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PATHWAYS DOCUMENT FOR INTEGRATED FLOOD RISK MANAGEMENT

GRUMP - Gawler River UNHARMED Mitigation Project

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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 Pathways 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 Final summary report.

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).

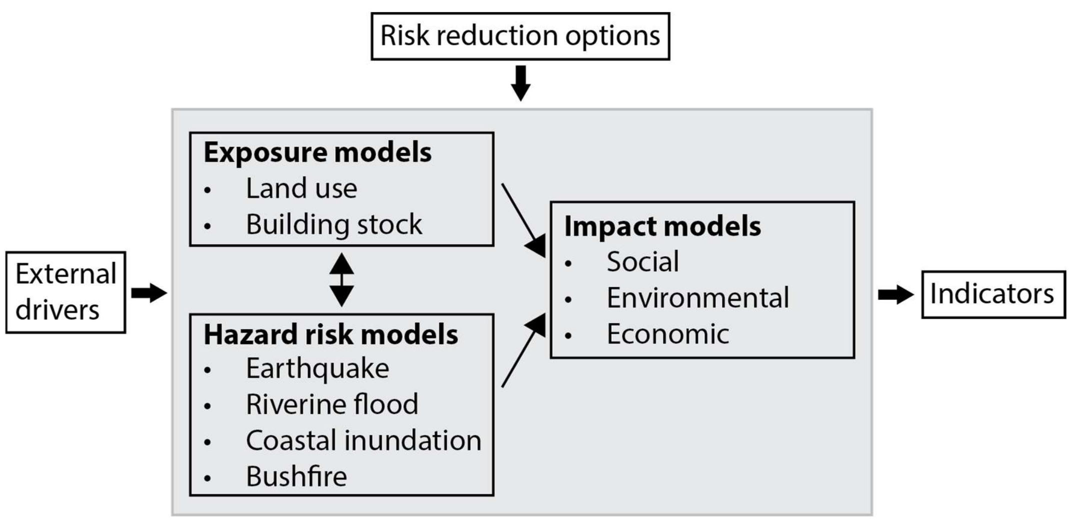

FIGURE 1: MODELLING COMPONENTS FOR INCLUSION WITHIN THE INTEGRATED MODELLING FRAMEWORK OF UNHARMED.

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 an evaluation of the use of UNHaRMED for the type of study conducted. In particular it discusses:

- Relevant input from previous project activities for developing the pathways;
- Results for a range of risk assessment simulations, indicating the effectiveness of different (portfolios of) risk reductions options;
- Development pathways for strategic floodplain management in the Gawler basin.

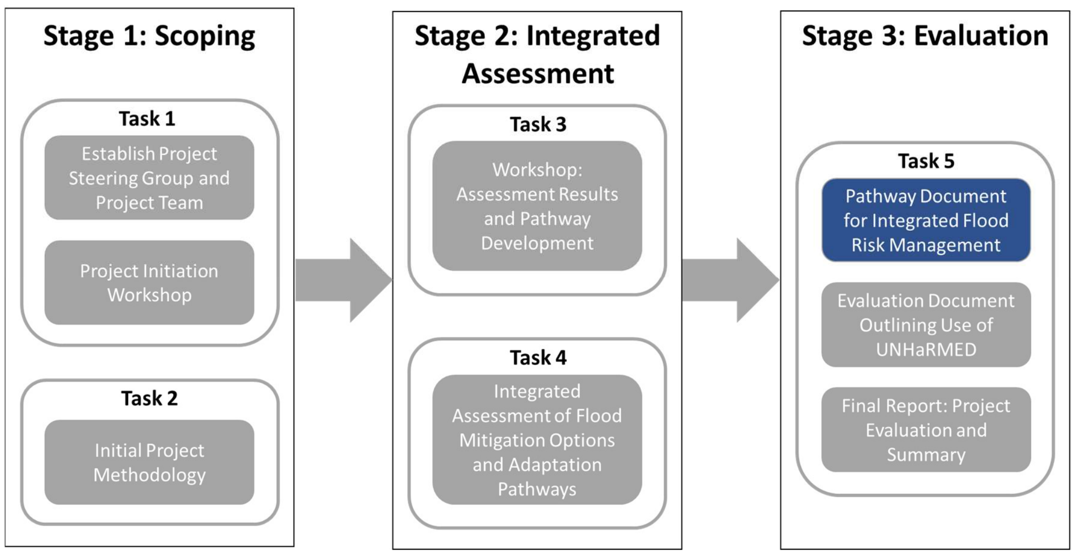

FIGURE 2: PROJECT STAGES (BLUE REFERS TO THE STAGE THIS REPORT ALIGNS TO).

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. As part of previous project activities, the **decision context** has been established. This has 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.

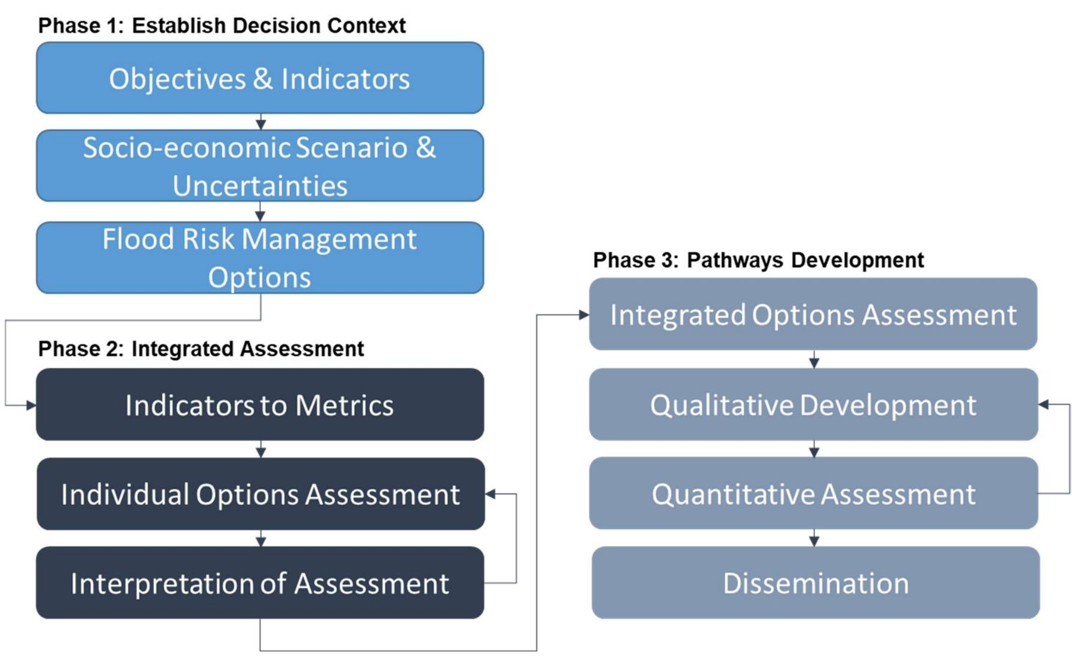

FIGURE 3: PATHWAYS DEVELOPMENT APPROACH

The workshop in June 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 quantitatively assessed to further fine-tune the pathways development.

