDRA however demonstration of risk assessment and risk treatment will focus on heatwave risks in Tasmania.

2.3.2 Risk foresight

2.3.2.1 Introduction

Risk foresight for Tasmania involved the development of scenarios for plausible futures of the region across relevant drivers for the disaster risk system (region, actors, other characteristics) under consideration. This section provides details on the development of these scenarios and summarises their narratives for the future of Tasmania in 2050, which is given in Chapter 2.3.1.1. Chapter 2.3.1.2 subsequently shows the implications of the process, how the risk foresight element interacts with assessment and treatment (forward and backwards interactions), and how the scenarios and development process answer the key questions required of an effective process, as discussed in Chapter 2.2.1 and summarised in Figure 2-2.

2.3.2.2 Application of framework

Two stages of engagement within the risk foresight process were used to define the system of interest, and drivers for risk across the state of Tasmania. An initial scoping stage identified key drivers of risk from participants who were involved across the State and Local Government emergency management sector, from response agencies to central planning departments. Key themes were determined as the drivers for risk in the state, including 1) population, demographics and associated vulnerabilities, 2) community understanding and perception of risk, 3) the State's economic development, 4) urbanisation (the split between urban, peri-urban and rural land use and their interactions) and 5) climate change (both its impact and societal responses). In the second stage, these drivers were coupled with a participatory exercise to determine the objectives for disaster risk reduction in Tasmania, which were used to frame subsequent discussions and provide a lens through which drivers and treatments could be considered.

As part of the participatory process individual participants were asked to describe their vision for disaster risk management in 2050 for Tasmania in a single sentence. Vision statements included sentences such as, “A resilient and diverse community that is able to respond to risk and recover from natural hazards” and, “That by 2050 natural disasters do not impede the social, economic and environmental objectives of Tasmania”. Policy objectives were determined based on individual reflections on the group’s vision statements responding to the question, “What are the key elements from the vision statements for policy objectives?” Participants’ responses to this were grouped into themes for the objectives, which were, 1) resilient communities, 2) community awareness, 3) strong economy, 4) decreased exposure and vulnerability (people, place, property), 5) environmental protection and 6) informed decisions. The role of identifying these objectives was to assist participants in scenario development processes within the risk foresight component to provide an overview of the factors considered most relevant in the disaster risk system for achieving their visions for the state (Riddell et al., 2016; Riddell et al., 2017) – see Appendix A and B respectively.

Three scenarios were developed with what participants considered to be the most likely future, as well what would be considered the best- and worst-case futures for Tasmania in 2050 considering the previously discussed vision and policy objectives for disaster risk management. The three scenarios are outlined across the five identified drivers in Table 2-2. Of particular note is the close relationship between the scenarios and the scope set by the risk assessment process – by informing the view (interaction process 4, Figure 2-3). This is clear in the specific references to hazard, exposure and vulnerability elements throughout the scenarios and clear linkages to the disaster risk system such as “low household spending capacity learning” to “reduced resilience and increased reliance on government support”. Using the risk assessment process to provide scope and the lens through which to undertake the foresight exercise allows the foresight process to be much more closely linked to decision assessment and making processes – identified as critical for policy relevant scenario exercises (Bryson et al., 2010; G. A. Riddell et al., 2018).

Table 2-2: Outline of three scenarios developed for Tasmania in 2050.

Risk Drivers	**Scenario**		
	Best-case	Most-likely	Worst-case
Population, Demographics & Associated Vulnerabilities	Sustainable population growth (600,000-650,000) contained within existing areas with improvement of infrastructure and services. Growth is seen in key, productive	Moderate to low population growth, maximum of 600,000 in 2050. Population growth is not sufficient to stimulate strong economic growth though. Increasingly	Low growth to decreasing population with increased aged proportion of the population. Low household spending capacity leading to reduced resilience and

Risk Drivers	**Scenario** Best-case	 Most-likely	 Worst-case
	age groups reversing the 'brain-drain'.	ageing population with educated youth moving to the mainland.	increased reliance on government support. Unsustainable and dispersed communities.
Community Risk Understanding & Perception	Community is aware of risk and understands the concept of shared responsibility. Decisions are made balancing risk, growth and environmental values. High levels of literacy supporting effectiveness of messaging.	Increased community expectation on role and impact of emergency management agencies to manage and respond to risk. Land use decision making, both public and private development, does not consider risk sufficiently.	Community expects to be rescued from all hazards without accepting guidance. Risk is generally ignored in decision making leading to draining resources for response.
Economic Development	Diversified and decarbonised economy that embraces technological advancements for increased productivity. Economic development does not come at the expense of other critically important values and is not a result of 'all development is good development'.	Tourism is main economic sector following the public services which grows with increasing provision of health services. Agriculture shifts focus due to impacts of climate change (e.g. changing wine varieties). Remote working expands with 'digital nomads'.	Simplified economy with only two main sectors (mining and agriculture) – still a carbon-based economy. State and Local Authorities accept all development in attempt to stimulate growth.
Urbanisation	Emphasis on consolidating communities and reducing urban sprawl. Increased densities with fewer peri-urban areas supported by effective public transport.	Urban growth mostly occurs in the suburbs leading to increased congestion, travel times and peri-urban environments. There are restrictions to new development in the highest risk areas but development still occurs, particularly in coastal regions.	Sprawl with increased reliance on private transport. Development focus shifts to coastal area and vegetated hills (tree / sea-change). Infrastructure badly maintained.
Climate Change & Our Response	Effective policy responses in the mitigation space reduce physical risks of climate change. Adaptive management strategies are implement to respond to changing threats and economic opportunities are seized from the need to mitigate and	Business as usual is embraced and hard climate mitigation decisions are not taken. There is less adaptation and greater focus on 'hard' solutions to climate risks.	Failure to respond with rate of change faster than predicted. Unforeseen impacts in second and third order effects have significant impact on region.

Risk Drivers	**Scenario**		
	Best-case	Most-likely	Worst-case
	adapt to climate change.		

2.3.2.3 Implications and interactions

The foresight exercise shown here produced three scenarios, as outlined above, to be incorporated within risk assessment and risk treatment processes following the framework. As part of this process, the three key questions identified in Chapter 2.2.1 were answered, with the foresight process providing key drivers for change presented in Chapter 2.3.1.1 and Table 2-2 – population and demographics, community perception and understanding of risk, economic development, urbanisation and climate change and our response. These drivers and how they look in 2050 across three alternate perspectives, including best-case, most-likely, and worst-case, provide the future conditions under which to test the effectiveness of treatments. These represent the first and third component that the foresight exercise is designed to answer. The second considers the objectives and indicators of impact / success to be considered within the risk management process. The natural hazard risk assessment process that was undertaken in Tasmania followed NERAG standards – Australia's National Emergency Risk Assessment Guidelines designed to standard risk assessment across scales and hazard (EMA, 2015) - and as such assess risk across 10 societal sectors – shown in Figure 2-2. Additional to these components were the vision and policy objectives detailed earlier in Chapter 2.3.1.1, which provide broader context against which to assess disaster risk and the effectiveness of treatments.

Feedforward processes that the risk foresight provide into component (b) of the framework – dynamic risk assessment – is 'setting context'. This provides the sectors and objectives under which the risk assessment should be conducted, as well as the future scenarios the risk assessment is to consider. The feedback process from risk foresight is to component (c) and provides its 'future impacts'. This involves providing the future conditions against which to test the effectiveness of risk management approaches to ensure emergent risks are incorporated into risk treatment plans and the range of drivers for which treatments need to be implemented for. The scenarios described in Table 2-2 provide risk managers the future context within which they need to prepare risk treatments over the next 30 years, shifting risk profiles away from worst-case to best-case regions.

2.3.3 Dynamic disaster risk assessment

2.3.3.1 Introduction

For this example application of the framework and its concepts, the disaster risk assessment undertaken for heatwave risk in Tasmania is used as a reference case. Although the study had already been completed prior to the foresight exercise, there is still value in highlighting the relevance of foresight approaches within the risk assessment. This section will first describe heatwave risk in the region, along with the results captured within the TSNDRA before showing how foresight could be integrated and some of the potential results that could be obtained if this were done.

Heatwaves / extreme heat, and their physiological impacts have been the biggest contributor to deaths from disasters in Australia over more than the last 100 years (Coates, Haynes, O'Brien, McAneney, & de Oliveira, 2014). Extreme heat events occur due to a large range of factors at different scales, including antecedent soil moisture and climate variability, as well as urban form, evapotranspiration and the topography of regions. Their impacts can be even more complex, as the degree of impact varies significantly with demographics and other social factors, with those considered to be most vulnerable to the impacts of extreme heat being very young, elderly, lower socio-economic groups, outside workers and people with existing illnesses (Luber & McGeehin, 2008). In Tasmania, past significant events have included a heatwave in early 2013, which resulted in a significant increase in medical workloads and ambulance call-outs. Climate change is expected to increase the likelihood and intensity of such events, with high climate change scenarios projecting an increase in summer days with temperature >25°C of 2-3 times compared with the recent past (White et al., 2013).

The Tasmanian State Natural Disaster Risk Assessment (2016) provided the below results for heatwave risk (Figure 2-4). This was done discursively based on a current 'worst case scenario' (note this is different to the scenarios presented in Table 2-2) based on the 2013 heatwave event and saw extreme temperatures over two days in January, as well as record breaking temperatures in several centres, including the capital Hobart, compounded by the temporarily increased population through the large number of tourists (interstate and overseas) visiting Tasmania at this time. Severe consequences were expected in terms of death, injury and illness with high confidence of deaths in excess of five, resulting in a major event in terms of 'consequence'. Also considered significant in terms of consequence was the economic impact, with general impacts considered to be greater than $100million, with particular concern for localised crop loss (stone and berry fruit) and the flow-on impacts to supply-chains, as well as personal health for outside workers.

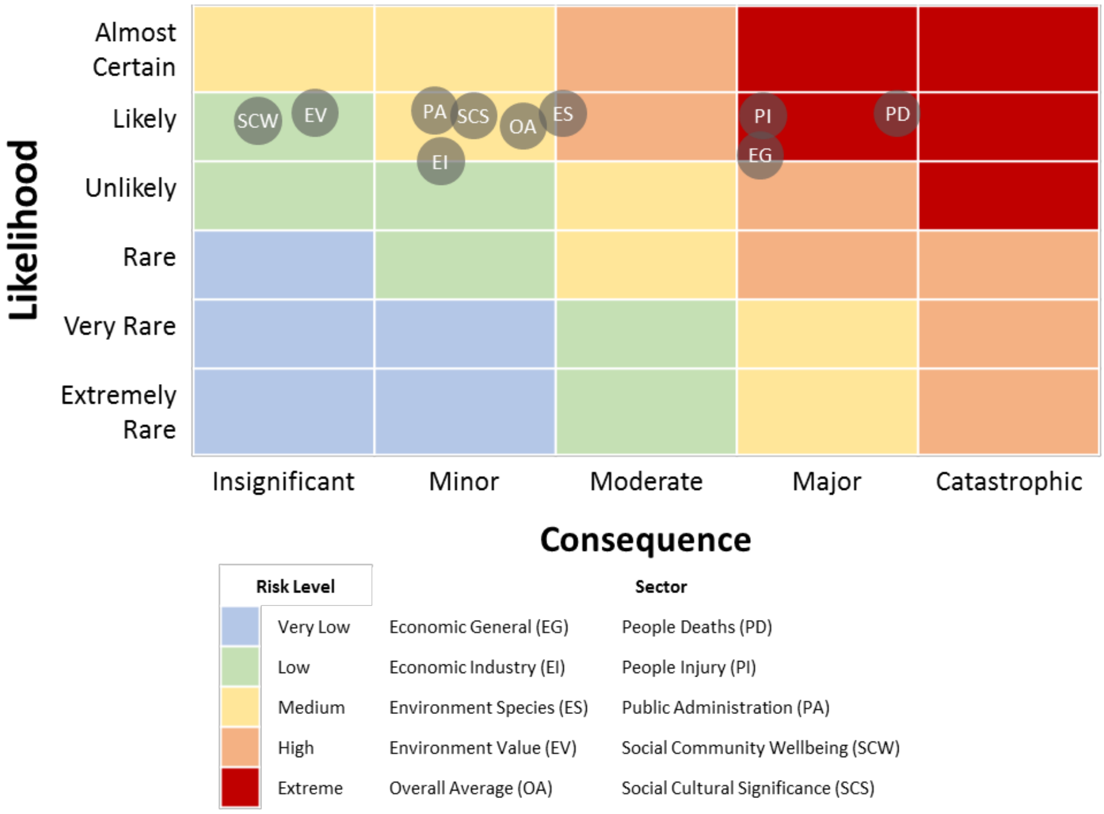

Figure 2-4: Risk of heatwave to sectors in current risk assessment adapted from (White, Remenyi et al. 2016).

2.3.3.2 Application of framework

Using the scenarios developed in risk foresight, future risks can also be considered, with the impact of risk drivers playing out on the heatwave risk assessment process. Scenarios summarised in Table 2 showed a variety of factors evident in each scenario, which were different for each of the scenarios. What is important during scenario analysis is considering both the differences and similarities across drivers for each of the scenarios. When different scenarios result in the same or similar impacts, effort must be placed in managing these are they have been shown to be likely to occur regardless of how the future unfolds. In contrast, for drivers with drastically different implications across scenarios, monitoring factors and triggering actions should be considered within the monitoring and evaluation stage of the framework to track which scenario is closest to reality or which particular driver is influencing risk and hence what action should be implemented. Differences across scenarios leading to significantly different risk implications should also be considered as part of the identifying process for treatments. This is because using the underlying drivers of the scenario with reduced risks is a hugely influential, proactive risk treatment and hence encouraging change aligned with a driver that produces lower risk would significantly reduce future risk.

Table 2-3 summarises some of the implications of the scenarios on each of the sectors from Figure 2-3. A similar matrix approach could be used to frame discussion with stakeholders as to implications across scenarios for the sectors of interest. From Table 2-3, we can see clear potential increases in risk for several sector types, particularly those related to human impacts, such as people deaths and injury (PD and PI), which is related to the continuing aging of Tasmania's population stimulated via migration to Tasmania for retirement and the moving of younger generations to mainland Australia for greater employment opportunities. Differences exist in sectors including social community wellbeing with the role of economic development and community engagement across different elements of society having different individual resilience and access to community support. Also different across sectors include economic sectors (EG and EI) which have variations in impact due to future structure of the economy which sees sectors such as agriculture changing over the scenarios as well as related impacts.

Table 2-3: Future, emergent risk assessment against three developed scenarios

Consequence Sectors	**Scenario 1 – Best Case**	**Scenario 2 – Most Likely**	**Scenario 3 – Worst Case**
Economic General (EG)	Economic impacts from lost work are reduced to the diversification of the economy and increasing service-based economy reducing outside work hours. Exposure however is also higher due to increased economic activity.	Increased impacts and likelihood of risk due to increasing dependence on tourism and agricultural industries - both of which are susceptible to heat events.	Simple economic structure dependent on manual labour sees reduced activity in heatwave conditions. Impacts on infrastructure also increase due to poor maintenance. Black-outs are a concern with industries cutting power supply to maintain residential supply.
Economic Industry (EI)	Adapted agricultural practices adopting real-time monitoring and response reduces impact of heat stress on agricultural losses and flow on impacts to seasonal workers.	Localised sectoral impacts on stone and berry fruit still greatest impact for an economic sector. Climate adaptation measures from industry have balanced out greater impacts.	Decreased adaptation efforts see increased agricultural impacts from heatwave events. Less use of technology sees greater need for manual work with flow-on health and safety issues for outdoor workers. With successive events there may be impact on sectors' ability to bounce back with less available social and financial capital to support recovery.

Consequence Sectors	**Scenario 1 – Best Case**	**Scenario 2 – Most Likely**	**Scenario 3 – Worst Case**
Environment Species (ES)	Unspecified	Unspecified	Unspecified
Environment Value (EV)	Unspecified	Unspecified	Unspecified
People Deaths (PD)	Relative people deaths are reduced (decreased consequence) due to messaging and communication more readily taken up leading to an improved risk perception. Shift in demographics sees decreased vulnerability but higher population growth increases exposure.	Ageing population is exposed to greater impacts of heatwave risk and increased chance of mortality. Increased dependencies on emergency services reduces health responses.	Increased reliance on private transport sees more vulnerable aged populations less able to access public areas of cool and with reduced household spending mortalities increase with less use of air-conditioning.
People Injury (PI)	Matched to 'People Deaths'	Matched to 'People Deaths'	Matched to 'People Deaths'
Public Administration (PA)	Increased individual resilience sees decreased reliance on government support. Well-structured support agencies deploy resources effectively to previously identified areas of need.	Increased pressure on public services during extreme heat events however with large public service resources can be redeployed across agencies to assist in extreme events.	Increased pressure on health and community service providers especially for regional and disadvantaged areas. General reliance on government services is exasperated during heat events with service providers significantly under-resourced.
Social Community Wellbeing (SCW)	Increased levels of economic development and keeping younger generation within the State sees individuals focussed on developing networks for personal and professional growth this leads to greater individual responsibility and improves the concept of shared-responsibility between community and EM agencies. This reduces impacts on SCW with greater local support networks	Those with individual capacity do not suffer any decrease in wellbeing, however those already at the margins are most exposed to these impacts. They also suffer from being less engaged with social service providers.	General decreased well-being of community is exasperated during heatwave events primarily due to electricity costs and reduced household spending capacity.
Social Cultural Significance (SCS)	Unspecified	Unspecified	Unspecified

2.3.3.3 Implications and interactions

For areas where it is not clear what the impact on the sector would be based on the information sourced from Risk Foresight (e.g. Environmental Species and Value and Social Cultural Significance), the feedback focussed on informing the foresight's view (item 4 in Figure 2-1 and described in Table 2-1) can be applied. Sectors considered critical to include, but for which a lack of detail was obtained as part of the initial foresight exercise, can then be revisited to inform the impact across scenarios for the sectors. It is, however, important to ensure that the scenarios remain internally consistent and any new assumptions / changes to the scenarios do not challenge this consistency with contradictory information. If this is the case, underlying concepts may need to be revised to ensure consistency and salience.

Considering feedforwards, risk assessment facilitates the identification of a broad array of options to be considered in risk treatment. As mentioned in Chapter 2.3.2.1, differences between scenarios can be used in this identification process, as they highlight an area for difference in risk to a sector through an emergent factor. Consequently, treatments can be designed to enable consideration of emergence in a more positive manner accounting for future risk.

As outlined in Chapter 2.2.2, foresight driven risk assessments must include three key elements. The first is explicit linkages between drivers identified in the risk foresight process. This is shown here through the use of scenarios against which to assess the risk of different sectors. Each scenario is developed using the identified drivers of risk (population and demographics, community risk understanding and perception, economic development, urbanisation and climate change and our response). The second element was the inclusion of interactions between risk factors and how interactions between them are able to cause emergent risk. These include, for example, the role economic diversification or simplification has on future heatwave risk with impacts emerging that increase the risk to agricultural sectors if climate change is not adapted to, and the impact becoming more significant in cases where there is a higher reliance on agricultural sectors. Similarly, in scenarios without increasing self-reliance and risk understanding, the over-reliance on government response and recovery assistance is challenged in heat events with under-resourced public administration functions unable to keep up with demand, which can result in cascading impacts on public health and economic recovery. Incorporating the ability for decisions being made to influence future risk, the third element identified to be included in foresight driven risk assessments can also be seen in Table 2-3.

This includes the scenario assumptions for the risk driver – 'Climate change and our response', with multiple references related to adaptation to climate change included in the future risk assessment in Table 2-3. Also significant in the risk assessment is the impact of development and transport policy, with Scenario 3 highlighting the increased people death impacts due to increased reliance on private transport, leaving those without or unable to rely on private vehicles unable to access public areas for heat relief services.

2.3.4 Risk treatment

2.3.4.1 Introduction

Risk treatment, as outlined in Chapter 2.2.3, is focussed on the reduction of risks as identified through the previous assessment process. For foresight supported risk treatment, methods of reduction are required for both existing / current and emergent aspects of disaster risk, instead of the traditional focus on current risks and their management. From Chapter 2.2.3, when foresight is incorporated within risk treatments, the critical components to consider are treating both existing and emergent risk, treatments across hazard, exposure and vulnerability components, and considering impacts across the entire risk system, both direct and indirect.

2.3.4.2 Reactive risk treatments

Within the TSNDRA for heatwave, a series of treatments were identified following the assessment process. These treatments, as summarised in Table 2-4, focus only on treating existing risks without the consideration of how the risk is changing. Some of the treatments are proactive in their nature, but they focus on improving understanding of heatwaves and improving community understanding through education. They do not, however, account for the drivers of emergent risk and look to mitigate these factors.

Table 2-4: Heatwave risk treatments identified for current risks (White, Remenyi et al. 2016).

Risk Treatments	
Improve knowledge and understanding of the effect heatwaves coinciding with other hazard events have on the effectiveness and capability of response and recovery capabilities.	Identify facilities that can be used as cool spaces during heatwaves and establish linkages between operators and emergency management organisations.
Include heatwave in existing preparedness programs.	Improve information about electricity demand during heatwaves.
Improve community educational information.	Quantify the effect of heatwaves on vulnerable people.

Risk Treatments

Develop arrangements to identify and communicate with people vulnerable to heat stress.	Incorporate heatwave surge response planning into business continuity planning.
Review community information and warning systems to ensure they cater for heatwave messages.	Develop innovative response models of patient care to improve surge capacity.
Create a stakeholder plan template to aid heatwave preparedness and response in facilities occupied by people vulnerable to heatwaves (e.g. nursing homes).	Exercise heatwave arrangements with a focus on the public administration sector and management of vulnerable people.

2.3.4.3 Application of framework

With the consideration of future risks using scenarios outlined in Chapter 2.3.2, Table 2-5 outlines strategic responses to manage the emergent risk factors across scenarios, as seen from the summary of impacts across scenarios in Table 2-3. These results are a summary of the range of actions that could be implemented to reduce current and emergent heatwave risks. Each treatment identified in Table 2-5 seeks to reduce risks across each of the scenarios for heatwaves in responses to changes in drivers for risk and impacts on different components of risk – hazard, exposure and vulnerability – such as increased green spaces looking to reduce urban heat island impacts, and increased decentralised, renewable energy production and storage to improve energy security and subsequent reliability of air-conditioning (this also contributes to climate mitigation, arguably the most strategic response to future climate risks).

Also shown in Table 2-5 is the risk element (hazard; exposure; and vulnerability) and risk driver (population, demographics and associated vulnerabilities; community understanding and perception of risk; the State's economic development; urbanisation - the split between urban, peri-urban and rural land use and their interactions; and climate change - both its impact and societal responses). As can be seen, some actions act across multiple drivers, however, it is important all of them are considered. More detailed engagement with stakeholders could further add to Table 2-5 through discussions on how each of these actions can have potential indirect impacts on the risk system. An example of such a potential indirect impact is how the increased provision of green spaces increases urban sprawl and fringe development in search of cheaper land prices to account for reduced return on real estate developments. Supporting economic diversification and the service-based economy has the potential to encourage developments in risky areas with respect to bushfire and coastal flooding. This is caused by individuals being less engaged with their communities and less aware of the landscape that surrounds them due to their work habits revolving around a global workforce from a home computer and the increased ability to generate income by working more hours, resulting in less time for community building and volunteer activities. Another potential indirect impact may be the incorporation of heat impacts into building codes, leading to increased costs passed to consumers, with subsequent reduced financial capacity to insure and recover from disaster events.

Table 2-5: Heatwave risk treatments identified for future risks

Options	**Risk Element**	**Risk Driver (Col. 1 Table 2-2)**
Increased green spaces within urban planning strategies	Hazard	Urbanisation
Hospital / respite areas designed to account for tourism factors and changed demographics	Vulnerability	Population, demographics & associated vulnerabilities
Increased decentralised energy production and storage decreasing reliance on ageing electricity infrastructure	Vulnerability	Economic development; Climate change & our response
Financial support to disadvantaged groups to support use of air-conditioning to reduce health impacts	Vulnerability	Population, demographics & associate vulnerabilities; Economic development; Risk understanding & perception
Incorporation of heat impacts into building code for all residential buildings	Vulnerability	Urbanisation; Risk understanding & perception
Future public transport services to include cooling and respite	Exposure	Urbanisation
Financial grant support to agriculturalists implementing technology to manage crop temperatures (e.g. temperature activated misting).	Hazard	Climate change (and our response to it)
Increased training for non-emergency management staff and volunteers to support during heatwave events, reducing pressure on EM workers during co-occurring events	Vulnerability	Population, demographics and associate vulnerabilities
Support economic diversification and service-based economic sectors through communications strategy and service provision (real estate, connectivity)	Exposure	Economic development
Use of future climate agricultural suitability mapping to zone and prioritise development in resilient areas	Exposure	Economic development; Climate change & our response

NB: This table has been developed by the authors as an illustrative application of the framework and how risk treatments can be developed for components of emergent risks.

Following the identification of risk treatments these options need to be evaluated before the implementation of a treatment plan or strategy. Evaluation of treatments needs to be conducted against both current and future risks with the overall plan or strategy devised balance the trade-offs between investing in future resilience and mitigating current risks. It should be noted that many of the risk treatments identified for future risks pose minimal direct costs in comparison to risk treatments for today given their more strategic nature. Foresight supported risk management however enables the identification and evaluation of these options which otherwise may have remained unconceived.

2.3.4.4 Implications and interactions

Within the framework process, these treatments (reactive and proactive) – play an important role in informing other components. Considering the feedforward process, the application of treatments will change the situation and as such may require continuing efforts in risk foresight. The results presented in Table 2-5 therefore can be used to inform and update the risk foresight process as the implemented actions begin to change the baseline and drivers for the foresight process – such as the use of decentralised, renewable energy and storage to increase electricity network resilience during extreme heat events. The foresight process may therefore consider the deployment of new technologies as a driver of future risk and consider how the maintenance and operation of these technologies influence future risk, as well as how the reduction of centralised and gridded networks impacts on ignition likelihoods (Miller et al., 2017) and peak demands (Auffhammer, Baylis, & Hausman, 2017).

The feedback process (item 5 in Figure 2-1) is the monitoring and evaluation process. This is a critical component of any risk management process, allowing for implemented risk treatments to be tested against the risk assessment metrics to assess real-world performance, and ensure implementation is done correctly – existing risk should be decreased following implementation in subsequent risk assessments. Additional to the standard function of monitoring and evaluation, with this framework and the inclusion of dynamic risk assessments and proactive risk treatments, the monitoring and evaluation process can also enable ex-ante assessment of proactive risk treatments, allowing the performance of measures to be tested against time for each scenario. Therefore, the impact of the provision of green spaces can be tested against each scenario to consider how impacts in consequence sectors (Table 2-3) are changed, enabling the treatment (provision of green space) to be evaluated.

As can be seen from Chapter 2.3.4.1 and 2.3.4.2, the framework has enabled the identification of risk treatments designed to mitigate risks, both current and emergent, through reactive and proactive strategies. Table 2-5 in Chapter 2.3.4.2 also shows how the proactive strategies have been designed to act across the elements of risk and impact on their identified drivers from the risk foresight process. Potential indirect and unintended impacts from the implementation of proactive strategies have also been identified and this shows how considering the future can open discussions about the complexity of risk management and enable more thoughtful actions.

2.4 Discussion

The following sections provide discussion on aspects of the framework, how to use it to support more proactive actions within disaster risk management and how to enhance its applicability. Chapter 2.4.1 looks at the application of the framework and its challenges and benefits. Chapter 2.4.2 discusses how it can be used as an engagement mechanism with broader stakeholder groups to enable proactive risk management and using foresight concepts integrated within risk assessment processes to change what can be a prescriptive process to a mechanism for collaboration and strategy development. Chapter 2.4.3 discusses the co-benefits that can be derived from the proactive treatment of disaster risk supported by the framework.

2.4.1 Challenges and benefits of the framework

The framework outlined in this paper is centred on the objective to integrate the benefits of foresight into risk assessment and treatment (risk management) processes. This is done to shift disaster risk assessment from a traditional occupation with exiting risk and reactive treatment, the effectiveness of which is limited due to the wickedness of the disaster risk system. Through the process of understanding the risk system via structured consideration of drivers and factors incorporated within the foresight processes, there are also benefits of increased appreciation of the system, which will support its assessment (through the use of appropriate modelling and/or stakeholder engagement processes) and management, with decreased likelihood of unintended consequences if system dynamics and characteristics have been captured appropriately.

This may see alternate modelling approaches utilised if drivers of future risk highlight particular areas of concern. This could include if the degree of urban sprawl within a region is found to be important, it might be required to incorporate land use modelling such as in van Delden and Hurkens (2011) within the dynamic risk assessment component. Similarly, if economic factors are considered a key vulnerability, such as over dependence on one sector, or shifting industry sectors away from traditional employers this may see particular modelling of economic assumptions using specifically selected models such as in Brandes (2008) and Partridge and Rickman (2010) might be relevant to include. Different stakeholders to be included within qualitative risk assessment processes may also be identified following the foresight process, with stakeholders broader than traditional emergency management or civil protection agencies required (i.e. urban planning, education sectors etc.).

These benefits of the approach, however, must be contrasted against its drawbacks for the utility of the framework to be assessed in an objective fashion. Use of the framework is more resource intensive than other risk assessment processes, with several sessions required to discuss and capture descriptions of the future. It also has the potential to be highly subjective and not entirely reproducible – a common criticism of many scenario processes that rely on stakeholder engagement processes (Alcamo, 2008; van Vuuren et al., 2012).

However, mitigating actions can be put in place to reduce these drawbacks in comparison to the benefits the framework provides in enabling more strategic responses to risk. These include technology focussed methodologies to source information from a variety of stakeholders, such as online community platforms (Accordino, 2013) and e-participation models (Chiabai, Paskaleva, & Lombardi, 2013) that have been shown in respective literature to offer value. Detailed processes for stakeholder identification are also important, and although this does not make the overall process more reproducible, it can be used to ensure representativeness across a wide range of relevant actors and stakeholders in the region under consideration. This increases legitimacy of the process, which could otherwise be challenged on the basis of its subjectivity.

2.4.2 Using risk foresight as an engagement method

Risk foresight, the first component of the framework, allows for broader engagement across agencies to discuss future change and how this impacts on disaster risk. During the engagement phase of the Tasmanian case study considered in this paper, 13 agencies were involved in discussing drivers of risk, uncertainties, and what Tasmania in 2050 could look like. Representatives included not just emergency management agencies with responsibility for hazards in the state, but also representatives from departments responsible for state growth, climate change and planning reform, as well as universities and local government associations – along with specific municipalities. Discussions focussed on future challenges and risk, providing a safe space in which collaboration can occur away from the daily challenges of emergency management and government policy.

The importance of this level of diversity in engagement during the foresight component is also that it creates greater momentum for strategic, proactive risk treatments. The proactive treatments identified in Table 2-5 generally fall outside of the remit of emergency management agencies, and often fall outside the remit of one agency alone. Therefore, in order to design and implement such policy and investment decisions, significant engagement across government (and likely the private sector and community) is required. Using the foresight process, and engaging again throughout subsequent components of the framework, enables these broader stakeholders to contribute and engage with disaster risk assessment and subsequent management actions, which is critical to reducing future risks.

It must be acknowledged that there are challenges in the actual implementation of any strategic action, and historically this has been challenging in the disaster risk management space. However, a framework that explicitly acknowledges the roles of broad drivers of change on disaster risk atleast enables these components to be integrated into the emergency management, and disaster risk sphere. Without this inclusion it is challenging to advocate for alternative measures as their value and effectiveness cannot be shown to disaster risk reduction.

2.4.3 Proactive treatments, co-benefits and mainstreaming

The framework's focus on future risk and managing these proactively by identifying their drivers not only allows for broader engagement across stakeholders (as discussed in Chapter 2.4.2), but also allows for disaster risk reduction options to fit into more strategic, whole-of-government, efforts in an integrated manner. As previously outlined, many of the actions required to proactively reduce risk sit outside of the remit of traditional emergency management agencies and functions – therefore a new approach is needed. Through using the framework and the foresight processes, disaster risk reduction efforts can more easily be integrated into other policy areas. This is clear when issues around decentralised energy generation and storage and increased service-based economic activity are discussed during risk assessment and treatment components of the framework.

These areas are not commonly identified as related to disaster risk reduction, however, if through the framework and interactions between risk assessment and treatment (allowing ex-ante assessment of proactive treatments), it can be shown that there are benefits of these changes to future disaster risk, then this can add to the policy narrative about supporting these policies for other areas in which they are beneficial, such as climate mitigation and economic development. The additional benefits (e.g. reduced expected losses) may also support the broader economic / impact analysis of such policies, contributing to their successful navigation through the policy cycle. Identifying these co-benefits, and viewing disaster risk reduction as a co-benefit of other policy decisions, supports the mainstreaming of disaster risk reduction across government.

This framework enables this understanding to be developed within the disaster risk assessment and treatment stages, not requiring separate assessment of co-benefits. It can also support emergency and disaster risk management agencies to pro-actively engage in the conversation on strategic, whole-of-government actions instead of being consulted towards the end of policy processes to devise reactive responses to risks created. Being on the front foot and understanding the implications of drivers and actions of other agencies on disaster risk is a key outcome of the framework.

2.5 Summary and Conclusions

This paper has proposed a framework to integrate the utility of foresight into risk assessment and treatment processes to support strategic and proactive disaster risk management. This is achieved by highlighting the role and insight provided by foresight activities and how they can provide information to risk assessments, making them future focussed and dynamic, capturing alternate futures. These alternate futures and their associated risks are then used to identify and inform proactive risk treatments, supporting a more holistic and integrated approach to disaster risk reduction. In doing this, the framework provides insight into emergent risks and shows how they can be integrated into standard risk management approaches.

The framework was applied to the Tasmanian State Natural Disaster Risk Assessment, focussing on heatwave risks to identify different plausible futures for the State, along with their impact on heatwave risk, and subsequently proactive treatments accounting for the drivers of future risk. This application of the framework, however, is limited in its scope and more work needs to be done to highlight the range of foresight and risk assessment and treatment processes / techniques that can fall within the application of the framework by applying in different settings.

Future steps will involve enhancing the application of the framework to cater to quantitative risk assessment approaches to better support investment and planning decisions for proactive risk reduction actions. Associated with this, however, is the challenge of modelling capable and appropriate for projecting risk into the future, based on identified drivers and interactions between them. The framework also needs to be enhanced to better incorporate complexities of interlinked hazards and risks and their cascading impacts. Scenarios offer a potentially powerful tool to facilitate this, however, developing them with stakeholders and integrating them into risk assessments (particularly quantitative approaches) remains a challenge. This improvement, however, will be significant in an ever more connected world and complex risk landscape.

2.6 Acknowledgements

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CHAPTER 3

Paper 2: Enhancing the policy relevance of exploratory scenarios: Generic approach and application to disaster risk reduction (Published paper)

Statement of Authorship

Statement of Authorship

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Name of Principal Author (Candidate)	Graeme A Riddell		
Contribution to the Paper	Conceptualisation of methodology, implementation and stakeholder engagement design and practice. Drafting of scenarios. Lead role in drafting manuscript.		
Overall percentage (%)	60		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature	[signature]	Date	15/04/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Signature		Date	15/04/19

Abstract

Exploratory scenarios (i.e. scenarios that question what could happen) have been widely applied to a vast array of complex and uncertain socio-environmental system problems. Despite this fact, they have also been criticised by policy makers for not being relevant to policy processes and assessment. This paper proposes a generic approach to enhance policy relevance in the development of exploratory scenarios. This is carried out by participatory exploration and categorisation of available policy responses and framing of scenarios in terms of challenges to these. An exploration of the factors that make these policies more or less effective is used to develop a narrative for temporal developments in scenario instantiation, in comparison to more generic drivers for change. Within this paper, this process is applied to a case-study exploring the future of natural disaster risk; improving understanding of future uncertainties and subsequently the effectiveness of long-term disaster risk reduction. The case-study application consider bushfire, earthquake, flooding and heatwaves and resulted in five scenarios framed on challenges to resilience and challenges to mitigation for policy makers in Adelaide, Australia.

Keywords: Exploratory scenarios; disaster risk; participation; policy; risk reduction

3.1 Introduction

The approach of developing and integrating exploratory scenarios into planning processes has been applied across many domains, including business (Bradfield et al., 2005; Schwartz, 1996; Wack, 1985a), the environment (Kok & van Delden, 2009; Mahmoud et al., 2009; Nakicenovic & Swart, 2000; Reed et al., 2013; Rounsevell & Metzger, 2010; van Vliet & Kok, 2015), and technology (Kuhlmann, 2001; McDowall & Eames, 2006; Misuraca, Broster, & Centeno, 2012). Its wide application and success are primarily due to the approach's ability to unearth assumptions about the future and test them, in an effort to reframe plausibility, rather than to forecast the future, which is in contrast to other planning methods (Ramirez & Wilkinson, 2014). van Vuuren et al. (2012) highlights three benefits and strengths of the exploratory scenario approach as 1) stimulating imagination and creativity while considering the future, 2) having the capacity to deal with inherent uncertainties and value judgements associated with unstructured problems and 3) helping to identify broad response categories within a certain context in an attempt to develop robust policies. However, despite these benefits, the success of the exploratory scenario approach in supporting policy processes has at times been questioned due to its perceived inability to explore the uncertain drivers affecting policy assessment and development, due to a broadness that makes it difficult to use it to support policy development (Bryson et al., 2010; Parker et al., 2015).

A review of several governmental organisations across Europe, and their interaction with scenarios, found policy-makers thought that the use of exploratory scenarios was not asking the correct questions, and that scenarios were not framed in an interesting and relevant way to policy-makers (Bryson et al., 2010). Similarly, (van Vuuren et al., 2012)note that exploratory scenarios often lack focus, particularly in relation to specific policy options. Common criticisms of the exploratory scenario approach by decision and policy-makers include their subjectivity, lack of targeting policy questions, inability to be included in a trade-off analysis for social and policy objectives, and overall inability to be connected to decision making processes (Bryson et al., 2010; Parker et al., 2015; Parson, 2008).

The lack of perceived policy relevance of exploratory scenarios, as noted above, may stem from their emphasis on exploring, and subsequent framing, of futures on system drivers and uncertainties, and temporal developments focusing on uncertain drivers. This is in contrast to placing the emphasis on available policy options / responses and their effectiveness. The development of shared socio-economic pathways (SSPs) (O'Neill et al., 2017; O'Neill et al.,

2014) provided some progress towards bridging the gap between exploring future drivers, and considering policy responses, by applying normative, outcome-based, axes to the exploration of uncertain drivers. This approach to the development of the SSPs enabled the exploration of uncertainties to be framed in relation to challenges to policies designed to combat climate change via either mitigation or adaptation. However, this isolated example did not offer a generic methodology for considering policy response frames and exploration of the future with the inclusion of local stakeholders working within the relevant policy realm.

An additional contributor to the perceived lack of policy relevance can also be attributed to the manner in which scenario narratives have traditionally been constructed. Aside from scenario framing on uncertainties, the construction of the scenario narratives themselves also typically considers developments across commonly accepted uncertain factors (society, technology, economics, environment and politics, also known as STEEP) (Bradfield et al., 2005; Rounsevell & Metzger, 2010). This is in contrast to factors directly relevant to the effectiveness of possible policy responses.

For improved relevance to policy processes, the consideration of these two elements of developing exploratory scenarios, framing and uncertain narrative factors, should also be driven by an embedded participatory process for scenario development (Kok, Patel, et al., 2006; Rotmans et al., 2000). Given this, the primary objective of this paper is to develop and demonstrate a generic approach for enhancing the policy relevance of exploratory scenarios. This builds on similar efforts, following critical reviews, of the application of exploratory scenarios in public policy areas, with efforts focussing on working with limited time and diverse stakeholders (Cairns, Wright, & Fairbrother, 2016; Cairns, Wright, Fairbrother, & Phillips, 2017; Pincombe, Blunden, Pincombe, & Dexter, 2013), improving links between long-term implications and short-term actions (Hughes, 2013), and orientation processes for scenario based strategy development (F. A. O'Brien & Meadows, 2013).

The methodology proposed to achieve improved policy relevance incorporates 1) framing scenarios in terms of policy responses, 2) exploring their temporal development in terms of factors relevant to the policy's effectiveness and 3) achieving 1) and 2) via an embedded participatory process in the policy-oriented scenario development process (see Chapter 3.2 for methodology outline). The proposed approach is applied to a case-study considering long-term natural disaster risk reduction planning for Adelaide, South Australia (Chapter 3.3), which is a relevant issue to scope with exploratory scenarios, given the complexities and uncertainties associated with understanding and reducing disaster risk (Donner & Rodríguez, 2008; Global Facility for Disaster Reduction and Global Facility for Disaster Reduction and Recovery, 2016; McGranahan, Balk, & Anderson, 2007; Newman et al., 2017). A discussion on the approach's advantages and comments on the applicability of the policy relevant scenarios developed using the approach to broader contexts is given in Chapter 3.4, and conclusions are provided in Chapter 3.5.

3.2 An Approach for Enhancing the Policy Relevance of Exploratory Scenarios

3.2.1 Overview

It is generally acknowledged that there is no overarching process for developing scenarios due to context specific issues and constraints such as time, budget and stakeholder composition (Ramirez & Wilkinson, 2016). However, exploratory scenario processes have some common elements (Figure 3-1, left panel), including the identification of the focal question (Step 1) and key drivers (Step 2a), determination of the scenario logic (Step 3a) and scenario assumptions (Step 4a) and an assessment of outcomes (Step 5). The approach introduced in this paper includes these elements, where Steps 2a to 4a are modified in order to increase the policy relevance of the resulting scenarios (Figure 3-1, right panel). In particular, the proposed approach focuses on changes to the scenario logic or framing (Steps 2b and 3b), and on the narrative development using scenario/policy response dependent factors (Step 4b). These adaptations fit within many common scenario processes [e.g. Alcamo (2008); Kok and van Vliet (2011); Reed et al. (2013); Schwartz (1996); van Vliet and Kok (2015)

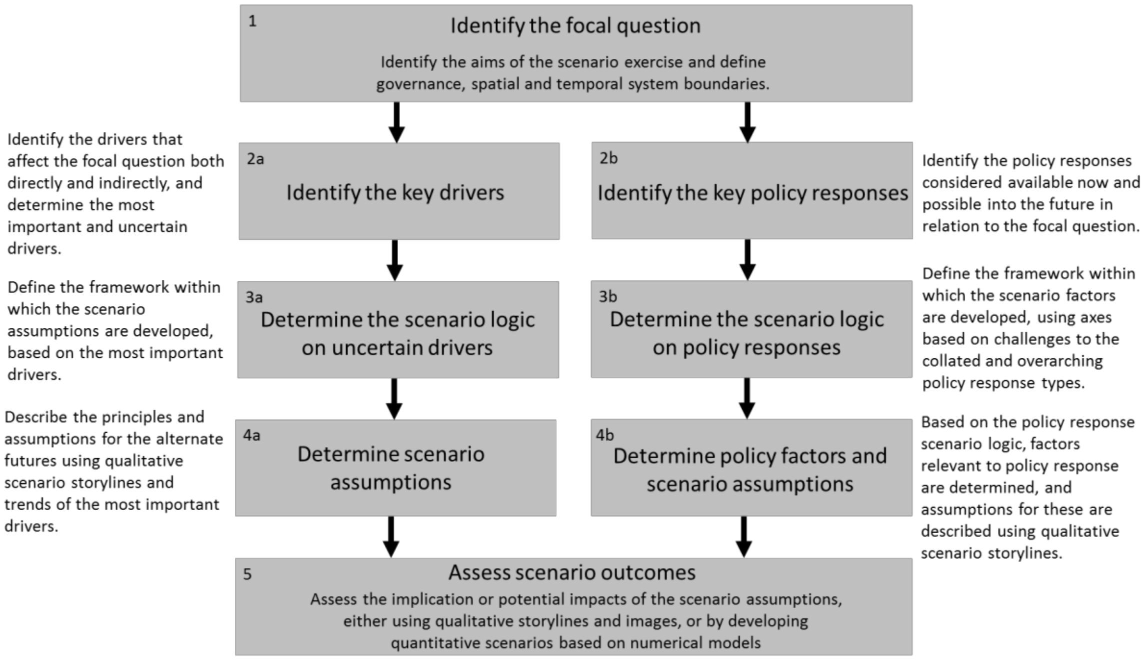

Figure 3-1: Stages for scenario development, and stages for enhanced policy relevance adapted from (Metzger, Rounsevell, van den Heiligenberg, Pérez-Soba, & Hardiman, 2010). The left panel highlights the general steps for scenario development, the right panel with Steps 2b to 4b, show the steps for enhanced policy relevance. Steps 1 and 5 are common to both approaches.

As discussed, the embedment of participatory processes is central to the modified approaches to scenario framing and narrative development introduced in this paper. There are many advantages of including stakeholder knowledge in the development of exploratory scenarios, but most importantly it has been shown to ensure relevance to local decision making (Walz et al., 2007). When scenarios are designed through participatory processes (including those directly involved in the region of interest and decision making processes), a number of benefits result in contrast to the use of expert-driven scenarios. Such benefits are the incorporation of local knowledge that external experts may not possess, enhancement of the internal consistency, logic and validity of scenarios, and an increase in trust and acceptance when scenarios are used in planning processes (Luz, 2000; Reed et al., 2013; Tress & Tress, 2003; Walz et al., 2007).

For complex problems, defined as multi-problem, multi-dimensional and multi-scale (van Asselt, 2000), participatory processes can also add significant value due to their ability to engage with different perspectives, understanding of causal relationships, and mental models (Dewulf, Craps, Bouwen, Taillieu, & Pahl-Wostl, 2005). Using exploratory scenarios developed with stakeholder input also raises the level of creativity in considering the future, leading to increased understanding of subtleties within the influence of social, environmental and economic drivers (Kok & van Vliet, 2011). Participatory processes can, under certain socio-economic and institutional arrangements, also improve the quality, legitimacy and effectiveness of any implemented management options, which is of clear value when considering the exploration of future developments orientated towards decision making and policy processes (Maskrey, Mount, Thorne, & Dryden, 2016; Roth & Winnubst, 2014; Sherman & Ford, 2014).

The following sections provide details on the proposed changes to the scenario logic or framing (Chapter 3.2.2) and narrative development using scenario/policy response dependent factors (Chapter 3.2.3), including the relevant theoretical background and motivation. Details of how participatory processes are embedded within these steps are also given.

3.2.2 Policy response scoping and framing – Steps 2 and 3 (Figure 3-1)

3.2.2.1 Background and motivation

The framing of scenarios is a critical component, as it provides the initial conditions and boundaries between alternate but equally plausible views of the future. Although scenarios do not require a predefined framing or logic, they often include such over-arching structures for ease of communication and clarity for both stakeholders involved in the scenario development process and the broader community (Ramirez & Wilkinson, 2014; van Asselt, 2012).

Commonly, a 2×2 matrix is applied as the scenario frame, as mentioned in the Introduction with reference to the STEEP factors. This frame places two key driving forces for the future on the vertical and horizontal axes, and is commonly referred to as a ‘standard’ by practitioners and academics (van Asselt, 2012). A study of scenarios commissioned by Natural England showed that of the 35 scenario studies considered, 24 were developed using the 2×2 matrix formulation (Natural Natural England, 2009). The 2×2 approach can clarify the communication of uncertainty, especially to those not involved in the scenario development (Ramirez & Wilkinson, 2014), however, it forces polarizing outcomes for each key driver, allowing implausibly ‘extreme’ futures to be considered (Randall, 1997).

Recent efforts to improve the link between decision making and exploratory scenarios has seen more ‘normative’ frames used for scenario development, while still including the concept of intuitive logics, ‘forward-chaining of causality’ approach. This forward-chaining approach looks to see how developments occur based on assumptions of causality and system understanding, and in the intuitive logics approach this sees exploratory scenarios developed based on considering how different assumptions unfold throughout the system beginning from the 'present. By applying normative frames to this forward-chaining, the outcome is already determined, often extreme 'good' or 'bad' futures, and developments are considered as to how those extreme futures are realised. An example of this is Cairns et al. (2016), combining the benefits of intuitive logics forward-chaining approach to developing scenarios with the 'backwards logic' method engaging stakeholders in constructing extreme scenarios of the future. Similar examples include de Bruin, Kok, and Hoogstra-Klein (2017) and Vervoort et al. (2014). These concepts also align with the 'incasting' work of Dator and the Manoa School (Dator, 2009), considering pre-defined futures and deductively reasoning alternative futures scenarios for the research objective. These approaches and emphasis on outcomes have been shown to provide a better linkage between scenario projects and planning, and decision making.

A further adaptation from this was offered in the recently published Shared Socio-Economic Pathways (SSPs), developed as a tool "for exploring the long-term consequences of anthropogenic climate change and available response options" (Kriegler et al., 2012), which are defined as, "reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or policies" (O'Neill et al., 2014). Instead of placing the outcomes of driving forces as the axes to frame scenarios, challenges to mitigation and adaptation (seen as approaches, or broad policy categories, to handle climate change) are placed there. This provided a framing of future socio-economic developments as to whether or not climate change mitigation or adaptation policies would be more or less challenging, a normative frame of policy options not drivers.

The advantage of framing the future with challenges to policy options, in comparison to key drivers or uncertainties, is that it more easily allows the incorporation of various uncertainties in each exploratory scenario and does not constrain the factors of uncertainty or make them the same across each scenario. This approach goes towards addressing the notion that framing on two uncertainties and their states limits the exploration space and the consequent ability to represent multiple relevant factors, but the approach can also maintain the benefits of a 2×2 framed scenario approach, which is considered to be representative of the ease with which scenarios can be understood and communicated (Lord, Helfgott, & Vervoort, 2016; Parker et al., 2015). Also, for policy impact assessment, the scenarios encapsulate future conditions specifically included to test the effectiveness of the policy alternatives, and not only scope the future based on what are considered the main drivers for general change. This is significant in terms of the ability of exploratory scenarios to be used for policy 'stress-testing' or the development of policies that are effective under relevant difficult future conditions and can subsequently be considered as robust (Maier et al., 2016). Additional to these benefits is that the scenarios can enable and build strategic capacity in policy makers for operating in difficult futures and also allow for an understanding of how to address these challenges, and catalyse actions against these futures, focusing more on the vision of a future with low challenges for policy effectiveness and implementation.

The proposed approach to generalising a policy-oriented scenario building approach is presented in the next sub-section. Balancing the exploratory capabilities of using drivers with evident policy-relevance is critical, as is including the input of relevant stakeholders, in contrast to expert-driven processes. The selection of axes is also critical to the value of the process when applying it to problem domains other than the challenge of climate change, where mitigation of greenhouse gas emissions and adaptation to the effects of climate change are considered the standard approaches to dealing with the problem under consideration (Watson, Zinyowera, & Moss, 1996).

3.2.2.2 Proposed approach

In the proposed approach for scoping and framing, Steps 2b and 3b - Figure 3-1, the focus on framing is on challenges to a policy response, identifying alternate futures where policies are more or less effective. To apply this broadly to policy questions, the problem needs to be scoped considering key challenges and the possible policy responses now and into the future. A participatory process including a combination of questionnaires, semi-structured interviews and workshops, ensuring a variety of communication and thought styles are incorporated, is proposed to understand the overarching challenge for which the scenario process has been initiated. Although it is difficult to prescribe exact details on the participatory processes and wording used in these processes, given they should be adapted to specific participants, the initial scoping phase should consider the uncertainties and drivers of change for the specific problem. This should then be used to open a dialogue on relevant policy responses available now and into the future that may form a portfolio of actions to influence the challenges considered. With a broad stakeholder group providing individual proposals, this enables the scenario team to better understand not only the challenges, but also the response options available.

The responses then need to be collated into similar, but disjoint, response categories. For example, for government budget reform, this may be taxation changes and efficiency drives, for schooling, this may be increased school autonomy and increased standardization and testing. The SSPs considered mitigation and adaptation as the responses to climate change, although these were accepted expert derived responses to the challenges based on the IPCC's Second Assessment Report in 1995. There is also no restriction to only two dimensions, with multiple policy response groups being displayed in multiple dimensions, however, the benefits of the 2×2 approach in terms of communication may be soon lost if dimensionality is increased (Lord et al., 2016; Ramirez & Wilkinson, 2014). There are also several methodologies for categorization in a participatory setting and group decision making, with OECD (2001); Tippett, Handley, and Ravetz (2007); and World World Bank (1996) all providing insights into participatory methods and tools to assist. The above process results in a scenario space framed by challenges to each policy response, as shown in Figure 2, with the axes linked to increasing challenges.

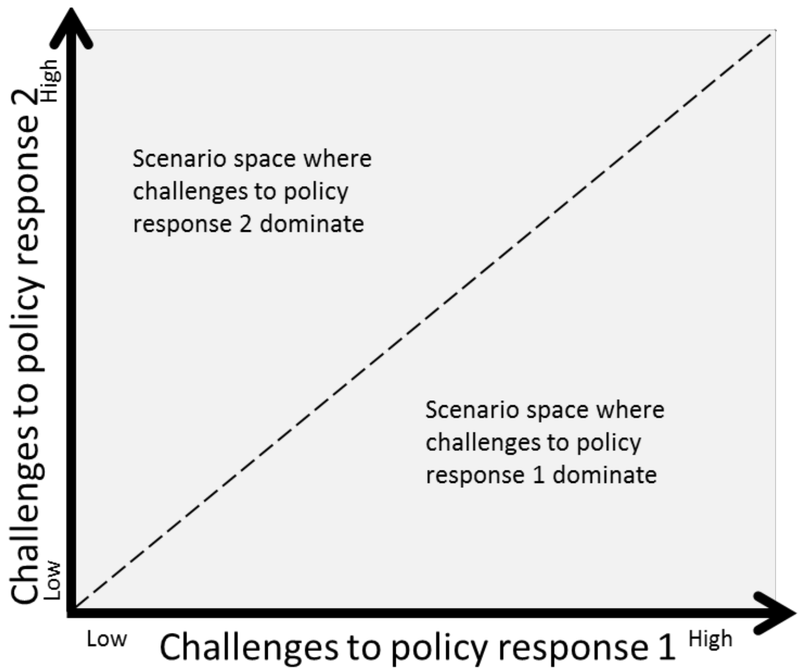

Figure 3-2: Scenario framing that places challenges to policy options on the axis to frame the scenario regions

3.2.3 Development of policy response factors and timelines – Step 4 (Figure 3-1)

3.2.3.1 Background and motivation

Following the choice of framing axes, scenario narratives are commonly developed using intuition, brainstorming, or expert elicitation (Bradfield et al., 2005). Regardless of the specific technique used, the process results in a series of qualitative assumptions about drivers of change, often framed as STEEP factors, in the context of the scenario framing or scenario logic (Rounsevell & Metzger, 2010). However, with the traditional focus on considering alternative assumptions for drivers, as opposed to the approach proposed in this paper, it has been shown that developed exploratory scenarios commonly fall into ‘scenario families’, a set of scenarios that share a similar storyline (de Vries & Petersen, 2009). van Vuuren et al. (2012) found six consistent scenario families across many global environmental scenarios (economic optimism/conventional markets, reformed markets, global sustainable development, regional competition/regional markets, regional sustainable development, business as usual/intermediate), demonstrating a lack of diversity, which could contribute to the concerns of scenarios not targeting the correct questions.

These reviewed scenario approaches also use common factors across each scenario, varying the assumptions to obtain extreme differences between the scenarios developed. This is intended to create the largest plausibility space within the set of drivers included. However, this may make them less tangible for policy analysis, especially if the factors varied are not critical to the effectiveness of a solution or policy. For constructing scenarios more targeted to policy options and assessment processes, consideration should be given to how these factors connect to the policy questions being asked.

Exploratory scenarios can also be developed without the consideration of specific factors, and instead created through discursive processes to detail narratives (Vervoort et al., 2014; Volkery, Ribeiro, Henrichs, & Hoogeveen, 2008). This process has significant benefits in terms of creating rich narratives, social learning, and consensus building between the parties involved in the process (Caves, Bodner, Simms, Fisher, & Robertson, 2013; Pahl-Wostl et al., 2007; Patel, Kok, & Rothman, 2007; Reed et al., 2013). This more discursive process, however, has been criticised in terms of its subjectivity, reliance on individuals involved, and the fact that those outside of the process have less of an understanding of the underlying assumptions made and, as such, find it more difficult to link to future policy assessments outside of the initial scenario process.

Therefore, there is a need for scenarios that clearly highlight the process in which they have been developed, to show the underlying assumptions and be valuable to future policy assessments. There is also a need for the scenarios’ assumptions to be clearly linked to specific policy responses, not more generic drivers for change, developing specific and policy relevant scenarios. The proposed approach looks at how to determine the relevant factors for each scenario without the need for the factors to be specific to scenarios, and therefore instead of causing the most diversity in future scenarios, this focus causes the most extreme cases for policy effectiveness to be captured in the scenarios.

3.2.3.2 Proposed methodology

With the scenarios framed, the factors relevant to each of these responses are considered as the building blocks of each scenario, in comparison to generic factors of development (STEEP), Step 4b – Figure 3-1. These factors are elicited by posing questions to stakeholders regarding their opinion as to what factors are most relevant to the framing of policy options and what makes them more or less difficult. The structure of these questions is dependent on the options under consideration, however, the questions should be designed to deeply explore the policy options and elicit the expert knowledge of the stakeholders.

For each policy response axis, relevant factors should be discussed by participants, resulting in a decision on core factors relevant to the effectiveness of that policy response. For example, if increased income taxation was the policy response, relevant factors may include economic activities of the region of interest and societal values on wealth distribution, versus a policy response of efficiency drivers, which may include factors of labour reform and technological change. The chosen factors are then used as the building blocks for the relevant scenarios. Factors relevant to policy option 1 would be used for all scenarios in region 1, and factors relevant to policy option 2 would be used for all scenarios in region 2 of Figure 3-2. For scenarios that lay on the interface between region 1 and 2, a combination of factors from both policy responses would be used.

As outlined, this construction process is in contrast to the construction process discussed in O'Neill et al. (2017) and many other scenario processes (e.g. Carlsen, Dreborg, and Wikman-Svahn (2013); Kok, Rothman, and Patel (2006); Lord et al. (2016)), which use consistent factors across all scenarios as building blocks, as this encourages different factors for scenario regions based on the policy responses considered. As such, by allowing stakeholders to build scenarios on the factors of each policy option, the workshop discussion is intended to relate more to the expertise and perception of stakeholders and therefore provide guidance to the development of valuable, policy relevant exploratory scenarios. Using factors relevant to each policy response helps overcome a challenge of many participatory scenario processes, where the development of socio-economic scenarios can become difficult, as participants may not have the expert knowledge to comment on areas outside of their policy expertise, such as economic, and demographic changes, or technological advances that are plausible in a region (Kok et al., 2014). This is less of a challenge with expert driven approaches (see SRES (Nakicenovic & Swart, 2000), Millenium Ecosystem Millennium Ecosystem Assessment

(2005), and SSPs (O'Neill et al., 2014)), as those involved are chosen due to their knowledge in areas of importance.

By developing future scenarios around the question "what would make their job easier or harder?", policy makers can more easily interact with exploring plausible futures, especially if they are not familiar with working at a strategic level. This discussion of policy relevant factors also allows the construction process to add value outside of creating scenario narratives. This is because the suggested scenario development process can enable learning and unlearning, along with a deeper fundamental understanding of the problem(s) (Schwartz, 1996; Wack, 1985b; Wilkinson & Eidinow, 2008). We propose that participatory exploration of the factors that become the building blocks of individual scenarios can provide these benefits and allow the scenarios to be more tangible to policy focussed participants.

3.3 Natural Disaster Risk Reduction Case-Study

To demonstrate the application of the proposed methodology, it was integrated into a scenario development process within a larger exploratory scenario approach and modelling effort to support natural disaster risk reduction planning for the Greater Adelaide region in South Australia, Australia. This case-study is designed to test the utility of the methodology for developing policy-relevant exploratory scenarios with regard to its ability to 1) frame scenarios in a relevant way for policy makers and, 2) target scenarios to specific policy options and assessment processes. The applicability of the proposed approach to natural disaster risk reduction is discussed in Chapter 3.3.1, followed by details of the specific case-study considered in Chapter 3.3.2. The application of the proposed approach to the case-study is detailed in Chapter 3.3.3, with results and discussion provided in Chapter 3.3.4.

3.3.1 Applicability of proposed approach to natural disaster risk reduction

The impacts of natural disasters globally are significant and growing. Comparing ten year averages, the annual total damage rose from $US14 billion for the period 1976-1985 to more than US$140 billion for the period 2005 – 2014 (Global Facility for Disaster Reduction and Global Facility for Disaster Reduction and Recovery, 2016). Several recent global agreements are, however, placing an emphasis on reducing these impacts. For example, the Sendai Framework for Disaster Risk Reduction 2015 - 2030 (UNISDR, 2015), along with the Paris Agreement of the United Nations Framework Convention on Climate Change (United United Nations, 2015aa), and the Sustainable Development Goals (United United Nations, 2015bb), are providing emphasis on reducing disaster impacts globally through disaster risk reduction activities. Disaster risk reduction is defined as,

> *"…the concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment and improved preparedness for adverse events" (United United Nations, 2009).*

There is also consensus that risk reduction efforts are cost effective in comparison to response and recovery with a recent review of benefit-cost ratios across multiple hazards and geographic locations showing a range of 1.3 to a staggering 1800 (Shreve & Kelman, 2014).

The exploration of futures in disaster risk and its subsequent reduction is therefore of critical importance, as the complexities and uncertainties within the dynamic relationships between climate change, population growth, economic change and urbanisation are significant. Natural disaster risk is a combination of the natural hazard, exposure and vulnerability. As a result, when considering future disaster risk and planning to reduce risk, the uncertainty and complexity of each factor must be considered. Influencing factors on the three components of risk include political decisions, economic development, technological advancement, and demographic changes coupled with a changing climate, which is also influenced by socio-economic factors (Bernknopf, Hearn, Wein, & Strong, 2007; de Moel & Aerts, 2011; Koks et al., 2015). All of these must be included when considering long-term disaster risk reduction planning.

Engaging with this level of uncertainty in the complex system of disaster risk is problematic for traditional planning processes, and as such, understanding the future dynamics of disaster risk and subsequently developing risk reduction plans can benefit from the use of exploratory scenarios and scenario planning (Maier et al., 2016; Zurek & Henrichs, 2007). However, given the significant impacts of disasters globally, as previously mentioned, there is an overarching need to better understand and subsequently reduce risk in the context of various policy responses to enable action. Therefore, there is added value in exploratory scenarios designed to consider the future of disaster risk to be directly linked with available policy responses. The following section will outline the process applied to the case-study following the steps in Figure 3-1.

3.3.2 Application of proposed approach

3.3.2.1 Step 1: Focal question and system boundaries

The case-study region is the Greater Adelaide region of South Australia (SA), a geographical region of around 1,800 km^2, and a population of 1.29 million. The study involved planning for the risk from bushfires, floods, earthquakes, heatwaves and coastal inundation for an extended planning period from the current year to 2050. The initiator within SA was the SA Fire and Emergency Commissioner (SAFECOM), who identified the State Mitigation Advisory Group (SMAG), along with other relevant state government organisations and non-government organisations (NGOs), as the critical stakeholders to be involved in the process. The overall process had the objective to improve the ability of policy makers to make more strategic and less responsive decisions in relation to minimising the likelihood and impact of natural hazards. This objective was based on a recent emphasis on considering multiple hazards and long term challenges from socio-economic development and climate change, highlighted by investigations post major events in Australia, including the 2009 Victorian Bushfires Royal Commission (2009 Victorian Bushfires Royal Commission, 2010) and the Commission of Inquiry into the 2010–11 Queensland floods (Queensland Floods Commission of Inquiry, 2012).

3.3.2.2 Step 2b and 3b: Policy responses and scenario logic – mitigation and resilience

An initial participatory scoping process was undertaken with the stakeholder group by the scenario team to explore and consider the framing of scenarios. The first stage of participatory work involved preparatory questionnaires and semi-structured interviews between members of the scenario team and stakeholders, followed by a workshop with the full stakeholder group and a day of exploring the problem. The emphasis of this engagement process was on understanding more about disaster risk reduction in the region, the policy options available, and how their effectiveness was judged. There was also emphasis on considering how both the currently available policy options would change, and what would impact their effectiveness into the future.

The participatory activities were organised to respond to the following three questions focused on the policy processes that stakeholders were involved in:

> *What are the possible risk reduction measures now and into the future for Greater Adelaide?*

What do you consider to be the main drivers for change and sources of uncertainty when considering the development of Greater Adelaide?

What indicators do you consider for policy assessment across risk, economic, social and environmental factors?

During the participatory sessions, meta-plans (individual responses to the questions grouped into similar responses by participants) (Schnelle, 1979), were developed independently by several break-out groups, which were then collated by the scenario team. Table 3-1 shows the most common responses by participants for question 1, clustered into themes using the meta-planning exercise and adapted by the scenario team after the session, placing greater emphasis on all hazards and risk reduction prior to the event, not response post event.

The responses, summarised in Table 3-1, allowed the scenario team to develop a greater understanding of the policy options and challenges for the case-study region. Based on discussions throughout the first stage of participatory work and the options highlighted in Table 3-1, two main themes arose, which were then used as the framing axes. These were mitigation orientated options and resilience orientated options. The split between these is indicated by (M) / (R) in Table 3-1. The division between these two option categories arose from discussions around risk reduction options that can be implemented by government (top-down, and considered as mitigation oriented) or are more community driven (bottom-up, and considered as resilience oriented). Examples of the former (mitigation orientated) include the construction of flood protection works; improving building code legislation; land management (e.g. planned burns for bushfires); or land use planning, restricting the exposure of assets to hazards, can be classified as mitigation-based approaches. In contrast, examples of the latter (resilience orientated) include whether risk is being reduced due to an improvement in society's ability to deal with a particular hazard, hence reducing their vulnerability. These two grouped policy responses were subsequently agreed to be the axis factors for the framed scenarios, with challenges to resilience orientated responses placed on the y-axis and challenges to mitigation orientated responses on the x-axis.

Table 3-1: Clustered risk reduction options following policy scoping process.

Clustered Theme	**Top 3 Risk Reduction Options**		
Building Codes	Increasing recurrence intervals for all hazards in code	Inclusion of hazard resistance for hazards not considered	Specific strengthening for buildings of community value *(M)*

	(M)	*(M)*	
Land Management	Planned burning, reduction of fuel load *(M)*	Improved enforcement mechanisms (e.g. illegal vegetation clearance) *(M)*	Land reclamations *(M)*
Community Based	Arson reductions programs *(R)*	Integration of hazard programs in school curriculum *(R)*	Increase community awareness (risks, safety strategies) *(R)*
Structural	Building hardening (e.g. for residential infrastructure) *(M)*	Increased assistance for owners of buildings in hazard areas to retrofit buildings *(R)*	Structural upgrade of legacy buildings not currently code compliant *(M)*
Circular Learning *(Event to planning)*	Agreement on residual risk for government and communities *(R)*	Implementation of business continuity plans *(R)*	Structured framework for lessons learnt *(R)*
Institutional Change	Establishment of multi-hazard agencies *(M)*	Tougher legislative requirements for building in higher risk zones *(M)*	Adaptive policies (e.g. thresholds) for decision making (linking with adaption to climate change) *(R)*
Land Use Planning	Building exclusion areas in e.g. floodplains / high risk bushfire areas *(M)*	Ensuring development in hazard prone areas are compliant to highest codes *(M)*	Increase access to information for property owners *(R)*
Legislation	Regulatory requirements to consider natural hazard risk in planning *(M)*	Provide hazard leaders/control agencies with greater powers to question developments *(M)*	Resource planning to mitigate response/recovery costs and impacts *(M)*
Financial Instruments	Effective cost/risk assessment *(M) / (R)*	Use of post-event levies to fund mitigation *(M)*	Funding to support institutional change (increased integration, coordination and planning) *(R)*

3.3.2.3 Step 4b: Policy relevant factors and scenario assumptions – exploring resilience and mitigation into the future

With the scenario logic agreed upon (Steps 2b and 3b, Figure 3-1), a second workshop was held with the same stakeholder group. The specific aim of this workshop was to develop qualitative, exploratory scenarios capable of exploring plausible futures for Greater Adelaide (Step 4b, Figure 3-1). These futures were designed to consider the effectiveness of common risk reduction strategies falling under the categories of resilience and mitigation. The workshop was planned around a series of preparatory presentations, introducing the concepts of exploratory scenarios, and break-out sessions to participants. Five scenarios were to be developed, including:

- one future for Greater Adelaide where it was simple to design and implement mitigation strategies and develop societal resilience, which was considered the vision for the region;
- one extreme future that challenged both resilience and mitigation strategies;
- two intermediate futures that challenged either resilience or mitigation to a greater degree; and
- one central future with moderate challenges to both resilience and mitigation.

To develop the scenarios on policy relevant factors, the first task was to explore the factors relevant to resilience and mitigation. Participants were asked to offer individual responses to the questions, *what factors are relevant when creating and encouraging resilience to disaster risk?* and, *what factors are relevant when designing and/or implementing mitigation policies to disaster risk?* A facilitated conversation also questioned what would make these factors more or less difficult going into the future. Individual responses were then clustered and, across breakout groups, factors relevant to resilience and mitigation were further refined to five factors that would be used for the participatory scenario development, Table 3-2.

Table 3-2: Relevant factors and their descriptions for policy response themes resilience and mitigation.

Policy Theme	**Factor**	**Description**
Resilience	Infrastructure	Network design for elasticity, adaptability and redundancy.
	Understanding and knowledge of hazard/risk	Community understanding of the level of hazard they are exposed to.
	Social cohesion	Structure of society that encourages neighbourhood interactions and community awareness.
	Resources for action	Availability of community level grants, seed funding and training for bottom up solutions.
	Efficacious policy	Policies that are effective in stimulating the required outputs not producing maladaptation impacts.
Mitigation	Data and knowledge	Availability of information and data to support the design of effective responses.
	Governance structures	Governance structures that allow funding for mitigation activities.
	Holistic policy	Policies that cover the entire risk triangle of hazard, exposure and vulnerability, from preparedness to recovery.

Institutional culture and perception	Community confidence in governmental institutes' ability to effectively reduce risk, along with a culture of mitigating risk (as opposed to an emphasis on response).
Cost benefit considerations	How to deal with growing costs of mitigation for increasingly high magnitude hazards.

Using the factors of resilience and mitigation, participants discussed assumptions for developments in each of these factors in terms of the scenario's frame (whether challenges to resilience or mitigation were high or low). In break-out groups for each scenario, narratives were noted out in terms of each factor relevant to the scenario's frame, and timelines were created, noting particular developments for each factor. An example selection of these assumptions and developments is shown in Figure 3-3, showing the timeline period of 2015 – 2025 for challenges to resilience across three factors, infrastructure, understanding and knowledge of hazard/risk and social cohesion. Groups were then moved on to modify and refine other scenarios to continue their development, where conditions were placed on the stakeholders to not change the scenario narrative or timeline, but only question why the challenge would happen, and what would happen next. This ensured that scenarios were developed and enriched with new perspectives, instead of being challenged and rewritten by each new group.

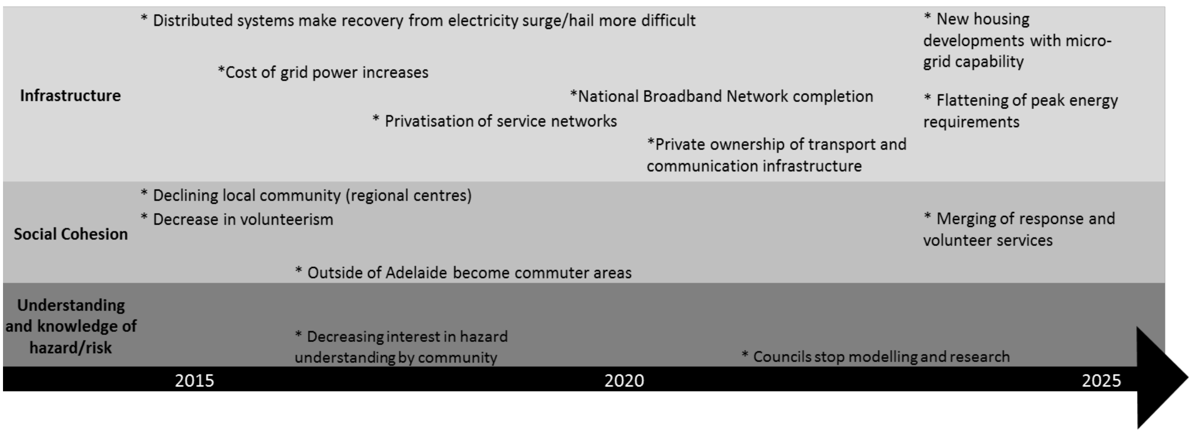

Figure 3-3: Timeline for the scenario considered as challenging resilience from 2015 to 2025. A selection of assumptions across three factors determined as relevant to resilience are shown; including infrastructure, social cohesion and an understanding and knowledge of hazard / risk.

This time-lining process of factors, followed by more detailed narrative writing by the scenario team, resulted in five fully documented scenarios considering disaster risk and reduction potential in Greater Adelaide. The scenarios are summarised in Table 3-3 and shown in their framing in Figure 3-5, with the full scenarios documented in Appendix C.

