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PROJECT SUMMARY AND EVALUATION

GRUMP - Gawler River UNHARMED Mitigation Project

Hedwig van Delden, Roel Vanhout, Graeme Riddell, Elco Koks, Douglas Radford, Graeme C. Dandy, Eike Hamers, Holger R. Maier, Aaron C. Zecchin

School of Civil, Environmental & Mining Engineering, University of Adelaide, Australia

Research Institute for Knowledge Systems, the Netherlands

Institute for Environmental Studies, Vrije Universiteit Amsterdam, the Netherlands

Australian Government
Department of Industry, Innovation and Science

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1 INTRODUCTION

The annual total economic cost of natural hazards in Australia is expected to increase from around $18.2 Billion in 2016 to around $39 Billion in 2050 (in 2017 dollars), based on recent estimates from Deloitte and the Australian Business Roundtable for Disaster Resilience and Safer Communities (Deloitte Access Economics, 2017). These estimates do not include the impact of climate change and some indirect costs, so the actual impact is likely to be larger than this.

In South Australia flooding is the most economically damaging natural hazard with average annual losses in the State in excess of $32 million (Burns, et. al., 2017).

This projected increase in the impact of natural hazards has led to the recognition that there is an urgent need to better understand disaster risk and in South Australia this requires improved understanding of future flooding risks and subsequent integrated management of flood-prone regions.

The large increases in costs are associated with changes to all components of risk, as conceptualised by the risk triangle (Crichton, 1999):

- Hazard severity is projected to increase into the future as a result of climate change;
- Exposure is likely to increase as a result of increasing populations and a larger proportion of the population living in more hazardous areas; and
- Vulnerability is likely to increase due to increases in the value of assets, ageing infrastructure and changing demographics.

In response to these stressors, over the past seven years the University of Adelaide, and the Research Institute for Knowledge Systems, supported and funded by the Bushfire & Natural Hazard Cooperative Research Centre (CRC), has been developing UNHaRMED (**U**nified **N**atural **Ha**zard **R**isk **M**itigation **E**xploratory **D**ecision Support System).

UNHaRMED is a decision support system designed to explore how to manage risk into the future in an integrated and dynamic fashion considering different drivers and options impacting on future risk. Its development has been supported by the inputs of many stakeholders around Australia, including South Australian State Government officials (including DEW, SASES, DPTI), and LGA SA, shaping what the tool should be able to do and what it should look like.

This project – Gawler River UNHaRMED Mitigation Project (GRUMP) - has been initiated to support the Gawler River Floodplain Management Authority (GRFMA) and other relevant stakeholders to consider how risk may change into the future. The purpose of this project is to develop a strategic masterplan for flood risk management within the catchment[1].

[1] This report outlines the Summary component of the final deliverable for the GRUMP project, and is one of a series of reports including: the Options Assessment; the Evaluation of UNHaRMED application; and the Pathways document.

This report details the development of adaptation pathways, considering how the performance of actions changes with time, and how options perform in portfolios.

1.1 BACKGROUND

1.1.1 Gawler River UNHaRMED Mitigation Project

The Gawler River UNHaRMED Mitigation Project (GRUMP) will support the exploration of the potential of UNHaRMED by considering specific pilot studies and analysis of risk treatments (such as the proposed Dam raise and Northern Floodway proposals) and developing a methodology for continued use of the program for integrated planning of flood mitigation actions by GRFMA.

The project will also provide an example for other local government authorities and floodplain managers in integrated flood risk management supported by integrated risk modelling. This supports the application of Handbook 7 – Guidelines for managing the floodplain (AIDR, 2017).

1.1.1.1 Project Aims

- To provide a platform for GRFMA constituent councils to compare flood mitigation options over time in an integrated and transparent manner, as the basis for preparing a master plan incorporating existing mitigation structures and on-going maintenance and operation for constituent councils and the community;
- To enable this platform to be used to engage the community in decision making, improve risk awareness and resilience and willingness to pay for risk reduction, depending on risk appetite;
- To integrate social, economic, and environmental risk factors for a broad understanding of the Gawler River Catchment to inform a landscape masterplan for long-term strategic planning;
- To highlight the role of research and science in local government decision-making and provide an example for similar councils and catchment management authorities across Australia;
- To develop a repeatable process to enable continued use of the project outputs and analysis frameworks for Local Government decision making across South Australia.

1.1.2 The Gawler River

The Gawler River flows in a westerly direction across the Northern Adelaide Plains from the confluence of the North Para and South Para Rivers just downstream of Gawler Township, to the Gulf St Vincent at Port Gawler. Land use within the floodplain is characterized by a mixture of intensive residential and commercial development in the growth areas of Angle Vale, Virginia and Two Wells, rural living areas, intensive animal husbandry and high value horticulture.

The catchment is identified in the state's flood hazard plan as a significant flood risk.

The River has been flooded on average every 10 years over the past 160 years. Most recently, large floods have occurred in 1992 (September, October, December), November 2005 and October 2016.

Following successful construction of a flood control Dam on the North Para River (Bruce Eastick North Para Flood Mitigation Dam) in 2007 and modification of the South Para Reservoir Dam and spillway in 2012, the GRFMA Board initiated the Gawler River Flood Mitigation Scheme Mark Two, which includes:

- Coordinate further development of the preliminary assessment of possible local area levees prepared in the 2008 Gawler River Floodplain Mapping Study at Gawler, Angle Vale and Two Wells, as well as development of a levee strategy for Virginia;
- Establishment of a protocol with the Floodplain Councils so that where development of land in areas identified as 'at risk of flooding' is planned to proceed by the implementation of a local area levee, mapping of the proposed levees on the Gawler River Floodplain Mapping Study Model will be required;
- Development of a funding strategy for flood protection that is delivered by local area levees on the questions of who should own and maintain the levees and whether local area levees are regional works that the GRFMA should fund or are local works that are the responsibility of the local Council;
- Investigation of opportunities for funding partners and grants to undertake the necessary assessments and designs;

In the 2016 flood event approximately 250 private properties along with local and state government infrastructure were severely affected and there was extensive loss of horticultural production, resulting in a significant damages repair bill in the order of $50 million.