This document reports on phase 3 of the project. Details about the integrated options assessment component of the approach are provided in Section 2.1. This is followed by a summary of the input used in developing the pathways from previous project activities (Section 3), the results from the assessment of the mitigation portfolios in Section 4.1 and the pathway development in Section 4.2. Some concluding remarks are provided in Section 5.

2.1 INTEGRATED OPTIONS ASSESSMENT

The initial stage of the assessment, as document in the Options Analysis report, explored how flood risk is impacted by changes over time for different future scenarios for 5 individual risk reduction options: *floodway*, *dam raise*, *zoning based on the ARI100 inundation zone*, *zoning based on the ARI 200 inundation zone*, and *raised floor/ground levels*.

A baseline and four exploratory scenarios were developed in a participatory setting to test the future resilience of society and 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.

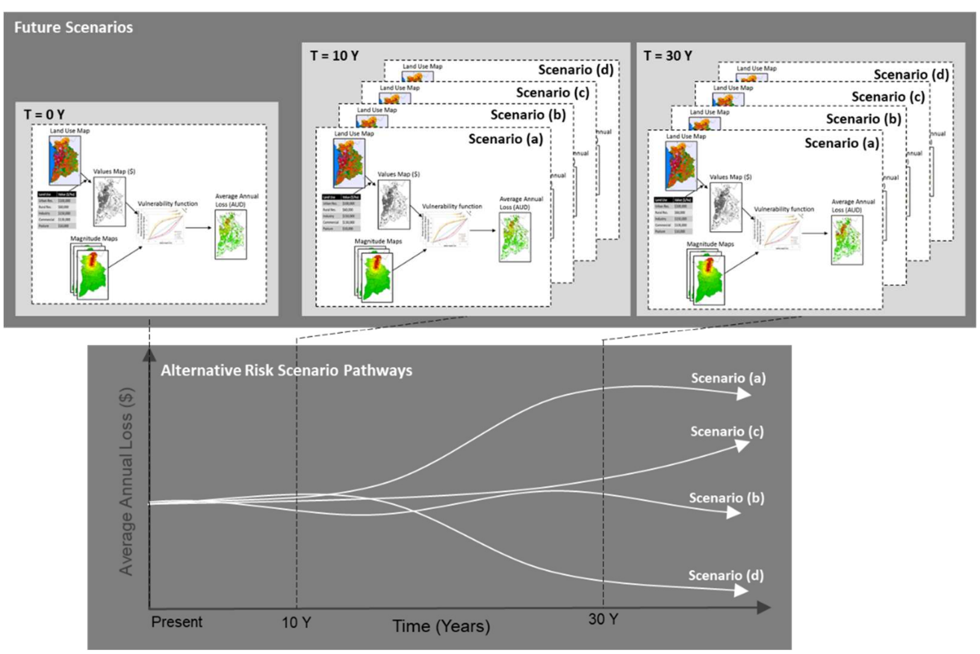

FIGURE 4: OVERVIEW OF RISK ASSESSMENT PROCESS AGAINST TIME

The 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: 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: 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).

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, and 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 other things, 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 in 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.

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

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 OUTPUT 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 set of above-mentioned risk reduction options was tested against the 5 scenarios (the baseline and 4 alternative scenarios). More information on the scenarios is provided in the Options Analysis report, together with details on the risk reduction assessment.

As part of this report, we have extended the number of risk reduction options by 1) creating variants of the measures assessed in the Options Analysis report, 2) combining measures and/or 3) varying their implementation year. For completeness, options that were previously assessed are also included in this report. We have selected 2018, 2030 and 2050 as years from which the options can be implemented and 2018, 2040 and 2060 as the years to report on, so the impact of the options can be assessed a few years after their implementation. As UNHaRMED carries out calculations at a yearly temporal resolution, intermediate information could also be provided.

Risk reduction options and their variations include[3]:

- Northern floodway implementation
- Bruce Eastick dam raise implementation

[3] More detailed information on the risk reduction options is provided in the Options Analysis report.

- 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) – included as a hypothetical option to assess the maximum benefit that could be obtained through this option;
    - 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);
    - 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).

In addition to increasing the number of options that are being assessed, another indicator has also been added. To integrate the damage assessment over the assessment period (2018-2060), we calculate the present value (PV) of the damages for 2018 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.

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.

Results of the risk reduction assessment are provided in Section 4.1.

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. SUB-COLUMNS IN THE OPTIONS COLUMN REFER TO THE YEAR OF IMPLEMENTATION.

	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 INPUT FROM PREVIOUS PROJECT ACTIVITIES

Various activities throughout the duration of the project have supported the pathway development. This section highlights the main input that has been used from activities earlier in the project: the workshops organized in 2019 and 2021 and the Options Assessment report.

3.1 STAKEHOLDER WORKSHOP 11/2019

In November 2019, a workshop was organized with the Stakeholder Advisory group in which participants assessed the feasibility of the different risk reduction options on criteria not included in the modelling.

Risk reduction options were assessed on the following criteria:

- Political acceptance;
- Community acceptance;
- Capital costs;
- Operational costs;
- Immediate effectiveness;
- Confidence in long-term success;
- Adaptation potential;
- Implementation time;
- Duration effectiveness.

Participants were asked to assess the different risk reduction options across these criteria indicating if they scored them as low, medium or high. Results per criterion were then combined by assigning a value to each of the qualitative assessments (low: 1; medium: 2; high: 3), multiplying the value by the number of participants and dividing the sum of the values by the number of participants who provided a ranking for the criterion. Results of this assessment for 5 different risk reduction options are presented in Table 3. Values close to 1 indicate that participants scored the criterion as low, values close to 2 that they scored it as medium, and values close to 3 that they scored it as high.