Table 3-3: Scenario summaries.

Scenario	**Frame**	**Summary**
Silicon Hills	Low challenges to both mitigation and resilience	*Greater Adelaide transitions towards a well-balanced technology focussed economy, driven by highly skilled and engaged locals and expatriates as well as immigrants looking to capitalise on the State's booming high-tech industry. Residents enjoy the relaxed, nature filled lifestyle the Mt Lofty Ranges and Adelaide Hills offer.*
Cynical Villagers	Mitigation challenges dominate	*A growing amount of rural residential developments, coupled with low population growth sees Greater Adelaide increasingly suffering from urban sprawl. This sprawl is due to shifting population dynamics with an increase in lower-middle income groups and hence a drive for affordable homes, and an ageing population looking to the hills for retirement. There is a strong community preference for protection of the state's areas of environmental significance, a growing environmental consciousness and appreciation of the landscape's amenity value. The interest in nature and the countryside leads to high levels of local knowledge regarding the risks from the landscape. However this risk awareness still unequal across the region, with less connected and more vulnerable communities still finding it difficult to build self-sufficiency.*
Ignorance of the Lambs	Resilience challenges dominate	*Greater Adelaide shifts towards an increasingly commuter lifestyle in the pursuit of lower cost housing. Population growth is high with increased immigration from migrants seeking a safe-haven in Australia from various global issues both climatic and socio-economic. The region experiences a decline in rural living, with a shift towards highly urbanised centres throughout the region and lengthening of commute times between residential centres and places of work. This results in increasing community vulnerability and heavy reliance on government for both social and hazard-related support.*
Appetite for Change	Moderate challenges to both mitigation and resilience	*Greater Adelaide continues on its current trajectory with declining manufacturing and slow population growth. In contrast to the decline in manufacturing, a rise of low value mining and an expansion of agricultural sectors over the next fifteen years leads to a slight expansion of rural residential areas and an increase in urban infill and sprawl around the suburban fringes.*
Internet of Risk	High Challenges to both mitigation and resilience	*Global connectedness drives an increasing reliance on the internet for social interaction and working styles. This reliance on the internet sees dispersed residential living as the attraction of the CBD and physical centres lessens and reduces population density. This leads to a significant loss of physical connectedness and an increase in siloed communication between similar individuals. Services by a small, but growing, services sector provide for the masses of online workers. The majority of workers use the internet to work across the world, placing pressure on government revenue streams.*

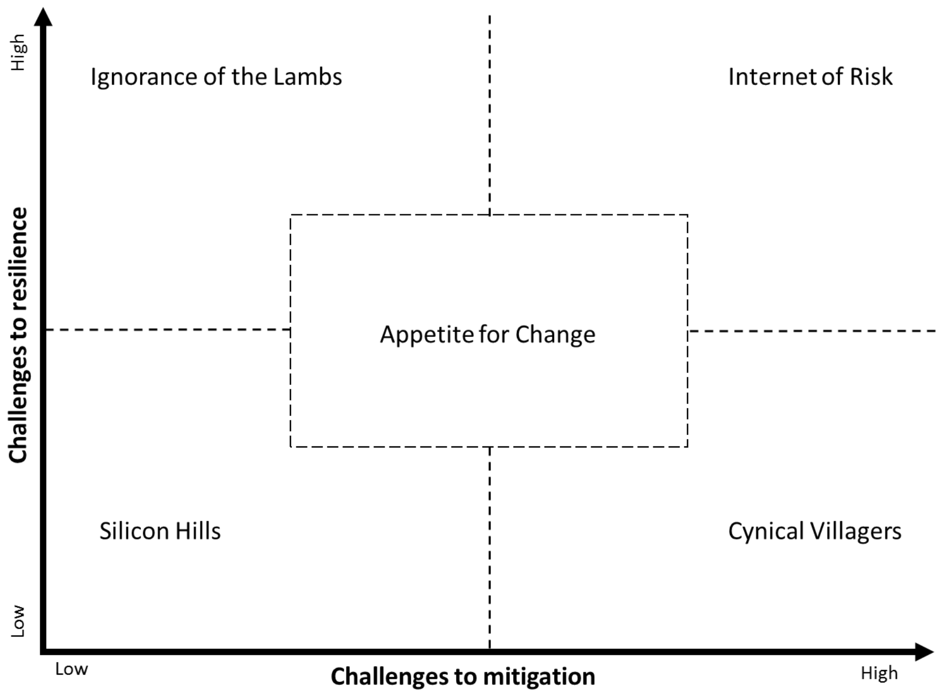

Figure 3-4: Scenario framing and layout.

3.3.2.4 Step 5: Assess scenario outcomes

The scenarios developed from the stakeholder discussions and timelines were then presented back to the stakeholder group, allowing for feedback on their representativeness, internal consistency and plausibility. A sample of the results from this feedback session are shown in Figure 3-5. Overall the feedback supported the developed scenarios with predominately positive feedback regarding representativeness, consistency and plausibility. Comments that highlighted any inconsistencies within the narratives were discussed and changes were made where appropriate. This is an important stage of the scenario development process allowing feedback from stakeholders.

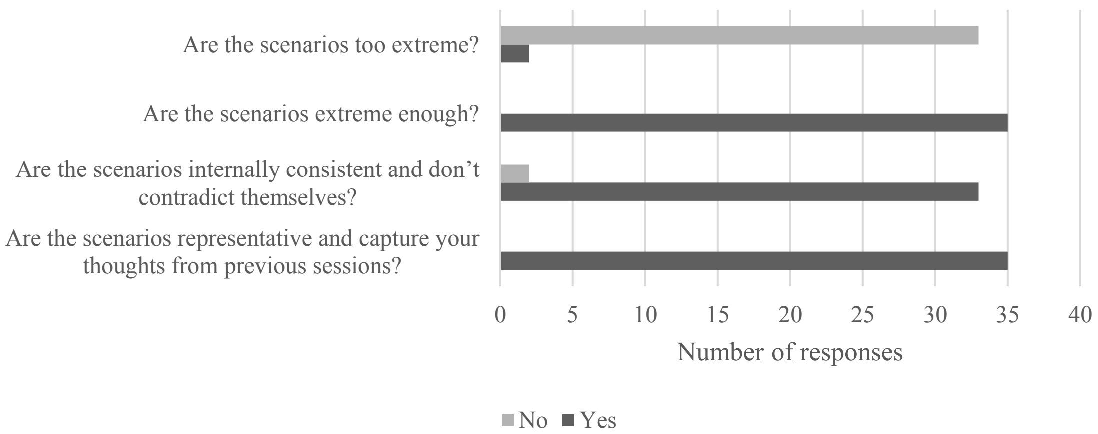

Figure 3-5: Participant feedback on the drafted scenarios.

The impacts and implications of the qualitative scenarios were subsequently discussed with participants. Discussions focussed on how different natural hazard events would impact on the community and environment across each of the scenarios. Subsequent work with the stakeholder group will look to quantify these scenarios and visually demonstrate different risk profiles for each of the scenarios with numerical simulation models.

3.4 Discussion

Following this application of the proposed exploratory scenario development framework, several insights and conclusions are drawn and discussed in the following sub-sections. These include assessing the policy orientation of the developed scenarios and how to balance stakeholder knowledge elicited through participatory processes with more detailed analysis by a small scenario team. Also discussed are the broader applicability of scenarios designed with processes focussed on policy options. That is, how well can policy-focussed scenarios be applied to broader questions outside of their original domain, and can they be translated or scaled to different areas?

3.4.1 Policy relevance of developed scenarios

A common challenge of all scenario development processes is to demonstrate their added value (Wodak & Neale, 2015). This is largely because their benefits are often not immediately tangible or obvious to participants, or convenors, due to much of their impact coming from the actual process itself. In terms of increased policy relevance due to the proposed construction and framing process, this is even more difficult to measure. However, stakeholder feedback throughout the process showed its promise, which was also highlighted by the confidence in the plausibility of the scenarios, as shown in Figure 3-5.

Additionally, from the scenario team's perspective, the thinking of participants in terms of how all scenarios impacted on their job and policy creation, reflected value in scenario development from both an outcome and process perspective (Hulme & Dessai, 2008; van Vuuren et al., 2012). Qualitative information from participants also provides an indication that the scenarios proved valuable and will continue to be so. An indicative quote from one participant was that,

> *"Making decisions that consider the aging population, changing demographics, climate change, economic growth and changing industry bases along with the impact of technology and internet certainly looked very complex to start with, however it made a lot of sense [in the end]. Putting these elements into the scenarios was where it all*

came together for me and then mapping it into the time schedule was particularly illuminating."

While feedback of this kind cannot provide sufficient evidence of changed practice, it does show the value of using scenarios to capture complex, uncertain information in an easily understandable context. However, due to the long-term nature of participatory scenario processes, and the many factors playing a role in disaster risk reduction management, judging success is inherently difficult.

3.4.2 Policy content of developed scenarios

In contrast to the assessment of impact on long term policy, the content of the scenarios can be considered in terms of their policy relevance, where the link to disaster risk reduction policies is clear. All scenarios include specific references to disaster risk reduction, with examples shown below and full details in Appendix C:

> *"The emphasis on enjoying and connecting with nature ensures well-maintained areas of local significance along with increased understanding and subsequent reduction of human impacts on the landscape." (Silicon Hills Scenario Narrative, Section 1.1, Appendix C)*

> *"Due to the rising costs of risk mitigation, the Federal Government plays an increasingly important role eventually resulting in the loss of state-based policy, with the State Government becoming more of a service provider than a policy maker." (Ignorance of the Lambs, Scenario Narrative, Section 3.1, Appendix C)*

By framing the scenarios on encouraging resilient communities or implementing mitigation activities, policy makers were easily able to see the relevance of the process to their operations. Considering scenarios, with the focus on the ease or difficulty to the design and implementation of policies, made what can at times be non-tangible discussions about the future more immediate and relevant.

The scenarios were also specifically focussed on policy responses by constructing them with specific, relevant factors. Scenarios that considered resilience looked at entirely different factors than those considering mitigation, and these differences may have been harder to capture by using the same, or more generic, factors, across all scenarios (e.g. STEEP factors). This is evidenced by comparison between the discussion on politics and institutions for

Ignorance of the Lambs (challenges to resilience) and *Cynical Villagers* (challenges to mitigation). Based on the factors considered relevant to resilience (e.g. social cohesion, infrastructure and understanding of risk), the narrative focussed on the need for large infrastructure projects requiring federal government funding, and hence State government becoming a service provider, not influencer. The narrative also assumed a lack of research and analysis investment by local governments due to lack of local level funds for projects. In contrast, considering factors relevant to mitigation (e.g. institutional perception, data availability and cost benefit considerations) had the scenario narrative focus on community opposition to mitigation activities seen to restrict individual rights and freedoms, supported by increasingly open data, consequently leaving the community more empowered to challenge governments through the courts.

Although the construction of scenarios based on policy relevant factors is critical to developing relevant scenarios, it also poses some challenges, despite the previously mentioned benefits. While some factors, such as *social cohesion* for resilience focussed scenarios, or *data and knowledge* for mitigation based activities, had clear concepts, and timelines that were easily developed by participants (i.e. considering how societal values, or funding for science, could change given various drivers), other factors proved more troublesome. For example, the resilience factor *efficacious policy,* described in Table 3-2, challenged the construction, as participants found it hard to create a timeline of changes for this in the context of resilience, despite the fact that it had come out of their earlier exploration of the policy option.

Therefore, careful consideration of the scenario factors selected is critical to allow an exploration of developments into the future. It may be suitable for the scenario team to select representative factors that, in their opinion, allow for temporal development from the previously collated responses from participants. This could, however, detract from the overall participatory approach. To maintain the participatory benefits, careful consideration should be given to the structure of the participatory exercises, along with effective facilitation for the selection of factors that can enable discussion of temporal developments. The scenario team could also be open to altering the factors during the process of time-lining to better allow for temporal developments, while maintaining the original concepts of the policy relevant factors.

3.4.3 Value of inclusion of participatory and expert knowledge

The inclusion of participatory knowledge in this study significantly improved its policy-relevance, as the participants represented the key decision-makers and advisors in risk reduction policy in the study region and were able to contribute the policy information they would find relevant. Participation by such individuals improves the quality of policy relevant factors, and allows the inputs to be much more focussed on the challenges facing the region. Several risk specific assumptions were included throughout the workshop discussion, which improved the relevance of the scenarios, and could only be garnered by involving policy focussed participants. Such assumptions/factors included the impact of governance structures and effective decision making in the region of interest (for examples, see Appendix C Section 3.1 and 3.3) and potential impacts of the digital economy (Appendix C Section 5.7) and inequality (Appendix C Section 2.4, 5.4, 5.5) on risk profiles.

However, the participatory process with these participants posed other challenges, namely that future-focussed thinking was not generally within the function of their role or organisation's remit. There was instead a greater emphasis on emergency response for most participants (as is appropriate to their day-to-day work), which resulted in the requirement for appropriate facilitation and process design to align future-focussed thinking and an understanding of the region's risk. The proposed scenario process significantly aided this, with targeted exercises to extract information related to risk and policy factors (Steps 2b and 3b), and then by framing the discussion on how these factors can change into the future (Step 4b). Expert facilitation is required to challenge participants to move stakeholder thinking from the present to the future, but the facilitators found this easier to do when participatory activities were framed around challenges to mitigation and resilience than a more abstract discussion around the changes considered plausible in society across consistent uncertain factors or drivers, as discussed in the Introduction (Chapter 3.1) and Chapter 3.2.3.

Using the information from the participatory workshops as inputs to the detailed narrative scenarios, the scenario team was not fully restricted to the outputs of participatory exercises. This allowed the scenario team to incorporate analysis of historical trends, and consider inconsistencies within and across scenarios. This enabled a broader consideration of future drivers for change to be coupled with participatorily derived policy focussed information. This combination of workshop sessions, and intermediary work by the scenario team allowed the scenarios to better combine policy and future uncertainty factors. Furthermore, it provided a structure to benefit from the value of participatory knowledge in scenario development, enhancing the legitimacy and impact of the process (Alcamo & Henrichs, 2008), while still allowing for the ability to include more novel and provocative ideas by the scenario team

(Chermack & Coons, 2015). This process also allowed for a more efficient scenario development process which is critical when working with senior decision makers with limited time (McBride et al., 2017; Pincombe et al., 2013). Cairns et al. (2016) also discuss these challenges, balancing the participants' ownership of the narratives, with the time available for participants to be involved in the process and role of the scenario team. This shows that limited, but strategic, engagement with senior decision makers as participants still allows for ownership to develop and for articulated, collective actions to be discussed and progressed.

3.4.4 Policy frames, applicability and scales

The construction of futures specifically designed to test policy responses allows for a clearer targeting of 'interesting' futures for policy analysis (Bryant & Lempert, 2010), compared to a scenario logic focussing on key uncertainties. However, this occurs at the potential loss of generality and transferability. Many large scale global scenario processes have been applied to domains outside of their original design intent, with the SRES being an example of this (7212 total citations of Nakicenovic and Swart (2000)) from diverse fields are listed on Google Scholar, accessed 06/03/2017). By framing the scenario development on key uncertainties, the futures are intended to be as diverse as possible, and as such may still be valuable for applying to different domains, especially if the uncertain factors that define the scenario axes are still significant, which was true for many of the applications of SRES. Therefore, if the scenarios are designed to be applied to multiple domains, and spatio-temporal scales, and direct policy analysis and decisions are less relevant, a scenario logic should be chosen that best supports this.

One of the challenges with a broader application of policy orientated frames outside of their intended, and designed for, application is that for effective application, they must be focussed at the appropriate area and scale of governance (Bryson et al., 2010). The policy options considered for the specific application under consideration relate to the governance scales appropriate for the problem being tackled. The policy options appropriate at one scale (geographical or governance) may not be the same as another, and as such there arises a conflict if policy framed scenarios are applied to different scales, where the options are no longer valid or outside of the original governance domain.

This is particularly true if the scenario process is driven by a participatory process, as stakeholders may not agree with the policy responses framing the scenarios being downscaled or applied to their problem context (as they may not be considered the main policy responses relevant to their context / scale). For example, there may exist a disconnect between what individuals and organisations can do at one scale, in comparison to what may be entirely appropriate at another governance or spatial scale, which might be the case for the mitigation of climate change, which, as a policy process that more commonly lies at the national and international scale, may prove difficult for local stakeholders to consider as the main driver for their scenarios (Lister, 2001; Urwin & Jordan, 2008). An approach to mitigate this may be to 'branch' scenarios as shown in Cairns et al. (2017) with locally focussed positive and negative scenarios fitting below alternate global scenarios. This is considered an approach for such policy orientated and framed scenarios to be developed under the influence of / nested within broader exploratory global/national scenarios.

3.5 Conclusions

This paper has proposed an approach to enhance the policy relevance of exploratory scenarios through specific consideration of their framing and the factors considered for temporal narrative development. This is achieved by exploring and categorising relevant policy options, and using these categorisations as the frame for the exploration of futures that present greater or smaller challenges to these policy categories. The scenarios themselves are developed by considering changes to factors found relevant to policy effectiveness, not factors that are considered to be the most uncertain (as is the case for traditional 2x2 scenario building approaches). In general this places the emphasis on exploring what future factors can impact on policy effectiveness, not only what could cause the greatest differences in future trends.

The approach was applied, for illustrative purposes, to consider natural disaster risk reduction in Greater Adelaide, Australia. This allowed for the participatory exploration of risk reduction options with the State Mitigation Advisory Group, a stakeholder group of civil servants, and emergency management professionals. This resulted in scenario frames of challenges to resilience (i.e. a community driven response to managing and minimising risk), and challenges to mitigation (i.e. where government led approaches of structural measures and restrictive policies are used to reduce risk). Five scenarios were developed within these framing axes based on factors considered relevant to either resilience or mitigation, including social cohesion, institutional culture and perceptions and governance structures. The developed scenarios explored concepts, themes and subsequent development trends that were found valuable for long-term policy development and analysis.

Subsequent work involves continued assessment of scenarios' use and impact in policy work by the stakeholder group and whether they were discussed in other contexts, outside of the scenario development process, by those involved. Future research should also consider how to best integrate exploratory scenarios, specifically designed for policy assessment, into policy development and impact assessment cycles. This could be supported by using combinatory activities such as the growing application of scenarios and serious gaming as described in Bontoux, Bengtsson, Rosa, and Sweeney (2016); Sweeney (2017); and Valkering, van der Brugge, Offermans, Haasnoot, and Vreugdenhil (2013), and with qualitative, quantitative approaches to scenario development (Alcamo, 2008; Kok & van Delden, 2009).

Design of participatory processes for eliciting the most valuable information from stakeholders, balancing strong opinions and reaching desired outcomes, is also an ongoing area of research, where facilitation is key to the success of any participatory scenario process. The approach introduced and applied to disaster risk reduction can also be applied to many other problems domains. Further application of the process would go towards standardising participatory processes, or determining which are most appropriate for the given context, to explore policy options, their relevant factors and develop exploratory scenarios with a greater utility for policy development and assessment.

3.6 Acknowledgements

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CHAPTER 4

Paper 3: Exploratory Scenario Analysis for Disaster Risk Reduction: Considering Alternative Pathways in Disaster Risk Assessment (Published paper)

Statement of Authorship

Statement of Authorship

Title of Paper	Exploratory Scenario Analysis for Disaster Risk Reduction: Considering Alternative Pathways in Disaster Risk Assessment
Publication Status	☐ Published ☐ Accepted for Publication ☑ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Submitted to 'International Journal of Disaster Risk Reduction'

Principal Author

Name of Principal Author (Candidate)	Graeme A Riddell		
Contribution to the Paper	Conceptualisation of approach, implementation and stakeholder engagement design and practice. Modelling of risk scenarios. Lead role in drafting manuscript.		
Overall percentage (%)	70		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	15/04/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Contribution to the Paper	Input to conceptual and modelling approach, stakeholder engagement and modelling of socio-economic futures modelling. Drafting of manuscript.		
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Contribution to the Paper	Input to conceptual and modelling approach and drafting of manuscript.		
Signature		Date	15/4/19

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Contribution to the Paper	Input to conceptual and modelling approach and drafting of manuscript.		
Signature		Date	16/4/19

Abstract

Disaster risk is a combination of natural hazards, along with society's exposure and vulnerability to them. Therefore, to ensure effective, long-term disaster risk reduction we must consider the dynamics of each of these components and how they change over extended periods due to population, economic and climatic drivers, as well as policy and individual decisions. This paper provides a methodology to capture these factors within exploratory scenarios designed to test the effectiveness of policy responses to reduce disaster losses. The scenarios developed and subsequent analysis of them combine knowledge and insight from stakeholders and experts, and make use of simulation modelling to enable scenarios with qualitative and quantitative elements to be integrated within risk assessment processes and contribute to strategic risk treatments. The methodology was applied to a case-study in Greater Adelaide, Australia, and used to assess how disaster risk for earthquakes, bushfire and coastal inundation changes from 2016 to 2050 under five exploratory scenarios for the future of the region. This analysis can be applied more broadly to consider how future risks impacts on regional viability, and suitability for investment related to the need to gain a better understanding of governmental and organisational exposure to physical risks.

Keywords: Disaster risk; scenarios; stakeholder engagement; simulation modelling; risk assessment

4.1 Introduction

The impacts of disasters from natural hazards globally are increasing, with 2017 being the most costly year ever in terms of insured losses, $234bn (USD) (Munich Re, 2018), and second in total losses to 2011, with $234bn (USD). Projections of economic and population growth, together with impacts of climate change, show that these losses are likely to increase in the future (Bouwer, 2013; Milly, Wetherald, Dunne, & Delworth, 2002). The need to reduce these losses therefore is significant. Disaster risk reduction encapsulates efforts to reduce the impacts of disasters and incorporates actions such as improving building standards, land use planning strategies, structural flood defences, and education / capacity building activities (Bouwer et al., 2014; Godschalk, 2003; Shreve & Kelman, 2014). However, decision-makers and planners designing and implementing disaster risk reduction strategies face difficult decisions around resource allocation, scheduling and planning priorities. Effective disaster risk reduction therefore requires the complexities of long-term change and multiple actors to be considered explicitly, along with significant sources of uncertainty, to develop integrated responses to the changing threats of disasters.

A complex decision making process can be conceptualised as multi-problem, multi-dimensional and multi-scale (van Asselt, 2000). This represents a process involving entwined problems, numerous concerned disciplines and influencing processes that operate at various scales (governance, spatial, temporal). Disaster risk reduction inherently displays these factors of complexity, with the problem including issues such as climate adaptation and mitigation, sustainable development and local strategic economic and environmental issues, among others (Donner & Rodríguez, 2008; Hallegatte et al., 2016; Hallegatte & Rozenberg, 2017; Mileti & Gailus, 2005; van Aalst, 2006; Wamsler, Brink, & Rivera, 2013). Designing, testing and implementing risk reduction strategies requires input from a range of disciplines, such as the computational abilities found in the physical sciences, an understanding of impact and associated costs from engineering and economics and understanding of community vulnerability and resilience that is the domain of social scientists (Berke et al., 2015; Bernknopf et al., 2007; Highfield, Peacock, & Van Zandt, 2014; Koks et al., 2015). The scales of disaster risk also cross from international efforts and agreements to small local communities (Brooks et al., 2005; Burby & Dalton, 1994; Rumbach, 2016; UNISDR, 2015; Ward et al., 2017). There is therefore a need to incorporate these aspects into disaster risk reduction planning and implementation to ensure unintended and perverse outcomes do not occur and to leverage significant co-benefits of approaches accounting for multiple factors.

The uncertainty in the factors influencing disaster risk is also significant, and this is particularly true for what is known as knowledge uncertainty or uncertainty about the future (UKCIP, 2003). These types of uncertainties produce significantly different trends in drivers and components of risk such as economic, population and climate change, rates of urbanisation, the influence of new technologies, and political factors. As disaster risk reduction requires actions to be implemented that will influence future developments, there is a need to incorporate how the future may unfold. Disaster risk reduction therefore needs to consider and integrate these uncertainties when plans are made and investment decisions for risk reduction actions are taken, otherwise their suitability and effectiveness may not be sufficient. Consideration of the future may also provide the opportunity to consider alternative methods of risk reduction, as opening a discussion on what may occur into the future enables the consideration of actions to influence this in a broader sense than what traditional actions would, such as reducing societal vulnerabilities and increasing adaptive capacity (Godschalk, 2003; Wagner, Chhetri, & Sturm, 2014).

Traditionally, disaster risk reduction efforts are underpinned by risk assessments and the identification of management actions that reduce these risks. However, such risk assessments have generally taken a static approach by either considering current risk, or risk at a future time slice, which is often insufficient to capture the complexities and uncertainties outlined previously (Global Facility for Disaster Reduction and Recovery, 2016). In recent studies, future uncertainty is also often considered by quantifying the impact of climate change on future hazard magnitude and probability, most commonly for hydro-meteorological disaster risk assessments (Hallegatte et al., 2013; van Aalst, 2006). This has allowed risk assessments to capture future changes in hazards, and through the use of environmental scenarios, such as representative concentration pathways (RCPs) (Alfieri et al., 2015; Jongman, Ward, & Aerts, 2012; Westerling & Bryant, 2008), downscaling can provide various estimates for future environmental conditions such as precipitation, or sea level rise, for inclusion in the assessment of risk at future time points (Murnane et al., 2017). Similar approaches can be seen in planning for wildfire mitigation in Bradstock et al. (2012), who considered alternate climate scenarios, including a high and low temperature scenario for the year 2050, along with variations of humidity and wind. Similar scenario-based considerations of hazard magnitude can be seen in Aleskerov, Iseri Say, Toker, Akin, and Altay (2005) (earthquake), Legg, Davidson, and Nozick (2013) (hurricane), Prudhomme, Wilby, Crooks, Kay, and Reynard (2010) (flood), and Panza, Mura, Peresan, Romanelli, and Vaccari (2012) (earthquake). However, none of these approaches consider uncertainties in other components of risk such as exposure or vulnerability, as their entire focus is on the hazard components and related uncertainties. There is also no consideration of the complexity of how these factors interact or how the complex dynamics of future changes are incorporated into the risk assessments, enabling more effective characterisation of future risk and how to reduce it.

Other risk assessments have considered changes to future exposure through considering population and economic projections and how regions and cities would look under these projections to subsequently assess various risk indicators. The work by de Kok, Kofalk, Berlekamp, Hahn, and Wind (2009), Mokrech et al. (2008), Zanuttigh et al. (2014), and Xu, Booij, and Mynett (2007) account for economic projections in increased exposed values. Barredo and Engelen (2010) made progress towards exploring the variation and growth in exposure using a combined model of flood risk and land use. However, only two scenarios were considered, consisting of two alternate urban developments, with one based on increased central, built up cluster and the other on more diverse growth influenced by roads. However, these approaches again do not take into account the broad range of factors that could influence the effectiveness of disaster risk reduction efforts, or provide a mechanism to incorporate the complexities of disaster risk that can allow decision makers to untangle the interconnectedness of disaster risk. Instead, these approaches represent the incorporation of generic scenarios of one or two dimensions to forecast possible futures of limited components of disaster risk. However, this fails to deliver risk assessments that incorporate the range of relevant uncertainties and complexities impacting on risk, nor a way to assess the effectiveness of risk reduction options.

In relation to the incorporation of uncertainty, the literature shows an increasing preference for accounting for changes to components of risk in the future, but none go as far as the call for a 'paradigm shift' in the manner in which risk assessments are done through implementing a more dynamic approach, accounting for future uncertainties and allowing for the understanding of today's and tomorrow's decisions on long term risk profiles (Global Facility for Disaster Reduction and Recovery, 2016). Such a shift would require the incorporation of the levels of uncertainty and complexity needed for understanding tomorrow's risk. This can be achieved by means of scenario analysis that incorporates relevant and challenging assumptions of tomorrow from a range of stakeholders and contexts, along with incorporating the complex dynamics between decisions made, and emerging socio-economic trends. Therefore, there is a need for an approach that can incorporate these elements within the scenarios used for risk assessments and ensure they are tailored to disaster risk contexts, embracing the range of uncertainties and complexities within the domain to enable them to have a greater impact in the policy and planning processes used for disaster risk reduction (Bryson et al., 2010; Graeme A. Riddell, Hedwig van Delden, Graeme C. Dandy, Aaron C. Zecchin, & Holger R. Maier, 2018).

This paper therefore has the objective to introduce an approach that can incorporate the range of complexities and uncertainties relevant to planning for a future of reduced disaster risk in a risk assessment process. The paper outlines the proposed approach in Chapter 4.2, highlighting both the difference in outputs from a traditional static risk assessment, along with the dynamic outputs obtained by using the proposed approach. Chapter 4.2 also provides details on the methodology for undertaking a risk assessment process that creates relevant and challenging scenarios. Chapter 4.3 provides specific details on the approach and its application to a case-study, which allows for greater description of the process and allows for highlighting the proposed approach's ability in incorporating the range of required knowledge sources into a risk assessment. Critical discussion on the approach is offered in Chapter 4.4, particularly considering how perspectives were combined within the approach, how to ensure assumptions are challenging and relevant for disaster risk assessment and how the approach can add value in other domains. Chapter 4.5 provides a summary and conclusions of the paper.

4.2 Proposed Approach to Incorporate Complexity and Uncertainty in Physical Risk Assessments through Exploratory Scenarios

4.2.1 Conceptual outline of approach

The approach proposed to improve disaster risk reduction planning (achieved through incorporating uncertainty and complexity to enhance risk assessment) integrates different types of knowledge and assessments, both qualitative and quantitative, through exploratory scenarios to consider extended planning horizons in a dynamic manner. This allows for the characterisation of risk against time for various scenarios that incorporate challenging and relevant assumptions on uncertain and complex factors and interactions influencing risk. This process enables decision makers to better consider the impact of different factors on risk, allows for an understanding of the impact on current decisions and policy on future risk and enables a collaborative approach to be undertaken to better plan for a less risky future. These are all currently challenging in the more commonly used static risk assessment processes (Figure 4-

1), aligned with reactive risk management, that do not account for future uncertainty or complexity in risk factors as outlined in the Introduction and instead aim to capture best available data for the current situation.

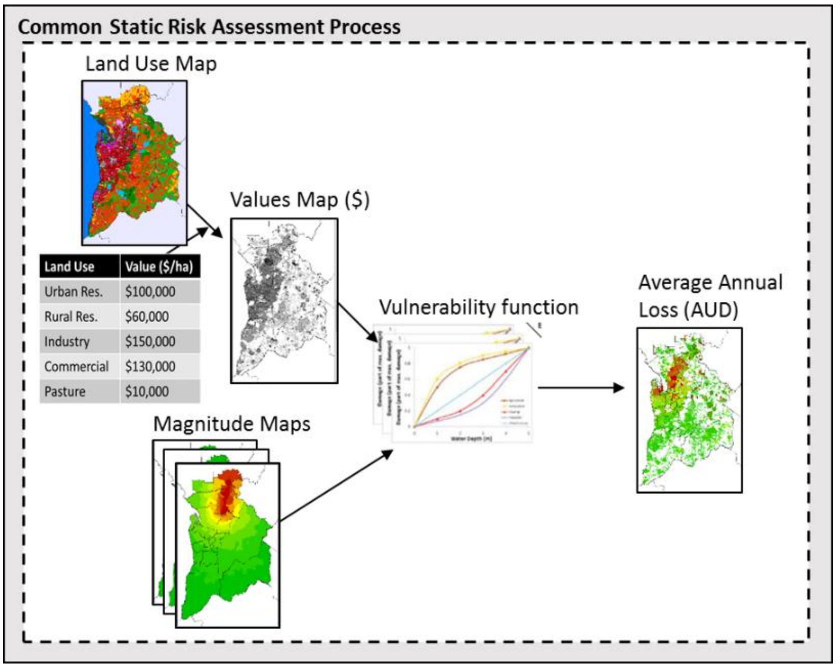


Figure 4-1: Sophisticated quantitative, static regional risk modelling assessment with exposure and hazard brought together through vulnerability / fragility / damage curves, see Gunasekera et al., 2015; Koks et al., 2015; UNISDR, 2017 for further details.

The proposed approach instead enables the development of dynamic, spatially explicit risk pathways that correspond to alternate, challenging and plausible future changes in hazards, and, exposure and vulnerabilities to them. These pathways also capture the complexity of interactions between these factors (hazard, exposure, vulnerability) and the uncertainty in their future trajectory in a realistic and informative manner. This approach drives the static risk modelling and assessment process with exploratory scenarios created with an integration of knowledge encapsulating some of the uncertain and relevant factors that impact disaster risk as outlined in the Introduction. By creating alternate scenarios, complexities arising from the different disciplines involved in disaster risk reduction can be described in each scenario, allowing competing perspectives to be introduced into the risk assessment process. Given the broad range of stakeholders involved in disaster risk reduction (who can provide insight into the complex influence of their actions and other drivers within the system), the creation of dynamic pathways based on different assumptions and actions taken also allows for the complexity of entwined problems (where pulling a lever in one part of the system can influence risk in other parts of the system) to be shown within a quantitative risk assessment. Alternative assumptions made on future uncertainties, highlighting their influence on risk, provide different trajectories for the scenarios. Assumptions from diverse actors involved in disaster risk can be incorporated regarding the influence of cultural and technological factors on risk, especially vulnerability, as well as how climate change and socio-economics will influence future hazard likelihood and intensity, as well exposed assets and populations.

Figure 4-2 shows the outcome of the approach of developing exploratory scenarios to create alternative pathways in the risk assessment process. This is in comparison to only capturing the average annual loss (or other relevant risk metric) for one, often current, time slice – shown in the above (Figure 4-1). However to achieve this outcome, with insight that is challenging and meaningful to users of risk information, and incorporates challenging assumptions on uncertainty and the complexity of risks into the future, the development of these pathways needs to be carefully considered. This development process, the proposed approach demonstrated in this paper, is critical to the value of the outcome achieved.

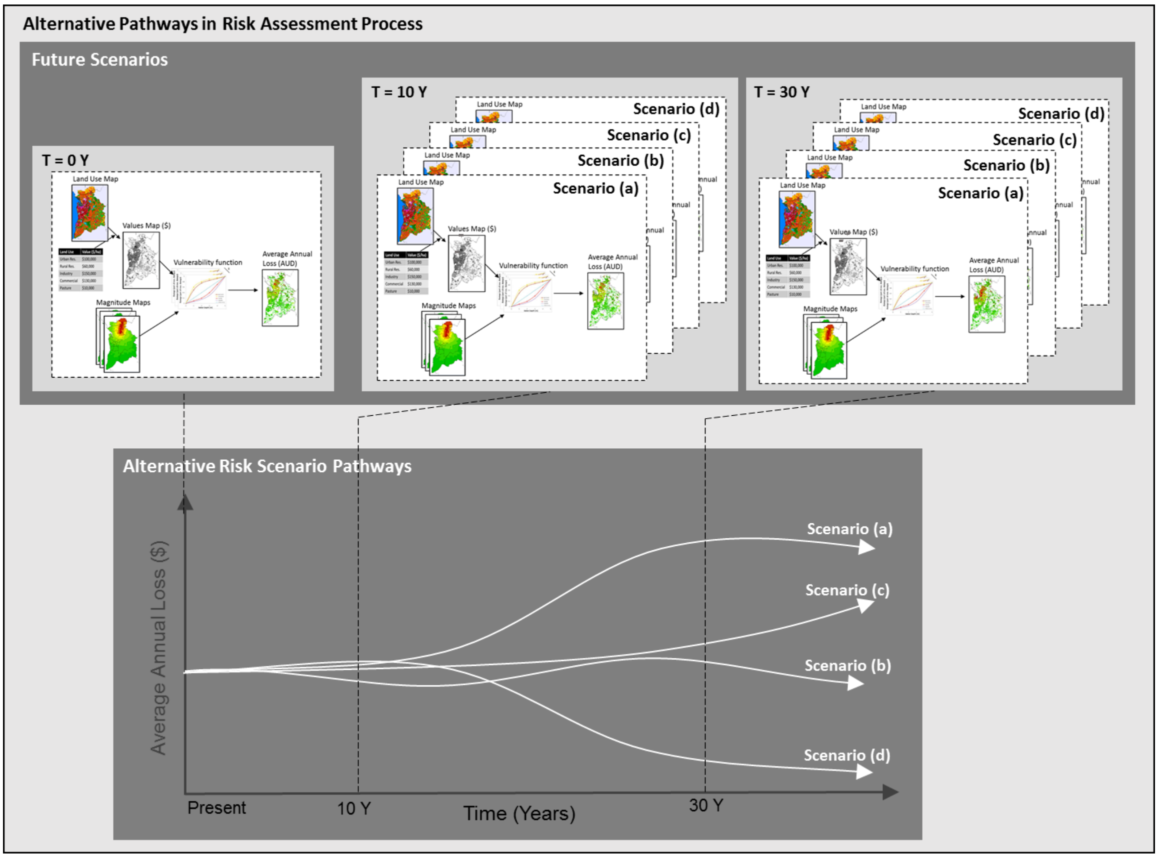


Figure 4-2: Outcome of the proposed approach, illustrated with four alternative scenarios (Scenario (a) – (d)), which include assumptions and drivers on any of the elements included within the calculation of risk (e.g. average annual loss in this representation).

The proposed approach achieves value through developing alternative risk pathways by integrating stakeholder participatory information, expert opinion and judgement and scenario simulation modelling with disaster risk assessments into exploratory scenarios to enable the exploration of risk profiles. These scenarios are exploratory in their content as they focus on what could happen (Börjeson et al., 2006) and are defined as internally consistent and plausible explanations, using words and numbers, of how events unfold with time (Gallopín & Raskin, 1998; Mahmoud et al., 2009; Raskin, 2005). By including both qualitative and quantitative factors in the developed exploratory risk scenarios, multiple benefits can be derived by combining participatory processes to develop qualitative storylines with integrated models for future projections and risk analysis. When scenarios are developed with participatory inputs with a diverse range of stakeholders, it can ensure greater relevance to local decision making, build trust and increase acceptance of planning decisions (Luz, 2000; Tress & Tress, 2003; Walz et al., 2007). Stakeholder involvement in scenario development can also empower those involved through the cogeneration of knowledge (Kok, Patel, et al., 2006; Reed et al., 2013).

Therefore, with the aid of the proposed approach, uncertainty and complexity can be considered by the exploratory storylines developed by stakeholders and offer rich, descriptive visions of future world states and incorporate various qualitative assumptions for alternative worldviews and risk profiles (Rounsevell & Metzger, 2010). The inclusion of 'numbers' in the exploratory scenarios, complementing the storylines, allows for a temporal representation of changes based on the qualitative assumptions and allows them to be used in the assessment and development of policies and plans. By quantifying and modelling scenarios, it can also be argued that they become more transparent, given assumptions need to be explicitly detailed in model parameters and processes (Alcamo, 2008).

4.2.2 Implementation of the approach – achieving challenging, relevant risk profiles

The approach's implementation is shown in Figure 4-3 across nine distinct steps, which can be grouped into four stages, problem formulation, qualitative scenario development, quantitative scenario development and future risk assessment. The feedbacks between the different steps and stages are also shown. To enable the approach's outcomes, its implementation is focussed on integrating participatory and qualitative information with quantitative modelling and analysis to enable the exploration of risk profiles (represented as average annual loss in Figure 4-2). How this is achieved across the nine implementation steps is also shown in Figure 4-3.

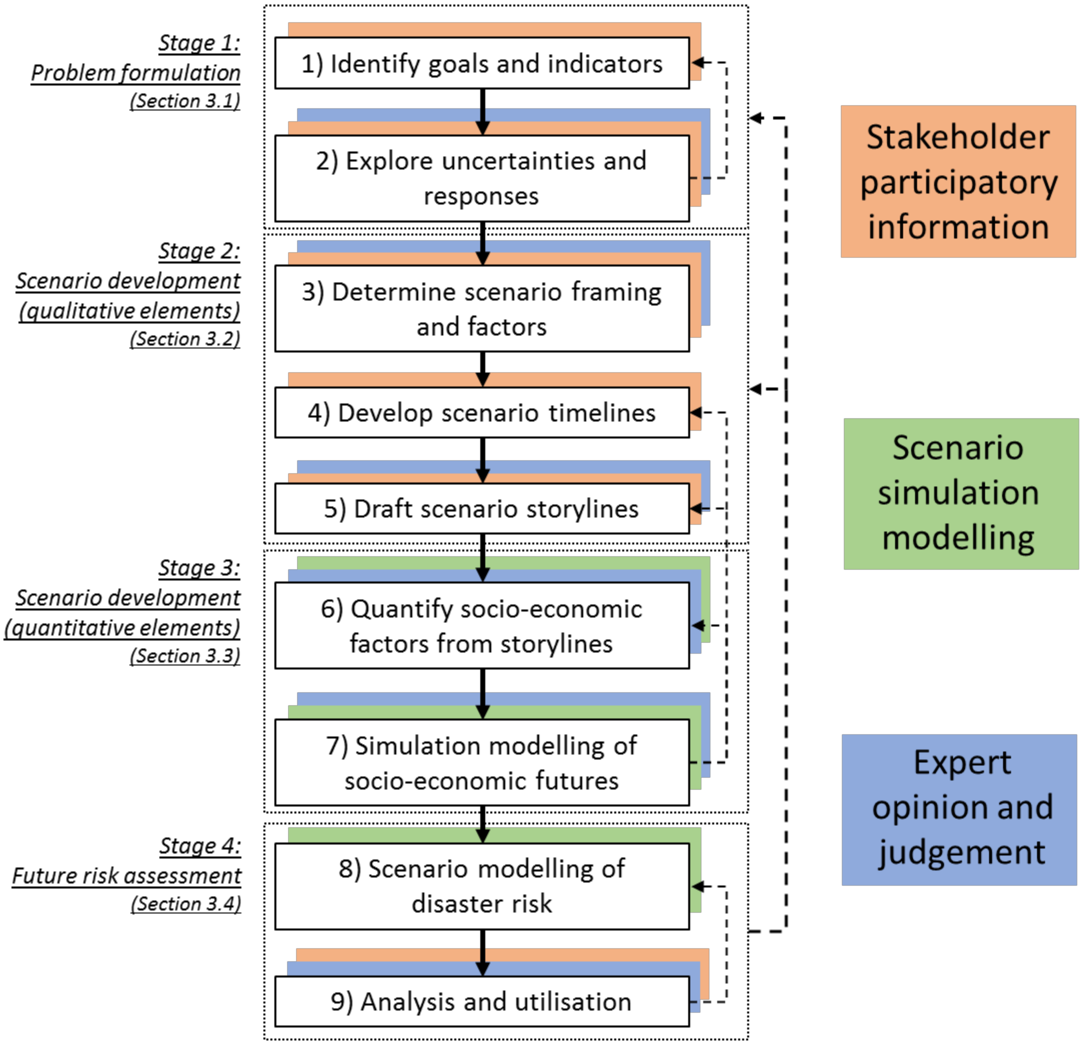


Figure 4-3: Outline of the nine steps of the approach to develop and use exploratory scenarios within disaster risk assessments. Coloured boxes indicate source of information type used in each step.

As mentioned above, the implementation process shown in Figure 4-3 consists of four key stages, which flow into each other. It is initially important to establish the context and formulate the problem to which the exploratory scenarios for disaster risk reduction is being applied to. This includes considering key goals and stakeholders for the process, and outlines critical components to be included within the scenario process. Stage 2 begins the detailing of scenarios, in a qualitative manner, using stakeholders to develop the components of the scenario that will allow the process' goals to be met. This then allows Stage 3 to quantify and simulate socio-economic futures based on their qualitative components. Stage 4 uses these futures to drive the quantitative risk assessment modelling to consider future risk and strategic risk reduction options.

The entire process incorporates different sources of information from either stakeholders, experts or simulation modelling at different points, with some stages focusing more on participatory input and others more on quantitative analysis, as shown in Figure 4-3. Each of these elements of information enable the process to better capture the challenges involved with dynamic risk assessments and allow scenario exploration of risk's uncertainties and complexities to be considered quantitatively and in a manner that enhances understanding by those involved in risk assessment and reduction. The following list provides details on information provided by each of these sources:

Stakeholder participatory information – stakeholders are defined as individuals who are either involved in making or impacted by a decision (Freeman, 2010). Information is generally collected from these individuals through designed processes including questionnaires, semi-structured interviews and workshops, however, all information is qualitative and subjective. Significant literature is dedicated to the method for identifying and working with stakeholders (see Reed (2008); Voinov and Bousquet (2010); Wu et al. (2016). The incorporation of stakeholder insight has a number of advantages, including (i) it enables more local knowledge / context to be incorporated, which is critical for complex decisions, (ii) ownership of outcomes and (iii) it addresses the uncertainty of social norms (Hurlbert & Gupta, 2016; Hurley et al., 2010; Jones, 2001; van Asselt, 2000)

Scenario simulation modelling – this is the use of computer-based modelling systems to simulate future dynamics based on input drivers and model parameters. To consider scenarios via the use of simulation, parameters, inputs, boundary conditions and the model structure itself are adapted to represent and better inform the scenario's narrative. Simulation modelling of scenarios supports the exploration of uncertainty by considering alternate drivers in a consistent comparable manner with the same quantitative outputs. It can also support the exploration and reduction of complexity and communication of uncertainty through its requirement to consider various interpretations of the future through exploration of a limited number of parameters and its value as a structuring device for problems (Kok & van Delden, 2009; van Asselt & Rotmans, 2002; van Pelt et al., 2015).

Expert opinion and judgement – domain specific knowledge can be integrated by the inclusion of experts for particular elements of the process. Expert opinion and judgement is considered to rely on a range of qualitative and quantitative information and apply desktop studies, statistical analysis and inference. The incorporation of expert opinion throughout the process can better balance the trade-off between stakeholder views and scientific credibility, and relevance to decision making and challenging, exploratory thinking / provocations about the future, along with providing insight into parameterization, provision of boundary conditions, and evaluation of the realism of outcomes, especially in areas where data may be lacking (Brooks et al., 2005; Krueger, Page, Hubacek, Smith, & Hiscock, 2012; McBride et al., 2017).

Critically important to the value of the approach is how it is implemented and how each of these three components come together, as no one method, or type of information, is sufficient to capture the complexity or uncertainty involved in disaster risk. This is why almost each step of the process involves input from multiple sources. It is also important to consider the feedbacks between steps, acknowledging the complexity of disaster risks, and that when actions and solutions are implemented, unexpected impacts can occur – therefore as with all scenario planning, iteration and cycles of planning and implementation are critical. Chapter 4.3 provides further details on the approach and how it was implemented with a case-study example.

4.3 Considering Alternative Pathways in Disaster Risk Assessment – Applying the Approach in Greater Adelaide, a Case-study

The following sections provide details on each step shown in Figure 3, along with the split between knowledge sources - stakeholder participatory knowledge, scenario simulation modelling, and expert opinion and judgement – and how they were integrated. The outlined approach and its implementation were applied to Greater Adelaide in South Australia, Australia, to demonstrate the utility of the approach in terms of its ability to incorporate uncertainty and complexity for future risk assessment. South Australia's risk profile consists of various hazards, with flooding being the costliest with average annual losses in excess of $32million (Burns et al., 2017). The State has also suffered significant bushfire events, with two significant fires in 2015 resulting in the loss of 2 lives, 24 homes and 95,000 hectares burnt (Country Fire Service, 2017).

Participants involved in the process of implementing the proposed approach (Figure 3) were determined based on the roles and responsibilities of different agencies involved in emergency management in the State. Generally, participants were representatives of agencies on the State Mitigation Advisory Group (SMAG), along with other relevant government and non-government organisations, who provided broader details on regional growth dynamics in the region. The participants included in the process are not the full representation of stakeholders who would be affected by impacts of natural hazards into the future (such as local residents), as the stakeholder selection process was constrained to consider those within the emergency management sector due to confidentiality and security issues. For further exploration of the results generated from this process, along with implementation of actions, engagement would be needed more broadly, including with other levels of government and local residents, for example. The scenario team, as referenced subsequently, were engaged for the project and are the authors of this paper.

Implementation of the proposed approach was supported using the UNHaRMED software application designed to explore future disaster risk in an integrated fashion, see Van Delden (2018). Figure 4-4 shows an overview of the components of UNHaRMED, and how it was used to simulate the exploratory scenarios developed as part of the approach introduced in Chapter 4.2. The nine steps of the methodology, shown in Figure 4-3 in Chapter 4.2.1, are mapped into the process shown in Figure 4-4, beginning with Goals and Indicators (Step 1) and how they are linked to various components/steps such as the qualitative elements of the scenarios (Step 3 – 5), regional disaster risk (Step 8) and utilisation and analysis (Step 9).

UNHaRMED is a software that has been designed for improving the long-term understanding of disaster risk and allows for the testing of different risk reduction options against alternate scenarios of socio-economic and environmental conditions. The software models the risk from multiple natural hazard types, in this application coastal flooding, bushfire and earthquake, and shows the user how the risks from each of the hazards change into the future by the production of policy-relevant metrics, such as average annual loss, for different scenarios and risk reduction decisions. Further details on UNHaRMED can be found in van Delden et al. (2017).

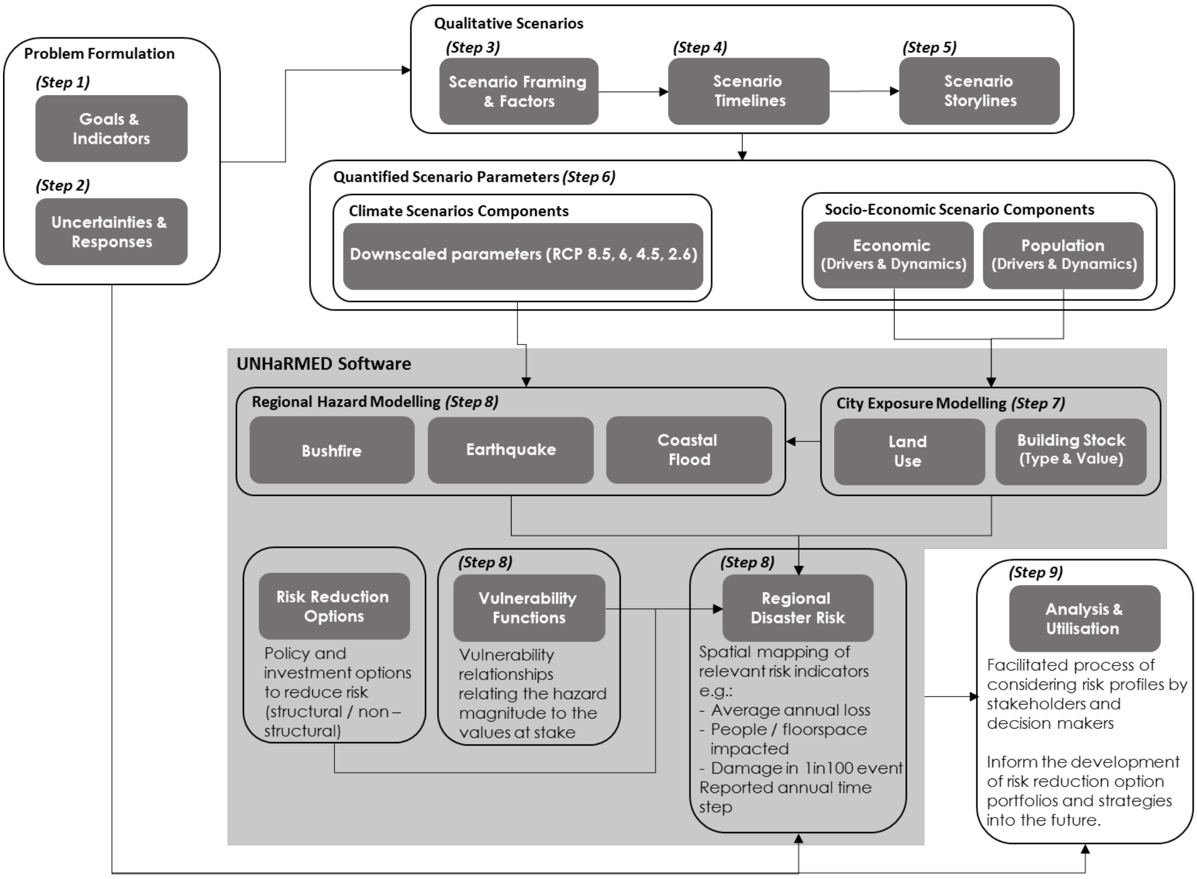


Figure 4-4: Approach flow diagram highlighting the role of UNHaRMED as applied in the Greater Adelaide case study.

The following sections outline the implemented steps in the Greater Adelaide case study, and highlight the outcomes and results of each. The first paragraph(s) of each section provide generic information regarding the approach, before providing specifics of the case-study application.

4.3.1 Stage 1: Problem formulation

4.3.1.1 Step 1: Identify goals and indicators

The first stage looks at problem formulation and scoping of issues. Step 1 of this stage allows stakeholders to provide input on the risk assessment process' overarching goals and identify indicators for this to be measured against. Setting the overall goal is critical to a successful process and to develop trust between different actors involved in the stakeholder group, and the project team. The goal should relate to the risk assessment and subsequent treatment process, which the scenarios and modelling complement. With goals determined, indicators are required to measure the success of the process, but also what indicators are included in the risk assessment, allowing for comparison across developed scenarios and for policy impact assessment. Enabling the joint determination of policy and process goals and indicators in a participatory manner supports the search for a frame that enables multiple actors to promote or protect their own interests and can support the reduction of uncertainty by consciously exposing alternative conceptualisations of agendas and challenges (Dewulf et al., 2005).

For application to the case study, this step required a facilitated process with stakeholders. This process took a visioning perspective to better enable productive, positive responses and reduce the potential trap of the framing being focused on current challenges around budgets and politics, given the exercise was future-focused. Therefore, responses were collected to the request for a one sentence description of participants' vision for the region related to natural hazards and risk for the year 2050, which were then shared with the group in an anonymous manner. Key elements of similarity were then debated by the group to enable the focus of the scenario analysis to be on considering multiple hazards and long-term challenges from socio-economic development and climate change. Examples of policy objectives include, "Thriving region because people choose to live in places that are safe, where risks can be mitigated and they can support themselves and their community", " Natural hazard risks & impacts are minimised sustainably", "A resilient future for our children", and "A healthy, prosperous & safe community with potential for growth & development".

For the process to be considered successful, it had to enable stakeholders to gain an understanding of differences in future risk via the scenario development and analysis. This required the process to be designed in a manner where continued sensemaking (Klein, Moon, & Hoffman, 2006) could occur between the scenario team and participants, and also that the results were in relevant metrics to enable comparison and insight. To support this, stakeholders outlined indicators to be provided for the scenario analysis to enable comparison across pathways, and also agreed to the process of engagement over the project combining structured events such as a series of workshops, along with the need for more informal meetings between certain stakeholders and the scenario team. Indicators considered relevant for the comparison and to be explored in terms of their feasibility by the project team are shown in Table 4-1.

Table 4-1: Overview of policy objectives and indicators for Greater Adelaide case study.

Dimension	**Indicator**
Economic	Cost of primary damage (average annual loss)
	Business disruption losses
	Loss of employment
	Damage to significant Government infrastructure (value >$1million)

Dimension	**Indicator**
Social	Amount of impact to critical infrastructure locations
	Impact on Gross Domestic Product (GDP)
	Loss of essential service provision
	Impact to areas of cultural significance
	Number of people impacted
	Change in morbidity / mortality rates
Environmental	Area of vulnerable/protected ecosystems impacted
	Area of primary agriculture impacted
	Area of heritage land impacted

4.3.1.2 Step 2: Explore uncertainties and responses

Step 2 focusses on the scenario development process by considering drivers for change and uncertainties, as well as implemented responses / risk treatment measures that could impact on the success of the goal and hence can be measured with the indicators. Here, there are inputs from both the stakeholder group and required experts, who can provide specific information regarding options available and broader understanding of the relevant trends that may influence long-term risk. By including expert opinion, broader knowledge can be captured in the process, and can stimulate stakeholders in new thinking (Inayatullah, 2018; McBride et al., 2017).

To inform this process in Greater Adelaide, questionnaires and semi-structured interviews were conducted with 14 stakeholders and experts in growth dynamics for the region to provide input as to key drivers for change in the state, along with key uncertainties that could affect how well the State is able to reduce the risk from natural hazards. Questionnaires with open-ended questions allowed participants to document freely their responses, and these responses along with collected and analysed discussion from the interviews are summarised in Figures 4-5 and 4-6 from Van Delden, et.al. (2015a).

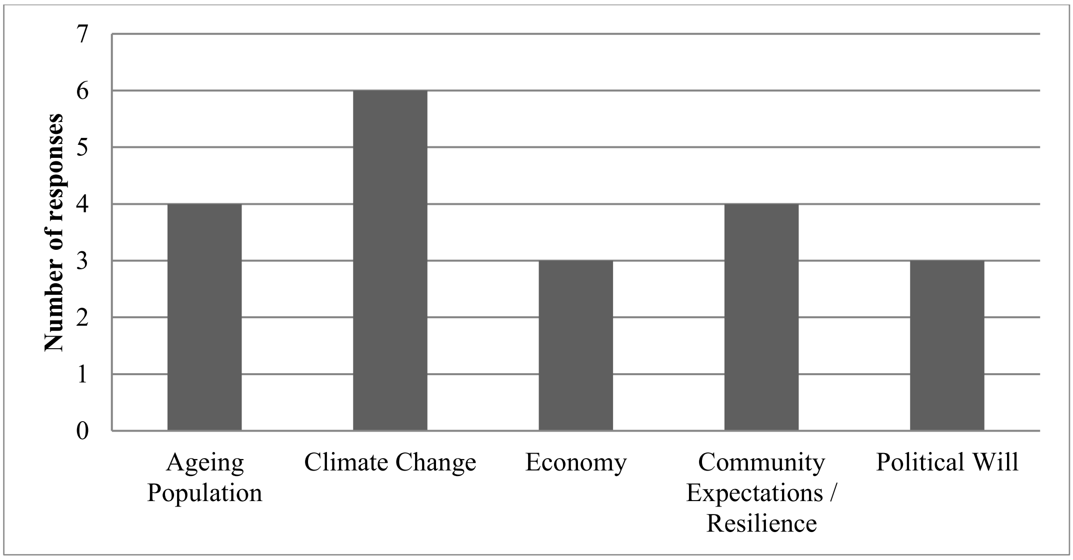


Figure 4-5: Stakeholder responses to the key drivers for change in South Australia over the next 50 years.

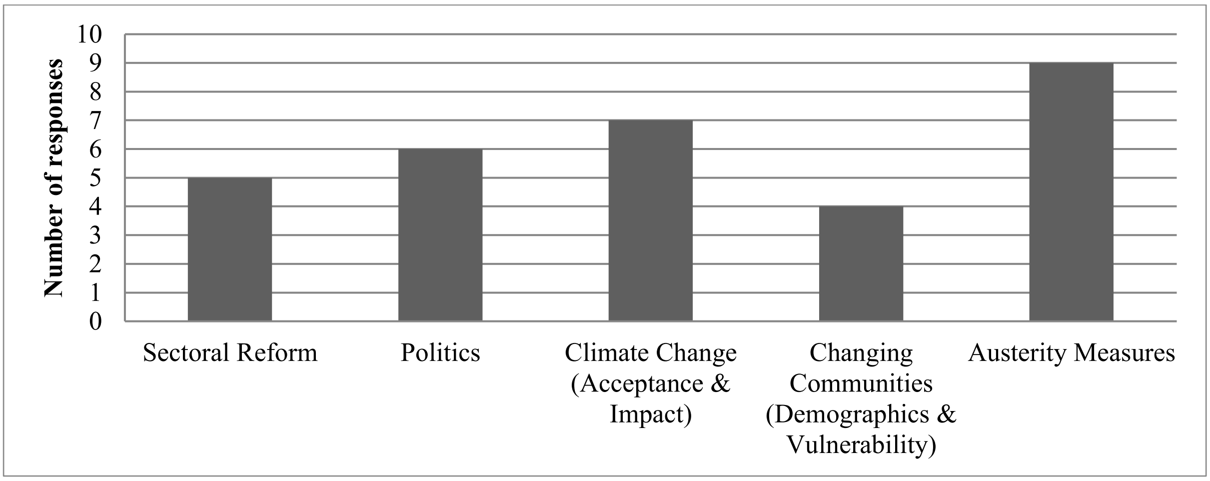


Figure 4-6: Stakeholder responses to the key uncertainties in SA's ability to reduce disaster risks in the next 50 years.

To support the process in its ability to be focused on risk treatments following the exploratory scenario-based risk assessment presented here, risk reduction options that could be implemented over extended periods of time were considered. These considered actions to reduce the likelihood and impact of a disaster event and were identified and collated in a brainstorming session with stakeholders and subject matter experts on the disaster types considered relevant to the region. This brainstorming session developed around 100 individual mitigation options clustered around nine key themes. A summary of the most repeated of these results is shown in Table 3-2. This collection of risk reduction options was then used within the scenario process, using them as drivers for framing the scenarios (see Chapter 4.3.3 – Step 3 and (G. A. Riddell et al., 2018), or Chapter 2), along with being considered in Step 9, analysis and utilisation (see Chapter 4.3.9), to enable comparison of the effectiveness of particular options against those of different options and portfolios of options.

Table 4-2: Risk reduction options collected during stakeholder engagement for Greater Adelaide case study.

Clustered Theme	**Prevalent Risk Reduction Options**		
Building Codes	Increasing recurrence interval for all hazards in code	Inclusion of hazard resistance for hazards not considered	Specific strengthening for buildings of community value
Land Management	Planned burning, reduction of fuel load	Improved enforcement mechanisms (e.g. illegal vegetation clearance)	Land reclamations
Community Based	Arson reductions programs	Integration of hazard programs in school curriculum	Increase community awareness (risks, safety strategies)
Structural	Building hardening (in particular for residential infrastructure) and structural upgrades for legacy buildings	Providing more assistance to owners of buildings in hazard areas to upgrade buildings	Hazard impact reduction measures such as levees, seawalls etc.
Learning *(Response to Plan and Prepare)*	Agreement on residual risk, government and communities	Implementation of business continuity plans	Structured framework for lessons learnt
Institutional Change	Establishment of multi hazard agencies	Tougher legislative requirements to build in higher risk zones	Adaptive policies (thresholds) for decision making (linking with adaption to climate change)
Land Use Planning	Building exclusion areas, flood plains, bushfire areas	Ensuring development in hazard prone areas are compliant to highest codes	Increase access to information for property owners
Legislation	Regulatory requirements to consider natural hazard risk in planning	Provide hazard leaders/control agencies with greater powers to question developments	Resource planning to mitigate response/recovery
Financial Instruments	Effective cost : risk assessment	Use of Emergency Services Levy to fund risk reduction	Funding to support institutional change (increased integration, coordination and planning)

4.3.2 Stage 2: Scenario development (qualitative elements)

4.3.2.1 Step 3: Determine scenario framing and factors

Qualitative scenarios describe different futures via words and visual symbols (Alcamo, 2008), often resulting in narrative storylines that either outline the condition of the region or system at a particular time in the future, or outline the timeline of events and trends that lead to a particular state at a slice in time. Often qualitative scenarios will combine these two. The approach applied looks to group responses (risk reduction options from the previous stage) into two categories, which create framing axes of the scenario space. These axes represent increasing challenges to the implementation and effectiveness of risk reduction treatments, so that as one progresses along either x or y axis the challenges increase. The space between axes can be split into quadrants representing combinations of drivers. This is shown as the outcomes of interest framing described in Riddell et. al., 2018 (Chapter 2).

Relevant factors to each axis are also discussed with stakeholders to provide the basis of the narratives to be developed. From workshop discussion with stakeholders and inputs from experts, these factors represent elements that are important in the implementation and effectiveness of responses – for example, sufficient resourcing is a factor relevant to how successful fuel reduction burns can be implemented. Experts are used to supplement stakeholder input if sufficient knowledge is not held within the stakeholder group regarding relevant factors to the effectiveness of policies and how they can be conceptualised within scenario development.

For the case study, based on the risk reduction options shown in Table 4-2, the scenarios were framed around increasing challenges to the development and implementation of risk reduction options by government (such as the construction of flood protection works, or land use planning strategies to reduce exposure to disasters), and options more driven by the community and focused on enhancing society's ability to deal with disasters. This grouping and split was done by experts from the scenario team with an understanding of the needs for these driving axes to enable more efficient scenario development and provide greater policy relevance to the scenario analysis. For full details on the methodology see (G. A. Riddell et al., 2018). Using the driving axes, stakeholders were then asked to consider the factors that would enable the design and implementation of government-led risk reduction options and create and enhance resilience to disaster risk. The factors formed the basis for the scenario timeline development (Step 4), with stakeholders proposing multiple factors for which assumptions would then be made regarding how they would change based relevant uncertainties.

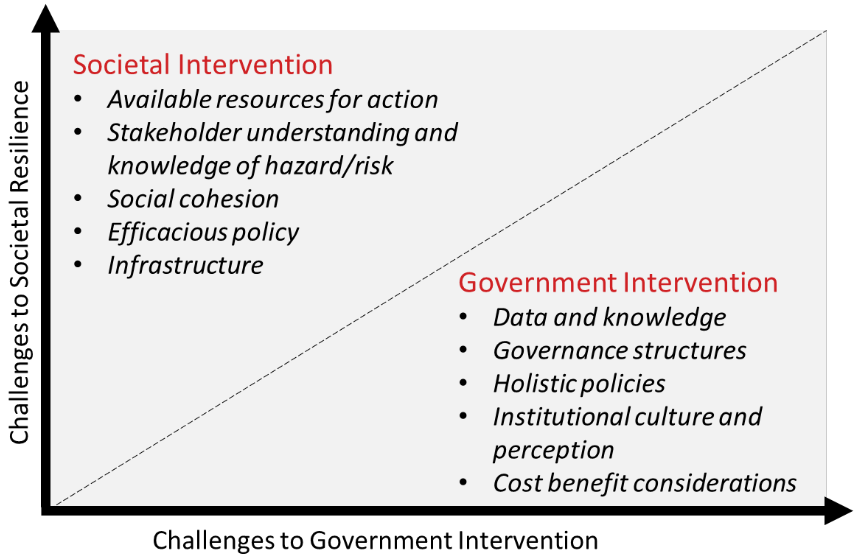


Figure 4-7: Overview of scenario drivers and elements for Greater Adelaide case study.

4.3.2.2 Step 4: Develop scenario timelines

Stakeholders, with the framed scenario space and relevant factors, then develop timelines for plausible assumptions for how factors may change with time based on the scenario's framing axes. This requires a facilitated process with small groups of stakeholders working with a facilitator to construct timelines for each scenario, for each factor relevant to the framing. This process enables stakeholders to explore the drivers of risk in the region, while considering the impact of uncertainties on the factors relevant to the effectiveness of risk reduction options. The outcome is a timeline of events related to each factor for each scenario, which forms the basis for the more detailed storylines developed by experts in the next step (Chapter 4.3.2.3).

For the case-study, due to limited time with stakeholders in participatory sessions, three timelines were developed to inform the construction of five scenarios. Stakeholders were split between groups to develop timelines for scenarios for the vision scenario (low challenges to both government actions and societal resilience), and for each of the scenarios which had high challenges to one of the risk reduction options and low challenges to the other. Coloured post-it notes for each factor were used to allow stakeholders to outline the events and place them on the timeline from 2015 to 2050, Figure 4-8 shows one of these timelines under-development during a session. These notes were then documented after the participatory sessions to enable the scenarios to be developed into cohesive, and salient storylines. Consideration during the drafting was given to each of the key factors (from Figure 4-7) progression with time against the indicators considered relevant for effective disaster risk management actions (from Table 4-1).

Figure 4-8: Stakeholder input developing a scenario timeline from 2015.

4.3.2.3 Step 5: Draft scenario storylines

Timelines developed in participatory workshops provide the skeleton for a first draft of the qualitative scenarios. These are detailed, with expert opinion supplementing the participatory timelines by drawing on previous experience, literature, existing scenario studies (at different scales – national, global), to draft coherent, consistent and salient narrative storylines. These storylines are then provided to stakeholders for comment and editing based on whether they considered the scenarios to be 1) representative of their thoughts in previous scenario sessions, 2) internally consistent and not contradictory, 3) extreme enough, and 4) too extreme.

For the case study, the scenario team used the three timelines developed by stakeholders to draft five storylines for the following scenario frames:

- one future for Greater Adelaide where it was simple to design and implement mitigation strategies and develop societal resilience, which was considered the vision for the region;
- one extreme future that challenged both resilience and mitigation strategies;
- two intermediate futures that challenged either resilience or mitigation to a greater degree; and
- one central future with moderate challenges to both resilience and mitigation.

Drafting was performed by a small team of writers, which enabled the process to combine both stakeholder knowledge of context factors along with the integration of broader perspectives and historical trends related to disaster risk. Scenarios were drafted to consist of a narrative summary, along with information for each of the five scenarios regarding multiple socio-economic components such as population and urbanisation, community profile, economy and lifestyle, and politics and institutions. Examples of the storylines include opening sentences for Silicon Hills as:

> "Greater Adelaide transitions towards a well-balanced technology focussed economy, driven by highly skilled and engaged locals and expatriates as well as immigrants looking to capitalise on the State's booming high-tech industry while enjoying the relaxed, nature filled lifestyle the Mt Lofty Ranges and Adelaide Hills offer".

And for Internet of Risk as:

> "Global connectedness drives an increasing reliance on the internet for social interaction and working styles. This reliance on the World Wide Web sees dispersed residential living as the attraction of the CBD and physical centers lessens, leading to a significant loss of physical connectedness and an increase in siloed communication between similar individuals and services by a small, but growing, services sector providing for the hordes of online workers."

These two openings show clear similarities in themes and drivers for the future, such as the role of technology and changing work patterns. These similarities in drivers is critical as the scenario storylines allow stakeholders to explore how each of them play out in terms of risks and what policy actions may be required to enable a more positive future with similar drivers for positive and negative futures. It is also important in how they are quantified in terms of where developments occur and what vulnerabilities exist within them. Figure 9 provides an overview of each of the five scenarios drafted, and their framing between axes. Results to the four questions posed to assess stakeholder acceptance of the qualitative storylines is shown in Figure 10, highlighting broad agreement. The areas where agreement was not universal resulted in discussion and, if needed, changes were made to the draft. Full details on scenarios can be seen in Riddell et al. (2018).

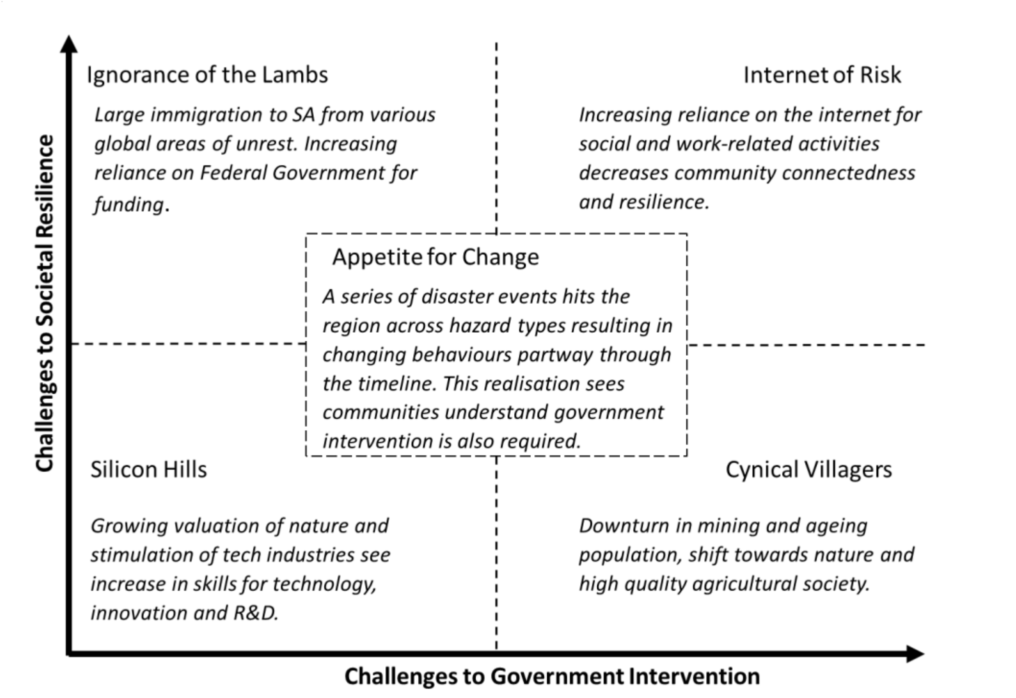


Figure 4-9: Overview of five qualitative scenarios developed for Greater Adelaide.