Subsequent to this event the GRFMA facilitated a fatal flaw screening assessment for the potential raising of the North Para Dam by up to 10 meters to provide additional flood protection for a 1 in 100 Annual Exceedance Probability (AEP) event to the township of Gawler and further downstream. This initiated the Gawler River 2016 Flood Review which has recommended a Gawler River Northern Floodway and upgrade of existing levee systems.

1.1.3 UNHaRMED

UNHaRMED is University of Adelaide and RIKS' spatial Decision Support System (DSS) for natural hazard risk reduction planning, funded by the BNHCRC. It consists of a dynamic, spatial land use change model and multiple hazard models to consider how risk changes into the future, both spatially and temporally.

It was developed through an iterative, stakeholder-focused process to ensure the system is capable of providing the analyses required by policy and planning professionals in the emergency management and risk fields. The process involved a series of interviews and workshops with members of the South Australian Government, aligning risk reductions to be included, policy relevant indicators and future uncertainties, such that the system can sit within existing policy processes. This has resulted in a tool that considers how land use changes over time, how various hazards interact with these changes, and what the effectiveness of a variety of risk reduction measures is.

Land use changes are simulated based on a number of different drivers. First there are external factors, such as population growth or the decrease of natural area, that determine the demand for different land uses. The land uses for every location are determined based on socio-economic factors (e.g., will a business flourish in this location?), policy options (e.g., are there policy rules in effect that restrict new housing development in this location?) and biophysical factors (e.g., is the soil suited for agriculture here?). Natural hazards are included as the specific application is set up. Hazards can include bushfire, earthquake, coastal inundation and riverine flooding. Each hazard is modelled differently, depending on its underlying physical processes, as detailed within this documentation.

A simplified version of the system diagram developed for UNHaRMED is shown in Figure 1, 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).

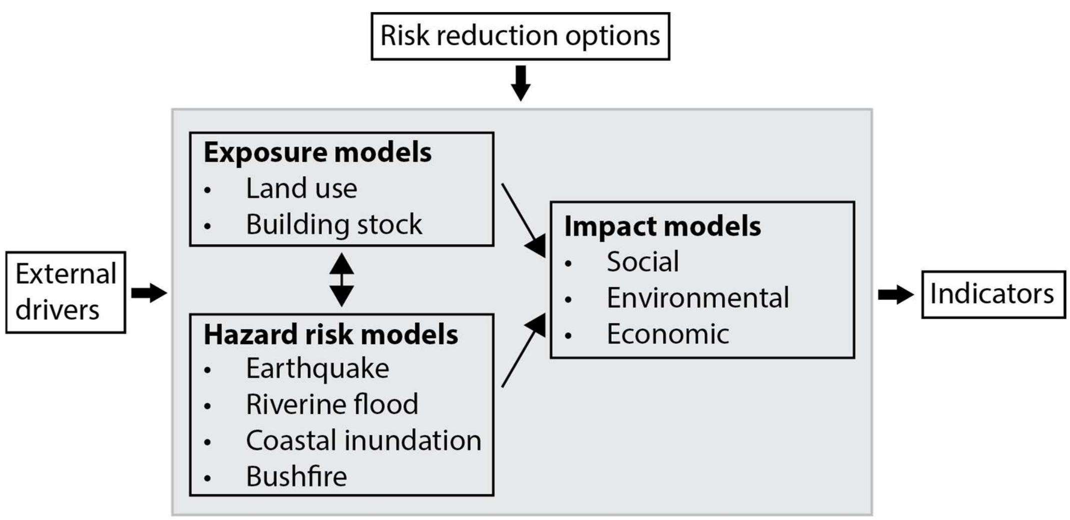

FIGURE 1: MODELLING COMPONENTS FOR INCLUSION WITHIN THE INTEGRATED MODELLING FRAMEWORK OF UNHARMED.

UNHaRMED is developed in the Geonamica software environment and comes as a stand-alone software application. The system includes the Map Comparison Kit for analysis of model results. All of the above tools use data formats that are compatible with standard GIS packages, such as ArcGIS.

1.2 PURPOSE OF THIS REPORT

This report is a key deliverable of Stage 3 of the project, as shown in Figure 2. It provides a summary of the project and evaluation on the use of UNHaRMED for the type of study conducted. In particular it discusses:

- The approach applied for the pathway development;
- Summary of the pathway results;
- Lessons learnt regarding the use of UNHaRMED for this type of study.

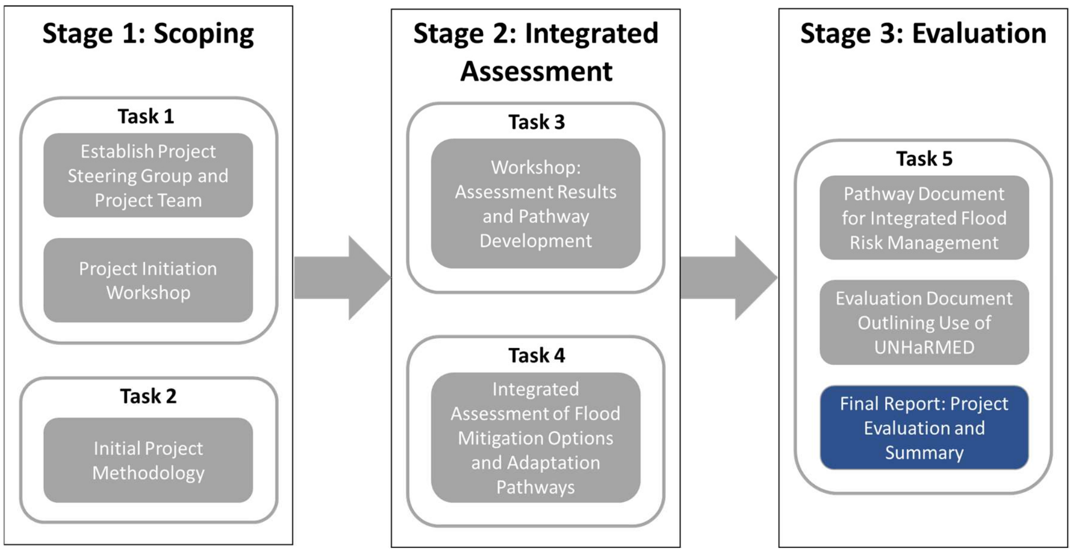

FIGURE 2: PROJECT STAGES (BLUE REFERS TO THE STAGE THIS REPORT ALIGNS TO).