The table indicates 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 costs, and to a lesser extent the Raised floor levels options (when applied to new developments), costs are expected to be low. 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. For the other options, the quantitative risk assessment was carried out as part of the Impact assessment phase in which individual options were assessed on their risk reduction potential under a set of 5 future socio-economic scenarios. These options are also included in the integrated options assessment in this report and the development pathways.

TABLE 3: OVERVIEW OF ASSESSMENT OF RISK REDUCTION OPTIONS ON CRITERIA NOT INCLUDED IN THE MODELLING.

	Floodway	**Dam raise**	**Hazard-based planning**	**Risk-based planning**	**Raised floor levels**
Political acceptance	2.5	2.5	2.5	1.6	2.3
Community acceptance	2.1	2.3	1.9	1.8	1.5
Capital costs	2.4	3.0	1.0	1.0	1.6
Operational costs	1.9	1.9	1.0	1.0	1.0
Immediate effectiveness	2.8	3.0	2.5	2.3	2.0
Confidence in long-term success	2.5	2.8	1.9	2.1	2.2
Adaptation potential	1.8	1.3	2.3	2.1	1.7
Implementation time	2.1	1.8	2.3	1.6	2.0
Duration effectiveness	2.6	2.5	2.4	1.9	2.5

3.2 STAKEHOLDER WORKSHOP 06/2021

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 of the assessment of advantages and disadvantages are provided in Table 4. The table indicates 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 have an intermediate ranking, while the risk-based zoning option and no mitigation were ranked last. As there was a large variation in ranking of the options amongst participants, in addition to an average score of all participations, the range of the rankings is also provided (Table 4, score based on ranking, value range between brackets).

Participants were also asked about their preference to combine and/or time certain options. There was a 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.

During the workshops comments were also made about the importance of the details of the options. Relevant issues that were raised, and answers (A) provided, include:

- How is urban infill development included in zoning?

> *A: In options with weak or medium zoning infill is allowed, in options with strict zoning infill is not allowed.*

- Zoning would allow development to occur but it would be resilient/designed to cater for 1 in 100-year flows as per planning policy.

> *A: In the assessment zoning based on ARI200 inundation areas is included to demonstrate the impact of zoning a larger area to accommodate to less frequent events and/or potentially larger inundation areas for a 1 in 100 year event due to climate change.*

- How feasible are zoning options in terms of limiting development, given the amount of land that is currently being earmarked for urban development (or already being developed)?

> A: Detailed plans for each LGA have not been included in this study, but could be uploaded in the UNHaRMED DSS and can thus easily be included.

- Could an approach along the lines of raising floor levels for buildings be applied to horticulture – i.e. prevention rather than cure?

> A: Yes. Vulnerability curves for agriculture (including horticulture) work in the same way as curves for building types and infrastructure.

- Is it possible to include more broader resilient building requirements rather than just the floor levels?

> A: As long as it is clear how these requirements impact on the vulnerability curves they can be included.

- Is there an option for upstream mitigation, rather than increase the Dam?

> A: In the current assessment no other structural options are included. Zoning and Raised floor level options are included throughout the inundated area.

Based on the workshop discussions, it was decided to include different variations of the individual options that were already included in the Integrated Assessment phase, and to assess the impact of combinations of options, in particular the combined Dam raise and Floodway implementations and combinations of the structural measures (Dam raise and Floodway) with zoning and Raised floor level options. Regarding zoning, options focusing on ARI 100 inundation levels that would not limit development (but rather require adaptation measures to prevent flood impacts to the development of interest) were also considered, as they were seen as the more realistic options, as were building requirements to new developments.

TABLE 4: ADVANTAGES AND DISADVANTAGES OF VARIOUS RISK REDUCTION OPTIONS. THE SCORE IS THE MEAN OF THE VALUES PROVIDED BY PARTICIPANTS AND THE VALUES IN BRACKETS REPRESENT THE RANGES OF VALUES PROVIDED.

	Advantages	Disadvantages	Score based on ranking
Dam raise	- Protection of greater area -Protection for larger events - Could provide good protection for lower scale, more intense rainfall events	- Significant cost to government - Does not protect area surrounding Virginia - Requires further land acquisition upstream - Still flooding downstream where capacity of the river is breached due to discharges from dam, it is a flood detention dam	1.9 (1-5)
Floodway	- Addresses current more frequent flow impacts - Protection of horticulture – all future intensification – potential for development of deferred land - Short-term benefits	-	2.7 (1-6)
Raising floor levels – new developments	- Moves costs to owners, builders, developers - Should be considered in future re-zonings	- NIL - Works for greenfields, but what about urban infill? Needs more broad flood resilient buildings.	3.3 (1-5)
Zoning based on ARI 100 inundation levels	- It is the current expected standard for zoning - Can accommodate flood tolerant development, e.g. certain crops	- Impact on horticulture production. What are the lost potential future income and economic activity?	3.7 (3-7)
Zoning based on ARI 200 inundation levels	- Low-cost option for government, cost with owners/developers - Reducing future risk - Can accommodate flood tolerant development, e.g. certain crops	- Not recognised nationally as an appropriate standard for building resilience. - Climate change impacts should be managed through rainfall and runoff predictions influencing standards for 1 in 100. I don't believe selecting a different frequency is appropriate.	4.1 (2-6)
Zoning based on AAD	-	-	5.3 (3-8)
Raising floor levels - retrofitting	- Good option for future development - Moves costs to owners, builders, developers	- Leaves residual risk with already-built assets. Limited by degree of uptake. - Feasibility of the option	5.6 (4-7)
No mitigation	- Maintains natural river / flood plain function - Soil enrichment from sediments deposited from frequent flooding	- Does not meet current community expectations. We are expected to do something - Insurance premiums increase, if you can even get insurance	7.3 (3-8)

3.3 OPTIONS ANALYSIS REPORT

The main findings of the Options Analysis report 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 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. 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 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.

4 PATHWAYS FOR INTEGRATED FLOOD RISK MANAGEMENT

This section starts with a discussion on the results from the risk reduction simulations that have been carried out (Section 4.1). These results are then used together with the input from previous activities, as described in Section 3, to arrive at the pathway development (Section 4.2).

