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UNHARMED FRAMEWORK REPORT:

A co-creation approach for the development and use of decision support systems for disaster risk reduction

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EXECUTIVE SUMMARY

This report proposes a generic approach for the development and use of decision support systems (DSSs) for disaster risk reduction (DRR). At the core of the DSS is an integrated model, consisting of a land use model and risk models for four hazards, including flooding, coastal inundation, bushfire and earthquake. The inputs to these models are affected by a number of external drivers that change over time, including demographics, climate change and economics, as well as a number of mitigation options, including spatial planning, land management, structural measures and community-based resilience efforts. The outputs from the integrated model include risk maps for the individual hazards that change over time, as well as cost-benefit, social and environmental indicators used for assessing the impact of risk reduction portfolios.

In addition to the generic structure of the DSS, this report outlines a generic process for the development and use of DSSs. While three prototype DSSs were developed for user-defined case studies as part of this CRC project - Greater Adelaide, Greater and Peri-urban Melbourne and Tasmania - the purpose and impact of this project go beyond these individual case studies in terms of developing capacity and appropriate processes that enable DRR DSSs to be developed elsewhere.

The separation of the development and use processes ensures adequate feedbacks between phases resulting in a more user friendly and applicable DSS for each case study as well as a more robust generic DSS through reapplication and continuous testing. There is a particular focus on ensuring end user engagement throughout the development phase such that the general DSS has the capacity to simulate key factors of pertinence to end users and ensuring the system is relevant to the policy decisions faced by these policymakers. There is a similar focus on engaging with stakeholders throughout the use phases to develop tailored indicators and scenarios which can test particular areas of interest and uncertainty to the stakeholders involved with the case studies.

The development process as a whole is focused around *A Methodology for the Design and Development of Decision Support Systems* as provided by Van Delden et al. (2011a). This looks to form collaborations between scientists, end-users and IT-specialists facilitated by a central architect, who is common across both the development and use phases. The process involves defining the scope of planning processes, development and selection of appropriate models and the integration of these models in an attempt to bridge the science policy gap, by enabling scientific principles and approaches influencing policy development.

This is then extended with the use process as stakeholders interact with modellers and facilitators to ensure the DSS is case specific to their region and policy questions. The integrated modelling framework can then be used to consider exploratory scenarios as developed through the interaction between end-users, modellers and facilitators. These scenarios allow the exploration of plausible, alternative futures to test the performance of mitigation portfolios and thus support the selection of risk reduction portfolios that align with overall regional development strategies.

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GLOSSARY

Actor: Individual or entity with the capacity to effect and / or influence change.

Algorithm: Set of step-by-step instructions that guide a computer in solving a set of equations.

Application: See Case study specific DSS.

Application process: Process of applying the generic disaster risk reduction DSS to a specific case study by selecting drivers, models, and indicators; by populating the models with data; and calibrating model parameters.

Average recurrence interval (ARI): The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that the periods between exceedances are generally random (Bureau of Meteorology, 2019).

Case study (specific) application: See Case study specific DSS.

Case study specific DSS: Application of the generic natural hazard risk reduction DSS to a specific case region. Case regions in the BNHCRC project are Greater Adelaide, Greater Melbourne and Tasmania.

Champion: Power user who actively stimulates the uptake of the DSS in their organisation. Champions seem to be personally inspired, and their actions in turn inspire behaviour of others. They often fulfil a critical role in increasing the practical value of the system as they have a direct link to the users.

Computer model: Set of equations that represent the interactions between the various components of a real system and that can be solved using a computer algorithm.

Decision support system (DSS): An interactive software system that provides information from data and models in such a way to support decision makers to more effectively solve decision problems (Van Delden et. al., 2011a).

Development process: The way DSSs for natural hazard risk reduction are developed. This involves the whole process related to the development of the modelling framework. This is a complete, and standalone software tool that can be tailored for use to a case study by a software engineer or modeller who populates the generic DSS with data and configures selected models within the generic DSS.

Disaster risk: 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, 2017). For disaster risk captured by models shown within this approach and report, capacity is not treated explicitly but instead is a component of either the hazard or vulnerability model for respective risks.

Disaster risk assessment: 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, 2017).

Disaster risk reduction (DRR): The prevention of new and reduction of existing disaster risk and management of residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development (UNGA, 2017).

Disaster risk reduction DSS: A modelling framework for disaster risk reduction that is generic and flexible enough to be applied to different case studies. This framework includes an extensive suite of drivers, models, indicators, analysis capability and/or decision science capabilities found useful for disaster risk reduction.

Exploratory scenarios: Plausible alternative futures that consider long time-frames, multiple drivers and multiple perspectives. Exploratory scenarios can be used to answer the question “what could happen?” under different future development pathways. They are meant to trigger out-of-the-box thinking and go beyond the possibility space into the broader plausibility space (Borjeson et al., 2006, Maier et al., 2016).

Generic DSS: See modelling framework.

Geonamica: A software platform that facilitates the integration of models, controls the execution of the integrated models when the DSS is running a simulation, and provides a collection of graphical user interface components to more rapidly build DSS interfaces (Hurkens et al., 2008).

Hazard Occurrence: The occurrence of a hazard event (that is, a natural phenomenon that takes place, which poses danger to people, communities, property, infrastructure or the environment) of a given magnitude, with a given spatial extent.

Land cover: The observed (bio)physical cover of the earth's surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished - basically, areas of vegetation (trees, bushes, fields, lawns), bare soil (even if this is a lack of cover), hard surfaces (rocks, buildings, other urban infrastructure) and wet areas and bodies of water (sheets of water and watercourses, wetlands) (based on Di Gregorio & Jansen, 2000).

Land use: Characterisation of a territory according to its functional dimension of socio-economic purpose. For example, areas may be used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. Land use is related to land cover; it may be possible to infer land use from land cover and conversely. But situations are often complicated where the link between land use and land cover is not so evident (based on European Commission, n.d.).

Methodological framework: A high-level conceptualisation of how something is achieved. For example, this report describes a methodological framework for DSS development and use, and therefore describes our approach for developing a natural hazards DSS and applying it to case studies.

Metronamica: A spatially explicit land use model used as a forecasting tool for planners to simulate and assess the integrated effects of their planning measures on urban and regional development (Van Delden and Hurkens, 2011).

Modelling framework: A suit of models, with their (inter)connections, and user-interface components, for a specific purpose, which can be selected and applied to a specific (geographical) area. For this project this entails the generic DSS for disaster risk reduction that includes a suit of socio-economic, land use, hazard and indicator model components, with their feedbacks and user interface components. This is the same as the Generic DSS.

Participatory techniques: A combination of techniques used to stimulate and catalyse stakeholder engagement and elicit critical information for the technical groups. This can involve questionnaires, interviews and workshops that employ activities such as brainstorming, clustering and group discussion.

Party: Group of actors.

Prototype DSS: Preliminary delivered software applications used for demonstration, learning and feedback. Prototypes can relate to both the generic disaster risk reduction DSS, as well as the case study specific DSS. As final deliverables for this project are prototype DSSs, we distinguish between preliminary prototypes that are being developed as preliminary versions of the prototype to be delivered and the final prototype, which is the deliverable.

Quantitative analysis: A combination of statistical and trend analysis to complement and assist in model calibration, scenario development, and bridging the science policy gap.

Risk reduction portfolio: A combination of risk reduction options.

Scenarios: A set of consistent, plausible assumptions about future states of the system of interest (Maier et al., 2016).

Simulation model: A computer model that starts with a set of initial conditions and simulates future development in subsequent time steps based on (a number of) drivers, taking into account the forces of action and reaction and incorporating the accompanying feedback loops between them (adapted from Van Delden et al., 2011a).

Stakeholder: individuals or entities who are either involved in making or are impacted by a decision (Freeman, 2010).

Statistical area: A geographic region defined for the purpose of statistical data collection.

UNHARMED: The generic DSS developed as part of this BNHCRC project and which has the characteristics as described under disaster risk reduction DSS.

Use process: The way the DSS is used in support of the selection of risk reduction options for disaster risk reduction. This process involves scoping a use case, tailoring of the pilot to a case study, forming a prototype DSS, creating scenarios and designing risk reduction options, running simulations with the DSS and making model results useful for policy support. It takes a broad view of use including workshops, etc., incorporating many components of the policy making process.

1 INTRODUCTION

Natural hazards are likely to increase in frequency and magnitude over the coming decades. While the current cost of disasters in Australia averages around AU$6.3 billion per year, this is expected to grow at an average rate of 3.5% annually in real terms, due to the concentration of wealth and economic development in urban areas (Deloitte Access Economics, 2013). Climate change is expected to cause the growth rate to be even higher than this (IPCC, 2014).

The ability to consider effective risk reduction is critical given the potentially enormous social and economic losses due to hazard impacts. However, developing and implementing long term risk reduction schemes is often difficult for various reasons: decision makers tend to invest in works with clear short-term benefits, the perceived risk attributed to disasters is prone to inaccuracy as disasters are relatively infrequent, the people influencing risk reduction activities may have little personal experience to guide their evaluation, and risk reduction budgets are always limited. Therefore, selecting the optimal trade-off of risk reduction options can be very difficult.

Decision support systems (DSSs) can be advantageous in helping overcome these obstacles, because of their analytical capabilities to combine various sources of information and support trade-off analysis. However, DSSs for disaster risk reduction have so far tended to focus on disaster preparedness and the immediate and post-crisis response to emergencies.

The Bushfire and Natural Hazard Cooperative Research Centre (CRC) is funding the project "Improved decision support for natural hazard risk reduction". This has the aim of developing user-friendly, computer-based prototype decision support tools that enable the assessment of different policy and planning options with regard to their impact on various economic, environmental and/or social objectives. These decision support tools are applied to three end-user defined case studies. The DSS enables the identification of the preferred hazard risk reduction options, thereby increasing disaster preparedness, as well as reducing disaster impact and the cost of disaster response and recovery.

Consequently, the specific objectives of the project are:

1. To develop a systematic and transparent approach for sifting through, evaluating and ranking disaster risk reduction options using analytical processes and tools.
2. To develop prototype decision support software tools that implement the above approach for three end-user defined case studies, Greater Adelaide, Greater and Peri-urban Melbourne and Tasmania.

The project outcomes are:

1. Demonstration of a systematic and transparent approach for evaluating disaster risk, and risk reduction options.
2. The ability to make more strategic and less responsive decisions in relation to mitigating the impact of disasters and in particular natural hazards through the availability of better information.
3. The ability of prototype DSSs for three case studies to enable recommended options to be identified by sifting through and evaluating a large number of options and combinations of options.
4. A better understanding of the trade-offs between economic, environmental and/or social objectives for various risk reduction options for three end-user defined case studies.

This report focuses on a generic approach for the development and use of DSSs for disaster risk reduction. The report initially presents an overview of the overarching concepts of the approach and highlights where and how the development and use process interact. Following this, the development and use processes are described in more detail and illustrated using examples from the Greater Adelaide, Greater and Peri-urban Melbourne and Tasmanian case studies and the pilot modelling framework that is being developed as a generic software system and applied to specific case studies. The final chapter describes the interaction between the development and use process and highlights how and where this interaction takes place. The generic approach and the accompanying modelling framework have been enhanced throughout the project based on the lessons learned from the development of the prototype and its application to and use in the three case studies and this report provides an updated version of the approach based on the lessons learned.

2 OVERARCHING CONCEPTS: CONNECTING DEVELOPMENT AND USE

The approach for the development and use of the disaster risk reduction DSS is focused on the creation of (1) a well-integrated modelling framework along with (2) a social-learning process aimed at capacity development around the effective application of the system to best assist policy development and planning. Based on these two outcomes, this report proposes a methodology for both development and use of the DSS, as outlined in this chapter. Figure 1 provides an illustration of the methodology, with the development process shown on the left-hand side and the use process on the right-hand side. Both are briefly explained below and further detailed in the following chapters.

> **Aim of "development"**: To deliver a disaster risk reduction DSS that is generic and flexible enough to be applied to different case studies. The developed system has a multi-hazard focus, is targeted towards long-term planning, and allows assessment and ranking (combinations of) risk reduction options under critical uncertainties. The developed system incorporates an integrated dynamic spatially explicit simulation model to assess the impacts of risk reduction options on a range of hazard, social, economic and environmental indicators.

As shown on the left side of Figure 1, DSS development is an iterative loop around three key processes and four distinct parties or groups of actors. *Scientists*, *IT-specialists* and *end-users*, facilitated by a central *architect*, complete specific tasks with continuous feedback to ensure a robust and scientifically sound final product. *Scientists* are responsible for the modelling of the main processes along with answering questions regarding scale and resolution for appropriate accuracy of the system. They are supported in this endeavour by *end-users*, who provide policy relevant questions and scope for the modelled processes, deliver policy context and define the overarching policy problems. *IT-specialists* develop and implement software technology with support from *scientists* in relation to model integration and support from *end-users* in relation to what is required from the software to be most effective for policy support. These processes and responsibilities are given further detail in Chapter 3.

> **Aim of "use"**: To provide support to the selection of risk reduction options for natural hazards. The use process includes a combination of scenarios, quantitative analysis, simulation modelling, and stakeholder deliberation techniques to assess and discuss the impact of risk reduction options on performance indicators under various scenarios and risk reduction portfolios. The Disaster Risk reduction DSS, applied to a specific case study, is used in this process for the technical assessment and evaluation of the risk reduction options. It also facilitates communication amongst the actors involved through its integrative nature and visualisation capacities.

It is important to consider the use of the DSS in conjunction with its development to ensure both align. As shown in the right-hand side of Figure 1, *Stakeholders*, *Modellers* and *Facilitators* work together with an *Architect* to provide support to disaster risk reduction. Stakeholders provide aim and focus of the use case, potential risk reduction options they consider to be feasible, and related performance metrics to assess the impact of these options. The process also includes facilitated discussions regarding the identification and development of scenarios to explore alternate, plausible futures, which are critical in the determination of robust and/or adaptive risk reduction portfolios. This requires qualitative and quantitative input from *end-users* to be translated by *modellers* into model parameters (including temporally varying drivers and boundary conditions) to explore these alternative futures within the DSS domain. *Stakeholders* can then use the model results to strengthen the internal consistency of their scenarios and to obtain analytical support in ranking risk reduction options. *Facilitators* collaborate with *modellers* and the *architect* in designing appropriate participatory activities and in supporting the use of the software by non-technical users to ensure model assumptions and limitations are clear and explicit. These processes are further elaborated on in Chapter 4.