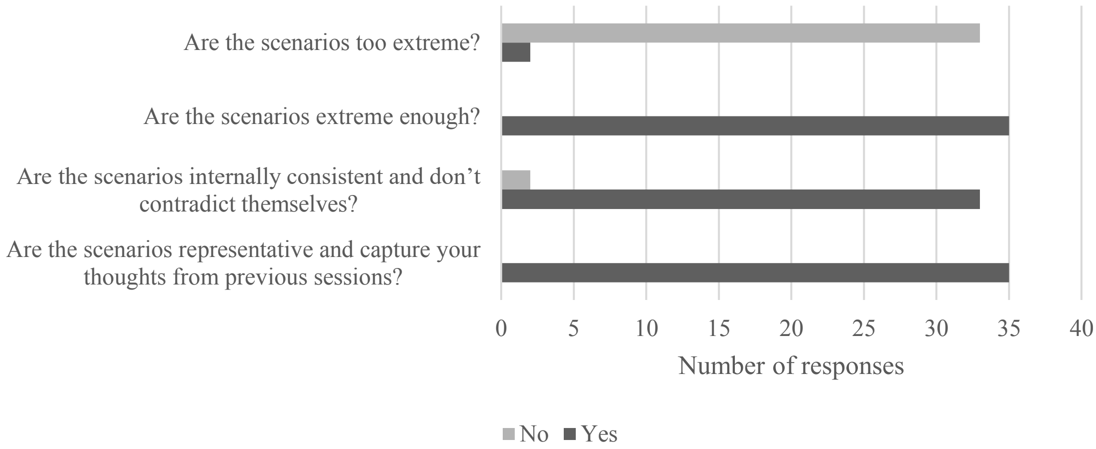


Figure 4-10: Stakeholder responses regarding the drafted scenarios sourced from Riddell et. al., 2018

4.3.3 Stage 3: Scenario development (quantitative elements)

4.3.3.1 Step 6: Quantify socio-economic factors from storylines

Quantitative elements of scenarios consist of the external drivers, parameters and possibly model structures used to temporally simulate the qualitative narrative elements. The quantification of factors from the storylines, Step 5, typically is undertaken by expert opinion and judgment of the modellers who look for elements from the storylines that can be used to inform elements of the model to be modified. This follows the identification of clues, indicators and impacts that inform the parameterization of the model. This approach follows the storyline and simulation approach as outlined in Alcamo (2008), and uses the CI2 methodology outlined in van Delden and Hagen-Zanker (2009).

For the case study, using the qualitative storylines, initial parameterization by experts was based on linking elements of the scenarios to existing government projections for growth for the region regarding population, and land requirements for economic demands. The simulation modelling of socio-economic (and disaster risk) scenarios was performed using UNHaRMED (van Delden et al., 2017) which utilises the Metronamica land use model (RIKS, 2011; van Delden & Hurkens, 2011) to project future land use change, and subsequently risk exposure. Using Metronamica to simulate land use futures requires determining the drivers for changes in dynamic land uses, which are demands for land in hectares per year per land use as well changes in biophysical conditions, infrastructure, zoning and human behaviour. The scenarios also informed the relationship between land uses in the form of neighbourhood dynamics, for instance in regard to how the scenario considered the densification or sprawl of residential development. Tables 3 and 4 highlight the quantification assumptions for population and employment change, along with how this was translated into requirements for land. There is a tight linking between Steps 6 and 7 with experts' opinion and judgement used for initial parameterization and then using simulation modelling to test the outcome of those assumptions before refining and iterating to arrive at internally consistent, alternative scenarios.

Table 4-3: Assumptions for scenario quantification of population and employment changes outlining changes in population and employment values from a baseline and what informed the assumption.

	Population and employment change in 2030/2050 compared to 2013 (%)					**Motivation**				
Element	S.1	S.2	S.3	S.4	S.5	S.1	S.2	S.3	S.4	S.5
Population	27 / 46	8 / 15	38 / 92	19 / 38	8 / 15	Adapted from 30 year plan based on storyline	Adapted from 30 year plan based on storyline	Adapted from 30 year plan based on storyline	Projections 30 year plan + extrapolation	Adapted from 30 year plan based on storyline
Population split over urban and rural	70 / 30*	66 / 34^ 64 / 36*	80 / 20^ 90 / 10*	72 / 28^ 75 / 25*	65 / 35^ 60 / 40 *	Current split	Adapted from current split based on storyline	Adapted from current split based on storyline	Initially current split, adapted based on model results	Adapted from current split based on storyline
Commercial	40 / 82	-3 / 5	8 / 17	8 / 17	15 / 30	Developed based on current employment and storyline	Medium projections PSA forecast -10% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation	Average of medium and high projections PSA forecast & extrapolation
Public institutions including education	40 / 82	-13 / -4	9 / 20	9 / 20	-13 / -4	Developed based on current employment and storyline	Medium projections PSA forecast -20% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast -20% & extrapolation

Industry	34 / 74	-14 / - 18	-14 / - 18	-4 / -9	-4 / -9	Developed based on current employment and storyline	Medium projections PSA forecast -10% & extrapolation	Medium projections PSA forecast -10% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation
Agriculture	-22 / - 22	5 / 10	-22 / - 49	5/ 26	-22 / - 49	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	Developed based on current employment and storyline	Medium projections PSA forecast & extrapolation
Horticulture	-22 / - 22	5 / 10	-22 / - 49	5 / 26	-22 / - 49	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	Developed based on current employment and storyline	Medium projections PSA forecast & extrapolation
Livestock	-22 / - 22	5 / 10	-22 / - 49	-12 / - 30	-22 / - 49	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	High projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation

^ Until 2030
* Until 2050
S.1 – Silicon Hills, S.2 – Cynical Villagers, S.3 – Ignorance of the Lambs, S.4 – Appetite for Change, S.5 – Internet of Risk.
NB 1: PSA – Planning SA who provide population and economic projections. 30 Year Plan is the main document outlining Adelaide's strategic plan for the next 30 years in terms of infrastructure and planning, produced by the Department of Planning, Transport and Infrastructure.
NB 2: Livestock, horticulture and agriculture demands held constant between 2030 and 2050 for Silicon Hills is aligned to the assumption of increased efficiency in land use and production and a non-increasing demand for "agricultural-related" land in the region which is predominately metropolitan.

Table 4-4: Assumptions for scenario quantification of land use change based on motivating factors from the scenarios.

	Land use change in 2030/2050 compared to 2013 (%)					**Motivation**				
Land Use	S.1	S.2	S.3	S.4	S.5	S.1	S.2	S.3	S.4	S.5
Residential (urban)	15 / 22	1 / 5	58 / 146	16 / 34	0 / -1	Densification 10% by 2030, 20% by 2050	No change in density	No change in density	Densification 5% by 2030, 10% by 2050	No change in density
Rural residential	15 / 22	2 / 7	-7 / -35	7 / 11	27 / 55	Densification , 10% by 2030, 20% by 2050	Densification , 20% by 2030, 30% by 2050	No change in density	Densification 5% by 2050	No change in density
Commercial	17 / 40	0 / 5	8 / 17	8 / 17	15 / 30	Densification 20% by 2030, 30% by 2050	No change in density	No change in density	No change in density	No change in density
Public institutions including education	8 / 21	-2 / -4	9 / 20	9 / 20	-2 / -4	Densification 30% by 2030, 50% by 2050	No change in density	No change in density	No change in density	No change in density
Recreation	15 / 22	2 / 7	0 / 0	10 / 18	0 / 0	Increase according to increase in residential surface	Increase according to increase in residential surface	No change in surface area	Increase according to increase in residential surface	No change in surface area
Industry	3 / 9	-14 / - 18	-14 / - 18	-4 / -9	-4 / -9	Densification 30% by 2030, 60% by 2050	No change in density	No change in density	No change in density	No change in density
Agriculture	-6 / -14	-2 / -4	-22 / - 49	1 / 5	-22 / - 49	Dispersion, 10% by 2050	Originally no change in density, based on model results 15% increase by 2050	No change in density	Intensificatio n, 4% by 2030, 20% by 2050	No change in density

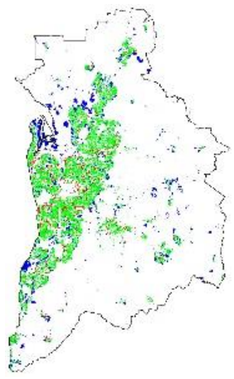
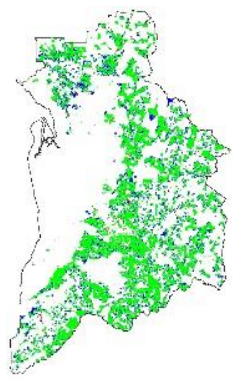
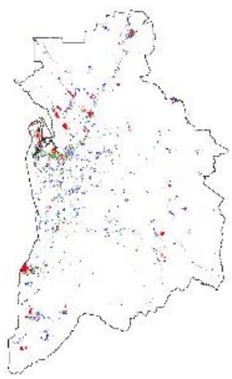
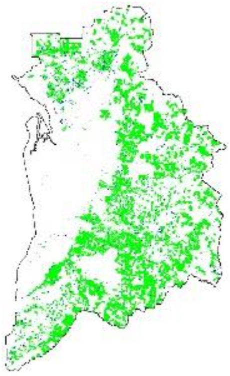
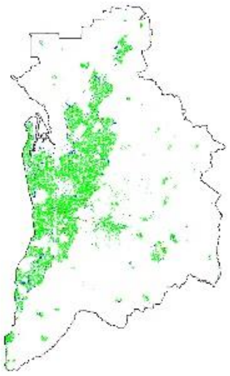
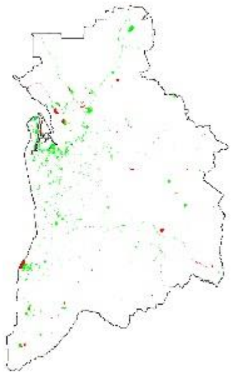
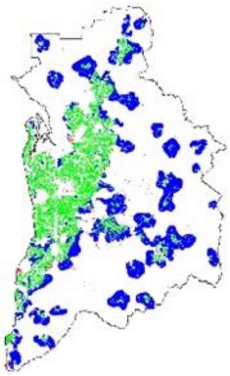
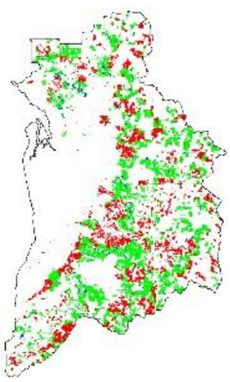
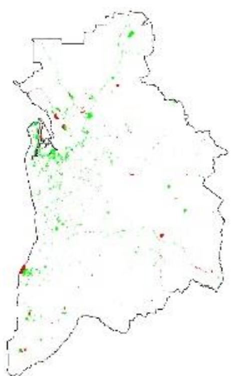
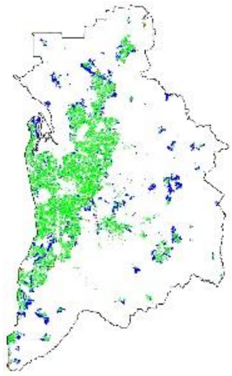
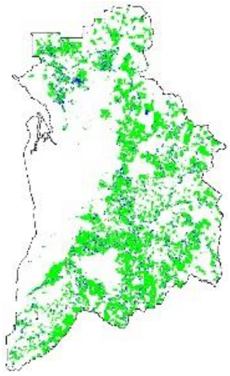
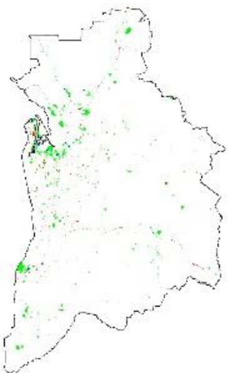
Horticulture	-22 / -22	-1 / -3	-22 / -49	1 / 5	-22 / -49	No change in density	Originally no change in density, based on model results 14% increase by 2050	No change in density	Intensification, 4% by 2030, 20% by 2050	No change in density
Livestock	-22 / -22	-1 / -2	-22 / -49	-16 / -33	-22 / -49	No change in density	Originally no change in density, based on model results 12% increase by 2050	No change in density	Intensification, 4% by 2030, 4% by 2050	No change in density

S.1 – Silicon Hills, S.2 – Cynical Villagers, S.3 – Ignorance of the Lambs, S.4 – Appetite for Change, S.5 – Internet of Risk.

4.3.3.2 Step 7: Simulation modelling of socio-economic futures

Simulation models are then modified based on each factor relevant to a particular scenario to then simulate socio-economic futures under each of the scenario conditions, Step 3 and 4. Critical is the feedback from scenario simulation modelling to inform both the parameterization and possible changes to the qualitative storylines. The simulated socio-economic futures should be used to edit the storylines if modelled extremities between scenarios are not found to be sufficient, and also if inconsistencies and incoherence are found in the scenarios. This is the value of combining both qualitative and quantitative elements with simulation modelling, as discrepancies that otherwise may have been missed are able to be highlighted.

As outlined in Step 6, UNHaRMED was used as part of the case study to perform the scenario analysis and, as such, the outputs in terms of socio-economic futures are produced in the form of land use maps. For Greater Adelaide, summaries of these are shown in the Figure 4-11 (see Appendix E for a report on the developed socio-economic scenarios). Here the change in critical urban land uses for the five scenarios can be seen, showing the growth and loss in each of the land use classes (residential, rural residential, and industrial). These outputs are then used to provide a component of exposure modelling for Step 8 – scenario modelling of disaster risk. As can be seen in the outputs for land use in 2050, clear differences are evident in terms of the urban form for the region under the different scenarios, with subsequent impacts of people and values exposed. For scenarios with greater economic growth, such as *Silicon Hills*, there is significantly more development of industrial land, aligning with the growth narrative. Similarly, *Ignorance of the Lambs* and *Appetite for Change* see more development in the rural residential space, with urban sprawl being a clear driver for change.

	Residential	**Rural Residential**	**Industrial**
Silicon Hills			
Cynical Villages			
Ignorance of the Lambs			
Appetite for Change			

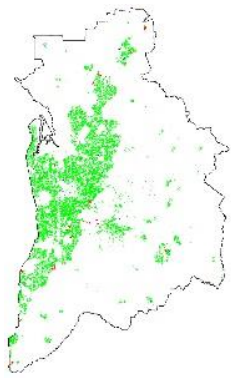
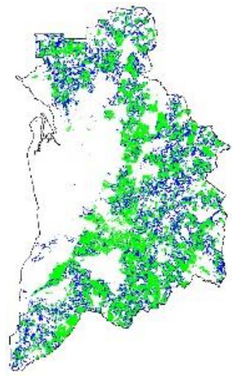
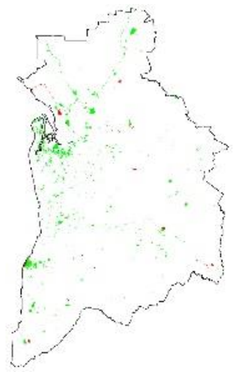
Internet of Risk			

Figure 4-11: Changes in land use classes between 2016 and 2050 for each of the five scenarios across urban land uses – residential, rural residential and commercial. Green represents same land use in both years (2016 and 2050), blue is new land development between years (i.e. new residential development between 2016 and 2050), and red is land decline between years (i.e. residential land use in 2016 and not in 2050).

4.3.4 Stage 4: Future risk assessment

4.3.4.1 Step 8: Scenario modelling of disaster risk

With the qualitative and quantitative elements of the scenario developed and agreed upon, scenario simulation modelling of disaster risk is then undertaken. The socio-economic drivers of risk (encapsulated within the scenarios) are used as inputs into the risk assessment providing trends of socio-economic development, and associated changes to exposure, vulnerability and hazard. Established climate change scenarios (i.e. downscaled regional RCPs) can also be integrated in a plausible manner, combining socio-economic and climatic drivers to consider future risk. The simulation modelling of risk enables a dynamic representation of how risk changes over the modelled horizon, with variations in risk profiles driven by the differences in scenario variables (model drivers, and parameters). The results of this modelling (spatial maps of average annual losses, and areas exposed to high risks, across different scenarios), are then used to consider the drivers and systems of risk.

As previously outlined, the simulation modelling of both socio-economic and risk components for the case study were undertaken using UNHaRMED, a software application designed to be used for this type of scenario analysis. Hazards modelled for the case study region were bushfire, coastal flooding and earthquake, with climate change scenarios used to drive factors such as temperature and relative humidity relevant to bushfire risk, along with sea-level rise considerations for coastal flooding. Full details on how each of the hazards is modelled is contained in van Delden et al. (2017). However, it should be noted that for earthquake and coastal flooding hazards, the modelling is performed externally and maps of hazard magnitude for specified return periods, at points in time related to a climate scenario (for coastal flooding), are used as inputs to UNHaRMED. Bushfire hazard is calculated internally considering vegetation types, climate and terrain factors, which allows for an interaction with urban growth dynamics via changes to vegetation layers and ignition likelihood. These inputs of hazard magnitude and likelihood are then used to provide estimates of risk when combined with land use layers and a building stock model that includes building types, and their associated value and vulnerability to hazard events.

Results of this analysis are shown in Figure 4-12, which plots total average annual loss (combined across bushfire, earthquake, and coastal inundation) against time for the five scenarios, all considering climate change scenario RCP 8.5. As can be seen, there are significant differences across scenarios in how average annual loss changes with time. *Ignorance of the Lambs* has far higher future potential losses related to the level of the development associated with the scenario, where this development takes place (mostly peri-urban regions) and the construction types associated with the developments favouring cheaper methods. *Silicon Hills*, through its qualitative development was written to have the least future risk however as shown in Figure 4-12, this is not the case. This is due to the degree of development within the region especially in the port region and subsequently will be exposed to future flooding from sea-level rise.

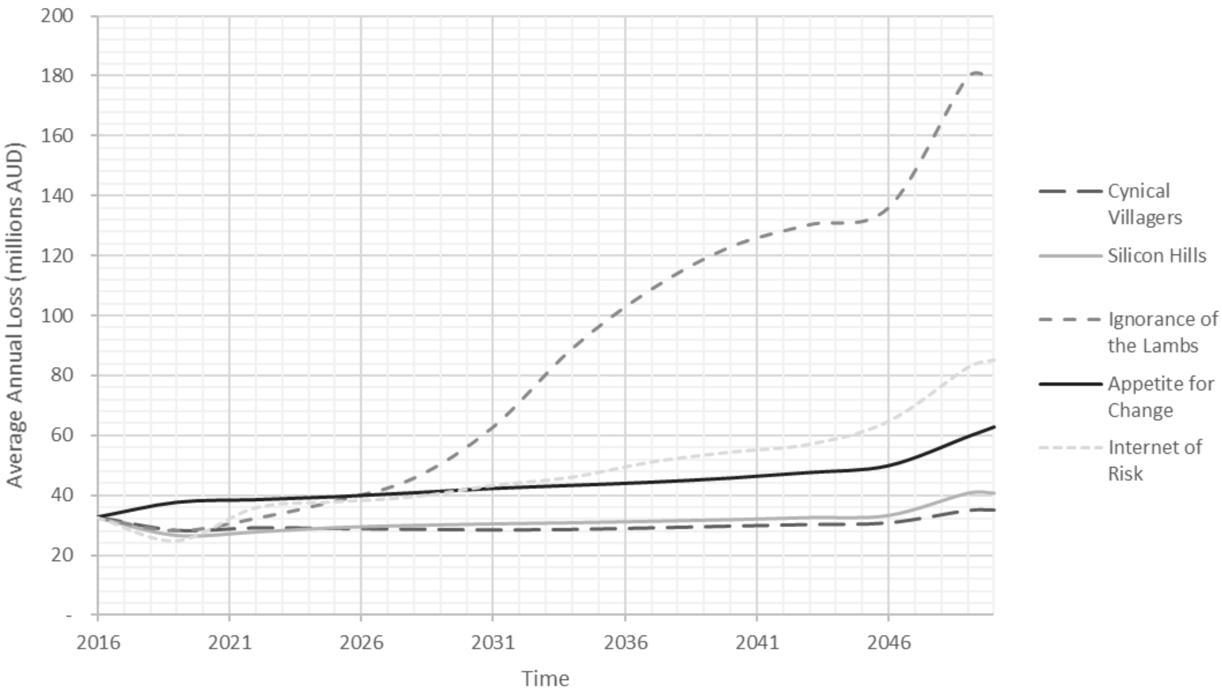


Figure 4-12: Plot of average annual loss in millions of Australian Dollars against time from 2016 to 2050.

Analysis of why these changes are occurring, and the similarities and differences between scenarios, allows for the development of strategies that may work across different alternate futures, making them more robust to future conditions (Maier et al., 2016; Scott et al., 2012). This type of analysis can also support the development of adaptive strategies, such as adaptation pathways which enable decision makers to consider when to change between strategies as conditions change and adaptation tipping points are met (Haasnoot, Kwakkel, Walker, & ter Maat, 2013; Kwadijk et al., 2010).

4.3.4.2 Step 9: Analysis and utilisation

Analysis of these results enables identification of risks that are prevalent regardless of scenarios and risks that are more dynamic and variable. This can then be used to inform appropriate risk treatments and how they perform under a variety of futures. This process of sensemaking enables stakeholders and decision makers to integrate the modelled data into their decision-making context and provides opportunities to discuss strategic responses to future risks, considering what can be influenced and altered over extended planning horizons, and what risks need to be treated with a more tactical approach. Figure 4-13 shows the participatory process undertaken in Greater Adelaide, with stakeholders engaging with the scenarios, representing the different socio-economic and risk futures.

Figure 4-13: Stakeholders during sensemaking workshop discussing model results.

Figure 4-14 shows visually the difference in risk across the five scenarios based on differences in land use and coastal inundation in the port region, highlighting the need to find an appropriate balance between urban expansion and risk appetite. These figures were used during workshop sessions with stakeholders, with experts engaging with them to compare differences between scenarios and gain an appreciation of the drivers of risk for the region. This process enabled stakeholders to consider the results in an interactive and participatory manner, which is critical to maintain consistent framing around goals – as discussed in Step 1 – and for these results to contribute to the development of integrated and strategic risk treatment strategies and plans. Consideration of the futures was discussed against the indicators identified in Step 1, and summarised in Table 4-1, and future risk reduction options were discussed in comparison to these indicators for each of the scenarios. Although the process within South Australia has not yet considered the development of risk treatment strategies using the scenarios to inform performance, studies are underway to enable this.

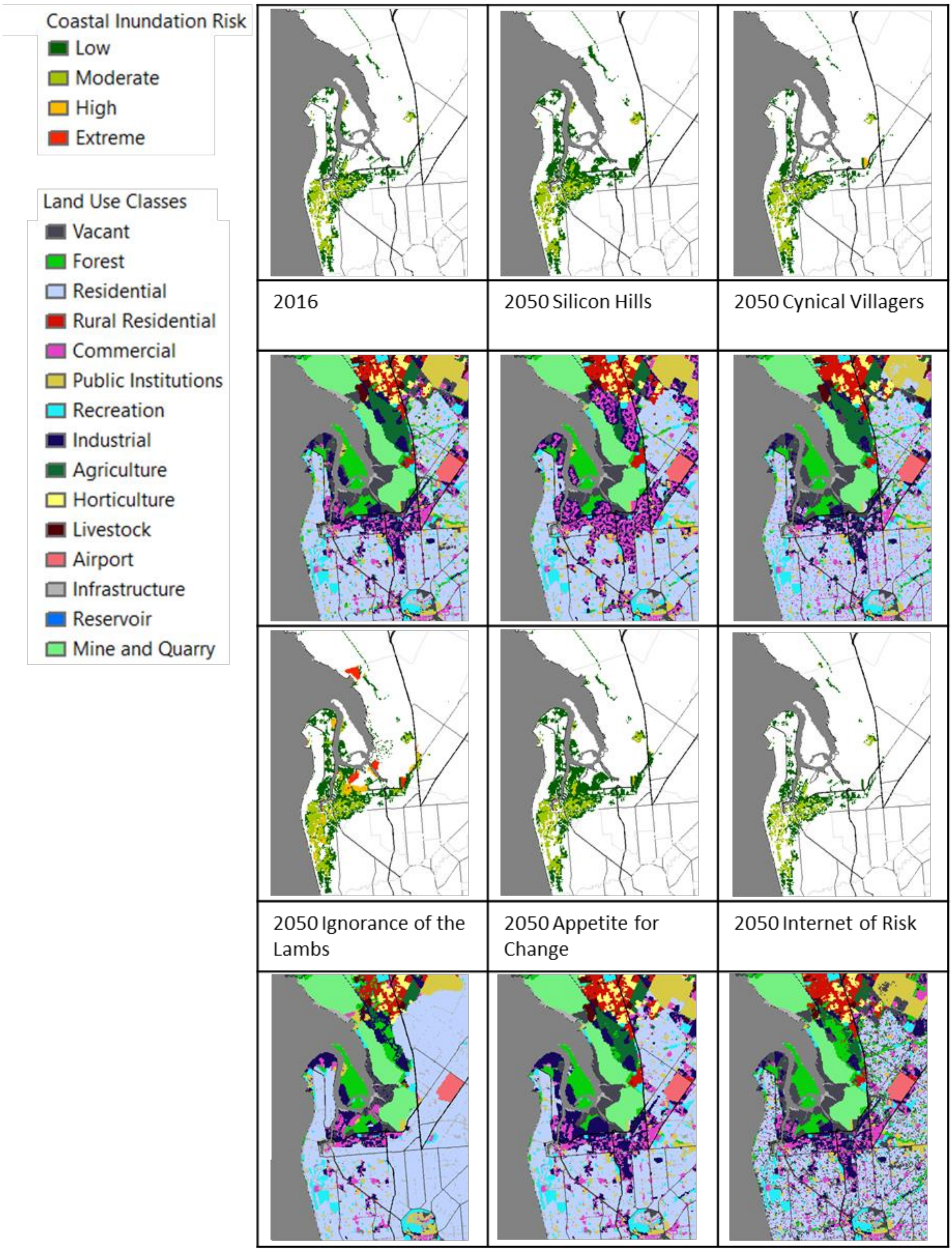


Figure 4-14: Coastal inundation risk (first and third figure rows) and land use (second and fourth rows) for 2016, and 2050 for five scenarios.

Following Figure 4-3, which provides an overview of the approach and its steps, there are also feedbacks from Step 9 to Stage 1 – Problem formulation, and Stage 2 – Scenario development (qualitative elements). These feedbacks are critical to allow both for assumptions made in the beginning of the process to be reflected upon and fed back into the ensuing risk assessment, and for the accounting of the implementation of determined actions, and assessing their effectiveness and how they change the initial context. Although the case study has not, to this stage, allowed for the consideration of these feedbacks given the constraints of the project, it is important to highlight that they should be considered, and efforts will be made to make this scenario planning and risk assessment process iterative across governments within the region.

4.4 Discussion

In this section, discussion is provided regarding the integration of different perspectives and sources of information during the process, the need for challenging and relevant scenarios when performing this type of scenario analysis to improve understanding, and how this process can be applied to other sub-areas within the entire risk management discipline including asset-level assessment and providing an understanding on cross-dependencies.

4.4.1 Combining perspectives to deal with uncertainty and complexity: stakeholders, experts and simulation modelling

A critical component of the methodology was integrating multiple perspectives into the risk assessment process. Consequently, how well this was achieved, and any potential future improvements, are important factors to consider and discuss. The methodology afforded opportunities to bring together different sources of information provided by stakeholders involved in risk reduction activities in the region, experts in scenario analysis and particular elements of the risk reduction planning for particular treatments and hazards, and the outputs from the use of simulation models, which provide quantitative information.

Following the roles outlined in Van Delden et al. (2019), the process relied on the roles of architects and facilitators to manage interaction between different groups providing input to the scenario modelling exercise. These roles were critical in maintaining clear, open lines of communication between all parties and ensuring a 'common language' was spoken. Challenging to the process of integrating diverse perspectives on risk and its future drivers is the need in this approach to translate it into model parameters or boundary conditions. To assist in this process, the architect, facilitators and modellers focused on a process of reduction and in aligning each assumption identified within the qualitative scenario process with an element of risk, either hazard, exposure or vulnerability. This ensured each assumption could be traced to a model component within UNHaRMED, highlighting the impact of each assumption on risk overall, and how they could be compared against other assumptions as to their overall significance.

The other significant challenge with this process is the quantification of elements and although mostly stakeholders agreed with the quantification and subsequent representation of the simulated risk scenarios, this process could definitely be improved. There also exist challenges with the representation of information that cannot be quantified and modelled, regardless of approach, and again, how to capture and describe this is an area for ongoing improvement. The method presented within this paper, however, tried to provide a balance of both quantitative and qualitative insight.

The consideration of complexity in the risk assessment process was also strengthened by the integration of different perspectives, as this increased the diversity of views and understandings involved in the 'establishing context' steps of common risk assessment processes (see ISO 31000, International Organization for Standardization (2018)). By encompassing a broad range of perspectives from stakeholders and experts through participatory processes, factors considered relevant to future risk can be explored, and differing perspectives can be captured through the different scenarios. An example of this was the interaction between risk and an increasingly technology focused world, which could see exposed assets reduced as economic value shifts away from fixed real assets, to technology and software. However, this may result in an increase in an individual's vulnerabilities due to the loss of the concept of 'place' and an understanding of the land where residents lived. Similarly, complexity across governance scales was encapsulated and explored by stakeholders across scenarios, with considerations of the interactions between Local, State, and Federal governments for planning, investment and revenue raising all questioned.

4.4.2 Complexity begets uncertainty: methodological uncertainty in integrated approaches

The approach described and implemented within this paper makes several methodological decisions that also create uncertainty in the outcome, even though the aim is to better understand and reduce these uncertainties. These can be considered methodological uncertainties, which are particularly relevant as an integrated approach, as presented here, brings together a range of methods and techniques from different disciplines, which all together lead to the final outcome.

Key methodological uncertainties include the framing of the problem as this sets the stage for the remainder of the exercise, the stakeholders included and the choice and application of simulation platform for risk quantification and modelling. In terms of problem frame, the funder and project team generally play a crucial role in defining this. This is where the needs for feedbacks from Step 9 to Stage 1 is critical as the introduction of new knowledge through the integrated approach may have altered this.

Considering selection of stakeholders, their inclusiveness and ability to imagine future uncertainties is also a key source of methodological uncertainty. In the case study, the selection was limited to stakeholders from government and NGO agencies, with no community level representatives, due to the governance arrangements of the State's emergency management processes. These are defined by relevant legislation and regulation around emergency management in the region, and thus the project team did not have significant influence on who was included as part of the process. As a result, there is the potential that more weight was added to institutional influence, with visions and objectives of agencies preferred over local communities. This is of especial concern if these visions do not align. This therefore brings uncertainty into the effectiveness of, especially with regard to the ability to implement, any risk reduction actions and is an uncertainty embedded within the case-study and limitation of the approach if not addressed in subsequent applications.

Related to the selection of stakeholders is how they are empowered and enabled throughout the process to ensure fair representation. The ability of the facilitator to create an environment that allows stakeholders to express their views and streamline these views is critical but uncertain. For key stages informed by stakeholders such as the selection of drivers and scenario framing this can have significant influence on the outcomes.

Another source of uncertainty that the methodology brings into the outcomes is the choice of simulation platform used for quantifying and exploring the risk profiles. Linked to this is also the process for quantifying qualitative information from the narratives (as already discuss in the previous section). In the case study application, Steps 6 and 7 were performed using the UNHaRMED platform, which is specifically designed to explore integrated scenarios of this nature (see Van Delden et al., 2019). However, if other specific uncertainties had been determined to being critical to explore, such as economic structure or individual behaviours, other simulation models might have been more appropriate, either as components integrated within UNHaRMED or used independently. The approach described within this paper is not designed to align to a particular simulation model, but instead uses appropriate tools to ensure uncertainty in scenarios is adequately captured and explored. Consequently, decisions on appropriate models should be left until at least Stage 2. Whether simulation model selection and results are appropriate can be tested through extensive engagement with stakeholders, which is why the integration of different knowledge sources is critical. Nevertheless, as part of the practical considerations within each project, the availability of existing or readily adaptable models is often a limiting factor in model selection (van Delden et al., 2011).

These above points have significant influence over the outcomes of the approach and hence decisions made should be taken carefully and in discussion with those initiating the project – for stakeholder holder selection; and those engaged as stakeholders – for modelling decisions. As with all steps of the approach transparency is key to developing trust between parties and confidence in results. However, it should be noted that it is an explicit component of the design of this approach to integrate different disciplines and techniques together to appropriately explore uncertainties in the outcomes especially those which arise from the use of a single approach which commonly occurs for risk assessments and modelling.

Further application of the approach would allow for more testing of outcome sensitivity to these key methodological decision points. This is especially true for application in domains outside of disaster risk assessments which are, necessarily, often constrained by strong regulations and requirements related to risk modelling and disclosures. When these restrictions do not occur in other domains the implications of these choices should be carefully considered to explore the full degree of complexity, and uncertainty that exists in the system and hopefully enable more effective implementation of any determined actions.

4.4.3 Challenging and relevant scenario assumptions for more effective scenario analysis

The value of scenario analysis to inform risk understanding is dependent on the relevance and challenges presented by the assumptions and drivers. Consequently, the methodology presented specifically tries to determine those assumptions that are relevant to the decision context. The one truth of scenario analysis is that the scenario developed, chosen, and/or applied to test the performance of a decision, or uncover vulnerabilities in a system, will never occur exactly as outlined. Instead, scenarios need to be relevant, challenging, plausible, and clear (Kahane, 2012). These conditions aim to ensure the outcomes produce interesting insights into system or decision performance and expose strengths and vulnerabilities. It is for this reason that a limited set of scenarios is presented, in an attempt to demonstrate key uncertainties in a transparent manner with no associated likelihoods or probabilities. Opportunities were, however, presented to stakeholders to further explore scenarios, their parameters, and how their value impacted outcomes during sense-making processes, as described in Van Delden et al. (2019).

As outlined in Chapter 4.3.2.3, Figure 4-10 shows that participants in the process agreed that the scenarios were representative and appropriately challenging – in terms of judgements on extremity. The commentary provided in (Graeme A. Riddell et al., 2018) also supports this assessment by considering the content of the scenarios in relation to their ability to include specific challenging assumptions to the performance of risk reduction options. However, with the addition of the quantification and simulation modelling, further insight can be gained from scenario analysis. Simulated scenarios provide significant insight into the impact of land use change on risk. With variations in growth dynamics, the extent of future disaster risks can be altered significantly. Alternative spatial configurations of exposed values over the alternate pathways highlight the role spatial planning can have on future risks, with subsequent impacts on average annual loss clear in both Figure 4-12 and 4-14.

An example of this is the increased exposure and subsequent risk in the vision for the region – *Silicon Hills*. This scenario was developed by stakeholders as the ideal outcome for the region while considering qualitative components. The quantification of this scenario, however, shows that with a stronger economy, particularly in technology related industries, there is increased demand for land and development in high-hazard areas, see Figure 4-14. This outcome provides evidence for the need for effective risk reduction options, with active management of exposure and vulnerabilities of new developments by government agencies, to meet the economic vision of the region.

4.4.4 Further applications of regional risk scenario analysis

Scenario analysis of disaster risk should enable the testing of performance of different strategies and enable planning against different futures. The benefits of understanding future risks as outlined in this paper are significant and it therefore should play a far greater role in a variety of disaster risk processes across the disaster risk management cycle, including through the approach for risk assessments shown in this paper. Scenario analysis has been introduced in the risk assessment space with the recent call from the Taskforce on Climate-related Financial Disclosures (TCFD) to use scenario analysis to consider exposure to climate risk from both a transition (risks arising from the transition to a low-carbon economy) and physical (risks arising from climate trends and shocks of disasters and extreme weather events) perspective (Taskforce on Climate-related Financial Disclosures, 2017). These efforts should be continued, however, with a particular focus on developing scenarios that are challenging for organisations under future climate regimes and extremes.

The application of the methodology proposed and demonstrated in this paper allows for the consideration of both transition and physical risk aspects, given their relationship when considering risk as the combination of hazard, exposure, and vulnerability is critical. The integration of perspectives, and participatory process of both scenario development, along with consideration of simulation modelling, is also important when assessing climate-related risks, to enable organisations to consider cross-dependencies and complexities in their supply-chains and markets in a systematic and repeatable manner. Critical assets could also be considered using the methodology outlined by overlaying their specific location, use and vulnerabilities onto future risk mapping. This can provide insight into the asset's future exposure to disaster risks, along with insight into the potential increased dependencies on it, for example, the change in households dependent on an electricity substation.

This paper has focussed on its application to disaster risk assessments and this section of the discussion has broadened this to consider hazard and climate-related risks for a range of users and implications, however, its use could be broadened (even) further. The proposed approach in Chapter 4.2 focusses on incorporating complexity and uncertainty into risk assessment processes and this presents opportunities to consider other dimensions of risk, such as the impact of new technology or policy decisions and how they could impact on societal development. In an overarching sense, scenarios provide a mechanism to support the assessment of potential and emergent risks. Challenges, however, still exist in the construction of these scenarios so that they are of most value to the assessment process – with this approach heavily focussed on the spatial assessment of disaster risks – but similar considerations would need to be taken for other domains.

4.5 Summary and Conclusions

This paper proposed an approach to integrate different types of information and insight through exploratory scenarios into the risk assessment process relevant to the levels of uncertainty and complexity required for planning for a future with reduced disaster risk. This was in response to the need for such an approach incorporating the broad and critical uncertainties and complexity that impact disaster risk and the effectiveness of actions trying to reduce tomorrow's risks. Tomorrow's risk is being created today and it is hoped that the exploration of various alternatives provides policy makers a broader understanding of the dynamics of risk and the power of their influence and actions.

The approach undertaken in this study to achieve this was to develop, in a participatory manner with representatives of multiple agencies, and respective opinions, scenarios designed to challenge common responses to disaster risk. This created futures which were challenging and relevant to the study's objectives, and by using quantitative modelling to assist this process, the scenarios become plausible future conditions under which to test the effectiveness of solutions against common, and agreed upon, metrics. The scenarios therefore become future stressing conditions under which to test risk reduction options, and UNHaRMED, the software used to facilitate this analysis, acts as a 'policy wind-tunnel' with the scenarios as simulated conditions testing the performance of designed solutions.

To illustrate the approach and its utility, scenarios were developed that represented plausible developments for Greater Adelaide, Australia, highlighting both challenges and opportunities for the region as it deals with future disaster risk. The integrated manner of these scenarios, considering various drivers for change in the region, allows for a more comprehensive consideration of risk. The results presented particularly emphasize the role of exposure in the calculation of disaster risk. Managing exposure to risk is one of the most powerful mechanisms to reduce future risk and in urban environments, as it is critical to consider future land developments. This process, however, is only the beginning of a true scenario planning process, with these results needing to be embedded within broader policy and strategy development process, which is why the approach is deliberately designed to be embedded within such processes.

This area needs continued research, and effort will continue to be placed working with stakeholders involved in this study on how to best integrate the insights offered by scenario development and analysis into standard policy processes for disaster risk reduction. Further efforts need to also be made in developing models, and systems of models, to enable the testing of assumptions and the effectiveness of policy responses on disaster risk. This study was performed using specifically designed simulation models, and continued development is needed to enable existing risk models to consider future drivers of risk and policy and investment strategies to influence that risk.

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CHAPTER 5

Conclusions

Disaster risk management and associated assessment processes should not only focus on capturing the current state of risk as these will be out-of-date as soon as they are published. Further, focussing only on the current state, omits profiling and subsequently treating emergent risks in a proactive manner. This research has developed a generic framework (Figure 5-1) along with specific approaches for integrating an understanding of the future into disaster risk assessment and management strategies to 1) better understand the drivers of risk; 2) characterise and assess future disaster risk; and 3) use this assessment to more effectively treat these risks considering all components of disaster risk – hazard, exposure and vulnerability.

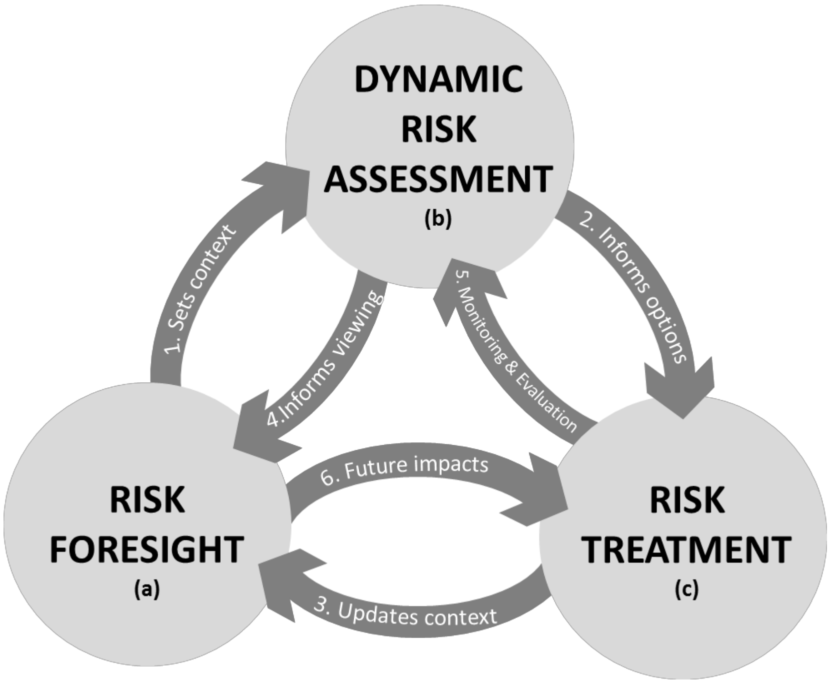

Figure 5-1: Generic framework for integrating risk foresight into disaster risk management processes.

The research has also developed specific approaches to support this integration along with demonstrated applications using exploratory scenarios for qualitative and quantitative disaster risk assessments (DRAs). These have been applied to case-studies in Tasmania and South Australia across multiple hazards and involved interacting with stakeholders across government and non-government organisations in each jurisdiction.

5.1 Research Contributions

The overall contribution of this thesis is a generic framework with a set of demonstrated approaches to integrate foresight into disaster risk assessment and management specifically for emergent risks and their treatments. This has been done through a variety of specific contributions as discussed below. However, it is also important to consider the broader implications of this research in the context of shifting DRAs away from static representations of today's risks and towards providing dynamic representations of risk, its drivers and revealing the effectiveness of policies and investments in reducing both emergent and existing disaster risk. With global goals of substantial reductions in mortality, people affected, and economic impacts by disasters, coupled with a growing and diversifying world and the changing threat posed by climatic change, understanding how and when to influence disaster risk in an effective manner is critical (UNISDR, 2015). It is hoped this research contributes one small step towards a more disaster resilient future.

The specific objectives of this research were to 1) highlight and demonstrate the value of foresight processes being integrated into disaster risk management and assessment processes; 2) provide specific improvements to scenario development and use processes so that they can support effective and insightful disaster risk assessment and subsequent strategic disaster risk management; and 3) provide a generic framework and specific approaches on how scenarios, as foresight processes, can be used within disaster risk assessments. The research, by addressing these objectives, has made the following contributions:

1. Demonstration that current definitions and approaches for disaster risk assessment are lacking in their ability to consider future risk and how to treat them. Based on this the research subsequently provides a new generic framework to integrate foresight into disaster risk assessment and treatment. This framework can be applied to any disaster risk assessment process to identify drivers of disaster risk, integrate them into DRAs, and then identify emergent risks and subsequent strategic, proactive treatments for them.

   This framework has been applied to a DRA for the State of Tasmania, Australia, and in particular for heatwave risk to demonstrate the diversity in risk profiles possible under what were considered plausible outcomes for the future across five key drivers for disaster risk in the state. This application showed 1) the potential increases in disaster risk if risk was not integrated into decision making and strategy for the state; but also 2) the scope for risk reduction with effective mainstreaming of risk reduction strategies across the whole of government (across all departments and levels– Local, State and Commonwealth).

2. A methodology driven by stakeholder engagement to develop exploratory scenarios with increased relevance to policy analysis and making. This methodology was

identified as essential to derive the greatest value from exploratory scenarios being integrated into DRM as previous efforts in other disciplines had identified several (potential) shortcomings to the approach including how the scenarios were designed, their ability to integrate into decision making with insightful, relevant information and their use for trade-off analysis. The methodology therefore contributed towards improving the policy relevance of scenarios along with their ability to be used in policy analysis by providing a mechanism to design them around key challenges to policy and strategy (in contrast to uncertainties) and to develop the scenarios around factors relevant to this. This is instead of traditional factors of uncertainty analysis such as STEEP – society, technology, environment, economy and politics.

The methodology saw scenarios designed in a manner such that they act as interesting or stressing conditions for policies to operate under and thus expose potential shortcomings. Therefore strategies can be developed that would be effective in meeting goals in futures specifically designed to test their effectiveness. This methodology was applied to a DRM context within the State of South Australia, Australia, and resulted in five scenarios for the region in 2050 focussing on challenges to societal resilience and government supported mitigation. Scenarios were developed with stakeholders from the State Mitigation Advisory Group – an advisory body to the State Emergency Management Committee.

3. Following on from the second contribution, as outlined above, these scenarios were subsequently used to inform an integrated modelling approach for quantitative, dynamic DRAs. The third contribution was the development of a methodology for integrating scenarios into quantitative DRMs and developing alternative pathways of disaster risk. This was again shown for the State of South Australia, Australia, and focussed on the metropolitan area – Greater Adelaide. Modelling was performed across multiple hazards, showing how risk changed in space and time across the five scenarios previously developed.

   The methodology also produced insight into how to integrate different information sources – stakeholder perspectives, expert opinion and simulation modelling – to provide insight into the complex and uncertain system of disaster risk. The five scenarios were modelled using a specifically designed software application – UNHaRMED (Unified Natural Hazard Risk Management Exploratory Decision support system (van Delden et al., 2017)). UNHaRMED takes as an input the drivers of disaster risk across hazard, exposure and vulnerability to model how regions change (land use, building stock and other assets) and how they interact with hazards (riverine and coastal flooding, bushfires and earthquakes). This scenario analysis produced spatially explicit pathways through time (2016 – 2050) showing how the average annual loss across different hazards changed following the narrative scenarios. The interaction between narratives and simulation modelling also strengthened the consistency and plausibility of the scenarios and supported their value in trade-off analysis for policy support (an identified, typical weakness of exploratory scenarios).

5.2 Research Limitations

Limitations of this research resulted from access and engagement with stakeholders, tested applicability of proposed methodologies across different contexts, modelling capability, data availability as well as the scope of the research and time constraints. These limitations and potential implications include:

1. **Access to stakeholders.** This research was heavily dependent on interaction with stakeholders who defined much of the scenario work in terms of relevant drivers and insight into their respective regions and jurisdictions. Although access to stakeholders across states was always willingly offered, inherent with all stakeholder work are questions regarding representativeness and whether all perspectives are covered (and covered equally). This in particular for futures work can have impacts on the legitimacy of the process and whether the futures represented are as diverse in opinion as they could be. Issue may also have arisen from the roles of stakeholders which commonly had an emphasis on emergency management and response and not strategic planning and foresight – this may have limited the degree of exploration of futures.

2. **Engagement with stakeholders.** Engagement (along with access) is critical in the context of continuity and available time to effectively engage. The issue of disaster risk is (as described substantially within this research) complex, and considering the future in this complex environment is challenging, and time-consuming. However dealing with public servants with other demands on their time, especially in the emergency management field where situations and availabilities can change quickly meant that consistency in stakeholders and sufficient time to meaningfully engage with the system complexity was not always available.

3. **Diversity in applied contexts.** Disaster risk is a significant challenge to the developed, Western world with all the advantages of continued economic growth and stability and investment in governance systems to manage and mitigate many of the treats from disasters that their communities are subject to – this however is not true for all parts of our world. The framework and approaches developed in this research have only been applied in the limited context of DRM in Australia, and consider only the Australian governance arrangements. This means that there are potential limitations in the

effectiveness of techniques, methodologies and frameworks described here applied in other contexts.

4. **Model capability.** Modelling for this research was undertaken using the UNHaRMED software which is designed to produce spatially and temporally dynamic risk profiles across different hazards. There are however limitations to its capabilities in terms of the dynamics of disaster risk components that it cannot model such as the interaction between changing urban form and flooding risks, and the impact of individual, human capacity and resilience under disaster conditions. This however is true of all modelling approaches – they can only ever be representative of elements of the system – and hence the need for qualitative supporting information and time with stakeholders to go through a process of insight and sense-making is critical.

5. **Data availability.** The availability and quality of data and information relevant to disaster risk is a continuous challenge. Accurately capturing exposed assets, the magnitude of hazard events along with damage estimates post an event is critical for informed decision making for future risk reduction activities. However this type of data is often not-available, and if it is, it contains bias towards the entity collecting the data (i.e. for insurance claims although insured losses represent only a small fraction of the impact of disaster events). With improved historical data across components of hazard, exposure and vulnerability, understanding future changes becomes significantly easier and without this type of information validation of qualitative and modelled results is challenging and a limitation of outputs of this research, and all research of this type.

6. **Translation into decision-making.** Due to the time and resource constraints of this research, along with the actual policy process of investing in risk reduction activities, the framework and approaches, as yet, have not been fully incorporated into the development of strategies and plans for DRM that acknowledge the changing nature of risk in a region. This limitation means that some of the benefits of these frameworks have not been realised yet (as to their ability to support strategic decision making) and this is further discussed in Chapter 5.3 – Future work.

5.3 Future Work

From the above limitations, future work is identified below:

1. Develop project plans for DRM using exploratory scenarios that explicitly outline the engagement process and specify the requirement for horizontal and vertical diversity in stakeholder identification. This is needed to ensure diversity in opinion in disaster futures but to also identify strategies that are equitable and inclusive – critical for resilient communities. This process can be built into the generic frameworks proposed within this research.

2. Apply the framework and approaches for integrating foresight into DRM and dynamic risk assessment into DRAs undertaken in developing contexts, and broader scales such as national or sub-continental. The application of the framework at these scales and with the further complexity of developing contexts will strengthen the generality of the framework and also support proactive risk management strategies through an understanding of future risks. With international capital (both private and from development banks) to support poverty reduction, the strategic use of these investments to reduce future disaster risks is significant and could be improved with the integration of scenario planning.

3. Increase model capability in terms of the ability to capture dynamics and interactions between components of risk. As UNHaRMED continues to be developed to support dynamic risk assessments and investment in risk reduction there is significant scope to improve the processes included within the modelling to capture currently unquantified dynamics. These include interactions between built environment and hazard models which currently integrate to calculate risk however could also show impacts on flood hazards with increased urbanisation change runoff patterns, as well as hazard models influencing social behaviour on where people want to live, work and recreate. Improving these dynamics within the integrated model will provide enhanced support to disaster risk understanding and reduction.

4. Establish data collection processes for the improved understanding of changing risk profiles is of critical importance. Often risk studies collect a significant amount of data but do not consider how this could be done to improve our understanding of how we

got to the risk profile that currently exists. Future research in this area is critical in terms of improved understanding of vulnerability – often the least understood component of disaster risk – and in terms of improving investment in risk reduction. This could see more strategic and systematised post disaster needs assessments, along with assessments of these historically to decipher trends in underlying components of disaster risk. This will allow us to better understand why impacts are increasing instead of just showing they are (as per Figure 1-1).

5. A key element of future work for this research is to integrate scenario development processes into the strategic DRM planning of a city, region, or country. This will see the development of methodologies that allow for robust or adaptive solutions for DRM considering the plausible alternative futures identified within the scenarios. Establishing the processes and demonstrating their utility from the beginning of a policy analysis cycle through to the development (and potential implementation) of a DRM strategy will be a significant step forward in management of emergent risks within DRM processes.

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Appendix A – Tasmania Stakeholder Engagement Report 1

TASMANIA DSS
STAKEHOLDER ENGAGEMENT STAGE 1 REPORT

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CONTENTS

1. INTRODUCTION

Disaster risk reduction planning is characterised by the need to make decisions in an increasingly complex, and integrated, socio-economic and natural environment. This decision making complexity comes in a number of forms, including (i) the need to make decisions by selecting from a very large number of options, (ii) the need to consider multiple, often competing, objectives during decision-making processes to account for a range of social, economic and environmental criteria, (iii) a lack of clearly-defined, measurable criteria with which to assess the utility of decisions, and (iv) uncertainty in future conditions, data and information.

At the same time, community expectation in relation to the level of protection that can be provided against disasters is increasing, while the frequency and severity of disasters is also likely to increase. Consequently, there is increased scrutiny of the decisions made in relation to disaster risk reduction, necessitating increased transparency in the decision-making process and wise use of limited resources.

However, decision-support tools that enable decision makers and authorities to achieve the above goals do not exist at present. Consequently, the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) is funding this current project to develop an integrated natural disaster risk reduction Decision Support System (DSS) framework, which will be used to develop prototype DSSs for three case studies. Of these three case studies, this report will consider the case study in Tasmania.

Through a stakeholder driven development cycle, this project will deliver prototype DSSs that will optimise the choice of risk reduction options, through assessing the performance of various options over the long term using simulation-optimisation approaches. The performance of risk reduction options will be evaluated in an integrated way, across a number of natural hazards (such as bushfire, flooding, coastal surge and storm events) whilst taking account of population, economic, land use and climate change.

For the Tasmanian DSS, several workshops are planned, which will be an integral part in materially shaping the design and functionality of the DSS. The workshop series will focus on the scope of the Tasmanian DSS, allow for feedback on the DSS prototype and testing of the prototype with scenarios. When relevant, the workshops will be complemented with questionnaires and/or interviews. A first round of questionnaires and interviews took place on the 4th and 5th of November 2015 and was followed by a workshop on the 6th of November. This document reports on these activities, their results and their impact on the scoping of the DSS.

Following this report a prototype DSS will be developed over the next year. This DSS will then be presented at a second workshop, organized in the second half of 2016. During this workshop, there will be time to evaluate the system and discuss its further development. At the same time, relevant use cases will be defined, including the development of scenarios. Following this, the scenarios will be quantified and modelled and the impact of mitigation portfolios assessed under various plausible future developments of the State, allowing for the use of the DSS to be further explored. This will be complemented by continuous feedback and refinement of the prototype DSS.

2. AIMS & ENGAGEMENT PROCESS

The first formal engagement process for the development of the Tasmanian DSS was designed to scope current thinking in emergency management and planning within the state and to frame conversations to focus on thinking about futures. The aim was not to determine any solution or to build a general consensus between participants, but to rather broaden discussion and elicit information that was critical to the development of the DSS. Focus was therefore on selecting and prioritizing hazards, discussing policy options, long-term drivers, and indicators, and discussing the implementation and use of such a DSS in organisations involved in natural hazards risk reduction.

The overall engagement process was broken into three components to develop a greater understanding of the sector and build relationships with and amongst key stakeholders, vital to the success of the DSS. Initially questionnaires were forwarded to stakeholders, followed up by interviews and then a workshop on the 6th November 2015. This staged process enabled personal interactions to learn about individuals' ideas, provide information relevant to the background and interest of the stakeholder and an in-depth discussion on the specific hazard expertise of the individual, together with group discussions in which different ideas were articulated and then complemented or elaborated on with additional knowledge from other participants. It thus allowed the project team to better align the project and developed prototype with practitioners' needs and requirements to facilitate / enhance future implementation of the system in their organisations, along with offering the greatest ability to determine critical factors for risk reduction planning and policy development.

2.1. QUESTIONNAIRES

Each stakeholder identified as relevant by end-user representative, Luke Roberts (DPaC OSEM), (full list of participants shown in Appendix A) was invited to complete a short questionnaire (Appendix B). These questionnaires were structured to elicit information regarding current planning practices, key drivers for change within Tasmania and emergency management along with critical uncertainties for Tasmania's future. Additionally, it was also important to establish each stakeholder's and their respective organisations' role in the emergency management sector in Tasmania. The linking of these responses allowed a greater exploration of the decision-making sphere within Tasmanian emergency management.

2.2. INTERVIEWS

Interviews with each stakeholder and two members of the project team had a dual purpose, 1) to clarify and extend upon questionnaire responses and 2) explain more about the DSS project and proposed framework. To frame the discussion, an overview of the project was first presented including aims and goals of the project, along with highlighting key personnel for future communication. Following this, a high level description of the simulation and optimisation procedure was provided, and any questions regarding the process were answered.

The purpose of the general discussion following this overview was to clarify interview responses and go into more detail regarding certain aspects of the interviewee's roles and responsibilities, and their organisation's decision making and future planning methodology. Also of importance during the interview was determining whether extra participants should be included in the process, prioritizing hazards and discovering possible case studies and available data for future analysis.

2.3. WORKSHOP

The workshop (undertaken on November 6th, 2015) was designed to be an inclusive day, ensuring all attendees had ample opportunity to engage with the facilitators and the process. The day was structured around introductory presentations framing the following break-out sessions; see Appendix C for an agenda of the day. The key exercises of the day are highlighted below:

Presentation of Project Overview and System. The first part of the workshop was to provide a more detailed overview of the entire research project. This included the project and system's proposed framework along with the major expected outcomes of this project. Along with this was also a description of the usefulness of DSS software, using previous case studies and short examples of the possible decision scenarios.

Exercise 1: Exploration of Disaster Risk Reduction Options. A critical outcome of the workshop was to begin developing a list of possible risk reduction options to be included in the DSS prototype. This was achieved by each participant considering the possible risk reduction options currently available and possibly available into the future for a range of hazards as determined relevant from questionnaire and interview results. The question was framed as, "What options exist or may exist to reduce hazard name risk (exposure, vulnerability and hazard)?"

Exercise 2: Consideration and preferencing of indicators. Participants were also asked to consider the indicators of a risk reduction option impact or performance across several classes. What is of interest to the project is a collection of indicators to be included in the DSS, at its prototype stage, to be of most value to the end user group but also to consider other factors for the future to ensure the scope of the DSS is not narrowed such that it cannot accommodate broader indicators. The questions were framed as, "In terms of factor what indicators of impact or performance would you like to include for risk reduction strategies?", with different potential types of factors including risk, the environment, and socio-economics. Per factor these indicators were then grouped and participants were asked to preference each indicator by placing one of three dots next to it.

Exercise 3: Discussion of Current & Future Usability. The final objective of the workshop was to consider the usability of the system. This was comprised of three components 1) scoping of current decision making sphere in terms of risk reduction options, 2) what specific questions participants want the system to be able to answer or like it to answer and 3) consideration of how the system would be used by the participant, by the participant's organisation and how participants felt another organisation should use it. The purpose of this was to further direct the system's development, ensuring its policy relevance and how it can fit into current decision making procedures supporting either the decision maker, an influencer or other stakeholder.

3. QUESTIONNAIRE & INTERVIEW RESULTS

The key outcome from interviews and questionnaires was to develop a greater understanding of the Tasmanian specific challenges to long term risk reduction planning in order to scope the requirements for a Hazard Risk Reduction DSS. Throughout all questionnaires and interviews there was a general sense of the challenges facing the EM sector in Tasmania, dealing with increasing challenges of climate change, along with significant pressures from slow economic development and the capacity to deal with increasing exposure in terms of both changing demographics and climate. However, there was a positive feeling towards how individuals work together in the EM sector in Tasmania with high levels of pragmatism, collaboration and willingness to tackle the challenges.

A broad range of hazards were mentioned as being relevant to Tasmania, as summarized in Figure 1. All participants mentioned bushfire and coastal inundation being of particular concern. Also of concern was the impact of riverine flooding and landslides. This information will be considered in the hazards to be incorporated in the DSS.

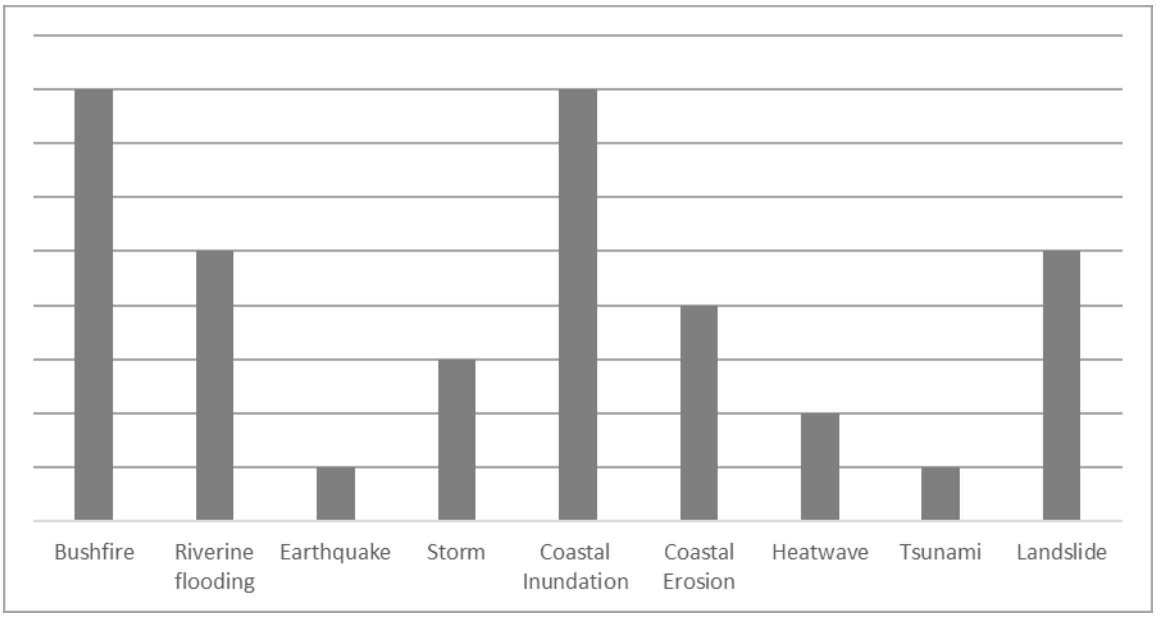

FIGURE 1: WHAT ARE, ACCORDING TO YOU, THE RELEVANT NATURAL HAZARDS FOR TASMANIA IN THE NEXT 50 YEARS?

Another key outcome of the interview process was to discuss the strengths and weaknesses in the State's ability to manage and minimise risk into the future. Although there was a tendency to consider the weaknesses, in particular Tasmania's economic development, there were also positive comments with several key strengths identified by participants. These included an expectation to collaborate across government departments (often driven by a lack of capacity), and an innovative, pragmatic approach to tackling problems. Also commented on was a significant ability to influence change due to the size of government, the availability of quality science and a willingness of government to utilise this science to reduce risk.

Some weakness were also identified encompassing governance, economic and physical factors. These included lack of resources both financial and human, the requirement for full consultation across many areas, although seen as beneficial, also placed significant pressures in terms of duration and there still exist legacy planning issues. Also commented on, was how exposed the population was in terms of bushfire and coastal inundation due to the length of interface, and that there may be too high an emphasis placed on personal responsibility. A summary of all questionnaire and interview output can be seen in Appendix D.

Also of critical importance in scoping of the Tasmanian DSS was the exploration of drivers for change and sources of uncertainty facing the region into the future. Common factors included climate change and Tasmania's demographic composition, in particular population growth (or lack of) and its ageing. Also discussed was the impact of planning reforms and land use changes in terms of where populations would decide to reside (increased coastal or city settlements). The influence of the Commonwealth in terms of leadership, commitment and funding arrangements were also mentioned by several participants.

The impact of climate change not only in terms of increased hazards but also its impact on Tasmania's economy, particularly agriculture and fisheries, was seen as a significant uncertainty in Tasmania's future. The future demographics of Tasmania were also mentioned by several and whether they would be influenced by increasingly retired migrants from the Australian mainland. Economic structure at a state and national level was also discussed as to whether a transition away from natural resources and mining was possible, with Tasmania focussing more on agriculture, aged care and associated services, tourism, education and IT. A full summary of outputs of drivers for change and uncertainties can be seen in Appendix E.

4. WORKSHOP RESULTS

As described in Section 2.3, the workshop was structured around introductory presentations and several break-out sessions. The following section looks to disseminate the responses of the participants during the break-out sessions.

4.1. OUTCOMES OF EXERCISE 1: EXPLORATION OF DISASTER RISK REDUCTION OPTIONS

This session asked for risk reduction options across the hazard, exposure and vulnerability factors for the six most common hazards as per Figure 1. The hazards considered were bushfire, riverine flooding, coastal inundation, and landslide. A summary of the most collectively emphasised options is shown in Table 1, with the full list of identified options in Appendix F.

TABLE 1: PREVALENT RISK REDUCTION OPTIONS ACROSS CLUSTERS

Clustered Theme	Top Risk Reduction Options Identified		
BUILDING CODES	Raise floor level standards	Improve building standards for bushfire	Improve foundation standards for areas of landslide risk
LAND MANAGEMENT	Vegetation corridors for runoff control / WSUD	Strategic planned burns	Water management plans considering impacts across several hazards (flood, landslide & bushfire)
COMMUNITY BASED	Appropriate maintenance of private property dependent on hazard risk, landslide – drainage, swimming pools, watering; bushfire – vegetation setbacks	Education and awareness for what to do during an event	Long term effort on changing mindsets, providing support when community educated and ready.
STRUCTURAL	Levies, dams and sea walls with appropriate level of design	Renewal of infrastructure for current and future conditions (pipes, roads etc.)	Consider shorter design lives for structures and allow for adaptation
GOVERNANCE & LEGISLATIVE	Greater sharing of information across jurisdictions and departments	Increase requirements to provide risk related information when selling property and land (vendor disclosure statements)	Willingness of industry, councils and government organisations to 'hand out' data to individuals.
LAND USE PLANNING	Strategic zoning plans based on risk for relevant hazards in region	Restrictions on rebuilding once an event has occurred	Appropriate sub-division design and hazard management at plot level
SCIENCE, DATA & RESEARCH	Refinement of existing modelling to consider finer, more appropriate scales	Have greater understanding of climate dynamics and impact on other factors such as vegetation	Improved and more early warning systems
FINANCIAL INSTRUMENTS	Insurance with risk based premiums	Land buy-backs / compulsory buy-backs	

Note: The authors have made minor edits to some options to place a greater emphasis on risk reduction and an all hazards approach.

4.2. OUTCOMES OF EXERCISE 2: CONSIDERATION AND PREFERENCING OF INDICATORS

The purpose of this session was to elicit policy assessment indicators across a range of factors. Participants were asked to offer four responses to each of the following questions:

1. *In terms of SOCIETY, what indicators for performance or impact would you like to include for risk reduction strategies?*
2. *In terms of ECONOMICS, what indicators for performance or impact would you like to include for risk reduction strategies?*
3. *In terms of the ENVIRONMENT, what indicators for performance or impact would you like to include for risk reduction strategies?*
4. *In terms of RISK, what indicators for performance or impact would you like to include for risk reduction strategies?*

Each question was asked individually with responses collated into a meta-plan. Clustered groups were then presented for ranking by participants as to what was of greatest importance to them. Figures 2, 3 and 4 show the results of this collation and ranking with full outputs shown in Appendix G.

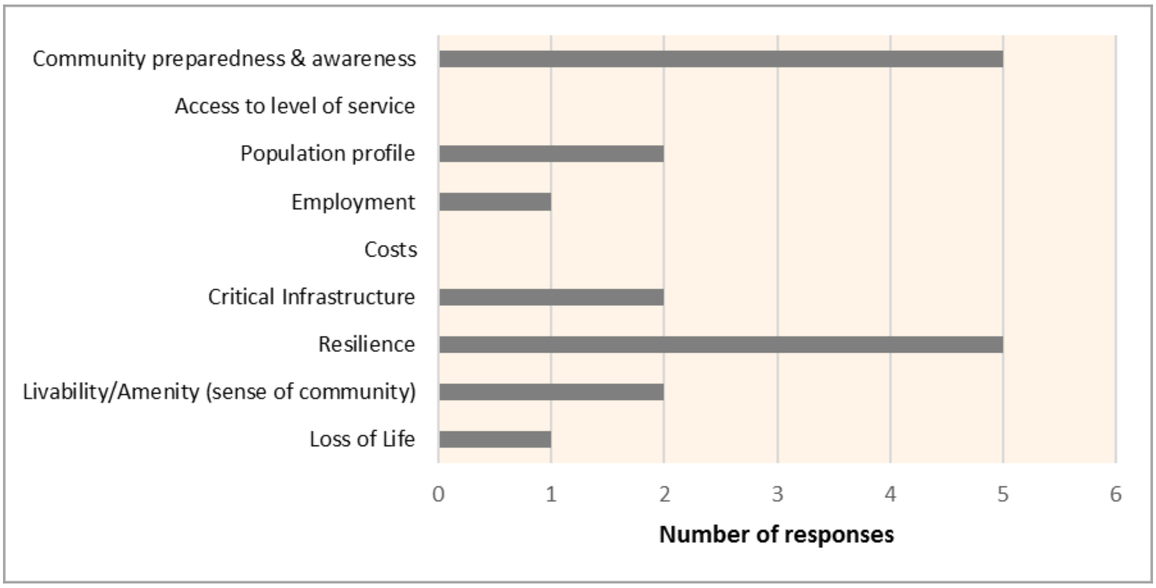

FIGURE 2: SOCIETAL INDICATOR RANKING

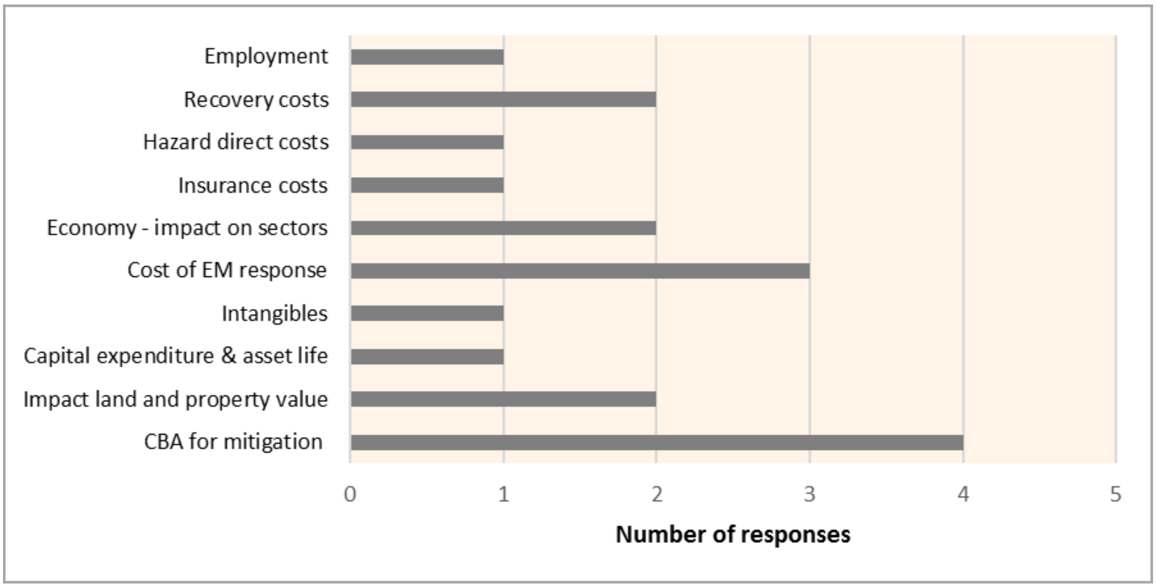

FIGURE 3 ECONOMIC INDICATOR RANKING

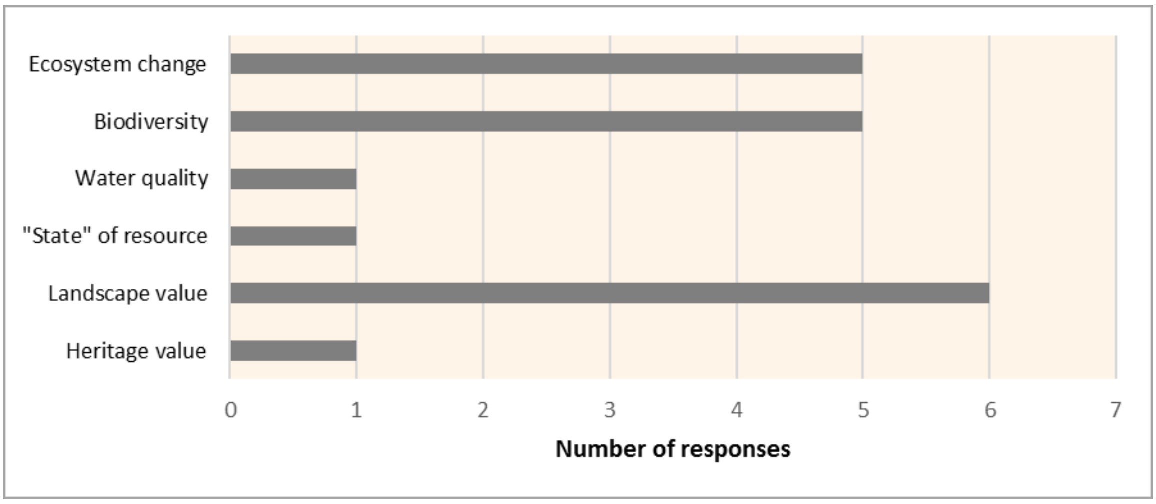

FIGURE 4: ENVIRONMENTAL INDICATOR RANKING

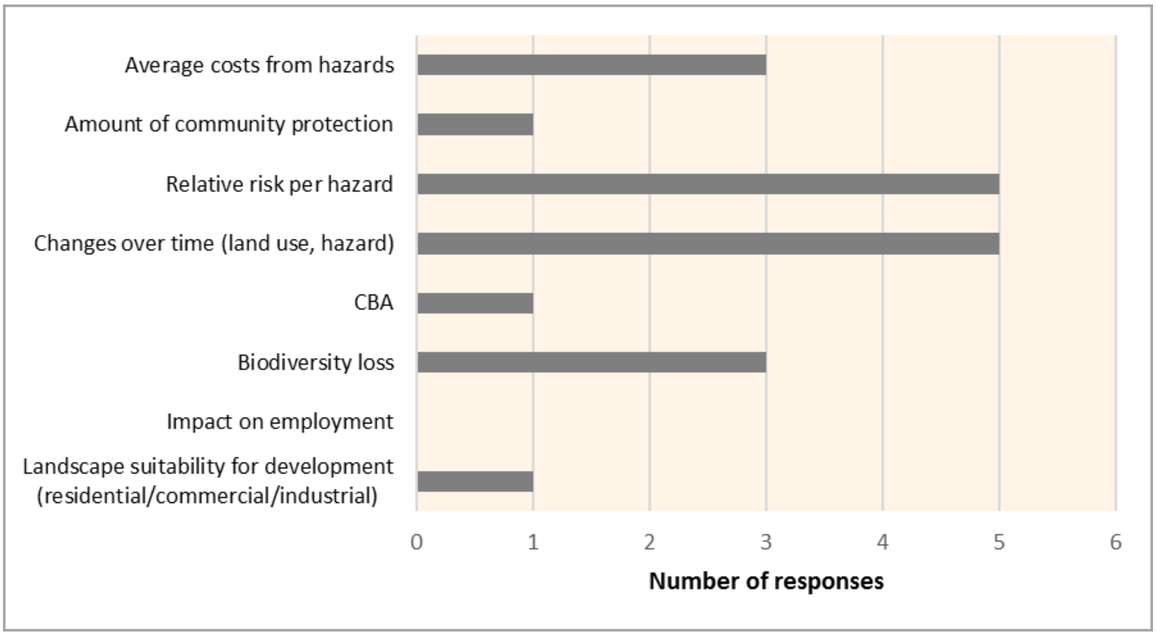

FIGURE 5: RISK INDICATOR RANKING

4.3. OUTCOMES OF EXERCISE 3: DISCUSSION OF CURRENT & FUTURE USABILITY

This session had three distinct components, each designed to consider the use of the system both currently and into the future.