2 OVERVIEW OF PATHWAYS APPROACH

Developing pathways for effective flood risk management is challenging, considering the diversity of flood impacts and values that exist within the region. Given the scope of this project and its emphasis on strategic planning (not detailed options analysis and design), a specific approach has been developed to enable insight and strategic options analysis for long-term flood risk management in the Gawler River floodplain.

This approach is not intended to fully quantify the spectrum of flood impacts, benefits of flood risk management treatments or other values within the floodplain, but instead provide a high-level assessment of options against identified metrics and how they fit together to manage risk and enable development.

An overview of the entire approach is provided in Figure 3. In the first phase, the **decision context** was established. This resulted in a set of objectives and related indicators; 5 different scenarios exploring potential futures for the river basin; and a selection of flood risk management options relevant for inclusion in the assessment.

Using the information from the first phase, in the **integration assessment** phase, metrics were defined for each of the key risk reduction indicators, and the impact of the selected options was assessed on these metrics. Results were interpreted and discussed during workshop sessions with the Stakeholder Advisory Board in November 2019 and June 2021.

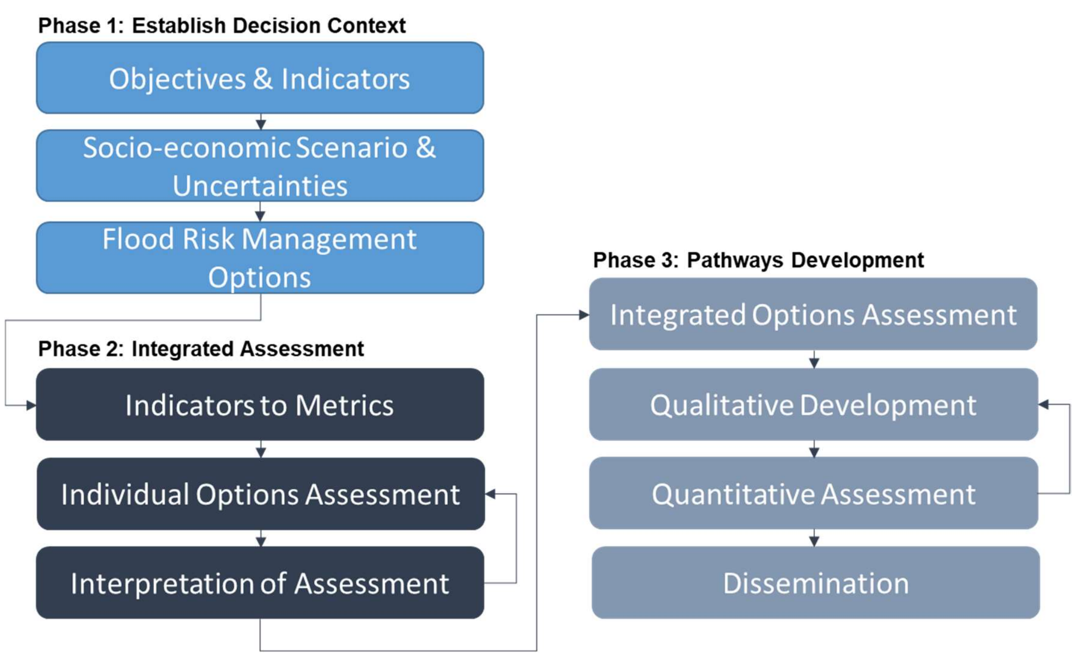

FIGURE 3: PATHWAYS DEVELOPMENT APPROACH

The workshop in June 2021 provided input into the adaptation and combination of available risk reduction options, so creating a set of mitigation portfolios (15 individual options and 10 combined options) to inform the **pathways development**. Using this information, qualitative pathway ideas were derived, and an additional set of combined options was defined and quantitatively assessed to further fine-tune the pathways development.

Details about the options assessment component of the approach are provided in Section 2.1. This is followed by a summary of the main project results (Section 3) and lessons learned in applying UNHaRMED for this type of study (Section 4). Some concluding remarks are provided in Section 5.

2.1 IMPACT ASSESSMENT OF RISK REDUCTION OPTIONS

Impact assessment of a range of individual and combined options was carried out both in phase 2 and phase 3 of the project. All flood risk management options considered are tested against a set of metrics and considered under a range of scenarios.

An important aspect of the assessment is to explore how the flood risk is impacted by changes over time for different future scenarios. A baseline and four exploratory scenarios were developed in a participatory setting to test the future resilience of the local community and the effectiveness of actions. These temporal risk profiles assist in understanding the impact of mitigation options under various future plausible conditions and thus assist in dealing with future uncertainties. The assessment of different scenarios against time and a common metric is illustrated in Figure 4.