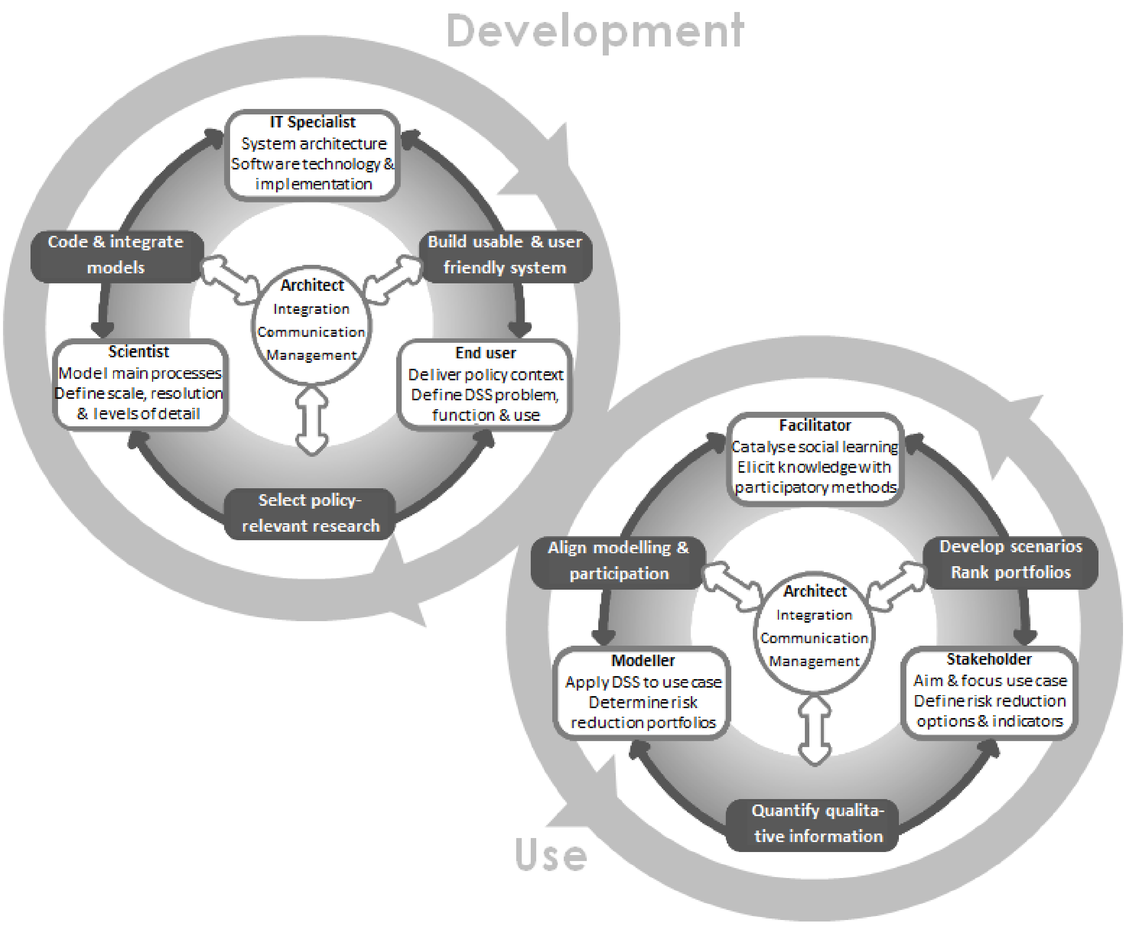


Figure 1: *The development and use processes of a DSS as separate, but closely linked processes.*

Throughout the life cycle of the DSS, development and use are separate processes, although they are closely interconnected and interdependent. During the development phase, the DSS modelling framework is designed and implemented, while in the use phase the DSS modelling framework is applied to a specific case study, by including case study specific (hazard) models, data and parameters; and it is used for specific scenario and impact assessment studies. In the early stages of the DSS life cycle, more effort goes into the development of the system, while in later stages the focus is on its use. The importance of including potential use of the system during its development is that it provides direction to the development and ensures that the final DSS will be able to support relevant use questions. It also allows evaluation of prototype systems on user requirements and can direct further development and fine-tuning of the system based on this. Moreover, involving users from the start of the development process creates support in the user group for using the system. Once the DSS has evolved into a functional pilot system, the developed system provides the boundary conditions for the type of support that can be given with it and the questions that can be answered within the limitations of the developed DSS. In case these conditions are too narrow, and limitations are found to be too severe, this can lead to further development of the system.

Development and use of a DSS for disaster risk reduction is very interdisciplinary and as a result also includes the application of a number of rigorous scientific methods and participatory techniques. The combination of modelling, quantitative analysis, and literature review, coupled with participatory inputs within each process allows the DSS to not only be scientifically sound, but also most relevant to decision makers and their respective policy contexts. The methodology detailed in the next chapters explains who is involved in which steps of the approach, which techniques are applied during which parts of the process and for what reason.

3 DSS DEVELOPMENT PROCESS

The main aim of the development process is to deliver a generic DSS that provides support to disaster risk reduction and is sufficiently generic and flexible to be applied to various regions and problem contexts and can thus be used to develop case study specific applications. Such a DSS incorporates an integrated simulation model with a model library consisting of spatially-explicit and dynamic model components for hazard, exposure, vulnerability and risk, exposed through a user-friendly and intuitive graphical user interface.

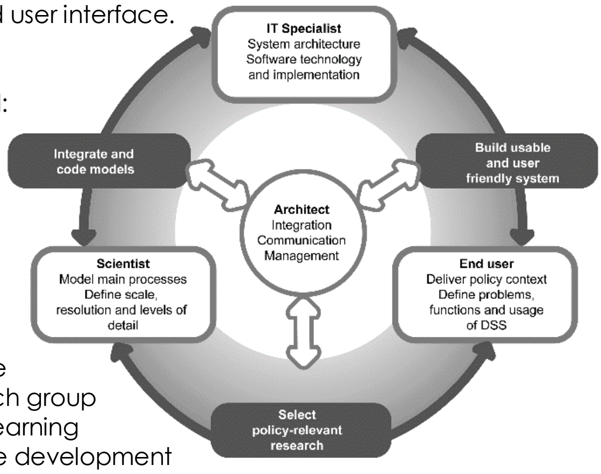
The development process is based on the *Methodology for the Design and Development of Decision Support Systems* as provided by Van Delden et al. (2011a) and adapted to fit the hazard risk reduction context. In the remainder of this chapter, the underlying methodology is highlighted in boxes and the adaptation of this methodology to the disaster risk reduction context is described in the text. This is illustrated with examples from the prototype system of the DSS developed as part of the project and named UNHARMED (Unified Natural Hazard Risk Mitigation Exploratory Decision support system) and its applications to Greater Adelaide, Greater and Peri-urban Melbourne and Tasmania.

3.1 ACTORS INVOLVED IN THE DEVELOPMENT PROCESS

As can be seen in Box 1, there are three main groups of actors involved in DSS development (*end-users*, *scientists* and *IT-specialists*), with each group fulfilling different roles throughout the process.

Box 1: Parties and roles in the development process

The development process can best be described as an iterative process of communication and social learning amongst three involved parties: 1) *End-users* of the system, who provide the policy context and define the policy problems and process, 2) *Scientists* (or other experts) responsible for the main model processes, assumptions and choices of scale, resolution and level of detail and 3) *IT-specialists* who design the system architecture and carry out the software implementation of the models and user interface.



Several decisions are made in group processes in which one party takes the lead: *Scientists*, together with *end-users* and *IT-specialists*, build effective linkages between the individual models, and *end-users* together with *IT-specialists* and *scientists* decide on relevant components to include in the user interface.

The interaction between the three groups involved is as important for the quality of the final product as the tasks carried out by each group individually. This interaction enables social learning between all involved, which is crucial for the development of a useful and user-friendly DSS. The *architect* has an important role in bringing all groups together, creating mutual understanding and respect and keeping the focus on the final product throughout all phases of the project.

A first group of *end-users* comes from organisations involved in disaster risk reduction that ideally includes one or more organisations with a multi-hazard focus. In addition, it is useful to identify groups who can make decisions or influence decisions related to risk reduction options, such as e.g. land use planners or governmental agencies in charge of zoning regulations or infrastructure development.

The *scientist* group includes people involved in data collection, analysis and modelling of various hazard risks, impact assessment of risk reduction options and understanding drivers of hazard occurrence and consequence. To be able to include different aspects of hazard occurrence and consequence, scientists from different disciplines should be included, such as engineers for structural risk reduction options such as levies and building codes, natural scientists for the impact of climate change on flood risk, economists for the economic implications and behavioural scientists looking at the impact of community education and awareness programs on the occurrence and impact of hazards.

IT-specialists are often people with a background in software architecture and development, coming from either research, commercial or in some cases user organisations.

The *architect* is responsible for bringing together the different expectations, desires and expertise in order to deliver a DSS that meets potential user requirements across the various regions and problem contexts to which it could be applied, while ensuring the system remains robust and scientifically sound. The role of the architect is ideally carried out by a person or a small, core team that leads the entire development and use process during and beyond the project. Required expertise in this core team is the ability to oversee the entire development and use process, to communicate with the different groups involved and facilitate interaction between them in order to establish social learning in a collaborative environment towards developing a transdisciplinary system and accompanying use approach.

3.2 ITERATIVE AND PARTICIPATORY DEVELOPMENT CYCLE

An iterative process is used for developing the DSS, in which the system evolves through a scoping phase and a number of prototypes into a final product (Figure 2).

As mentioned previously, in the BNHCRC project this occurs through three case study applications of the generic DSS. Based on the lessons learned from these case study applications, the generic DSS is continuously being further developed and enhanced.

We distinguish the following tasks and issues in this development process:

1. Scope definition
    a. Who is going to use the generic DSS and its applications, what for, and what added value does it provide?
    b. What are relevant themes, issues, disaster risk reduction options (structural, management, policy), external drivers and performance indicators?
2. Model selection
    a. What processes are included in the integrated model?
    b. How are these processes represented in the integrated model?
3. Model integration
    a. How do the individual models operate together? What feedback loops are included?
    b. How do we deal with models with different spatial and temporal scales and modelling paradigms?

4. Bridging the science-policy gap
    a. How do we translate scientific knowledge into policy relevant information?
    b. How do we facilitate social learning amongst the groups involved?
5. User experience (UX) design and development
    a. What are the best ways to balance ease of use with flexibility?
    b. How do we best visualize modelling results?

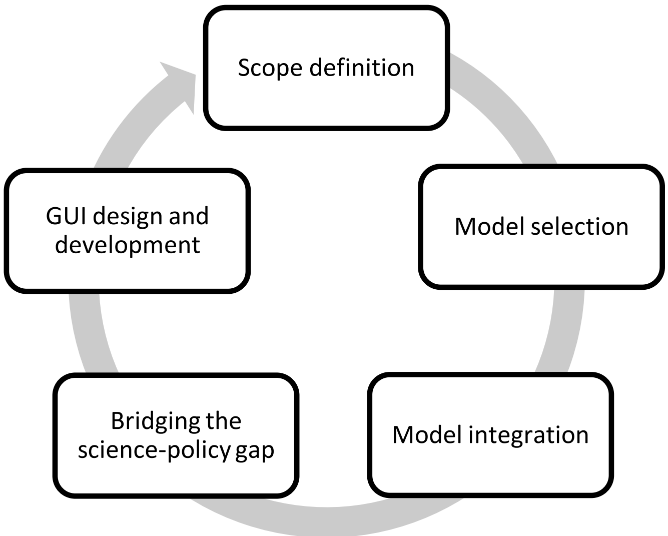


Figure 2: *Tasks in the dss development process (carried out iteratively).*

It should be noted that these five tasks need not (and often cannot) be executed in a strictly sequential order. After each of these tasks, an evaluation needs to be carried out to assess what adaptations to previous tasks should be made. This evaluation is to a large extent carried out based on feedback from using case-study specific prototype DSSs, which have been tailored from prototypes of the generic DSS, within decision making processes, and assessing whether the current system provides sufficient support to relevant use cases. This discussion, and actions resulting from the discussion, play a vital role in the implementation of DSSs in user organisations and can be facilitated by *champions* (See Box 2).

Box 2: The value of champions

In practice, many development trajectories that include users focus on the factual elements of policy making (e.g. policy options, indicators, etc.), while the institutional, cultural, and personal issues are often forgotten or neglected. Like any decision-making process, DSS development, as well as the decision to use a DSS, depends on individual preferences and includes human emotion and imagination. The individual plays a central role as creator, actor and carrier in the decision-making process and organisational decision processes are often driven by the forces of affect, insight and inspiration of these decision makers acting collectively (Langley et al., 1995). This makes the role of champions crucial in the design and development process and especially during the implementation. Our experience teaches us that champions seem to be personally inspired, and their actions in turn inspire the behaviour of others. Common characteristics identified by champions is that they are visionary people with a good network within their organisation (and often beyond) and a high interest in exploring new techniques, the latter facilitating communication with the developers and in particular the architect(s).

The interaction between the *architect* and the *champion* plays an important role throughout the design, development and implementation phase. The *champion* is the direct link to the users and the *architect* is the direct link to the development team. To succeed, both should gain the respect of the *users* and the development team, trust and rely on each other, and have excellent communication between each other.

"Pitfalls in the development process are a lack of respect between and within the different groups, a focus on the individual work instead of on the collaborative product and miscommunication or a lack of communication" (Van Delden, 2011a). All too often, different groups think they understand each other, while they are actually talking about completely different things. To overcome these pitfalls in this project, frequent interaction between the various groups has taken place and, furthermore, a strategy paper was developed and maintained throughout the development of the DSS describing the current status and planned development of the DSS.