The first component looked to better understand the decision making process in Tasmania regarding emergency management and risk reduction. Based on the outcomes of Task 1 (Section 4.1 eliciting risk reduction options for Tasmania), participants were asked to comment on the responsibilities and influence of organisations on a selection of risk reduction options. The questions were phrased as:

For each risk reduction option:

> *Who is the decision maker?*
> *Who can influence the decision?*
> *Who has a stake in the decision?*

The purpose of this was to gain a greater appreciation for the decision making process, insure all relevant parties were involved in the DSS development and use process and allow for easier collection of data in the future. The results are collated in Table 2 on the next page.

TABLE 2: DECISION MAKERS, INFLUENCERS & STAKEHOLDERS FOR RISK REDUCTON OPTIONS

Risk Reduction Option	Decision Maker	Influence	Stake
Structural Measures	Local Government (permit)	State Government, private landholders, dam regulations, EPA, PCAB, NRM Boards	Industry bodies, LGA
Emergency Structural Response	State Government		
Land-Use Planning	Local Government (permit), State Government (sign off planning schemes), TFS (bushfire management plan), EPBC (Fed)	Local Government (regional groupings), Industry (incld. Developers), NRM Boards, TFS, SES	LGA, Private landholders
Land Management	Land Owner (private/public), EPBC (Fed)	TFS, Local Government, NRM Boards, SES (if flood related)	
Education / Awareness	Hazard Owner	Local Government, State Government (SES, TFS), NGOs, Industry Groups, Federal Government (BOM / GA)	Dept. Education, Local Government, Universities, BNHCRC
Codes / Regulations	Director of Building Controls (DoJ), Local Government (permit)	Master Builders Association, ABCB, Industry Groups (incld. Developers), DPaC	Land owners, renters

NB: Community has a stake in all options. Commonwealth Government also has important and significant influence across all options through funding mechanisms.

The second component looked to elicit information regarding specific areas or questions of interest that participants felt the DSS may be able to explore. The session was a facilitated discussion around the question:

"*What particular questions do you see the system being used to answer or would like it to answer?*"

Full responses can be seen in Appendix H with a selection of common or significant questions listed below.

- What are the broader implications of defending coastal communities or what would happen if we decided not to?
- Are building controls, land use planning and other legislative instruments fair?
- What are the implications of recent policy announcements regarding population targets in Tasmania?
- What is the effectiveness of fuel management and community safety programs?

Several general comments on the systems use also revolved around the following perceived benefits:

- Allows for the consideration of approaches across 'triple-bottom line'.
- Allow for the prioritisation of resources and EM service provision.
- Look to better understand and balance conflicting priorities.

The third component of the usability task looked to receive responses to the following three questions:

1. *How would you like to use the system?*
2. *How would you like your organisation to use the system?*
3. *How would you like another organisation to use the system?*

	How individuals would want to use the DSS	***How individuals would like their organisation to use the DSS***	***How individuals would like this organisation to use the DSS***
DPaC (OSEM)	To develop policy on risk and hazard management	To support policy recommendations through evidence	State Policy Development
			Planning Code Development
			Develop hazard management instruments and data
TFS (Strategic Fuel)	Prioritise the implementation of different mitigation activities	Future organisational design and ability to keep meeting organisation goals	Provide evidence based for policy effectiveness
	Identify priority areas for treatment	Support policy recommendations	
	Assess the benefits of mitigation activities	Resource to risk capability planning	

	How individuals would want to use the DSS	*How individuals would like their organisation to use the DSS*	*How individuals would like this organisation to use the DSS*
	Provide advice to Government regarding future operational and mitigation needs	Prioritising response	
SES	Inform mitigation planning for hazards and EM response	Assist municipalities/Government in EM planning arrangements	Planning for emergency responses
	Identify areas of community risk in relation to flood, storm and other hazards		
Planning Commission			Support planning decisions
			State policy development
			Support assessment of rezoning applications
Local Government	Strategic planning	Climate change adaptation policy and implementation	Support regional and strategic planning
	Land use strategy	Emergency management education and awareness	Assist municipalities identify EM considerations to hazards relevant to them
	Climate change adaptation policy and implementation	Community plan	
	Vulnerability assessment	Strategic Plan	
	Community contribution charge	Asset management plan	
		Budget	
State Growth	To develop and assess policy on population and infrastructure		
	Understand impacts of infrastructure planning		
	Implications of population strategy		
TFS			To prioritise resource management and community protection

	How individuals would want to use the DSS	*How individuals would like their organisation to use the DSS*	*How individuals would like this organisation to use the DSS*
DPaC (CC)	Test and validate 'policy' options		
	Evidence based decision making		

5. OUTCOMES & CONCLUSIONS

The purpose of this first series of stakeholder engagements was to develop relationships with key stakeholders and elicit information vital to the development of the DSS. Critically, at this stage of the development was the elicitation of several aspects to include in the modelling framework, including external drivers, risk reduction options and indicators of risk reduction performance or hazard impact. This section looks to synthesise the output from the engagement process and highlight factors to be considered in the prototype DSS development. The stakeholder derived inputs summarised now provide direction to the project team in how to best tailor the DSS for greatest practicality and implementation. This initial, formal process of engagement will be followed up by a series of more informal communications between the project team and stakeholders on project progress.

Model drivers impact on the 'state of the world' being considered by the model and lets modellers and policy makers explore critical uncertainties about the future, primarily through the use of scenarios. The critical drivers identified throughout this process will be included in these scenarios and hence will form a key component of the system's usability. The list of drivers to be considered at this stage of the analysis is shown below and forms the basis for system development. It should, however, be noted these are not final and will depend on data and model availability. They will also be added to by an extensive literature review and current global/national scenarios of socio-economic and environmental factors.

Drivers & key considerations:

- Population, demographics and associated vulnerabilities
- Community understanding and perception
- State's economic development
- Urbanisation (urban, peri-urban and rural land use interactions)
- Climate change (impacts and our response)

Hazards to be considered within the Tasmanian DSS are dependent on model and data availability.

Of particular interest is any organisation which have existing models they feel are relevant to be included.

Spatial extent is proposed to include 27 LGAs, as listed below (Table 3) and shown in Figure 6. This region covers the mainland of Tasmania. Initially the extent was to exclude the World Heritage and National Parks area in the South West of the main island however based on the fire events of summer 2015/2016 the model extent was increased. This is dependent however on data and model availability.

TABLE 3: LISTED OF LGA'S IN PROPOSED SPATIAL EXTENT

Break O'Day (M)	Dorset (M)	Launceston (C)
Brighton (M)	George Town (M)	Meander Valley (M)
Burnie (C)	Glamorgan / Spring Bay (M)	Northern Midlands (M)
Central Coast (M)	Glenorchy (C)	Sorell (M)
Central Highlands (M)	Hobart (C)	Southern Midlands (M)
Circular Head (M)	Huon Valley (M)	Tasman (M)

Clarence (C)	Kentish (M)	Waratah / Wynyard (M)
Derwent Valley (M)	Kingborough (M)	West Coast (M)
Devonport (C)	Latrobe (M)	West Tamar (M)

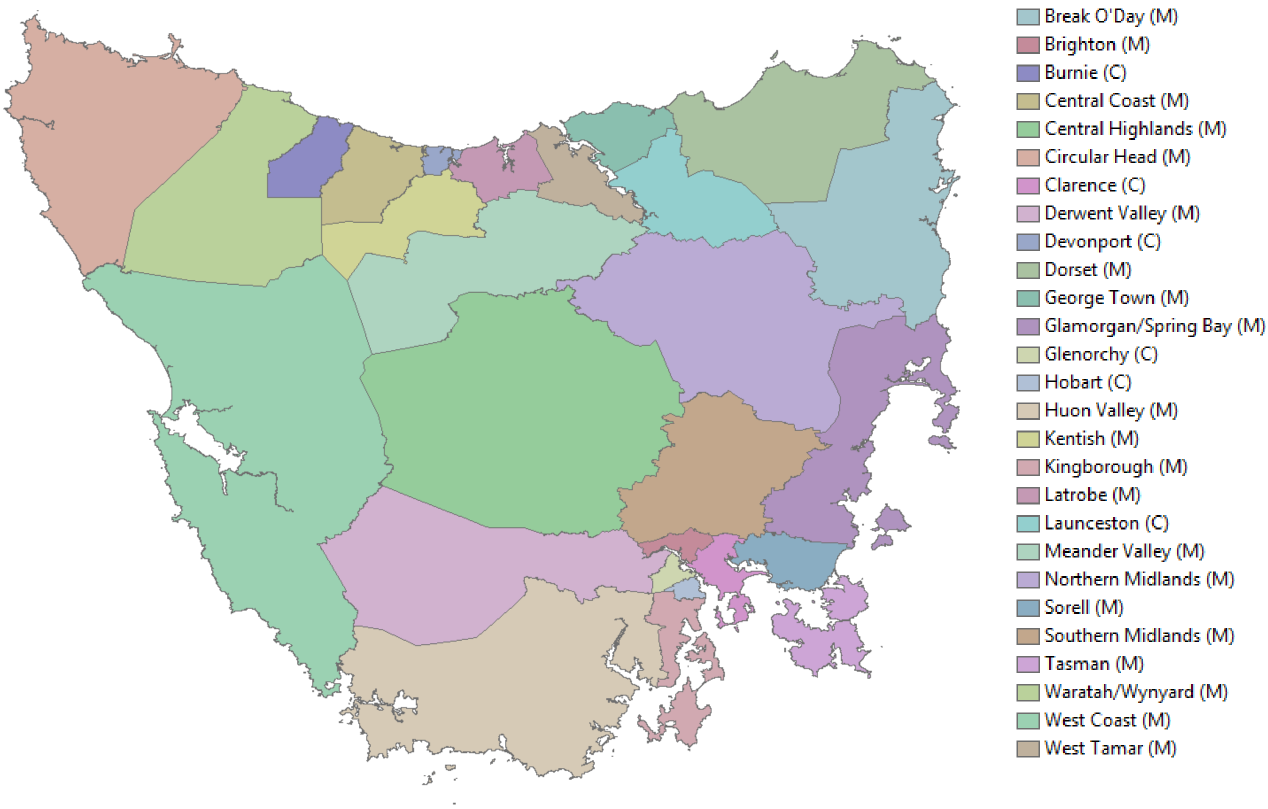

FIGURE 6: PROPOSED MODEL LGA EXTENT

Also considered from the workshop session was the specific inclusion of a range of indicators, feasible with the system and dependent on model and data availability. Table 4 highlights possible indicators to be included in the prototype, although several will require extensive further research outside of the current scope of the project but will be considered to ensure developed prototype can enable their inclusion into the future. These indicators have been selected from the information given by participants by the project team as feasible, and in keeping with the modelling approach of the overarching framework.

TABLE 4 - POSSIBLE INDICATORS IDENTIFIED ALONG WITH REQUIRED DATA/MODELS

Objective	Indicator	Requirements
Social	Essential Service Disruption	• Vulnerability curves of service provision and risk levels
	Population impacted	• Spatial population density data
	Morbidity / Mortality Rates	• Vulnerability curves of fatality risk
Economic	Cost of primary damage	• Capital and contents value associated to location and land use

		• Level of risk and impact curves for each hazard
	Business disruption losses	• Business vulnerability curves
	Loss of / impact on employment	• Spatial data/modelling of employment • Vulnerability of employment curves
	Critical Infrastructure impacted	• Spatial data on location
	Impact on GDP	• Modelling of economic factors and outputs
	Impact on amenity value and tourism	• Spatial data on values of interest
Environmental	Impact of vulnerable/protected ecosystems	• Spatial data on location • Model (vulnerability information) relating hazard to impact
	Ecosystem Change	• Framework of ecosystem considerations – tipping points and dynamics • Relevant spatial data • Vulnerability information
	Biodiversity impacted	• Spatial data/modelling • Vulnerability information
	Area of primary agriculture impacted	• Spatial data/modelling • Vulnerability information
Risk	Cost Benefit (Risk reduction vs. costs)	• Cost of risk reduction activities
	Number of Assets at risk	• Property information
	Average Annual Loss	• Location of assets • Asset values • Hazard modelling • Vulnerability information linking hazard to impact

Further workshops are planned in 2016, with presentation of the initial DSS prototype, further refinement of modelling processes based on stakeholder preference and scenario development to explore future uncertainties and risk reduction option portfolios. Table 5 outlines the next stages of engagement, highlighting indicative timing and purpose. Further information will be provided closer to the date.

TABLE 5 – STAGES OF STAKEHOLDER ENGAGEMENT

Stage	Purpose	Description	Indicative Date
2	Land Use & Hazard Model Development	End user input on land use model components, principally classification, suitability, accessibility and historic trends. End user input on hazard model specifications. (½ day)	Nov 2016
3	DSS Feedback, Scenario development and Scoping of policy support	Presentation of first iteration of DSS with opportunity for feedback. Development of qualitative scenarios for the future of Tasmania. (½ day)	Nov 2016
4	Scenario modelling and Policy support	Presentation of modelled scenarios and risk profiles. Critical feedback on their	2017

		extremity, plausibility, consistency and representativeness. (½ day) Presentation and discussing on policy support mechanisms and results from optimisation of risk reduction portfolios and consideration of robust and adaptive approaches for future uncertainty. (½ day)	

APPENDICES

APPENDIX A - PARTICIPANTS

This appendix specifies the individual participants of the workshop along with their respective organisations.

Facilitators:

- A/Prof Hedwig van Delden (RIKS / The University of Adelaide)
- Mr Graeme Riddell (The University of Adelaide)
- Prof Graeme Dandy (The University of Adelaide)
- Prof Holger Maier (The University of Adelaide)

Workshop Participants:

- Luke Roberts (DPaC OSEM)
- Rowena Salter (SES)
- Sandra White (TFS)
- David Palmer (DPaC CC)
- Belinda Loxley (Kingborough Council)
- Matt Haynes (BNHCRC)

Interviewed participants (unable to attend workshop):

- Chris Collins (TFS)
- Jon Doole (Kingborough Council)
- Brian Risby (Planning Reform Taskforce)

APPENDIX B - QUESTIONNAIRE

This questionnaire was sent to each stakeholder as identified by DPaC OSEM.

This survey is meant to provide input into the scoping phase of the Decision Support System that will be developed as part of the Bushfire Natural Hazards CRC Project titled: "Decision support systems (DSSs) for assessment of policy and planning investment options for optimal natural hazard mitigation planning". The survey will be used in preparation of the interviews (taking place between 4th and 5th November) and workshop (scheduled for November 6th) to scope a DSS for Tasmania. We kindly ask you to return the survey by Friday October 30th.

About you

Name:

Role:

Responsibilities relating to natural hazards:

About your agency

Name:

Responsibilities relating to natural hazards:

What decisions do you and/or your organisation make that are relevant to natural hazards or effected by natural hazards?

How are these decisions currently made? What is the time frame for decision-making?

What decision support methodologies and tools do you currently use?

What sources of data, knowledge and expertise do you consult?

What are, according to you, the relevant natural hazards for Tasmania in the next 50 years?

What are the key factors which currently affect Tasmania's ability to mitigate these hazards? (Strengths, vulnerabilities and other features)

What do you see as the key drivers of change in Tasmania over the next 50 years?

What are the key uncertainties over the next 50 years that could affect how well Tasmania is able to mitigate natural hazards? (Social, economic, environmental, political)

What are the policy options, program options or other interventions that your organisation would consider to mitigate these hazards?

Do you see these options changing in the next 50 years, and how so?

Which other organisations do you currently interact with for different purposes (e.g. knowledge exchange, expertise sharing, resources, finance, implementation etc.)

Who are the key people/organisations who are/should be involved in natural hazard mitigation in Tasmania?

Who else do you think we should be talking to to learn about natural hazard mitigation?

APPENDIX C - AGENDA

This appendix specifies the workshop content and final agenda for the workshop held on the 23rd October.

10:00am	Registration	
10:30am	Project and Framework Introduction	Prof Holger Maier
10:45am	DSS Introduction	A/Prof Hedwig van Delden
11:15am	Morning Tea	
11:45am	Exercise 1: Risk Reduction Policy Options	A/Prof Hedwig van Delden
12:45pm	Lunch	
13:30	DSS Indicators Presentation	A/Prof Hedwig van Delden
13:45	Exercise 2: DSS Indicators	Group Activity
14:45	Afternoon Tea	
15:05	DSS Use Presentation	A/Prof Hedwig van Delden
15:20	Exercise 3: DSS Usability	Group Activity
16:20	Exercise 4: DSS Usability Feedback	Group Activity
16:50	Wrap Up	Prof Holger Maier
5:00pm	Close	

APPENDIX D – TASMANIA'S STRENGTH & VULNERABILITIES

This appendix provides a full list of all strengths and vulnerabilities impacting on the State's ability to deal with risk into the future discussed during the interviews on 4th and 5th November 2015.

Strengths

- Not afraid of addressing bureaucratically
- Inter-agency cooperation
- High degree of pragmatism
- High level of personal resilience
- Good at bushfire management
- Continued awareness of storm and flood risk from the community
- Can influence change (size of government)
- Can-do innovative islander perspective
- No separation, work cross agency and tenure, more often than not expectation to collaborate
- Cohesiveness and togetherness leading to community resilience
- Identification of hazard vulnerability
- Willingness to do something
- Acceptance of the problem and its worsening
- Government agency collaboration
- High emphasis on community and stakeholder engagement
- Team based approach
- Groundswell support for mitigation
- Good science & access
- Information good and improving
- Slow pace of growth makes it easier to put in place adaptation and mitigation measures
- Not much ministerial influence on planning due to strength of commission

Weaknesses

- Not much money
- Takes a long time (full consultation)
- Extent to which issues are addressed and dealt with
- Still some traditional silo thinking in agencies
- Making plans more practical at a municipal level
- Capacity is a huge issue
- Recognition of limitation of control and scale of challenges
- Political willingness
- NIMBY
- Heads in the sand
- Legacy planning issues
- Governance roles and responsibilities
- Funding
- Who is responsible and liable?
- Who is paying and how it's paid?
- Very exposed population to bushfire due to length of interface
- Political commitment
- Resourcing
- Legal questions, jurisdictions – uncertainty
- Risk evaluation and communication
- State planning (or lack of)

- Political accessibility, very easy to dominate lobby with small influential groups
- Too much emphasis on personal responsibility

APPENDIX E – DRIVERS & UNCERTAINTIES

This appendix provides a full list of all drivers for change and uncertainties impacting on the State's future discussed during the interviews on 4th and 5th November 2015.

Drivers for Change

- Low population growth
- Low skilled workforce
- Ageing population
- Economic decline, apart from tourism and retirees
- Education in emergency management
- Climate change as a forcing hand
- Everyone has access to tangible evidence
- Risk of flooding to real estate
- More community awareness
- Climate
- Ageing population
- Ability to respond to now and catch up on future (not even thinking about it yet)
- Legacy development/planning issues
- Planning reform agenda
- Development of statewide codes
- Climate change
- Demographic changes
- Land use change (shift in settlements city or coast?)
- Political target to increase population, vulnerabilities/impacts not considered
- Community expectations of government's role will increase
- Insurance and Federal government influence
- Setting up to fail with high investment in prescribed burning (people will stop managing our backyards, rely on government)
- Climate change
- Ageing demographics
- Retirement migration
- Leadership and commitment (Commonwealth?)
- Occurrence of events
- Regional partnerships
- Population changes
- Increased roles in regional strategic planning with stronger acceptance by the State Government to intervene in planning area

Uncertainties

- Capacity at crunch time
- Can we muddle through?
- Ageing population and vulnerable people, how to include those people in EM framework
- Flow on impacts of global events to local impacts
- Temperature impacts on agriculture and fisheries, becoming an economic issue
- Extent of climate change (globally and locally)
- Balancing socio-economic and risk issues, competing priorities, (mitigation impacts broadly on other societal factors)
- Impact of global politics and unrest
- Climate change

- Demographic change (ageing, retirees moving to Tas, climate refugees)
- Mitigation cost too high
- Residual risks
- Climate impacts
- Political climate
- Economic vulnerability
- Demographic vulnerability due to ageing population
- economic shift from natural resource/mining to agriculture, tourism (possible education & IT)
- Community pressures for unconstrained settlement and development

APPENDIX F – RISK REDUCTION OPTIONS

This appendix provides a full list of all risk reduction options elicited in Task 1 of the Tasmania Workshop 1.

Bushfire Risk

- Fuel reduction (burning, mechanical)
- Fire roads (access/egress)
- Water supply
- Land use planning
  - Rural / urban interface
  - Strategic use of proportions of land
  - Sub-division design
  - Hazard management planning at plot level
- Building standards
- Background data, have national datasets but not location of rural buildings
- Have most of this data in Tasmania (building age, construction type)
- Weather forecasting (gaps in knowledge, downscaling of weather across Tasmania)
- Changing climate (number of bushfire danger days)
- Understanding vegetation change (linked to climate)
- Burning program, 7 year program, need to better understand how this influences occurrence
- Failing in land use policy that doesn't say when and where it's bad to build
- Full urbanisation of high risk areas
- Increasing volunteer base
- Insurance, risk based premiums
- Restricting development in settlement boundaries
- Funding for recovery post event
- Strategic modelling of key areas, reduce risk further by managing key ignition areas
- Modelling impact zones
  - Highlights where fuel reduction isn't an option, can then look for alternatives
- Refinement of existing models to look at appropriate scale
- Training and accreditation
- Mindset of possibility of property loss
- Considering greater climate dynamics (including vegetation)

Coastal Risk

- Minimum floor level
- Complete prohibition (but increase risk somewhere else)
- Planning and engineering levels (based on dynamic maps and extreme events)
- More dynamics would be good in hazard mapping
- Correct' information not conflicting
- What about existing, legacy issues?
- Community awareness to risks
- Willingness to hand out data (industry, councils)
- Need to be transparent (respect community)
- Better information when you buy a house
- Levies, sea-walls (level required likely to be expensive)
- Mapped zones to notify community
- Relocations (forced or volunteered)
- Build for certain time frame (20 years)
- Ensuring good use after sub-division
- Movies, visualisation information for education

- Setbacks (Statewide)
- Coastal retreat, taking people out of landscape, relocation
- Well informed land use planning (linked to setbacks)
- Mapping the hazard under different sea level rise scenarios
- Adaptation projects preparation
- Vendor disclosure statements about risk (required through policy?)
- Small engineering (temporary defences, sandbags etc.)
- How do we make someone leave beside 'hard' approach?
- Changing mindset, provide support when community ready
- Land buy backs (unlikely)
- Different education process than others (eg. bushfire), long term gradual process
- Generational (start with kids)
- Not place vulnerable uses in vulnerable areas

Flood Risk

- Big engineering around roads, bridges (level of design)
- Levies
- Stormwater management
- Water sensitive urban design
- Water capture (dams, tanks, underground)
- Detention storage in urban areas
- Land use controls (impact on runoff and buildings)
- Renew pipes
- Look at water quality impacts
- Difference residential and business
- Protection of special assets
- Prohibit people living in floodplains
- Extension to existing regulation
- Community engagement
- Information sharing
- Catch attention (movie)
- Floor level regulations
- Think about top soil
- Vegetation corridors
- Investment in asset infrastructure (sewer, stormwater etc.)
- Consider end of life (assets)
- Prevent removal of vegetation from catchment
- More golf/green areas (pervious, infiltration, multi-use areas)
- Flood attenuation areas
- Retrofitting (houses up)
- Design of drainage systems
- Stop vegetation clearing
- Identify vulnerable communities
- Understanding transport routes
- Emergency management planning
- Community education about driving in river
- Replace lost/damaged infrastructure with improved infrastructure
- Identify vulnerable and/or critical infrastructure
- Critical infrastructure information on location being available for land use planning
- Not allowed to make public inundation areas (dam failure is an issue)
- Owner is to maintain dam/CI to appropriate standard

Landslide Risk

- Land use planning
- Hazard identification and mapping
- Building controls
  - Site classification (L/M/H)
  - Foundation construction
  - Home stabilisation
  - Groundworks
  - Water management
- Strategic zoning plans
- Landslide drivers (susceptibility, climate, EQ, human behaviour)
- Susceptibility is already mapped
- Infrastructure planning, network/pipe planning over susceptible areas
- Education
  - Don't build swimming pools/ponds
  - Signs to look for
  - Building below areas of risk
- Dig out site
- Drainage on site, stabilisation
- Council awareness of land use planning schemes for landslide
- Maintenance of swimming pools and amount of watering
- Compulsory purchase due to risk/event
- Geological susceptibility
- Once event has happened, rebuilding or not
- Observation points (Snowy Mt for example)
- Sensors of movement in land
- What is happening on fringes, impact of drainage to susceptible zones

APPENDIX G - INDICATORS

This appendix provides a full list of all indicator options (societal/economic/environmental/risk) elicited in Task 2 of the Tasmanian Workshop 1. Whenever the same indicator is mentioned by different people all instances are noted in the lists below.

Societal Indicators

Population Profile	• Location and statistical change in population profile
Preparedness & Awareness	• Preparedness (community) • Measure of hazard awareness
Resilience	• Resilience
Loss of Life	• Number and severity of injury • Loss of life
Liveability & Sense of Community	• Loss of choice of location / lifestyle • Liveability' lifestyle, health, environment • Viability & 'sense of community' of rural townships
Access to & Level of Service	• Access to services community needs • Access to essential/support services
Employment	• Employment • Employment streams • Employment (opportunities, losses)
Critical Infrastructure	• Critical infrastructure locations • Vulnerable communities / infrastructure
Cost	• Cost ($) • Impact (hazard event, $, loss life, CI)
Amenity	• Map type of change in amenity due to a mitigation plan (beach, access etc.)

Economic Indicators

CBA for Mitigation (Now & Future)	• Costing the environment • Future/anticipated mitigation expenses (CBA) • CBA (Triple bottom line) of mitigation • CBA
Economy (Various Sectors)	• Disruption to economy • Ability to sustain local economy • $ Impact on sectors of the economy • Industry/Sectors (the amount of the present, the amount that would rebuild)
Employment	• Employment • Employment
Impact Land Value / Property Price	• Property price changes • Impact on land value
Cost of EM Response	• Cost of emergency response • Sharing (tax) the cost of mitigation (rates)
Recovery Costs	• Cost of recovery, reinstatement etc.

Insurance Costs	• Cost of insurance • Insurance
Hazard Direct Costs	• Total cost of hazard • $ cost of assets lost to hazard events (or replacement costs)
Capital Expenditure & Asset Life Costs	• Capital expenditure of risk reduction options • On-going costs of assets

Environmental Indicators

Heritage Value	• What is the cultural/heritage value applied to a location?
"State" of Resource	• Protection • What is the "state" of the resource?
CBA	• Value of natural resources as a resource • CBA
Water Quality	• Water quality indicator
Landscape Impact	• Landscape impact • Visual impact • Changes in character
Ecosystem Change	• % Change of environment types in an area (decrease or increase) • % Change of land cover at a location and subsequent impacts • Maps or % change environmental impact (loss or gain) between mitigation options and no mitigation (landscape services, species, habitat)
Biodiversity	• Change or loss in biodiversity • Uniqueness of a location • Amount of vegetation types in an area

Risk Indicators

Changes Over Time	• Baseline 'No mitigation' maps and stats on AAL, LU, population, vulnerability • Change map (between hazards, land uses, annual loss) • Change in LU and LC over time
Relative Risk (per hazard)	• Changes to assessed (quantified) vulnerability • Reduction in overall relative risk from bushfire
Landscape Suitability for Development	• Reduction in % of community exposed to a particular hazard • % of landscape suitable for residential/commercial development over time
Impact on Employment - GDP	• Employment changes • Economic viability and productivity changes over time
Average Cost from Hazards & CBA	• Cost of mitigation vs cost of recovery • Change of resources to EM • Average cost over time of hazard events
Biodiversity	• Biodiversity changes • Cost of biodiversity

APPENDIX H – SYSTEM USE QUESTIONS

This appendix provides a full list of all responses to- *what particular questions do you see the system being used to answer or would you like it to answer?* - elicited in Exercise 3 of the Tasmanian Workshop 1.

- Are building controls fair?
- Is land-use policy fair?
- Does a specific policy actually impact on risk?
- How can we best balance conflicting priorities?
- Perform evidence based decision-making
- If decide to defend coastal communities, what are the broader implications of that?
- What if we choose not to defend?
- What is the cost to society?
- Measuring effectiveness of fuel management and community safety?
- Measuring impact of population policy on risk?
- Where will they live (new population policy)?
- Age and vulnerability (new population policy)?
- Look at risk reduction approaches across triple bottom line
- Consider spatial and temporal context
- Show vulnerability, and consider how this would change?
- Prioritising communities for resourcing, EM service provision?
- How much risk it in under in the first place?

Appendix B – Tasmania Stakeholder Engagement Report 2

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TASMANIA MULTI-HAZARD MITIGATION PLANNING

Stakeholder problem formulation

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INTRODUCTION

Natural hazard risk is a complex interaction between a changing hazard, exposure and vulnerability. Planning for the long-term reduction of risk therefore requires a consideration of each of these factors and how they may change into the future based on various drivers and uncertainties. The Bushfire & Natural Hazard Cooperative Research Centre (CRC) has therefore funded the development of a spatial decision support system (DSS) for multi-hazard, long-term risk reduction planning in Tasmania. This DSS aims to support decision makers for integrated natural hazard risk reduction planning, by improving both the understanding of long-term risk dynamics and, the efficient use of risk reduction resources, via a transparent process.

The case study region is shown in Figure 1 and consists of the entire state. Details on the participatory development of this DSS for Tasmania can be found in the project's framework report, van Delden et al. (2015), and report on a previous stage of stakeholder engagement, Riddell et al. (20 designed to provide input into the design, development and subsequent use of the Tasmanian DSS.

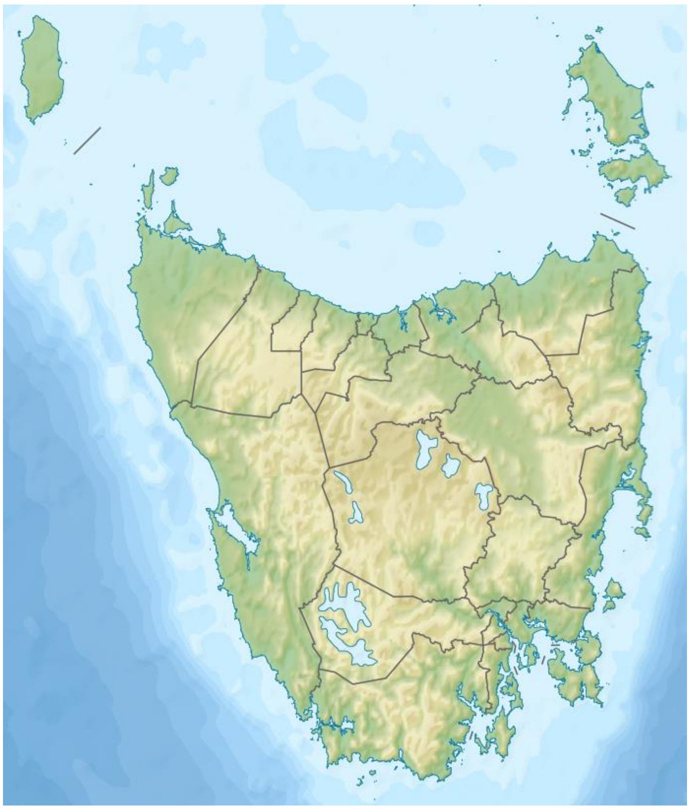

FIGURE 1: MAP OF TASMANIA

This report is based on a workshop held on November 7th 2017 in Hobart, Tasmania and focuses on the participatory development of optimization questions based on the methodology described in van Delden et al. (2015) and Wu et al. (2016). Multi-objective optimization, using evolutionary algorithms, will be performed on the Tasmanian case study to assist in the development of trade-off curves for various risk reduction options, their effectiveness and impacts. This will result in various portfolios of risk reductions options that perform well at balancing constraints and performing against various objectives.

This report summarizes the qualitative information regarding values and objectives for risk reduction planning in Tasmania (Section 2), specific risk reduction questions to consider within the optimization process (Section 4), and commentary on acceptance, effectiveness and impacts of risk reduction options considered relevant to the region and optimization questions (Section 5). Also considered are the uncertainties impacting on future risk profiles. Discussions around the best and worst case for natural hazard risk in 2050 for Tasmania along with the most likely for Tasmania in 2050 were held, and these are summarized in this report in the form of 3 alternate scenarios (Section 3).

This report will then be open for comments from stakeholders in Tasmania prior to the translation of qualitative inputs to quantitative factors required for simulation and optimization.

GOALS & VALUES

The optimization process will consider various risk reduction options and how they might contribute to an overarching vision for a future Tasmania considering natural hazard risk. Under this vision sits various objectives which will be aligned with model indicators or assessed post optimization to consider the performance and ranking of different risk reduction strategies.

VISION

Vision statements, a one sentence description for a vision of Tasmania related to natural hazard and risks for the year 2050, were collected from each participant during the workshop as listed below.

Stakeholder visions:

- A resilient and diverse community that is able to respond to risk and recover from natural hazards.
- Tasmania's communities, environment, economy and cultural heritage are resilient to natural disasters.
- A resilient community who understand their vulnerabilities in a climate change driven hazard rich landscape – with risk mitigation strategies in place and implemented.
- Contained settlements – no further development in vulnerable landscapes
- That by 2050 natural disaster do not impede the social, economic and environmental objectives of Tasmania.
- The Tasmanian community have a good understanding of the risks from natural hazards and how to respond.
- Policies and plans in place to ensure risks of natural hazards are managed to an acceptable level and do not increase.
- That people are protected/limited in exposure to significant/high levels of natural hazard risk.
- Leading the nation in educational attainment, innovation and sustainable food production.
- To reduce the vulnerability of Tasmanian communities from current levels.

OBJECTIVES

With consideration of the individual vision statements, underlying objectives, which are factors against which the overall vision can be measured against. The following six objectives were derived from collecting individual objectives from participants and clustering them into related themes. These have subsequently been written into the six statements at the end of this section.

Stakeholder objectives:

Resilient communities

- Resilient communities and economies
- By 2050 Tasmanian society is resilient to hazard impacts
- Resilient communities through education

Informed decisions

- Mitigation activities are targeted for best risk reduction
- Decisions based on evident / information
- Land use planning and building codes adaptive to changing environment
- Awareness
- Integrated decision making
- Rational / evidence based decision on risk management
- Policies and plans support risk based planning
- Improved data on hazard vulnerability over time
- Responsive and adaptive management

Community awareness

- Increased community awareness to hazards
- Education
- Knowledge and understanding
- Community education programs
- Community awareness of risk
- Educate the community through training and support programs
- Educate community on risk

Environment

- Tasmanian communities have successfully adapted to a changing climate
- By 2050 Tasmania's environment is adapting to climate impacts
- Tasmania has strategies in place to manage natural disaster risks to environmental values

Economy

- Tasmania has a diversified economy
- By 2050 the economy's GDP is resilient to natural hazard impacts

Decrease exposure and vulnerability (people, place, property)

- Reduced vulnerable development in hazard areas
- Response capability at levels that meet future requirements
- Limit development in high risk areas
- Limit exposure to risk through informed land use planning
- Decrease community vulnerability
- Integrated planning and building controls
- Manage community exposure
- Limit potential for new exposure to risk from natural hazards
- Write and implement community specific hazard management plans

Collective Objectives:

1. Resilient Tasmania communities
2. Risk reduction decisions are informed
3. Increased community awareness on hazards and risks
4. A sustainable Tasmanian environment adapting to the challenges of climate change
5. A diverse, resilient Tasmanian economy
6. Decreased exposure and vulnerability of Tasmania's people, places, and properties

FUTURE SCENARIOS

Scenarios are defined as, internally consistent and plausible explanations, using words and numbers, of how events unfold with time (Raskin et al., 2002, Mahmoud et al., 2009). Scenarios for the future of Tasmania were discussed across five factors, considered the most significant uncertainties for Tasmania's development (see previous stakeholder engagement report, Riddell et al., 2015).

1. Population and demographics
2. Community risk understanding and perception
3. Economic development
4. Urbanisation
5. Climate change and responses.

Three scenarios were considered during the workshop, best case, worst case and most likely. Details on each of these are provided in the following sections. The scenarios will subsequently be quantified and modelled to include in the optimization problem to consider how different risk reduction options perform under different futures.

BEST CASE

Factor	Description
Population and demographics	High population growth (650,000 in 2050) but in demographic groups that offset the impacts of an ageing society. The state will be able to not only hold onto the 'best and brightest' but also attract new talent. This population growth however is maintained In existing settlements and reduce the exposure to natural hazards.
Community risk understanding and perception	There is shift in perception and the community is aware of risk and how to manage the risks they are exposed and vulnerable to. This is coupled with an acceptance of shared responsibility for managing risks, where response agencies, communities and individuals acknowledge and accept their respective roles in managing risks. There Is also a significant increase in the state's literacy improving the effectiveness of messaging.
Economic development	Tasmania's economy is decarbonised and is now a global leader in clean technology and climate solutions. This was achieved by embracing the idea that not all development is good development in the long term. Responsible, sustainable and sensible tourism and forestry are also key components of a diversified economy which adapts to changing threats. Technological advances have also seen innovation in agriculture.
Urbanisation	Development trends focus on consolidation of communities, limiting urban sprawl and minimising the wildland urban Interface. Some location also see a reduction of the current footprint with increasing density in urban centres. This increasing urban density enables more sustainable energy and transport solutions with improvements to public transport networks reducing the reliance on personal vehicles.
Climate change and responses	Global and national responses to climate change see reduced impacts on Tasmania. Adaptive management processes are adopted to deal with the impacts that are felt, including enhanced response and recovery capabilities. The state also capitalises on the economic opportunities of climate adaptation.

TABLE 1: FACTORS AND DESCRIPTIONS OF THE BEST CASE SCENARIO FOR TASMANIA IN THE FUTURE

MOST LIKELY CASE

Factor	Description
Population and demographics	There is some growth in population, which sees its stable at around 600,000 in 2050, but this is not sufficient to stimulate strong economic growth. The ageing of the population is also of concern with young and educated people leaving the state in the hope of better employment prospects.
Community risk understanding and perception	There is an increasing expectation on emergency agencies to manage the risk by most of the population and what knowledge and understanding of hazards that exists within the community is uneven. Land use decisions are still focussed on other objectives rather than considering risk sufficiently.
Economic development	Public services main sector of the economy with increasing healthcare needs, and investment in education. Following that tourism and agriculture are the main productive economic sectors, however these industries need to, and have, become adaptive to changing climate. The other growing sector is creative, technology and knowledge workers with increased remote employment opportunities allowing them to tap into global markets.
Urbanisation	There is limited densification and instead an increased peri-urban region and a sprawling of settlements, both residential and commercial, relative to growth. Inner urban areas do see an increase in density but there Is still sprawling of the edges into semi-rural land. This leads to increased travel times and pressure on peri-urban environments. There is an improved effectiveness of constraining development in high risk areas however it still occurs particularly for coastal settlements.
Climate change and responses	The response to climate change is not sufficient to reduce the occurrence of extreme events in Tasmania which instead suffers annual asset losses from various climate affected hazards. A business-as-usual response is prevalent which focuses less on adaptation to new climate conditions and more on hard solutions to risk reduction. There is some limited progress in proactive planning processes for coastal hazards with combined efforts of defence and retreat.

TABLE 2: FACTORS AND DESCRIPTIONS OF THE MOST LIKELY SCENARIO FOR TASMANIA IN THE FUTURE

WORST CASE

Factor	Description
Population and demographics	The population of Tasmania is losing younger generations in search of employment Interstate and overseas at a rapid rate leaving the population significant aged. This sees a decrease in skills retention and unsustainable and dispersed communities. These dispersed communities also sees an increasing isolation for individuals and disconnection from social networks.
Community risk understanding and perception	Tasmania's communities and citizens increasingly expect to be rescued from all hazard either due to their inability to mitigate their own risks or their decision to disregard guidance provided. This sees a draining of resources as risks are ignored.
Economic development	Tasmania's economy becomes increasingly simplified with one major sector (agriculture) and is vulnerable to global markets. This is countered by government with an emphasis on any development is good development. There are also stresses placed on energy supply due to lack of infrastructure investment and limited renewable energy capacity.
Urbanisation	Reducing development controls in an effort to stimulate investment and growth sees sprawl into high risk areas (vegetated areas in peri-urban region and coastal areas). This also sees critical/valuable land uses and assets placed in at risk areas. The continued sprawl also sees the loss of cities 'economies of scale' effect and results in lower service provision and worn out/failing infrastructure.
Climate change and responses	There is a failure to respond to mitigate and adapt to the challenges of climate change and results impacts greater than predicted with uncontrollable events ever more frequent. The public are left uninformed and panicked with emergency services unable to cope with climate driven events. There are also unforeseen, secondary and tertiary order, effects of climate change with broad social and economic impacts.

TABLE 3: FACTORS AND DESCRIPTIONS OF THE WORST CASE SCENARIO FOR TASMANIA IN THE FUTURE

OPTIMISATION PROBLEMS

The following sections outline inputs for three hazard based optimization questions considered by stakeholders during the November 2017 workshop.

1. Bushfire – whole of landscape risk reduction
2. Coastal hazards – retreat, defend or something else?
3. Multiple hazards – legislative instruments, what is fair?

For each of these questions participants discussed whether specific locations were of interest, what risk reduction options were relevant along with any limitations or specific challenges that would be relevant to either the location or the implementation of risk reduction options. Also discussed were spatial and temporal factors such as where and who are costs and benefits relevant to (whole state/LGA/land holders) and what temporal increments where of interest for costing and assessment.

The below sections summarise these discussions for input into quantitative optimization problem formulation.

BUSHFIRE - WHOLE OF LANDSCAPE RISK REDUCTION

Bushfire is considered a whole of landscape risk and as such then entire model region should be considered in the optimization problem.

Decision variables - risk reduction options

- Fuel reduction burns
- Do nothing
- Community education
- Planning and regulation (land use planning)
- Hardening of (critical) infrastructure
- Response and preparedness

Constraints

- Community acceptance (especially to fuel reduction and land use planning)
- Vegetation and physical landscape impacts on effectiveness/feasibility of fuel reduction burns
- Being a good corporate citizen (minimising backlash – changes to regulation/legislation, need to be conscious of acceptance)
- Human resources / capacity
- Literacy / cognisance in regard to community education and messaging.
- King Island against burning, Flinders Island values grass grazing

Spatial & Temporal Factors

- TFS operates across whole of landscape to reduce risk

- Treatments at different scales and objectives vary at different scale (minimise overall risk to landscape, minimise life and property loss at community)

- Annual works program for fuel reduction programs 5 year planning horizon
- Community education needs refreshing
- Building hardening and regulatory options long term
- Minimise risk annual through works program (cumulative impacts)
- Frequency impacts on treatment effectiveness.

COASTAL HAZARDS - RETREAT, DEFEND OR SOMETHING ELSE?

This question considers specific areas of interest of the Tasmanian coastline, identified below in Figure ##. The question considers when coastal retreat or defense may be preferable risk reduction options, or whether there are other options to reduce the risk from coastal hazards.

FIGURE 2: MAP OF TASMANIA FOR AREAS OF INTEREST TO COASTAL HAZARDS

Decision variables - risk reduction options

- Allow individuals to accept the risk (including restricted covenant/limited tenure) – with no offsite impacts
- Replenishment
- Coastal hardening
- Accommodate (let permanent inundation occur and engineer solution)
- Retreat: progressive & abandonment

- Land use planning: limiting future development (focus appropriate land use in vulnerable areas)
- Site specific mitigation (raise house level)

Constraints

- Public and government risk tolerance and appetite for change
- Financial cost, liabilities
- Environmental costs (sand dunes, bird breeding sites)
- Social costs (loss of community)
- Political risks (influential residents on prime locations)
- Who owns cost of treatment implementation
- Greater vulnerability for lower socio-economic groups who don't have influence

Spatial & Temporal Factors

- State responsibility for policy, options suite, finance (regulation on who will pay)
- Local and site decisions regarding options selection, costs, operations

- New development proposals potentially require actions
- Existing development require different suite of risk reduction options
- Risk is event (or development) driven, rather than time driven

MULTIPLE HAZARDS - LEGISLATIVE INSTRUMENTS, WHAT IS FAIR?

The question regarding multiple hazards looks to answer what mix of legislative instruments are fair across society. This is particularly of interest for the south east of Tasmania and the Greater Hobart region.

FIGURE 3: MAP OF TASMANIA FOR AREAS OF INTEREST TO MULTIPLE HAZARDS

Decision variables

- Better building performance criteria in building controls, especially in what are considered low risk areas
- Raised floor heights
- Restrict development
- Movable housing
- No residential development in high risk areas

Constraints

- Who pays, broader community / individual?
- Dealing with legacy issues with legislation
- Impacts on community and infrastructure
- Liability, right to develop
- Building codes take time to impact
- May require government subsidies
- How to prove compliance?

Spatial & Temporal Factors

- Planning based on high risk areas

- Temporal factors on timing of developments

RISK REDUCTION OPTIONS ANALYSIS

The following sections outline data collected regarding various factors relevant to the acceptance, effectiveness and impacts of risk reduction options considered relevant to the Tasmanian case study and identified as possible options to be considered within optimization problems.

Risk reduction options considered where:

1. Coastal hardening
2. Fuel reduction burns
3. Temporary development approvals (limited tenure)
4. 'Do nothing'
5. Retrospective building codes
6. Restrictive land use planning
7. Coastal retreat
8. Community education

Each section shows the results of stakeholder commentary on the impacts (positive and negative) on socio-cultural, economic, amenity and environmental factors. Stakeholders also provided input on various components of the risk reduction option, these components are outlined in Table ##. Stakeholders were asked to respond with either high / medium / low to each of the components for each of the eight considered risk reductions.

Component	Description
Duration of Effectiveness	The length of time the risk reduction option will maintain an acceptable level of risk after it has been implemented.
Implementation Time	The time required to implement the risk reduction option. This may include, for example, the time required for community engagement, passing of legislation, design or construction of option.
Adaptive Capacity	The ability of the risk reduction to be altered in the future to handle new conditions.
Long-Term Confidence	The degree to which the option provides a robust solution for risk reduction and there Is little uncertainty in the option's ability to reduce risk.
Immediate Effectiveness	Following the implementation of the risk reduction option the length of time the option requires to have a significant impact on risk.
Operational Costs	All costs involved in the on-going use of the risk reduction option.
Capital Costs	All costs involved In the design and implementation of the risk reduction option.
Community Acceptance	The degree of which the risk reduction option is accepted (without attempts to change, protest or halt) by members of the community.
Political Acceptance	The degree of which the risk reduction is accepted (without attempts to change, protest or halt) by members of the political class.

TABLE 4: DESCRIPTIONS OF COMPONENTS RELEVANT TO THE EFFECTIVENESS AND IMPLEMENTATION OF RISK REDUCTION OPTIONS

COASTAL HARDENING

Considered the implementation of structural solutions to prevent inundation from storm surges and sea level rise. This risk reduction option is considered 'hard' infrastructure solutions and would include breakwater systems (storm surge barriers) and seawalls (Bouwer et al., 2014).

Factor	Commentary
Socio-cultural	The expectation built of doing this is very large especially for peri-urban it seems to promote doing more than that is done, this flows to economics and environmental.
	More acceptable if you are the individual affected by the hazard - at a community level less acceptable
Economic	Cost shared by whole community but benefits very few
	Creates false perception of protected assets - high risk for investors
Amenity	Loss of attractive coastline and attractiveness to tourists
Environmental	Significant impacts on coastal processes causing indirect impacts elsewhere
	High cost if hardening prevents natural coastal processes eg. saltmarsh retreat, flooding in wetlands etc.
	Sand dune loss
	Shorebird nesting loss
	Change in coastal processes

TABLE 5 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF COASTAL HARDENING

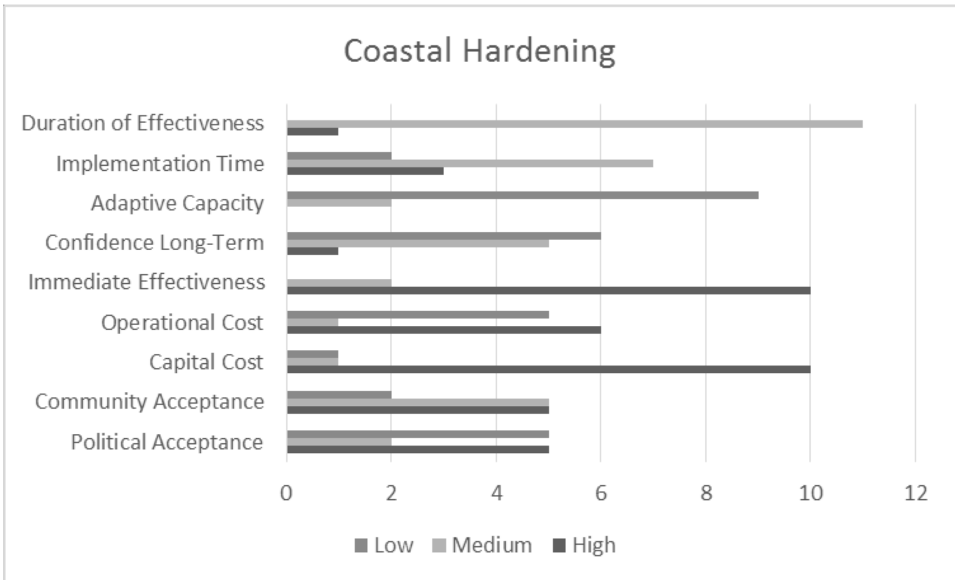

FIGURE 4: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF COASTAL HARDENING

FUEL REDUCTION BURNS

Fuel reduction burns or prescribed/planned burning is a technique for reducing the rate of spread and intensity of fires, by reducing the available fuel load prior to a bushfire emergency situation (State Fire Management Council, 2014).

Factor	Commentary
Socio-cultural	A known and measurable benefit
	Air quality health impacts, respiratory illness
	Community will need to adapt / accept impacts
Economic	Suppression will decrease with a well implemented, planned and strategic burning program
	Tourism: landscape scars
	Viticulture: smoke taint
Environmental	High environmental cost if frequency, timing, heat and location of burns doesn't take into account needs of ecosystems
	Ecological impacts can be positive and negative
	Air quality impacts are negative
	Fuel reduction burning can meet multiple land management objectives, not just risk reduction. Can restore ecosystem function
	Fire is a natural part of the environment and we can use to minimise adverse outcomes
	Concerns regarding smoke on health
	Loss of habitat when wildlife (birds, eagles) nesting
	Inappropriate fire regimes will have unintended consequences

TABLE 6 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF FUEL REDUCTION BURNS

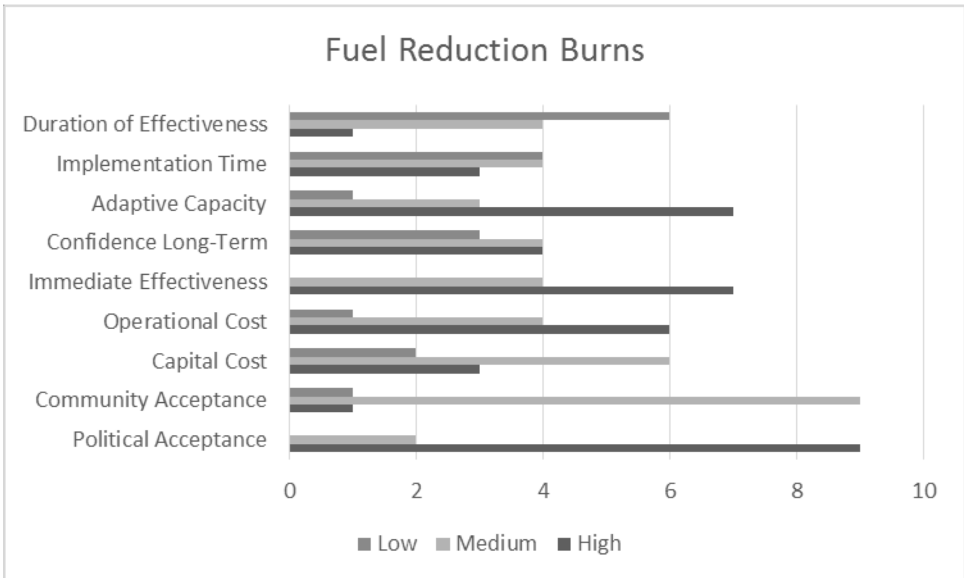

FIGURE 5: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF FUEL REDUCTION BURNS

TEMPORARY DEVELOPMENT APPROVALS (LIMITED TENURE)

Land tenure is defined as, 'the terms and conditions on which land is held, used and transacted, within a particular system of rights and institutions that govern access to and use of land.' (Reale and Handmer, 2011). Temporary development approvals or limited tenure as a risk reduction option constrains the terms and conditions to a limited time, following which usage rights are returned to the crown if deemed risk is sufficient.

Factor	Commentary
Socio-cultural	People can develop "ownership" quickly and refuse to change / leave.
Economic	Likely to be naively accepted.

TABLE 7 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF COASTAL HARDENING

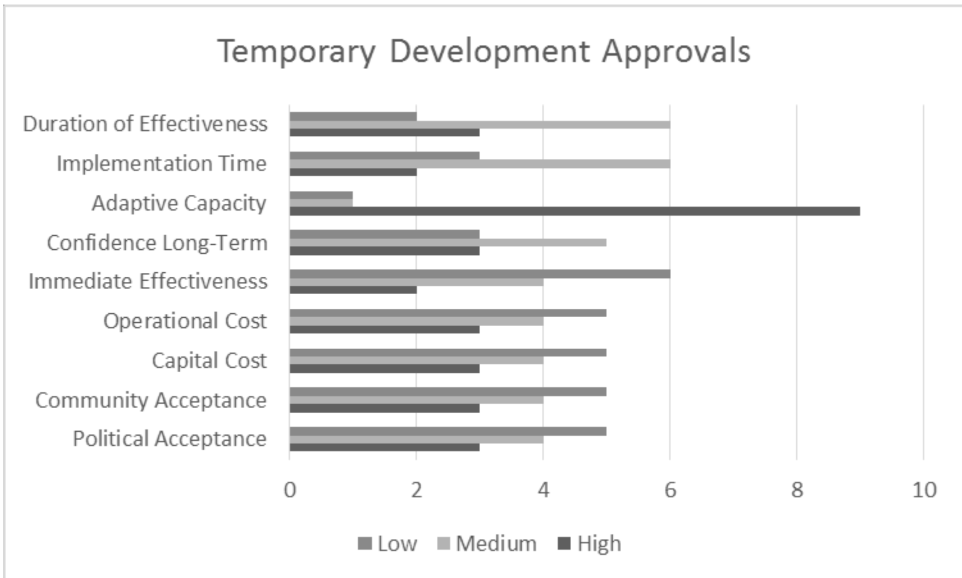

FIGURE 6: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF TEMPORARY DEVELOPMENT APPROVALS

'DO NOTHING'

The risk reduction option of 'do nothing' considers that the state government and its agencies does not actively engage to mitigate risk within the landscape and community. The commentary below considers the impacts of this decision.

Factor	Commentary
Environmental	Positive environmental impact in areas which require/rely on fire e.g. eucalypt forests.
	High impact if in sensitive environments e.g. alpine.

TABLE 8 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF COASTAL HARDENING

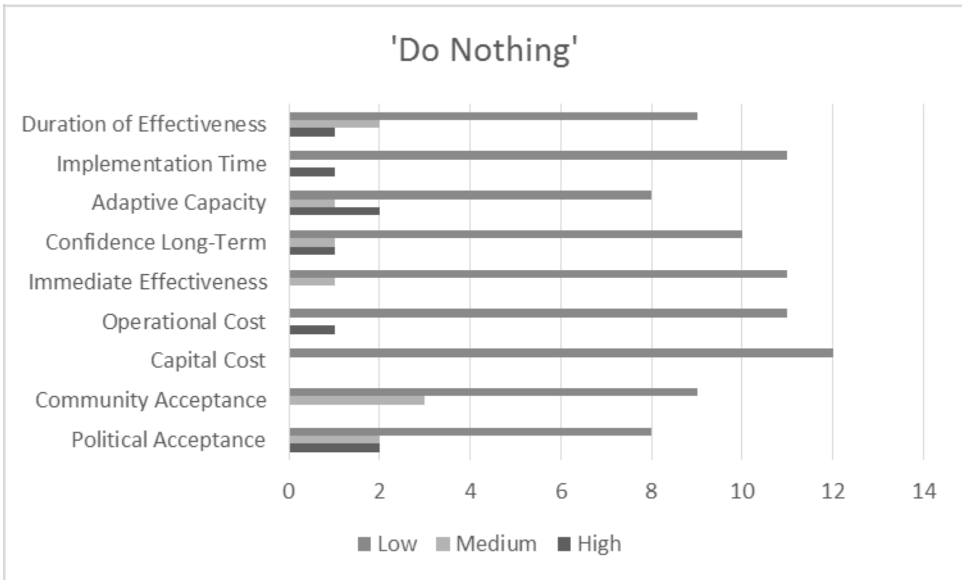

FIGURE 7: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF 'DO NOTHING'

RETROSPECTIVE BUILDING CODE CHANGES (RETROFITS)

Retrospective changes to building codes to enforce retrofits to at risk capital stock and infrastructure are focused on reducing the vulnerability of assets, rather than reducing the hazard itself. This would involve regulations enforcing the strengthening of structures (against wind, or earthquake loads or fire intensities), or measures to flood-proof properties (raising floor levels, dry-proofing measures) (Bouwer et al., 2014).

Factor	Commentary
Economic	Reduced capital and discretionary spending by households.
	Boost to building sector.
	Coupled with planning - good long term sustainable approach.
	Unlikely to happen

TABLE 9 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF COASTAL HARDENING

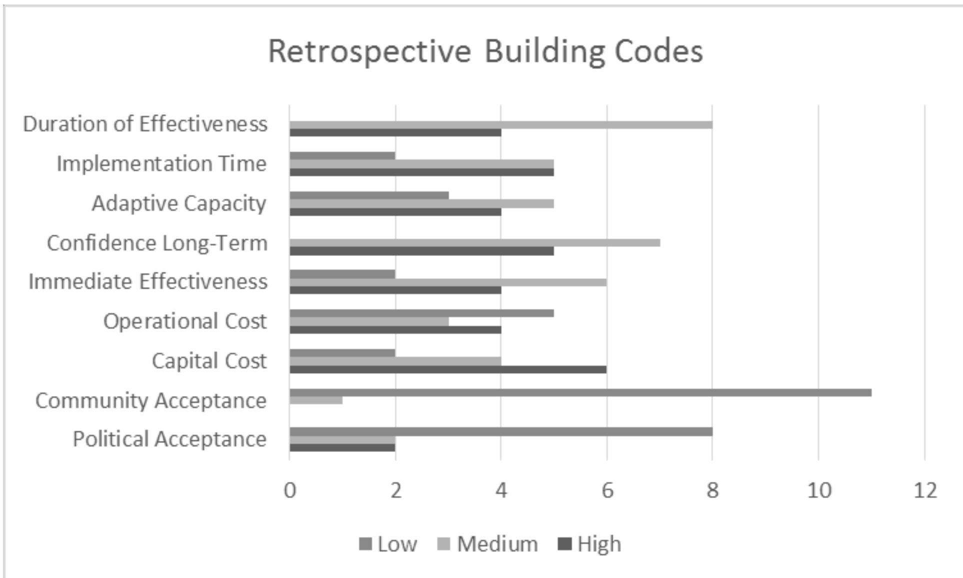

FIGURE 8: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF RETROSPECTIVE BUILDING CODES

RESTRICTIVE LAND USE PLANNING

Restrictive land use planning refers to use of regulation and legislation to restrict new development in areas deemed to be of high risk. This looks to reduce the exposure and vulnerability to natural hazards and can be implemented through restricting permitted land uses or densities, by applying zoning overlays or defining setbacks or buffer zones (Bouwer et al., 2014, Lyles et al., 2014).

Factor	Commentary
Socio-cultural	Most socially acceptable and strategic - communities accept it over time
	People feel this imposes on property rights, natural justice, free markets etc. It needs to be implemented slowly to gain acceptance.
Economic	Reduced development potential and capital value of land parcels.

TABLE 10 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF RESTRICTIVE LAND USE PLANNING

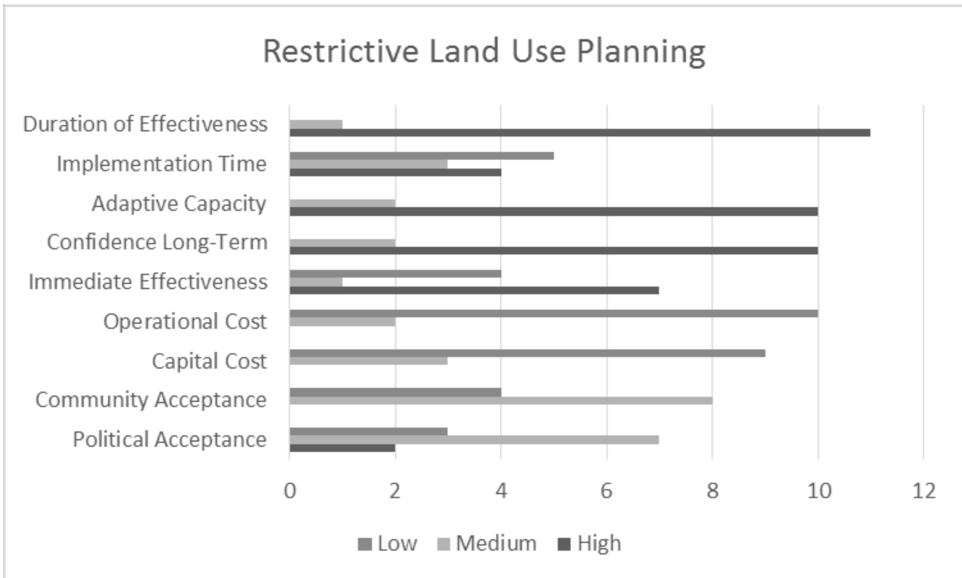

FIGURE 9: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF RESTRICTIVE LAND USE PLANNING

COASTAL RETREAT

Coastal retreats refers to the planned retreat of developed areas subjected to rising sea-levels and coastal surges. This could be implemented via the creation of setback areas from oceans and the provision of assistance for relocation of assets (Lyles et al., 2014).

Factor	Commentary
Socio-cultural	Social disruption / dislocation.
Economic	Hidden costs in moving towns and associated infrastructure
	Lack of certainty and reluctance to invest due to limited resale
Amenity	Conflict between recreational users (beach) and residential
Environmental	Positive environmental impact as allows continuation of coastal processes and reduces expectations of coastal protection.

TABLE 11 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF COASTAL HARDENING

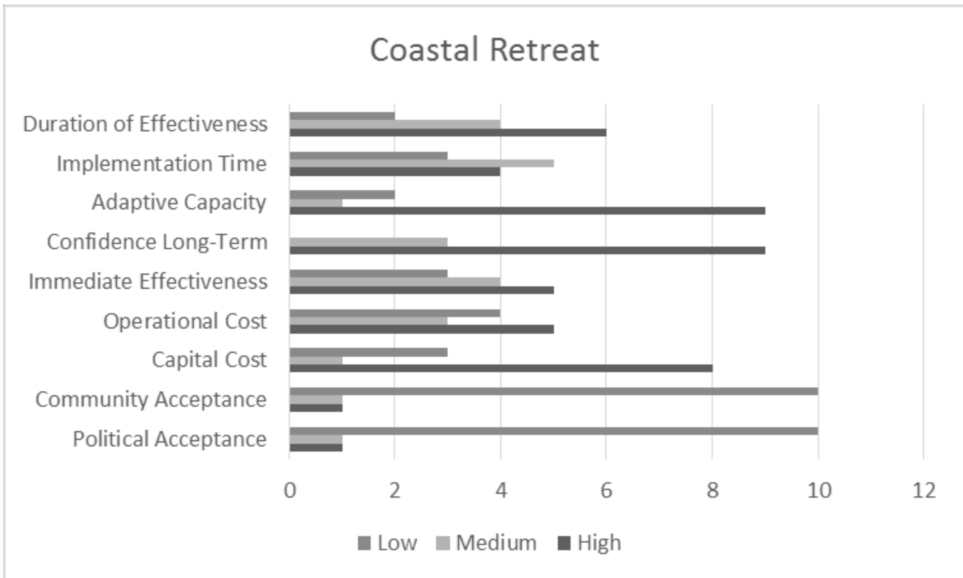

FIGURE 10: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF COASTAL RETREAT

COMMUNITY EDUCATION

Community education is aimed at changing people and communities apathy towards natural hazards. This is focused on education programs to increase protective actions by different individuals and societal groups by providing information on hazards, risks and available options to reduce impacts (McEntire and Myers, 2004).

Factor	Commentary
Socio-cultural	Need to (individualise) messages around when fuel reduction isn't appropriate or requires permits.

TABLE 12 - COMMENTARY ON POSTIVE AND NEGATIVE IMPACTS OF COASTAL HARDENING

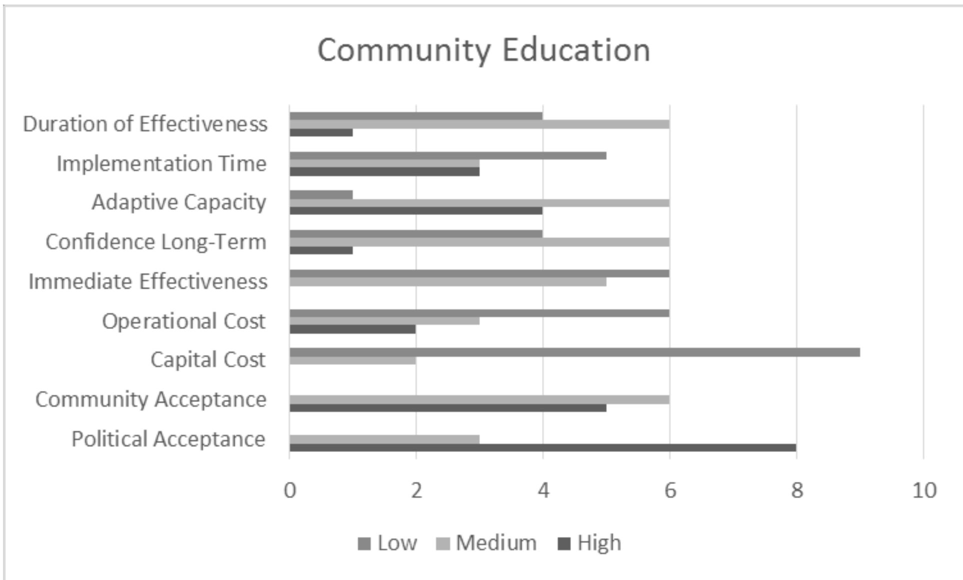

FIGURE 11: RESULTS ON IMPLEMENTATION AND EFFECTIVENESS OF COMMUNITY EDUCATION

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Tomorrow's disasters Embedding foresight principles into disaster risk assessment and treatment

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ABSTRACT

Disaster risk is a complex, uncertain and evolving threat to society which changes based on broad drivers of hazard, exposure and vulnerability such as population, economic and climatic change, along with new technologies and social preferences. It also evolves as a function of decisions of public policy and public/private investment which alters future risk profiles. These factors however are often not captured within disaster risk assessments and explicitly excluded from the UN General Assembly definition of a disaster risk assessment which focuses on the current state of risk. This means that 1) we cannot adequately capture changes in risk and risk assessments are out of date as soon as published but also 2) we cannot show the benefit of proactive risk treatments in our risk assessments. This paper therefore outlines a generic, scale-neutral, framework for integrating foresight thinking about the future into risk assessment methodologies. This is demonstrated by its application to a disaster risk assessment of heatwave risk in Tasmania, Australia, and shows how risk changes across three future scenarios and what proactive treatments could be possible mitigating the identified drivers of future risk.

1. Introduction

Disasters are complex in their nature, based on the interaction between three elements. One, natural events - potentially cascading and compounding in their behaviour, hazards. Two, the area in which they impact and the assets that exist there, such as people, buildings, hospitals, areas of cultural and historical significance, exposure. And, three, the degree to which these assets are susceptible to the hazard events, vulnerability; [1 3].

Each of these elements is also continuously in flux. The nature of hazards is changing with climate change, which alters the frequency and intensity of events [4,5]. Exposure, similarly, is changing in its nature due to technological change and urbanisation rates, which are some of the many drivers of exposure. Vulnerability, which can act as the relationship between hazard and exposure, also changes with time. For example, vulnerability changes as infrastructure deteriorates with weathering and usage [6,7], along with the increasing connectedness of society, creating new dependencies and vulnerabilities [8].

These factors highlight the changing and complex nature of disasters. They are not simply natural events but a function of interactions between changing environmental threats and societal developments and decisions. Disaster risk, when considered in this manner, is an inherently complex system displaying characteristics of emergence, and wickedness [9 11]. This complexity, and uncertainty, must be incorporated into the thinking and conceptualisation of disaster risk, pushing past a probabilistic understanding of risk, which is inherently a past-oriented paradigm, and instead conceptualising risk as a dynamic system. This paper proposes a framework to enable this conceptual definition to be incorporated into the planning for the assessment and treatment of disaster risks.

Efforts to minimise disasters or manage their impacts are traditionally facilitated by disaster risk assessment processes [12,13]. Risk assessment is an effort to understand the uncertain factors and influences that may impact on an organisation's ability to achieve its objectives [14] (ISO). Under the ISO principles, risk is focussed on uncertainty and defined as the consequence of an organisation setting and pursuing objectives against an uncertain environment [14]. With this definition, risk is not inherently negative, but instead includes events that could have an effect on an organisation's objectives, either positive or negative, that are uncertain.

In the disaster/natural hazards and emergency management spheres, there is, however, a difference in how risk is generally defined and considered, as well as how risk assessments and subsequent management activities are developed and implemented. Terminology of

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the United Nations International Strategy on Disaster Reduction (UNISDR) defines disaster risk as the the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a *specific period of time*, determined probabilistically as a function of hazard, exposure, vulnerability and capacity [15]. Similarly, disaster risk assessment is defined as a qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating *existing conditions* of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend [15].

Consequently, while the ISO definition of risk includes reference to uncertain environments, the definitions of risk used in the disaster/natural hazard management sphere focus on current conditions while omitting the consideration of uncertainties, especially those resulting from future changes. This is a significant shortcoming, as the impact of uncertain future conditions impacts on our understanding of disaster risk and how to effectively treat it. This focus on the current risk, and probabilistic understanding from UNISDR likely originates from a historical emphasis on response and recovery in comparison to prevention along with the significant role quantitative risk modelling plays in insurance markets following the rise of catastrophe modelling since the late 1980s. Therefore quantitative risk assessments have mostly been designed for a detailed current understanding of disaster risk to more accurately price risk within insurance markets for a 1 3 year policy horizon.

Risk assessments within the literature follow this UNGA definition and focus on capturing data on the current situation, using census, economic and land use information to inform the development of exposure information such as in Gunasekera et al. [16]; Aubrecht et al. [17]; and Santa María et al. [18]. Similarly, information regarding vulnerabilities is described based on either socio-economic indicators of societal resilience and vulnerability to hazards [19 23], or the physical characteristics of assets that make them more or less susceptible to hazard events, such as construction types, ages and floor heights [24,25]. This results in risk assessments focussed on the current risk, based on latest information, with little consideration of how this is changing, and what emergence is occurring within the exposure and vulnerability elements of risk.