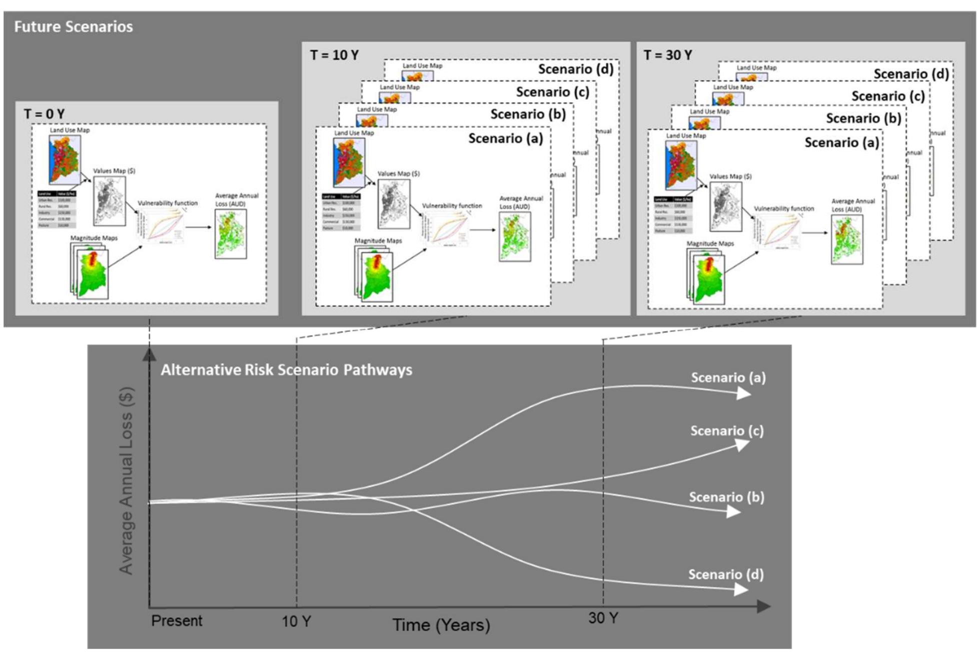

FIGURE 4: OVERVIEW OF RISK ASSESSMENT PROCESS AGAINST TIME

The risk reduction options were assessed according to the following key risk metrics:

- Impact per ARI (Average Recurrence Interval): the land area, number of buildings, and length of (road) infrastructure affected as a result of a flood event with a specific ARI in a specific year;
- Damage per ARI: damages to capital stock (properties, crops, and infrastructure) of a flood event with a specific ARI in a specific year;
- Average annual damage (AAD): expected damage per year, accounting for the range of ARIs considered. Similar to the previous point, this includes damages to capital stock (properties, crops and infrastructure). The calculation includes inundation maps for the set of ARIs and respective probabilities;
- Average annual output loss (AAOL): productivity losses associated with direct damage to capital loss.
- Present value (PV) of the damages in 2018 dollars of the future stream of damages (i.e. where the total annual damage is the sum of the average annual damage, and the average annual output loss). The PV of the damages is calculated over a 42-year time frame (2018-2060) with a discount rate of 7% per annum. This makes it possible to include the implementation year of various options in the assessment.

The first three risk metrics were calculated on an annual basis from 2018 – 2060, the fourth metric is provided for 2018, 2040 and 2060 for the baseline scenario, including the mitigation options tested under this scenario. The final metric is used to integrate the damage assessment over the assessment period (2018-2060). We have selected 2018, 2030 and 2050 as years from which the options can be implemented, so the impact of the options can be assessed a few years after their implementation.

The assessment was based on 30 m resolution inundation maps for a range of ARIs (i.e. 1/20, 1/50, 1/100, 1/200, 1/500), together with 100 m resolution land use maps. As no climate change impacts were included, inundation maps did not change over time. Socio-economic developments over roughly a 40-year period led to changes in land use, impacting on, amongst others, residential, industrial, commercial, and agricultural uses and hence changes in exposed values.

To capture the spatial detail of the inundation maps, impact calculations included the area inundated of each land use cell as the sum of the areas inundated in the underlying, more detailed, inundation map.

Risk modelling was carried out by using the value of the asset (exposure) with vulnerability functions that translate the magnitude of the hazard (flood depth) to the percentage of damage done to the asset, with 100% being complete destruction.

Direct damages are calculated at the grid level (i.e., 100m resolution) and summed across the floodplain.

In order to assess the *indirect impacts* - impacts of flooding on the broader economy outside of damage to assets - a multiregional supply-use model (subsequently referred to as the MultiRegional Impact (MRIA) model) is used[2] to provide information at a river basin level.

The MRIA model allows for estimating a new economic equilibrium as a result of lost economic activity due to flooding. The model calculates how economic transactions between economic actors may change because of flooding. Positive and negative economic transactions are considered both within a region and from- and to- other regions. These transactions (or trade flows) are the main driver of the economic impacts in the affected and surrounding regions. Negative economic impacts will occur when the reduction in production capacity cannot be substituted by other economic actors. Positive impacts may occur if the affected economic actors can find a substitute for either their supply or demand within their existing trade relations.

Indirect impacts were assessed across three different durations, given the large uncertainty in impacts to production losses. Table 1 outlines the number of days of outages for a low, medium and high production impact event that were tested within the modelling.

TABLE 1: NUMBER OF DAYS FOR PRODUCTION OUTPUTS LOSS FOR INDIRECT DAMAGE ASSESSMENT

ARI	Low	Medium	High
20	5	10	20
50	15	30	60
100	30	60	120
200	45	90	180
500	90	180	360

Using the above approach, a series of risk reduction options was tested against the 5 different scenarios (the baseline and 4 alternative scenarios).

[2] For a complete description of the used model, refer to Koks and Thissen (2016).

3 PROJECT RESULTS

This section gives a short overview of the main results of the project with references to the reports in which more details can be found.