3.2.1 Scope definition

The aim of the scoping task is to define the focus of the overall system, as described in Box 3.

> **Box 3: Scoping**
> The scoping task relates to the context of the DSS, as well as its intended use, and is ideally guided by the users. It is the main guideline for the design and development of the DSS. Over time this focus can be further fine-tuned or adapted, but very often drastic changes in the scope result in major adaptations of all tasks that need to be carried out. On the other hand, experience indicates that it is hardly ever possible to define a full set of system specifications at the beginning of the process. An iterative process is required that allows for fine-tuning at later stages, together with adaptations to the initial ideas once prototypes are developed, and a better understanding of the possibilities and limitations is obtained. Strategy papers help in specifying the issues raised and decisions made and in communicating them to all involved parties. When updated throughout the design and development process, these documents can become an important backbone of this process. At the end of the scoping task, it should be clear what added value the DSS could and should bring to the current practice and, given the time and financial resources for the development process, what is the best way to reach this goal.

Scoping for the DRR-DSS developed in this research project started during the research proposal phase of the BNHCRC, in which the overall context was developed by a key group of actors representing all roles during the initial conception of this work and then further refined through scoping workshops in each of the three regions for which applications were to be developed. Actors involved in this represented 39 agencies across the three states representing central agencies such as Department of Premier and Cabinet and Department of Treasury and Finance, respective emergency management departments and response agencies (e.g. fire and emergency services providers) and departments responsible for planning and regional development. This process resulted in the following statements outlining the aims of the generic DSS:

> *To provide a systematic and transparent approach to sifting through, evaluating and ranking disaster risk reduction options using analytical processes and tools, in particular a spatially explicit integrated simulation model.*

Through review of the literature and a series of stakeholder workshops for three case studies, this aim has been translated into concrete requirements for a generic software tool. This includes the choice for an all hazard approach and the selection of risk reduction options, external drivers and indicators for which an overview is provided below. For each item, we provide a generic description followed by specificities for the UNHARMED system and/or its development process to illustrate the generic approach.

Drivers

Drivers are split into (1) external drivers, which cannot be affected by policy makers and planners making decisions on the case study under consideration and (2) risk reduction and planning options which can be affected by policy makers and planners.

Climate and socio-economic developments are obvious exogenous drivers for most risk-focused systems, while risk reduction options normally fall within the following categories: structural, land management, land use planning, education and awareness and regulatory measures (Bouwer et al., 2014; Godschalk, 2003; Lyles et al., 2014).

In UNHARMED, drivers to include are specific for each application. However generic external drivers (1) considered relevant across all applications are:

- Climate: Maps and/or graphs with various relevant climatic variables for hazard dynamics which can be entered exogenously through the user interface.
- Economic development: Considered through adapting trendlines for land use requirements for economic activities.
- Population development: Considered through adapting trendlines for land use requirements for residential development.

Risk reduction and planning options (2) included in the prototype UNHARMED DSS are provided in table 1.

Performance indicators

Performance indicators represent quantifiable measures against which policy options can be assessed. Tracking indicators allows to assess the impact of an option against a scenario of no action. It also allows for a performance measure to be tracked against time to see how it changes under external drivers (1) not just risk reduction and planning options (2).

Indicators are scoped in a participatory manner to ensure policy relevance of the generic DSS. Ideally the generic system provides sufficient flexibility to select and tune indicators for optimal relevance to the specific context and its users.

For risk assessment and reduction, a set of performance indicator groups should be specified within which indicators (i.e. key policy-relevant simulation outputs) will need to be determined according to the scope of the DSS. These include:

- Indicators to assess the risk, as well as the underlying exposure, vulnerability and hazard, in units that allow for a comparison across the various hazards, e.g. average annual loss, economic loss due to specific hazard events, and number of fatalities.
- Economic indicators, such as a cost-benefit assessment of the cost of mitigation options versus their benefits in reduction of losses and the wider economic implications of mitigation options (e.g. increased travel costs due to prohibiting development in hazard prone areas as well as relocation or buy-back schemes).
- Socio-cultural indicators, such as the number of vulnerable people living in areas at risk, as well as the impact on indigenous communities, but also the wider social implications of risk reduction options, e.g. visual implications of structural measures on the landscape.
- Environmental indicators, such as the threatened species living in areas at risk, as well as the implications of risk reductions options such as planned burns on biodiversity.

The breadth of the indicators depends to a large extent on the scope of the DSS. A DSS to support disaster risk reduction likely has a scope that is narrower than a system aimed to support overall regional development with disaster risk reduction being an integral part of that.

Performance indicators selected for inclusion in the UNHARMED prototype are provided in Table 1.

Table 1: Selected risk reduction options and performance indicators included in the UNHARMED prototype

Risk reduction option	Natural Hazard	Risk component affected	Performance indicator
• Reduction of fuel load via: prescribed burns, vegetation clearing and changes in vegetation types	• Bushfire	• Hazard	• Value at risk • Cost of risk reduction options applied • Classified risk (hazard specific map with risk categories e.g. low, medium, high) • Average annual loss per hazard • Total average annual loss • Cost-benefit of risk reduction portfolio over simulation period • Socio-economic and environmental impacts
• Changes to the vulnerability of buildings, reflecting the impact of building code changes (i.e. raising minimum floor-levels or building strengthening)	• Bushfire • Earthquake • Riverine flooding • Coastal inundation	• Vulnerability	
• Arson reduction through education and awareness	• Bushfire	• Hazard	
• Construction of structural measures such as floodgates / storm-surge barriers, sea-walls and levees	• Riverine flooding • Coastal inundation	• Hazard	
• Spatial planning, zoning regulations to stimulate, prohibit or discourage development	• Bushfire • Earthquake • Riverine flooding • Coastal inundation	• Exposure	

3.2.2 Model selection

When establishing the scope, it is often necessary to strike a compromise between catering to current problems and those that could arise in the future, requiring the developed DSS to have a certain degree of flexibility (Van Delden et al., 2011a). Therefore, it is important to aim for a level of abstraction in the design that allows for a broader application of the system than simply to the specific region(s) and use cases under consideration. Consequently, considering DSSs for a number of different geographical regions and use cases as part of the development process helps to make the system more generic in its design, as it provides concrete examples of the types of features to be included in the generic structure of the DSS, while clarifying what parameters will need to be tuned based on the context and area of application.

In relation to the development of UNHARMED, to increase flexibility and generality, a framework for social, economic and environmental indicators consisting of a set of algorithms that can be used to create and tune indicators to application specific contexts was included, as was the ability to include additional hazards. Furthermore, due to the importance of the role of spatial planning in adopting risk reduction options, the DSS design and software environment offer the possibility to be extended to a more general system for urban and regional development, so in the future, it could be used as a system for DRR with spatial planning as a key risk reduction option, as well as a system for urban and regional development with the incorporation of disaster risk and risk reduction components.

Box 4: Model selection
Important considerations in selecting the models to be incorporated include the intended use and user (as defined during the scoping in Section 3.1), the availability of data and models, and time and budgetary constraints (for more details, see Van Delden et al, 2011b). Furthermore, the processes should be represented at the appropriate scale and with the appropriate level of detail (Van Delden et al, 2011b).

Decisions need to be made on the complexity of the models, the number of variables, relations and processes modelled, as well as their appropriate temporal and spatial scales – extent and resolution. These decisions depend on a number of factors, of which the most important are:

- Intended use of the DSS and the requirements that follow from this. Choices will have to be made between simple process representations that allow the system to run fast and therefore promote its use in workshop sessions, or more detailed and accurate representations that require longer run times.
- Choice of scale, resolution and level of complexity required from a scientific point of view to be able to provide information on the scale and level of detail defined in the previous task. The guiding principle regarding model complexity is not to be more complicated than necessary; that is not to introduce more (spatial or temporal) detail or (process and interaction) complexity than warranted for the purpose, while on the other hand not omitting crucial drivers and processes (Occam's razor).
- Availability of existing models that are fit for purpose or can be adapted to fit the required purposes, versus the possibility and need to develop new components. If models are available that fit the purpose or can easily be adapted to fit the purpose, this is preferred from the point of view of reusability. However, since individual models are often developed for a different purpose, this might be an expensive task, making it easier, sometimes, to develop new components (see also Oxley et al., 2004).
- Data availability. Much of the data required for the development of integrated systems are scarce. If limited data are available, selection of simpler process representations is preferred to avoid problems in setting up the model, as well as its calibration and validation (Mulligan, 2004; van Delden et al., 2009). The quality and detail of the data available have direct impact on the quality and accuracy of the results.
- Time available to develop, set-up, calibrate and validate the application. If time is limited, it is best to develop or select relatively simple components that can be calibrated and validated within the available budget.
- Human capacity available to use the system. When the system is not intended to be used by experts, this sets limitations on the type of models and level of complexity that can be included. It is crucial that users are able to interpret results correctly. To be able to do this, a good understanding of the models included in the overall system, as well as their underlying assumptions, is essential. The time and resources available for

To acknowledge the importance of human and natural aspects of disasters, the processes to be included should capture all three components of the risk triangle: hazards, capturing the extent, severity and frequency of the hazard; exposure, capturing the social, cultural, economic, and environmental assets in places that could be adversely affected by the hazard; and vulnerability, capturing the susceptibility of people, assets and other (in)tangible values to hazard severity (based on Crichton, 1999). Developing a system diagram (Meadows, 2008) helps to select the processes for which models should be sought. Such a diagram also provides a starting point for the model integration described in the next section.

Model selection is usually performed by the *architect* in collaboration with the *scientists*. Sometimes *champions* are also included in this task, as they provide insight into the criteria user organisations might have in model selection.

Based on the requirements of modelling the impact of drivers on a range of indicators, selecting models that enable to do this, is critical. In the process of selecting models for disaster risk reduction DSSs, two important aspects need to be considered:

- Natural hazard risk and risk reduction options have an essential spatial element associated with them.
- There is a large uncertainty related to the future likelihood of hazard occurrence (spatial and temporal) and magnitude, and the future conditions under which hazards might take place. These future likelihoods and conditions are volatile due to climate change, changes in socio-economic developments, and behaviour towards risk.

These aspects have important consequences on model selection, but also on the way models are integrated (further discussed in the next section). Modelling these aspects is best undertaken by dynamic simulation models that allow the exploration of the future under various assumptions. Where relevant these models should also be spatially explicit, so the local characteristics and spatial configuration of the area can be included.

The selection of models to be included in the integrated simulation model takes into account the important characteristics for disaster risk reduction as mentioned above and is further based on the factors relevant for model selection listed in Box 4.

A simplified version of the system diagram developed for UNHARMED is shown in Figure 3, which includes exposure, hazard risk and impact models, as well as the way they interact with the external drivers, risk reduction options and indicators. Socio-economic drivers affect land use, whereas climate drivers affect hazards such as bushfire and flooding. Risk reduction options can affect exposure (e.g. land use planning), hazard (e.g. the construction of levees can reduce flooding and prescribed burning can reduce bushfires) and vulnerability (e.g. building hardening and changes in building codes can affect infrastructure vulnerability).

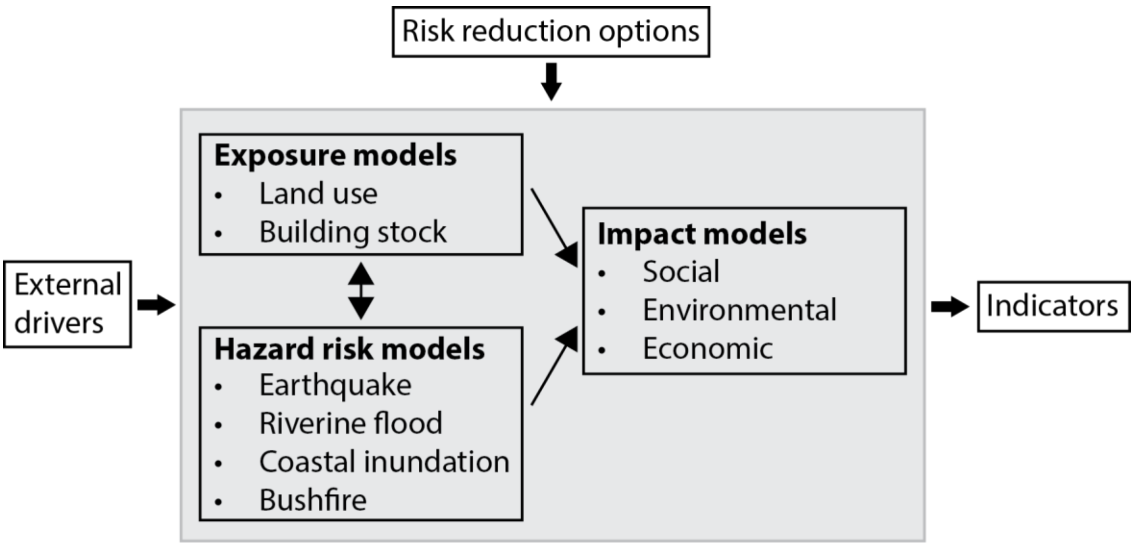


Figure 3: *Modelling components for inclusion within the integrated modelling framework of UNHARMED.*

For UNHARMED, the following model components are selected:

- Exposure models: the Metronamica cellular automata-based land use model that simulates changes in the social, natural and built environment as a result of socio-economic developments, spatial planning, physical characteristics of locations, accessibility and human behaviour (e.g. attractiveness of the neighbourhood, cultural factors, inertia and economic and political power to occupy locations of interest), which can be impacted by land use planning and infrastructure development

(www.metronamica.nl, Van Delden & Hurkens, 2011), and a building stock model that provides information on the mix of building types at each location and allows for changes in the building composition based on renewal rates and changes in the built environment as calculated by the land use model.
- Hazard risk models: specific models for calculating the risk of each hazard incorporated in the framework, by combining the hazard (calculated through hazard specific components to determine the spatially distributed hazard magnitude and frequency), the exposure provided by the exposure models, and vulnerability functions for assessing the impact of the severity of the hazard on the value at stake.
- Impact models: a group of model components related to the calculation of the wider impacts of risk and risk reduction options, social, environmental and economic implications, such as a cost benefit analysis that calculates the total costs and benefits over the simulation period for a selected risk reduction portfolio under a set of assumed external conditions.