For hazards, although some consideration is given to future conditions via the impacts of future projections of climate change (when relevant) on the frequency and intensity of hazard events [4,26], little consideration is given to 1) emergence between the risks associated with multiple hazards (e.g. compounding events of coastal storms and riverine flooding, the occurrence of wildfire leading to increased likelihood of flooding due to loss of vegetation and top-soil); or 2) the influence of future exposure changes on the nature of the hazard (e.g. changing amount of permeability on flood risks, and road and electricity infrastructure on wildfire ignition probability). This lack of consideration of dynamics, emergence (newly created, identified or increasing [27]) and wickedness (variety of stakeholders, conflicting views and diverging perspective of solutions [28]) of disaster risk is shown in multiple recent disaster/natural hazard risk assessments, including Depietri et al. [29]; who consider multiple hazards across New York city. They assess the region's relative exposure and vulnerability is to heatwaves, inland and coastal flooding based on socio-economic factors. However, there is little consideration of how these factors change in time and in relation to each other. This is also the case in Bernal et al. [30]; which assesses multi-hazard risks in taking a probabilistic modelling approach to earthquakes and landslides while considering only existing housing inventories; and similarly in Feroz Islam et al. [31] and Novelo-Casanova et al. [32]; both of which present innovative studies on risk assessment and include discussion on the role of urban planning as risk mitigation strategy but do not include drivers of future risk.

As evidenced above, there is therefore an absence of risk assessment processes within disaster risk management that capture the degree of wickedness within the disaster risk system. This means that changes in disaster risk, and therefore the risks to organisations and communities, are not adequately captured. There are also broader implications for disaster risk assessment and management considering the principles of risk management. Considering ISO31000, risk treatments are determined based on risk identification, analysis and evaluation, and are then reviewed against these components through monitoring and review phases. Therefore, as risk treatments identified and subsequently evaluated cannot be tested against reduction of future or emergent risks, treatments will only have reactive functions (treating existing risk), not proactively treating emergent risk in a strategic manner. This represents a fundamental blind-spot, and a significant loss in the ability of risk assessments to inform risk reduction actions for tomorrow's disasters. This is substantial given 85% of the increase in insured losses from 1980 to 2014 could be attributed to increase in urbanisation and economic value (Aon [33].

Additional to disaster risk assessments not being able to inform risk reduction actions for tomorrow adequately, by not doing this, treatments implemented, or decisions made in other domains of public and private entities, may result in maladaptation and negative risk outcomes over the long-term. These include environmental degradation and displacement, even in the case of implementing structural risk reduction activities (dams etc.), which can exacerbate vulnerabilities in communities impacted [34]. Short-term reactions to disaster events, not considering future implications, often leads to either decreased resilience locally or misuse of limited resources. This is shown in the case of excessive fire suppression in the USA post the 1910 wildfires in the western United States, which has led to many forests becoming more flammable and less controllable as the natural fire regime has been removed [35]. The levee-effect where the provision of flood defences leads to increased risk is another example of how the lack of consideration and exploration of interactions and dynamics of risk into the future has led to negative outcomes [36,37]. These are just a few examples of how future considerations not being accounted for within disaster risk assessment and management can lead to adverse outcomes. There are many others including coping mechanisms leading to longer term vulnerability [38]; increased fuel management in areas with recent fire experience leading to reduce fuel management efforts in other similar regions; and a focus on short-term actions and a lack of focus on systemic changes through land use planning [35].

In other applications of risk management there is growing use of the principles of foresight to inform strategic risk management   a process for identifying, assessing and managing risks and uncertainties, affected by internal and external events or scenarios, that could inhibit an organization's ability to achieve its strategy and strategic objectives with the ultimate goal of creating and protecting shareholder and stakeholder value [39,40]. Foresight can be considered as a process of strategic thinking that looks to challenge common perceptions of what will happen, and allow for an expanded range of strategic options to be considered in a planning process [41]. In an organisational setting, foresight can enable decision makers to see the future with different perspectives, and improve understanding of the implications of various trends in society [42 45].

There have been few examples of concepts that fall under the banner of foresight linked with disaster risk assessments. These include Kwadijk et al. [46]; who look at future climate scenarios and coastal risks in the Netherlands; Lempert et al. [47]; who use exploratory simulation models to test flood risk management strategies against future uncertainties; and Riddell et al. [48]; who develop exploratory scenarios to assist disaster risk planning for a metropolitan region. However, these represent disparate examples, and are lacking in an overarching framework to incorporate the benefits of foresight with a disaster risk assessment to enable proactive and strategic risk treatments.

Challenges do exist in the integration of foresight into disaster risk management including the lack of resources currently to support risk assessment and reduction activities [49]; quantification challenges of future changes into disaster risk models [50]; and challenges associated with foresight studies in general including lack of focus on policy and planning and decision-making, subjectivity of findings and true representativeness [48,51,52]. The benefits however if integration is performed well can be substantial.

Therefore, the objectives of this paper are to 1) introduce and describe a framework for using the principles of foresight for proactive, strategic disaster risk management, 2) provide greater insight into the role that foresight can provide to disaster risk assessment and management, and 3) highlight the utility of foresight through applying the framework to a disaster risk assessment (the Tasmanian State Natural Disaster Risk Assessment 2016). The paper aims to achieve these objectives by, in Section 2, outlining a proposed framework for the integration of foresight with risk assessment and risk treatment, and then in Section 3, applying this framework to an existing disaster risk assessment via engagement with representatives in the case study region to explore drivers of risk. Section 4 provides discussion of the framework, its applications and future directions for research. Conclusions are offered in Section 5.

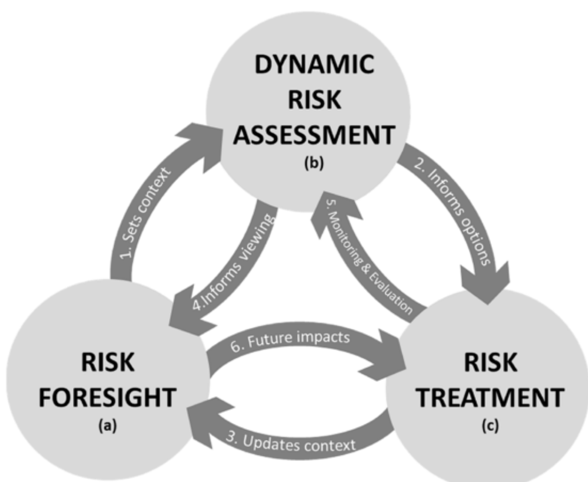

Fig. 1. Overview of framework, its three key components (a c), and six interaction process (1 6).

2. Embedding foresight into disaster risk management: a framework for managing Tomorrow's disasters

Foresight can be integrated into risk management procedures by allowing a broader consideration of the context pertinent to the risk assessment. It can also allow for the consideration of treatment effectiveness under future, uncertain conditions. Fig. 1 shows the outline of the proposed framework to enable foresight to be used to inform dynamic risk assessments and risk treatments, and how each of these components relate, inform and update each other. It is thought this framework can support any disaster risk assessment process at any scale and hazard. For example, the framework could be used to assessing multiple natural hazards impacting on a growing urban area/city. Alternatively, the framework could be used to inform and assess national level disaster risk management policies in a non-spatial manner developing futures of national change.

The three key components 1) risk foresight, 2) dynamic risk assessment and 3) risk treatment (labelled a, b, and c, respectively Fig. 1) allow for disaster risk management processes to draw on insights from each component, along with the information they provide other components, resulting in an iterative framework. Each component of the framework provides critical insight into the disaster risk management processes, these key roles of the components are described in Fig. 2. Also important to the framework is the interactions between components these are labelled 1 6 in Fig. 1. The following sections provide further details on each of the framework's main components (Section 2.1 Section 2.3) and their interaction processes (Section 2.4).

2.1. Risk foresight

Foresight allows for the strategic and transparent consideration of driving forces impacting on disaster risk, and the system of values in a region undergoing a risk assessment and management processes. Foresight is a process that enables drivers of change globalisation, urbanisation, technological development, changing societies and work patterns etc. to be considered and how they impact on the system moving into the future. Importantly, there is an emphasis on foresight not being a predictive process, but an approach to understand features

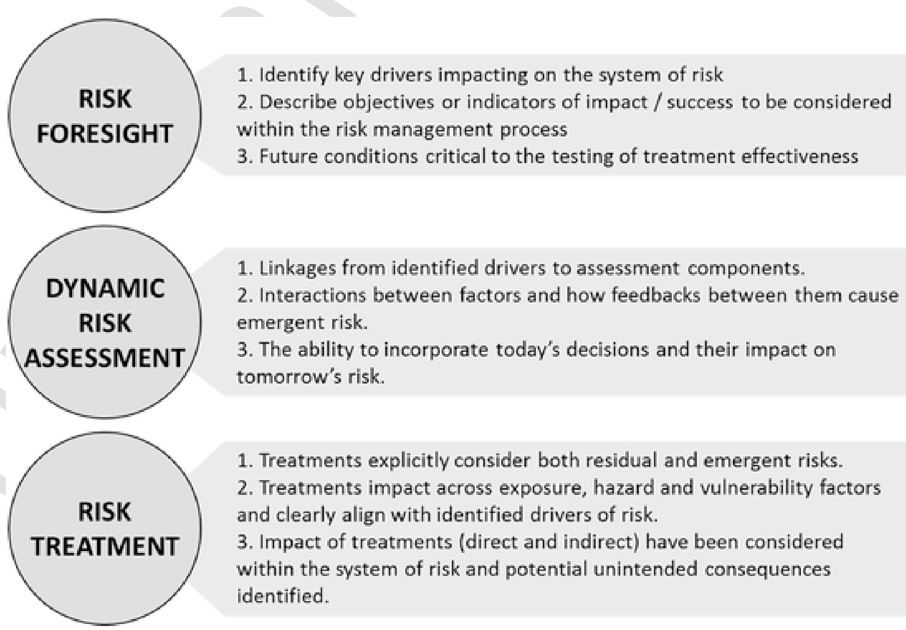

Fig. 2. Three key roles of each of the framework's components.

or drivers that can have an impact on the long-term effectiveness of a strategy.

There is significant literature on the role of foresight approaches within organisations and companies, allowing them to better position themselves to deal with external factors - see Bradfield et al. [53]; Wright et al. [54]; and Ramirez and Wilkinson [55]. However, the key purpose of foresight exercises, and the embedding of foresight approaches into strategy development and decision making, is in the conscious effort to enhance and enrich the context within which the planning, implementation and execution of a strategy are undertaken. It is under this concept of defining the context that foresight can also assist significantly in the risk assessment and treatment process. Foresight allows for a broader context to be considered when assessing risks and allowing an expanded range of strategic risk treatments to be considered by challenging assumptions and perceptions.

Multiple techniques can be used to challenge assumptions/perceptions in a foresight process. Such techniques generally involve the creation of a working group and participatory processes, along with scanning of current trends to assess possible future directions [56,57]. Other methods take a more quantitative approach and exploit existing modelling systems to determine vulnerabilities and interesting cases for strategy development [58,59]. Regardless of the process, foresight should provide insight into the impact of drivers on risk, for example, the density of residential developments and agricultural decline causing migration to urban areas.

Arguably the most common approach used in foresight studies is the development of scenarios and the integration of these scenarios into planning processes. Scenarios are typically defined as coherent descriptions of alternative hypothetical futures that reflect different perspectives in past, present and future developments which can serve as a basis for action [60], and often in the context of foresight studies portray future plausible states, and pathways that led to their development. They can be considered, from Börjeson et al. [61] and Maier et al. [62]; as either predictive - questioning what will happen (although still posing multiple results), exploratory - designed to question what could happen, and normative - which considers how a specific future can be realised. This is different to how scenarios are often considered in disaster risk assessment, which focus on a specific series of events in an emergency or disaster situation and often do not include any forward-looking perspectives on future conditions as contained within the above definition from Van Notten [60].

Scenario development can take many forms, including participatory processes with large stakeholder groups [63], trend analysis and extrapolation using forecasting models [64], as well as a combination of simulation models and stakeholder/expert input [65,66]. Purely quantitative methods can also be applied, such as scenario discovery [58] or decision-scaling [67], when quantitative system models exist, which is especially true for risk assessment processes at an asset or closed system level, such as water supply systems. Other mechanisms of foresight that provide value within the context of considering tomorrow's disasters include the use of mega-trends, Delphi studies and exploratory modelling approaches, of which more can be found out about in Hamarat et al. [68]; Kwakkel and Pruyt [59]; Liimatainen et al. [69]; Moallemi et al. [70]; Reimers-Hild [57]; Smeets-Kristkova et al. [71]; and Toppinen et al. [72].

Critical to the success of the process though, irrespective of mechanisms selected to provide foresight which could be selected based on scale, resources, available time, are several key questions the exercise must answer. These are 1) what are the key drivers impacting on the system of interest, 2) what objectives or indicators of impact/success are to be considered within the risk management process and 3) what future conditions are critical to the testing of treatment effectiveness (these key questions are summarised in Fig. 2 for each of the components). By responding to these, the foresight exercise provides: critical insight into drivers of risk that must be incorporated into the risk assessment process at an appropriate scale; future conditions or states of world for treatments to be tested against; and a mechanism by which assumptions can be exposed, and challenged in a way that reduces unintended consequences that occur when influencing a wicked problem.

2.2. Dynamic risk assessment

Following Fig. 1, after the risk foresight process, dynamic risk assessment processes occur. As outlined in the Introduction (Section 1), traditionally disaster risk assessments focus on the capture of accurate data related to the exposure of people, assets and other values to the attributes of a natural hazard that could cause them damage (e.g. water level from flooding, peak ground acceleration for earthquake). For quantitative risk assessments that produce damage estimates, such as average annual loss, effort is then concentrated on defining the relationship between the magnitude and likelihood of the natural event with the damage it produces against a chosen exposure class, which is defined as vulnerability, and is commonly expressed with stage-damage curves [24,73].

Non-quantitatively focused risk assessment processes may see results shown in a matrix format of likelihood vs consequence, such as Santos et al. [74] and Saunders and Kilvington [75]; or visually map the intersection between exposure and hazard without quantifying the impact of the interaction and instead using representative indices for vulnerability such as Koks et al. [76]. There is significant description of these processes in EMA [77] and UNISDR [13]. Depending on the exposure of interest, more sophisticated quantitative assessments may also take place that look at the broader economic impacts such as Hallegatte [78]; and Koks and Thissen [79].

For a foresight enabled dynamic risk assessment on tomorrow's disaster, the above components of a risk assessment procedure do not change, they are however framed in a dynamic context allowing for them to provide insight into how the risk is changing, and importantly why. Using the defined context from risk foresight, the disaster risk assessment processes must account for the identified drivers of risk for the context and scale of interest. For rapidly urbanising regions, this may see the modelling used within the risk assessment process requiring consideration of changing land use, and its subsequent influence on exposure (increased urban footprint), vulnerability (changed stage-damage curves for new construction), and hazard (increased urbanisation changing flood magnitude, flow paths and infiltration rates). For regions where there is economic decline, consideration should be given to how this influences risk components as well (e.g. in increased socio-economic vulnerability to recover from events, and capability to invest in risk reduction methods from central governments with a declining tax base).

Similar consideration also needs to be given to all potential drivers of risk including climate change. Incorporation of climate impacts within the hazard modelling may show increases in intensity, frequency and duration of certain events [26,80]. Extreme uncertainty that may arise from downscaling of climate parameters should also be tested from considering the effects which can cause the greatest uncertainty against the objectives of the region or organisation. Consideration of other climate impacts such as transition risks on economic activity may also be relevant [81]. By connecting drivers of risks to the risk assessment process, insight can be gained on how to best inform the assessment process by including more relevant information related to exposure and vulnerability such as the need to consider changing economic fortunes for vulnerability assessments. It also shows how to best treat risk and emergent risks based on mitigating the factors causing them to occur.

Similar to the foresight process, the mechanisms employed for the risk assessment process can be broad, depending on a variety of factors, scope, resources etc. However, key information must be included. Risk assessment processes that account for the wickedness of tomorrow's disaster must include 1) linkages from the identified drivers to assessment component; 2) interactions between factors and how feedbacks between them cause emergent risk; and 3) the ability to incorporate today's decisions and their impact on tomorrow's risk, providing a wind-tunnel for risk management actions. By ensuring the inclusion of these three factors and embedding them within the qualitative or quantitative process that is used to determine the nature of the disaster risk, dynamic risk assessments can be produced, which provide insight as to how disaster risk changes with uncertainty across its drivers and how treatments can be designed to manage this.

2.3. Risk treatment

Risk treatment is the final stage in the framework and utilises the risk assessment process to evaluate potential options to be implemented to avoid, remove, change or share the risk (or potentially accept it). Disaster risk treatments traditionally have focused on response capabilities as performed by civil protection and emergency management agencies. A growing focus has been on the mitigation of disaster risks, with a study showing cost-benefit analysis of mitigation efforts ranging from 1.3:1 to 1800:1 [82]. Risk mitigation efforts see the design and construction of levees and dykes informed by risk modelling [83,84], as well as fuel load reduction burns to minimise the threat of wildfire [85] and retrofitting options to roof structures to mitigate the impact of extreme wind and cyclone hazards [86].

There is also a broad group of treatment options that can influence across the elements of risk - exposure, vulnerability, and hazard. Bouwer et al. [87] provide an overview of the range of risk reduction options that are possible, most of which focus on a traditional conceptualisation of disaster risk. Urban/spatial planning, included within Bouwer et al. [87]; is discussed as one of the most powerful but under-utilised risk reduction methodologies [88 90]. However, given risk assessment and treatments emphasis on reactive actions on current risk, and that the influence of urban planning primarily is on future disaster risk, the under-utilisation of urban/spatial planning is not necessarily a surprise.

For foresight-informed risk treatments, portfolio approaches may need to be embraced to deal with both existing and emergent disaster risks. This is focused on managing and reducing existing risks through risk reduction methods, as previously outlined, but also integrating measures and treatments that influence the drivers of future risk and reduce the role of bad decisions made today, leaving tomorrow's risk behind for emergency management and civil protection agencies to respond to and recover from. Evaluation and prioritisation of treatment actions should consider performance against time, and how well individual treatments can be combined into portfolios. Therefore treatment's robustness, adaptability and long-term performance or deterioration become highly relevant.

Systemic and forward thinking risk assessment and treatment should see risk reduction measures being considered across a broad range of activities to act on the disaster risk system. This may encompass actions such as improving school education to increase the effectiveness of messaging and other child-orientated actions [91], reforestation (or slowing deforestation) of large areas reducing flood risk [92] or explicit incorporation of the systemic causes of vulnerability (societal dynamics and power structures, poverty etc.) to effectively address them [93]. It also enables a systematic understanding of the full potential impacts of intended risk reduction activities, or other actions that influence the disaster risk system, such as the provision of road infrastructure to improve accessibility of response vehicles and evacuation routes, which could also induce increased urban growth and subsequent exposed values, as well as change flood paths by decreasing infiltration and acting as channel [94,95], and increasing the likelihood of ignition for wildfire disaster risk [96,97].

As with previous components, the procedures used to determine appropriate risk treatments and their form are not as significant as their key ability to deliver critical information. For risk treatments, key questions to respond to are 1) does the treatment (or portfolio of treatments) explicitly consider both existing and emergent risks, 2) do treatments impact across exposure, hazard and vulnerability factors and clearly align with the identified drivers of risk, and 3) have the impacts (direct and indirect) of treatments been considered across the system of risk - identifying potential unintended consequences and influence. Responses to these questions enable the risk treatments to strategically treat and proactively reduce risks, using the decisions of today to positively influence on tomorrow's risk profile.

2.4. Interaction processes

Outside of the three key components of the framework, the interactions and flow of information between them is critical for a foresight informed risk assessment and management approach. Previously Fig. 1 and Section 2 provided high level details on the interactions and this section will provided further details. Table 1 summarises linkages between components in both forward and backward interaction processes.

Following the feedforward processes (items 1 3 in Fig. 1), risk foresight provides information into the dynamic risk assessment (item 1), with dynamic risk assessment informing risk treatment (item 2) and finally completing the loop with treatment informing subsequent foresight activities (item 3). For risk foresight to have influence over the risk assessment process as outlined earlier, setting the context is critical. Within sets context risk foresight needs to provide the risk assessment an outline of the disaster risk system of interest now and into the future including system elements and linkages, actors and drivers. With this understanding, the risk assessment process can look to assess the relative significance of each of the elements and how they can be included in each of the hazard, exposure, and vulnerability elements of disaster risk assessments.

Risk assessment informs options to be considered within the treatment component. This involves highlighting the risks that need to be treated, both emergent and existing, and the factor of risk contributing to or driving the change in risk profile. This is then used within the risk treatment component to identify, evaluate and subsequently imple-

Table 1
Overview and description of the proposed framework's linkages.

Provider	Receiver	Link	Description
Feedforward processes			
Risk Foresight	Risk Assessment	Sets context	Provides the basis of risk assessment as to hazards considered, environmental and social setting, time horizon, stakeholders involved etc.
Risk Assessment	Risk Treatment	Informs options	Provides insight as to areas requiring treatment and information on appropriate treatments.
Risk Treatment	Risk Foresight	Updates context	The application of treatments will change the situation and as such may require updates to conditions providing the basis for foresight and assessment.
Feedback processes			
Risk Treatment	Risk Assessment	Monitoring & Evaluation	The application of treatments is measured and monitored against risk assessment to evaluate performance.
Risk Assessment	Risk Foresight	Informs viewing	Provides the conditions and influences the framing within which to undertake the foresight exercises and identifies specific information required.
Risk Foresight	Risk Treatment	Future impacts	Provides future conditions under which risk treatments can be assessed in relation to their impact on emergent risk.

ment treatments that can reduce, change, transfer or accept the assessed risks.

The final feedforward links risk treatment back to risk foresight and enables the context to be updated due to the design and implementation of risk treatment options. This iterative loop supports the effectiveness of foresight processes so that assumptions made within risk foresight can be tested against development, and re-occurring foresight supported risk assessment allows for drivers and assumptions to be greatly improved, as analysis on the dynamics of change can be undertaken and incorporated within the next iteration. Examples of this could include the implementation of urban planning strategy to restrict residential development in a region this can be included within the refreshed foresight process along with any impacts this may have also had such as the increased density in areas surrounding the exclusion zone (causing potential emergent risk).

The backwards interaction processes are also critical between components, with the link between risk treatment and assessment providing the basis for monitoring and evaluation of implemented treatments. Risk assessment has the feedback to risk foresight by establishing the boundary conditions for the foresight exercise (e.g. defining hazards of interest) and outlining the types of relevant information the foresight exercise can provide to the risk assessment (e.g. specific exploration of known vulnerabilities in the current system and values to be included in the assessment). Risk foresight to risk treatment provides future conditions for risk treatments to be effective for managing emergence, which allows a mechanism for their effectiveness to be tested ex-ante by assessing against the same metrics of the risk assessment.

3. Embedding foresight into disaster risk management in Tasmania: case study application of framework

3.1. Case study background

The above framework, its key components and interactions, are demonstrated by its application to a disaster risk assessment in the state of Tasmania, Australia. This section demonstrates the application of the framework through detailing engagement processes for the risk foresight component of the framework, before highlighting how this can be used to inform a disaster risk assessment by showing how it can be integrated into the previously commissioned Tasmanian State Natural Disaster Risk Assessment (TSNDRA) [98].

Fig. 3 provides an overview of the following sections and results, as to how they represent the implemented framework for risk assessment in Tasmania. Each panel represents a component of the framework risk foresight, assessment and treatment and shows the types of information and methods used for each component in the application of the framework. Boxes in light grey Tas. State Natural Disaster Risk Assessment , and Reactive risk treatments summarise work done previously within the TSNDRA, dark grey boxes represent additional information and insight derived from the application of the framework. Each of the following sections provides insight into existing work done on the disaster risk assessment, subsequent insight derived from the application of the framework and its implications (interactions with other components of the framework).

Tasmania is Australia's island state and has a population of approximately 522,000. It is subject to a range of natural hazards and has been severely impacted recently by both bushfires and floods. In the context of this application the framework was based on a previously performed risk assessment, the TSNDRA. Following this disaster risk assessment process, engagement was undertaken with various government representatives, developing alternate scenarios that were relevant to future disaster risk in the state. This engagement involved two workshops and semi-structured interviews with 13 state agencies over a year period.

The engagement process informed the risk foresight section of this demonstration. Stakeholders were subsequently not engaged in the other demonstrated elements of the case-study. Results shown for dynamic risk assessment (Section 3.3) and risk treatments (Section 3.4) were done by the authors and future research will consider further interaction with stakeholders. The risk foresight process was designed for all hazards included within the TSNDRA however demonstration of risk assessment and risk treatment will focus on heatwave risks in Tasmania.

The following sections are structured to present the framework introduced in Section 2 to the Tasmanian case study. Risk foresight of the framework is shown in Section 3.2; Dynamic disaster risk assessment in Section 3.3; and Risk treatment in Section 3.4. Each sections provides an introduction before outlining the results of the processes and then the implication and interactions with other components.

3.2. Risk foresight

3.2.1. Introduction

Risk foresight for Tasmania involved the development of scenarios for plausible futures of the region across relevant drivers for the disaster risk system (region, actors, other characteristics) under consideration. This section provides details on the development of these scenarios and summarises their narratives for the future of Tasmania in 2050, which is given in Section 3.1.1. Section 3.1.2 subsequently shows the implications of the process, how the risk foresight element inter-

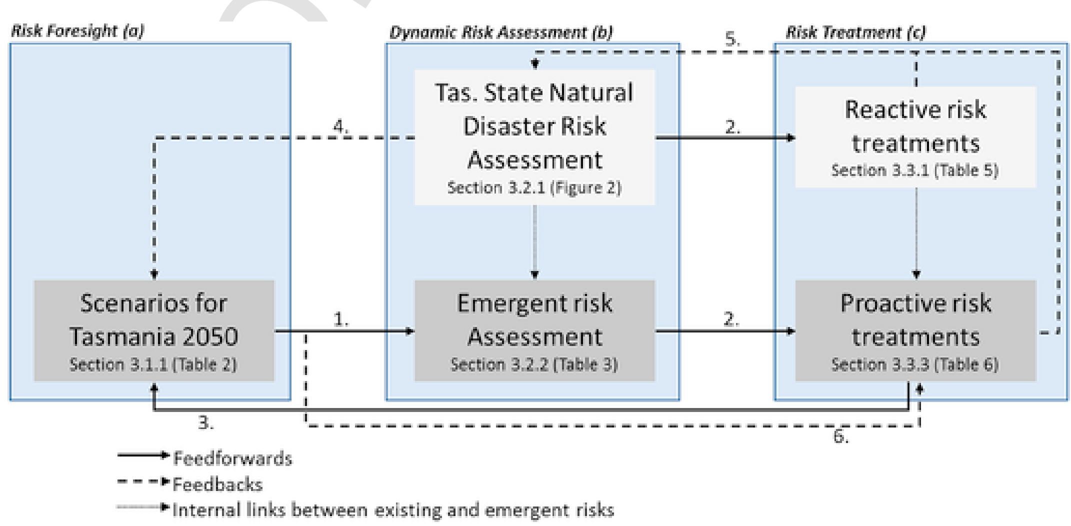

Fig. 3. Overview of application of framework to Tasmanian case-study. Connectors describe the relationship between components of the framework with labelled numbers linked back to the interaction processes as described in Fig. 1 and Table 1.

acts with assessment and treatment (forward and backwards interactions), and how the scenarios and development process answer the key questions required of an effective process, as discussed in Section 2.1 and summarised in Fig. 2.

3.2.2. Application of framework

Two stages of engagement within the risk foresight process were used to define the system of interest, and drivers for risk across the state of Tasmania. An initial scoping stage identified key drivers of risk from participants who were involved across the State and Local Government emergency management sector, from response agencies to central planning departments. Key themes were determined as the drivers for risk in the state, including 1) population, demographics and associated vulnerabilities, 2) community understanding and perception of risk, 3) the State's economic development, 4) urbanisation (the split between urban, peri-urban and rural land use and their interactions) and 5) climate change (both its impact and societal responses). In the second stage, these drivers were coupled with a participatory exercise to determine the objectives for disaster risk reduction in Tasmania, which were used to frame subsequent discussions and provide a lens through which drivers and treatments could be considered.

As part of the participatory process individual participants were asked to describe their vision for disaster risk management in 2050 for Tasmania in a single sentence. Vision statements included sentences such as, A resilient and diverse community that is able to respond to risk and recover from natural hazards and, That by 2050 natural disasters do not impede the social, economic and environmental objectives of Tasmania . Policy objectives were determined based on individual reflections on the group's vision statements responding to the question, What are the key elements from the vision statements for policy objectives? Participants' responses to this were grouped into themes for the objectives, which were, 1) resilient communities, 2) community awareness, 3) strong economy, 4) decreased exposure and vulnerability (people, place, property), 5) environmental protection and 6) informed decisions. The role of identifying these objectives was to assist participants in scenario development processes within the risk foresight component to provide an overview of the factors considered most relevant in the disaster risk system for achieving their visions for the state [99,100].

Three scenarios were developed with what participants considered to be the most likely future, as well what would be considered the best- and worst-case futures for Tasmania in 2050 considering the previously discussed vision and policy objectives for disaster risk management. The three scenarios are outlined across the five identified drivers in Table 2. Of particular note is the close relationship between the scenarios and the scope set by the risk assessment process by informing the view (interaction process 4, Fig. 3). This is clear in the specific references to hazard, exposure and vulnerability elements throughout the scenarios and clear linkages to the disaster risk system such as low household spending capacity learning to reduced resilience and increased reliance on government support . Using the risk assessment process to provide scope and the lens through which to undertake the foresight exercise allows the foresight process to be much more closely linked to decision assessment and making processes identified as critical for policy relevant scenario exercises [48,101].

3.2.3. Implications and interactions

The foresight exercise shown here produced three scenarios, as outlined above, to be incorporated within risk assessment and risk treatment processes following the framework. As part of this process, the three key questions identified in Section 2.1 were answered, with the foresight process providing key drivers for change presented in Section 3.1.1 and Table 2 population and demographics, community perception and understanding of risk, economic development, urbanisation and climate change and our response. These drivers and how they look in 2050 across three alternate perspectives, including best-case, most-

Table 2
Outline of three scenarios developed for Tasmania in 2050.

Risk Drivers	Scenario		
	Best-case	Most-likely	Worst-case
Population, Demographics & Associated Vulnerabilities	Sustainable population growth (600,000 650,000) contained within existing areas with improvement of infrastructure and services. Growth is seen in key, productive age groups reversing the brain-drain .	Moderate to low population growth, maximum of 600,000 in 2050. Population growth is not sufficient to stimulate strong economic growth though. Increasingly ageing population with educated youth moving to the mainland.	Low growth to decreasing population with increased aged proportion of the population. Low household spending capacity leading to reduced resilience and increased reliance on government support. Unsustainable and dispersed communities.
Community Risk Understanding & Perception	Community is aware of risk and understands the concept of shared responsibility. Decisions are made balancing risk, growth and environmental values. High levels of literacy supporting effectiveness of messaging.	Increased community expectation on role and impact of emergency management agencies to manage and respond to risk. Land use decision making, both public and private development, does not consider risk sufficiently.	Community expects to be rescued from all hazards without accepting guidance. Risk is generally ignored in decision making leading to draining resources for response.
Economic Development	Diversified and decarbonised economy that embraces technological advancements for increased productivity. Economic development does not come at the expense of other critically important values and is not a result of all development is good development .	Tourism is main economic sector following the public services which grows with increasing provision of health services. Agriculture shifts focus due to impacts of climate change (e.g. changing wine varieties). Remote working expands with digital nomads .	Simplified economy with only two main sectors (mining and agriculture) still a carbon-based economy. State and Local Authorities accept all development in attempt to stimulate growth.
Urbanisation	Emphasis on consolidating communities and reducing urban sprawl. Increased densities with fewer peri-urban areas supported by effective public transport.	Urban growth mostly occurs in the suburbs leading to increased congestion, travel times and peri-urban environments. There are restrictions to new development in the highest risk areas but development still occurs, particularly in coastal regions.	Sprawl with increased reliance on private transport. Development focus shifts to coastal area and vegetated hills (tree/sea-change). Infrastructure badly maintained.

Table 2 (*Continued*)

Risk Drivers	Scenario		
	Best-case	Most-likely	Worst-case
Climate Change & Our Response	Effective policy responses in the mitigation space reduce physical risks of climate change. Adaptive management strategies are implement to respond to changing threats and economic opportunities are seized from the need to mitigate and adapt to climate change.	Business as usual is embraced and hard climate mitigation decisions are not taken. There is less adaptation and greater focus on hard solutions to climate risks.	Failure to respond with rate of change faster than predicted. Unforeseen impacts in second and third order effects have significant impact on region.

likely, and worst-case, provide the future conditions under which to test the effectiveness of treatments. These represent the first and third component that the foresight exercise is designed to answer. The second considers the objectives and indicators of impact/success to be considered within the risk management process. The natural hazard risk assessment process that was undertaken in Tasmania followed NERAG standards Australia's National Emergency Risk Assessment Guidelines designed to standard risk assessment across scales and hazard [77] - and as such assess risk across 10 societal sectors shown in Fig. 4. Additional to these components were the vision and policy objectives detailed earlier in Section 3.1.1, which provide broader context against which to assess disaster risk and the effectiveness of treatments.

Feedforward processes that the risk foresight provide into component (b) of the framework dynamic risk assessment is setting context . This provides the sectors and objectives under which the risk assessment should be conducted, as well as the future scenarios the risk assessment is to consider. The feedback process from risk foresight is to component (c) and provides its future impacts . This involves providing the future conditions against which to test the effectiveness of risk management approaches to ensure emergent risks are incorporated into risk treatment plans and the range of drivers for which treatments need to be implemented for. The scenarios described in Table 2 provide risk managers the future context within which they need to prepare risk treatments over the next 30 years, shifting risk profiles away from worst-case to best-case regions.

3.3. Dynamic disaster risk assessment

3.3.1. Introduction

For this example application of the framework and its concepts, the disaster risk assessment undertaken for heatwave risk in Tasmania is used as a reference case. Although the study had already been completed prior to the foresight exercise, there is still value in highlighting the relevance of foresight approaches within the risk assessment. This section will first describe heatwave risk in the region, along with the results captured within the TSNDRA before showing how foresight could be integrated and some of the potential results that could be obtained if this were done.

Heatwaves/extreme heat, and their physiological impacts have been the biggest contributor to deaths from disasters in Australia over more than the last 100 years [102]. Extreme heat events occur due to a large range of factors at different scales, including antecedent soil moisture and climate variability, as well as urban form, evapotranspiration and the topography of regions. Their impacts can be even more complex, as the degree of impact varies significantly with demographics and other social factors, with those considered to be most vulnerable to the impacts of extreme heat being very young, elderly, lower socio-economic groups, outside workers and people with existing illnesses [103]. In Tasmania, past significant events have included a heatwave in

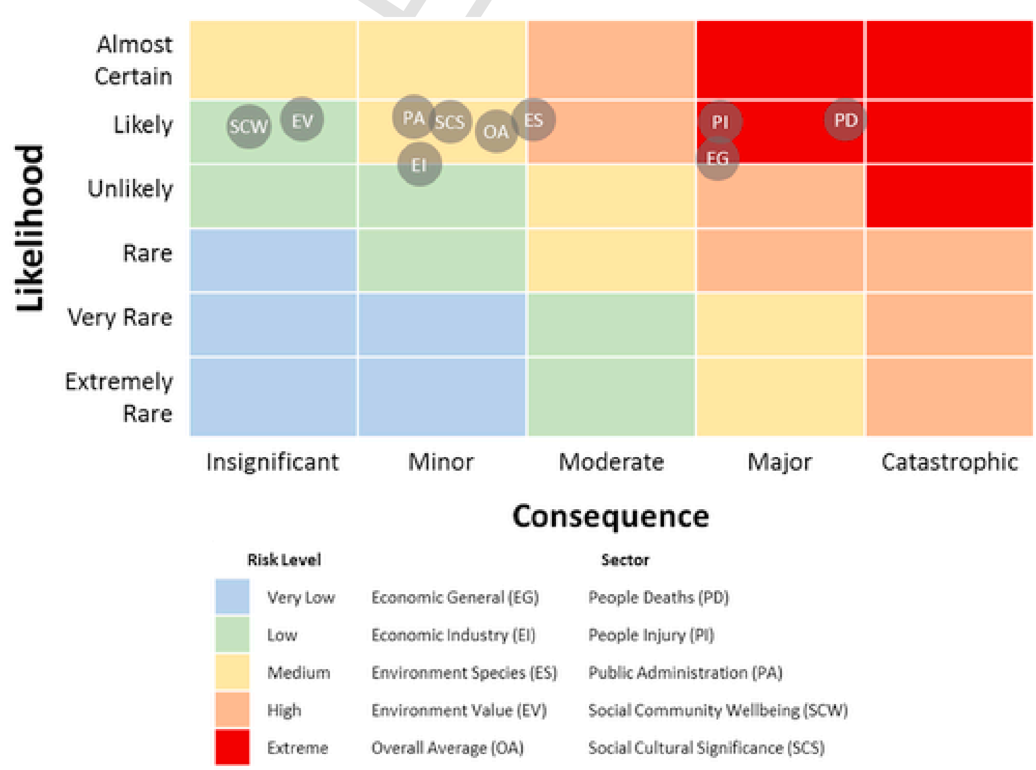

Fig. 4. Risk of heatwave to sectors in current risk assessment adapted from Ref. [98].

early 2013, which resulted in a significant increase in medical workloads and ambulance call-outs. Climate change is expected to increase the likelihood and intensity of such events, with high climate change scenarios projecting an increase in summer days with temperature >25 °C of 2 3 times compared with the recent past [104].

The Tasmanian State Natural Disaster Risk Assessment (2016) provided the below results for heatwave risk (Fig. 4). This was done discursively based on a current worst case scenario (note this is different to the scenarios presented in Table 2) based on the 2013 heatwave event and saw extreme temperatures over two days in January, as well as record breaking temperatures in several centres, including the capital Hobart, compounded by the temporarily increased population through the large number of tourists (interstate and overseas) visiting Tasmania at this time. Severe consequences were expected in terms of death, injury and illness with high confidence of deaths in excess of five, resulting in a major event in terms of consequence . Also considered significant in terms of consequence was the economic impact, with general impacts considered to be greater than $100million, with particular concern for localised crop loss (stone and berry fruit) and the flow-on impacts to supply-chains, as well as personal health for outside workers.

3.3.2. Application of framework

Using the scenarios developed in risk foresight, future risks can also be considered, with the impact of risk drivers playing out on the heatwave risk assessment process. Scenarios summarised in Table 2 showed a variety of factors evident in each scenario, which were different for each of the scenarios. What is important during scenario analysis is considering both the differences and similarities across drivers for each of the scenarios. When different scenarios result in the same or similar impacts, effort must be placed in managing these are they have been shown to be likely to occur regardless of how the future unfolds. In contrast, for drivers with drastically different implications across scenarios, monitoring factors and triggering actions should be considered within the monitoring and evaluation stage of the framework to track which scenario is closest to reality or which particular driver is influencing risk and hence what action should be implemented. Differences across scenarios leading to significantly different risk implications should also be considered as part of the identifying process for treatments. This is because using the underlying drivers of the scenario with reduced risks is a hugely influential, proactive risk treatment and hence encouraging change aligned with a driver that produces lower risk would significantly reduce future risk.

Table 3 summarises some of the implications of the scenarios on each of the sectors from Fig. 3. A similar matrix approach could be used to frame discussion with stakeholders as to implications across scenarios for the sectors of interest. From Table 3, we can see clear potential increases in risk for several sector types, particularly those related to human impacts, such as people deaths and injury (PD and PI), which is related to the continuing aging of Tasmania's population stimulated via migration to Tasmania for retirement and the moving of younger generations to mainland Australia for greater employment opportunities. Differences exist in sectors including social community wellbeing with the role of economic development and community engagement across different elements of society having different individual resilience and access to community support. Also different across sectors include economic sectors (EG and EI) which have variations in impact due to future structure of the economy which sees sectors such as agriculture changing over the scenarios as well as related impacts.

3.3.3. Implications and interactions

For areas where it is not clear what the impact on the sector would be based on the information sourced from Risk Foresight (e.g. Environmental Species and Value and Social Cultural Significance), the feedback focussed on informing the foresight's view (item 4 in Fig. 1 and described in Table 1) can be applied. Sectors considered critical to in-

Table 3
Future, emergent risk assessment against three developed scenarios.

Consequence Sectors	Scenario 1 Best Case	Scenario 2 Most Likely	Scenario 3 Worst Case
Economic General (EG)	Economic impacts from lost work are reduced to the diversification of the economy and increasing service-based economy reducing outside work hours. Exposure however is also higher due to increased economic activity.	Increased impacts and likelihood of risk due to increasing dependence on tourism and agricultural industries - both of which are susceptible to heat events.	Simple economic structure dependent on manual labour sees reduced activity in heatwave conditions. Impacts on infrastructure also increase due to poor maintenance. Black-outs are a concern with industries cutting power supply to maintain residential supply.
Economic Industry (EI)	Adapted agricultural practices adopting real-time monitoring and response reduces impact of heat stress on agricultural losses and flow on impacts to seasonal workers.	Localised sectoral impacts on stone and berry fruit still greatest impact for an economic sector. Climate adaptation measures from industry have balanced out greater impacts.	Decreased adaptation efforts see increased agricultural impacts from heatwave events. Less use of technology sees greater need for manual work with flow-on health and safety issues for outdoor workers. With successive events there may be impact on sectors' ability to bounce back with less available social and financial capital to support recovery.
Environment Species (ES)	Unspecified	Unspecified	Unspecified
Environment Value (EV)	Unspecified	Unspecified	Unspecified
People Deaths (PD)	Relative people deaths are reduced (decreased consequence) due to messaging and communication more readily taken up leading to an improved risk perception. Shift in demographics sees decreased vulnerability but higher population growth increases exposure.	Ageing population is exposed to greater impacts of heatwave risk and increased chance of mortality. Increased dependencies on emergency services reduces health responses.	Increased reliance on private transport sees more vulnerable aged populations less able to access public areas of cool and with reduced household spending mortalities increase with less use of air-conditioning.
People Injury (PI)	Matched to People Deaths	Matched to People Deaths	Matched to People Deaths

Table 3 (*Continued*)

Consequence Sectors	Scenario 1 Best Case	Scenario 2 Most Likely	Scenario 3 Worst Case
Public Administration (PA)	Increased individual resilience sees decreased reliance on government support. Well-structured support agencies deploy resources effectively to previously identified areas of need.	Increased pressure on public services during extreme heat events however with large public service resources can be redeployed across agencies to assist in extreme events.	Increased pressure on health and community service providers especially for regional and disadvantaged areas. General reliance on government services is exasperated during heat events with service providers significantly under-resourced.
Social Community Wellbeing (SCW)	Increased levels of economic development and keeping younger generation within the State sees individuals focussed on developing networks for personal and professional growth this leads to greater individual responsibility and improves the concept of shared-responsibility between community and EM agencies. This reduces impacts on SCW with greater local support networks	Those with individual capacity do not suffer any decrease in wellbeing, however those already at the margins are most exposed to these impacts. They also suffer from being less engaged with social service providers.	General decreased well-being of community is exasperated during heatwave events primarily due to electricity costs and reduced household spending capacity.
Social Cultural Significance (SCS)	Unspecified	Unspecified	Unspecified

clude, but for which a lack of detail was obtained as part of the initial foresight exercise, can then be revisited to inform the impact across scenarios for the sectors. It is, however, important to ensure that the scenarios remain internally consistent and any new assumptions/changes to the scenarios do not challenge this consistency with contradictory information. If this is the case, underlying concepts may need to be revised to ensure consistency and salience.

Considering feedforwards, risk assessment facilitates the identification of a broad array of options to be considered in risk treatment. As mentioned in Section 3.2.1, differences between scenarios can be used in this identification process, as they highlight an area for difference in risk to a sector through an emergent factor. Consequently, treatments can be designed to enable consideration of emergence in a more positive manner accounting for future risk.

As outlined in Section 2.2, foresight driven risk assessments must include three key elements. The first is explicit linkages between drivers identified in the risk foresight process. This is shown here through the use of scenarios against which to assess the risk of different sectors. Each scenario is developed using the identified drivers of risk (population and demographics, community risk understanding and perception, economic development, urbanisation and climate change and our response). The second element was the inclusion of interactions between risk factors and how interactions between them are able to cause emergent risk. These include, for example, the role economic diversification or simplification has on future heatwave risk with impacts emerging that increase the risk to agricultural sectors if climate change is not adapted to, and the impact becoming more significant in cases where there is a higher reliance on agricultural sectors. Similarly, in scenarios without increasing self-reliance and risk understanding, the over-reliance on government response and recovery assistance is challenged in heat events with under-resourced public administration functions unable to keep up with demand, which can result in cascading impacts on public health and economic recovery. Incorporating the ability for decisions being made to influence future risk, the third element identified to be included in foresight driven risk assessments can also be seen in Table 3. This includes the scenario assumptions for the risk driver Climate change and our response , with multiple references related to adaptation to climate change included in the future risk assessment in Table 3. Also significant in the risk assessment is the impact of development and transport policy, with Scenario 3 highlighting the increased people death impacts due to increased reliance on private transport, leaving those without or unable to rely on private vehicles unable to access public areas for heat relief services.

3.4. Risk treatment

3.4.1. Introduction

Risk treatment, as outlined in Section 2.3, is focussed on the reduction of risks as identified through the previous assessment process. For foresight supported risk treatment, methods of reduction are required for both existing/current and emergent aspects of disaster risk, instead of the traditional focus on current risks and their management. From Section 2.3, when foresight is incorporated within risk treatments, the critical components to consider are treating both existing and emergent risk, treatments across hazard, exposure and vulnerability components, and considering impacts across the entire risk system, both direct and indirect.

Within the TSNDRA for heatwave, a series of treatments were identified following the assessment process. These treatments, as summarised in Table 4, focus only on treating existing risks without the consideration of how the risk is changing. Some of the treatments are proactive in their nature, but they focus on improving understanding of heatwaves and improving community understanding through education. They do not, however, account for the drivers of emergent risk and look to mitigate these factors.

Table 4
Heatwave risk treatments identified for current risks [98].

Risk Treatments	
Improve knowledge and understanding of the effect heatwaves coinciding with other hazard events have on the effectiveness and capability of response and recovery capabilities.	Identify facilities that can be used as cool spaces during heatwaves and establish linkages between operators and emergency management organisations.
Include heatwave in existing preparedness programs.	Improve information about electricity demand during heatwaves.
Improve community educational information.	Quantify the effect of heatwaves on vulnerable people.
Develop arrangements to identify and communicate with people vulnerable to heat stress.	Incorporate heatwave surge response planning into business continuity planning.
Review community information and warning systems to ensure they cater for heatwave messages.	Develop innovative response models of patient care to improve surge capacity.
Create a stakeholder plan template to aid heatwave preparedness and response in facilities occupied by people vulnerable to heatwaves (e.g. nursing homes).	Exercise heatwave arrangements with a focus on the public administration sector and management of vulnerable people.

3.4.2. Application of framework

With the consideration of future risks using scenarios outlined in Section 3.2, Table 5 outlines strategic responses to manage the emergent risk factors across scenarios, as seen from the summary of impacts across scenarios in Table 3. These results are a summary of the range of actions that could be implemented to reduce current and emergent heatwave risks. Each treatment identified in Table 5 seeks to reduce risks across each of the scenarios for heatwaves in responses to changes in drivers for risk and impacts on different components of risk hazard, exposure and vulnerability such as increased green spaces looking to reduce urban heat island impacts, and increased decentralised, renewable energy production and storage to improve energy security and subsequent reliability of air-conditioning (this also contributes to climate mitigation, arguably the most strategic response to future climate risks).

Also shown in Table 5 is the risk element (hazard; exposure; and vulnerability) and risk driver (population, demographics and associated vulnerabilities; community understanding and perception of risk; the State's economic development; urbanisation - the split between urban, peri-urban and rural land use and their interactions; and climate change - both its impact and societal responses). As can be seen, some actions act across multiple drivers, however, it is important all of them are considered. More engagement with stakeholders could further add to Table 5 through discussions on how each of these actions can have potential indirect impacts on the risk system. An example of such a potential indirect impact is how the increased provision of green spaces increases urban sprawl and fringe development in search of cheaper land prices to account for reduced return on real estate developments. Supporting economic diversification and the service-based economy has the potential to encourage developments in risky areas with respect to bushfire and coastal flooding. This is caused by individuals being less engaged with their communities and less aware of the landscape that surrounds them due to their work habits revolving around a global workforce from a home computer and the increased ability to generate income by working more hours, resulting in less time for community building and volunteer activities. Another potential indirect impact may be the incorporation of heat impacts into building codes, leading to increased costs passed to consumers, with subsequent reduced financial capacity to insure and recover from disaster events.

Following the identification of risk treatments these options need to be evaluated before the implementation of a treatment plan or strategy. Evaluation of treatments needs to be conducted against both current and future risks with the overall plan or strategy devised balance the trade-offs between investing in future resilience and mitigating current risks. It should be noted that many of the risk treatments identified for future risks pose minimal direct costs in comparison to risk treatments for today given their more strategic nature. Foresight supported risk management however enables the identification and evaluation of these options which otherwise may have remained unconceived.

Table 5
Heatwave risk treatments identified for future risks.

Options	Risk Element	Risk Driver (Col. 1 Table 2)
Increased green spaces within urban planning strategies	Hazard	Urbanisation
Hospital/respite areas designed to account for tourism factors and changed demographics	Vulnerability	Population, demographics & associated vulnerabilities
Increased decentralised energy production and storage decreasing reliance on ageing electricity infrastructure	Vulnerability	Economic development; Climate change & our response
Financial support to disadvantaged groups to support use of air-conditioning to reduce health impacts	Vulnerability	Population, demographics & associate vulnerabilities; Economic development; Risk understanding & perception
Incorporation of heat impacts into building code for all residential buildings	Vulnerability	Urbanisation; Risk understanding & perception
Future public transport services to include cooling and respite	Exposure	Urbanisation
Financial grant support to agriculturalists implementing technology to manage crop temperatures (e.g. temperature activated misting).	Hazard	Climate change (and our response to it)
Increased training for non-emergency management staff and volunteers to support during heatwave events, reducing pressure on EM workers during co-occurring events	Vulnerability	Population, demographics and associate vulnerabilities
Support economic diversification and service-based economic sectors through communications strategy and service provision (real estate, connectivity)	Exposure	Economic development
Use of future climate agricultural suitability mapping to zone and prioritise development in resilient areas	Exposure	Economic development; Climate change & our response

NB: This table has been developed by the authors as an illustrative application of the framework and how risk treatments can be developed for components of emergent risks.

3.4.3. Implications and interactions

Within the framework process, these treatments (reactive and proactive) play an important role in informing other components. Considering the feedforward process, the application of treatments will change the situation and as such may require continuing efforts in risk foresight. The results presented in Table 5 therefore can be used to inform and update the risk foresight process as the implemented actions begin to change the baseline and drivers for the foresight process such as the use of decentralised, renewable energy and storage to increase electricity network resilience during extreme heat events. The foresight process may therefore consider the deployment of new technologies as a driver of future risk and consider how the maintenance and operation of these technologies influence future risk, as well as how the reduction of centralised and gridded networks impacts on ignition likelihoods [105] and peak demands [106].

The feedback process (item 5 in Fig. 1) is the monitoring and evaluation process. This is a critical component of any risk management process, allowing for implemented risk treatments to be tested against the risk assessment metrics to assess real-world performance, and ensure implementation is done correctly existing risk should be decreased following implementation in subsequent risk assessments. Additional to the standard function of monitoring and evaluation, with this framework and the inclusion of dynamic risk assessments and proactive risk treatments, the monitoring and evaluation process can also enable ex-ante assessment of proactive risk treatments, allowing the performance of measures to be tested against time for each scenario. Therefore, the impact of the provision of green spaces can be tested against each scenario to consider how impacts in consequence sectors (Table 3) are changed, enabling the treatment (provision of green space) to be evaluated.

As can be seen from Section 3.4.1 and 3.4.2, the framework has enabled the identification of risk treatments designed to mitigate risks, both current and emergent, through reactive and proactive strategies. Table 5 in Section 3.4.2 also shows how the proactive strategies have been designed to act across the elements of risk and impact on their identified drivers from the risk foresight process. Potential indirect and unintended impacts from the implementation of proactive strategies have also been identified and this shows how considering the future can open discussions about the complexity of risk management and enable more thoughtful actions.

4. Discussion

The following sections provide discussion on aspects of the framework, how to use it to support more proactive actions within disaster risk management and how to enhance its applicability. Section 4.1 looks at the application of the framework and its challenges and benefits. Section 4.2 discusses how it can be used as an engagement mechanism with broader stakeholder groups to enable proactive risk management and using foresight concepts integrated within risk assessment processes to change what can be a prescriptive process to a mechanism for collaboration and strategy development. Section 4.3 discusses the co-benefits that can be derived from the proactive treatment of disaster risk supported by the framework.

4.1. Challenges and benefits of the framework

The framework outlined in this paper is centred on the objective to integrate the benefits of foresight into risk assessment and treatment (risk management) processes. This is done to shift disaster risk assessment from a traditional occupation with existing risk and reactive treatment, the effectiveness of which is limited due to the wickedness of the disaster risk system. Through the process of understanding the risk system via structured consideration of drivers and factors incorporated within the foresight processes, there are also benefits of increased appreciation of the system, which will support its assessment (through the use of appropriate modelling and/or stakeholder engagement processes) and management, with decreased likelihood of unintended consequences if system dynamics and characteristics have been captured appropriately.

This may see alternate modelling approaches utilised if drivers of future risk highlight particular areas of concern. This could include if the degree of urban sprawl within a region is found to be important, it might be required to incorporate land use modelling such as in van Delden and Hurkens [107] within the dynamic risk assessment component. Similarly, if economic factors are considered a key vulnerability, such as over dependence on one sector, or shifting industry sectors away from traditional employers this may see particular modelling of economic assumptions using specifically selected models such as in Brandes [108] and Partridge and Rickman [109] might be relevant to include. Different stakeholders to be included within qualitative risk assessment processes may also be identified following the foresight process, with stakeholders broader than traditional emergency management or civil protection agencies required (i.e. urban planning, education sectors etc.).

These benefits of the approach, however, must be contrasted against its drawbacks for the utility of the framework to be assessed in an objective fashion. Use of the framework is more resource intensive than other risk assessment processes, with several sessions required to discuss and capture descriptions of the future. It also has the potential to be highly subjective and not entirely reproducible   a common criticism of many scenario processes that rely on stakeholder engagement processes [51,110].

However, mitigating actions can be put in place to reduce these drawbacks in comparison to the benefits the framework provides in enabling more strategic responses to risk. These include technology focussed methodologies to source information from a variety of stakeholders, such as online community platforms [111] and e-participation models [112] that have been shown in respective literature to offer value. Detailed processes for stakeholder identification are also important, and although this does not make the overall process more reproducible, it can be used to ensure representativeness across a wide range of relevant actors and stakeholders in the region under consideration. This increases legitimacy of the process, which could otherwise be challenged on the basis of its subjectivity.

4.2. Using risk foresight as an engagement method

Risk foresight, the first component of the framework, allows for broader engagement across agencies to discuss future change and how this impacts on disaster risk. During the engagement phase of the Tasmanian case study considered in this paper, 13 agencies were involved in discussing drivers of risk, uncertainties, and what Tasmania in 2050 could look like. Representatives included not just emergency management agencies with responsibility for hazards in the state, but also representatives from departments responsible for state growth, climate change and planning reform, as well as universities and local government associations   along with specific municipalities. Discussions focussed on future challenges and risk, providing a safe space in which collaboration can occur away from the daily challenges of emergency management and government policy.

The importance of this level of diversity in engagement during the foresight component is also that it creates greater momentum for strategic, proactive risk treatments. The proactive treatments identified in Table 5 generally fall outside of the remit of emergency management agencies, and often fall outside the remit of one agency alone. Therefore, in order to design and implement such policy and investment decisions, significant engagement across government (and likely the private sector and community) is required. Using the foresight process, and engaging again throughout subsequent components of the framework, enables these broader stakeholders to contribute and engage with disaster risk assessment and subsequent management actions, which is critical to reducing future risks.

It must be acknowledged that there are challenges in the actual implementation of any strategic action, and historically this has been challenging in the disaster risk management space. However, a framework that explicitly acknowledges the roles of broad drivers of change on disaster risk atleast enables these components to be integrated into the emergency management, and disaster risk sphere. Without this inclusion it is challenging to advocate for alternative measures as their value and effectiveness cannot be shown to disaster risk reduction.

4.3. Proactive treatments, co-benefits and mainstreaming

The framework's focus on future risk and managing these proactively by identifying their drivers not only allows for broader engagement across stakeholders (as discussed in Section 4.2), but also allows for disaster risk reduction options to fit into more strategic, whole-of-government, efforts in an integrated manner. As previously outlined, many of the actions required to proactively reduce risk sit outside of the remit of traditional emergency management agencies and functions   therefore a new approach is needed. Through using the framework and the foresight processes, disaster risk reduction efforts can more easily be integrated into other policy areas. This is clear when issues around decentralised energy generation and storage and increased service-based economic activity are discussed during risk assessment and treatment components of the framework.

These areas are not commonly identified as related to disaster risk reduction, however, if through the framework and interactions between risk assessment and treatment (allowing ex-ante assessment of proactive treatments), it can be shown that there are benefits of these changes to future disaster risk, then this can add to the policy narrative about supporting these policies for other areas in which they are beneficial, such as climate mitigation and economic development. The additional benefits (e.g. reduced expected losses) may also support the broader economic/impact analysis of such policies, contributing to their successful navigation through the policy cycle. Identifying these co-benefits, and viewing disaster risk reduction as a co-benefit of other policy decisions, supports the mainstreaming of disaster risk reduction across government.

This framework enables this understanding to be developed within the disaster risk assessment and treatment stages, not requiring separate assessment of co-benefits. It can also support emergency and disaster risk management agencies to pro-actively engage in the conversation on strategic, whole-of-government actions instead of being consulted towards the end of policy processes to devise reactive responses to risks created. Being on the front foot and understanding the implications of drivers and actions of other agencies on disaster risk is a key outcome of the framework.

5. Summary and conclusions

This paper has proposed a framework to integrate the utility of foresight into risk assessment and treatment processes to support strategic and proactive disaster risk management. This is achieved by highlighting the role and insight provided by foresight activities and how they can provide information to risk assessments, making them future focussed and dynamic, capturing alternate futures. These alternate futures and their associated risks are then used to identify and inform proactive risk treatments, supporting a more holistic and integrated approach to disaster risk reduction. In doing this, the framework provides insight into emergent risks and shows how they can be integrated into standard risk management approaches.

The framework was applied to the Tasmanian State Natural Disaster Risk Assessment, focussing on heatwave risks to identify different plausible futures for the State, along with their impact on heatwave risk, and subsequently proactive treatments accounting for the drivers of future risk. This application of the framework, however, is limited in its scope and more work needs to be done to highlight the range of foresight and risk assessment and treatment processes/techniques that can fall within the application of the framework by applying in different settings.

Future steps will involve enhancing the application of the framework to cater to quantitative risk assessment approaches to better support investment and planning decisions for proactive risk reduction actions. Associated with this, however, is the challenge of modelling capable and appropriate for projecting risk into the future, based on identified drivers and interactions between them. The framework also needs to be enhanced to better incorporate complexities of interlinked hazards and risks and their cascading impacts. Scenarios offer a potentially powerful tool to facilitate this, however, developing them with stakeholders and integrating them into risk assessments (particularly quantitative approaches) remains a challenge. This improvement, however, will be significant in an ever more connected world and complex risk landscape.

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Appendix A. Supplementary data

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Appendix D – Paper 2 Supplementary Material

Supplementary Information 1 – Scenario Descriptions

1. Silicon Hills

Frame: ***Low challenges to resilience. Low challenges to top-down mitigation***

1.1 - Narrative:

Greater Adelaide transitions towards a well-balanced technology focussed economy, driven by highly skilled and engaged locals and expatriates as well as immigrants looking to capitalise on the State's booming high-tech industry while enjoying the relaxed, nature filled lifestyle the Mt Lofty Ranges and Adelaide Hills offer. The emphasis on enjoying and connecting with nature ensures well-maintained areas of local significance along with increased understanding and subsequent reduction of human impacts on the landscape. The focus on technology also sees an increase in localised industrial and commercial zones along with a growing service based economy, providing the convenience of a global city with the relaxed lifestyle of Adelaide. Greater Adelaide continues to be a place of high multi-culturalism, with new residents that have an appreciation of the land and are active in their pursuit of greater understanding and protection of nature. This leads to a focus on nature-based solutions to natural hazards, and a planning system focussed on understanding the risks prior to development. Community togetherness grows with new technology firms allowing employees the flexibility to engage in many activities outside the office. The increased wealth within society allows for a greater emphasis on diverse urban form and development, and with improvement in construction technology, new buildings and infrastructure are becoming less and less vulnerable to multiple hazards.

1.2 - Motivating factors: A growing global valuation of the environment coupled with Adelaide's low cost of living with high amenity value sees an increase in immigrants with skills in technology, innovation and research & development. This leads to a shift in the economy stimulating high tech developments and a move away from low value industries. The international, highly-skilled work force facilitates global trade and awareness of and preparedness for global change. The wealth of the society in combination with their awareness of risks opens the road to effective mitigation in conjunction with enhanced community resilience, in line with global efforts for positive adaptation to climate change.

1.3 - Population and urbanisation: With the increased emphasis on technology and increasing international standing of local universities and start-up companies, skilled, highly educated immigrants look to Adelaide as an innovative city and a gateway into Asian markets yet still with Australia's strict commercial protection laws. This sees a growing population with immigration from Europe and the Americas, along with increasing Asian student numbers who look to settle in Adelaide after graduation. There is a government emphasis to design new residential developments to incorporate greenspace and the latest in urban design as well as considering the hazard risk in initial developments due to the increasing environmental awareness of residents. These developments lead to an increase in higher density city living, due to Adelaide CBD's close links to green areas and the beach, along with further developments in the Adelaide Hills facilitating a 'tree-change'.

1.4 - Community Profile: Greater Adelaide's multi-cultural community continues to grow in diversity but due to an increased will to integrate, driven by environmental awareness and the desire to be part of the community, vulnerability in new immigrants is low. The desire to integrate, along with increased government revenue, results in a rising enrolment and investment in public schools. This reduces inequality between those not capitalising as easily in the technology industries and provides increased local knowledge throughout the community including the immigrant population.

1.5 - Economy & Lifestyle: Over the next 15 years small investments in tech start-ups and innovative activities focussed on small scale, advanced manufacturing begin to take effect, leading to increased innovation in both the services and commercial sectors. Several 'tech-hubs' take form, focussing industrial and commercial industries in high intensity areas. With the initial investments seeding the industry, coupled with the increased human capacity due to skilled immigration, an economy focussed on innovation and technology takes grip and sees income levels and government revenues grow as Adelaide becomes a central technology centre in the Asia Pacific region, and increasingly influential globally. Coupled with increasing research funding and growing service economy in support of high end technology, SA's economy is positioning itself as one of the fastest growing in Australia.

1.6 - Politics & Institutions: With growing immigration and an increasing interest in planning and SA's future there is a slowly changing mentality in the community around government intervention. State government policies grow in influence through an emphasis on community consultation and stakeholder engagement together with the rising awareness that government intervention is required to deal with increasing risk of hazards. This results in regulations becoming more effective and easily implemented, and an emphasis on risk based land use planning.

1.7 - Technology & Infrastructure: The emphasis on harnessing technology for good grips the state and several entrepreneurial efforts prove to have significant benefits for the minimisation of risk. Mostly this lies in reducing the vulnerability of residents with immersive technologies used for education programs as to how to respond to a hazard event and also what safe communities should look like. Virtual experience centres enlarge the community's hazard preparedness as they simulate the hazard experience and coping strategies. Globally there is an effort being made around early warning systems and sensors for many hazards, particularly bushfire, earthquake and flood. This global interest coupled with the hazards present in the region and booming tech-industry results in the city becoming a global expert in knowledge and technology for risk reduction. Greater Adelaide also capitalises on efforts made in 2015-2020 in turning the city into a 'smart-city' to greatly improve its data collection and analysis capabilities which allow for a much more evidence based, and adaptive planning system.

2. Cynical Villagers

Frame: ***Low challenges to resilience. High challenges to top-down mitigation.***

2.1 - Narrative:

A growing amount of rural residential developments, coupled with low population growth sees Greater Adelaide increasingly suffering from urban sprawl. This sprawl is due to shifting population dynamics with an increase in lower-middle income groups and hence a drive for affordable homes and an ageing population looking to the hills for retirement. The landscape is a mixture of low density rural residential, natural vegetation and agricultural plots. There is a strong community preference for protection of the state's areas of environmental significance, a growing environmental consciousness and appreciation of the landscape's amenity value. The interest in nature and the countryside leads to high levels of local knowledge regarding the risks from the landscape however this is still unequal, with less connected and more vulnerable communities still finding it difficult to build self-sufficiency. Economically, mining has taken a downturn with no other sector replacing its activity, and with the relatively small workforce an insular economy based on small scale agriculture and commercial industries is predominant in SA, making government revenue difficult. Due to restrictions in government revenue raising, and hence spending, there is a low emphasis on innovation and science and with greater online, public data availability government is further hamstrung by empowered citizens challenging government intervention with a NIMBY mentality. This is supported by data and a desire to challenge in the courts.

2.2 - Motivating factors: With the downturn of the mining activity and an ageing population, Greater Adelaide experiences a shift towards a more nature based and high quality agricultural society, keen on living in the outer areas and hills and knowledgeable and protective about its land, the property on it, its surroundings and the local community. Local resilience flourishes driven by the availability of good quality data on the internet. Not all communities however have the same capacity to build resilience and there are have's and have not's in respect to hazard resilience. The wealth of information empowers the community and strengths their resilience, but also impacts on them challenging government with many court cases paralysing policy development and implementation.

2.3 - Population and urbanisation: Greater Adelaide sees a slowing in population growth, particularly regarding the immigration of younger, skilled workers. Instead the steadily ageing population, full of baby-boomers, spreads out from Adelaide further, searching for their block of land. Urban sprawl grows particularly through an increase of rural residential developments. This results in a growing patchwork of homes throughout the Adelaide Hills interwoven with small agricultural and wooded blocks increasing the hazard interface to a significant extent. Although the population grows to be more resilient during the first decades of the scenario, this resilience declines with the increasingly ageing population, still living in the countryside, but no longer able to manage hazards at crunch time.

2.4 - Community Profile: The growing rural residential lifestyle results in increased local understanding, especially of nature, its value and its risks. However this understanding is highly localised and often misses larger scale concepts. Due to low economic returns and the highly inward looking economy there is a growth of the lower middle income groups. This has impacts on community dynamics with some communities with greater community engagement, skills and disposable resources able to organise and manage themselves, while others are left behind, generally those with less financial flexibility, the elderly or those less socially connected.

2.5 - Economy & Lifestyle: South Australia steadily sees the downturn in manufacturing and mining and the subsequent impact of reducing revenue to State Government coffers. In general there is no replacement activity to the same scale and instead the economy looks local with an increase in commercial and agricultural sectors. SA's economy also reduces its export capacity due to a smaller workforce, and as such becomes much more tuned to being self-sufficient. This builds resilience in the economy by stripping it to the State's requirements, however it significantly reduces the capacity for revenue raising for capital intensive projects.

2.6 - Politics & Institutions: Tight knit local communities, protective over their property and individual freedom, see the government severely restricted in the development and implementation of policy. Community opposition is rife to central government decision making if it is seen to impose on the rights and freedoms of an individual. Growing availability of information and access of it through the internet empowers the population. Court cases to 'fight for one's right' are ominous, paralysing government to implement broader scale mitigation options as well as zoning regulations to avoid development in hazard-prone areas. Government paralysis is further compounded by its lessening revenue, particularly for capital intensive investment, and instead revenue is going increasingly into health and aged-care.

2.7 - Technology & Infrastructure: The world and SA is data rich but information poor. The people are empowered by access to data, allowing them to confirm anything they need confirmed regarding their small block of land or their community at the click of a button. This however sees community groups increasingly capable of challenging government and business in court. There is also a decline in innovation, and investment in science and research in SA, as it experiences a return to cottage-industries.

3. Ignorance of the Lambs

Frame: *High challenges to resilience. Low challenges to top-down mitigation.*

3.1 - Narrative:

Greater Adelaide shifts towards an increasingly commuter lifestyle in the pursuit of lower cost housing. The region experiences a decline in rural living, with a shift towards highly urbanised centres throughout the region and lengthening of commute times between residential centres and places of work. Population growth is high with increased immigration from migrants seeking a safe-haven in Australia from various global issues both climatic and socio-economic. This results in increasing community vulnerability and heavy reliance on government for both social and hazard-related support. Due to the rising costs of risk mitigation, the Federal Government plays an increasingly important role eventually resulting in the loss of state-based policy, with the State Government becoming more of a service provider than a policy maker. Coinciding with this is the loss of the manufacturing industry, and subsequent economic decline in the region. Because of this unemployment grows, adding to the need for Federal Government support, while those who can leave to work on the Eastern seaboard or overseas do so. However, they face challenges selling their properties with the immigrant population having a preference for cheap new builds in commuter suburbs rather than the more expensive inner suburbs.

3.2 - Motivating factors: Changes in community profile due to large immigration with Greater Adelaide becoming a refuge for people around the world, decreases the population's resilience, requiring a stronger role from government to protect its citizens. Due to the economic down-turn and increasing mitigation spending, federal government's role increases with the influence of the state diminishing. There is an acceptance of top-down mitigation, but due to limited finances only so much can be done. The population feels secure but reality creeps up on them when top-down mitigation is no longer able to protect them when severe hazards strike. The well-educated and 'old money' groups move to the east coast but with declining house prices in the State many are left on the market for extended periods as they are beyond the budget range of the immigrants and cannot easily be sold.

3.3 - Population and urbanisation: SA's population is growing over the next 10 years, through increasing immigration from the Asian-Pacific region looking to capture some of the nation's prosperity in comparison to stagnating developing economies. There is also a growing refugee community from various conflict zones around the world. Rural residential communities slowly begin to disappear as new immigrants look for new, low cost developments. These urban centres are generally developed in the lowest cost land, far from the CBD and other centres of employment, in the Adelaide Hills, and Southern and Northern Plains. This leads to a focus on infrastructure corridors, allowing commuter suburbs to grow further and further from the CBD. This development pattern is precipitated by a lack of local and state-based planning regulations and more direction of a distant Commonwealth Government, which early in the scenario sees standard and enforced planning regulations, while this changes in the subsequent years as revenue demands overrule planning.

3.4 - Community Profile: Work-life balance pressures and the increasing distance from work to home places pressures on communities. There is a decline in local knowledge, understanding of the area and community connectedness. The region's demographic profile also shifts with Adelaide increasingly known for its low cost of living. Skilled workers see the struggles Adelaide is under with changing social and urban fabrics and look to move to the Eastern seaboard for greater employment opportunities. There is however minimal opportunity for the sale of their properties with many leaving inner suburban homes empty as they move East.

3.5 - Economy & Lifestyle: The region is under growing pressure due to the sudden collapse of the manufacturing industry and few options for transition industries. This results in growing unemployment and increased reliance on the government for social support. Those who have the capacity and ability to leave for work do so. This begins with an increasing fly in/fly out lifestyle for professionals working East, but subsequently turns to many moving permanently to the growing metropoles in Melbourne, Sydney and Brisbane. Growing unemployment also sees a more disengaged youth and increasing crime rates, especially in outer, commuter suburbs.

3.6 - Politics & Institutions: The economic climate for SA, and increased emphasis on large infrastructure projects sees the Commonwealth growing in influence due to its capacity to fund. There is every-growing social reliance on the Commonwealth. The State increasingly becomes a service provider for the Commonwealth and has significantly less influence and decision-making ability. Local governments are also removed from many planning and mitigation activities, eventually they reason that if they have no resources to fund activities what is the purpose in researching and considering them?

3.7 - Technology & Infrastructure: Infrastructure solutions are seen as the most effective, with urban centres in at risk areas seeing significant structural mitigation measures put in place by the Commonwealth. In an attempt to raise capital the State begins to privatise infrastructure over the next 20 years. However with the increasingly dire economic circumstances of the region's residents, private entities experience less and less profit and subsequently reduced expenditure on maintenance. From 2035 onwards the state begins to inherit poorly-maintained infrastructure networks with massive costs to the public purse.

4. Appetite for Change

Frame: ***Moderate challenges to resilience and top-down mitigation***

4.1 - Narrative:

Greater Adelaide continues on its current trajectory with declining manufacturing and slow population growth. In contrast to the decline in manufacturing, a rise of low value mining and an expansion of agricultural sectors over the next fifteen years leads to a slight expansion of rural residential areas and an increase in urban infill and sprawl around the fringes following the Greater Adelaide Plan. This places increased pressure on urban drainage, not designed to meet the increasing stresses of urbanisation, and therefore increasing flooding. Property developers hold significant influence in terms of new development locations with an emphasis on profit not planning. However with the increasingly apparent impacts of climate related hazards both globally and at home, a swelling in community awareness of risks sees the government become more empowered and enabled to set policy directions and fund some mitigation activities without voter disproval. This is catalysed by an accumulation of events impacting on both urban centres with the CBD suffering from drainage issues during intense rainfall events, and rural areas experiencing several significant bushfires in the Mt Lofty Ranges. This leads to improved risk governance structures and growing resilience to known and expected hazards in the later years of the scenario.