4.1 RISK REDUCTION ASSESSMENT

The main indicators for the quantitative risk assessment include the present value (PV) of the total damages (sum of AAD and AAOL) (Figure 5 and Table 5) and the expected damage for specific years (Figures 6a-c). The latter is provided for three years (2018, 2040 and 2060) as the Average annual damage (direct damage of buildings, agriculture, and infrastructure), the Average annual output loss (indirect damage), and the sum of both. Annex 1 provides an overview of the various risk assessment indicators (AAD, AAOL, and total damage for 2018, 2040 and 2060 and the present values of the damages) in a table. Information is extracted from this table for the figures presented in this section.

We first provide a high-level overview of the performance of the 31 options considered, followed by an assessment by type of mitigation option (i.e. structural options, zoning (land use planning) and raising floor levels).

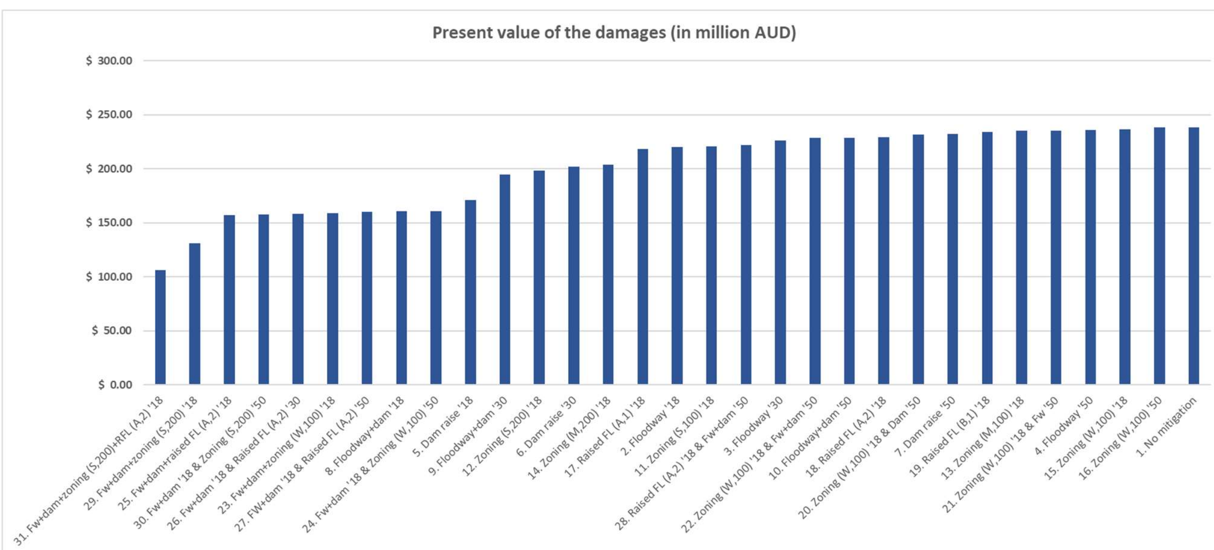

FIGURE 5: PRESENT VALUE OF DAMAGES PER RISK REDUCTION OPTION RANK FROM LOW TO HIGH (DETAILS OF THE OPTIONS ARE GIVEN IN TABLE 2)

FIGURES 6A-C: DAMAGE (AAD+AAOL) PER RISK REDUCTION OPTION FOR 2018, 2040 AND 2060
FW: FLOODWAY, S: STRICT, M: MEDIUM, W: WEAK, 100: ARI 100, 200: ARI 200, A: ALL DEVELOPMENT, B: NEW DEVELOPMENT, 1: ENTIRE BUILDING, 2: BASE PROTECTION.

TABLE 5: 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. 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												
2.Floodway '18	16	220	X											
3.Floodway '30	19	226		X										
4.Floodway '50	28	236			X									
5.Dam raise '18	10	171				X								
6.Dam raise '30	13	202					X							
7.Dam raise '50	24	232						X						
8.Floodway+dam '18	8	161	X			X								
9.Floodway+dam '30	11	195		X			X							
10.Floodway+dam '50	21	229			X			X						
11.Zoning '18	17	221							S,100					
12.Zoning '18	12	198							S,200					
13.Zoning '18	26	235							M,100					
14.Zoning '18	14	204							M,200					
15.Zoning '18	29	236							W,100					
16.Zoning '50	30	238									W,100			
17.RFL '18	15	218										A,1		
18.RFL '18	22	229										A,2		
19.RFL '18	25	234										B,1		
20.Z '18 & Dam '50	23	231			X				W,100					
21.Z '18 & Fw '50	27	235						X	W,100					
22.Z '18 & Fw+D '50	20	228			X			X	W,100					
23.Fw+D+Z '18	6	159	X			X			W,100					
24.Fw+D '18 & Z '50	9	161	X			X					W,100			
25.Fw+D+RFL '18	3	157	X			X						A,2		
26.Fw+D '18 & RFL '30	5	159	X			X							A,2	
27.Fw+D '18 & RFL '50	7	160	X			X								A,2
28.RFL '18 & Fw+D '50	18	222			X			X				A,2		
29.Fw+D+Z '18	2	131	X			X			S,200					
30.Fw+D '18 & Z '50	4	158	X			X					S,200			
31.FW+D+Z+RFL '18	1	106	X			X			S,200			A,1		

4.1.1 Overview

Based on visual inspection of the results in Figure 5 and Table 5, there are distinct groupings of options with similar PV of the damages (Table 6). The first grouping corresponds to options with a PV of the damages in the range of ~$220-240 M, which includes approximately half of the options considered (i.e. 17 out of 31 options). These options generally consist of either structural options that are implemented in later years, weak or medium zoning or strict zoning based on ARI100 inundation extent, or the raising of floor levels (or equivalent for horticulture). The second grouping corresponds to four options with an PV of the damages of around $200 M, which generally consist of either structural options that are implemented in intermediate years or strong zoning. The third grouping corresponds to eight options with an PV of the damages in the range of ~$160-170 M. These generally consist of the combination of both structural options (i.e. floodway and dam raise) that are implemented in 2018, coupled with either weak zoning or raised floor levels (or equivalent for horticulture).