To capture temporal dynamics, all model components operate at an annual time step. To include sufficient spatial detail, we propose to set up the models using a grid with a resolution between 25 and 200 m. The exact choice regarding the spatial resolution will be decided during the use process, depending on data availability and the extent of the modelled area. During the use process also decisions regarding the inclusion of hazard risk components will be made.

Specifications of the models included in UNHARMED are documented in Van Delden et al., 2017.

3.2.3 Model integration

There are a number of scientific challenges related to model integration (see Box 5). Specific challenges regarding the development of a multi-hazard DSS for disaster risk reduction relate to:

- Integrating components operating on different spatial resolutions and incorporating different levels of detail. An example of this is combining knowledge from a local land use model operating at a high level of spatial detail (50-200 m. grid cells), but coarse detail in the classes included (e.g. one class for all residential development), with components derived from census data available at census area units (coarser spatial detail), but with more information per class (e.g. different building types within a census area unit).
- Comparing different hazards in a consistent way that takes into account different average recurrence intervals (ARIs) for the scenarios developed for each hazard. This is particularly challenging for compound events (e.g. for a disaster event that is caused by two hazards occurring simultaneously, see for example Leonard et al (2014)).
- Finding appropriate ways of integrating hazard risk indicators (or their underlying components) into an integrated hazard risk indicator. This includes the above-mentioned issue and in addition dealing with the socio-economic changes over time, impacting on the consequences of the hazards.The ability to include the impact of a range of risk reduction options and offer a cost benefit assessment of risk reduction portfolios.

The architect normally plays a key role in the conceptual aspects of model integration and is supported in this by the scientists to tackle the challenges surrounding the integration of models developed using different modelling paradigms; the IT-specialists to discuss the appropriate software environment, technical possibilities, limitations and budgetary implications; and the champions to ensure choices made are in line with user needs.

A first step in model integration is to decide which of the processes should be modelled endogenously and which ones exogenously. Factors influencing this decision include:

- The importance of creating feedbacks between components.
- The computation time in relation to the desired use.
- The development and maintenance budget available.

The UNHARMED framework allows for two different ways of incorporating the likelihood of hazard occurrence of a given magnitude, both complemented with dynamically calculated impact (exposure and vulnerability) to assess risk:

1. Use of exogenous maps for characterising the spatial extent of the likelihood of the magnitude of the hazard. These can be time and magnitude-stamped to enable users to interpolate between sequential maps or magnitudes (e.g. in the case of changes in coastal inundation due to gradual sea level rise) or included as events (e.g. in the case of changes in coastal inundation due to the construction of a levee).
2. Use of endogenous models to calculate the likelihood and intensity of hazard occurrence. This option provides greater flexibility regarding impact assessment of risk reduction options, as these can be directly calculated by the model incorporated in the system. Examples are the selection of the locations of levees in order to reduce flood risk or the adaptation of vegetation types in order to reduce fuel load and hence bush fire risk.

Box 5: Model integration

The task of model integration comprises both the coupling of the individual models and their software implementation. In doing so, we face some scientific and technical challenges. The main scientific challenges are related to:

- Dealing with models representing processes operating on different scales and having different spatial and temporal resolutions (see van Delden et al., 2007; van Delden et al., 2011 for more information).
- Dealing with different types of models developed using different modelling paradigms (c.f. Seppelt, 2003; van Delden et al., 2007); many disciplines have their own specific way to construct a model and linking them is not always clearly evident.

Technical challenges are related to the development of a software platform that is able to integrate the individual components through dynamic feedback loops, is flexible enough to incorporate or eliminate models over time or for different simulation runs, allows interaction with the user and is able to provide fast running speeds. Since development of models is a very time consuming and expensive task, a modular approach that allows reusability of components is also preferred.

To facilitate reusability of components, DSS generators or modelling frameworks are available, consisting of a software platform and a number of (model) components that can easily be configured to create specific DSSs for particular problems.
A point often raised is that integrated models should not be too complex, especially when they have the aim to be used in a policy context. For integrated models, similar principles are true as for individual models: reduction of complexity without omitting crucial components is in many cases the best solution. Nonetheless, the final system might still be rather complex, since the real-world system the model is attempting to simulate is inherently complex. Our experience has shown that policy makers are very capable of dealing with complexity, which is likely a result from their daily practice of operating in an interdisciplinary field with many different actors and processes. This might also lead to their preference for systems that include a rather high level of complexity, their main concern being the transparency of underlying assumptions, the way processes are modelled and making the uncertainty in the results explicit.

A second step is to decide on the details of the interactions between the incorporated models. A key challenge we were confronted with was to find a way to compare risk across the included hazards. We found large differences regarding the way risk is conceptualised and calculated in the different (hazard) disciplines. Models representing different hazards are often developed based on very different modelling paradigms. Understanding the details of why certain processes are modelled in a certain way for the specific hazards helps to align the models. We found that differences occur partly due to the nature of the hazard (their key drivers, frequency, and ability to be specific about the likely locations where the hazard takes place) and partly due to the origin of the discipline and the background of the groups who developed these models.

For UNHARMED average annual loss was adopted as a means to combine the risks from the various incorporated hazards and to combine them into a single value. This required adaptations to some of the hazard models, as not all included the ability to characterise the relationship between the hazard event average recurrence interval and magnitude.

For the integration of model components, we selected the Geonamica software environment, as it uses principles from system dynamics to create interaction between components (Hurkens et al., 2008). Consequently, for all model components included in UNHARMED, state variables and flows can be defined and interactions between model components can take place within or in-between time steps. In the first prototype version of UNHARMED, most processes are calculated sequentially: at a specific point in time, hazard and exposure are calculated as separate processes, and by subsequently integrating these using the vulnerability curves, the corresponding risk is calculated.

The use of dynamic risk models, based on the calculation of average annual loss per year, also enabled the inclusion of cost-benefit assessments, deemed important from the scope definition. Risk reduction options incorporated in UNHARMED can be implemented at different future points in time and include associated lifecycle costs. This allows for costs and benefits to be calculated by comparing two scenarios of future risk with the difference between scenarios in terms of average annual loss, the loss avoided by the implementation of risk reduction options – and hence the benefit within the CBA – assessed against lifecycle costs of the implemented reduction options.

Scaling issues were dealt with on a case-by-case basis, taking into account the data availability, the scientific considerations and the use requirements. More information about scaling and scaling issues can be found in Van Delden et al. (2011).

3.2.4 Bridging the science-policy gap

Most research is not directly policy-relevant, and links need to be created to ensure relevant information can be provided by the integrated model incorporated in the DSS (see also Box 6).

Challenges in bridging this science-policy gap for DRR DSSs are:

- To find the most appropriate way of having specific hazard risk reduction options impact on the model components incorporated in the system.
- To find scientifically defensible and user-accepted algorithms to calculate the risk indicators.
- To include a very diverse group of potential users in the development process and have them provide direction, or at least input, into the development of a targeted DRR DSS. The group of potential users is likely to come up with very different requirements for the system, leading to potential conflicts regarding the best direction forward.

This task builds on the framing of the drivers and indicators defined in the scoping phase and has a twofold focus. Firstly, it is about finding the most appropriate way of having specific hazard mitigation options impact on the model components incorporated in the system. Secondly, it is also about finding scientifically defensible and user-accepted algorithms to calculate the risk indicators. This includes an integrated risk indicator to assess the overall risk to show which areas are prone to multiple hazards or are impacted the most by the combination of hazards.

Box 6: Science-policy interface

The science-policy interface is one of the crucial elements in any DSS design and development process and creates the link between task 1 – scoping (mainly driven by the users) and tasks 2 and 3 – model selection and integration (mainly driven by the developers). Often research models are not directly suitable for incorporation into DSSs (Engelen, 2000; Oxley et al., 2004). To move beyond a research model and provide added value to decision and policy-making, a model needs to connect to the policy context and process and, moreover, provide added value to those working with it.

In the process of linking scientific knowledge and policy-relevant information it is important to clarify the terminology used, and to develop a common terminology for use among all involved parties. Very often problems occur because of a lack of understanding of one another's vernacular. Discussing the details of what is meant and including a glossary in the scoping paper facilitates communication.

Research models often stop at the point where the process is modelled correctly for the purpose of deriving a specific scientific answer. This answer might have implications for policy questions, but the model itself does not facilitate an interactive use. For a DSS, however, it is crucial that the user can analyse the impact of various policy alternatives on a selected set of policy relevant indicators (see Volk et al., 2008; Volk et al., 2007). Furthermore, it is important that they can assess the sensitivity or robustness of these policy alternatives under different assumptions about the external driving forces that they cannot influence. The outcome of the assessment has to be provided as results that have meaning beyond the model itself. Therefore, it is not sufficient to merely provide model output; it is crucial to define indicators that relate to the policy context. Very often there are discrepancies between the information needs from the users and the available data and models from the scientists.

One of the most important challenges in the design, development and implementation of DSSs is to ensure that they will actually be used by the intended users. In bridging the science – policy interface, users and developers need to work together towards shared goals as active co-producers in the social process of knowledge construction. Often problems arise in the early phases of the design and development process in understanding each other: because using integrated models for policy support is not (yet) common practice, users often do not know what they can expect and what the limitations of such systems are. Developers normally have a scientific or technical background and often have no experience in policy making, resulting in a limited understanding of the policy practice and the process in which policy decisions are being made and to which the DSS aims to provide support. To be able to learn from one another, openness plays a crucial role. Developers need to manage the expectations of users by communicating both the potential and the limitations of DSSs to avoid unpleasant surprises during the implementation and use of the systems. Users need to explain their daily practice, the policy process they are involved in and the organisational structure and context they operate in. As described by Oxley et al. (2004), this process of social learning requires building relationships of mutual trust and respect. In doing so, it is essential that contact is frequent, personal and relaxed. Unfortunately, time for interaction is often limited due to its high costs.

As part of the development of UNHARMED, alignment with the (Australian) National Emergency Risk Assessment Guidelines (NERAG) (Emergency Management Australia, 2015) was found to be important by the (potential) user group and this led to the incorporation of a risk assessment map indicator, which categorises each location on an ordinal scale (i.e. low, medium, high, extreme), based on a combination of a categorised hazard magnitude (for defined occurrence) and a categorised consequence. These categories are user defined within the GUI with modellers able to define minimum and maximum values for five classes of hazard magnitude for respective hazards (e.g. depth for flood hazards, peak ground acceleration for earthquake); and for five categories of exposed value (i.e. total value at stake). Users can then define how each of five classes for is combined to produce the ordinal risk scale. Figure 4 shows the table users can define values for this integration (in the figure default values are shown).

Hazard → Consequence ↓	Very Low (1)	Low (2)	Moderate (3)	High (4)	Extreme (5)
Very Low (1)	1	1	2	2	2
Low (2)	1	2	2	3	3
Moderate (3)	2	2	3	3	3
High (4)	2	3	3	3	4
Extreme (5)	2	3	3	4	4

Figure 4: *Hazard-consequence table forming the basis of the categorised risk assessment indicator, one of the risk maps calculated by UNHARMED.*

This indicator therefore creates a map of classified risk values (1 → 4) in addition to the annual average loss indicator described in previous sections. Conceptualising risk as occurrence versus consequence fits well with the concept of the risk triangle as either exposure or a combination of exposure and vulnerability can be used as proxies for consequence enabling the alignment of the indicator with current practices.

We also found that 'softer' risk reduction options, such as building community awareness and education, require special attention, as current risk models are often not directly able to incorporate these drivers. To facilitate this process, use of available knowledge from different sources has been adopted (including literature, data and experts) in the incorporation of these options, including the way their impact is calculated. As part of this process, discussion of the issues identified, and assumptions made, were undertaken with the relevant end-users in order to manage expectations as to what type of support the system is able to provide.

Bridging the science-policy gap encompasses more than a focus on the relevant content of the system. It is also key in dealing with the context and implementation of the system in user organisations and DRR processes. Participatory activities to clarify the role of organisations in the decision-making process, and the way the system can provide support to each of them, provide a good starting point for the implementation process. This will then lead to discussions on which organisations and which individuals should be involved in each DRR process, the place of the DSS in the DRR process, the home of the DSS, the organisations and individuals responsible for using, maintaining and updating (components of) the DSS and the potentially relevant use cases.

Examples of the participatory activities that have taken place in the case studies are documented in e.g. the workshop reports from Greater and Peri-Urban Melbourne (Riddell et al, 2016a) and Greater Adelaide (Van Delden et al., 2015). Findings from these activities have provided important input into both the development and the use cycle, as it creates a shared understanding of the formal and informal decision processes, as well as details of the risk reduction options that could be tested and relevant performance indicators that could be calculated using the DSS.

While the co-creation approach suggested in this paper provides useful input with regard to linking the generic DSS to the DRR practice, it also fulfils another important function as it builds ownership. In each of our case regions we had a few champions who have provided a leading role in the development and adoption through their active participation in workshops and continued support.

3.2.5 GUI design and development

DRR DSSs have two different types of professionals using the system: policy analysts/advisors and hazard, exposure and vulnerability modellers. The first use the DSS to perform integrated assessment and scenario analysis in relation to the assessment of the spatial and temporal distribution of risk and the impact of different risk reduction strategies on these risk profiles. The second make changes to the component models themselves, including to the data, parameter values and potentially the model structure. To cater to both of these groups, it is advantageous for the DSS to have a dual interface. Consequently, the interface catering to the first group should only present outputs that are relevant to policy analysis, rather than including outputs from the various sub-models. This requires raw model outputs to be transformed to policy relevant indicators. In contrast, the interface catering to the second group should provide access to and present outputs from all relevant sub-models (see also Box 7 for more detail).