4.2 - Motivating factors: The current projections hold steady, however, part way through a series of hazard events leads to an increased community awareness of the hazard risk. A change of behaviour occurs a few years later following on from the occurrence of a combination of hazard events. The realisation that large events cannot solely be dealt with through community preparedness and resilience and that top-down mitigation should be part of the equation too, leads to the subsequent acceptance of government intervention.

4.3 - Population and urbanisation: Population trends progress as expected, following the medium projection scenario for Greater Adelaide. In general development follows the 30 Year plan with an emphasis on infill within the outer suburbs and low expansion into rural residential areas. New developments are left in the domain of developers with a greater importance placed on revenue than risk based planning. This begins to change with greater community awareness of risk, especially of coastal hazards, which has had the most prominent impact globally due to climate change.

4.4 - Community Profile: The mix of socio-economic status from those who successfully transition between industrial sectors to those left behind sees variation in community structure and strength. Some communities experience a tightening with growing resilience to known hazards (both in type and magnitude), however others become more disparate. Not all individuals and households have the capacities to self-sustain while the communities that do, due to increased financial certainty, still remain unaware to the full range of events that could occur.

4.5 - Economy & Lifestyle: The economy of Greater Adelaide experiences a transition from capitalising on manufacturing, which suffers a rapid collapse over the next five years and mining which is used as a partial transition industry over fifteen years, to a world increasingly more aware of the environmental impacts of fossil fuels and the subsequent fall in their price. For Greater Adelaide this results in an increase in agriculture in the peri-urban area as it looks to position itself as a global food source especially to growing markets in Asia Pacific with a flavour for high quality South Australian produce. In conjunction with this professional services and commercial enterprises have remained stable shifting their focus from manufacturing to agriculture, with a marked increase in the healthcare profession meeting the challenges of an ageing population.

4.6 - Politics & Institutions: The shifting economy and initial lack of obvious foresight and planning by government sees an era of mistrust and disillusionment grow. There is a greater emphasis on individual rights and responsibilities with most residents developing local level resilience to known events (in type and magnitude). However as events grow in impact, the realisation comes that individual resilience is not sufficient and government is given more flexibility and allowance to develop and implement risk mitigation policies. This is particularly true in structural measures for riverine and coastal flooding, along with land management for bushfire risk which was previously not in line with community expectations. Governance issues across all hazards also improve, and as government is restricted in size by revenue, it approaches risk management in a more integrated, all of government approach.

4.7 - Technology & Infrastructure: Urban infrastructure is increasingly put under pressure with increasing rates of infill stretching, in particular urban drainage, in its capacity to serve the public's function. Due to the loss of manufacturing industry the state also loses significant expertise in STEM related areas. There is however a small resurgence with the shift to agriculture as SA is seen as a leader globally in quality agricultural practices. There is also interest in exporting this knowledge around the world, especially the growing skills in agriculture in a semi-arid (increasingly arid) landscape, developing and implementing innovative renewable energy and irrigation techniques to maintain productivity.

5. Internet of Risk

Frame: ***High challenges to resilience. High challenges to top-down mitigation.***

5.1 - Narrative:

Global connectedness drives an increasing reliance on the internet for social interaction and working styles. This reliance on the World Wide Web sees dispersed residential living as the attraction of the CBD and physical centres lessens, leading to a significant loss of physical connectedness and an increase in siloed communication between similar individuals and services by a small, but growing, services sector providing for the masses of online workers. The majority of workers use the internet to work across the world, placing pressure on government revenue streams. Governments are struggling to re-adjust from revenue collection from the traditional economy which is slowly dying off with a loss of industrial and commercial sectors. This loss of revenue weakens institutional power, and the easy access to information is making a generation of 'Google Experts' who increasingly become more reluctant to accept government intervention. There is also growing inequality between those capitalising on the global technology markets and those in service roles, who find themselves increasingly reliant on a government with increasing costs and decreasing ability to raise funds.

5.2 - Motivating factors: The increasing reliance on the internet for social and work-related activities decreases the community connectedness and hence resilience due to the focus on global instead of local networks. The ability to search the net empowers the population, but without knowledge of the local conditions and communities it doesn't build the required understanding and awareness to deal with actual hazards. The understanding of theory rather than practice together with the feeling of empowerment leads to a reluctance to accept government intervention by the 'haves', while government funding is not sufficient to adequately support the 'have-nots'. Moreover the lack of resources in conjunction with an increase in hazard events limits the government's ability to put effective mitigation strategies in place.

5.3 - Population and urbanisation: Population growth is low before stagnating in 2030-2040 due to low immigration and migration from SA by those who have the skills and capacity to do so. The urban landscape is also increasingly placed under pressure due to dispersed residential living with low levels of strategic planning and allocation of land for development.

There are low levels of new urban development outside of residential, with demand for industrial sites reducing significantly post 2020, and commercial sites falling after that.

5.4 - Community Profile: Inequality is rife in the region post 2035 after steadily growing differences in individual's ability to work. Those trapped in traditional economies of manufacturing fail to transition to the new technology focussed economy, and with little re-training support from the State Government find themselves struggling to find work and requiring financial support. Their notion about risk is very limited as is their faith in being able to change any course of action. Those that were able to capitalise on the global technology markets however find themselves growing increasingly well-off. There is a growing arrogance with regards to the government, thereby limiting the acceptance of any top-down strategies. The digitalisation of the workplace makes the need to interact with local community obsolete and not knowing ones neighbours decreases the resilience of the community. The detachment from the land is an aggravating factor to this.

5.5 - Economy & Lifestyle: South Australia's economy is greatly impacted by the prevalence of technology and the ability to work anywhere in the world from the comfort of your own home and laptop. There is significant loss in intensive industry and commercial sectors. This leads to significant inequality between those capable of working within an economy centred on software development and other digital services provided through the web and those unable to sufficiently retrain post the decline of traditional sectors. Due to the large amount of free enterprise in the online economy, governments struggle for revenue raising as individuals work for multiple clients in a largely unregulated system. There is a small service sector that provides support services to those capitalising on the tech-economy including healthcare, education and personal services.

5.6 - Politics & Institutions: Institutions within State Government struggle for effectiveness as revenue tightens. Society as a whole also begins to become less engaged with politics particularly at a State level as their interests and investments lie overseas. Governance issues are rife, most residing within central government agencies which feel their influence becoming less and less. This filters throughout the public service with an increasing emphasis on centralisation and 'small-government'. This also results in increasing privatisation of government services, as the State looks to raise capital. Private developers rule the landscape as government cannot resist their pressure to buy and develop pristine or hazard-prone locations. The ability for citizens to access immense amounts of information online, allows for continued opposition to government policies, resulting in political disengagement by the community. Residents of Greater Adelaide instead increasingly become individualistic with little concern for governance and society as a whole.

5.7 - Technology & Infrastructure: Technology in Greater Adelaide is booming in a backyard sense. Every home is increasingly wired into the web, however State owned infrastructure is creaking under the strain of disperse residential centres and a limited ability to undertake maintenance leading to an increasing risk of infrastructure failure impacting on prevention (e.g. levies, sea walls) as well as the suppression capabilities (roads, bridges, etc.). With the increased emphasis on online connectedness, community centres are also placed under pressure as they grow ever more redundant.

Appendix E – Paper 2 Published Version

Published version of Paper 2 from Chapter 3

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Enhancing the policy relevance of exploratory scenarios: Generic approach and application to disaster risk reduction

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ABSTRACT

Exploratory scenarios (i.e. scenarios that question what could happen) have been widely applied to a vast array of complex and uncertain socio-environmental system problems. Despite this fact, they have also been criticised by policy makers for not being relevant to policy processes and assessment. This paper proposes a generic approach to enhance policy relevance in the development of exploratory scenarios. This is carried out by participatory exploration and categorisation of available policy responses and framing of scenarios in terms of challenges to these. An exploration of the factors that make these policies more or less effective is used to develop a narrative for temporal developments in scenario instantiation, in comparison to more generic drivers for change. Within this paper, this process is applied to a case-study exploring the future of natural disaster risk; improving understanding of future uncertainties and subsequently the effectiveness of long-term disaster risk reduction. The case-study application consider bushfire, earthquake, flooding and heatwaves and resulted in five scenarios framed on challenges to resilience and challenges to mitigation for policy makers in Adelaide, Australia.

1. Introduction

The approach of developing and integrating exploratory scenarios into planning processes has been applied across many domains, including business (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005; Schwartz, 1996; Wack, 1985a), the environment (IPCC, 2000; Kok & van Delden, 2009; Mahmoud et al., 2009; Reed et al., 2013; Rounsevell & Metzger, 2010; Van Vliet & Kok, 2014), and technology (Kuhlmann, 2001; McDowall & Eames, 2006; Misuraca, Broster, & Centeno, 2012). Its wide application and success are primarily due to the approach's ability to unearth assumptions about the future and test them, in an effort to reframe plausibility, rather than to forecast the future, which is in contrast to other planning methods (Ramirez & Wilkinson, 2014). Van Vuuren et al. (2012) highlight three benefits and strengths of the exploratory scenario approach as 1) stimulating imagination and creativity while considering the future, 2) having the capacity to deal with inherent uncertainties and value judgements associated with unstructured problems and 3) helping to identify broad response categories within a certain context in an attempt to develop robust policies. However, despite these benefits, the success of the exploratory scenario approach in supporting policy processes has at times been questioned due to its perceived inability to explore the uncertain drivers affecting policy assessment and development, due to a broadness that makes it difficult to use it to support policy development (Bryson, Piper, & Rounsevell, 2010; Parker, Srinivasan, Lempert, & Berry, 2015).

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A review of several governmental organisations across Europe, and their interaction with scenarios, found policy-makers thought that the use of exploratory scenarios was not asking the correct questions, and that scenarios were not framed in an interesting and relevant way to policy-makers (Bryson et al., 2010). Similarly, Van Vuuren et al. (2012) note that exploratory scenarios often lack focus, particularly in relation to specific policy options. Common criticisms of the exploratory scenario approach by decision and policy-makers include their subjectivity, lack of targeting policy questions, inability to be included in a trade-off analysis for social and policy objectives, and overall inability to be connected to decision making processes (Bryson et al., 2010; Parker et al., 2015; Parson, 2008).

The lack of perceived policy relevance of exploratory scenarios, as noted above, may stem from their emphasis on exploring, and subsequent framing, of futures on system drivers and uncertainties, and temporal developments focusing on uncertain drivers. This is in contrast to placing the emphasis on available policy options/responses and their effectiveness. The development of shared socio-economic pathways (SSPs) (O'Neill et al., 2014, 2015) provided some progress towards bridging the gap between exploring future drivers, and considering policy responses, by applying normative, outcome-based, axes to the exploration of uncertain drivers. This approach to the development of the SSPs enabled the exploration of uncertainties to be framed in relation to challenges to policies designed to combat climate change via either mitigation or adaptation. However, this isolated example did not offer a generic methodology for considering policy response frames and exploration of the future with the inclusion of local stakeholders working within the relevant policy realm.

An additional contributor to the perceived lack of policy relevance can also be attributed to the manner in which scenario narratives have traditionally been constructed. Aside from scenario framing on uncertainties, the construction of the scenario narratives themselves also typically considers developments across commonly accepted uncertain factors (society, technology, economics, environment and politics, also known as STEEP) (Bradfield et al., 2005; Rounsevell & Metzger, 2010). This is in contrast to factors directly relevant to the effectiveness of possible policy responses.

For improved relevance to policy processes, the consideration of these two elements of developing exploratory scenarios, framing and uncertain narrative factors, should also be driven by an embedded participatory process for scenario development (Kok, Patel, Rothman, & Quaranta, 2006; Rotmans et al., 2000). Given this, the primary objective of this paper is to develop and demonstrate a generic approach for enhancing the policy relevance of exploratory scenarios. This builds on similar efforts, following critical reviews, of the application of exploratory scenarios in public policy areas, with efforts focussing on working with limited time and diverse stakeholders (Cairns, Wright, & Fairbrother, 2016; Cairns, Wright, Fairbrother, & Phillips, 2017; Pincombe, Blunden, Pincombe, & Dexter, 2013), improving links between long-term implications and short-term actions (Hughes, 2013), improving knowledge and experience of foresight methods in organisations (Rijkens-Klomp, 2012), and orientation processes for scenario based strategy development (O'Brien & Meadows, 2013).

The methodology proposed to achieve improved policy relevance incorporates 1) framing scenarios in terms of policy responses, 2) exploring their temporal development in terms of factors relevant to the policy's effectiveness and 3) achieving 1) and 2) via an embedded participatory process in the policy-oriented scenario development process (see Section 2 for methodology outline). The proposed approach is applied to a case-study considering long-term natural disaster risk reduction planning for Adelaide, South Australia (Section 3), which is a relevant issue to scope with exploratory scenarios, given the complexities and uncertainties associated with understanding and reducing disaster risk (Donner & Rodríguez, 2008; McGranahan, Balk, & Anderson, 2007; Newman et al., 2017; Global Facility for Disaster Reduction and Recovery, 2016). A discussion on the approach's advantages and comments on the applicability of the policy relevant scenarios developed using the approach to broader contexts is given in Section 4, and conclusions are provided in Section 5.

2. An approach for enhancing the policy relevance of exploratory scenarios

2.1. Overview

It is generally acknowledged that there is no overarching process for developing scenarios due to context specific issues and constraints such as time, budget and stakeholder composition (Ramirez & Wilkinson, 2016). However, exploratory scenario processes have some common elements (Fig. 1, left panel), including the identification of the focal question (Step 1) and key drivers (Step 2a), determination of the scenario logic (Step 3a) and scenario assumptions (Step 4a) and an assessment of outcomes (Step 5). The approach introduced in this paper includes these elements, where Steps 2a–4a are modified in order to increase the policy relevance of the resulting scenarios (Fig. 1, right panel). In particular, the proposed approach focuses on changes to the scenario logic or framing (Steps 2b and 3b), and on the narrative development using scenario/policy response dependent factors (Step 4b). These adaptations fit within many common scenario processes [e.g. Alcamo (2008); Kok and van Vliet (2011); Reed et al. (2013); Schwartz (1996); Van Vliet and Kok (2014)].

As discussed, the embedment of participatory processes is central to the modified approaches to scenario framing and narrative development introduced in this paper. There are many advantages of including stakeholder knowledge in the development of exploratory scenarios, but most importantly it has been shown to ensure relevance to local decision making (Walz et al., 2007). When scenarios are designed through participatory processes (including those directly involved in the region of interest and decision making processes), a number of benefits result in contrast to the use of expert-driven scenarios. Such benefits are the incorporation of local knowledge that external experts may not possess, enhancement of the internal consistency, logic and validity of scenarios, and an increase in trust and acceptance when scenarios are used in planning processes (Luz, 2000; Reed et al., 2013; Tress & Tress, 2003; Walz et al., 2007).

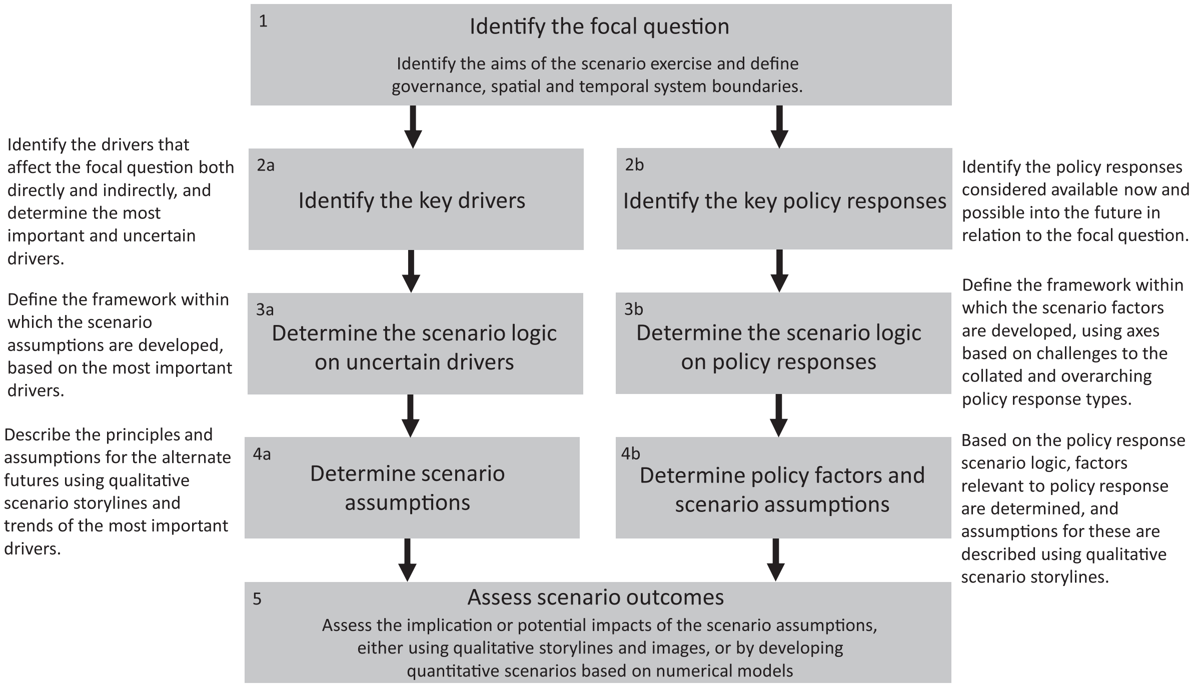

Fig. 1. Stages for scenario development, and stages for enhanced policy relevance adapted from Metzger, Rounsevell, van den Heiligenberg, Pérez-Soba, & Hardiman (2010). The left panel highlights the general steps for scenario development, the right panel with Steps 2b–4b, show the steps for enhanced policy relevance. Steps 1 and 5 are common to both approaches.

For complex problems, defined as multi-problem, multi-dimensional and multi-scale (Van Asselt, 2000), participatory processes can also add significant value due to their ability to engage with different perspectives, understanding of causal relationships, and mental models (Dewulf, Craps, Bouwen, Taillieu, & Pahl-Wostl, 2005). Using exploratory scenarios developed with stakeholder input also raises the level of creativity in considering the future, leading to increased understanding of subtleties within the influence of social, environmental and economic drivers (Kok & van Vliet, 2011). Participatory processes can, under certain socio-economic and institutional arrangements, also improve the quality, legitimacy and effectiveness of any implemented management options, which is of clear value when considering the exploration of future developments orientated towards decision making and policy processes (Maskrey, Mount, Thorne, & Dryden, 2016; Reed, 2008; Roth & Winnubst, 2014; Sherman & Ford, 2014).

The following sections provide details on the proposed changes to the scenario logic or framing (Section 2.2) and narrative development using scenario/policy response dependent factors (Section 2.3), including the relevant theoretical background and motivation. Details of how participatory processes are embedded within these steps are also given.

2.2. Policy response scoping and framing – Steps 2 and 3 (Fig. 1)

2.2.1. Background and motivation

The framing of scenarios is a critical component, as it provides the initial conditions and boundaries between alternate but equally plausible views of the future. Although scenarios do not require a predefined framing or logic, they often include such over-arching structures for ease of communication and clarity for both stakeholders involved in the scenario development process and the broader community (Ramirez & Wilkinson, 2014; Van Asselt, 2012).

Commonly, a 2 × 2 matrix is applied as the scenario frame, as mentioned in the Introduction with reference to the STEEP factors. This frame places two key driving forces for the future on the vertical and horizontal axes, and is commonly referred to as a 'standard' by practitioners and academics (Van Asselt, 2012). A study of scenarios commissioned by Natural England showed that of the 35 scenario studies considered, 24 were developed using the 2 × 2 matrix formulation (Natural England, 2009). The 2 × 2 approach can clarify the communication of uncertainty, especially to those not involved in the scenario development (Ramirez & Wilkinson, 2014), however, it forces polarizing outcomes for each key driver, allowing implausibly 'extreme' futures to be considered (Randall, 1997).

Recent efforts to improve the link between decision making and exploratory scenarios has seen more 'normative' frames used for scenario development, while still including the concept of intuitive logics, 'forward-chaining of causality' approach. This forward-chaining approach looks to see how developments occur based on assumptions of causality and system understanding, and in the intuitive logics approach this sees exploratory scenarios developed based on considering how different assumptions unfold throughout the system beginning from the 'present. By applying normative frames to this forward-chaining, the outcome is already determined, often extreme 'good' or 'bad' futures, and developments are considered as to how those extreme futures are realised. An example of this is Cairns et al., 2016, combining the benefits of intuitive logics forward-chaining approach to developing scenarios with the 'backwards logic' method engaging stakeholders in constructing extreme scenarios of the future. Similar examples include De Bruin, Kok, and Hoogstra-Klein (2017) and Vervoort et al. (2014). These concepts also align with the 'incasting' work of Dator and the Manoa School (Dator, 2009), considering pre-defined futures and deductively reasoning alternative futures scenarios for the research objective. These approaches and emphasis on outcomes have been shown to provide a better linkage between scenario projects and planning, and decision making.

A further adaptation from this was offered in the recently published Shared Socio-Economic Pathways (SSPs), developed as a tool "for exploring the long-term consequences of anthropogenic climate change and available response options" (Kriegler et al., 2012), which are defined as, "reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or policies" (O'Neill et al., 2014). Instead of placing the outcomes of driving forces as the axes to frame scenarios, challenges to mitigation and adaptation (seen as approaches, or broad policy categories, to handle climate change) are placed there. This provided a framing of future socio-economic developments as to whether or not climate change mitigation or adaptation policies would be more or less challenging, a normative frame of policy options not drivers.

The advantage of framing the future with challenges to policy options, in comparison to key drivers or uncertainties, is that it more easily allows the incorporation of various uncertainties in each exploratory scenario and does not constrain the factors of uncertainty or make them the same across each scenario. This approach goes towards addressing the notion that framing on two uncertainties and their states limits the exploration space and the consequent ability to represent multiple relevant factors, but the approach can also maintain the benefits of a 2 × 2 framed scenario approach, which is considered to be representative of the ease with which scenarios can be understood and communicated (Lord, Helfgott, & Vervoort, 2016; Parker et al., 2015). Also, for policy impact assessment, the scenarios encapsulate future conditions specifically included to test the effectiveness of the policy alternatives, and not only scope the future based on what are considered the main drivers for general change. This is significant in terms of the ability of exploratory scenarios to be used for policy 'stress-testing' or the development of policies that are effective under relevant difficult future conditions and can subsequently be considered as robust (Maier et al., 2016). Additional to these benefits is that the scenarios can enable and build strategic capacity in policy makers for operating in difficult futures and also allow for an understanding of how to address these challenges, and catalyse actions against these futures, focusing more on the vision of a future with low challenges for policy effectiveness and implementation.

The proposed approach to generalising a policy-oriented scenario building approach is presented in the next sub-section. Balancing the exploratory capabilities of using drivers with evident policy-relevance is critical, as is including the input of relevant stakeholders, in contrast to expert-driven processes. The selection of axes is also critical to the value of the process when applying it to problem domains other than the challenge of climate change, where mitigation of greenhouse gas emissions and adaptation to the effects of climate change are considered the standard approaches to dealing with the problem under consideration (Watson, Zinyowera, & Moss, 1996).

2.2.2. Proposed approach

In the proposed approach for scoping and framing, Steps 2b and 3b – Fig. 1, the focus on framing is on challenges to a policy response, identifying alternate futures where policies are more or less effective. To apply this broadly to policy questions, the problem needs to be scoped considering key challenges and the possible policy responses now and into the future. A participatory process including a combination of questionnaires, semi-structured interviews and workshops, ensuring a variety of communication and thought styles are incorporated, is proposed to understand the overarching challenge for which the scenario process has been initiated. Although it is difficult to prescribe exact details on the participatory processes and wording used in these processes, given they should be adapted to specific participants, the initial scoping phase should consider the uncertainties and drivers of change for the specific problem. This should then be used to open a dialogue on relevant policy responses available now and into the future that may form a portfolio of actions to influence the challenges considered. With a broad stakeholder group providing individual proposals, this enables the scenario team to better understand not only the challenges, but also the response options available.

The responses then need to be collated into similar, but disjoint, response categories. For example, for government budget reform, this may be taxation changes and efficiency drives, for schooling, this may be increased school autonomy and increased standardization and testing. The SSPs considered mitigation and adaptation as the responses to climate change, although these were accepted expert derived responses to the challenges based on the IPCC's Second Assessment Report in 1995. There is also no restriction to only two dimensions, with multiple policy response groups being displayed in multiple dimensions, however, the benefits of the 2 × 2 approach in terms of communication may be soon lost if dimensionality is increased (Lord et al., 2016; Ramirez & Wilkinson, 2014). There are also several methodologies for categorization in a participatory setting and group decision making, with OECD (2001); Tippett, Handley, and Ravetz (2007); World Bank (1996) all providing insights into participatory methods and tools to assist. The above process results in a scenario space framed by challenges to each policy response, as shown in Fig. 2, with the axes linked to increasing challenges.

2.3. Development of policy response factors and timelines – Step 4

2.3.1. Background and motivation

Following the choice of framing axes, scenario narratives are commonly developed using intuition, brainstorming, or expert elicitation (Bradfield et al., 2005). Regardless of the specific technique used, the process results in a series of qualitative assumptions about drivers of change, often framed as STEEP factors, in the context of the scenario framing or scenario logic (Rounsevell & Metzger, 2010). However, with the traditional focus on considering alternative assumptions for drivers, as opposed to the approach proposed in this paper, it has been shown that developed exploratory scenarios commonly fall into 'scenario families', a set of scenarios that share a similar storyline (De Vries & Petersen, 2009). Van Vuuren et al. (2012) found six consistent scenario families across many global environmental scenarios (economic optimism/conventional markets, reformed markets, global sustainable development, regional competition/regional markets, regional sustainable development, business as usual/intermediate), demonstrating a lack of diversity, which could contribute to the concerns of scenarios not targeting the correct questions.

These reviewed scenario approaches also use common factors across each scenario, varying the assumptions to obtain extreme differences between the scenarios developed. This is intended to create the largest plausibility space within the set of drivers included. However, this may make them less tangible for policy analysis, especially if the factors varied are not critical to the effectiveness of a solution or policy. For constructing scenarios more targeted to policy options and assessment processes, consideration should be given to how these factors connect to the policy questions being asked.

Exploratory scenarios can also be developed without the consideration of specific factors, and instead created through discursive processes to detail narratives (Vervoort et al., 2014; Volkery, Ribeiro, Henrichs, & Hoogeveen, 2008). This process has significant benefits in terms of creating rich narratives, social learning, and consensus building between the parties involved in the process (Caves, Bodner, Simms, Fisher, & Robertson, 2013; Pahl-Wostl et al., 2007; Patel, Kok, & Rothman, 2007; Reed et al., 2013). This more discursive process, however, has been criticised in terms of its subjectivity, reliance on individuals involved, and the fact that those outside of the process have less of an understanding of the underlying assumptions made and, as such, find it more difficult to link to future policy assessments outside of the initial scenario process.

Therefore, there is a need for scenarios that clearly highlight the process in which they have been developed, to show the underlying assumptions and be valuable to future policy assessments. There is also a need for the scenarios' assumptions to be clearly linked to specific policy responses, not more generic drivers for change, developing specific and policy relevant scenarios. The proposed approach looks at how to determine the relevant factors for each scenario without the need for the factors to be specific to scenarios, and therefore instead of causing the most diversity in future scenarios, this focus causes the most extreme cases for policy effectiveness to be captured in the scenarios.

2.3.2. Proposed methodology

With the scenarios framed, the factors relevant to each of these responses are considered as the building blocks of each scenario, in comparison to generic factors of development (STEEP), Step 4b – Fig. 1. These factors are elicited by posing questions to stakeholders regarding their opinion as to what factors are most relevant to the framing of policy options and what makes them more or less difficult. The structure of these questions is dependent on the options under consideration, however, the questions should be designed to deeply explore the policy options and elicit the expert knowledge of the stakeholders.

For each policy response axis, relevant factors should be discussed by participants, resulting in a decision on core factors relevant to the effectiveness of that policy response. For example, if increased income taxation was the policy response, relevant factors may include economic activities of the region of interest and societal values on wealth distribution, versus a policy response of efficiency drivers, which may include factors of labour reform and technological change. The chosen factors are then used as the building blocks for the relevant scenarios. Factors relevant to policy option 1 would be used for all scenarios in region 1, and factors relevant to policy option 2 would be used for all scenarios in region 2 of Fig. 2. For scenarios that lay on the interface between region 1 and 2, a combination of factors from both policy responses would be used.

As outlined, this construction process is in contrast to the construction process discussed in O'Neill et al. (2015) and many other scenario processes (e.g. Carlsen, Dreborg, and Wikman-Svahn (2013); Kok, Patel et al. (2006); Kok, Rothman et al. (2006); Lord et al. (2016)), which use consistent factors across all scenarios as building blocks, as this encourages different factors for scenario regions based on the policy responses considered. As such, by allowing stakeholders to build scenarios on the factors of each policy option,

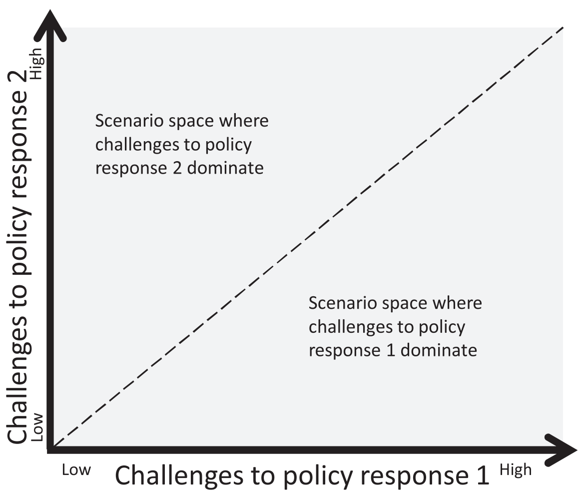

Fig. 2. Scenario framing that places challenges to policies options on the axis to frame the scenario regions.

the workshop discussion is intended to relate more to the expertise and perception of stakeholders and therefore provide guidance to the development of valuable, policy relevant exploratory scenarios. Using factors relevant to each policy response helps overcome a challenge of many participatory scenario processes, where the development of socio-economic scenarios can become difficult, as participants may not have the expert knowledge to comment on areas outside of their policy expertise, such as economic, and demographic changes, or technological advances that are plausible in a region (Kok et al., 2014). This is less of a challenge with expert driven approaches (see SRES (IPCC, 2000), Millennium Ecosystem Assessment (2005), and SSPs (O'Neill et al., 2014)), as those involved are chosen due to their knowledge in areas of importance.

By developing future scenarios around the question "what would make their job easier or harder?", policy makers can more easily interact with exploring plausible futures, especially if they are not familiar with working at a strategic level. This discussion of policy relevant factors also allows the construction process to add value outside of creating scenario narratives. This is because the suggested scenario development process can enable learning and unlearning, along with a deeper fundamental understanding of the problem(s) (Schwartz, 1996; Wack, 1985a,b; Wilkinson & Eidinow, 2008). We propose that participatory exploration of the factors that become the building blocks of individual scenarios can provide these benefits and allow the scenarios to be more tangible to policy focussed participants.

3. Natural disaster risk reduction case-study

To demonstrate the application of the proposed methodology, it was integrated into a scenario development process within a larger exploratory scenario approach and modelling effort to support natural disaster risk reduction planning for the Greater Adelaide region in South Australia, Australia. This case-study is designed to test the utility of the methodology for developing policy-relevant exploratory scenarios with regard to its ability to 1) frame scenarios in a relevant way for policy makers and, 2) target scenarios to specific policy options and assessment processes. The applicability of the proposed approach to natural disaster risk reduction is discussed in Section 3.1, followed by details of the specific case-study considered in Section 3.2. The application of the proposed approach to the case-study is detailed in Section 3.3, with results and discussion provided in Section 3.4.

3.1. Applicability of proposed approach to natural disaster risk reduction

The impacts of natural disasters globally are significant and growing. Comparing ten year averages, the annual total damage rose from $US14 billion for the period 1976–1985 to more than US$140 billion for the period 2005–2014 (Global Facility for Disaster Reduction and Recovery, 2016). Several recent global agreements are, however, placing an emphasis on reducing these impacts. For example, the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR, 2015), along with the Paris Agreement of the United Nations Framework Convention on Climate Change (United Nations, 2015a), and the Sustainable Development Goals (United Nations, 2015b), are providing emphasis on reducing disaster impacts globally through disaster risk reduction activities. Disaster risk reduction is defined as,

> *"…the concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment and improved preparedness for adverse events"* (United Nations, 2009).

There is also consensus that risk reduction efforts are cost effective in comparison to response and recovery with a recent review of benefit-cost ratios across multiple hazards and geographic locations showing a range of 1.3 to a staggering 1800 (Shreve & Kelman, 2014).

The exploration of futures in disaster risk and its subsequent reduction is therefore of critical importance, as the complexities and uncertainties within the dynamic relationships between climate change, population growth, economic change and urbanisation are significant. Natural disaster risk is a combination of the natural hazard, exposure and vulnerability. As a result, when considering future disaster risk and planning to reduce risk, the uncertainty and complexity of each factor must be considered. Influencing factors on the three components of risk include political decisions, economic development, technological advancement, and demographic changes coupled with a changing climate, which is also influenced by socio-economic factors (Bernknopf, Hearn, Wein, & Strong, 2007; De Moel & Aerts, 2011; Koks, Bočkarjova, de Moel, & Aerts, 2015). All of these must be included when considering long-term disaster risk reduction planning.

Engaging with this level of uncertainty in the complex system of disaster risk is problematic for traditional planning processes, and as such, understanding the future dynamics of disaster risk and subsequently developing risk reduction plans can benefit from the use of exploratory scenarios and scenario planning (Author et al., 2016; Zurek & Henrichs, 2007). However, given the significant impacts of disasters globally, as previously mentioned, there is an overarching need to better understand and subsequently reduce risk in the context of various policy responses to enable action. Therefore, there is added value in exploratory scenarios designed to consider the future of disaster risk to be directly linked with available policy responses. The following section will outline the process applied to the case-study following the steps in Fig. 1.

3.2. Application of proposed approach

3.2.1. Step 1: Focal question and system boundaries

The case-study region is the Greater Adelaide region of South Australia (SA), a geographical region of around 1800 km^2, and a population of 1.29 million. The study involved planning for the risk from bushfires, floods, earthquakes, heatwaves and coastal inundation for an extended planning period from the current year to 2050. The initiator within SA was the SA Fire and Emergency Commissioner (SAFECOM), who identified the State Mitigation Advisory Group (SMAG), along with other relevant state government organisations and non-government organisations (NGOs), as the critical stakeholders to be involved in the process. The overall process had the objective to improve the ability of policy makers to make more strategic and less responsive decisions in relation to minimising the likelihood and impact of natural hazards. This objective was based on a recent emphasis on considering multiple hazards and long term challenges from socio-economic development and climate change, highlighted by investigations post major events in Australia, including the 2009 Victorian Bushfires Royal Commission (Victorian Bushfires Royal Commission, 2010) and the Commission of Inquiry into the 2010–11 Queensland floods (Queensland Floods Commission of Inquiry, 2012).

3.2.2. Step 2b and 3b: Policy responses and scenario logic – mitigation and resilience

An initial participatory scoping process was undertaken with the stakeholder group by the scenario team to explore and consider the framing of scenarios. The first stage of participatory work involved preparatory questionnaires and semi-structured interviews between members of the scenario team and stakeholders, followed by a workshop with the full stakeholder group and a day of exploring the problem. The emphasis of this engagement process was on understanding more about disaster risk reduction in the region, the policy options available, and how their effectiveness was judged. There was also emphasis on considering how both the currently available policy options would change, and what would impact their effectiveness into the future.

The participatory activities were organised to respond to the following three questions focused on the policy processes that stakeholders were involved in:

What are the possible risk reduction measures now and into the future for Greater Adelaide?

What do you consider to be the main drivers for change and sources of uncertainty when considering the development of Greater Adelaide?

What indicators do you consider for policy assessment across risk, economic, social and environmental factors?

During the participatory sessions, meta-plans (individual responses to the questions grouped into similar responses by participants) (Schnelle, 1979), were developed independently by several break-out groups, which were then collated by the scenario team. Table 1 shows the most common responses by participants for question 1, clustered into themes using the meta-planning exercise and adapted by the scenario team after the session, placing greater emphasis on all hazards and risk reduction prior to the event, not response post event.

The responses, summarised in Table 1, allowed the scenario team to develop a greater understanding of the policy options and challenges for the case-study region. Based on discussions throughout the first stage of participatory work and the options highlighted in Table 1, two main themes arose, which were then used as the framing axes. These were mitigation orientated options and resilience orientated options. The split between these is indicated by (M)/(R) in Table 1. The division between these two option categories arose from discussions around risk reduction options that can be implemented by government (top-down, and considered as mitigation oriented) or are more community driven (bottom-up, and considered as resilience oriented). Examples of the former (mitigation

Table 1
Cluster risk reduction options following policy scoping process.

Clustered Theme	Top 3 Risk Reduction Options		
BUILDING CODES	Increasing recurrence intervals for all hazards in code *(M)*	Inclusion of hazard resistance for hazards not considered *(M)*	Specific strengthening for buildings of community value *(M)*
LAND MANAGEMENT	Planned burning, reduction of fuel load *(M)*	Improved enforcement mechanisms (e.g. illegal vegetation clearance) *(M)*	Land reclamations *(M)*
COMMUNITY BASED	Arson reductions programs *(R)*	Integration of hazard programs in school curriculum *(R)*	Increase community awareness (risks, safety strategies) *(R)*
STRUCTURAL	Building hardening (e.g. for residential infrastructure) *(M)*	Increased assistance for owners of buildings in hazard areas to retrofit buildings *(R)*	Structural upgrade of legacy buildings not currently code compliant *(M)*
CIRCULAR LEARNING (Event to planning)	Agreement on residual risk for government and communities *(R)*	Implementation of business continuity plans *(R)*	Structured framework for lessons learnt *(R)*
INSTITUTIONAL CHANGE	Establishment of multi-hazard agencies *(M)*	Tougher legislative requirements for building in higher risk zones *(M)*	Adaptive policies (e.g. thresholds) for decision making (linking with adaption to climate change) *(R)*
LAND USE PLANNING	Building exclusion areas in eg. floodplains/high risk bushfire areas *(M)*	Ensuring development in hazard prone areas are compliant to highest codes *(M)*	Increase access to information for property owners *(R)*
LEGISLATION	Regulatory requirements to consider natural hazard risk in planning *(M)*	Provide hazard leaders/control agencies with greater powers to question developments *(M)*	Resource planning to mitigate response/ recovery costs and impacts *(M)*
FINANCIAL INSTRUMENTS	Effective cost/risk assessment *(M)*/ *(R)*	Use of post-event levies to fund mitigation *(M)*	Funding to support institutional change (increased integration, coordination and planning) *(R)*

NB: The notation of *(M)* and *(R)* denote whether the risk reduction option was considered a “mitigation focussed” or “resilience focussed” policy response.

orientated) include the construction of flood protection works; improving building code legislation; land management (e.g. planned burns for bushfires); or land use planning, restricting the exposure of assets to hazards, can be classified as mitigation-based approaches. In contrast, examples of the latter (resilience orientated) include whether risk is being reduced due to an improvement in society's ability to deal with a particular hazard, hence reducing their vulnerability. These two grouped policy responses were subsequently agreed to be the axis factors for the framed scenarios, with challenges to resilience orientated responses placed on the y-axis and challenges to mitigation orientated responses on the x-axis.

3.2.3. Step 4b: Policy relevant factors and scenario assumptions – exploring resilience and mitigation into the future

With the scenario logic agreed upon (Steps 2b and 3b, Fig. 1), a second workshop was held with the same stakeholder group. The specific aim of this workshop was to develop qualitative, exploratory scenarios capable of exploring plausible futures for Greater Adelaide (Step 4b, Fig. 1). These futures were designed to consider the effectiveness of common risk reduction strategies falling under the categories of resilience and mitigation. The workshop was planned around a series of preparatory presentations, introducing the concepts of exploratory scenarios, and break-out sessions to participants. Five scenarios were to be developed, including:

- one future for Greater Adelaide where it was simple to design and implement mitigation strategies and develop societal resilience, which was considered the vision for the region;
- one extreme future that challenged both resilience and mitigation strategies;
- two intermediate futures that challenged either resilience or mitigation to a greater degree; and
- one central future with moderate challenges to both resilience and mitigation.

To develop the scenarios on policy relevant factors, the first task was to explore the factors relevant to resilience and mitigation. Participants were asked to offer individual responses to the questions, *what factors are relevant when creating and encouraging resilience to disaster risk?* and, *what factors are relevant when designing and/or implementing mitigation policies to disaster risk?* A facilitated conversation also questioned what would make these factors more or less difficult going into the future. Individual responses were then clustered and, across breakout groups, factors relevant to resilience and mitigation were further refined to five factors that would be used for the participatory scenario development, Table 2.

Using the factors of resilience and mitigation, participants discussed assumptions for developments in each of these factors in terms of the scenario's frame (whether challenges to resilience or mitigation were high or low). In break-out groups for each scenario, narratives were noted out in terms of each factor relevant to the scenario's frame, and timelines were created, noting particular developments for each factor. An example selection of these assumptions and developments is shown in Fig. 3, showing the timeline period of 2015–2025 for challenges to resilience across three factors, infrastructure, understanding and knowledge of hazard/risk and social cohesion. Groups were then moved on to modify and refine other scenarios to continue their development, where conditions were placed on the stakeholders to not change the scenario narrative or timeline, but only question why the challenge would happen, and what would happen next. This ensured that scenarios were developed and enriched with new perspectives, instead of being challenged and rewritten by each new group (Fig. 4).

This time-lining process of factors, followed by more detailed narrative writing by the scenario team, resulted in five fully documented scenarios considering disaster risk and reduction potential in Greater Adelaide. The scenarios are summarised in Table 3 and shown in their framing in Fig. 5, with the full scenarios documented in Supplementary material 1.

3.2.4. Step 5: Assess scenario outcomes

The scenarios developed from the stakeholder discussions and timelines were then presented back to the stakeholder group, allowing for feedback on their representativeness, internal consistency and plausibility. A sample of the results from this feedback session are shown in Fig. 5. Overall the feedback supported the developed scenarios with predominately positive feedback regarding representativeness, consistency and plausibility. Comments that highlighted any inconsistencies within the narratives were discussed

Table 2
Relevant factors and their descriptions for policy response themes resilience and mitigation.

Policy Theme	Factor	Description
Resilience	Infrastructure	Network design for elasticity, adaptability and redundancy.
	Understanding and knowledge of hazard/risk	Community understanding of the level of hazard they are exposed to.
	Social cohesion	Structure of society that encourages neighbourhood interactions and community awareness.
	Resources for action	Availability of community level grants, seed funding and training for bottom up solutions.
	Efficacious policy	Policies that are effective in stimulating the required outputs not producing maladaptation impacts.
Mitigation	Data and knowledge	Availability of information and data to support the design of effective responses.
	Governance structures	Governance structures that allow funding for mitigation activities.
	Holistic policy	Policies that cover the entire risk triangle of hazard, exposure and vulnerability, from preparedness to recovery.
	Institutional culture and perception	Community confidence in governmental institutes' ability to effectively reduce risk, along with a culture of mitigating risk (as opposed to an emphasis on response).
	Cost benefit considerations	How to deal with growing costs of mitigation for increasingly high magnitude hazards.

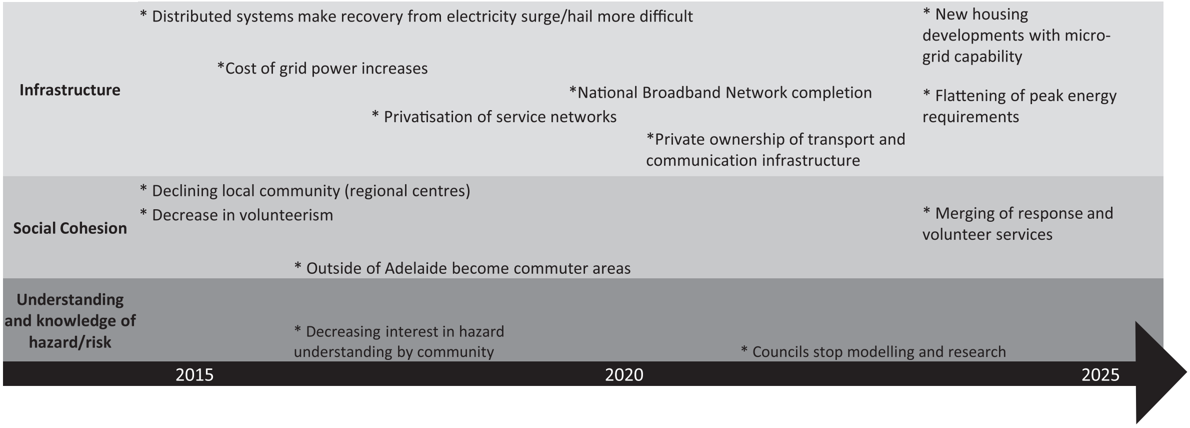

Fig. 3. Timeline for the scenario considered as challenging resilience from 2015 to 2025. A selection of assumptions across three factors determined as relevant to resilience are shown; including infrastructure, social cohesion and an understanding and knowledge of hazard/risk.

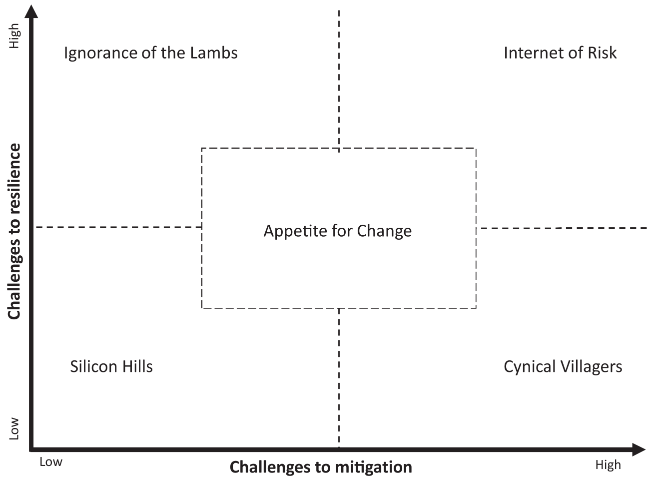

Fig. 4. Scenario framing and layout.

and changes were made where appropriate. This is an important stage of the scenario development process allowing feedback from stakeholders.

The impacts and implications of the qualitative scenarios were subsequently discussed with participants. Discussions focussed on how different natural hazard events would impact on the community and environment across each of the scenarios. Subsequent work with the stakeholder group will look to quantify these scenarios and visually demonstrate different risk profiles for each of the scenarios with numerical simulation models.

4. Discussion

Following this application of the proposed exploratory scenario development framework, several insights and conclusions are drawn and discussed in the following sub-sections. These include assessing the policy orientation of the developed scenarios and how to balance stakeholder knowledge elicited through participatory processes with more detailed analysis by a small scenario team. Also discussed are the broader applicability of scenarios designed with processes focussed on policy options. That is, how well can policy-focussed scenarios be applied to broader questions outside of their original domain, and can they be translated or scaled to different areas?

4.1. Policy relevance of developed scenarios

A common challenge of all scenario development processes is to demonstrate their added value (Wodak & Neale, 2015). This is largely because their benefits are often not immediately tangible or obvious to participants, or convenors, due to much of their impact coming from the actual process itself. In terms of increased policy relevance due to the proposed construction and framing process, this is even more difficult to measure. However, stakeholder feedback throughout the process showed its promise, which was also

Table 3
Scenario summaries.

Scenario	Frame	Summary
Silicon Hills	Low challenges to both mitigation and resilience	*Greater Adelaide transitions towards a well-balanced technology focussed economy, driven by highly skilled and engaged locals and expatriates as well as immigrants looking to capitalise on the State's booming high-tech industry. Residents enjoy the relaxed, nature filled lifestyle the Mt Lofty Ranges and Adelaide Hills offer.*
Cynical Villagers	Mitigation challenges dominate	*A growing amount of rural residential developments, coupled with low population growth sees Greater Adelaide increasingly suffering from urban sprawl. This sprawl is due to shifting population dynamics with an increase in lower-middle income groups and hence a drive for affordable homes, and an ageing population looking to the hills for retirement. There is a strong community preference for protection of the state's areas of environmental significance, a growing environmental consciousness and appreciation of the landscape's amenity value. The interest in nature and the countryside leads to high levels of local knowledge regarding the risks from the landscape. However this risk awareness still unequal across the region, with less connected and more vulnerable communities still finding it difficult to build self-sufficiency.*
Ignorance of the Lambs	Resilience challenges dominate	*Greater Adelaide shifts towards an increasingly commuter lifestyle in the pursuit of lower cost housing. Population growth is high with increased immigration from migrants seeking a safe-haven in Australia from various global issues both climatic and socio-economic. The region experiences a decline in rural living, with a shift towards highly urbanised centres throughout the region and lengthening of commute times between residential centres and places of work. This results in increasing community vulnerability and heavy reliance on government for both social and hazard-related support.*
Appetite for Change	Moderate challenges to both mitigation and resilience	*Greater Adelaide continues on its current trajectory with declining manufacturing and slow population growth. In contrast to the decline in manufacturing, a rise of low value mining and an expansion of agricultural sectors over the next fifteen years leads to a slight expansion of rural residential areas and an increase in urban infill and sprawl around the suburban fringes.*
Internet of Risk	High Challenges to both mitigation and resilience	*Global connectedness drives an increasing reliance on the internet for social interaction and working styles. This reliance on the internet sees dispersed residential living as the attraction of the CBD and physical centres lessens and reduces population density. This leads to a significant loss of physical connectedness and an increase in siloed communication between similar individuals. Services by a small, but growing, services sector provide for the masses of online workers. The majority of workers use the internet to work across the world, placing pressure on government revenue streams.*

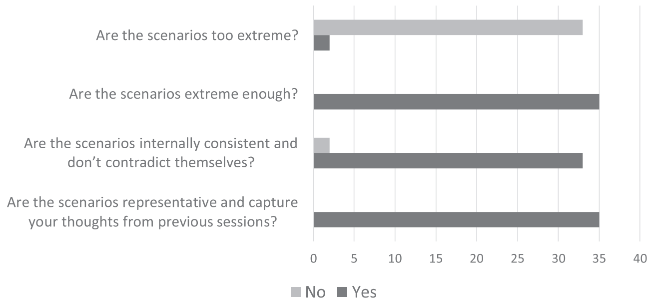

Fig. 5. Participant feedback on the drafted scenarios.

highlighted by the confidence in the plausibility of the scenarios, as shown in Fig. 5.

Additionally, from the scenario team's perspective, the thinking of participants in terms of how all scenarios impacted on their job and policy creation, reflected value in scenario development from both an outcome and process perspective (Hulme & Dessai, 2008; Van Vuuren, Kok, Girod, Lucas, & de Vries, 2012). Qualitative information from participants also provides an indication that the scenarios proved valuable and will continue to be so. An indicative quote from one participant was that,

> *"Making decisions that consider the ageing population, changing demographics, climate change, economic growth and changing industry bases along with the impact of technology and internet certainly looked very complex to start with, however it made a lot of sense [in the end]. Putting these elements into the scenarios was where it all came together for me and then mapping it into the time schedule was particularly illuminating."*

While feedback of this kind cannot provide sufficient evidence of changed practice, it does show the value of using scenarios to capture complex, uncertain information in an easily understandable context. However, due to the long-term nature of participatory scenario processes, and the many factors playing a role in disaster risk reduction management, judging success is inherently difficult.

4.2. Policy content of developed scenarios

In contrast to the assessment of impact on long term policy, the content of the scenarios can be considered in terms of their policy relevance, where the link to disaster risk reduction policies is clear. All scenarios include specific references to disaster risk reduction, with examples shown below and full details in Supplementary material 1:

> *"The emphasis on enjoying and connecting with nature ensures well-maintained areas of local significance along with increased understanding and subsequent reduction of human impacts on the landscape." (Silicon Hills Scenario Narrative, Section 1.1, Supplementary material 1)*

> *"Due to the rising costs of risk mitigation, the Federal Government plays an increasingly important role eventually resulting in the loss of state-based policy, with the State Government becoming more of a service provider than a policy maker." (Ignorance of the Lambs, Scenario Narrative, Section 3.1, Supplementary material 1)*

By framing the scenarios on encouraging resilient communities or implementing mitigation activities, policy makers were easily able to see the relevance of the process to their operations. Considering scenarios, with the focus on the ease or difficulty to the design and implementation of policies, made what can at times be non-tangible discussions about the future more immediate and relevant.

The scenarios were also specifically focussed on policy responses by constructing them with specific, relevant factors. Scenarios that considered resilience looked at entirely different factors than those considering mitigation, and these differences may have been harder to capture by using the same, or more generic, factors, across all scenarios (e.g. STEEP factors). This is evidenced by comparison between the discussion on politics and institutions for *Ignorance of the Lambs* (challenges to resilience) and *Cynical Villagers* (challenges to mitigation). Based on the factors considered relevant to resilience (e.g. social cohesion, infrastructure and understanding of risk), the narrative focussed on the need for large infrastructure projects requiring federal government funding, and hence State government becoming a service provider, not influencer. The narrative also assumed a lack of research and analysis investment by local governments due to lack of local level funds for projects. In contrast, considering factors relevant to mitigation (e.g. institutional perception, data availability and cost benefit considerations) had the scenario narrative focus on community opposition to mitigation activities seen to restrict individual rights and freedoms, supported by increasingly open data, consequently leaving the community more empowered to challenge governments through the courts.

Although the construction of scenarios based on policy relevant factors is critical to developing relevant scenarios, it also poses some challenges, despite the previously mentioned benefits. While some factors, such as *social cohesion* for resilience focussed scenarios, or *data and knowledge* for mitigation based activities, had clear concepts, and timelines that were easily developed by participants (i.e. considering how societal values, or funding for science, could change given various drivers), other factors proved more troublesome. For example, the resilience factor *efficacious policy,* described in Table 2, challenged the construction, as participants found it hard to create a timeline of changes for this in the context of resilience, despite the fact that it had come out of their earlier exploration of the policy option.

Therefore, careful consideration of the scenario factors selected is critical to allow an exploration of developments into the future. It may be suitable for the scenario team to select representative factors that, in their opinion, allow for temporal development from the previously collated responses from participants. This could, however, detract from the overall participatory approach. To maintain the participatory benefits, careful consideration should be given to the structure of the participatory exercises, along with effective facilitation for the selection of factors that can enable discussion of temporal developments. The scenario team could also be open to altering the factors during the process of time-lining to better allow for temporal developments, while maintaining the original concepts of the policy relevant factors.

4.3. Value of inclusion of participatory and expert knowledge

The inclusion of participatory knowledge in this study significantly improved its policy-relevance, as the participants represented the key decision-makers and advisors in risk reduction policy in the study region and were able to contribute the policy information they would find relevant. Participation by such individuals improves the quality of policy relevant factors, and allows the inputs to be much more focussed on the challenges facing the region. Several risk specific assumptions were included throughout the workshop discussion, which improved the relevance of the scenarios, and could only be garnered by involving policy focussed participants. Such assumptions/factors included the impact of governance structures and effective decision making in the region of interest (for examples, see Supplementary material 1 Section 3.1 and 3.3) and potential impacts of the digital economy (Supplementary material 1 Section 5.7) and inequality (Supplementary material 1 Section 2.4, 5.4, 5.5) on risk profiles.

However, the participatory process with these participants posed other challenges, namely that future-focussed thinking was not generally within the function of their role or organisation's remit. There was instead a greater emphasis on emergency response for most participants (as is appropriate to their day-to-day work), which resulted in the requirement for appropriate facilitation and process design to align future-focussed thinking and an understanding of the region's risk. The proposed scenario process significantly aided this, with targeted exercises to extract information related to risk and policy factors (Steps 2b and 3b), and then by framing the discussion on how these factors can change into the future (Step 4b). Expert facilitation is required to challenge participants to move stakeholder thinking from the present to the future, but the facilitators found this easier to do when participatory activities were framed around challenges to mitigation and resilience than a more abstract discussion around the changes considered plausible in society across consistent uncertain factors or drivers, as discussed in the Introduction and Section 2.3.

Using the information from the participatory workshops as inputs to the detailed narrative scenarios, the scenario team was not fully restricted to the outputs of participatory exercises. This allowed the scenario team to incorporate analysis of historical trends, and consider inconsistencies within and across scenarios. This enabled a broader consideration of future drivers for change to be coupled with participatorily derived policy focussed information. This combination of workshop sessions, and intermediary work by the scenario team allowed the scenarios to better combine policy and future uncertainty factors. Furthermore, it provided a structure to benefit from the value of participatory knowledge in scenario development, enhancing the legitimacy and impact of the process (Alcamo & Henrichs, 2008), while still allowing for the ability to include more novel and provocative ideas by the scenario team (Chermack & Coons, 2015). This process also allowed for a more efficient scenario development process which is critical when working with senior decision makers with limited time (Pincombe et al., 2013; McBride et al., 2017). Cairns et al. (2016) also discuss these challenges, balancing the participants' ownership of the narratives, with the time available for participants to be involved in the process and role of the scenario team. This shows that limited, but strategic, engagement with senior decision makers as participants still allows for ownership to develop and for articulated, collective actions to be discussed and progressed.

4.4. Policy frames, applicability and scales

The construction of futures specifically designed to test policy responses allows for a clearer targeting of 'interesting' futures for policy analysis (Bryant & Lempert, 2010), compared to a scenario logic focussing on key uncertainties. However, this occurs at the potential loss of generality and transferability. Many large scale global scenario processes have been applied to domains outside of their original design intent, with the SRES being an example of this (7212 total citations of Nakicenovic and Swart (2000) from diverse fields are listed on Google Scholar, accessed 06/03/2017). By framing the scenario development on key uncertainties, the futures are intended to be as diverse as possible, and as such may still be valuable for applying to different domains, especially if the uncertain factors that define the scenario axes are still significant, which was true for many of the applications of SRES. Therefore, if the scenarios are designed to be applied to multiple domains, and spatio-temporal scales, and direct policy analysis and decisions are less relevant, a scenario logic should be chosen that best supports this.

One of the challenges with a broader application of policy orientated frames outside of their intended, and designed for, application is that for effective application, they must be focussed at the appropriate area and scale of governance (Bryson et al., 2010). The policy options considered for the specific application under consideration relate to the governance scales appropriate for the problem being tackled. The policy options appropriate at one scale (geographical or governance) may not be the same as another, and as such there arises a conflict if policy framed scenarios are applied to different scales, where the options are no longer valid or outside of the original governance domain.

This is particularly true if the scenario process is driven by a participatory process, as stakeholders may not agree with the policy responses framing the scenarios being downscaled or applied to their problem context (as they may not be considered the main policy responses relevant to their context/scale). For example, there may exist a disconnect between what individuals and organisations can do at one scale, in comparison to what may be entirely appropriate at another governance or spatial scale, which might be the case for the mitigation of climate change, which, as a policy process that more commonly lies at the national and international scale, may prove difficult for local stakeholders to consider as the main driver for their scenarios (Lister, 2001; Urwin & Jordan, 2008). An approach to mitigate this may be to 'branch' scenarios as shown in Cairns et al. (2017) with locally focussed positive and negative scenarios fitting below alternate global scenarios. This is considered an approach for such policy orientated and framed scenarios to be developed under the influence of/nested within broader exploratory global/national scenarios.

5. Conclusions

This paper has proposed an approach to enhance the policy relevance of exploratory scenarios through specific consideration of their framing and the factors considered for temporal narrative development. This is achieved by exploring and categorising relevant policy options, and using these categorisations as the frame for the exploration of futures that present greater or smaller challenges to these policy categories. The scenarios themselves are developed by considering changes to factors found relevant to policy effectiveness, not factors that are considered to be the most uncertain (as is the case for traditional 2×2 scenario building approaches). In general this places the emphasis on exploring what future factors can impact on policy effectiveness, not only what could cause the greatest differences in future trends.

The approach was applied, for illustrative purposes, to consider natural disaster risk reduction in Greater Adelaide, Australia. This allowed for the participatory exploration of risk reduction options with the State Mitigation Advisory Group, a stakeholder group of civil servants, and emergency management professionals. This resulted in scenario frames of challenges to resilience (i.e. a community driven response to managing and minimising risk), and challenges to mitigation (i.e. where government led approaches of structural measures and restrictive policies are used to reduce risk). Five scenarios were developed within these framing axes based on factors considered relevant to either resilience or mitigation, including social cohesion, institutional culture and perceptions and governance structures. The developed scenarios explored concepts, themes and subsequent development trends that were found valuable for long-term policy development and analysis.

Subsequent work involves continued assessment of scenarios' use and impact in policy work by the stakeholder group and whether they were discussed in other contexts, outside of the scenario development process, by those involved. Future research should also consider how to best integrate exploratory scenarios, specifically designed for policy assessment, into policy development and impact assessment cycles. This could be supported by using combinatory activities such as the growing application of scenarios and serious gaming as described in Bontoux, Bengtsson, Rosa, and Sweeney, 2016, Sweeney (2017), and Valkering, van der Brugge, Offermans, Haasnoot, and Vreugdenhil, 2013, and with qualitative, quantitative approaches to scenario development (Alcamo, 2008; Kok & van Delden, 2009).

Design of participatory processes for eliciting the most valuable information from stakeholders, balancing strong opinions and reaching desired outcomes, is also an ongoing area of research, where facilitation is key to the success of any participatory scenario process. The approach introduced and applied to disaster risk reduction can also be applied to many other problems domains. Further application of the process would go towards standardising participatory processes, or determining which are most appropriate for the given context, to explore policy options, their relevant factors and develop exploratory scenarios with a greater utility for policy development and assessment.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.futures.2018.03.006.

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Appendix F – Greater Adelaide Scenarios Report

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FUTURES GREATER ADELAIDE 2050

An exploration of disaster risk and the future

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CONTENTS

INTRODUCTION

Better to build a fence at the top of a cliff, than park an ambulance at the bottom
Helen Clark – 2015 Sendai Conference on Disaster Risk Reduction

Natural disaster risk is a combination of the natural hazard[1], exposure[2] and vulnerability[3]. As a result when considering future disaster risk and planning to minimise it, the uncertainty and complexity of each factor must be considered. Influencing factors on the three components of risk include political decisions, economic development, technological advancement, demographic changes and changing climate, many of which are mutually influential as well. The uncertainty and complexity that arise from these factors are critical to understand when considering long term disaster risk reduction planning, especially when planning decisions can have long lasting influence and large expense.

In an attempt to characterise, understand and subsequently make better decisions under these conditions the BNHCRC funded project *"Decision Support System (DSS) for Assessment of Policy & Planning Investment Options for Optimal Natural Hazard Mitigation",* was initiated. For Greater Adelaide the project looks to develop an integrated spatial DSS to model long term changes in risk and subsequently assist decision makers plan and implement disaster risk reduction policies and investments. Incorporated with the development of the prototype software package is a facilitated stakeholder engagement process informing the development and then subsequent use of the system.

In September 2014 the first stage of this process was completed with results documented in Van Delden et al. (2015). The second phase, of which this report documents, incorporated the development of exploratory scenarios[4] to better understand relevant uncertainties, develop strategic capacity in decision makers to consider uncertainties impacting on policies and provide a better understanding of the value and use of the developed DSS.

The process looked to discover critical elements relevant to disaster risk reduction[5] and consider how they change into the future. As a method for exploring the future, scenarios were developed considering the changes from 2013 to 2050. Five alternate futures for Greater Adelaide were developed by members of SA's State Mitigation Advisory Group (SMAG), assisted by the scenarios team at the University of Adelaide and Research Institute for Knowledge Systems. These were subsequently modelled and results of the qualitative and quantitative scenarios will be presented in this report.

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[1] Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage. (UNISDR 2015)
[2] People, property, systems or other elements present in hazard zones that are thereby subjected to potential losses (UNISDR, 2009)
[3] The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UNISDR, 2009)
[4] Plausible descriptions of how the future might develop, as based on a coherent and internally consistent set of assumptions about the key relationships and driving forces (van Vuuren et. al., 2012).
[5] The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through the reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events. (UNISDR, 2009)

RESILIENCE

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

UNISDR 2015

Following the first stage of stakeholder engagement building resilience was considered as one main approach to managing and minimising disaster risk in Greater Adelaide. For the development of exploratory scenario factors, workshops participants were asked to answer the following two questions:

1. *What factors are relevant when creating and encouraging resilience for disaster risk reduction?*
2. *What would make these factors easy or difficult?*

In response to the first question participants offered four personal responses that were subsequently clustered together. These clustered responses are characterised below. In total 53 factors were noted across three break-out groups, which were clustered into 17 headings.

The five most prominent factors which were subsequently used in the scenario development process were:

- Available resources for action
- Stakeholder understanding and knowledge of hazard/risk
- Social cohesion
- Efficacious policy
- Infrastructure

Participants then discussed what would make these factors more or less difficult, and these discussions underpinned the scenario development.

MITIGATION

The lessening or limitation of the adverse impacts of hazards and related disasters.
UNISDR 2015

State funded mitigation activities were also considered as the main approach to minimising disaster risk, in collaboration with resilience. These two approaches can be considered top-down (mitigation) and bottom-up (resilience), and participants considered these effective methods for SA to manage disaster risk.

Again two questions were posed to participants:

1. *What factors are relevant when designing and/or implementing mitigation policies for disaster risk reduction?*
2. *What would make these factors easy or difficult?*

For question one, 47 responses were collected as being relevant factors for the design and implementation of mitigation policies. These were clustered into 15 groups and again are characterised by the below figure.

The five most prominent factors for effective mitigation policies are listed below. These factors were carried through to construct futures that would be either easy or hard to design and implement mitigation policies under.

- Data and knowledge
- Governance structures
- Holistic policies
- Institutional culture and perception
- Cost benefit considerations

Participants then discussed what would make these factors easier or more difficult and this fed into the developed visions.

SCENARIOS

Imagination is more important than knowledge Albert Einstein

The purpose of scenarios are to explore plausible pathways into the future. The future is a volatile, uncertain, ambiguous and complex place, but decisions and policies need to be implemented. Through a series of workshop these factors were explored with members of the State Mitigation Advisory Group (SMAG). Uncertainties and drivers were considered which resulted in five alternative futures for the City.

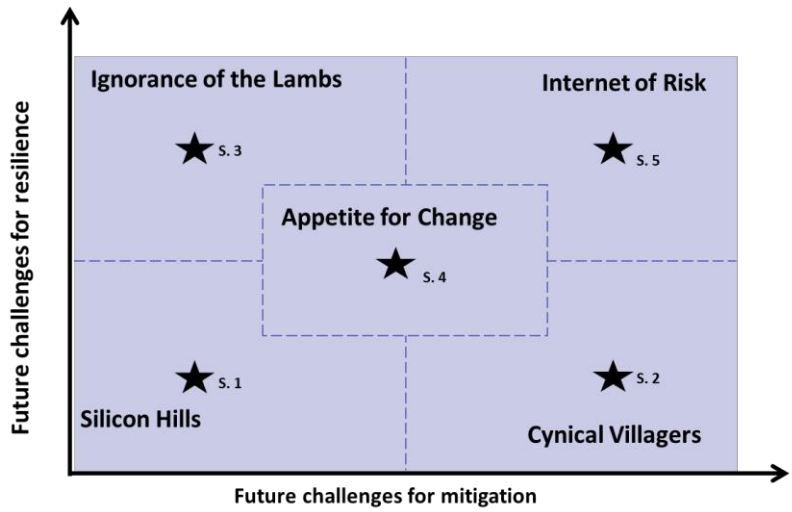
Exploratory scenarios offer rich, qualitative and quantitative descriptions of a future world state and look to incorporate assumptions for alternate world views (Rounsevell and Metzger, 2010). These assumptions can involve diverse ideas and opinions. The construction of exploratory storylines allows for the consideration of future, uncertain drivers by asking, "what can happen?" (Börjeson et al., 2006). This exploration of uncertain change in drivers can allow decision makers to test policy options in alternate, but plausible, future conditions.

By developing these scenarios with a diverse range of influencers and decision makers ambiguity can be challenged by encapsulating alternate worldviews and minimize it through facilitated discussion. Complexity is addressed by incorporating mental models of domain experts and stakeholders to identify causal relationships that could be difficult to ascertain from a purely scientific base, into a model framework. The increased creativity that is possible through participatory workshops and scenarios can also often lead to an increased understanding of the subtleties within the influence of social, economic and environmental drivers (Kok et al., 2011).

The scenarios developed for Greater Adelaide focused on two axes considering resilience and mitigation and the State's ability to reduce disaster risk. By focusing on these axes scenarios for the future were created to explore what would challenge the effectiveness of policies.

These scenarios and the development process had aims to:

1. To develop policy relevant scenarios capable of testing the efficacy of proposed policies, and to be used in the design of efficacious policies (either robust, adaptive or flexible).
2. Allow for social capital to be grown with participants and increasing strategic capacity in decision makers when consider policy alternatives and uncertain futures.
3. Allow for an understanding of difficult futures for decision makers to operate in and subsequently allow for an understanding of how to avoid this and catalyse action against these futures, if within the influence of participants and their networks.



Silicon Hills

Low challenges to mitigation and resilience

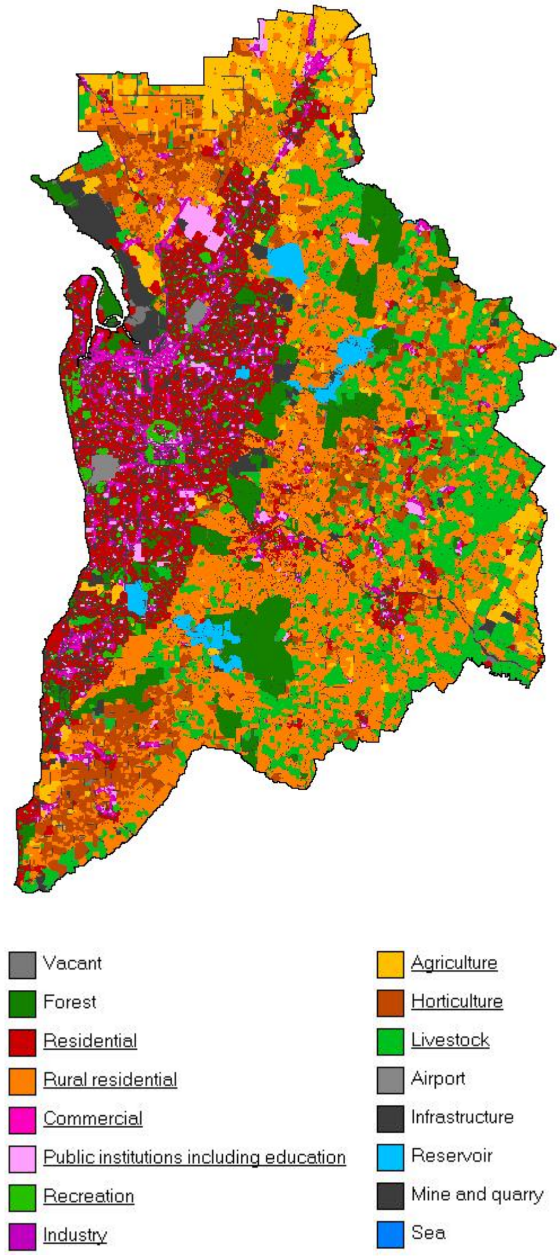
Greater Adelaide transitions towards a well-balanced technology focussed economy, driven by highly skilled and engaged locals and expatriates as well as immigrants looking to capitalise on the State's booming high-tech industry while enjoying the relaxed, nature filled lifestyle the Mt Lofty Ranges and Adelaide Hills offer.

The emphasis on enjoying and connecting with nature ensures well-maintained areas of local significance along with increased understanding and subsequent reduction of human impacts on the landscape. The focus on technology also sees an increase in localised industrial and commercial zones along with a growing service based economy, providing the convenience of a global city with the relaxed lifestyle of Adelaide.

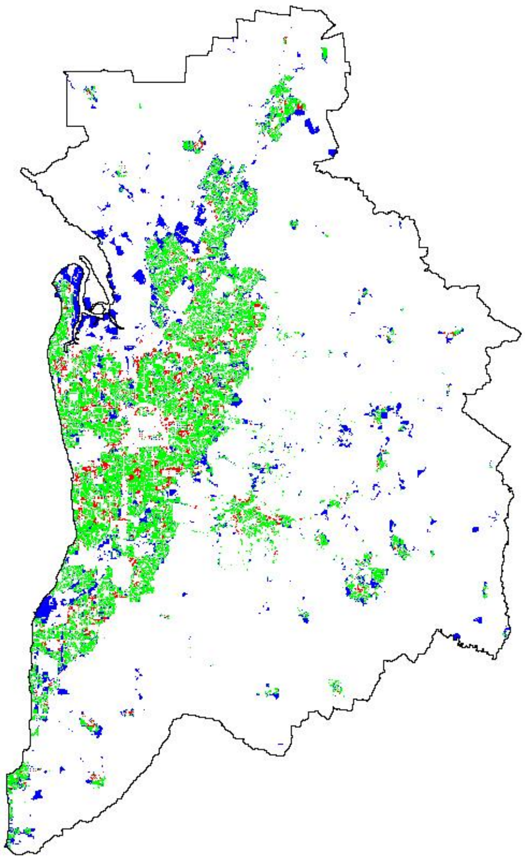
Greater Adelaide continues to be a place of high multi-culturalism, with new residents that have an appreciation of the land and are active in their pursuit of greater understanding and protection of nature. This leads to a focus on nature-based solutions to natural hazards, and a planning system focussed on understanding the risks prior to development. Community togetherness grows with new technology firms allowing employees the flexibility to engage in many activities outside the office.