TABLE 6: OVERVIEW OF GROUPINGS OF OPTION PORTFOLIOS BASED ON PRESENT VALUE OF THE DAMAGES (PV-D) AND CORRESPONDING CHARACTERISTICS OF OPTIONS

PV-D (M$)	**Number of option portfolios (Corresponding options in Brackets)**	**General Option Characteristics**
~220-240	17 (1-4, 7, 10, 11, 13, 15-22, 28)	No mitigation or Structural solutions implemented in later years or Weak and Medium zoning, or Strict zoning based on ARI100 inundation extent, or Raising of floor levels (or equivalent)
~200	4 (6, 9, 12, 14)	Structural solutions implemented in intermediate years or Strong zoning based on ARI200 inundation event
~160-170	8 (5, 8, 23-27, 30)	Combined structural solutions implemented in 2018 and (Weak zoning or Raised floor levels (or equivalent))
131	1 (29)	Combined Structural solutions and Strong zoning, both implemented in 2018
106	1 (31)	Combined structural solutions and Strong zoning and Raised floor levels all implemented in 2018

The last two "groupings" consist of individual options, both of which result in distinct decreases in present value of the damages compared with all other options. The first of these, Option 29, results in an present value of the damages of $131 M and consists of a combination of both structural options and strong zoning, all of which are implemented in 2018. The second of these, Option 31, is the option with the lowest overall present value of the damages of $106 M and corresponds to the combined implementation of both structural options, strong zoning and raised floor levels, all of which are implemented in 2018.

4.1.2 Structural options: Floodway and Dam raise

Comparing options 2, 5 and 8 shows the difference in impact of implementing the floodway (2), the dam raise (5) and the combination of both (8) in the initial year (2018). The combination of both structural interventions clearly outperforms any of the individual interventions. Looking at the individual interventions, the dam raise (5) outperforms the floodway (2). Figure 5 also provides information on the impact of the implementation year, with the earlier implementations leading to better results. For the floodway/dam raise combination, the present value of the damages for an implementation in 2018 (8) is $161 M, for an implementation in 2040 (9) the present value of the damages is $195 M, and for an implementation in 2050 (10) the present value of the damages is $229 M. The individual structural options (2, 3, 4 for the Floodway and 5, 6, 7 for the Dam raise) show a similar pattern - the earlier in time the implementation, the lower the present value of the damages overall.

As can be seen from figures 6A-C, with an implementation of the structural options in 2018, the reduction in risk becomes effective immediately, and with later implementations reduction can be found from the year of implementation onwards. As was concluded from the Options Analysis report, and can be seen from figures 6A-C as well, the Dam raise option performs very well in reducing the risk, and the combination of the Dam Raise with the Floodway gives a further improved reduction in risk, as the Floodway targets especially the smaller floods especially (1/20 year, 1/50 year), while the Dam raise is very effective for the larger floods (1/50 year, 1/100 year, 1/200 year).

4.1.3 Zoning (land use planning) options

In the modelling approach used, we differentiate between Strong, Medium and Weak zoning, where Strong zoning prohibits new development as well as infill or subdivisions, Medium zoning prohibits new development, but allows infill or subdivisions and Weak zoning discourages new development and allows infill or subdivisions. Furthermore, the difference between zoning the area inundated during a 1 in 100 year event (ARI 100) and a 1 in 200 year event (ARI 200) was assessed.

When comparing the various zoning options in Figure 5 and Table 5, we see that zoning options that start earlier perform better in reducing the risk, as the sooner the zoning starts, the more effective it is in redirecting development to other locations. In the present value of the damages assessment there are two options that rank very similarly: 12. Strict zoning (no new development, no infill) based on the ARI 200 inundation area, and 14. Medium zoning (no new development, infill allowed) based on the ARI 200 inundation area. When looking at Figures 6A-6C, option 12. Strict zoning (no new development, no infill) based on the ARI 200 inundation area, clearly outperforms the other option over time (by 2060). This is in line with expectation, as over time there will be increasing pressure to build in the flood prone area due to socio-economic development.

Weak zoning (development discouraged) based on the ARI 100 inundation area performs poorly compared to all other options (ranked close to no mitigation, see options 15 and 16). Also, in alternatives where Weak zoning based on the ARI

100 inundation area is combined with other options (alternatives 20-24), risk reduction does not seem to increase much due to the zoning.

In drawing lessons from this assessment, it is however important to understand how zoning is incorporated in the modelling. In the modelling weak zoning means it is more difficult to build in the zoned area, but once a building is allocated in the area, no mitigation measures are included. In reality, however, there is often conditional zoning, which for example would require one to build in a more resilient way if one was to build in a zoned area, so in reality, option 19, where new buildings are allowed if they meet certain criteria (in our case they should be built to at least cope with 30 cm of inundation), would be more realistic.

Nonetheless, what the (strict and medium) zoning options clarify is that not increasing the exposure in the flood prone area by limiting or avoiding both new development and infill is a very effective option in reducing the risk.

4.1.4 Raising floor levels, more resilient buildings

In the modelling approach used, raising floor levels is used as a proxy for having more resilient buildings. Simulations have been carried out to both new developments and all developments (so including the existing building stock) to better understand the impact of the option. In addition, the modelling varied between only raising the floor level (so raising the point from which inundation would result in damage from 15 cm for buildings, or 10 cm for horticulture, to 30 cm) or placing the entire building at a higher level (by shifting the vulnerability function by 30 cm).

Looking at options 17-19 in Figure 5 and Table 5, we see that the options have some impact in reducing the risk, but that this is not of the same magnitude as the structural options or the (strict/medium) zoning options. The more extreme option (all developments, entire building placed at higher level) clearly outperforms the other options (PV of the damages $218 M vs $229 M for the option where only the base of the building/horticulture is protected, and $234 M for the option where the entire building was placed at a higher level, but only for new developments). With the no mitigation option having a present value of the damages of $239 M, the latter option does not provide much reduction the in present value of the damages. It should be noted, however, that this option looked at increasing building floor levels by only a small amount (15 cm); raising this number could give much better results.

In alternatives where different variations of this option are combined with other options (25-28), this does provide some additional risk reduction and hence combining this option with other options might be useful, in particular for new developments. From the workshops it became clear that retrofitting costs are not expected to outweigh the benefits.

4.2 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. These best performing portfolios were included as the potential pathways that deserve further consideration. They are summarised in Table 7 and further elaborate on below.

TABLE 7: 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 an 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 gives a considerable extra risk reduction (PV-D $161 M) compared to an implementation in 2030 (PV-D $195 M) or 2050 (PV-D $229 M).

Combining this 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 development. 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.