To provide outputs that are relevant for answering specific questions for particular end-user groups, the interface should enable the relevant indicators to be visualised in a variety of ways, such as maps, tables and graphs. Maps are particularly useful for communicating the spatially explicit nature of risk and animations for demonstrating their temporal dynamics. Other important aspects to consider include the level of aggregation of the output, e.g. should outputs be presented as probability maps or aggregated into risk classes, should outputs be aggregated into spatial administrative units, and should outputs be aggregated over a time period, as would be required for the lifecycle assessment of risk reduction options? The use of mock-up DSS software interfaces early-on in the development process provides a useful means of exploring these issues with stakeholders and experts to ensure the actual interface design meets end-user requirements as closely as possible.

Box 7: GUI design and development

An important task for the developer of a DSS is to bridge the gap from scientific tools to user friendly systems, by creating a graphical user interface (GUI) that is easy to use, provides access to different policy options and external factors and presents model output and indicators in a visual form. Because the DSSs described in this methodology encompass complex integrated models and aim to provide policy support, the GUI should be able to provide access to two different types of users: the policy makers or their resource people who use the system as part of their policy process and who carry out impact assessment studies with the model; and the scientists or modellers who can update the underlying data and parameters and possibly even the model structure. The first group benefits from a GUI that follows the steps of a scenario or impact assessment process. The second prefers to look at the system components and values easy access to individual disciplinary models.

It is very important to keep the different goals of the two types of users in mind. In most cases, exposing the full flexibility that is offered by the models adds no value to a policy user. On the contrary, it will actively hinder optimal use by them. Providing them with a list of configuration parameters and leaving it up to them to decide the best combination for their specific use detracts from the system's usability. Design of user-friendly interfaces is about anticipating the user's needs, adopting their worldview and expressing the workings of real-world processes in a way that fits their experiences, needs, vocabulary and expectations – and requiring no more user action than is strictly necessary.

UNHARMED makes use of a dual user interface to facilitate (1) the use of the system for scenario analysis, integrated assessment, and (2) the updating of data and parameters. Only those settings relevant for the use of the model are included in the *policy interface*. The sub-models with all their adjustments are still accessible for model experts through the *modeller* *interface*. The elements of this part of the user interface are grouped per model; each individual model has its own access point through the system diagram (similar to the conceptual diagram described in the Model Selection section). Access to settings for the policy user is structured not by where they fit into the model, but according to their logical function. On a high level, access is organized by the steps that a user takes to carry out an impact assessment analysis: configure drivers, create integrated scenarios, run the simulation, review output through the indicators, and analysis. When the user zooms in on each of these parts, settings and outputs are displayed and grouped together by their type and their domain; for example all risk reduction options are grouped together and structured per type of option (spatial planning, structural, land management and community resilience), and all external factors are grouped together, all indicators grouped together and structured per type of indicator (risk, social, environmental), etc.

An overview of the resulting interface is provided in Figure 6**:** and 6. Examples of the interactions a user has through the policy interface are the ability to insert and adapt demographic projections, the incorporation of spatial land use plans and the ability to interpret these plans in terms of zoning status for the included land use activities, and the

incorporation of a renewal rate for buildings within regional sub-divisions. The modeller interface gives access to all relevant input data and parameters as required by those involved in the modelling, either as model provider or model user.

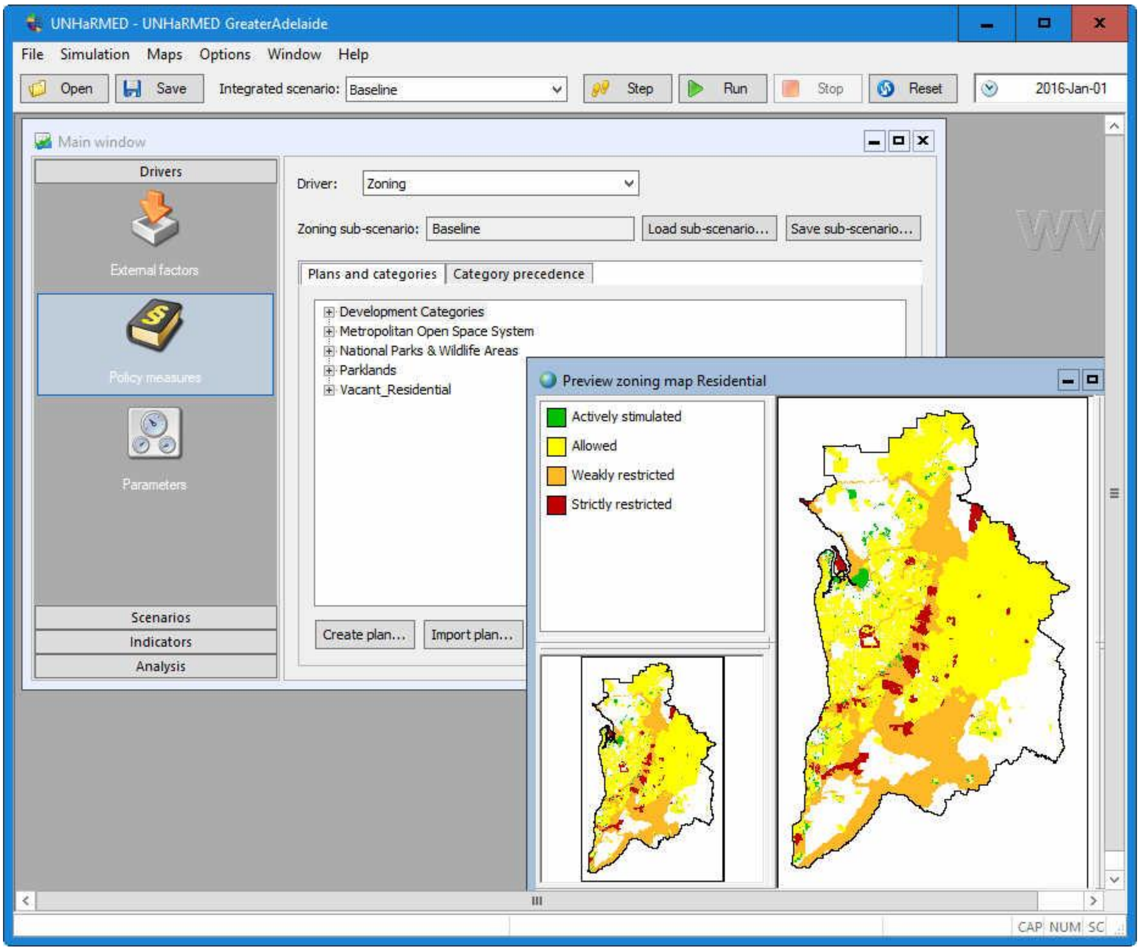


Figure 5: *Screenshot of the policy interface of UNHARMED, showing the different spatial plans incorporated and an interpretation of them for residential land use in the respective zoning map.*

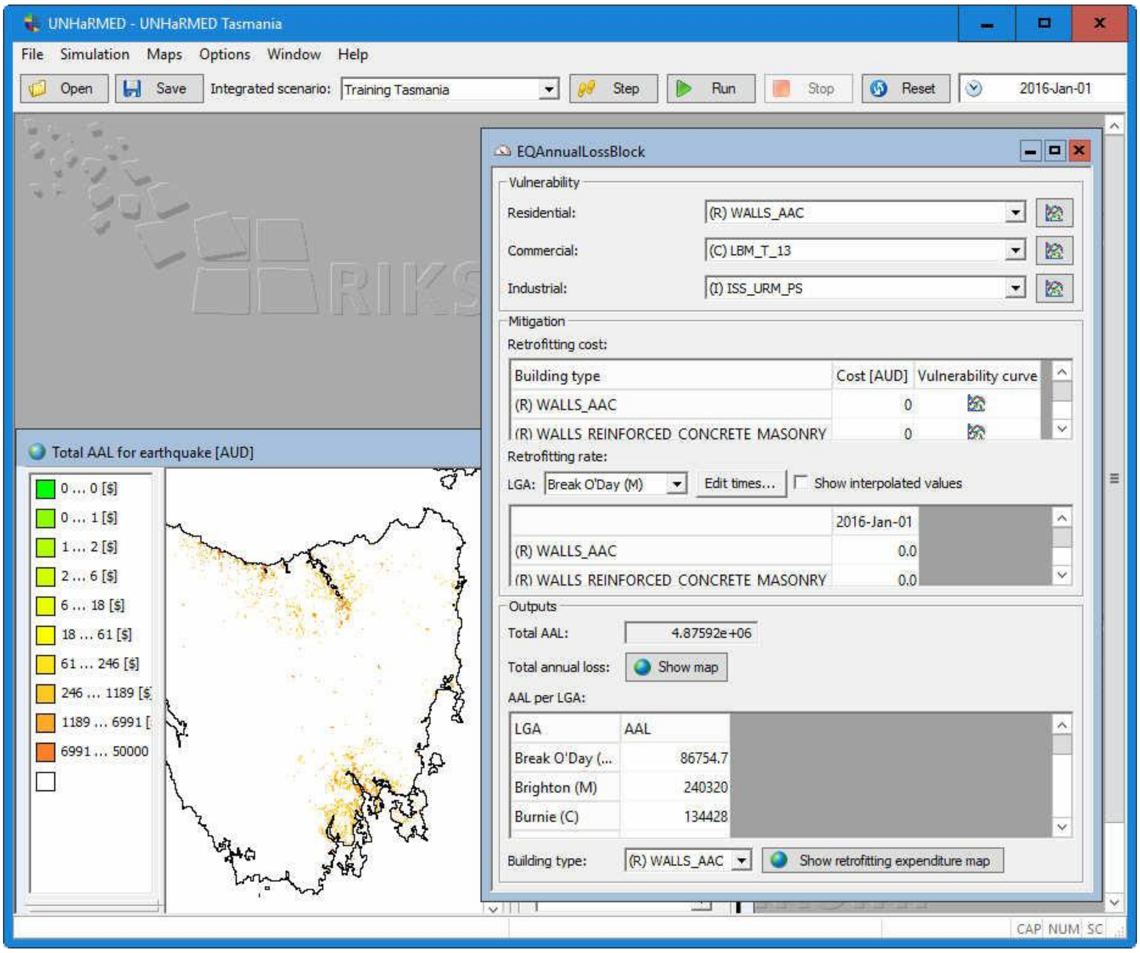


Figure 6: *Screenshot of the UNHARMED modeller interface, showing an example of the earthquake model block and a calculated earthquake risk map.*

As part of the UNHARMED development process mock-up software interfaces were created early in the development process and provided to stakeholders and experts for feedback (see Van Delden et al., 2016). To facilitate feedback from potential users of the system, training on a first prototype was provided to show direction and provide opportunity to adapt and provide input to further development.

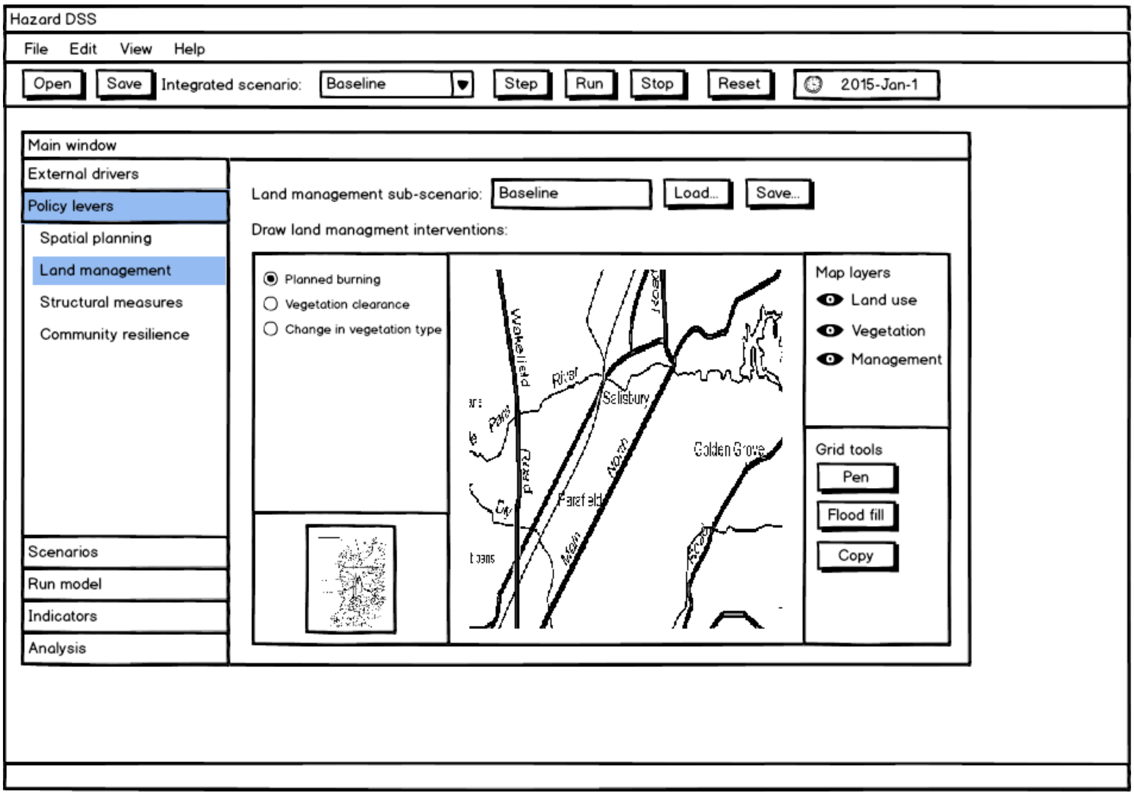


Figure 7: *Example of a component of the mock-up software interface for UNHARMED, used to discuss the actual graphical user interface of the system as well as broader usability aspects.*

4 USE OF UNHARMED

The main aim of the use process is to provide support to the selection of planning and policy options for disaster risk reduction. Core aspects of the process are an integrated assessment of the impact of risk reduction options on policy-relevant indicators under various external conditions.