3.1 SELECTION OF RISK REDUCTION OPTIONS TO BE EXPLORED

Throughout the project, risk reduction options have been selected, fine-tuned and combined as part of participatory processes and based on findings from impact assessment modelling. This resulted in the following risk reduction options and their variations:

- Northern floodway implementation
- Bruce Eastick dam raise implementation
- Land use planning
    - Different alternatives based on the ARI for which the inundation map is used as a basis for zoning regulations: ARI 100 (100) or ARI 200 (200);
    - Different alternatives based on the restrictions imposed:
        - Strict (S): no new development allowed in the zone, no infill development or subdivisions allowed;
        - Medium (M): no new development on new locations (greenfield-development) allowed in the zone, infill development or subdivisions allowed;
        - Weak (W): new development, infill and subdivision discouraged.
- Raised Floor levels
    - Different alternatives for the extent of application:
        - Application to all new and existing buildings in the flood prone area (A);
        - Application only to new developments in the flood prone area (B).
    - Different alternatives for enhanced resilience:
        - Raising the entire building or horticultural activity by 15 cm, so assuming the building or horticultural activity will be developed at a higher level (1)[3];
        - Protecting the base of the building only, so increasing the inundation level from which damage occurs from 15 cm for buildings and 10 cm for horticulture to 30 cm for both (2).

[3] Please note that the combination (A,1) consisting of applying the floor level raising to all existing buildings and horticulture areas is clearly hypothetical, and included for the sake of comparison.

Table 2 provides an overview of all (portfolios of) reduction options for which the impact has been assessed using UNHaRMED and the MRIA model. The table also indicates the implementation year of the option(s). Once implemented, options are expected to remain implemented until (at least) 2060, the final year of the assessment.

A summary of the results of the risk reduction assessment are provided in Section 3.3. More information is provided in the Options Analysis report and the Pathways document.

TABLE 2: OVERVIEW OF ASSESSMENT OPTIONS INCLUDED IN THE RISK ASSESSMENT. S: STRICT ZONING, M: MEDIUM ZONING, W: WEAK ZONING, 100: ARI 100, 200: ARI200, A: ALL DEVELOPMENTS, B: NEW DEVELOPMENTS, 1: ENTIRE BUILDING, 2: BASE PROTECTION.

	Floodway			**Dam**			**Zoning**			**Raised FL**		
	'18	**'30**	**'50**	**'18**	**'30**	**'50**	**'18**	**'30**	**'50**	**'18**	**'30**	**'50**
1.No mitigation												
2.Floodway '18	X											
3.Floodway '30		X										
4.Floodway '50			X									
5.Dam raise '18				X								
6.Dam raise '30					X							
7.Dam raise '50						X						
8.Floodway+dam '18	X			X								
9.Floodway+dam '30		X			X							
10.Floodway+dam '50			X			X						
11.Zoning '18							S,100					
12.Zoning '18							S,200					
13.Zoning '18							M,100					
14.Zoning '18							M,200					
15.Zoning '18							W,100					
16.Zoning '50									W,100			
17.Raised FL '18										A,1		
18.Raised FL '18										A,2		
19.Raised FL '18										B,1		
20.Zoning '18 & Dam '50			X				W,100					
21.Zoning '18 & Fw '50						X	W,100					
22.Zoning '18 & Fw+dam '50			X			X	W,100					
23.Fw+dam+zoning '18	X			X			W,100					
24.Fw+dam '18 & Zoning '50	X			X					W,100			
25.Fw+dam+raised FL '18	X			X						A,2		
26.Fw+dam '18 & Raised FL '30	X			X							A,2	
27.Fw+dam '18 & Raised FL '50	X			X								A,2
28.Raised FL '18 & Fw+dam '50			X			X				A,2		
29.Fw+dam+zoning '18	X			X			S,200					
30. Fw+dam '19 & Zoning '50	X			X					S,200			
31.Fw+dam+zoning+Raised FL '18	X			X			S,200			A,1		

3.2 SCENARIOS FOR EXPLORING FUTURE UNCERTAINTIES

As a method for exploring the future, scenarios were developed considering plausible changes from 2013 to 2050. Members of SA's State Mitigation Advisory Group (SMAG), assisted by the scenarios team at the University of Adelaide and Research Institute for Knowledge Systems, developed five alternate plausible futures for Greater Adelaide.

These scenarios are detailed in *Futures Greater Adelaide 2020 – An exploration of disaster risk and the future* (Riddell et. al., 2016).

The purpose of scenarios is to explore plausible pathways into the future. The future is a volatile, uncertain, ambiguous and complex place, but decisions and policies need to be implemented regardless. Through a series of workshops, these factors were explored with members of the State Mitigation Advisory Group (SMAG). Uncertainties and drivers were considered, which resulted in five alternative futures for the region. Figure 4 provides a visual guide to four of the developed scenarios, framed around increasing challenges to government intervention and societal resilience.

For their application to the GRUMP project, the scenarios were presented to stakeholders for discussion and refinement to the project's context, including localisation to the floodplain and associated councils.

FIGURE 3: OVERVIEW OF EXPLORATORY SCENARIOS

More information on the scenarios is provided in the Options Analysis report. The impact of the risk reduction options under the various scenarios is described in Sections 3.3. and 3.4.

3.3 ASSESSMENT OF RISK REDUCTION OPTIONS

The options assessment included both a quantitative risk assessment using UNHaRMED and the MRIA model, as well as stakeholder input on the feasibility of various options. Both are briefly summarised in this section.

The main findings of the quantitative risk assessment include:

- The Dam raise is overall very effective in reducing risk, and even more so during large flood events. Nonetheless, both zoning (land use planning) options outperform all other options in the later years, especially for very large flood events. The Floodway option is mostly suited to reducing impacts of smaller floods and outperforms other options in doing so initially (note that the floodway was designed for the smaller ARI events). Although it remains equally effective in reducing risk over time, the impact on risk reduction of the ARI 200 flood overlay is so dominant in 2060 that it outperforms all other options for all ARIs.
- For some options, risk reduction is immediate (starting from 2018 in this study) and consistent over time. This is the case for the Floodway, the Dam raise and the Raised floor levels. For the latter, this is under the assumption that changes to floor levels can be made to existing buildings and horticultural areas can be better protected against inundation. Zoning options only affect future values, as they only impact on new developments. Results show that the impact of zoning on risk reduction increases over time, which makes sense, as new developments increase over time and no longer allocating them in flood prone areas avoids increasing damages.
- Assessing results across scenarios shows that some options score well under all scenarios, while other options perform especially well under specific scenarios. The Dam raise performs very well across all scenarios and all time periods (between 34-39% reduction in risk compared to not implementing any mitigation). Zoning options perform particularly well in scenarios with significant development as they are very effective in redirecting new development away from the hazard-prone areas.