The impact assessment modelling shows that a combination of the above options clearly outperforms individual options or a more limited set of options, as it results in the lowest present value ($106 M compared to $239 M without any mitigation options). Individual options implemented in 2018 have a present value of the damages values of $220 M (Floodway), $171 M (Dam raise), $198/$200 M (Strict zoning ARI200/ARI100 inundation area) and $218 M (Raised flood levels), while the combination of the Floodway and Dam raise implementation in 2018 results in a present value of the damages of $161 M, the combination of the Floodway, Dam raise, and Zoning (ARI200, strict zoning) option results in a present value of the damages of $131 M and the combination of the Floodway, Dam raise and Raised floor levels option results in a present value of the damages of $157 M.

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 potential 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. The feasibility of these would need to be assessed, as it is expected that strict zoning would have little community acceptance, and retrofitting all buildings would be prohibitively expensive. Where it is unlikely that all existing buildings in the flood prone area could be retrofitted, avoiding new development in flood prone 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 to make 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 notion 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. A present-day 1/200 year flood explored as part of this study might be the future 1/100 year flood and likewise the present-day 1/100 year flood the future 1/50 year flood (for example). However, additional 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 the assets substantially, leading to high exposed values if these are located in the flood prone area, 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 8 shows that the performance of the different options is rather consistent across the various socio-economic scenarios. Only in scenarios where there is very little growth or even a decline (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 (Ignorance of the Lambs).

TABLE 8: SUMMARY OF REDUCTION OF AVERAGE ANNUAL DAMAGES AND PRESENT VALUE OF THE DAMAGES UNDER DIFFERENT SOCIO-ECONOMIC SCENARIO FOR DIFFERENT RISK REDUCTION OPTIONS UNDER CONSIDERATION. THE FIRST THREE ROWS FOR EACH MITIGATION OPTIONS REPRESENT VALUES IN 2018 (TOP ROW), 2040 (MIDDLE ROW) AND 2060 (THIRD ROW), THE FINAL ROW REPRESENT THE PRESENT VALUE OF THE DAMAGES (PV-D). FOR RAISED FLOOR LEVELS A: ALL DEVELOPMENTS, 1: ENTIRE BUILDING, 2: BASE PROTECTION.

Option	Period	Baseline (% change compared to no mitigation)	Silicon Hills (% change compared to no mitigation)	Cynical Villagers (% change compared to no mitigation)	Ignorance of the Lambs (% change compared to no mitigation)	Internet of Risk (% change compared to no mitigation)
8.Floodway + dam '18	2018	-39	-39	-39	-39	-39
	2040	-40	-38	-42	-36	-40
	2060	-37	-38	-43	-36	-39
	PV-D	-39	-39	-40	-37	-39
25.Floodway + Dam + Raised Floor Levels (A,2) '18	2018	-41	-41	-41	-41	-41
	2040	-42	-46	-47	-42	-46
	2060	-39	-48	-48	-42	-45
	PV-D	-41	-44	-44	-41	-43
29.Floodway + Dam + Zoning Strict ARI200 '18	2018	-39	-39	-39	-39	-39
	2040	-52	-57	-47	-73	-48
	2060	-60	-59	-50	-74	-60
	PV-D	-47	-49	-43	-60	-45
31.Floodway + Dam + Zoning Strict ARI200 + Raised Floor levels (A,1) '18	2018	-44	-44	-44	-44	-44
	2040	-57	-61	-52	-75	-52
	2060	-63	-63	-55	-76	-59
	PV-D	-52	-54	-48	-64	-49

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 in relation to other social, economic and environmental objectives.

5 CONCLUSIONS

This study has presented a pathways approach for integrated flood management using UNHaRMED and the MRIA model, which has been applied to the Gawler river basin. Using the outlined 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 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.

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 at 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, 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.

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ANNEX 1: DAMAGE INFORMATION GAWLER RIVER BASIN

This annex provides an overview of the damage assessment per risk reduction option or portfolio. More specifically, information is provided for 3 years (2018, 2040 and 2060) on:

- Average annual damage (AAD);
- Average annual output loss (AAOL);
- Sum of the AAD and the AAOL;
- Present value of the damages (PV-D), calculated for 2018 over a 42-year time frame (2018-2060) with a discount rate of 7% per annum.

The information in Table A1 on the next page is organized according to the following structure.

	2018		2040		2060		PV-D
RISK REDUCTION OPTION NAME	AAD	AAOL	AAD	AAOL	AAD	AAOL	PV-D
	TOTAL		TOTAL		TOTAL		

TABLE A1: 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. PV-D IS THE PRESENT VALUES OF THE DAMAGES.

	2018		2040		2060		PV-D
1. NO MITIGATION	10	5	13	7	15	12	239
	15		20		27		
2. FLOODWAY '18	9	4	12	6	14	10	220
	14		18		24		
3. FLOODWAY '30	10	5	12	6	14	10	226
	15		18		24		
4. FLOODWAY '50	10	5	13	7	14	10	236
	15		20		24		
5. DAM RAISE '18	6	4	8	6	10	10	171
	10		14		20		
6. DAM RAISE '30	10	5	8	6	10	10	202
	15		14		20		
7. DAM RAISE '50	10	5	13	7	10	10	232
	15		20		20		
8. FLOODWAY+DAM '18	6	4	8	6	10	9	161
	10		13		18		
9. FLOODWAY+DAM '30	10	5	8	6	10	9	195
	15		13		18		
10. FLOODWAY+DAM '50	10	5	13	7	10	9	229
	14		20		18		
11. ZONING (S,100) '18	10	5	11	6	13	11	221
	15		17		23		
12. ZONING (S,200) '18	10	5	10	4	10	7	198
	15		14		17		
13. ZONING (M,100) '18	10	5	13	7	14	12	235
	15		20		25		
14. ZONING (M,200) '18	10	5	11	4	12	7	204
	15		15		19		
15. ZONING (W,100) '18	10	5	13	7	15	12	236
	15		20		27		
16. ZONING (W,100) '50	10	5	13	7	15	12	238
	15		20		27		
17. RAISED FL (A,1) '18	9	5	11	7	13	12	218