The use process combines (narrative) scenarios, quantitative analysis and modelling through a process that includes *stakeholders*, *modellers* and *facilitators*. It thus makes use of an approach of triangulation that compares insight obtained through multiple qualitative and quantitative methods to deepen the understanding of plausible future pathways. This use of contrasting but complimentary methods of exploration ensures, to the greatest possible degree, an improved understanding of plausible futures in order to best assess the robustness of risk reduction portfolios. The use process has been applied to the three case studies and the framework methodology is enhanced based on the lessons learnt. In the remainder of this chapter we describe this process in more detail. Follow the same format as the description of the development process, background information from previous research is provided in the boxes.

4.1 ACTORS INVOLVED IN THE USE PROCESS

Similar to the development process, the use process is carried out iteratively as a collaborative effort of all actors involved. The process incorporates stakeholder engagement through questionnaires, interviews, small group discussions and workshops, which are supported by quantitative analysis and modelling.

The main groups involved in the use of the DSS are shown in Figure 8. Stakeholders provide the aim and focus of the use case, are responsible for providing feasible risk reductions options and selecting relevant indicators to assess the performance of these options. Modellers develop a case study specific application and provide analytical support for assessing the impacts and performance of risk reduction options, based on the context provided by the users. As part of this, they collaborate on quantifying knowledge important for inclusion in the modelling process and the scenario development.

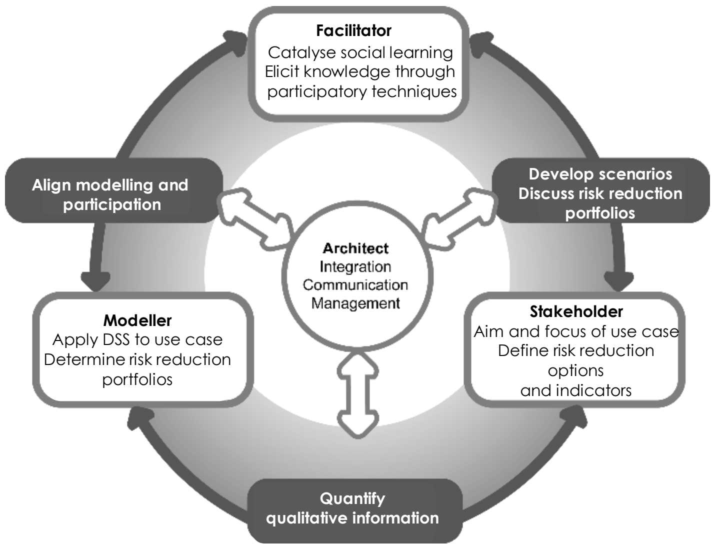


Figure 8: *Parties and their shared responsibilities related to the use of a DSS.*

The facilitator takes the lead in the participatory activities and in doing so collaborates with stakeholders on the development of scenarios and the ranking of risk reduction portfolios, while including information provided by the modellers. Aligning modelling and participation is therefore an important joint responsibility of the facilitator and the modeller. The facilitator also has an important task in catalysing social learning amongst the actors involved and is supported in this process by the architect, who oversees the entire use process and makes the link between the use process and the development process.

4.2 ITERATIVE AND PARTICIPATORY USE CYCLE

For the use process we can define six main tasks, as shown in Figure 9, with issues addressed listed below:

1. Establishing context
    a. Who are the stakeholders?
    b. What is the scope of the exercise?
2. Exploration of risk dynamics
    a. What are the relevant factors, actors, and sectors exposed to risk, now and into the future?
    b. What developments, changes, uncertainties, and complexities drive risk and risk reduction?
3. DSS application
    a. What are the model boundaries?
    b. What model parameters best reflect the context and dynamics?
4. Risk assessment
    a. How do we translate scenario information on hazard, vulnerability, exposure and their dynamics into model inputs?
    b. What are the best ways to quantify risk in time and space in a meaningful and policy relevant manner?
5. Insight and sensemaking
    a. How do we analyse and interpret the results from the risk assessment?
    b. What are the policy-relevant insights for DRR?
6. Development of risk reduction portfolios
    a. How can we provide transparent and consistent impact assessment of risk reduction options?
    b. How can operational, tactical and strategic planning options be integrated in DRR?

The process starts with stakeholder engagement focused on defining the problem context for the policy making process and quantitative analyses to understand relevant developments. This focus then moves to understanding future uncertainties through developing scenarios in a participatory process with stakeholders. Based on the problem definition and the scenarios, the generic DSS developed during the development process is applied to the region relevant for the use case. This involves discussion regarding the selection of models from the choices contained within the generic DSS, an assessment of data availability, and calibration of the application to the context of the case region. Using quantitative analysis and participatory activities, scenario drivers are provided as model input in order to simulate various possible future developments of the city, region or country at stake. Risk reduction portfolios are then designed using the assessment of performance against chosen impact indicators. These risk reduction portfolios are subsequently discussed and ranked in a workshop setting to provide support to disaster risk reduction.

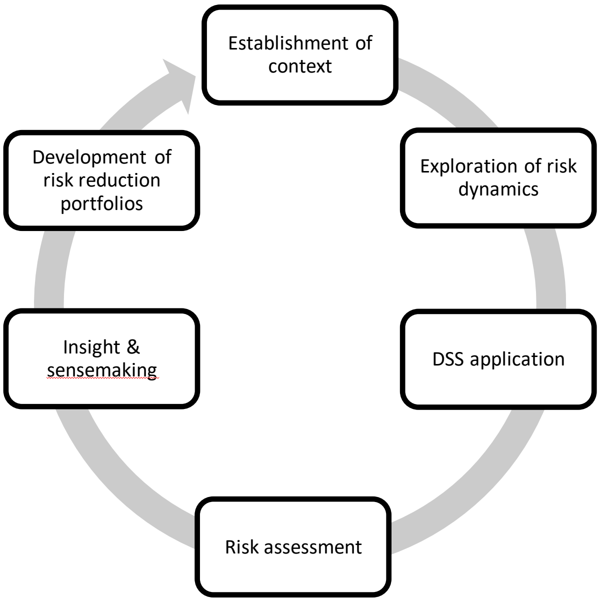


Figure 9: *An iterative and participatory cycle for using a decision support system to support disaster risk reduction.*

Although there is a logical sequence in which these tasks are carried out, the process also allows going back to one or more previous steps to adjust or fine-tune previously made choices. Important feedback loops can be found throughout the first three tasks as the selection of risk reduction options, external drivers and indicators to be modelled can change based on data availability or additional insight when doing the scenario development. There is also an important interaction between the participatory scenario development (task 2) and the scenario translation (task 4), as assessing the impacts of scenario drivers through (spatially explicit) modelling can provide input into the scenario development, especially regarding causal relations, internal consistency and visualisation. Finally, from what is learnt during the analysis and discussion of risk reduction portfolios identified through simulation and sensemaking, it may be desirable to fine-tune aspects of tasks 1-3, to include additional indicators or constraints, or to prioritise the exploration of certain types of portfolios. Key learnings from the use case, such as the desire to incorporate new or adapted disaster risk reduction option or impact assessment indicators, or even new hazards, provides important input into the development phase leading to adaptation of the generic system either during or after a use case.

Each of these six tasks is described in more detail in the remainder of this chapter.

4.2.1 Establishment of context

The aim of this task is to establish the context of the specific use case in which the DSS is being deployed. The primary focus of this first stage is not on the DSS, but about obtaining insight into planning and policy questions relevant in the DRR process, or elements of the process specific to the use case, and then considering ways in which the DSS can support this.

Stakeholder selection is the initial step in establishing the context based on the general scope of the exercise or use case and is commonly provided by an administrative body in the natural hazard / risk management space – however this is not a requirement. Stakeholders can broadly be defined as individuals who are either involved in making or are impacted by a decision (Freeman, 2010). Likely stakeholders in the natural hazard field are, amongst others, the organisations involved in DRR, risk owners (individual or entity who is responsible, accountable or paying for action or value) (Young et al., 2017) and those affected by or contributing to the risk, with the understanding that these groups are not mutually exclusive.

For the case studies in the project, the process of stakeholder identification was influenced heavily by governance structures that existed within risk management plans and legislation at State-government levels. All three States have procedures outlining which actors should be involved in the management of, and are responsible for, particular hazards and actions, see e.g. the Tasmanian Emergency Management Plan (Department of Police and Emergency Management, 2013).

Following stakeholder identification, the scope of the use process, including risk setting – hazards considered, spatial extent and time horizon – and the specific purpose of the process, need to be decided upon. As the use process requires the generic DSS resulting from the development process to be applied to a particular region in a specific decision context, information is also sought regarding the possible risk reduction options to be considered in the analysis and what performance indicators are necessary for the testing of such options. During this task, stakeholders may consider hazards, risk reduction option or indicators to be necessary or valuable that have not yet been included in the generic DSS, which will feed then feed back into the development process if time and resources permit this and thus become part of the iterative process shown in Figure 1.

As an example, stakeholder groups for Greater and Peri-urban Melbourne and Tasmania identified bushfire, coastal inundation, riverine flooding and earthquakes as relevant hazards to be included, while further commenting that landslide, coastal erosion, heatwave, and storm risk could potentially be of (secondary) interest – see Riddell et al., 2016a and Riddell et al., 2016b. This resulted in prioritising additional hazards to be included in the DSS and a preliminary investigation into and development of a heat-wave component for the generic system.

In addition, the case study stakeholders proposed risk reduction options and performance indicators that were not yet included in UNHARMED. Examples of resulting improvements made to the system are the inclusion of a vulnerable population indicator and an enlarged assessment of risk beyond buildings by including additional assets and infrastructure (Riddell et al., 2016a). Bilateral interactions led to improved mechanisms for including risk reduction options based on changes to building codes and the incorporation of bushfire fuel reduction.

For this scoping task, we propose a facilitated participatory approach with stakeholders led by the facilitator to integrate stakeholders' views, ideas and problem frames and offer input to what they consider is relevant. This facilitated process should offer multiple methods for engagement and be conscious of power dynamics, learning and communication styles and allow for trust to be built between stakeholders and the facilitation team. Following this, the architect should have a clear understanding regarding specific questions that should be answered using the DSS, the region and time horizon of interest, along with risk reduction options and impact assessment metrics to be considered within the use process.

For the case study regions, a combination of whole stakeholder group workshops, semi-structured interviews and questionnaires was used to define the scope, see for more information (van Delden et al. 2014, Riddell et al. 2016a, Riddell et al. 2016b).

4.2.2 Exploration of risk dynamics

Exploring risk dynamics in the use phase is focused on determining and subsequently considering how different factors and sectors impact and relate to risk and then how they can impact on risk into the future. Factors, actors and sectors (FAS) are defined below (Kok 2006b, Absar Preston 2015):

> **Factor:** aspect of a social or natural system around which there are broad policy issues of particular interest
>
> **Actor:** individual or entity with the capacity to effect and or influence change
>
> **Sector:** sub-component of a national or social system

Stakeholder engagement processes, and desktop analysis (quantitative and qualitative information) are required to define which factors, actors and sectors are relevant to risk, now and into the future, across the risk components of hazard, exposure and vulnerability. Driving forces that influence and change FAS over time are also required to be considered to explore the uncertainties of risk in the region of interest. These drivers and their related uncertainties are then captured in the development of scenarios consisting of relevant drivers, uncertainties and complexities. The type of scenario required for the exercise depends on the context established in Step 1 and the degree of uncertainties considered relevant. Box 8 outlines scenario types to be decided upon.

Methods to support this process include facilitated workshop(s) in which stakeholders are the main group driving the results (Kok et al., 2006). The workshop's aim(s) and scenario selection need to contribute to the scope defined in the previous task and are ideally discussed by the

architect, the facilitator and one of more champions, after which the facilitator takes the lead in developing the workshop activities.

Box 8: Scenario typology (adapted from Borjeson et al. (2006) and Maier et al. (2016))

Scenarios – possible futures states of the world that represent alternative plausible conditions under different assumptions (Mahmoud 2009), can be broken into three overarching types:

> Predictive – answer the question, *what will happen?* The aim of this scenario type is to attempt in predicting what will happen, they are mostly used to plan for situations expected to occur. Business as Usual (BAU) or forecasts of specific conditions are considered predictive scenarios.
>
> Explorative – answer the question, *what could happen?* The aim of exploratory scenarios is to consider situations / developments that are possible or plausible. Long time frames are normally used in exploratory scenarios in comparison to predictive.
>
> Normative – answer the question, *how can a specific target be met?* Normative scenarios begin with a pre-determined starting / ending point and the focus is therefore on how that end condition is to be reached.

As an example, for Greater Adelaide, exploratory scenarios were developed based on two driving axes – challenges to mitigation (the design and implementation of structures and policies by governments) and challenges to resilience (the ability for communities, networks and infrastructure to respond and recover) using the approach of Riddell et al. (2018a). Distinct exploratory qualitative scenarios were developed - posing high challenges to either mitigation, resilience or both, in addition to a low- challenges scenario and an intermediary scenario - considering the region in 2050 and the timeline of change that would enable these futures. For more details about the process and the results, see Riddell et al. (2018a).

In contrast, for Tasmania, a decision was taken to work with a more traditional and less stakeholder intensive scenario approach in which three scenarios considering most likely, best and worst case in terms of risk for the region were developed based on existing projections and forecasts for development. This decision was based on the specific focus of the Tasmanian use process on consideration of spatial zoning mechanisms for risk reduction, and as such, had to align with existing State based projections on population and economics. This allowed stakeholders to base scenarios on these projections, while still including some more relevant risk-related uncertainties considered relevant, formulated along with existing projections.

4.2.3 DSS application

In this task, the generic DSS (as discussed in Chapter 3 – Development) is configured to the context of the case regions, by developing specific applications for each region that incorporate the risk setting - hazards, risk reduction options, indicators – and subsequently necessary models and related data, as determined in the 'Establishment of context' step. Drivers, such as socio-economic projections and climate information, should also be included.
Based on the selected boundary conditions and available data, the DSS is applied to the case area using a spatial and temporal scale and resolution that matches both the drivers and the application range of the models. When the generic DSS includes a variety of models to simulate the same hazard, a choice for the most appropriate model would need to be made based on the scope of the use process, while considering data, time and budget constraints. If the scope asks for a different type of model and the resources are there to develop this, then this would provide a feedback into the development process.