The following main findings were obtained regarding the feasibility of the different risk reduction options on criteria not included in the modelling:

- As part of the Stakeholder Advisory group workshop organized in November 2019, participants were asked to comment on a set of criteria for each of the individual risk reduction options as listed in Section 3.1: political/community acceptance, capital/operational costs, effectiveness, confidence in long-term success, adaptation potential, and implementation time.

  Participants agreed that capital costs, especially of the Dam raise and to a lesser extent the Floodway, are expected to be high, but that these options are also expected to do very well in terms of immediacy and duration of effectiveness. In addition, participants have a lot of confidence in the long-term success of these options. For both planning options, and to a lesser extent the Raised floor levels options, costs are expected to be low (when applied to new developments). However, in terms of community acceptance, these options score rather low and there is less confidence in their long-term success. The risk-based planning option scores poorly for several criteria and was seen as a measure that was too complex to implement. For this reason, risk-based planning was excluded from further analysis in this study.

- As part of the Stakeholder Advisory group workshop organized in June 2021, participants discussed the advantages and disadvantages of the various risk reduction options and provided them with a ranking from 1-8, with 1 being the most preferred option and 8 the least preferred option.

  Results indicated a clear preference for the Dam raise option, followed by the Floodway implementation and the Raised Floor levels for new developments. The hazard-based zoning options had an intermediate ranking, while the risk-based zoning option and no mitigation were ranked last. There was, however, a large variation in ranking of the options amongst participants.

  Participants were also asked about their preference to combine and/or time certain options. There was broad agreement that it would be relevant to combine the Dam raise and the Floodway option. It was also suggested that these could be combined with Raised floor levels in new development and Zoning.

3.4 PATHWAY DEVELOPMENT

Developing pathways for integrated flood risk management requires focusing on a set of indicators that together present the values in the region. We are therefore seeking a solution that scores well across the following objectives:

- Protection of current assets, and avoiding damage to new developments;
- Protection against minor and major floods;
- Protection under a range of climate scenarios and socio-economic futures;
- Selection of options that are effective in reducing risk and perform well on other social, economic and environmental indicators representing additional objectives in the river basin.

By iteratively assessing the risk reduction impact of (portfolios of) options, we found that a combination of options would be required to meet all of the above objectives, as different options have their own merits. The four best performing portfolios of options from the impact assessment were included as the potential pathways that deserve further consideration. They are summarised in Table 3 and further elaborate on below.

TABLE 3: OVERVIEW OF OPTIONS MOST RELEVANT FOR DEVELOPING THE PATHWAYS. S: STRICT ZONING, M: MEDIUM ZONING, W: WEAK ZONING, 100: ARI 100, 200: ARI200, A: ALL DEVELOPMENTS, B: NEW DEVELOPMENTS, 1: ENTIRE BUILDING, 2: BASE PROTECTION. PV-D IS THE PRESENT VALUE OF THE DAMAGES.

	Rank	**PV-D (M$)**	**Floodway**			**Dam**			**Zoning**			**Raised FL**		
			'18	**'30**	**'50**	**'18**	**'30**	**'50**	**'18**	**'30**	**'50**	**'18**	**'30**	**'50**
1.No mitigation	31	239												
8.Floodway+dam '18	8	161	X			X								
25.Fw+D+RFL '18	3	157	X			X						A,2		
29.Fw+D+Z '18	2	131	X			X			S,200					
31.FW+D+Z+RFL '18	1	106	X			X			S,200			A,1		

The Northern Floodway implementation and the Bruce Eastick dam raise implementation in 2018 will lead to immediate protection of current assets, and together are likely to do so for minor floods (ARI 20, ARI 50) through the Northern Floodway implementation, as well as larger events (ARI 50, ARI 100, ARI 200) through the Bruce Eastick dam raise. Implementing the structural options in 2018 provides considerable additional risk reduction (PV-D $161 M) compared to an implementation in 2030 (PV-D $195 M) or 2050 (PV-D $229 M).

By combining the above approach with Zoning (land use planning) that is implemented in 2018, damages to new developments can be avoided and assets will be better protected against floods of all sizes, including very large floods (ARI 500), by prohibiting or limiting new developments. It should be noted that although these Zoning regulations come into effect immediately, their impact (benefit) is felt increasingly over time as new developments occur, therefore providing adaptive capacity as the population in the region grows.

Increasing the resilience of new and existing buildings and horticultural areas by raising the floor levels or implementing additional options with the same effect, further contributes to a reduced risk.

To arrive at the various options and option portfolios, the implementation of the Northern Floodway and the Bruce Eastick dam raise were included in the assessment as a given option, due to their high scores in the risk reduction assessment, while various alternatives were assessed for the Zoning (land use planning) and the Raised floor levels options. It is important to acknowledge that high risk reduction results were obtained for strict zoning alternatives and for retrofitting existing buildings. However, the feasibility of these would need to be assessed. Where it is unlikely that all existing buildings in the flood prone areas could be retrofitted, avoiding new development in these areas might be more realistic. Depending on the attractiveness of the location within the flood prone area for different activities, combinations of strict zoning for some activities and lesser restrictions for others, while combining the latter with mitigating options (such as raising the floor levels of buildings and infrastructure, making them more resilient, or finding smart ways to protect high-value agriculture) could provide a way forward. Nonetheless, the larger the degree to which new developments can be located outside of the flood prone area, the lower the risk, as not all damages can be avoided by incorporating mitigating measures.