The increased wealth within society allows for a greater emphasis on diverse urban form and development, and with improvement in construction technology, new buildings and infrastructure are becoming less and less vulnerable to multiple hazards.

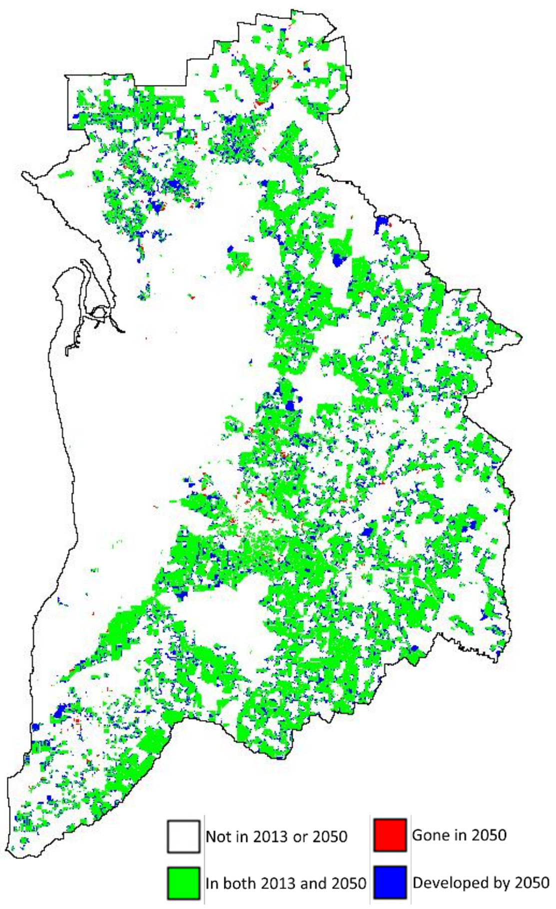
LAND USE - 2050



RESIDENTIAL LAND



RURAL RESIDENTIAL LAND USE



MOTIVATING FACTORS

A growing global valuation of the environment coupled with Adelaide's low cost of living with high amenity value sees an increase in immigrants with skills in technology, innovation and research & development. This leads to a shift in the economy stimulating high tech developments and a move away from low value industries. The international, highly-skilled work force facilitates global trade and awareness of and preparedness for global change. The wealth of the society in combination with their awareness of risks opens the road to effective mitigation in conjunction with enhanced community resilience, in line with global efforts for positive adaptation to climate change.

POPULATION & URBANISATION

With the increased emphasis on technology and increasing international standing of local universities and start-up companies, skilled, highly educated immigrants look to Adelaide as an innovative city and a gateway into Asian markets yet still with Australia's strict commercial protection laws. This sees a growing population with immigration from Europe and the Americas, along with increasing Asian student numbers who look to settle in Adelaide after graduation. There is a government emphasis to design new residential developments to incorporate greenspace and the latest in urban design as well as considering the hazard risk in initial developments due to the increasing environmental awareness of residents. These developments lead to an increase in higher density city living, due to Adelaide CBD's close links to green areas and the beach, along with further developments in the Adelaide Hills facilitating a 'tree-change'.

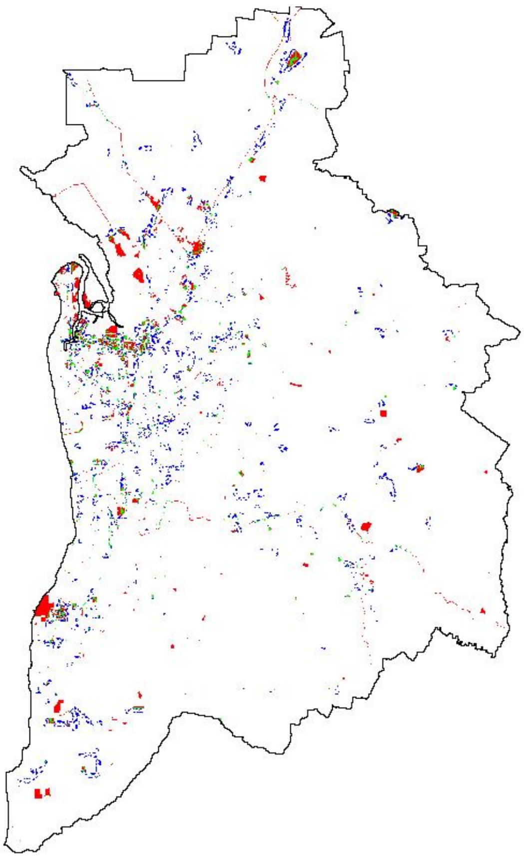
COMMUNITY PROFILE

Greater Adelaide's multi-cultural community continues to grow in diversity but due to an increased will to integrate, driven by environmental awareness and the desire to be part of the community, vulnerability in new immigrants is low. The desire to integrate, along with increased government revenue, results in a rising enrolment and investment in public schools. This reduces inequality between those not capitalising as easily in the technology industries and provides increased local knowledge throughout the community including the immigrant population.

ECONOMY & LIFESTYLE

Over the next 15 years small investments in tech start-ups and innovative activities focussed on small scale, advanced manufacturing begin to take effect, leading to increased innovation in both the services and commercial sectors. Several 'tech-hubs' take form, focussing industrial and commercial industries in high intensity areas. With the initial investments seeding the industry, coupled with the increased human capacity due to skilled immigration, an economy focussed on innovation and technology takes grip and sees income levels and government revenues grow as Adelaide becomes a central technology centre in the Asia Pacific region, and increasingly influential globally. Coupled with increasing research funding and growing service economy in support of high end technology, SA's economy is positioning itself as one of the fastest growing in Australia.

INDUSTRIAL LAND USE



POLITICS & INSTITUTIONS

With growing immigration and an increasing interest in planning and SA's future there is a slowly changing mentality in the community around government intervention. State government policies grow in influence through an emphasis on community consultation and stakeholder engagement together with the rising awareness that government intervention is required to deal with increasing risk of hazards. This results in regulations becoming more effective and easily implemented, and an emphasis on risk based land use planning.

TECHNOLOGY & INFRASTRUCTURE

The emphasis on harnessing technology for good grips the state and several entrepreneurial efforts prove to have significant benefits for the minimisation of risk. Mostly this lies in reducing the vulnerability of residents with immersive technologies used for education programs as to how to respond to a hazard event and also what safe communities should look like. Virtual experience centres enlarge the community's hazard preparedness as they simulate the hazard experience and coping strategies. Globally there is an effort being made around early warning systems and sensors for many hazards, particularly bushfire, earthquake and flood. This global interest coupled with the hazards present in the region and booming tech-industry results in the city becoming a global expert in knowledge and technology for risk reduction. Greater Adelaide also capitalises on efforts made in 2015-2020 in turning the city into a 'smart-city' to greatly improve its data collection and analysis capabilities which allow for a much more evidence based, and adaptive planning system.

Cynical Villagers

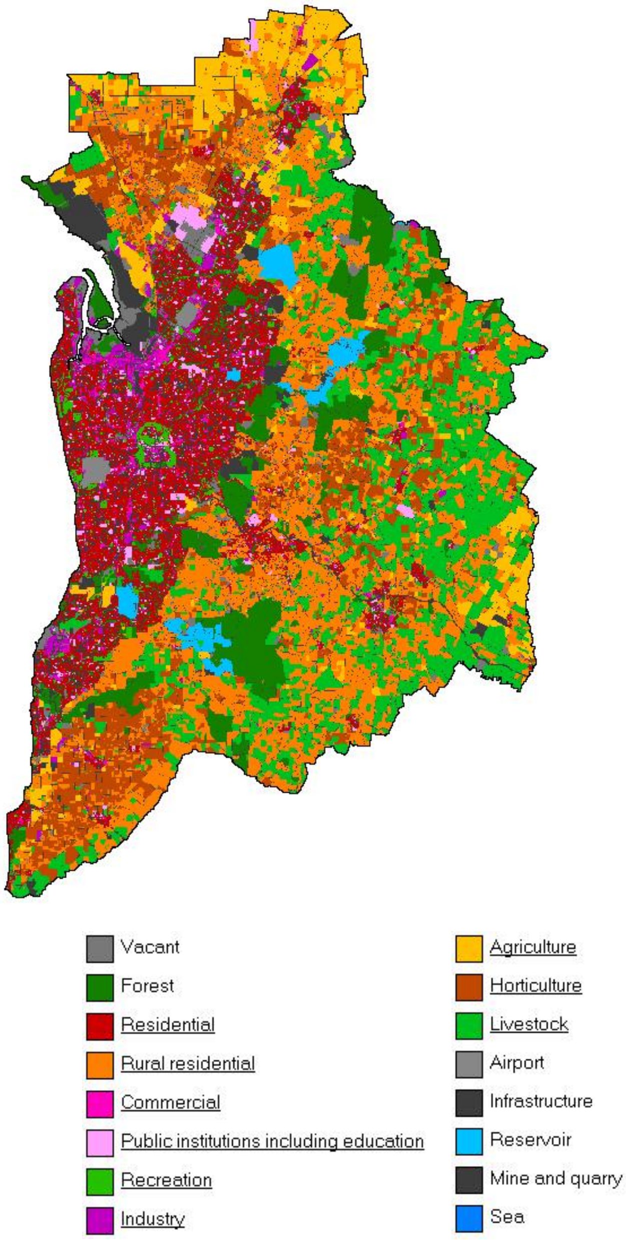
Low challenges to resilience. High challenges to mitigation

A growing amount of rural residential developments, coupled with low population growth sees Greater Adelaide increasingly suffering from urban sprawl. This sprawl is due to shifting population dynamics with an increase in lower-middle income groups and hence a drive for affordable homes and an ageing population looking to the hills for retirement.

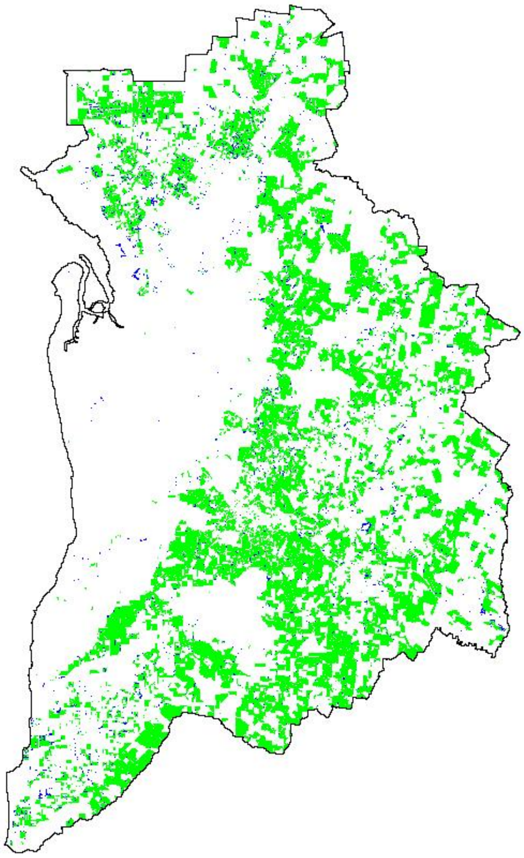
The landscape is a mixture of low density rural residential, natural vegetation and agricultural plots. There is a strong community preference for protection of the state's areas of environmental significance, a growing environmental consciousness and appreciation of the landscape's amenity value. The interest in nature and the countryside leads to high levels of local knowledge regarding the risks from the landscape however this is still unequal, with less connected and more vulnerable communities still finding it difficult to build self-sufficiency.

Economically, mining has taken a downturn with no other sector replacing its activity, and with the relatively small workforce an insular economy based on small scale agriculture and commercial industries is predominant in SA, making government revenue difficult. Due to restrictions in government revenue raising, and hence spending, there is a low emphasis on innovation and science and with greater online, public data availability government is further hamstrung by empowered citizens challenging government intervention with a NIMBY mentality. This is supported by data and a desire to challenge in the courts.

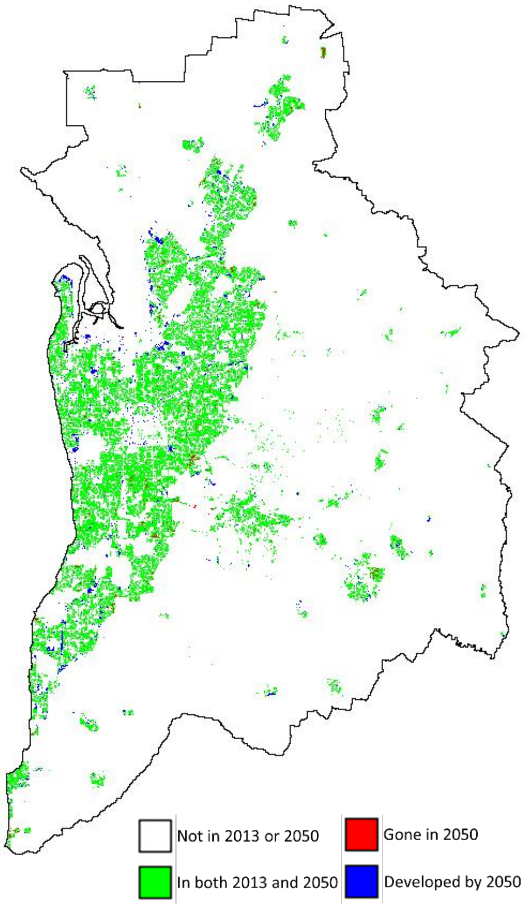
LAND USE - 2050



RESIDENTIAL LAND



RURAL RESIDENTIAL LAND USE



MOTIVATING FACTORS

With the downturn of the mining activity and an ageing population, Greater Adelaide experiences a shift towards a more nature based and high quality agricultural society, keen on living in the outer areas and hills and knowledgeable and protective about its land, the property on it, its surroundings and the local community. Local resilience flourishes driven by the availability of good quality data on the internet. Not all communities however have the same capacity to build resilience and there are have's and have not's in respect to hazard resilience. The wealth of information empowers the community and strengths their resilience, but also impacts on them challenging government with many court cases paralysing policy development and implementation.

POPULATION & URBANISATION

Greater Adelaide sees a slowing in population growth, particularly regarding the immigration of younger, skilled workers. Instead the steadily ageing population, full of baby-boomers, spreads out from Adelaide further, searching for their block of land. Urban sprawl grows particularly through an increase of rural residential developments. This results in a growing patchwork of homes throughout the Adelaide Hills interwoven with small agricultural and wooded blocks increasing the hazard interface to a significant extent. Although the population grows to be more resilient during the first decades of the scenario, this resilience declines with the increasingly ageing population, still living in the countryside, but no longer able to manage hazards at crunch time.

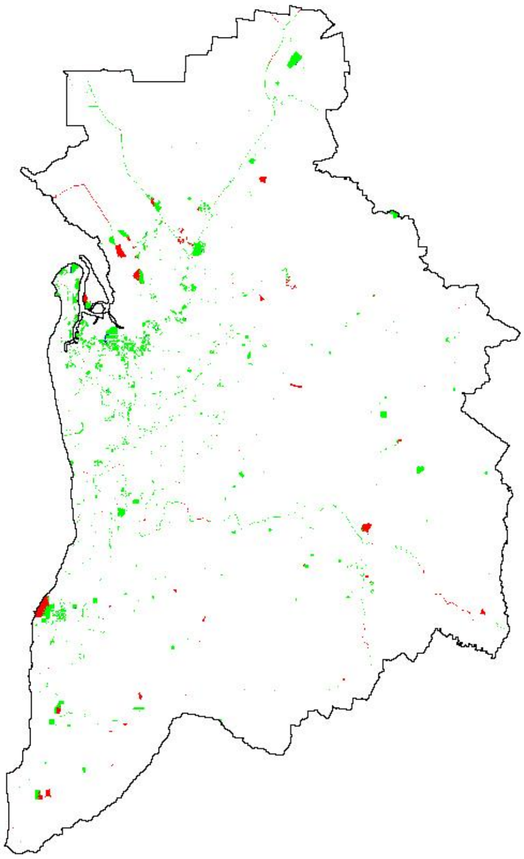
COMMUNITY PROFILE

The growing rural residential lifestyle results in increased local understanding, especially of nature, its value and its risks. However this understanding is highly localised and often misses larger scale concepts. Due to low economic returns and the highly inward looking economy there is a growth of the lower middle income groups. This has impacts on community dynamics with some communities with greater community engagement, skills and disposable resources able to organise and manage themselves, while others are left behind, generally those with less financial flexibility, the elderly or those less socially connected.

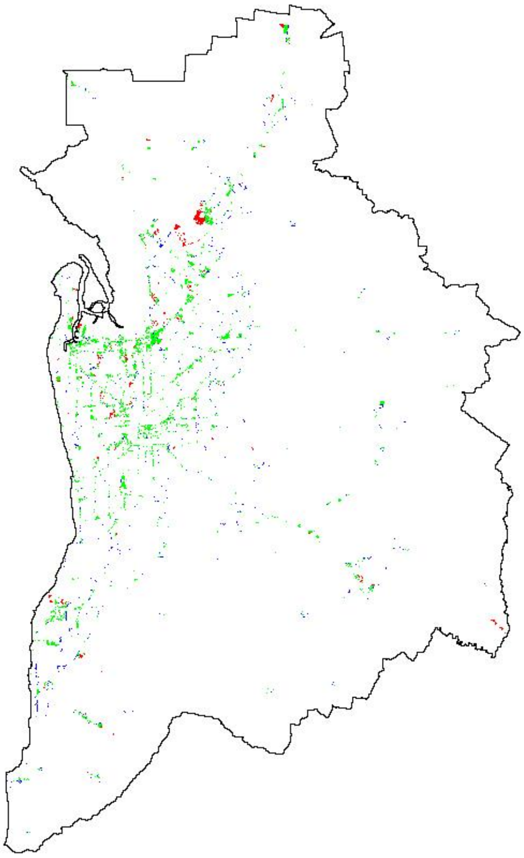
ECONOMY & LIFESTYLE

South Australia steadily sees the downturn in manufacturing and mining and the subsequent impact of reducing revenue to State Government coffers. In general there is no replacement activity to the same scale and instead the economy looks local with an increase in commercial and agricultural sectors. SA's economy also reduces its export capacity due to a smaller workforce, and as such becomes much more tuned to being self-sufficient. This builds resilience in the economy by stripping it to the State's requirements, however it significantly reduces the capacity for revenue raising for capital intensive projects.

INDUSTRIAL LAND



COMMERCIAL LAND USE



POLITICS & INSTITUTIONS

Tight knit local communities, protective over their property and individual freedom, see the government severely restricted in the development and implementation of policy. Community opposition is rife to central government decision making if it is seen to impose on the rights and freedoms of an individual. Growing availability of information and access of it through the internet empowers the population. Court cases to 'fight for one's rights are ominous, paralysing government to implement broader scale mitigation options as well as zoning regulations to avoid development in hazard-prone areas. Government paralysis is further compounded by its lessening revenue, particularly for capital intensive investment, and instead revenue is going increasingly into health and aged-care.

TECHNOLOGY & INFRASTRUCTURE

The world and SA is data rich but information poor. The people are empowered by access to data, allowing them to confirm anything they need confirmed regarding their small block of land or their community at the click of a button. This however sees community groups increasingly capable of challenging government and business in court. There is also a decline in innovation, and investment in science and research in SA, as it experiences a return to cottage-industries.

Ignorance of the Lambs

High challenges to resilience. Low challenges to mitigation

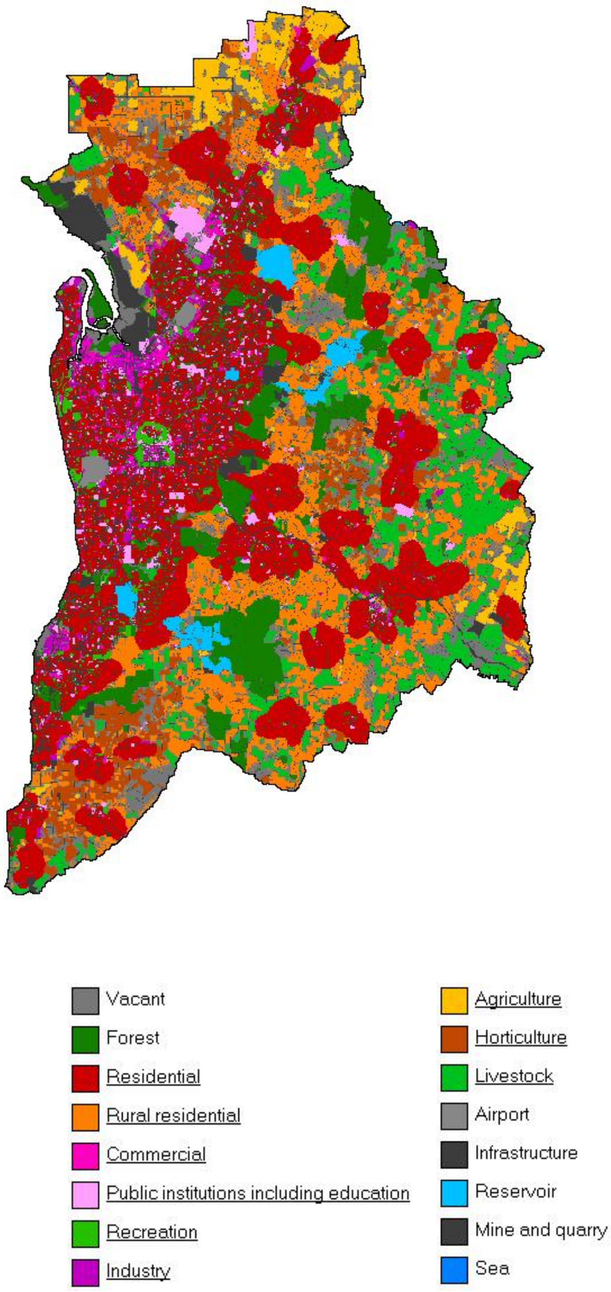
Greater Adelaide shifts towards an increasingly commuter lifestyle in the pursuit of lower cost housing. The region experiences a decline in rural living, with a shift towards highly urbanised centres throughout the region and lengthening of commute times between residential centres and places of work.

Population growth is high with increased immigration from migrants seeking a safe-haven in Australia from various global issues both climatic and socio-economic. This results in increasing community vulnerability and heavy reliance on government for both social and hazard-related support.

Due to the rising costs of risk mitigation, the Federal Government plays an increasingly important role eventually resulting in the loss of state-based policy, with the State Government becoming more of a service provider than a policy maker.

Coinciding with this is the loss of the manufacturing industry, and subsequent economic decline in the region. Because of this unemployment grows, adding to the need for Federal Government support, while those who can leave to work on the Eastern seaboard or overseas do so. However, they face challenges selling their properties with the immigrant population having a preference for cheap new builds in commuter suburbs rather than the more expensive inner suburbs.

LAND USE - 2050



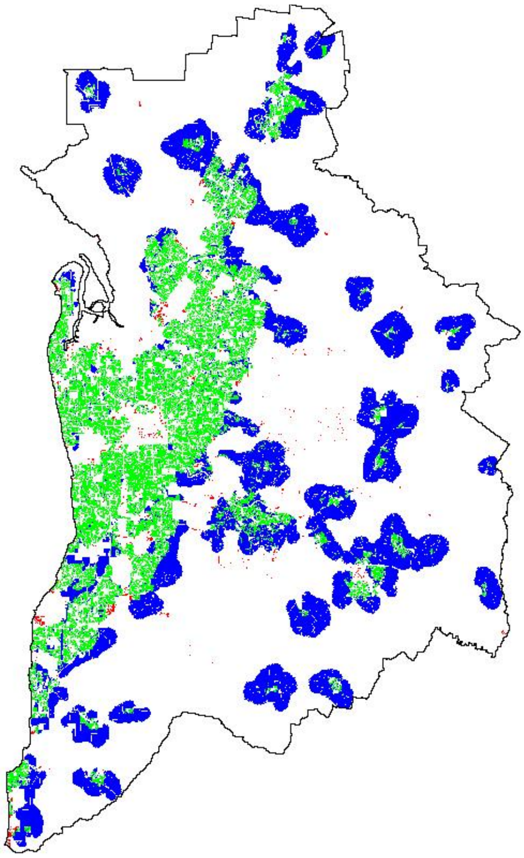
MOTIVATING FACTORS

Changes in community profile due to large immigration with Greater Adelaide becoming a refuge for people around the world, decreases the population's resilience, requiring a stronger role from government to protect its citizens. Due to the economic down-turn and increasing mitigation spending, federal government's role increases with the influence of the state diminishing. There is an acceptance of top-down mitigation, but due to limited finances only so much can be done. The population feels secure but reality creeps up on them when top-down mitigation is no longer able to protect them when severe hazards strike. The well-educated and 'old money' groups move to the east coast but with declining house prices in the State many are left on the market for extended periods as they are beyond the budget range of the immigrants and cannot easily be sold.

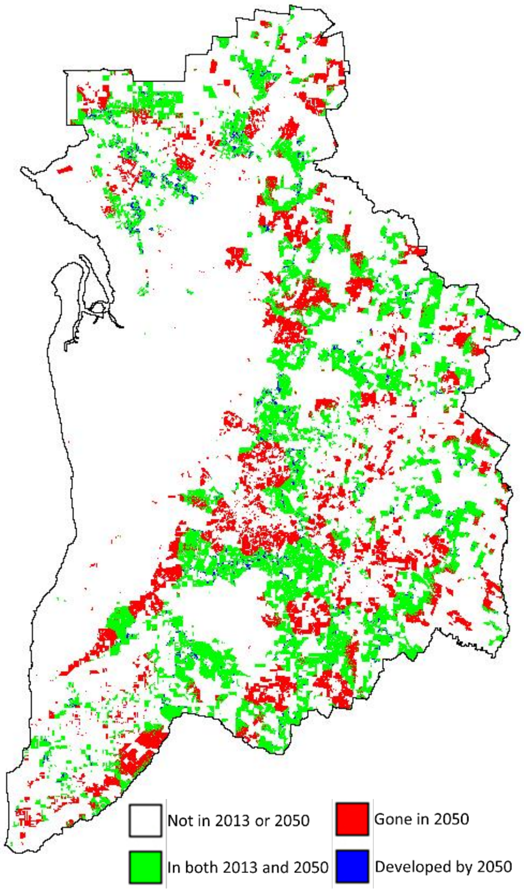
POPULATION & URBANISATION

SA's population is growing over the next 10 years, through increasing immigration from the Asian-Pacific region looking to capture some of the nation's prosperity in comparison to stagnating developing economies. There is also a growing refugee community from various conflict zones around the world. Rural residential communities slowly begin to disappear as new immigrants look for new, low cost developments. These urban centres are generally developed in the lowest cost land, far from the CBD and other centres of employment, in the Adelaide Hills, and Southern and Northern Plains. This leads to a focus on infrastructure corridors, allowing commuter suburbs to grow further and further from the CBD. This development pattern is precipitated by a lack of local and state-based planning regulations and more direction of a distant Commonwealth Government, which early in the scenario sees standard and enforced planning regulations, while this changes in the subsequent years as revenue demands overrule planning.

RESIDENTIAL LAND USE



RURAL RESIDENTIAL LAND USE



COMMUNITY PROFILE

Work-life balance pressures and the increasing distance from work to home places pressures on communities. There is a decline in local knowledge, understanding of the area and community connectedness. The region's demographic profile also shifts with Adelaide increasingly known for its low cost of living. Skilled workers see the struggles Adelaide is under with changing social and urban fabrics and look to move to the Eastern seaboard for greater employment opportunities. There is however minimal opportunity for the sale of their properties with many leaving inner suburban homes empty as they move East.

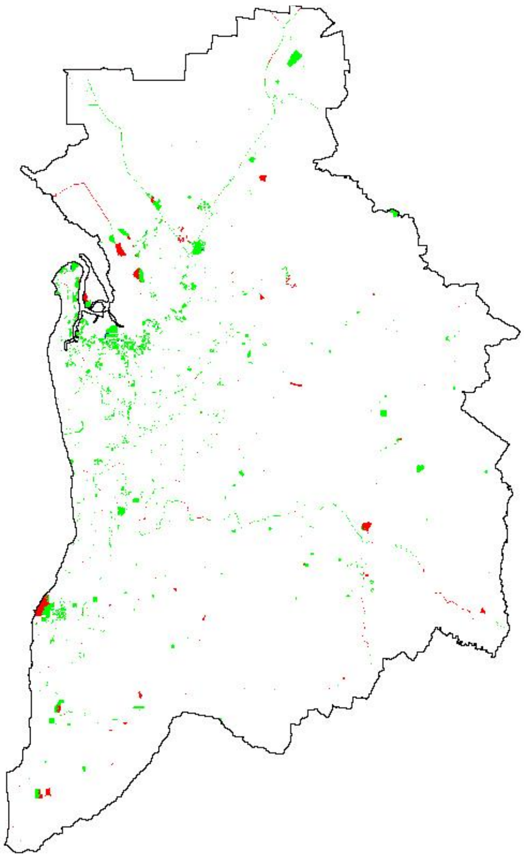
ECONOMY & LIFESTYLE

The region is under growing pressure due to the sudden collapse of the manufacturing industry and few options for transition industries. This results in growing unemployment and increased reliance on the government for social support. Those who have the capacity and ability to leave for work do so. This begins with an increasing fly in/fly out lifestyle for professionals working east, but subsequently turns to many moving permanently to the growing metropoles in Melbourne, Sydney and Brisbane. Growing unemployment also sees a more disengaged youth and increasing crime rates, especially in outer, commuter suburbs.

POLITICS & INSTITUTIONS

The economic climate for SA, and increased emphasis on large infrastructure projects sees the Commonwealth growing in influence due to its capacity to fund. There is every-growing social reliance on the Commonwealth. The State increasingly becomes a service provider for the Commonwealth and has significantly less influence and decision-making ability. Local governments are also removed from many planning and mitigation activities, eventually they reason that if they have no resources to fund activities what is the purpose in researching and considering them?

INDUSTRIAL LAND USE



TECHNOLOGY & INFRASTRUCTURE

Infrastructure solutions are seen as the most effective, with urban centres in at risk areas seeing significant structural mitigation measures put in place by the Commonwealth. In an attempt to raise capital the State begins to privatise infrastructure over the next 20 years. However with the increasingly dire economic circumstances of the region's residents, private entities experience less and less profit and subsequently reduced expenditure on maintenance. From 2035 onwards the state begins to inherit poorly-maintained infrastructure networks with massive costs to the public purse.

Appetite for Change

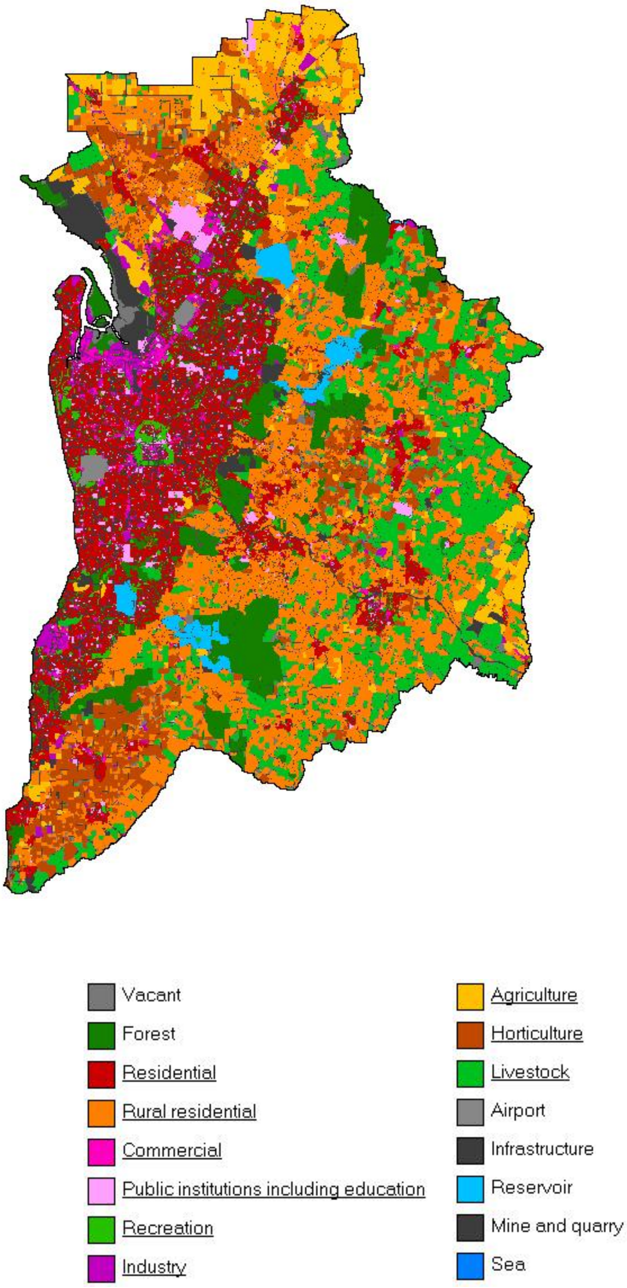
Moderate challenges to resilience and mitigation

Greater Adelaide continues on its current trajectory with declining manufacturing and slow population growth. In contrast to the decline in manufacturing, a rise of low value mining and an expansion of agricultural sectors over the next fifteen years leads to a slight expansion of rural residential areas and an increase in urban infill and sprawl around the fringes following the Greater Adelaide Plan.

This places increased pressure on urban drainage, not designed to meet the increasing stresses of urbanisation, and therefore increasing flooding. Property developers hold significant influence in terms of new development locations with an emphasis on profit not planning.

However with the increasingly apparent impacts of climate related hazards both globally and at home, a swelling in community awareness of risks sees the government become more empowered and enabled to set policy directions and fund some mitigation activities without voter disproval. This is catalysed by an accumulation of events impacting on both urban centres with the CBD suffering from drainage issues during intense rainfall events, and rural areas experiencing several significant bushfires in the Mt Lofty Ranges. This leads to improved risk governance structures and growing resilience to known and expected hazards in the later years of the scenario.

LAND USE - 2050



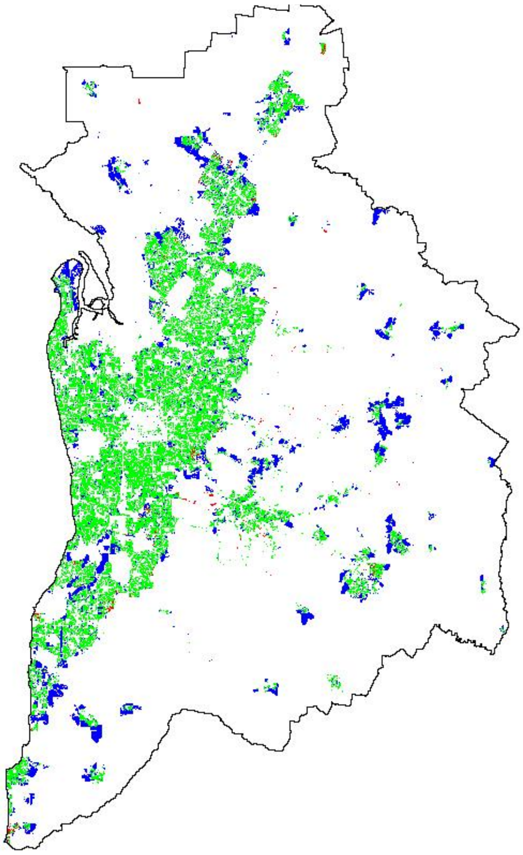
MOTIVATING FACTORS

The current projections hold steady, however, part way through a series of hazard events leads to an increased community awareness of the hazard risk. A change of behaviour occurs a few years later following on from the occurrence of a combination of hazard events. The realisation that large events cannot solely be dealt with through community preparedness and resilience and that top-down mitigation should be part of the equation too, leads to the subsequent acceptance of government intervention.

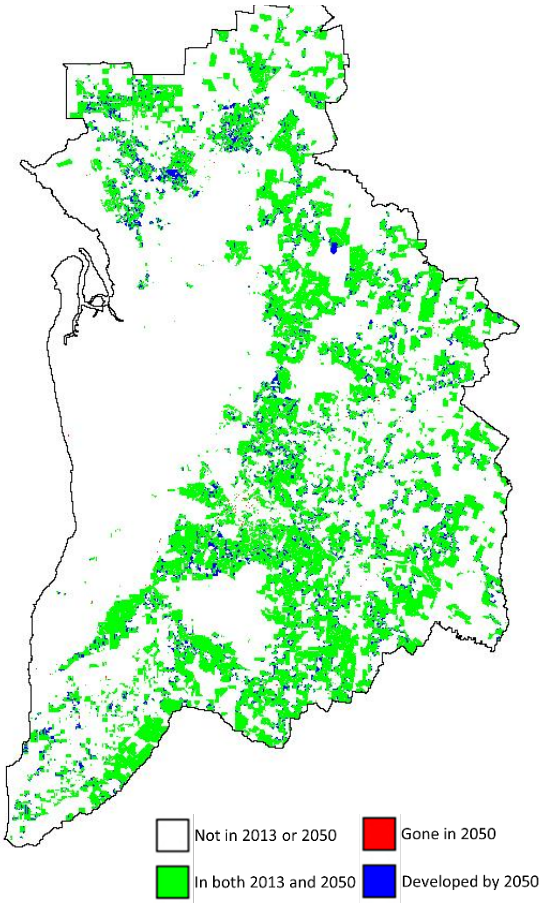
POPULATION & URBANISATION

Population trends progress as expected, following the medium projection scenario for Greater Adelaide. In general development follows the 30 Year plan with an emphasis on infill within the outer suburbs and low expansion into rural residential areas. New developments are left in the domain of developers with a greater importance placed on revenue than risk based planning. This begins to change with greater community awareness of risk, especially of coastal hazards, which has had the most prominent impact globally due to climate change.

RESIDENTIAL LAND USE



RURAL RESIDENTIAL LAND USE



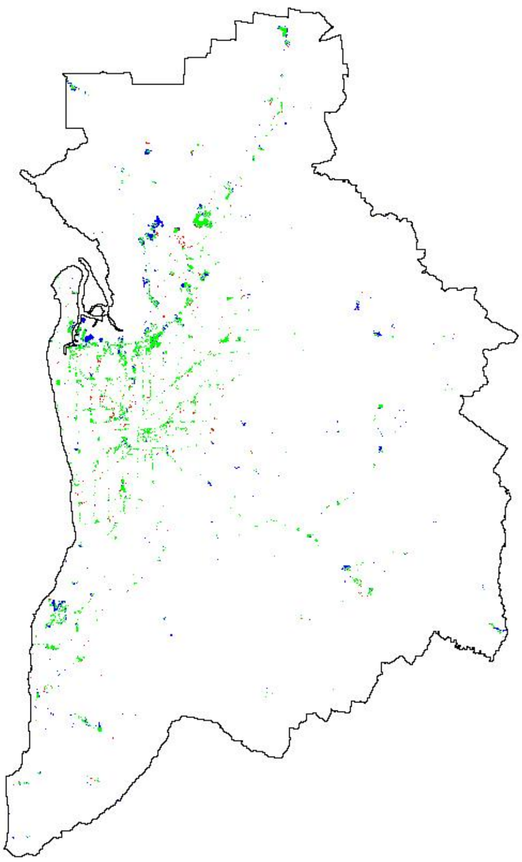
COMMUNITY PROFILE

The mix of socio-economic status from those who successfully transition between industrial sectors to those left behind sees variation in community structure and strength. Some communities experience a tightening with growing resilience to known hazards (both in type and magnitude), however others become more disparate. Not all individuals and households have the capacities to self-sustain while the communities that do, due to increased financial certainty, still remain unaware to the full range of events that could occur.

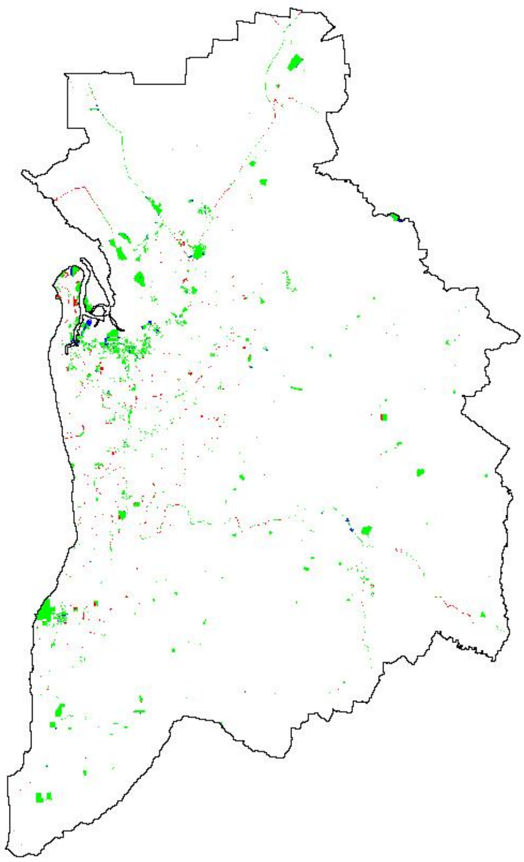
ECONOMY & LIFESTYLE

The economy of Greater Adelaide experiences a transition from capitalising on manufacturing, which suffers a rapid collapse over the next five years and mining which is used as a partial transition industry over fifteen years, to a world increasingly more aware of the environmental impacts of fossil fuels and the subsequent fall in their price. For Greater Adelaide this results in an increase in agriculture in the peri-urban area as it looks to position itself as a global food source especially to growing markets in Asia Pacific with a flavour for high quality South Australian produce. In conjunction with this professional services and commercial enterprises have remained stable shifting their focus from manufacturing to agriculture, with a marked increase in the healthcare profession meeting the challenges of an ageing population.

COMMERCIAL LAND USE



INDUSTRIAL LAND USE



POLITICS & INSTITUTIONS

The shifting economy and initial lack of obvious foresight and planning by government sees an era of mistrust and disillusionment grow. There is a greater emphasis on individual rights and responsibilities with most residents developing local level resilience to known events (in type and magnitude). However as events grow in impact, the realisation comes that individual resilience is not sufficient and government is given more flexibility and allowance to develop and implement risk mitigation policies. This is particularly true in structural measures for riverine and coastal flooding, along with land management for bushfire risk which was previously not in line with community expectations. Governance issues across all hazards also improve, and as government is restricted in size by revenue, it approaches risk management in a more integrated, all of government approach.

TECHNOLOGY & INFRASTRUCTURE

Urban infrastructure is increasingly put under pressure with increasing rates of infill stretching, in particular urban drainage, in its capacity to serve the public's function. Due to the loss of manufacturing industry the state also loses significant expertise in STEM related areas. There is however a small resurgence with the shift to agriculture as SA is seen as a leader globally in quality agricultural practices. There is also interest in exporting this knowledge around the world, especially the growing skills in agriculture in a semi-arid (increasingly arid) landscape, developing and implementing innovative renewable energy and irrigation techniques to maintain productivity.

Internet of Risk

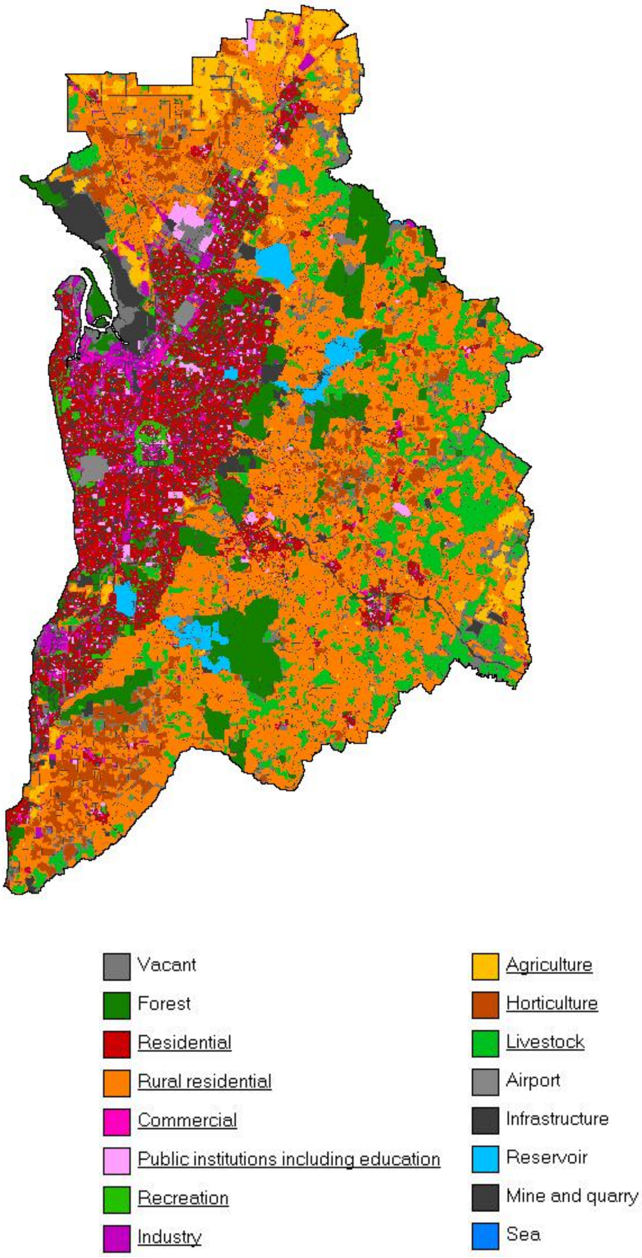
High challenges to resilience. High challenges to mitigation

Global connectedness drives an increasing reliance on the internet for social interaction and working styles. This reliance on the World Wide Web sees dispersed residential living as the attraction of the CBD and physical centres lessens, leading to a significant loss of physical connectedness and an increase in siloed communication between similar individuals and services by a small, but growing, services sector providing for the hordes of online workers.

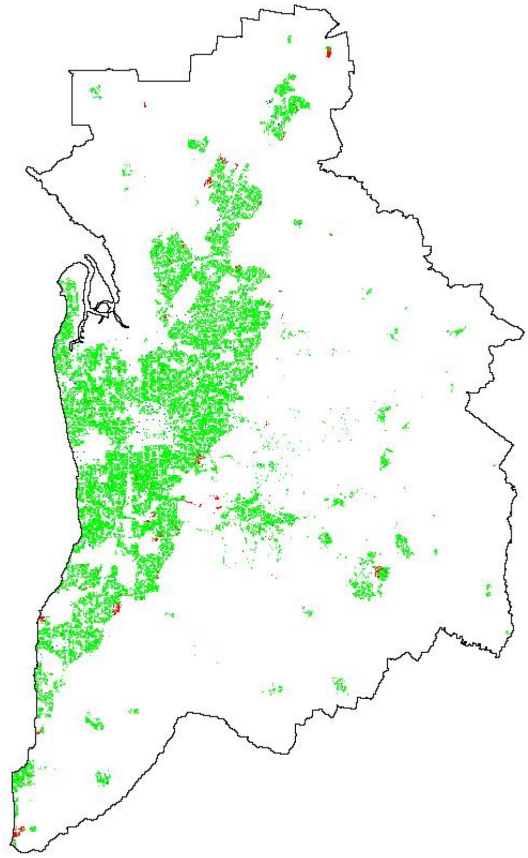
The majority of workers use the internet to work across the world, placing pressure on government revenue streams. Governments are struggling to re-adjust from revenue collection from the traditional economy which is slowly dying off with a loss of industrial and commercial sectors. This loss of revenue weakens institutional power, and the easy access to information is making a generation of 'Google Experts' who increasingly become more reluctant to accept government intervention.

There is also growing inequality between those capitalising on the global technology markets and those in service roles, who find themselves increasingly reliant on a government with increasing costs and decreasing ability to raise funds.

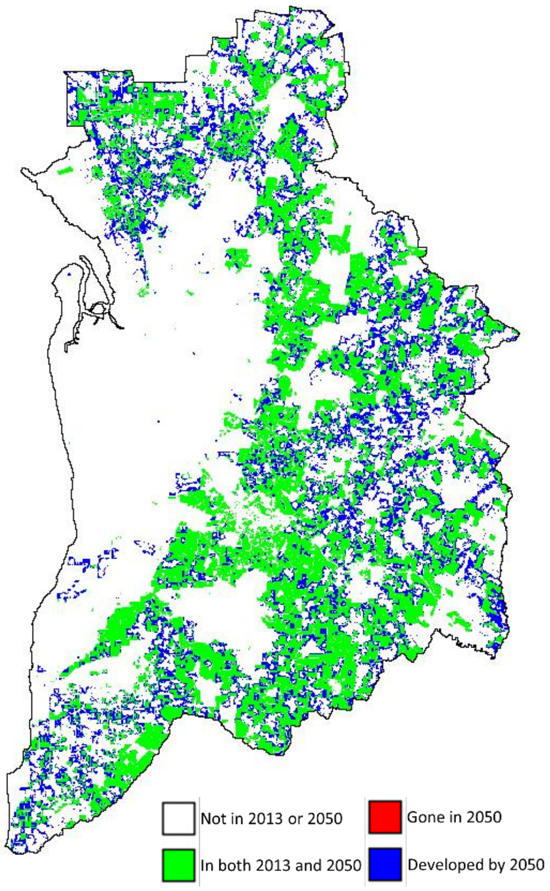
LAND USE - 2050



RESIDENTIAL LAND



RURAL RESIDENTIAL LAND USE



MOTIVATING FACTORS

The increasing reliance on the internet for social and work-related activities decreases the community connectedness and hence resilience due to the focus on global instead of local networks. The ability to search the net empowers the population, but without knowledge of the local conditions and communities it doesn't build the required understanding and awareness to deal with actual hazards. The understanding of theory rather than practice together with the feeling of empowerment leads to a reluctance to accept government intervention by the 'haves', while government funding is not sufficient to adequately support the 'have-nots'. Moreover the lack of resources in conjunction with an increase in hazard events limits the government's ability to put effective mitigation strategies in place.

POPULATION & URBANISATION

Population growth is low before stagnating in 2030-2040 due to low immigration and migration from SA by those who have the skills and capacity to do so. The urban landscape is also increasingly placed under pressure due to dispersed residential living with low levels of strategic planning and allocation of land for development. There are low levels of new urban development outside of residential, with demand for industrial sites reducing significantly post 2020, and commercial sites falling after that.

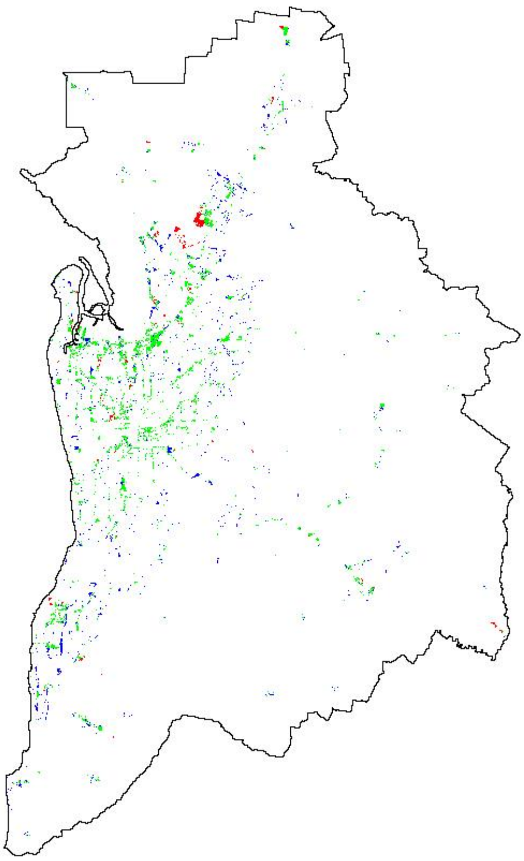
COMMUNITY PROFILE

Inequality is rife in the region post 2035 after steadily growing differences in individual's ability to work. Those trapped in traditional economies of manufacturing fail to transition to the new technology focussed economy, and with little re-training support from the State Government find themselves struggling to find work and requiring financial support. Their notion about risk is very limited as is their faith in being able to change any course of action. Those that were able to capitalise on the global technology markets however find themselves growing increasingly well-off. There is a growing arrogance with regards to the government, thereby limiting the acceptance of any top-down strategies. The digitalisation of the workplace makes the need to interact with local community obsolete and not knowing ones neighbours decreases the resilience of the community. The detachment from the land is an aggravating factor to this.

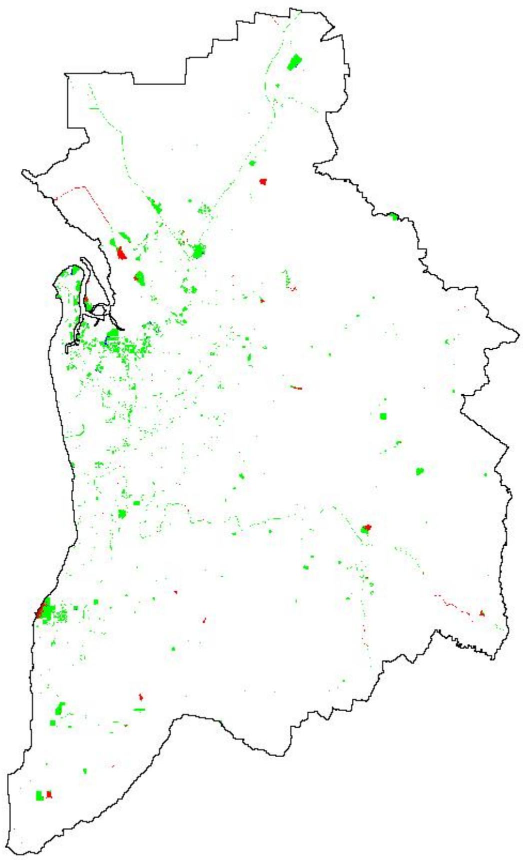
ECONOMY & LIFESTYLE

South Australia's economy is greatly impacted by the prevalence of technology and the ability to work anywhere in the world from the comfort of your own home and laptop. There is significant loss in intensive industry and commercial sectors. This leads to significant inequality between those capable of working within an economy centred on software development and other digital services provided through the web and those unable to sufficiently retrain post the decline of traditional sectors. Due to the large amount of free enterprise in the online economy, governments struggle for revenue raising as individuals work for multiple clients in a largely unregulated system. There is a small service sector that provides support services to those capitalising on the tech-economy including healthcare, education and personal services.

COMMERCIAL LAND USE



INDUSTRIAL LAND USE



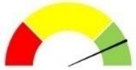
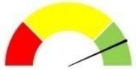
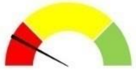
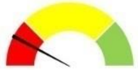
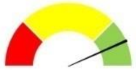
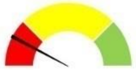
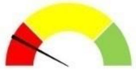
POLITICS & INSTITUTIONS

Institutions within State Government struggle for effectiveness as revenue tightens. Society as a whole also begins to become less engaged with politics particularly at a State level as their interests and investments lie overseas. Governance issues are rife, most residing within central government agencies which feel their influence becoming less and less. This filters throughout the public service with an increasing emphasis on centralisation and 'small-government'. This also results in increasing privatisation of government services, as the State looks to raise capital. Private developers rule the landscape as government cannot resist their pressure to buy and develop pristine or hazard-prone locations. The ability for citizens to access immense amounts of information online, allows for continued opposition to government policies, resulting in political disengagement by the community. Residents of Greater Adelaide instead increasingly become individualistic with little concern for governance and society as a whole.

TECHNOLOGY & INFRASTRUCTURE

Technology in Greater Adelaide is booming in a backyard sense. Every home is increasingly wired into the web, however State owned infrastructure is creaking under the strain of disperse residential centres and a limited ability to undertake maintenance leading to an increasing risk of infrastructure failure impacting on prevention (e.g. levies, sea walls) as well as the suppression capabilities (roads, bridges, etc.). With the increased emphasis on online connectedness, community centres are also placed under pressure as they grow ever more redundant.

Main scenario drivers and outcomes

	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
Population in 2050	1.9 M	1.5 M	2.5 M	1.8 M	1.5 M
Economy					
Community resilience					
Building stock resilience					
Residential land use developments	*Gradual growth urban and rural areas*	*Large increase in rural residential, mixed with other land uses*	*Residential commuter communities in the hills*	*Infill, some sprawl on the fringe and rural residential development*	*Large increase in rural residential*
Land use planning					
Education & awareness					
Structural mitigation					

Population and Employment

Population and employment change in 2030/2050 compared to 2013 (%)

	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
Population	27/46	8/15	38/92	19/38	8/15
Population split over urban and rural	70/30 until 2050	66/34 until 2030 64/36 until 2050	80/20 until 2030 90/10 until 2050	72/28 until 2030 75/25 until 2050	65/35 until 2030 60/40 until 2050
Urban population	27/46	1/5	58/146	22/48	0/-1
Rural population	27/46	23/40	-7/-35	12/16	27/55
Commercial	40/82	-3/5	8/17	8/17	15/30
Public institutions including education	40/82	-13/-4	9/20	9/20	-13/-4
Industry	34/74	-14/-18	-14/-18	-4/-9	-4/-9
Agriculture	-22/-22	5/10	-22/-49	5/26	-22/-49
Horticulture	-22/-22	5/10	-22/-49	5/26	-22/-49
Livestock	-22/-22	5/10	-22/-49	-12/-30	-22/-49

Population and Employment

Motivation for employment and population quantification

	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
Population	Adapted from 30 year plan based on storyline	Adapted from 30 year plan based on storyline	Adapted from 30 year plan based on storyline	Projections 30 year plan + extrapolation	Adapted from 30 year plan based on storyline
Population split over urban and rural	Current split	Adapted from current split based on storyline	Adapted from current split based on storyline	Initially current split, adapted based on model results	Adapted from current split based on storyline
Commercial	Developed based on current employment and storyline	Medium projections PSA forecast -10% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation	Average of medium and high projections PSA forecast & extrapolation
Public institutions including education	Developed based on current employment and storyline	Medium projections PSA forecast -20% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast -20% & extrapolation
Industry	Developed based on current employment and storyline	Medium projections PSA forecast -10% & extrapolation	Medium projections PSA forecast -10% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation
Agriculture	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	Developed based on current employment and storyline	Medium projections PSA forecast & extrapolation
Horticulture	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	Developed based on current employment and storyline	Medium projections PSA forecast & extrapolation
Livestock	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	High projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation

NB: PSA – Planning SA, Source: Greater Adelaide Economy and Employment, Background Technical Report, Planning SA, September 2008.

Land Use

Land use change in 2030/2050 compared to 2013 (%)

	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
Residential (urban)	15/22	1/5	58/146	16/34	0/-1
Rural residential	15/22	2/7	-7/-35	7/11	27/55
Commercial	17/40	0/5	8/17	8/17	15/30
Public institutions including education	8/21	-2/-4	9/20	9/20	-2/-4
Recreation	15/22	2/7	0/0	10/18	0/0
Industry	3/9	-14/-18	-14/-18	-4/-9	-4/-9
Agriculture	-6/-14	-2/-4	-22/-49	1/5	-22/-49
Horticulture	-22/-22	-1/-3	-22/-49	1/5	-22/-49
Livestock	-22/-22	-1/-2	-22/-49	-16/-33	-22/-49

Land Use

Motivation for converting population and employment into land use demands

	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
Residential (urban)	Densification, 10% by 2030, 20% by 2050	No change in density	No change in density	Densification 5% by 2030, 10% by 2050	No change in density
Rural residential	Densification, 10% by 2030, 20% by 2050	Densification, 20% by 2030, 30% by 2050	No change in density	Densification 5% by 2050	No change in density
Commercial	Densification, 20% by 2030, 30% by 2050	No change in density	No change in density	No change in density	No change in density
Public institutions including education	Densification, 30% by 2030, 50% by 2050	No change in density	No change in density	No change in density	No change in density
Recreation (area projection)	Increase according to increase in residential surface	Increase according to increase in residential surface	No change in surface area	Increase according to increase in residential surface	No change in surface area
Industry	Densification 30% by 2030, 60% by 2050	No change in density	No change in density	No change in density	No change in density
Agriculture	Dispersion, 10% by 2050	Originally no change in density, based on model results 15% increase by 2050	No change in density	Intensification, 4% by 2030, 20% by 2050	No change in density
Horticulture	No change in density	Originally no change in density, based on model results 14% increase by 2050	No change in density	Intensification, 4% by 2030, 20% by 2050	No change in density
Livestock	No change in density	Originally no change in density, based on model results 12% increase by 2050	No change in density	Intensification, 4% by 2030, 4% by 2050	No change in density

CONCLUDING REMARKS

Uncertainty is an uncomfortable position. But certainty is an absurd one.
Voltaire

The scenarios presented in this report represent plausible developments for Greater Adelaide highlighting both challenges and opportunities for the region as it deals with future disaster risk.

The integrated manner of these scenarios, considering various drivers for change in the region, allows for a more comprehensive consideration of risk. Tomorrow's risk is being created today and it is hoped that the exploration of various alternatives provides policy makers a broader understanding of the dynamics of risk and the power of their influence and actions.

The results presented in this report particularly emphasise the role of exposure in the calculation of disaster risk. Managing exposure to risk is one of the most powerful mechanisms to reduce future risk and in urban environments it is critical to consider future land developments with global population projections estimating an increase of 400 million exposed to coastal and river flooding between 2010 and 2050 (Jongman et al., 2012).

The scenarios presented form the beginning of the scenario planning process. This process is designed to consider uncertainty and at its core is a non-predictive strategy for considering the future. Instead of considering probabilities about future outcomes, these scenarios present plausible stories that have been co-constructed and co-established by the group involved with their development. Therefore they present an integrated narrative of what could occur.

The five scenarios presented show both favourable and non-favourable narratives that can then be used to consider future initiatives and interventions. For each of the narratives responses can be considered as to how to navigate the challenges and opportunities presented in them. The narratives can also be used to test strategic options, considering under which future conditions these options are nullified or magnified.

Another report will follow in this series presenting the associated risk profiles for each of future scenarios. For each scenario, risk from hydro-meteorological, bushfire and earthquake hazards will be presented along with details regarding the drivers for these changes allowing policy makers a more dynamic form of risk assessments.

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Appendix G – Paper 3 Published Version

Published version of Paper 3 from Chapter 4

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Exploratory scenario analysis for disaster risk reduction: Considering alternative pathways in disaster risk assessment

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Stakeholder engagement
Simulation modelling
Risk assessment

ABSTRACT

Disaster risk is a combination of natural hazards, along with society's exposure and vulnerability to them. Therefore, to ensure effective, long-term disaster risk reduction we must consider the dynamics of each of these components and how they change over extended periods due to population, economic and climatic drivers, as well as policy and individual decisions. This paper provides a methodology to capture these factors within exploratory scenarios designed to test the effectiveness of policy responses to reduce disaster losses. The scenarios developed and subsequent analysis of them combine knowledge and insight from stakeholders and experts, and make use of simulation modelling to enable scenarios with qualitative and quantitative elements to be integrated within risk assessment processes and contribute to strategic risk treatments. The methodology was applied to a case-study in Greater Adelaide, Australia, and used to assess how disaster risk for earthquakes, bushfire and coastal inundation changes from 2016 to 2050 under five exploratory scenarios for the future of the region. This analysis can be applied more broadly to consider how future risks impact on regional viability, and suitability for investment related to the need to gain a better understanding of governmental and organisational exposure to physical risks.

1. Introduction

The impacts of disasters from natural hazards globally are increasing, with 2017 being the most costly year ever in terms of insured losses, $234bn (USD) [1], and second in total losses to 2011, with $234bn (USD). Projections of economic and population growth, together with impacts of climate change, show that these losses are likely to increase in the future [2,3]. The need to reduce these losses therefore is significant. Disaster risk reduction encapsulates efforts to reduce the impacts of disasters and incorporates actions such as improving building standards, land use planning strategies, structural flood defences, and education/capacity building activities [4–6]. However, decision-makers and planners designing and implementing disaster risk reduction strategies face difficult decisions around resource allocation, scheduling and planning priorities. Effective disaster risk reduction therefore requires the complexities of long-term change and multiple actors to be considered explicitly, along with significant sources of uncertainty, to develop integrated responses to the changing threats of disasters.

A complex decision making process can be conceptualised as multi-problem, multi-dimensional and multi-scale [7]. This represents a process involving entwined problems, numerous concerned disciplines and influencing processes that operate at various scales (governance, spatial, temporal). Disaster risk reduction inherently displays these factors of complexity, with the problem including issues such as climate adaptation and mitigation, sustainable development and local strategic economic and environmental issues, among others [8–13]. Designing, testing and implementing risk reduction strategies requires input from a range of disciplines, such as the computational abilities found in the physical sciences, an understanding of impact and associated costs from engineering and economics and understanding of community vulnerability and resilience that is the domain of social scientists [14–17]. The scales of disaster risk also cross from international efforts and agreements to small local communities [18–22]. There is therefore a need to incorporate these aspects into disaster risk reduction planning and implementation to ensure unintended and perverse outcomes do not occur and to leverage significant co-benefits of approaches accounting for multiple factors.

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2212-4209/

The uncertainty in the factors influencing disaster risk is also significant, and this is particularly true for what is known as knowledge uncertainty or uncertainty about the future [23]. These types of uncertainties produce significantly different trends in drivers and components of risk such as economic, population and climate change, rates of urbanisation, the influence of new technologies, and political factors. As disaster risk reduction requires actions to be implemented that will influence future developments, there is a need to incorporate how the future may unfold. Disaster risk reduction therefore needs to consider and integrate these uncertainties when plans are made and investment decisions for risk reduction actions are taken, otherwise their suitability and effectiveness may not be sufficient. Consideration of the future may also provide the opportunity to consider alternative methods of risk reduction, as opening a discussion on what may occur into the future enables the consideration of actions to influence this in a broader sense than what traditional actions would, such as reducing societal vulnerabilities and increasing adaptive capacity [5,24].

Traditionally, disaster risk reduction efforts are underpinned by risk assessments and the identification of management actions that reduce these risks. However, such risk assessments have generally taken a static approach by either considering current risk, or risk at a future time slice, which is often insufficient to capture the complexities and uncertainties outlined previously [25]. In recent studies, future uncertainty is also often considered by quantifying the impact of climate change on future hazard magnitude and probability, most commonly for hydro-meteorological disaster risk assessments [12,26]. This has allowed risk assessments to capture future changes in hazards, and through the use of environmental scenarios, such as representative concentration pathways (RCPs) [27–29], downscaling can provide various estimates for future environmental conditions such as precipitation, or sea level rise, for inclusion in the assessment of risk at future time points [30]. Similar approaches can be seen in planning for wildfire mitigation in Bradstock et al. [31]; who considered alternate climate scenarios, including a high and low temperature scenario for the year 2050, along with variations of humidity and wind. Similar scenario-based considerations of hazard magnitude can be seen in Aleskerov et al. [32] (earthquake), Legg et al. [33] (hurricane), Prudhomme et al. [34] (flood), and Panza et al. [35] (earthquake). However, none of these approaches consider uncertainties in other components of risk such as exposure or vulnerability, as their entire focus is on the hazard components and related uncertainties. There is also no consideration of the complexity of how these factors interact or how the complex dynamics of future changes are incorporated into the risk assessments, enabling more effective characterisation of future risk and how to reduce it.

Other risk assessments have considered changes to future exposure through considering population and economic projections and how regions and cities would look under these projections to subsequently assess various risk indicators. The work by de Kok et al. [36]; Mokrech et al. [37]; Zanuttigh et al. [38]; and Xu et al. [39] account for economic projections in increased exposed values. Barredo and Engelen [40] made progress towards exploring the variation and growth in exposure using a combined model of flood risk and land use. However, only two scenarios were considered, consisting of two alternate urban developments, with one based on an increased central, built up cluster and the other on more diverse growth influenced by roads. However, these approaches again do not take into account the broad range of factors that could influence the effectiveness of disaster risk reduction efforts, or provide a mechanism to incorporate the complexities of disaster risk that can allow decision makers to untangle the interconnectedness of disaster risk. Instead, these approaches represent the incorporation of generic scenarios of one or two dimensions to forecast possible futures of limited components of disaster risk. However, this fails to deliver risk assessments that incorporate the range of relevant uncertainties and complexities impacting on risk, or provide a way to assess the effectiveness of risk reduction options.

In relation to the incorporation of uncertainty, the literature shows an increasing preference for accounting for changes to components of risk in the future, but none go as far as the call for a 'paradigm shift' in the manner in which risk assessments are done through implementing a more dynamic approach, accounting for future uncertainties and allowing for the understanding of today's and tomorrow's decisions on long term risk profiles [25]. Such a shift would require the incorporation of the levels of uncertainty and complexity needed for understanding tomorrow's risk. This can be achieved by means of scenario analysis that incorporates relevant and challenging assumptions of tomorrow from a range of stakeholders and contexts, along with incorporating the complex dynamics between decisions made, and emerging socio-economic trends. Therefore, there is a need for an approach that can incorporate these elements within the scenarios used for risk assessments and ensure they are tailored to disaster risk contexts, embracing the range of uncertainties and complexities within the domain to enable them to have a greater impact in the policy and planning processes used for disaster risk reduction [41,42].

This paper therefore has the objective to introduce an approach that can incorporate the range of complexities and uncertainties relevant to planning for a future of reduced disaster risk in a risk assessment process. The paper outlines the proposed approach in Section 2, highlighting both the difference in outputs from a traditional static risk assessment, along with the dynamic outputs obtained by using the proposed approach. Section 2 also provides details on the methodology for undertaking a risk assessment process that creates relevant and challenging scenarios. Section 3 provides specific details on the approach and its application to a case-study, which allows for greater description of the process and allows for highlighting the proposed approach's ability in incorporating the range of required knowledge sources into a risk assessment. Critical discussion on the approach is offered in Section 4, particularly considering how perspectives were combined within the approach, how methodological decisions impact on uncertainty within the outcomes, how to ensure assumptions are challenging and relevant for disaster risk assessment and how the approach can add value in other domains. Section 5 provides a summary and conclusions of the paper.

2. Proposed approach to incorporate complexity and uncertainty in physical risk assessments through exploratory scenarios

2.1. Conceptual outline of approach

The approach proposed to improve disaster risk reduction planning (achieved through incorporating uncertainty and complexity to enhance risk assessment) integrates different types of knowledge and assessments, both qualitative and quantitative, through exploratory scenarios to consider extended planning horizons in a dynamic manner. This allows for the characterisation of risk against time for various scenarios that incorporate challenging and relevant assumptions on uncertain and complex factors and interactions influencing risk. This process enables decision makers to better consider the impact of different factors on risk, allows for an understanding of the impact on current decisions and policy on future risk and enables a collaborative approach to be undertaken to better plan for a less risky future. These are all currently challenging in the more commonly used static risk assessment processes (Fig. 1), aligned with reactive risk management, that do not account for future uncertainty or complexity in risk factors, as outlined in the Introduction, and instead aim to capture best available data for the current situation.

The proposed approach instead enables the development of dynamic, spatially explicit risk pathways that correspond to alternate, challenging and plausible future changes in hazards, and, exposure and vulnerabilities to them. These pathways also capture the complexity of interactions between these factors (hazard, exposure, vulnerability) and the uncertainty in their future trajectory in a realistic and informative

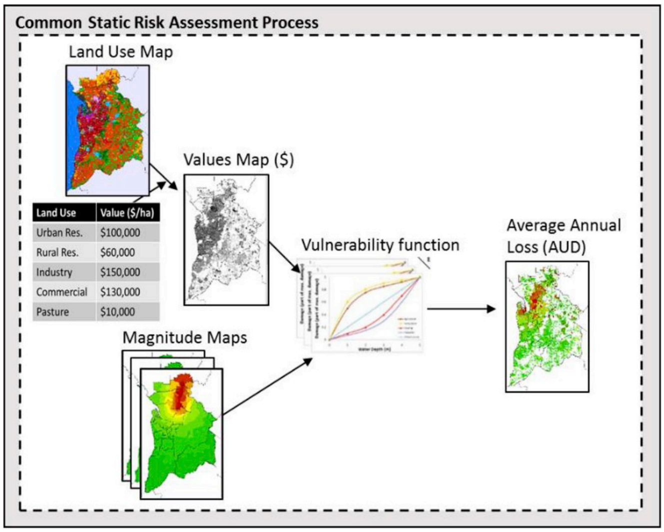

Fig. 1. Sophisticated quantitative, static regional risk modelling assessment with exposure and hazard brought together through vulnerability/fragility/damage curves, see Gunasekera et al. [43]; Koks et al. [17]; UNISDR [44] for further details.

manner. This approach drives the static risk modelling and assessment process with exploratory scenarios created with an integration of knowledge encapsulating some of the uncertain and relevant factors that impact disaster risk as outlined in the Introduction. By creating alternate scenarios, complexities arising from the different disciplines involved in disaster risk reduction can be described in each scenario, allowing competing perspectives to be introduced into the risk assessment process. Given the broad range of stakeholders involved in disaster risk reduction (who can provide insight into the complex influence of their actions and other drivers within the system), the creation of dynamic pathways based on different assumptions and actions taken also allows for the complexity of entwined problems (where pulling a lever in one part of the system can influence risk in other parts of the system) to be shown within a quantitative risk assessment. Alternative assumptions made on future uncertainties, highlighting their influence on risk, provide different trajectories for the scenarios. Assumptions from diverse actors involved in disaster risk can be incorporated regarding the influence of cultural and technological factors on risk, especially vulnerability, as well as how climate change and socio-economics will influence future hazard likelihood and intensity, as well exposed assets and populations.