For the applications to Greater Adelaide and Greater and Peri-urban Melbourne, the full set of risk modules incorporated in UNHARMED was incorporated, while for Tasmania, riverine flooding was omitted due to a lack of readily available data. When tailoring UNHARMED to the Greater Adelaide, Greater and Peri-urban Melbourne and Tasmanian applications, model boundaries corresponding to the region of interest were selected by the stakeholders. This was based on common statistical areas, the dynamics and growth patterns of the region and interfaces between hazard and exposure; and adjusted based on stakeholder needs throughout the process.
During the process, there was a request for the Tasmanian application to increase the spatial resolution, while at the same time enlarging the model boundaries. This led to adaptations to the generic UNHARMED system to meet the requirement of dealing with large datasets.

Tailoring UNHARMED for each case region resulted in different choices for land use classes and vegetation types. For instance, to capture the residential growth dynamics of Greater and Peri-urban Melbourne, a finer thematic resolution of residential density classes was included (i.e. rural, low, conventional, medium and high, aligned with the Victorian Planning Authority's classification). Another specific land use class decision was to create a tourism class within the subset of residential classes, to highlight the specific vulnerabilities of these areas due to risk awareness and preparation. Vegetation types were also specified for each application, with new types and their specific fire behaviour equations being added to the generic bushfire risk model.

Once the model boundaries have been established, model parameters are set and fine-tuned to obtain a calibrated application using historic data, quantitative analysis, and an understanding of the drivers and processes in both previous tasks. The quality of the calibrated application is assessed using a set of evaluation metrics. As part of the calibration, stakeholders can provide valuable insight in the interpretation of the data and observed developments. After the calibration is completed, the obtained parameter set is applied to an independent data set –often for a different time period– to validate the application. This calibration and validation process should be based on appropriate evaluation metrics for the risk dynamics considered and specific questions to be answered. If resources permit, a sensitivity and uncertainty analysis should be carried out, as well as a set of robustness checks (Van Delden et al., 2011). These help to better understand the behaviour of the application and interpret the simulated results correctly. We furthermore advocate to complement the formal calibration and validation with an expert evaluation by modellers and stakeholders to further improve the application and build ownership and understanding amongst those involved (see Hewitt et al., 2014 for more information about participatory calibration).

For the case applications, historic data were available only for some of the model components, and in those cases, these were included in the calibration process. The calibrations were therefore largely carried out based on process understanding and previous applications of the individual models, complemented by robustness checks, with selected values that are more extreme than those included in the scenarios. Evaluation of the application's behaviour was carried out using expert judgement in combination with objective metrics, where possible. This less-comprehensive approach to calibration was not perceived as a major problem, as directions of change as portrayed by the scenarios could be well-simulated with the included parameter settings, which was sufficient for the scope of the use process.

4.2.4 Risk assessment

In this task, the scenarios developed in the 'Explore risk dynamics' task are translated and implemented within the applied DSS. This includes the parameterisation of models based on the developed scenarios to allow the assessment of hazard, exposure and vulnerability factors. A main challenge in this task lies in the qualitative form of the scenarios, which doesn't directly link to general model requirements of state variables and parameters. The

process of quantification is not only a process of specification, but also of reduction (Van Delden and Hagen-Zanker, 2009). The emphasis on interaction between modellers and stakeholders and the co-creation of new knowledge and understanding for both groups of actors therefore requires an iterative process. Mechanisms and processes exist to support this process, with iterations between modellers and stakeholders. Box 9 provides details on a quantification process. Other examples include Alcamo (2008), Kok (2009) and (Liimatainen et al., 2014).

Box 9: Scenario quantification
The emphasis on interaction between modellers and stakeholders and the co-production of new knowledge and understanding for both parties therefore sees an iterative process proposed following Van Delden and Hagen – Zanker (2009) with the following sub-steps:

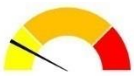
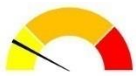
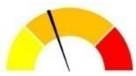
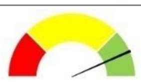
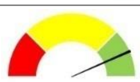
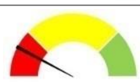
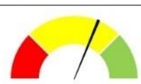
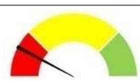
1. Identify developments ('clues') in the scenario.
2. Identify driving forces and parameters in the model.
3. Reassess the model configuration to the scenario context.
4. Quantify external scenario drivers.
5. Adjust model parameters to reflect the scenario context.
6. Identify elements for which no one-to-one translation is possible.

An important step in the translation from scenarios to quantitative models is the identification of 'clues' (sub-step 1). Clues are meaningful text fragments in the storylines that contain a statement about a state, a change in a state, a quality, a quantity, a trend, a location, an action, an interaction, a stock, a flow, a migration, a process, etc., about the geographical system, a sub-system of the latter, the region, a part of the region, the world outside the region, an agent, a group of agents, a population, groups within the population, etc., that is (are) the subject of the scenario exercise. The term meaningful has to be interpreted here both in terms of the accurate description of the system as it is available from the storyline, and, the purpose of the scenario exercise (Van Delden and Hagen-Zanker, 2009).

To ensure the quantification of risk across multiple scenarios is meaningful and policy relevant, transparency and comparability across qualitative, semi-quantitative, and fully quantified outputs is critical. While the modeller takes the lead in the quantification, transparency and discussion of the assumptions across the actor groups improves the quantification, creates ownership and builds confidence that the modelling provides useful input into the DRR process. The facilitator, supported by the architect, works with the stakeholders to improve the scenarios based on the modelling to enable a greater understanding of what drives risk in time and space, and find out what their policy decisions may be sensitive to. As part of this process the distinguishing factors between scenarios are clarified to ensure sufficient difference in the modelled risk profiles of different scenarios. Clear documentation and communication are vital in this task to ensure transparency and support regarding the assumptions and decisions made.

Results from the above approach for the Greater Adelaide case region are shown in Figure 10. In this figure a semi-quantitative overview of the main scenario drivers and their setting for each scenario is presented. Based on this, a further quantification of driver and parameter values was carried out with which the application was populated, and risk profiles were calculated for the developed scenarios (Riddell et al. 2016c).

A second example comes from the Tasmanian case. Due to the type of scenarios selected, government projections on population and jobs were used as inputs and the main quantification activities related to the interpretation of their spatial planning mechanisms into the application. This was a less intensive process compared to the quantification exercises carried out for Greater Adelaide due to the context of the use cycle. Factors such as land use planning, education and awareness and structural mitigation were not included in the quantified parameters allowing for explicit testing of policy options over the next 10 years against the three scenarios – best, worst-case and most-likely.

Scenario drivers	**Greater Adelaide scenarios**				
	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
	Low challenges to resilience and mitigation actions	*Low challenges to resilience and high challenges to mitigation actions*	*High challenges to resilience actions and low challenges to mitigation actions*	*Moderate challenges to resilience and mitigation actions*	*High challenges to resilience and mitigation actions*
Population in 2050	1.9 M	1.5 M	2.5 M	1.8 M	1.5 M
Economy					
Community resilience					

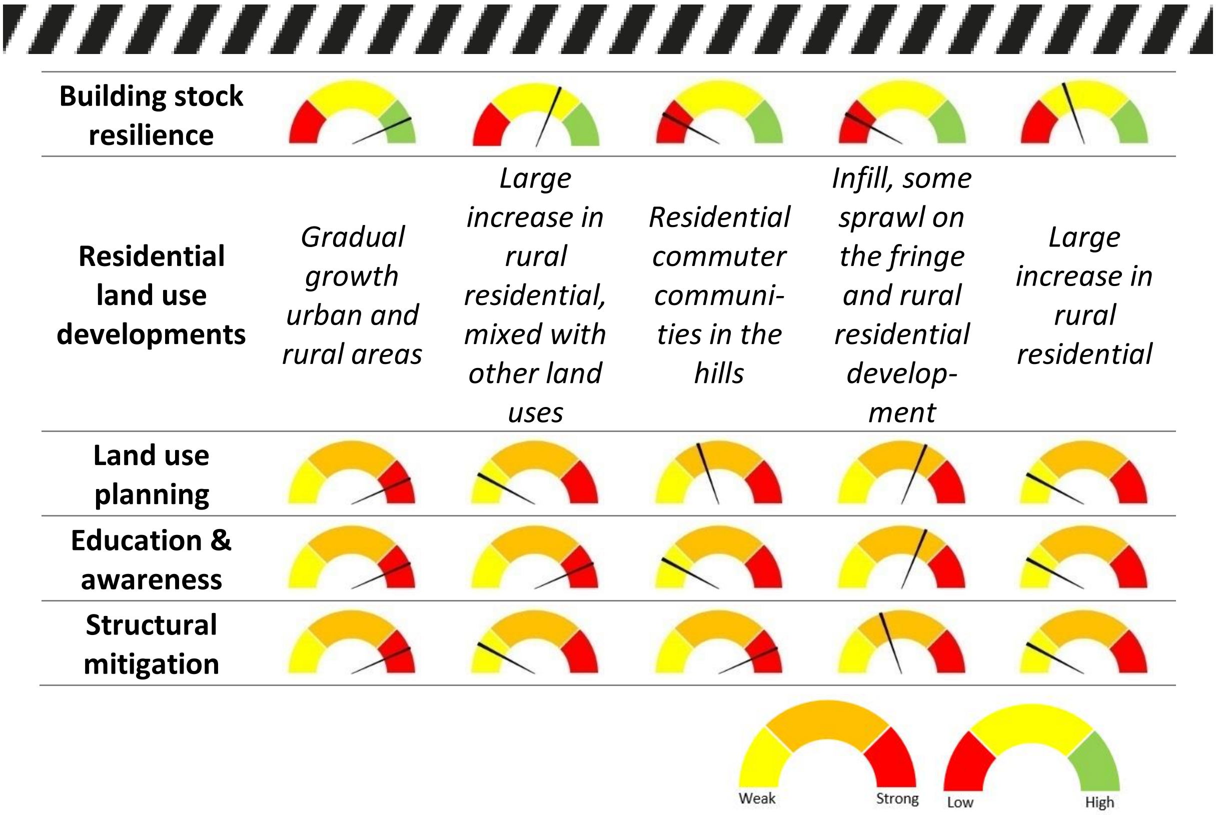


Figure 10: *Semi-quantitative translation of main scenario drivers for the Greater Adelaide scenarios.*

4.2.5 Insight and sensemaking

The interpretation of the risk assessment outputs allows stakeholders to gain insight into the implications of the quantitative modelled risk profiles from the risk assessment task above and relate the obtained information to the actual practice.

As part of a facilitated participatory process, stakeholders and modellers carry out activities for analysing, questioning and interpreting modelled results, providing insight as to why changes occur in risk across space, time and scenarios. This process provides an enhanced understanding into the drivers of risk as well as their impacts, and hence allows better appreciation for future risk reduction options. The other critical element of this process is to enable feedback to previous steps based on increased understanding; process questions may be altered, scenario drivers and factors changed, and the quantification of these edited.

Insight must also be provided that is policy relevant, and this means the quantified analysis be contextualized to fit within the broader policy context. This requires the facilitator to enable a sensemaking process to occur:

> Sensemaking can be seen as a "motivated, continuous effort to understand connections (which can be among people, places and events) in order to anticipate their trajectories and act effectively" (Klein et al., 2006).

Within the DSS use process sensemaking activities sees *facilitators* work with *stakeholders* in making connections between the risk data analysis and their own individual and institutional framing. This step is vital in bridging the policy-science gap, and allows plausible future developments and quantified analysis to sit within a broader context of risk understanding.

Insight and sensemaking activities for each of the three applications were carried out through workshop sessions in which the modelled outputs were presented visually for various land use (exposure) scenarios, and their associated risk profiles across relevant natural hazards for each region (see Figure 11). These risk outputs showed the average annual loss at three time slices (2015, 2030, 2050) for each scenario, and for each hazard, along with damages from specific event magnitudes, at the request of stakeholders, such as a 1 in 100-year flood (a common design standard).

In addition to the static outputs, modellers were also available to show the exposure, hazard and risk dynamics as little movies as well as the changes of exposure, hazard and risk with each time step for different simulations. This enabled stakeholders to gain greater insight into what changes caused specific outcomes, an example being the vast impact of gradual urban growth processes on the future urbanized area and resulting risk profiles. Additional interesting assessments by stakeholders considered the similarities and differences between different scenarios and provoked questions as to why certain risks emerged under some conditions but not others. This level of insight is critical to enable decision-makers to consider their own influence on how risk may change into the future, and how they can act to manage and reduce this.

To consider how the outputs discussed above can best fit within the larger DRR processes in the case regions, facilitators questioned stakeholders regarding their short term aims for integration of the results, and also longer-term goals of how such a process can be used for integrated decision making across jurisdictions and departments. This saw pathways developed for the modellers and facilitators to continue to support stakeholders in the use of these risk outputs within existing projects and processes of the organisations, departments and agencies included within the stakeholder group.

With greater insight and consideration of how the outputs of the use process have been brought together, stakeholders can provide more clarity and new ideas into previous tasks of the use process, as well as feedback on and suggestions for the risk reductions options and performance indicators that are or could be included in the generic DSS through the development process.

Figure 11: *Insight and sensemaking exercise during a workshop in Greater Adelaide.*

4.2.6 Development of risk reduction portfolios

Risk reduction portfolios are groups of options that provide risk reduction benefits. They can be designed collaboratively between all actors involved in the use process. With the developed and applied DSS, risk reduction options can be implemented and tested against performance metrics incorporated in the DSS thus providing a transparent and repeatable integrated assessment of their effectiveness and potential side-effects under various external conditions.

Modellers, *stakeholders* and *facilitators* are all involved in this process, with modellers providing the analysis of possible risk reduction options discussed in the previous paragraph. The *architect* together with the *facilitators* have to ensure that non-quantifiable assessment factors can be considered and incorporated into the assessment process. This may involve multi-criteria decision making, stakeholder deliberations or the utilisation of other decision-making methodologies (Goicoechea et al., 1982), dependent on stakeholder and governance requirements.