A final consideration in the pathways development is to be aware of the climate and socio-economic uncertainty in the medium and long term, together with the fact that current development decisions have a high impact on the future risk of the region due to the high inertia of (urban) developments and high value agriculture. Due to climate change, a present-day 1 in 200 year flood, as explored as part of this study, might be the future 1 in 100 year flood and likewise, the present-day 1 in 100 year flood might be the future 1 in 50 year flood , for example. However, additional hydrological and flood modelling would be required to better understand the actual changes in flood frequency and inundation depth. In addition, new residential and economic development in the region will increase the value of assets substantially, leading to high exposed values if these are located in the flood prone areas, either through greenfield development, or by infill or subdivisions. Being aware of those developments and the potential increase in risk they bring will facilitate the development of future-proof pathways.

Table 4 shows for each of the selected pathways: the direct damage for the baseline (BAU) scenario; the variation in direct damage across the different socio-economic scenarios; the indirect damage for the BAU scenario using a medium number of days per ARI for production output loss (see Table 1 for more details on the low, medium and high outage durations); the variation in indirect damages for the BAU scenario based on the duration of the outage and the total of the direct and indirect damages for the BAU scenario, using the medium outage duration. Damage information is provided for three different years, in addition to the NPV of the damages (2018 value, calculated over a 42-year time frame (2018-2060) with a discount rate of 7% per annum).

Table 4 shows that the options listed have the potential to reduce the present value of the damages from $ 239 M (no mitigation option), to $ 106-161 M (options listed in Table 4). From the table it can furthermore be concluded that the performance of the options is rather consistent across the various socio-economic scenarios. Only in scenarios where there is very little growth, or even decline (i.e. Cynical Villagers), a combination of structural options with zoning does not outperform a combination of structural options with more resilient buildings. The table also confirms the findings of the Options Analysis report in indicating that zoning options are especially effective under high socio-economic growth and related developments (i.e. Ignorance of the Lambs). More information on the damage values per scenarios can be found in the Pathways document.

TABLE 4: SUMMARY OF (REDUCTION OF) DIRECT DAMAGES (AAD) AND RELATED PRESENT VALUE OF THE DAMAGES (PV-D), INCLUDING THEIR RANGE UNDER DIFFERENT SOCIO-ECONOMIC SCENARIOS, (REDUCTION OF) INDIRECT DAMAGES (AAOL) AND RELATED PV-D, INCLUDING THE VARIATION UNDER DIFFERENT OUTAGE DURATIONS, AND THE SUM OF THE DIRECT AND INDIRECT DAMAGES UNDER THE BAU SCENARIO, FOR SELECTED PATHWAY OPTIONS. FOR RAISED FLOOR LEVELS A: ALL DEVELOPMENTS, 1: ENTIRE BUILDING, 2: BASE PROTECTION.

Option portfolio	Year/ PV-D	Direct Damage – BAU scenario (M$)	Direct Damage reduction range, across scenarios	Indirect Damage – Med. BAU scenario (M$)	Indirect Damage Range BAU scenario (M$)	Total Damage BAU scenario: direct + indirect medium (M$)
8. Floodway + dam '18	2018	6.0 (-39%)	-39%, -39%	3.9 (-20%)	2.0-7.8	9.9 (-33%)
	2040	7.7 (-40%)	-36%, -42%	5.7 (-21%)	2.9-11.4	13.4 (-33%)
	2060	9.5 (-37%)	-36%, -43%	8.9 (-26%)	4.4-17.7	18.4 (-32%)
	PV-D	93 (-39%)	-37%, -39%	67 (-21%)	34-134	161 (-33%)
25. Floodway + Dam + Raised floor levels (A,2) '18	2018	5.8 (-41%)	-41%, -41%	3.9 (-20%)	2.0-7.8	9.7 (-34%)
	2040	7.4 (-42%)	-42%, -47%	5.7 (-21%)	2.9-11.4	13.1 (-34%)
	2060	9.2 (-39%)	-42%, -48%	8.9 (-26%)	4.4-17.7	18.1 (-33%)
	PV-D	90 (-41%)	-41%, -44%	67 (-21%)	34-134	157 (-34%)
29. Floodway + Dam + Zoning strict ARI200 '18	2018	6.0 (-39%)	-39%, -39%	3.9 (-20%)	2.0-7.8	9.9 (-33%)
	2040	6.0 (-52%)	-47%, -73%	3.2 (-55%)	1.6-6.4	9.2 (-54%)
	2060	6.1 (-60%)	-40%, -74%	5.0 (-58%)	2.5-10.0	11.1 (-59%)
	PV-D	81 (-47%)	-43%, -60%	50 (-41%)	25-100	131 (-45%)
31. Floodway + Dam + Zoning strict ARI200 + Raised floor levels (A,1) '18	2018	5.5 (-44%)	-44%, -44%	1.7 (-65%)	0.9-3.5	7.2 (-51%)
	2040	5.5 (-57%)	-52%, -75%	3.2 (-55%)	1.6-6.4	8.7 (-56%)
	2060	5.6 (-63%)	-55%, -76%	2.1 (-83%)	1.0-4.2	7.7 (-72%)
	PV-D	74 (-52%)	-48%, -64%	32 (-62%)	16-64	106 (-56%)

Although this study focuses on the risk reduction assessment of the different risk reduction portfolios, a consideration of their impact in a broader context would be required as well, to arrive at a regional development pathway that includes risk reduction amongst other social, economic and environmental objectives.

4 LESSONS LEARNT

This section provides some of the relevant technical considerations in carrying out similar exercises with UNHaRMED, and provides an overview of the discussion on use of the system in future projects.