	14		18		25		
18. RAISED FL (A,2) '18	9	5	12	7	14	12	229
	14		19		26		
19. RAISED FL (B,1) '18	10	5	12	7	14	12	234
	15		19		26		
20. ZONING (W,100) '18 & DAM '50	10	5	13	7	10	12	231
	15		20		22		
21. ZONING (W,100) '18 & FW '50	10	5	13	7	14	12	235
	15		20		26		
22. ZONING (W,100) '18 & FW+DAM '50	10	5	13	7	10	9	228
	15		20		18		
23. FW+DAM+ZONING (W,100) '18	6	4	8	5	10	9	159
	10		13		18		
24. FW+DAM '18 & ZONING (W,100) '50	6	4	8	6	10	9	161
	10		13		18		
25. FW+DAM+RAISED FL (A,2) '18	6	4	7	6	9	9	157
	10		13		18		
26. FW+DAM '18 & RAISED FL (A,2) '30	6	4	7	6	9	9	159
	10		13		18		
27. FW+DAM '18 & RAISED FL (A,2) '50	6	4	8	6	9	9	160
	10		13		18		
28. RAISED FL (A,2) '18 & FW+DAM '50	9	5	12	7	9	9	222
	14		19		18		
29. FW+DAM+ZONING (S,200) '18	6	4	6	3	6	5	131
	10		9		11		
30. FW+DAM '18 & ZONING (S,200) '50	6	4	8	6	8	8	158
	10		13		15		
31. FW+DAM+ZONING (S,200)+RFL (A,2) '18	5	2	5	3	6	2	106
	7		9		8		

ANNEX 2: DAMAGE INFORMATION PER COUNCIL

This annex provides an overview of the risk per council without any mitigation and for a selection of mitigation options:

- Northern floodway implementation + Dam raise implementation ’18 (option 8);
- Northern floodway implementation + Dam raise implementation + Raised floor levels, all development, base protection ’18 (option 25);
- Northern floodway implementation + Dam raise implementation + Strict zoning ARI 200 (option 29);
- Northern floodway implementation + Dam raise implementation + Strict zoning ARI 200 (option 31).

For each council, damage information for buildings and agriculture is provided per ARI. In addition, total direct damage, Average annual damage (AAD) and Average annual output loss (AAOL) is provided for the river basin.

TABLE A2: SUMMARY OF DAMAGES (MILLION $) - NO MITIGATION 2018.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0	1	41	2	6	11	60
50	0	1	83	3	55	16	159
100	0	1	198	5	127	18	348
200	0	1	234	6	166	20	427
500	0	2	368	18	256	39	682
AAD / AAOL							**14.70**

TABLE A3: SUMMARY OF DAMAGES (MILLION $) - NO MITIGATION 2040.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0	1	51	8	6	13	79
50	0	1	100	14	61	29	204
100	0	1	224	22	156	33	437
200	0	1	264	26	210	37	538
500	0	2	409	50	329	69	859
AAD / AAOL							**19.89**

TABLE A4: SUMMARY OF DAMAGES (MILLION $) - NO MITIGATION 2060.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0	3	65	9	6	28	110
50	0	4	121	15	64	45	249
100	0	4	256	23	164	50	498
200	0	4	300	27	222	54	607
500	0	6	458	52	347	110	973
AAD / AAOL							**27.10**

TABLE A5: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE 2018. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A2.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-15%)	35 (-15%)	1 (-15%)	5 (-17%)	7 (-34%)	49 (-19%)
50	0 (0%)	1 (-34%)	35 (-58%)	1 (-51%)	23 (-58%)	8 (-51%)	69 (-57%)
100	0 (0%)	1 (-40%)	43 (-78%)	2 (-64%)	61 (-52%)	10 (-44%)	117 (-67%)
200	0 (0%)	1 (-35%)	48 (-79%)	2 (-67%)	95 (-43%)	16 (-20%)	162 (-62%)
500	0 (0%)	2 (0%)	368 (0%)	18 (0%)	256 (0%)	39 (0%)	682 (0%)
AAD / AAOL							**14.70**

TABLE A6: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A3.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-15%)	44 (-14%)	7 (-20%)	5 (-17%)	3 (-76%)	59 (-25%)
50	0 (0%)	1 (-34%)	44 (-55%)	7 (-51%)	26 (-57%)	4 (-86%)	82 (-60%)
100	0 (0%)	1 (-40%)	54 (-76%)	7 (-67%)	84 (-46%)	7 (-78%)	154 (-65%)
200	0 (0%)	1 (-35%)	60 (-77%)	9 (-67%)	132 (-37%)	27 (-25%)	228 (-58%)
500	0 (0%)	2 (0%)	409 (0%)	50 (0%)	329 (0%)	69 (0%)	859 (0%)
AAD / AAOL							**13.38**

TABLE A7: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A4.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	2 (-16%)	55 (-15%)	7 (-19%)	5 (-17%)	17 (-37%)	87 (-21%)
50	0 (0%)	2 (-35%)	56 (-54%)	7 (-51%)	28 (-57%)	18 (-59%)	111 (-55%)
100	0 (0%)	2 (-39%)	66 (-74%)	8 (-66%)	88 (-46%)	22 (-56%)	187 (-62%)
200	0 (0%)	3 (-34%)	74 (-75%)	9 (-67%)	138 (-38%)	44 (-19%)	268 (-56%)
500	0 (0%)	6 (0%)	458 (0%)	52 (0%)	347 (0%)	110 (0%)	973 (0%)
AAD / AAOL							**18.38**

TABLE A8: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + RAISED FLOOR LEVELS, ALL DEVELOPMENT, BASE PROTECTION 2018. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A2.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-16%)	34 (-17%)	1 (-20%)	5 (-24%)	7 (-35%)	48 (-21%)
50	0 (0%)	1 (-35%)	35 (-59%)	1 (-54%)	20 (-63%)	7 (-54%)	64 (-60%)
100	0 (0%)	1 (-41%)	43 (-78%)	2 (-66%)	51 (-60%)	9 (-50%)	105 (-70%)
200	0 (0%)	1 (-36%)	47 (-80%)	2 (-68%)	80 (-52%)	13 (-32%)	143 (-66%)
500	0 (0%)	2 (-1%)	359 (-2%)	17 (-5%)	234 (-9%)	32 (-17%)	643 (-6%)
AAD / AAOL							**9.66**

TABLE A9: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + RAISED FLOOR LEVELS, ALL DEVELOPMENT, BASE PROTECTION 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A3.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-16%)	43 (-16%)	7 (-22%)	5 (-24%)	3 (-77%)	58 (-27%)
50	0 (0%)	1 (-35%)	44 (-56%)	7 (-52%)	23 (-63%)	3 (-88%)	77 (-62%)
100	0 (0%)	1 (-41%)	53 (-76%)	7 (-67%)	72 (-54%)	5 (-84%)	138 (-68%)
200	0 (0%)	1 (-36%)	58 (-78%)	8 (-68%)	112 (-47%)	17 (-53%)	197 (-63%)
500	0 (0%)	2 (-1%)	399 (-2%)	49 (-2%)	303 (-8%)	47 (-33%)	800 (-7%)
AAD / AAOL							**13.07**