Fig. 2 shows the outcome of the approach of developing exploratory scenarios to create alternative pathways in the risk assessment process. This is in comparison to only capturing the average annual loss (or other relevant risk metric) for one, often current, time slice – shown in (Fig. 1). However, to achieve this outcome, with insight that is challenging and meaningful to users of risk information, and incorporates challenging assumptions on uncertainty and the complexity of risks into the future, the development of these pathways needs to be carefully considered. This development process, the proposed approach demonstrated in this paper, is critical to the value of the outcome achieved.

The proposed approach achieves value through developing alternative risk pathways by integrating stakeholder participatory information, expert opinion and judgement and scenario simulation modelling with disaster risk assessments into exploratory scenarios to enable the exploration of risk profiles. These scenarios are exploratory in their content as they focus on what could happen [45] and are defined as internally consistent and plausible explanations, using words and numbers, of how events unfold with time [46–48]. By including both qualitative and quantitative factors in the developed exploratory risk scenarios, multiple benefits can be derived by combining participatory processes to develop qualitative storylines with integrated models for future projections and risk analysis. When scenarios are developed with participatory inputs from a diverse range of stakeholders, it can ensure greater relevance to local decision making, build trust and increase acceptance of planning decisions [49–51]. Stakeholder involvement in scenario development can also empower those involved through the cogeneration of knowledge [52,53].

Therefore, with the aid of the proposed approach, uncertainty and complexity can be considered by the exploratory storylines developed by stakeholders, which offer rich, descriptive visions of future world states and incorporate various qualitative assumptions for alternative worldviews and risk profiles [54]. The inclusion of 'numbers' in the exploratory scenarios, complementing the storylines, allows for a temporal representation of changes based on the qualitative assumptions and allows them to be used in the assessment and development of policies and plans. By quantifying and modelling scenarios, it can also be argued that they become more transparent, given assumptions need to be explicitly detailed in model parameters and processes [55].

2.2. Implementation of the approach – achieving challenging, relevant risk profiles

The approach's implementation is shown in Fig. 3 across nine distinct steps, which can be grouped into four stages, including problem formulation, qualitative scenario development, quantitative scenario development and future risk assessment. The feedbacks between the different steps and stages are also shown. To enable the approach's outcomes to be achieved, its implementation is focussed on integrating participatory and qualitative information with quantitative modelling and analysis to enable the exploration of risk profiles (represented as average annual loss in Fig. 2). How this is achieved across the nine implementation steps is also shown in Fig. 3.

As mentioned above, the implementation process shown in Fig. 3 consists of four key stages, which flow into each other. It is initially important to establish the context and formulate the problem to which the exploratory scenarios for disaster risk reduction are being applied to. This includes considering key goals and stakeholders for the process, and outlines critical components to be included within the scenario process. Stage 2 begins the detailing of scenarios, in a qualitative manner, using stakeholders to develop the components of the scenarios that will allow the process' goals to be met. This then allows Stage 3 to quantify and simulate socio-economic futures based on their qualitative components. Stage 4 uses these futures to drive the quantitative risk assessment modelling to consider future risk and strategic risk reduction options.

The entire process incorporates different sources of information from either stakeholders, experts or simulation modelling at different points, with some stages focusing more on participatory input and others more on quantitative analysis, as shown in Fig. 3. Each of these sources of information enable the process to better capture the challenges involved with dynamic risk assessments and allow scenario exploration of risk's uncertainties and complexities to be considered quantitatively and in a manner that enhances understanding by those involved in risk assessment and reduction. The following list provides details on information provided by each of these sources:

Stakeholder participatory information – stakeholders are defined as individuals who are either involved in making or impacted by a decision [56]. Information is generally collected from these individuals through designed processes, including questionnaires, semi-structured interviews and workshops, however, all information is qualitative and subjective. Significant literature is dedicated to the method for identifying and working with stakeholders (see Refs. [57–59]). The incorporation of stakeholder insight has a number of advantages, including (i) it enables more local knowledge/context to be incorporated, which is critical for complex decisions, (ii)

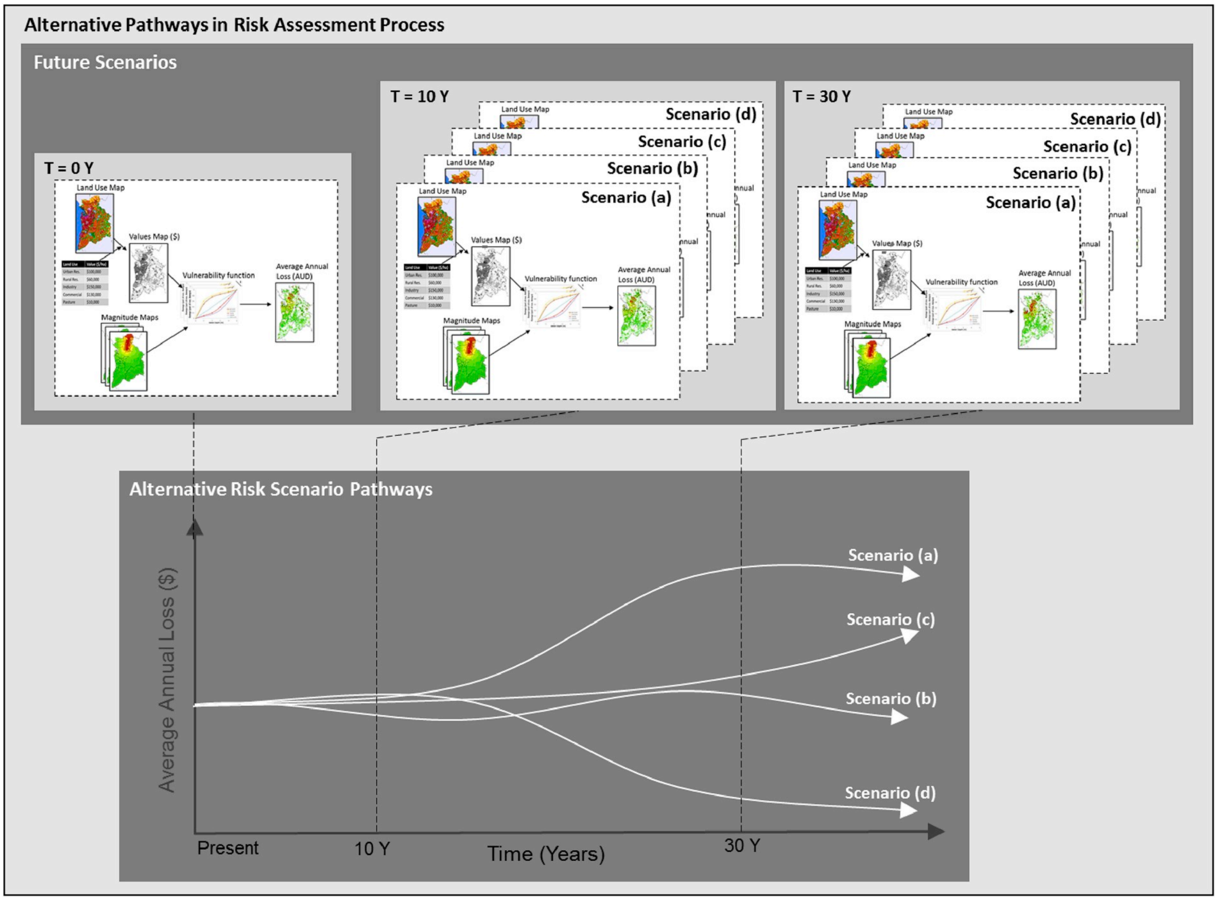

Fig. 2. Outcome of the proposed approach, illustrated with four alternative scenarios (Scenario (a)–(d)), which include assumptions and drivers on any of the elements included within the calculation of risk (e.g. average annual loss in this representation). By the simulation of risk each year across different future scenarios, alternative risk scenario pathways can be developed, plotting risk against time for each pathway.

ownership of outcomes and (iii) it addresses the uncertainty of social norms [7,60–62].

Scenario simulation modelling – this is the use of computer-based modelling systems to simulate future dynamics based on input drivers and model parameters. To consider scenarios via the use of simulation, parameters, inputs, boundary conditions and the model structure itself are adapted to represent and better inform the scenario's narrative. Simulation modelling of scenarios supports the exploration of uncertainty by considering alternate drivers in a consistent, comparable manner with the same quantitative outputs. It can also support the exploration and reduction of complexity and communication of uncertainty through its requirement to consider various interpretations of the future through exploration of a limited number of parameters and its value as a structuring device for problems [63–65].

Expert opinion and judgement – domain specific knowledge can be integrated by the inclusion of experts for particular elements of the process. Expert opinion and judgement is considered to rely on a range of qualitative and quantitative information and uses a combination of desktop studies, statistical analysis and inference. The incorporation of expert opinion throughout the process can better balance the trade-off between stakeholder views and scientific credibility, and relevance to decision making and challenging, exploratory thinking/provocations about the future, along with providing insight into parameterization, provision of boundary conditions, and evaluation of the realism of outcomes, especially in areas where data may be lacking [18,66,67].

Critically important to the value of the approach is how it is implemented and how each of these three components come together, as no one method, or type of information, is sufficient to capture the complexity or uncertainty involved in disaster risk. This is why almost each step of the process involves input from multiple sources. It is also important to consider the feedbacks between steps, acknowledging the complexity of disaster risks, and that when actions and solutions are implemented, unexpected impacts can occur – therefore as with all scenario planning, iteration and cycles of planning and implementation are critical. Section 3 provides further details on the approach and how it was implemented with a case-study example.

3. Considering alternative pathways in disaster risk assessment – applying the approach in Greater Adelaide, a case-study

The following sections provide details on each step shown in Fig. 3, along with the split between knowledge sources - stakeholder participatory knowledge, scenario simulation modelling, and expert opinion and judgement – and how they were integrated. The outlined approach and its implementation were applied to Greater Adelaide in South Australia, Australia, to demonstrate the utility of the approach in terms of its ability to incorporate uncertainty and complexity for future risk assessment. South Australia's risk profile consists of various hazards, with flooding being the costliest with average annual losses in excess of $32 million [68]. The State has also suffered significant bushfire events, with two significant fires in 2015 resulting in the loss of 2 lives, 24 homes and 95,000 ha burnt [69].

Participants involved in the process of implementing the proposed approach (Fig. 3) were determined based on the roles and responsibilities of different agencies involved in emergency management in the

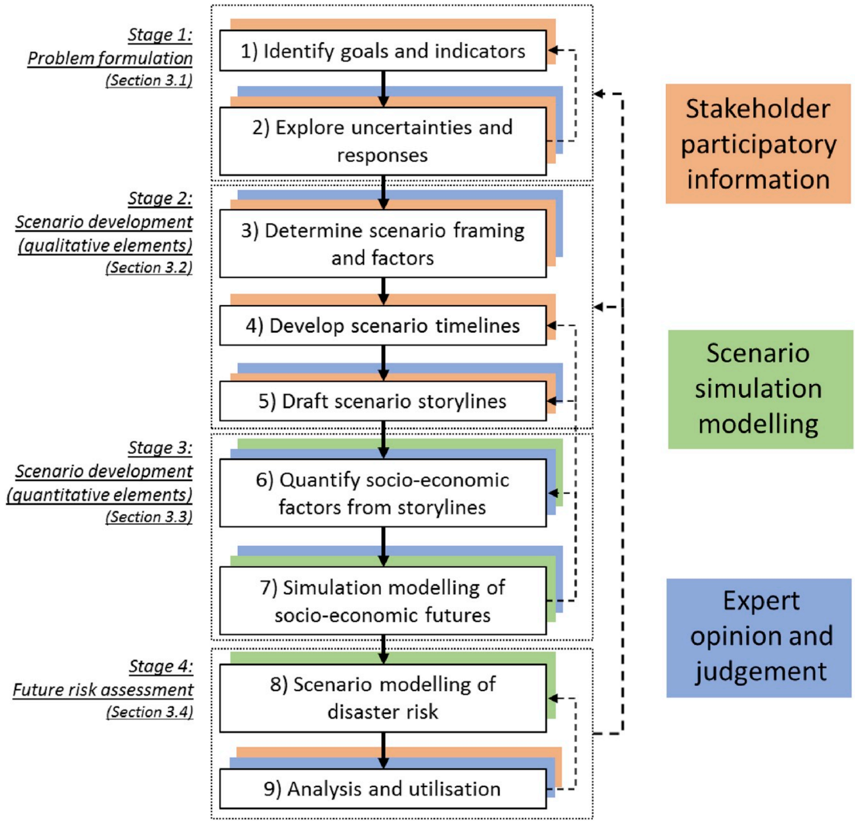

Fig. 3. Outline of the nine steps of the approach to develop and use exploratory scenarios within disaster risk assessments. Coloured boxes indicate source of information type used in each step.

State. Generally, participants were representatives of agencies on the State Mitigation Advisory Group (SMAG), along with other relevant government and non-government organisations, who provided broader details on regional growth dynamics in the region. The participants included in the process are not the full representation of stakeholders who would be affected by impacts of natural hazards into the future (such as local residents), as the stakeholder selection process was constrained to consider those within the emergency management sector due to confidentiality and security issues. For further exploration of the results generated from this process, along with implementation of actions, engagement would be needed more broadly, including with other levels of government and local residents, for example. The scenario team, as referenced subsequently, were engaged for the project and are the authors of this paper.

Implementation of the proposed approach was supported using the UNHaRMED software application designed to explore future disaster risk in an integrated fashion, see van Delden et al. [70]. Fig. 4 shows an overview of the components of UNHaRMED, and how it was used to simulate the exploratory scenarios developed as part of the approach introduced in Section 2. The nine steps of the methodology, shown in Fig. 3 in Section 2.1, are mapped into the process shown in Fig. 4, beginning with Goals and Indicators (Step 1) and how they are linked to various components/steps such as the qualitative elements of the scenarios (Step 3–5), regional disaster risk (Step 8) and utilisation and analysis (Step 9).

UNHaRMED is a software that has been designed for improving the long-term understanding of disaster risk and allows for the testing of different risk reduction options against alternate scenarios of socio-economic and environmental conditions. The software models the risk from multiple natural hazard types, in this application coastal flooding, bushfire and earthquake, and shows the user how the risks from each of the hazards change into the future by the production of policy-relevant metrics, such as average annual loss, for different scenarios and risk reduction decisions. Further details on UNHaRMED can be found in van Delden et al. [70].

The following sections outline the implemented steps in the Greater Adelaide case study, and highlight the outcomes and results of each. The first paragraph(s) of each section provide generic information regarding the approach, before providing specifics of the case-study application.

3.1. Stage 1: problem formulation

3.1.1. Step 1: identify goals and indicators

The first stage looks at problem formulation and scoping of issues. Step 1 of this stage allows stakeholders to provide input on the risk assessment process' overarching goals and identify indicators for this to be measured against. Setting the overall goal is critical to a successful process and to develop trust between different actors involved in the stakeholder group, and the project team. The goal should relate to the risk assessment and subsequent treatment process, which the scenarios and modelling complement. With goals determined, indicators are required to measure the success of the process, but also what indicators are included in the risk assessment, allowing for comparison across developed scenarios and for policy impact assessment. Enabling the joint determination of policy and process goals and indicators in a participatory manner supports the search for a frame that enables multiple actors to promote or protect their own interests and can support the reduction of uncertainty by consciously exposing alternative conceptualisations of agendas and challenges [71].

For application to the case study, this step required a facilitated process with stakeholders. This process took a visioning perspective to better enable productive, positive responses and reduce the potential trap of the framing being focused on current challenges around budgets

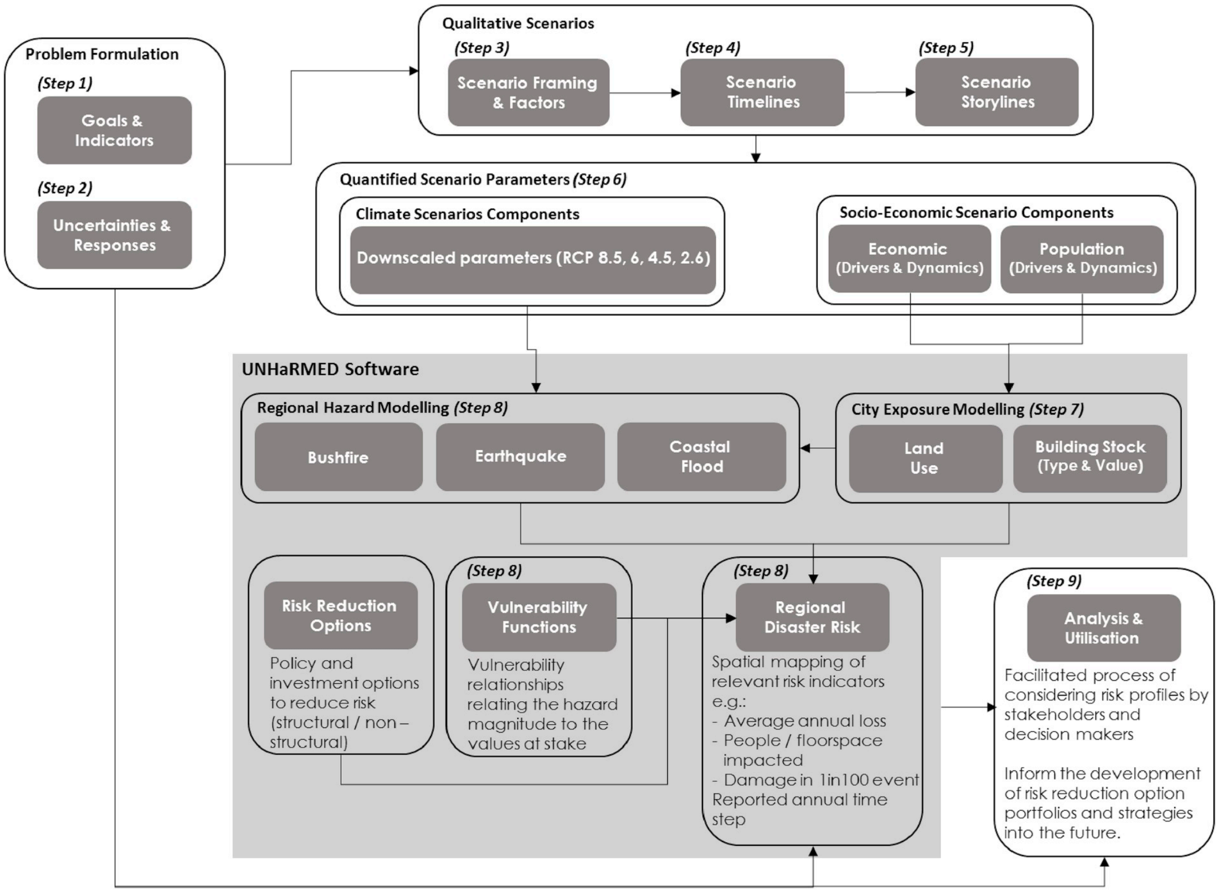

Fig. 4. Approach flow diagram highlighting the role of UNHaRMED as applied in the Greater Adelaide case study.

and politics, given the exercise was future-focused. Therefore, responses were collected to the request for a one sentence description of participants' vision for the region related to natural hazards and risk for the year 2050, which were then shared with the group in an anonymous manner. Key elements of similarity were then debated by the group to enable the focus of the scenario analysis to be on considering multiple hazards and long-term challenges from socio-economic development and climate change. Examples of policy objectives include, “Thriving region because people choose to live in places that are safe, where risks can be mitigated and they can support themselves and their community”, “Natural hazard risks & impacts are minimised sustainably”, “A resilient future for our children”, and “A healthy, prosperous & safe community with potential for growth & development”.

For the process to be considered successful, it had to enable stakeholders to gain an understanding of differences in future risk via the scenario development and analysis. This required the process to be designed in a manner where continued sensemaking [72] could occur between the scenario team and participants, and also that the results were in relevant metrics to enable comparison and insight. To support this, stakeholders outlined indicators to be provided for the scenario analysis to enable comparison across pathways, and also agreed to the process of engagement over the project combining structured events such as a series of workshops, along with the need for more informal meetings between certain stakeholders and the scenario team. Indicators considered relevant for the comparison and to be explored in terms of their feasibility by the project team are shown in Table 1.

Table 1
Overview of indicators across three dimensions to compare different futures and risk reduction options.

Dimension	Indicator
Economic	Cost of primary damage (average annual loss)
	Business disruption losses
	Loss of employment
	Damage to significant Government infrastructure (value > $1 million)
	Amount of impact to critical infrastructure locations
	Impact on Gross Domestic Product (GDP)
Social	Loss of essential service provision
	Impact to areas of cultural significance
	Number of people impacted
	Change in morbidity/mortality rates
Environmental	Area of vulnerable/protected ecosystems impacted
	Area of primary agriculture impacted
	Area of heritage land impacted

3.1.2. Step 2: explore uncertainties and responses

Step 2 focusses on the scenario development process by considering drivers for change and uncertainties, as well as implemented responses/risk treatment measures that could impact on the success of the goal and hence can be measured with the indicators. Here, there are inputs from both the stakeholder group and required experts, who can provide specific information regarding options available and broader understanding of the relevant trends that may influence long-term risk. By including expert opinion, broader knowledge can be captured in the process, and can stimulate stakeholders in new thinking [67,73].

To inform this process in Greater Adelaide, questionnaires and semi-structured interviews were conducted with 14 stakeholders and experts in growth dynamics for the region to provide input as to key drivers for change in the state, along with key uncertainties that could affect how well the State is able to reduce the risk from natural hazards. Questionnaires with open-ended questions allowed participants to document freely their responses, and these responses, along with

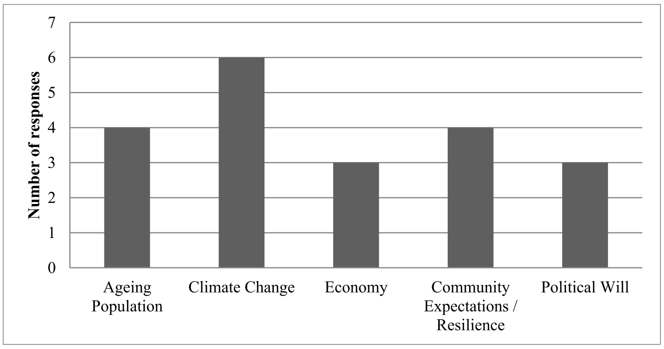

Fig. 5. Responses to the key drivers for change in South Australia over the next 50 years collected from 14 stakeholders.

collected and analysed discussion from the interviews, are summarised in Figs. 5 and 6 from Ref. [74].

To support the process in its ability to be focused on risk treatments following the exploratory scenario-based risk assessment presented here, risk reduction options that could be implemented over extended periods of time were considered. These considered actions to reduce the likelihood and impact of a disaster event and were identified and collated in a brainstorming session with stakeholders and subject matter experts on the disaster types considered relevant to the region. This brainstorming session developed around 100 individual mitigation options clustered around nine key themes. A summary of the most repeated of these results is shown in Table 2. This collection of risk reduction options was then used within the scenario process, using them as drivers for framing the scenarios (see Section 3.3 – Step 3 and Riddell et al. [42], along with being considered in Step 9, analysis and utilisation - see Section 3.9), to enable comparison of the effectiveness of particular options against those of different options and portfolios of options.

3.2. Stage 2: scenario development (qualitative elements)

3.2.1. Step 3: determine scenario framing and factors

Qualitative scenarios describe different futures via words and visual symbols [55], often resulting in narrative storylines that either outline the condition of the region or system at a particular time in the future, or outline the timeline of events and trends that lead to a particular state at a slice in time. Often qualitative scenarios will combine these two. The approach applied looks to group responses (risk reduction options from the previous stage) into two categories, which create framing axes of the scenario space. These axes represent increasing challenges to the implementation and effectiveness of risk reduction treatments, so that as one progresses along either x or y axis the challenges increase. The space between axes can be split into quadrants representing combinations of drivers. This is shown as the outcomes of interest framing described in Riddell et al. [42].

Relevant factors to each axis are also discussed with stakeholders to provide the basis of the narratives to be developed. From workshop discussion with stakeholders and inputs from experts, these factors represent elements that are important in the implementation and effectiveness of responses – for example, sufficient resourcing is a factor relevant to how successfully fuel reduction burns can be implemented. Experts are used to supplement stakeholder input if sufficient knowledge is not held within the stakeholder group regarding relevant factors to the effectiveness of policies and how they can be conceptualised within scenario development.

For the case study, based on the risk reduction options shown in Table 2, the scenarios were framed around increasing challenges to the development and implementation of risk reduction options by government (such as the construction of flood protection works, or land use planning strategies to reduce exposure to disasters), and options more driven by the community and focused on enhancing society's ability to deal with disasters. This grouping and split was done by experts from the scenario team with an understanding of the needs for these driving axes to enable more efficient scenario development and provide greater policy relevance to the scenario analysis. For full details on the methodology see Riddell et al. [42]. Using the driving axes, stakeholders were then asked to consider the factors that would enable the design and implementation of government-led risk reduction options and create and enhance resilience to disaster risk. The factors formed the basis for the scenario timeline development (Step 4), with stakeholders proposing multiple factors for which assumptions would then be made regarding how they would change based on relevant uncertainties.

3.2.2. Step 4: develop scenario timelines

Stakeholders, with the framed scenario space and relevant factors, then develop timelines for plausible assumptions for how factors may change with time based on the scenario's framing axes. This requires a facilitated process with small groups of stakeholders working with a facilitator to construct timelines for each scenario, for each factor relevant to the framing. This process enables stakeholders to explore the drivers of risk in the region, while considering the impact of uncertainties on the factors relevant to the effectiveness of risk reduction options. The outcome is a timeline of events related to each factor for each scenario, which forms the basis for the more detailed storylines developed by experts in the next step (Section 3.2.3).

For the case study, due to limited time with stakeholders in participatory sessions, three timelines were developed to inform the construction of five scenarios. Stakeholders were split between groups to develop timelines for scenarios for the vision scenario (low challenges to both government actions and societal resilience), and for each of the scenarios which had high challenges to one of the risk reduction options and low challenges to the other. Coloured post-it notes for each factor were used to allow stakeholders to outline the events and place them on the timeline from 2015 to 2050. Fig. 8 shows one of these timelines

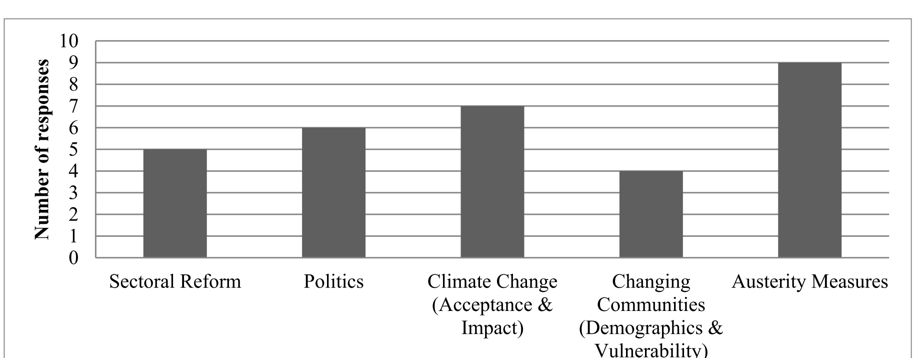

Fig. 6. Responses to the key uncertainties in South Austalia's ability to reduce disaster risks in the next 50 years collected from 14 stakeholders.

Table 2
Risk reduction options collected during stakeholder engagement for Greater Adelaide case study.

Clustered Theme	Prevalent Risk Reduction Options		
BUILDING CODES	Increasing recurrence interval for all hazards in code	Inclusion of hazard resistance for hazards not considered	Specific strengthening for buildings of community value
LAND MANAGEMENT	Planned burning, reduction of fuel load	Improved enforcement mechanisms (e.g. illegal vegetation clearance)	Land reclamations
COMMUNITY BASED	Arson reductions programs	Integration of hazard programs in school curriculum	Increase community awareness (risks, safety strategies)
STRUCTURAL	Building hardening (in particular for residential infrastructure) and structural upgrades for legacy buildings	Providing more assistance to owners of buildings in hazard areas to upgrade buildings	Hazard impact reduction measures such as levees, seawalls etc.
LEARNING (Response to Plan and Prepare)	Agreement on residual risk, government and communities	Implementation of business continuity plans	Structured framework for lessons learnt
INSTITUTIONAL CHANGE	Establishment of multi hazard agencies	Tougher legislative requirements to build in higher risk zones	Adaptive policies (thresholds) for decision making (linking with adaption to climate change)
LAND USE PLANNING	Building exclusion areas, flood plains, bushfire areas	Ensuring development in hazard prone areas are compliant to highest codes	Increase access to information for property owners
LEGISLATION	Regulatory requirements to consider natural hazard risk in planning	Provide hazard leaders/control agencies with greater powers to question developments	Resource planning to mitigate response/recovery
FINANCIAL INSTRUMENTS	Effective cost: risk assessment	Use of Emergency Services Levy to fund risk reduction	Funding to support institutional change (increased integration, coordination and planning)

Fig. 7. Overview of scenario drivers and elements for Greater Adelaide case study.

under-development during a session. These notes were then documented after the participatory sessions to enable the scenarios to be developed into cohesive and salient storylines. Consideration during the drafting was given to each of the key factors' (from Fig. 7) progression with time against the indicators considered relevant for effective disaster risk management actions (from Table 1).

3.2.3. Step 5: draft scenario storylines

Timelines developed in participatory workshops provide the skeleton for a first draft of the qualitative scenarios. These are detailed, with expert opinion supplementing the participatory timelines by drawing on previous experience, literature, existing scenario studies (at different scales – national, global), to draft coherent, consistent and salient narrative storylines. These storylines are then provided to stakeholders for comment and editing based on whether they considered the scenarios to be 1) representative of their thoughts in previous scenario sessions, 2) internally consistent and not contradictory, 3) extreme enough, and 4) too extreme.

For the case study, the scenario team used the three timelines developed by stakeholders to draft five storylines for the following scenario frames:

- one future for Greater Adelaide where it was simple to design and implement mitigation strategies and develop societal resilience, which was considered the vision for the region;
- one extreme future that challenged both resilience and mitigation strategies;
- two intermediate futures that challenged either resilience or mitigation to a greater degree; and

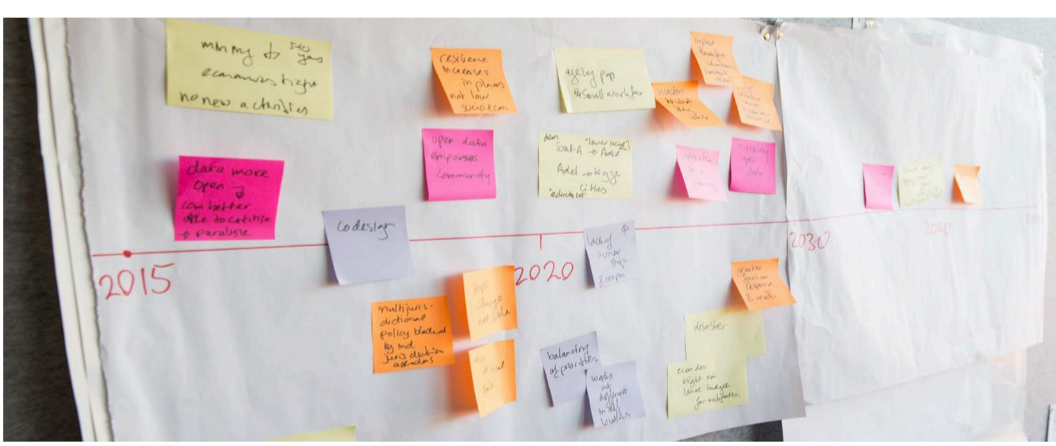

Fig. 8. Stakeholder input developing a scenario timeline from 2015.

- one central future with moderate challenges to both resilience and mitigation.

Drafting was performed by a small team of writers, which enabled the process to combine both stakeholder knowledge of context factors along with the integration of broader perspectives and historical trends related to disaster risk. Scenarios were drafted to consist of a narrative summary, along with information for each of the five scenarios regarding multiple socio-economic components such as population and urbanisation, community profile, economy and lifestyle, and politics and institutions. Examples of the storylines include opening sentences for Silicon Hills as:

> "Greater Adelaide transitions towards a well-balanced technology focussed economy, driven by highly skilled and engaged locals and expatriates as well as immigrants looking to capitalise on the State's booming high-tech industry while enjoying the relaxed, nature filled lifestyle the Mt Lofty Ranges and Adelaide Hills offer".

And for Internet of Risk as:

> "Global connectedness drives an increasing reliance on the internet for social interaction and working styles. This reliance on the World Wide Web sees dispersed residential living as the attraction of the CBD and physical centers lessens, leading to a significant loss of physical connectedness and an increase in siloed communication between similar individuals and services by a small, but growing, services sector providing for the hordes of online workers."

These two openings show clear similarities in themes and drivers for the future, such as the role of technology and changing work patterns. These similarities in drivers is critical as the scenario storylines allow stakeholders to explore how each of them play out in terms of risks and what policy actions may be required to enable a more positive future with similar drivers for positive and negative futures. It is also important in how they are quantified in terms of where developments occur and what vulnerabilities exist within them. Fig. 9 provides an overview of each of the five scenarios drafted, and their framing between axes. Results to the four questions posed to assess stakeholder acceptance of the qualitative storylines is shown in Fig. 10, highlighting broad agreement. The areas where agreement was not universal resulted in discussion and, if needed, changes were made to the draft. Full details on scenarios can be seen in Riddell et al. [42].

3.3. Stage 3: scenario development (quantitative elements)

3.3.1. Step 6: quantify socio-economic factors from storylines

Quantitative elements of scenarios consist of the external drivers, parameters and possibly model structures used to temporally simulate the qualitative narrative elements. The quantification of factors from the storylines, Step 5, typically is undertaken by expert opinion and judgment of the modellers who look for elements from the storylines that can be used to inform elements of the model to be modified. This follows the identification of clues, indicators and impacts that inform the parameterization of the model. This approach follows the storyline and simulation approach as outlined in Alcamo [55]; and uses the CI2 methodology outlined in van Delden and Hagen-Zanker [75].

For the case study, using the qualitative storylines, initial parameterization by experts was based on linking elements of the scenarios to existing government projections for growth for the region regarding population, and land requirements for economic demands. The simulation modelling of socio-economic (and disaster risk) scenarios was performed using UNHaRMED [70] which utilises the Metronamica land use model [76,77] to project future land use change, and subsequently risk exposure. Using Metronamica to simulate land use futures requires determining the drivers for changes in dynamic land uses, which are demands for land in hectares per year per land use as well changes in biophysical conditions, infrastructure, zoning and human behaviour. The scenarios also informed the relationship between land uses in the form of neighbourhood dynamics, for instance in regard to how the scenario considered the densification or sprawl of residential development. Tables 3 and 4 highlight the quantification assumptions for population and employment change, along with how this was translated into requirements for land. There is a tight linking between Steps 6 and 7 with experts' opinion and judgement used for initial parameterization and then using simulation modelling to test the outcome of those

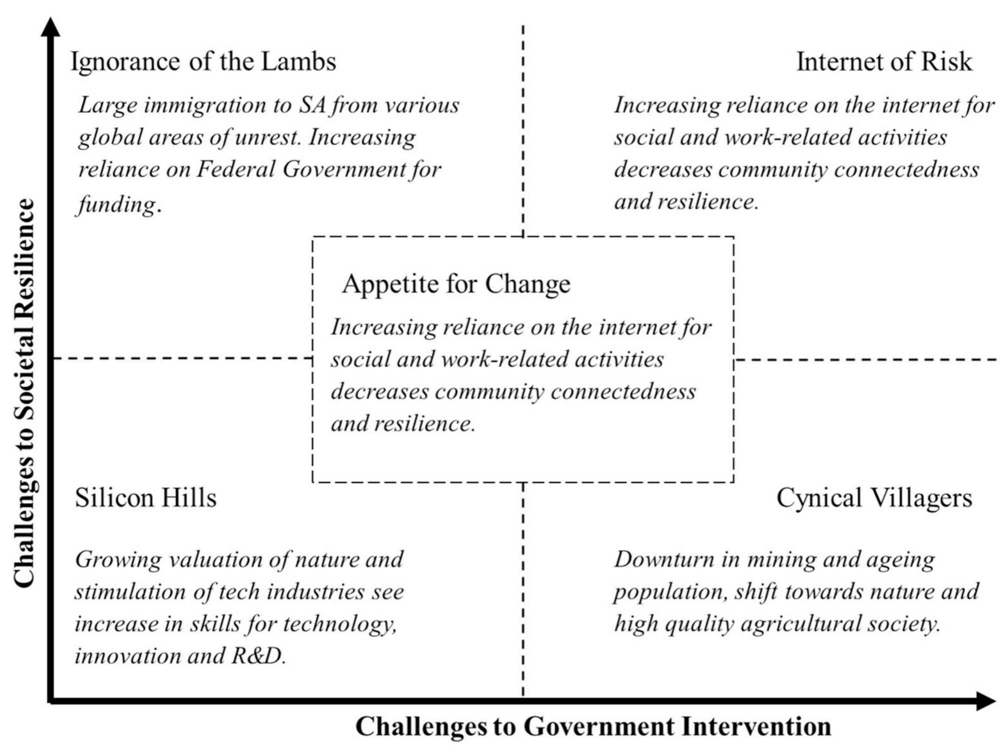

Fig. 9. Overview of five qualitative scenarios developed for Greater Adelaide.

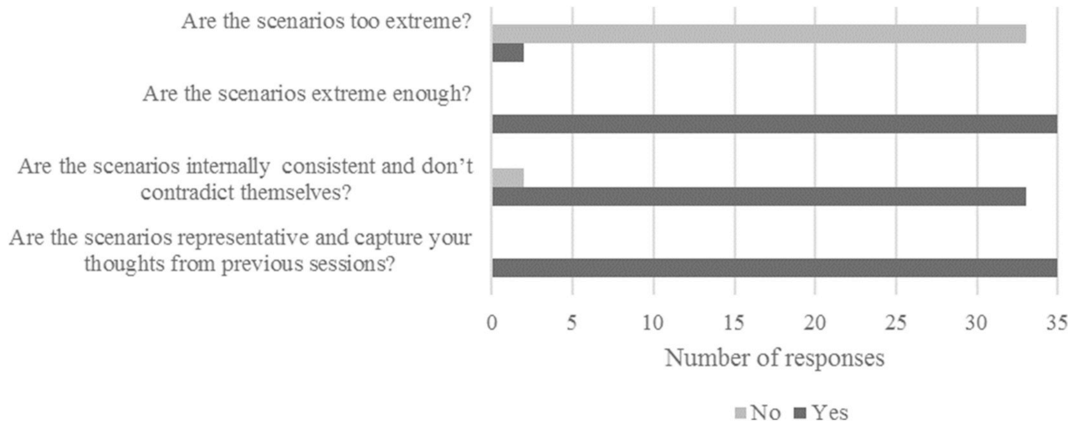

Fig. 10. Stakeholder responses regarding the drafted scenarios sourced from Riddell et al. [42].

assumptions before refining and iterating to arrive at internally consistent, alternative scenarios.

3.3.2. Step 7: simulation modelling of socio-economic futures

Simulation models are then modified based on each factor relevant to a particular scenario to then simulate socio-economic futures under each of the scenario conditions, Step 3 and 4. Critical is the feedback from scenario simulation modelling to inform both the parameterization and possible changes to the qualitative storylines. The simulated socio-economic futures should be used to edit the storylines if modelled extremities between scenarios are not found to be sufficient, and also if inconsistencies and incoherence are found in the scenarios. This is the value of combining both qualitative and quantitative elements with simulation modelling, as discrepancies that otherwise may have been missed are able to be highlighted.

As outlined in Step 6, UNHaRMED was used as part of the case study to perform the scenario analysis and, as such, the outputs in terms of socio-economic futures are produced in the form of land use maps. For Greater Adelaide, summaries of these are shown in Fig. 11. Here the change in critical urban land uses for the five scenarios can be seen, showing the growth and loss in each of the land use classes (residential, rural residential, and industrial). These outputs are then used to provide a component of exposure modelling for Step 8 – scenario modelling of disaster risk. As can be seen in the outputs for land use in 2050, clear differences are evident in terms of the urban form for the region under the different scenarios, with subsequent impacts of people and values exposed. For scenarios with greater economic growth, such as *Silicon Hills*, there is significantly more development of industrial land, aligning with the growth narrative. Similarly, *Ignorance of the Lambs* and *Appetite for Change* see more development in the rural residential space, with urban sprawl being a clear driver for change.

3.4. Stage 4: future risk assessment

3.4.1. Step 8: scenario modelling of disaster risk

With the qualitative and quantitative elements of the scenario developed and agreed upon, scenario simulation modelling of disaster risk is then undertaken. The socio-economic drivers of risk (encapsulated within the scenarios) are used as inputs into the risk assessment providing trends of socio-economic development, and associated changes to exposure, vulnerability and hazard. Established climate change scenarios (i.e. downscaled regional RCPs) can also be integrated in a plausible manner, combining socio-economic and climatic drivers to consider future risk. The simulation modelling of risk enables a dynamic representation of how risk changes over the modelled horizon, with variations in risk profiles driven by the differences in scenario variables (model drivers, and parameters). The results of this modelling (spatial maps of average annual losses, and areas exposed to high risks, across different scenarios), are then used to consider the drivers and systems of risk.

As previously outlined, the simulation modelling of both socio-economic and risk components for the case study were undertaken using UNHaRMED, a software application designed to be used for this type of scenario analysis. Hazards modelled for the case study region were bushfire, coastal flooding and earthquake, with climate change scenarios used to drive factors such as temperature and relative humidity relevant to bushfire risk, along with sea-level rise considerations for coastal flooding. Full details on how each of the hazards is modelled is contained in van Delden et al. [70]. However, it should be noted that for earthquake and coastal flooding hazards, the modelling is performed externally and maps of hazard magnitude for specified return periods, at points in time related to a climate scenario (for coastal flooding), are used as inputs to UNHaRMED. Bushfire hazard is calculated internally considering vegetation types, climate and terrain factors, which allows for an interaction with urban growth dynamics via changes to vegetation layers and ignition likelihood. These inputs of hazard magnitude and likelihood are then used to provide estimates of risk when combined with land use layers and a building stock model that includes building types, and their associated value and vulnerability to hazard events.

Results of this analysis are shown in Fig. 12, which plots total average annual loss (combined across bushfire, earthquake, and coastal inundation) against time for the five scenarios, all considering climate change scenario RCP 8.5. As can be seen, there are significant differences across scenarios in how average annual loss changes with time. *Ignorance of the Lambs* has far higher future potential losses related to the level of the development associated with the scenario, where this development takes place (mostly peri-urban regions) and the construction types associated with the developments favouring cheaper methods. *Silicon Hills*, through its qualitative development, was designed to have the least future risk, however, as shown in Fig. 12, this is not the case. This is due to the degree of development within the region, especially in the port region, which will subsequently be exposed to future flooding from sea-level rise.

Analysis of why these changes are occurring, and the similarities and differences between scenarios, allows for the development of strategies that may work across different alternate futures, making them more robust to future conditions [78,79]. This type of analysis can also support the development of adaptive strategies, such as adaptation pathways, which enable decision makers to consider when to change between strategies as conditions change and adaptation tipping points are met [80,81].

3.4.2. Step 9: analysis and utilisation

Analysis of these results enables identification of risks that are prevalent regardless of scenarios and risks that are more dynamic and

Table 3
Assumptions for scenario quantification of population and employment changes outlining changes in population and employment values from a baseline and what informed the assumption.

	Population and employment change in 2030/2050 compared to 2013 (%)					Motivation				
Element	S.1	S.2	S.3	S.4	S.5	S.1	S.2	S.3	S.4	S.5
Population	27/46	8/15	38/92	19/38	8/15	Adapted from 30 year plan based on storyline	Adapted from 30 year plan based on storyline	Adapted from 30 year plan based on storyline	Projections 30 year plan + extrapolation	Adapted from 30 year plan based on storyline
Population split over urban and rural	70/30[b]	66/34[a] 64/36[b]	80/20[a] 90/10[b]	72/28[a] 75/25[b]	65/35[a] 60/40[b]	Current split	Adapted from current split based on storyline	Adapted from current split based on storyline	Initially current split, adapted based on model results	Adapted from current split based on storyline
Commercial	40/82	−3/5	8/17	8/17	15/30	Developed based on current employment and storyline	Medium projections PSA forecast −10% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation	Average of medium and high projections PSA forecast & extrapolation
Public institutions including education	40/82	−13/−4	9/20	9/20	−13/−4	Developed based on current employment and storyline	Medium projections PSA forecast −20% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast −20% & extrapolation
Industry	34/74	−14/−18	−14/−18	−4/−9	−4/−9	Developed based on current employment and storyline	Medium projections PSA forecast −10% & extrapolation	Medium projections PSA forecast −10% & extrapolation	Medium projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation
Agriculture	−22/−22	5/10	−22/−49	5/26	−22/−49	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	Developed based on current employment and storyline	Medium projections PSA forecast & extrapolation
Horticulture	−22/−22	5/10	−22/−49	5/26	−22/−49	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	Developed based on current employment and storyline	Medium projections PSA forecast & extrapolation
Livestock	−22/−22	5/10	−22/−49	−12/−30	−22/−49	Medium projections PSA forecast, constant after 2030	Developed based on current employment and storyline	Medium projections PSA forecast + extrapolation	High projections PSA forecast & extrapolation	Medium projections PSA forecast & extrapolation

S.1 – Silicon Hills, S.2 – Cynical Villagers, S.3 – Ignorance of the Lambs, S.4 – Appetite for Change, S.5 – Internet of Risk.
NB 1: PSA – Planning SA who provide population and economic projections. 30 Year Plan is the main document outlining Adelaide's strategic plan for the next 30 years in terms of infrastructure and planning, produced by the Department of Planning, Transport and Infrastructure.
NB 2: Livestock, horticulture and agriculture demands held constant between 2030 and 2050 for Silicon Hills is aligned to the assumption of increased efficiency in land use and production and a non-increasing demand for "agricultural-related" land in the region which is predominately metropolitan.
[a] Until 2030.
[b] Until 2050.

Table 4
Assumptions for scenario quantification of land use change based on motivating factors from the scenarios.

	Land use change in 2030/2050 compared to 2013 (%)					Motivation				
Land Use	S.1	S.2	S.3	S.4	S.5	S.1	S.2	S.3	S.4	S.5
Residential (urban)	15/22	1/5	58/146	16/34	0/−1	Densification 10% by 2030, 20% by 2050	No change in density	No change in density	Densification 5% by 2030, 10% by 2050	No change in density
Rural residential	15/22	2/7	−7/−35	7/11	27/55	Densification, 10% by 2030, 20% by 2050	Densification, 20% by 2030, 30% by 2050	No change in density	Densification 5% by 2050	No change in density
Commercial	17/40	0/5	8/17	8/17	15/30	Densification 20% by 2030, 30% by 2050	No change in density	No change in density	No change in density	No change in density
Public institutions including education	8/21	−2/−4	9/20	9/20	−2/−4	Densification 30% by 2030, 50% by 2050	No change in density	No change in density	No change in density	No change in density
Recreation	15/22	2/7	0/0	10/18	0/0	Increase according to increase in residential surface	Increase according to increase in residential surface	No change in surface area	Increase according to increase in residential surface	No change in surface area
Industry	3/9	−14/−18	−14/−18	−4/−9	−4/−9	Densification 30% by 2030, 60% by 2050	No change in density	No change in density	No change in density	No change in density
Agriculture	−6/−14	−2/−4	−22/−49	1/5	−22/−49	Dispersion, 10% by 2050	Originally no change in density, based on model results 15% increase by 2050	No change in density	Intensification, 4% by 2030, 20% by 2050	No change in density
Horticulture	−22/−22	−1/−3	−22/−49	1/5	−22/−49	No change in density	Originally no change in density, based on model results 14% increase by 2050	No change in density	Intensification, 4% by 2030, 20% by 2050	No change in density
Livestock	−22/−22	−1/−2	−22/−49	−16/−33	−22/−49	No change in density	Originally no change in density, based on model results 12% increase by 2050	No change in density	Intensification, 4% by 2030, 4% by 2050	No change in density

S.1 – Silicon Hills, S.2 – Cynical Villagers, S.3 – Ignorance of the Lambs, S.4 – Appetite for Change, S.5 – Internet of Risk.

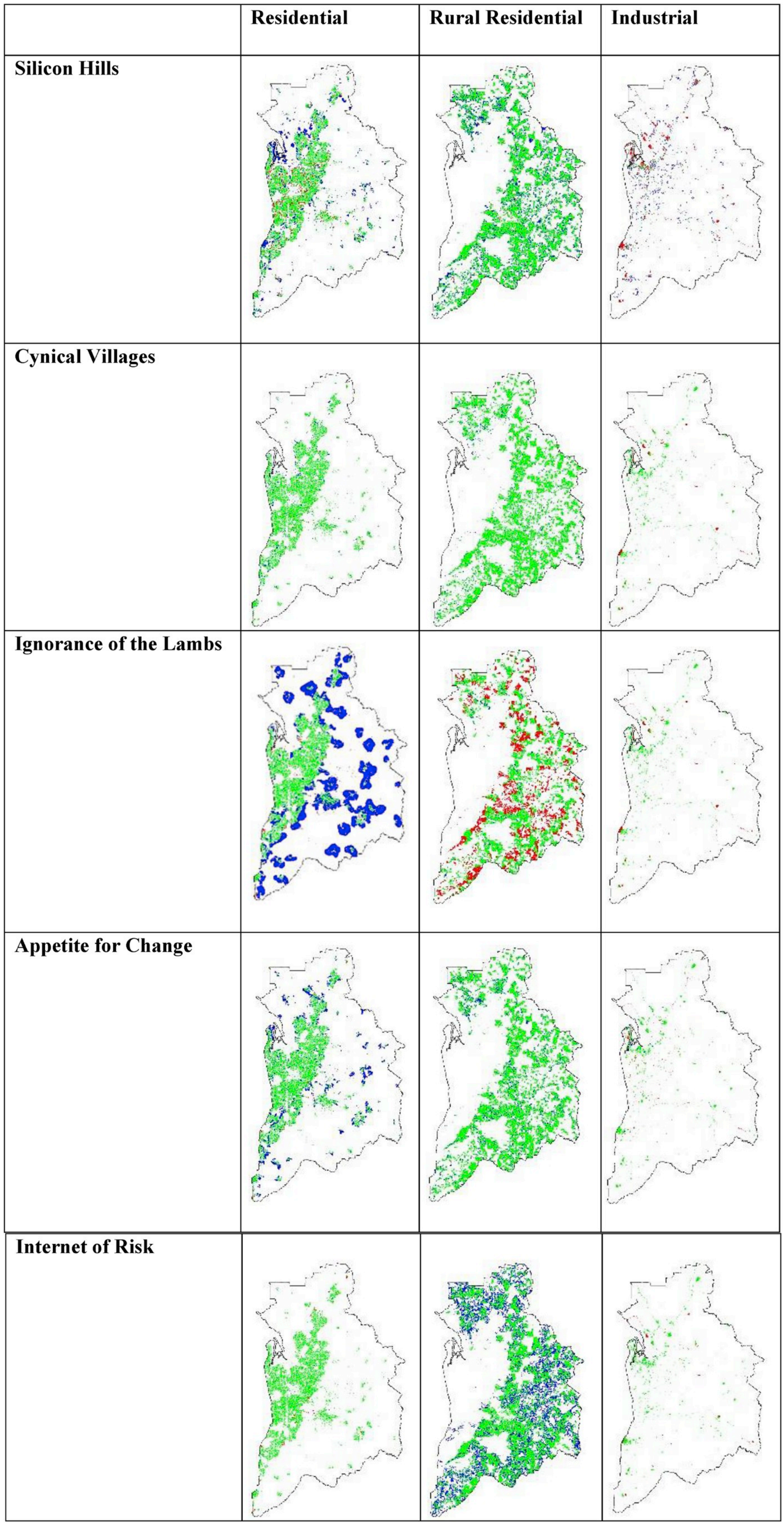

Fig. 11. Changes in land use classes between 2016 and 2050 for each of the five scenarios across urban land uses – residential, rural residential and commercial. Green represents the same land use in both years (2016 and 2050), blue is new land development between years (i.e. new residential development between 2016 and 2050), and red is land decline between years (i.e. residential land use in 2016 and not in 2050). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

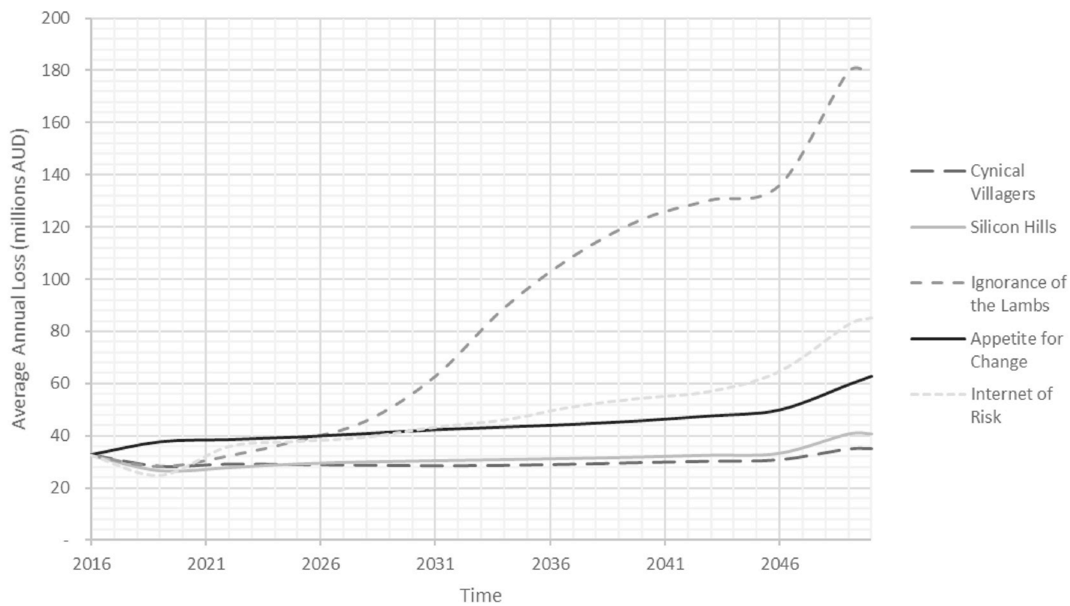

Fig. 12. Plot of average annual loss in millions of Australian Dollars against time from 2016 to 2050.

Fig. 13. Stakeholders during sensemaking workshop discussing model results.

variable. This can then be used to inform appropriate risk treatments and how they perform under a variety of futures. This process of sensemaking enables stakeholders and decision makers to integrate the modelled data into their decision-making context and provides opportunities to discuss strategic responses to future risks, considering what can be influenced and altered over extended planning horizons, and what risks need to be treated with a more tactical approach. Fig. 13 shows the participatory process undertaken in Greater Adelaide, with stakeholders engaging with the scenarios, representing the different socio-economic and risk futures.

Fig. 14 shows visually the difference in risk across the five scenarios based on differences in land use and coastal inundation in the port region, highlighting the need to find an appropriate balance between urban expansion and risk appetite. These figures were used during workshop sessions with stakeholders, with experts engaging with them to compare differences between scenarios and gain an appreciation of the drivers of risk for the region. This process enabled stakeholders to consider the results in an interactive and participatory manner, which is critical to maintain consistent framing around goals – as discussed in Step 1 – and for these results to contribute to the development of integrated and strategic risk treatment strategies and plans. Consideration of the futures was discussed against the indicators identified in Step 1, and summarised in Table 1, and future risk reduction options were discussed in comparison to these indicators for each of the scenarios. Although the process within South Australia has not yet considered the development of risk treatment strategies using the scenarios to inform performance, studies are underway to enable this.

Following Fig. 3, which provides an overview of the approach and its steps, there are also feedbacks from Step 9 to Stage 1 – Problem formulation, and Stage 2 – Scenario development (qualitative elements). These feedbacks are critical to allow both for assumptions made in the beginning of the process to be reflected upon and fed back into the ensuing risk assessment, and for the accounting of the implementation of determined actions, and assessing their effectiveness

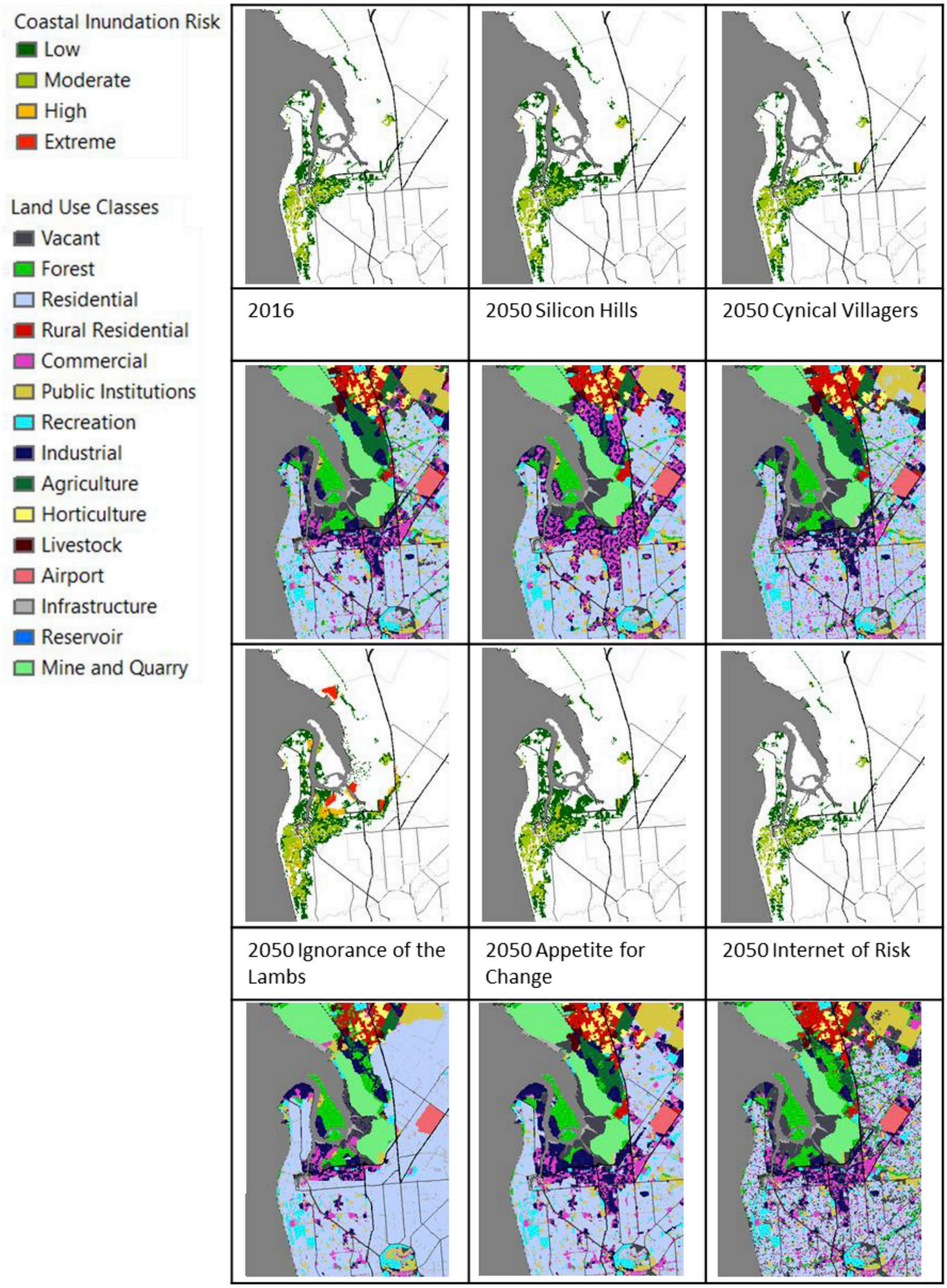

Fig. 14. Coastal inundation risk (first and third figure rows) and land use (second and fourth rows) for 2016, and 2050 for five scenarios.

and how they change the initial context. Although the case study has not, to this stage, allowed for the consideration of these feedbacks given the constraints of the project, it is important to highlight that they should be considered, and efforts will be made to make this scenario planning and risk assessment process iterative across governments within the region.

4. Discussion

In this section, discussion is provided regarding the integration of different perspectives and sources of information during the process, the need for challenging and relevant scenarios when performing this type of scenario analysis to improve understanding, and how this process can be applied to other sub-areas within the entire risk management discipline, including asset-level assessment and providing an understanding on cross-dependencies.

4.1. Combining perspectives to deal with uncertainty and complexity: stakeholders, experts and simulation modelling

A critical component of the methodology was integrating multiple perspectives into the risk assessment process. Consequently, how well this was achieved, and any potential future improvements, are important factors to consider and discuss. The methodology afforded opportunities to bring together different sources of information provided by stakeholders involved in risk reduction activities in the region, experts in scenario analysis and particular elements of the risk reduction planning for particular treatments and hazards, and the outputs from the use of simulation models, which provide quantitative information.

Following the roles outlined in Van Delden et al. [82]; the process relied on the roles of architects and facilitators to manage interaction between different groups providing input to the scenario modelling exercise. These roles were critical in maintaining clear, open lines of communication between all parties and ensuring a ‘common language’ was spoken. Challenging to the process of integrating diverse perspectives on risk and its future drivers is the need in this approach to translate it into model parameters or boundary conditions. To assist in this process, the architect, facilitators and modellers focused on a process of reduction and in aligning each assumption identified within the qualitative scenario process with an element of risk, either hazard, exposure or vulnerability. This ensured each assumption could be traced to a model component within UNHaRMED, highlighting the impact of each assumption on risk overall, and how they could be compared against other assumptions as to their overall significance.

The other significant challenge with this process is the quantification of elements and although mostly stakeholders agreed with the quantification and subsequent representation of the simulated risk scenarios, this process could definitely be improved. There also exist challenges with the representation of information that cannot be quantified and modelled, regardless of approach, and again, how to capture and describe this is an area for ongoing improvement. The method presented within this paper, however, tried to provide a balance of both quantitative and qualitative insight.

The consideration of complexity in the risk assessment process was also strengthened by the integration of different perspectives, as this increased the diversity of views and understandings involved in the ‘establishing context’ steps of common risk assessment processes (see ISO 31000, International Organization for Standardization [83]). By encompassing a broad range of perspectives from stakeholders and experts through participatory processes, factors considered relevant to future risk can be explored, and differing perspectives can be captured through the different scenarios. An example of this was the interaction between risk and an increasingly technology focused world, which could see exposed assets reduced as economic value shifts away from fixed real assets, to technology and software. However, this may result in an increase in an individual's vulnerabilities due to the loss of the concept of ‘place’ and an understanding of the land where residents lived. Similarly, complexity across governance scales was encapsulated and explored by stakeholders across scenarios, with considerations of the interactions between Local, State, and Federal governments for planning, investment and revenue raising all questioned.

4.2. Complexity begets uncertainty: methodological uncertainty in integrated approaches

The approach described and implemented within this paper makes several methodological decisions that also create uncertainty in the outcome, even though the aim is to better understand and reduce these uncertainties. These can be considered methodological uncertainties, which are particularly relevant as an integrated approach, as presented here, brings together a range of methods and techniques from different disciplines, which together lead to the final outcome.

Key methodological uncertainties include the framing of the problem, as this sets the stage for the remainder of the exercise, the stakeholders included and the choice and application of simulation platform for risk quantification and modelling. In terms of problem frame, the funder and project team generally play a crucial role in defining this. This is where the needs for feedbacks from Step 9 to Stage 1 is critical as the introduction of new knowledge through the integrated approach may have altered this.

Considering selection of stakeholders, their inclusiveness and ability to imagine future uncertainties is also a key source of methodological uncertainty. In the case study, the selection was limited to stakeholders from government and NGO agencies, with no community level representatives, due to the governance arrangements of the State's emergency management processes. These are defined by relevant legislation and regulation around emergency management in the region, and thus the project team did not have significant influence on who was included as part of the process. As a result, there is the potential that more weight was added to institutional influence, with visions and objectives of agencies preferred over those of local communities. This is of particular concern if these visions do not align. This, therefore, brings uncertainty into the effectiveness of, especially with regard to the ability to implement, any risk reduction actions and is an uncertainty embedded within the case-study and limitation of the approach if not addressed in subsequent applications.

Related to the selection of stakeholders a key issue is how they are empowered and enabled throughout the process to ensure fair representation. The ability of the facilitator to create an environment that allows stakeholders to express their views and streamline these views is critical but uncertain. For key stages informed by stakeholders, such as the selection of drivers and scenario framing, this can have significant influence on the outcomes.

Another source of uncertainty that the methodology brings into the outcomes is the choice of simulation platform used for quantifying and exploring the risk profiles. Linked to this is also the process for quantifying qualitative information from the narratives (as already discussed in the previous section). In the case study application, Steps 6 and 7 were performed using the UNHaRMED platform, which is specifically designed to explore integrated scenarios of this nature, see Ref. [82]. However, if other specific uncertainties had been determined to be critical to explore, such as economic structure or individual behaviours, other simulation models might have been more appropriate, either as components integrated within UNHaRMED or used independently. The approach described within this paper is not designed to align to a particular simulation model, but instead uses appropriate tools to ensure uncertainty in scenarios is adequately captured and explored. Consequently, decisions on appropriate models should be left until at least Stage 2. Whether simulation model selection and results are appropriate can be tested through extensive engagement with stakeholders, which is why the integration of different knowledge sources is critical. Nevertheless, as part of the practical considerations within each project, the availability of existing or readily adaptable models is often a limiting factor in model selection [84].

These above points have significant influence over the outcomes of the approach and hence decisions made should be taken carefully and in discussion with those initiating the project – for stakeholder selection; and those engaged as stakeholders – for modelling decisions. As with all steps of the approach, transparency is key to developing trust between parties and confidence in results. However, it should be noted that it is an explicit component of the design of this approach to integrate different disciplines and techniques to appropriately explore uncertainties in the outcomes, especially those which arise from the use of a single approach, which commonly occurs for risk assessments and modelling.

Further application of the approach would allow for more testing of outcome sensitivity to these key methodological decision points. This is especially true for application in domains outside of disaster risk assessments which are, necessarily, often constrained by strong regulations and requirements related to risk modelling and disclosures. When these restrictions do not occur in other domains, the implications of these choices should be carefully considered to explore the full degree of complexity, and uncertainty that exists in the system, to hopefully enable more effective implementation of any determined actions.

4.3. Challenging and relevant scenario assumptions for more effective scenario analysis

The value of scenario analysis to inform risk understanding is dependent on the relevance and challenges presented by the assumptions and drivers. Consequently, the methodology presented specifically tries to determine those assumptions that are relevant to the decision context. The one truth of scenario analysis is that the scenario developed, chosen, and/or applied to test the performance of a decision, or uncover vulnerabilities in a system, will never occur exactly as outlined. Instead, scenarios need to be relevant, challenging, plausible, and clear [85]. These conditions aim to ensure the outcomes produce interesting insights into system or decision performance and expose strengths and vulnerabilities. It is for this reason that a limited set of scenarios is presented, in an attempt to demonstrate key uncertainties in a transparent manner, with no associated likelihoods or probabilities. Opportunities were, however, presented to stakeholders to further explore scenarios, their parameters, and how their value impacted outcomes during sense-making processes, as described in Van Delden et al. [82].

As outlined in Section 3.2.3, Fig. 10 shows that participants in the process agreed that the scenarios were representative and appropriately challenging – in terms of judgements on extremity. The commentary provided in Ref. [42] also supports this assessment by considering the content of the scenarios in relation to their ability to include specific challenging assumptions to the performance of risk reduction options. However, with the addition of the quantification and simulation modelling, further insight can be gained from scenario analysis. Simulated scenarios provide significant insight into the impact of land use change on risk. With variations in growth dynamics, the extent of future disaster risks can be altered significantly. Alternative spatial configurations of exposed values over the alternate pathways highlight the role spatial planning can have on future risks, with subsequent impacts on average annual loss clear in both Figs. 12 and 14.

An example of this is the increased exposure and subsequent risk in the vision for the region – *Silicon Hills*. This scenario was developed by stakeholders as the ideal outcome for the region while considering qualitative components. The quantification of this scenario, however, shows that with a stronger economy, particularly in technology related industries, there is increased demand for land and development in high-hazard areas, see Fig. 14. This outcome provides evidence for the need for effective risk reduction options, with active management of exposure and vulnerabilities of new developments by government agencies, to meet the economic vision of the region.

4.4. Further applications of regional risk scenario analysis

Scenario analysis of disaster risk should enable the testing of performance of different strategies and enable planning against different futures. The benefits of understanding future risks as outlined in this paper are significant and it therefore should play a far greater role in a variety of disaster risk processes across the disaster risk management cycle, including through the approach for risk assessments shown in this paper. Scenario analysis has been introduced in the risk assessment space with the recent call from the Taskforce on Climate-related Financial Disclosures (TCFD) to use scenario analysis to consider exposure to climate risk from both a transition (risks arising from the transition to a low-carbon economy) and physical (risks arising from climate trends and shocks of disasters and extreme weather events) perspective [86]. These efforts should be continued, however, with a particular focus on developing scenarios that are challenging for organisations under future climate regimes and extremes.

The application of the methodology proposed and demonstrated in this paper allows for the consideration of both transition and physical risk aspects, given their relationship when considering risk as the combination of hazard, exposure, and vulnerability is critical. The integration of perspectives, and participatory process of both scenario development, along with consideration of simulation modelling, is also important when assessing climate-related risks, to enable organisations to consider cross-dependencies and complexities in their supply-chains and markets in a systematic and repeatable manner. Critical assets could also be considered using the methodology outlined by overlaying their specific location, use and vulnerabilities onto future risk mapping. This can provide insight into the asset's future exposure to disaster risks, along with insight into the potential increased dependencies on it, for example, the change in households dependent on an electricity substation.

This paper has focussed on its application to disaster risk assessments and this section of the discussion has broadened this to consider hazard and climate-related risks for a range of users and implications, however, its use could be broadened (even) further. The proposed approach in Section 2 focusses on incorporating complexity and uncertainty into risk assessment processes and this presents opportunities to consider other dimensions of risk, such as the impact of new technology or policy decisions and how they could impact on societal development. In an overarching sense, scenarios provide a mechanism to support the assessment of potential and emergent risks. Challenges, however, still exist in the construction of these scenarios so that they are of most value to the assessment process – with this approach heavily focussed on the spatial assessment of disaster risks – but similar considerations would need to be taken for other domains.

5. Summary and conclusions

This paper proposed an approach to integrate different types of information and insight through exploratory scenarios into the risk assessment process relevant to the levels of uncertainty and complexity required for planning for a future with reduced disaster risk. This was in response to the need for such an approach incorporating the broad and critical uncertainties and complexity that impact disaster risk and the effectiveness of actions trying to reduce tomorrow's risks. Tomorrow's risk is being created today and it is hoped that the exploration of various alternatives provides policy makers a broader understanding of the dynamics of risk and the power of their influence and actions.

The approach undertaken in this study to achieve this was to develop, in a participatory manner with representatives of multiple agencies, and respective opinions, scenarios designed to challenge common responses to disaster risk. This created futures which were challenging and relevant to the study's objectives, and by using quantitative modelling to assist this process, the scenarios become plausible future conditions under which to test the effectiveness of solutions against common, and agreed upon, metrics. The scenarios therefore become future stressing conditions under which to test risk reduction options, and UNHaRMED, the software used to facilitate this analysis, acts as a 'policy wind-tunnel' with the scenarios as simulated conditions testing the performance of designed solutions.

To illustrate the approach and its utility, scenarios were developed that represented plausible developments for Greater Adelaide, Australia, highlighting both challenges and opportunities for the region as it deals with future disaster risk. The integrated manner of these scenarios, considering various drivers for change in the region, allows for a more comprehensive consideration of risk. The results presented particularly emphasize the role of exposure in the calculation of disaster risk. Managing exposure to risk is one of the most powerful mechanisms to reduce future risk and in urban environments, as it is critical to consider future land developments. This process, however, is only the beginning of a true scenario planning process, with these results needing to be embedded within broader policy and strategy development process, which is why the approach is deliberately designed to be embedded within such processes.

This area needs continued research, and effort will continue to be placed working with stakeholders involved in this study on how to best integrate the insights offered by scenario development and analysis into standard policy processes for disaster risk reduction. Further efforts need to also be made in developing models, and systems of models, to enable the testing of assumptions and the effectiveness of policy responses on disaster risk. This study was performed using specifically designed simulation models, and continued development is needed to enable existing risk models to consider future drivers of risk and policy and investment strategies to influence that risk.

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