The process should also allow for the consideration of risk reduction options across the spectrum of operation, tactical and strategic responses. Some of these options may be quantified within the DSS, however for those that cannot be, *stakeholders* and the *architect* should work together to consider how developed DRR plans can encompass these, and are aligned with the previously conceived context and risk dynamics. This may involve drawing on expert opinion and judgement, other assessment work, and similar efforts in different processes.

As part of the modelling exercises in each of the case regions, impacts of risk reduction options and portfolios were simulated with the DSSs for the respective case region, and

subsequently discussed with the stakeholders in facilitated workshops. To consider relevant adoption criteria for the risk reduction options that could not be modelled, such as the political and social (community) acceptance of the options and the efforts regarding their proper implementation (capital costs, operational costs, implementation time), a group exercise was included as a workshop activity. Stakeholders were asked individually to express their opinion regarding each adoption criterion on an ordinal scale (low, medium high) as can be seen in Figure 12.

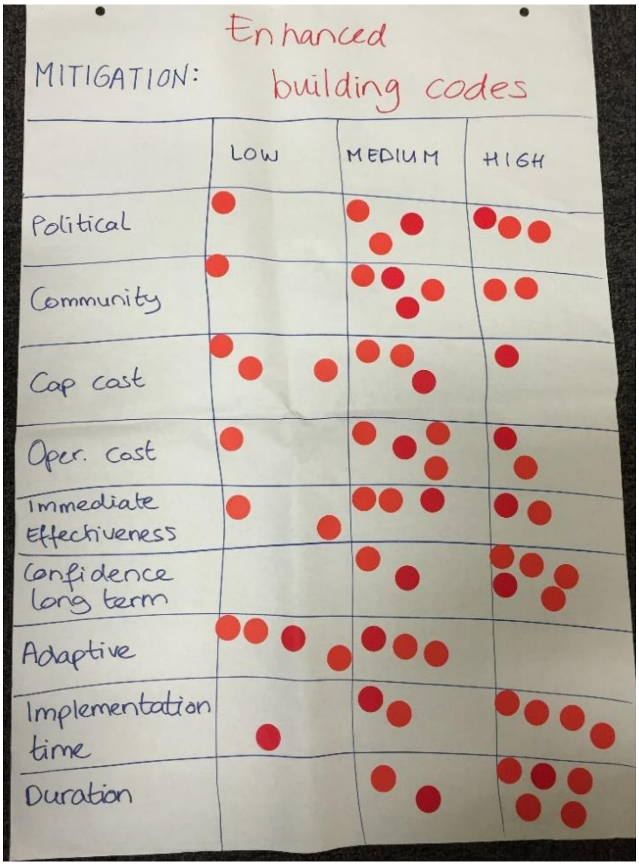


Figure 12: *Example of the adoption criteria and their assessment by stakeholders for a mitigation option included in the Tasmanian case. The number of bullets indicate the number of stakeholders assessing the adoption criterion as low, medium or high. Each stakeholder was asked to select one class for each criterion.*

A key insight obtained from the modelling was the impact of future land use developments on future risk profiles, and linked to this, the value of land use planning in restricting development in certain regions in comparison to, for example, structural measures to reduce the risk from coastal inundation. This led to the realisation that to implement the most effective risk reduction plan, close collaboration between emergency management organisations and planning departments is critical.

The ideal outcome of the overall use process would be to provide results that can be directly integrated in operational, tactical or strategic DRR plans. However, this might not be feasible with a large stakeholder group given common governance arrangements, which sees infrastructure investments and policy development as a complex process with multiple sources of input. In this case, analysis and discussion can occur within individual organisations with decision-making and investment influence. An example of such an outcome for Greater Adelaide includes the collaboration between specific organisations on developing fuel reduction burn plans, for more informed long-term understanding of bushfire risk.

Another example from Greater Adelaide has been work performed analysing the risks of urbanisation in the Gawler River floodplain using UNHARMED. Initial analysis was performed to

highlight hotspots of areas most likely to urbanise between 2016 and 2050, this was then compared to inundation modelling of flood events with an ARI of 50, 100 and 200 years (see Riddell et al., 2018b and Figure 13). This has subsequently been developed into a project to provide integrated assessment of risk reduction options (structural and non-structural) supporting a long-term floodplain management strategy.

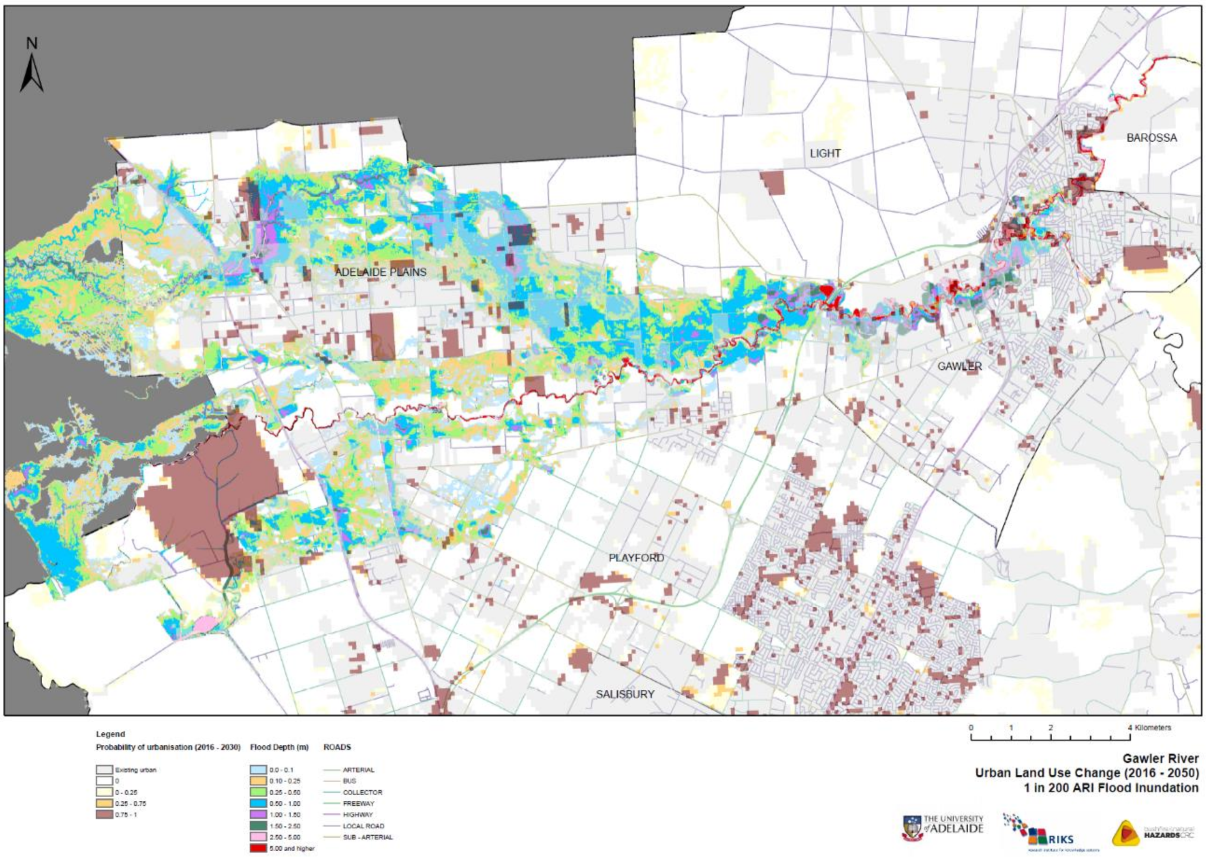


Figure 13: *Map showing part of the Gawler river floodplain with in grey the current urban areas, in shades of yellow and brown the likelihood of urbanisation in 2050 (darker colours indicate a higher probability) and in a mixture of colours the expected flood depth (m) for flood with an ARI of 200 years. The map indicates that some future urbanisation is expected in areas prone to flooding.*

5 CONCLUSIONS AND LESSONS LEARNT

This report presents a generic co-creation approach for the development and use of decision support systems (DSSs) tailored to disaster risk reduction (DRR). It therefore incorporates a range of elements relevant for DRR including:

- The incorporation of all three aspects of the risk triangle (hazard, exposure and vulnerability).
- A risk assessment over time and in space, by dynamically simulating hazard, exposure and vulnerability.
- The ability to assess the impact of risk reduction portfolios consisting of a range of options under conditions of a changing climate and changing socio-economic developments.

We have shown how this process has been implemented to develop a generic DSS for multi-hazard DRR, together with applications for different geographical regions, and introduced a *use process* that provides:

- An understanding of future developments relevant to risk assessment and reduction.
- An assessment of multi-hazard risk over space and time under different plausible futures, and the impact of risk reduction portfolios on risk and other relevant performance criteria in each of these futures.
- Understanding and incorporation of the quantified analysis within a larger policy context.

The strength of the proposed approach is that it enables the integration of the development and use processes. While we see these as distinct processes with distinct actor groups, we emphasize the important feedbacks between them.

Key features of the approach in this regard are:

- Co-creation of knowledge to build on the vast amount of relevant information available amongst the actors involved.
- Distinct actor roles within each process, with some actors taking on roles in both processes: ideally there is an overlap between the scientists and the modellers as well as the end-users and the stakeholders to facilitate knowledge transfer between both processes. For the same reason it is also preferred if the same architect (or some of the architect(s) in case this role is fulfilled by a group of people) is involved in both processes.
- Messy and iterative tasks within each process that allow the adaptation of previous work if new insight demands this, and time and budget permits this.
- Incorporation of modelling and participatory activities and integration of qualitative and quantitative information to build on the widest range of approaches and sources of information possible.
- The development of a generic DSS framework that can be used by many groups and thus becomes more and more robust over time as the user group expands and the system is more widely used. This facilitates the system being well-tested under a variety of conditions. Furthermore, the generic nature of the DSS enables re-use of the components and the possibility to build on them, which is more cost-efficient than “re-inventing the wheel” for each new DSS. The co-creation of components enables the incorporation of knowledge from a range of experts as part of their development and enhancement.
- Modular design of the DSS to enable flexibility in the selection and specification of model components (hazard, level of detail of components, differentiation of certain components for specific cases based on case-specific context, etc.) and enhances its transparency.

- Flexibility in setting up applications for different regions, which enables the system to be tailored to DRR needs within a particular context.
- Separation of the development and use processes and their treatment as individual processes with their own actors, purpose and time frames, which gives each process the attention it deserves.
- The provision of feedback between the development and use processes, which enables the system to be improved based on experience obtained from its use in (many) DRM applications, while at the same time making improvements to the system available for further use in DRM processes.

The proposed approach facilitates the adoption of DSSs in DRR by considering relevant aspects associated with the use of the system, as provided across Chapters 3 and 1, in the following ways:

- The scoping task of the *development process* ensures that the developed system will be relevant and add value to current DRR processes. The feedback from the *use process* to the *development process* ensures that relevance is maintained and allows for changes based on new cases/applications, while the scoping task in the *use process* ensures that the generic DSS is tailored towards the relevant context.
- By developing a generic DSS that incorporates a flexible and modular modelling framework, models can be selected - or developed and incorporated - to be commensurate with the scope and available data. By bringing together people from various backgrounds and organisations in discussing data issues, model assumptions and decisions on the conceptualisation of the specific applications, including the incorporation of narratives into the scenarios, new knowledge is created by filling gaps in existing data and information, and assessing the quality of, and providing improved insight on, what is available.
- Using a combination of a formal calibration using historic data, and expert evaluation by *modellers* and *stakeholders*, as part of the calibration and scenario quantification, improves the behaviour and results of the applications, and provides insight into the results and the way they should be interpreted, thus building confidence that the application can be used for its intended purposes.
- The proposed dual interface facilitates tailored usability by different users, namely policy advisers, and modellers. In addition, the involvement of *users* and *modellers* in the development of user interface elements for setting drivers enables these to be tailored to be intuitive and achieve the desired outcomes. This type of interface helps to address issues surrounding the inherent complexity of a large integrated model, such as that incorporated in the DSS, as it guides users to those parts of the integrated model that are most relevant to them. In addition, the fact that the *use process* exemplifies use of DSSs in DRM and shows how different tasks can be performed by different groups, clarifies potential use and makes the entire disaster risk assessment and management enabled with the DSS more manageable.
- The importance of champions is recognised, as they are essential to embedding the use of the system in DRR processes, and play a key role in the 'scoping' and the 'science-policy interface' tasks of the *development process*, as well as in embedding the DSS in the DRM process as part of the *use process*. DSS adoption is further strengthened through the co-creation process, which improves the connection of the DSS with DRM, building ownership and providing pathways regarding the implementation of the system in DRM processes.

The goal of the approach is not adoption of the system at DRR organisations per se, rather it aims to identify the most effective role of the DSS in the DRR process. This could be via its adoption by DRR organisations themselves, or through third party support. The role the DSS plays in supporting the DRR process is also not intended to be prescribed but instead enables, via the *use process*, organisations to engage with it through a method that best supports their role in the DRR process. For example, this could be via detailed analysis of multi-year fuel reduction burn programs for a specific organisation in this role, or a coordinating agency to use the DSS to engage with a broad range of stakeholders as to their current and future disaster risks to generate a collaborative management approach.

However, there are no DSSs or models that capture everything relevant for decision making in a DRR context, and there is also no need for any DSS or model to capture everything for it to provide utility. What is important is to embed the use of DSSs or models in a wider DRR process, to clearly communicate what the DSS can and cannot offer and to investigate how a DSS or model can be used in conjunction with other methods and techniques to provide the best support possible to DRR processes.

Although the current approach has a focus on DRR, the nature of it is such that it can easily be expanded to include a broader scope beyond disaster risk, such as regional planning or sustainable development. Key features of the approach, such as the interaction between the *development process* and the *use process*, as well as the tasks within each process, can easily be represented in a more generic way and should be able to provide support to developing generic DSSs and adopting them in decision processes in different domains as well.

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