TABLE A10: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + RAISED FLOOR LEVELS, ALL DEVELOPMENT, BASE PROTECTION 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A4.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	2 (-17%)	54 (-17%)	7 (-21%)	5 (-25%)	17 (-37%)	85 (-23%)
50	0 (0%)	2 (-35%)	55 (-55%)	7 (-52%)	24 (-63%)	18 (-61%)	106 (-58%)
100	0 (0%)	2 (-39%)	65 (-75%)	8 (-66%)	75 (-54%)	20 (-61%)	170 (-66%)
200	0 (0%)	3 (-34%)	72 (-76%)	9 (-67%)	118 (-47%)	33 (-39%)	234 (-61%)
500	0 (0%)	6 (-1%)	448 (-2%)	51 (-2%)	319 (-8%)	79 (-28%)	903 (-7%)
AAD / AAOL							**18.03**

TABLE A11: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 2018. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A2.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-15%)	35 (-15%)	1 (-15%)	5 (-17%)	7 (-34%)	49 (-19%)
50	0 (0%)	1 (-34%)	35 (-58%)	1 (-51%)	23 (-58%)	8 (-51%)	69 (-57%)
100	0 (0%)	1 (-40%)	43 (-78%)	2 (-64%)	61 (-52%)	10 (-44%)	117 (-67%)
200	0 (0%)	1 (-35%)	48 (-79%)	2 (-67%)	95 (-43%)	16 (-20%)	162 (-62%)
500	0 (0%)	2 (0%)	368 (0%)	18 (0%)	256 (0%)	39 (0%)	682 (0%)
AAD / AAOL							**9.88**

TABLE A12: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A3.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-15%)	35 (-32%)	1 (-83%)	5 (-19%)	3 (-76%)	45 (-43%)
50	0 (0%)	1 (-34%)	35 (-65%)	2 (-89%)	23 (-62%)	4 (-87%)	65 (-68%)
100	0 (0%)	1 (-40%)	43 (-81%)	2 (-92%)	61 (-61%)	6 (-81%)	113 (-74%)
200	0 (0%)	1 (-35%)	48 (-82%)	2 (-92%)	95 (-55%)	23 (-38%)	169 (-69%)
500	0 (0%)	2 (0%)	368 (-10%)	19 (-62%)	256 (-22%)	60 (-13%)	705 (-18%)
AAD / AAOL							**9.26**

TABLE A13: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A4.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-74%)	35 (-47%)	1 (-83%)	5 (-21%)	3 (-89%)	45 (-59%)
50	0 (0%)	1 (-80%)	35 (-71%)	2 (-90%)	23 (-64%)	4 (-91%)	65 (-74%)
100	0 (0%)	1 (-81%)	43 (-83%)	2 (-92%)	61 (-63%)	6 (-87%)	113 (-77%)
200	0 (0%)	1 (-80%)	48 (-84%)	2 (-92%)	95 (-57%)	23 (-58%)	169 (-72%)
500	0 (0%)	2 (-70%)	368 (-20%)	19 (-63%)	256 (-26%)	71 (-35%)	716 (-26%)
AAD / AAOL							**11.10**

TABLE A14: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 DAMAGES (MM $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 + RAISED FLOOR LEVELS, ALL DEVELOPMENT, BASE PROTECTION 2018. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A2.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-19%)	33 (-20%)	1 (-24%)	4 (-28%)	7 (-36%)	46 (-24%)
50	0 (0%)	1 (-37%)	33 (-60%)	1 (-56%)	17 (-69%)	7 (-56%)	60 (-62%)
100	0 (0%)	1 (-43%)	41 (-79%)	2 (-68%)	42 (-67%)	8 (-53%)	94 (-73%)
200	0 (0%)	1 (-38%)	46 (-80%)	2 (-69%)	67 (-60%)	12 (-40%)	127 (-70%)
500	0 (0%)	2 (-2%)	336 (-9%)	15 (-14%)	199 (-22%)	26 (-32%)	579 (-15%)
AAD / AAOL							7.22

TABLE A15: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 DAMAGES (MM $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 + RAISED FLOOR LEVELS, ALL DEVELOPMENT, BASE PROTECTION 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A3.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-19%)	33 (-36%)	1 (-84%)	4 (-30%)	3 (-78%)	42 (-47%)
50	0 (0%)	1 (-37%)	33 (-66%)	1 (-90%)	17 (-71%)	3 (-89%)	56 (-73%)
100	0 (0%)	1 (-43%)	41 (-82%)	2 (-93%)	42 (-73%)	4 (-87%)	90 (-79%)
200	0 (0%)	1 (-38%)	46 (-83%)	2 (-93%)	66 (-68%)	11 (-71%)	125 (-77%)
500	0 (0%)	2 (-2%)	336 (-18%)	16 (-67%)	200 (-39%)	29 (-57%)	584 (-32%)
AAD / AAOL							8.70

TABLE A16: SUMMARY OF DAMAGES (MILLION $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 DAMAGES (MM $) - NORTHERN FLOODWAY + DAM RAISE + ZONING, STRICT, ARI200 + RAISED FLOOR LEVELS, ALL DEVELOPMENT, BASE PROTECTION 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE A4.

ARI	Adelaide Hills	Barossa	Gawler	Light	Adelaide Plains	Playford	Total
20	0 (0%)	1 (-75%)	33 (-49%)	1 (-85%)	4 (-32%)	3 (-90%)	42 (-62%)
50	0 (0%)	1 (-81%)	33 (-72%)	1 (-91%)	17 (-73%)	3 (-93%)	56 (-77%)
100	0 (0%)	1 (-82%)	41 (-84%)	2 (-93%)	42 (-74%)	4 (-91%)	90 (-82%)
200	0 (0%)	1 (-81%)	46 (-85%)	2 (-93%)	66 (-70%)	11 (-80%)	125 (-79%)
500	0 (0%)	2 (-71%)	336 (-27%)	16 (-68%)	200 (-42%)	34 (-69%)	589 (-39%)
AAD / AAOL							7.64