4.1 TECHNICAL CONSIDERATIONS

In carrying out any modelling or assessment study (including studies with UNHaRMED), data, parameters and assumptions play a critical role, together with the technical capability of the tool. Our main reflections and lessons learned in this regard include:

- Aligning any additional modelling relevant for the study at hand (in this particular study the inundation modelling) with the risk assessment modelling with UNHaRMED would facilitate the work and improve the validity of the results;
- Due to the high inertia of the building stock, infrastructure and high-value agriculture, data reflecting the current status is also important for modelling future exposure. Improved initial (present-day) data, especially on the value and location of buildings and agricultural practices, would improve the accuracy of the results, as could improved damage values for road infrastructure. Although this is a reflection on the current flood study, it is generally applicable to risk studies across various hazards;
- An improved understanding of the vulnerability of various assets in the region of interest, as well as their sensitivity to the calculated risk, would enhance the validity of the risk assessment. Like the previous point, this statement is relevant also beyond flood risk as it applies to other hazards also;
- Assumptions made during the modelling impact on the results. It is therefore important to communicate these to the extent possible and include their impact in the interpretation of the results;
- The current project served as a first case to apply UNHaRMED to a practical flood management study. To do so, a number of improvements were made to the software, which have made the system better suited to practical flood management. Several of the improvements can directly be applied to other hazards as well. Further applying UNHaRMED to practical risk assessment and reduction studies involving different hazards will likely lead to further suggestions for improvement and increased realism;
- UNHaRMED provides added value to existing models by providing a suite of indicators that can be tailored to user needs, and by exploring the impact of future climate change impacts and socio-economic developments on risk and the impact of risk reduction options. It would be useful to expand the functionality of UNHaRMED with more automated approaches for the latter.

4.2 USE OF UNHARMED

In June 2021, a workshop was conducted with stakeholders from the GRFMA (Gawler River Floodplain Management Authority). This section builds on the reflections provided and is structured around the questions posed during the workshop. Responses are bulleted below the participant questions.

Question: *For what types of questions can a system like UNHaRMED provide support?*

- To assess the impact of mitigation options and to facilitate discussing and selecting the preferred option;
- To support business case development for mitigation;
- Future land use planning in a broad sense.

Question: *How and by whom should a system like UNHaRMED be used?*

- An important consideration in this decision is the ease of use of the system and the capability and capacity of the organisation;
- UNHaRMED seems to be best suited for use at regional or state level, e.g. by a State Agency, but there might be potential at local government too.

Question: *What are the main challenges in using a system like UNHaRMED?*

- The need for good data, as the accuracy of the model results depend on the accuracy and completeness of the input data;
- The available skill set, knowledge and technology and maintaining the awareness of its availability and its use over time.

Question: *What are the main benefits of using a system like UNHaRMED?*

- Holistic understanding of benefits and impacts of alternative mitigation options under a range of scenarios;
- Provides a structured assessment and decision process;
- Good foundations on cost benefit analysis. Might be an alternative to the approach for a SMP (Stormwater Management Plan);
- Helps to focus on new data collection.

Question: *What do you see as the main capabilities of UNHaRMED in its current form?*

- Spatial analysis linked to economic analysis and hydrological analysis;
- Comparison of options in terms of average annual damages;

- Provides a good basis to understand the risk and possible impacts. The various scenarios and ability to map the benefits of suggested flood (hazard) mitigation options is useful.

What would you like to see added for the improvement of UNHaRMED?

- Feedback loop between land use change and flood risk.

Further suggestions on potential use cases for different organisations is provided in the report on the Evaluation of the UNHaRMED application.

5 CONCLUSIONS

This study has presented a pathways approach for integrated flood management using UNHaRMED and the MRIA model, which was applied to the Gawler river basin. Using the approach, a range of risk reduction options has been quantitatively assessed, and combined with participatory activities, to develop potential pathways for integrated flood management for the Gawler river basin.

Important considerations in this pathways approach included:

- Protection of current assets, and avoiding damage to new developments;
- Protection against minor and major floods;
- Protection under a range of socio-economic futures and climate scenarios[4];
- Selection of options that are effective in reducing risk and perform well on other social, economic and environmental indicators representing additional objectives in the river basin.

The impact assessment modelling of individual options, as well as combinations of options, shows that a combination of options with immediate effectiveness in protecting existing assets, and the ability to avoid future risk due to new developments, would be desirable.

Combining the Northern Floodway implementation with the Bruce Eastick dam raise implementation reduces the risk of existing assets across floods of different severities, while (strict) zoning avoids new development in the flood prone areas. These options can be combined with options to increase the resilience of the assets, and hence reduce their vulnerability against flood events, especially in locations at risk. The selection of the more detailed options to limit development and increase the resilience of existing and future assets would need to be tailored to specific local characteristics and interests.

In implementing risk reduction options, and especially zoning regulations that limit new developments, it is important to consider a range of climate scenarios, as well as future socio-economic developments. This is in order to future proof flood management strategies, by being aware of changing risk profiles and being able to put appropriate risk reduction strategies in place.

Although this report focuses on the risk reduction assessment of the different risk reduction portfolios, a consideration of their impact in a broader context would be required as well, to arrive at a regional development pathway that includes risk reduction amongst other social, economic and environmental objectives.

This study has demonstrated both the value and challenges of applying UNHaRMED for regional flood risk master planning.

In terms of benefits, applying UNHaRMED enables:

[4] The impact of climate scenarios was mimicked by using the ARI200 inundation area instead of the ARI100 inundation area for zoning, in the absence of ARI100 inundation information for different climate scenarios.

- All aspects of risk to be considered, including hazard, exposure and vulnerability;
- The temporal and spatial evolution of risk under different plausible future scenarios to be determined, providing information on potential future flood risk hot spots, and the comparison across different socio-economic scenarios;
- The relative effectiveness of different mitigation strategies, targeting hazard, exposure and vulnerability, to be assessed in an integrated manner;
- The most promising future risk reduction pathways to be identified;
- Clear communication of the evolution of future risk through time and the relative effectiveness of different risk reduction strategies;
- The incorporation of stakeholder input, as well quantitative information, in an integrated fashion.

In terms of challenges, the successful application of UNHaRMED requires:

- The availability of high-quality data on all factors affecting risk, as this has a direct impact on the uncertainty of the results obtained. This is, however, a requirement of all risk studies;
- Potential tailoring of the software to meet application-specific end user needs, which, while possible, can require significant resources;
- Tailoring to local conditions to obtain reliable results.

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