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INTEGRATED ASSESSMENT OF FLOOD MITIGATION OPTIONS

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].

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

This report details the integrated assessment, including direct and indirect economic impacts of a range of mitigation strategies against alternative scenarios. These results will be used for subsequent 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 Event 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 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 and extreme heat. 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).

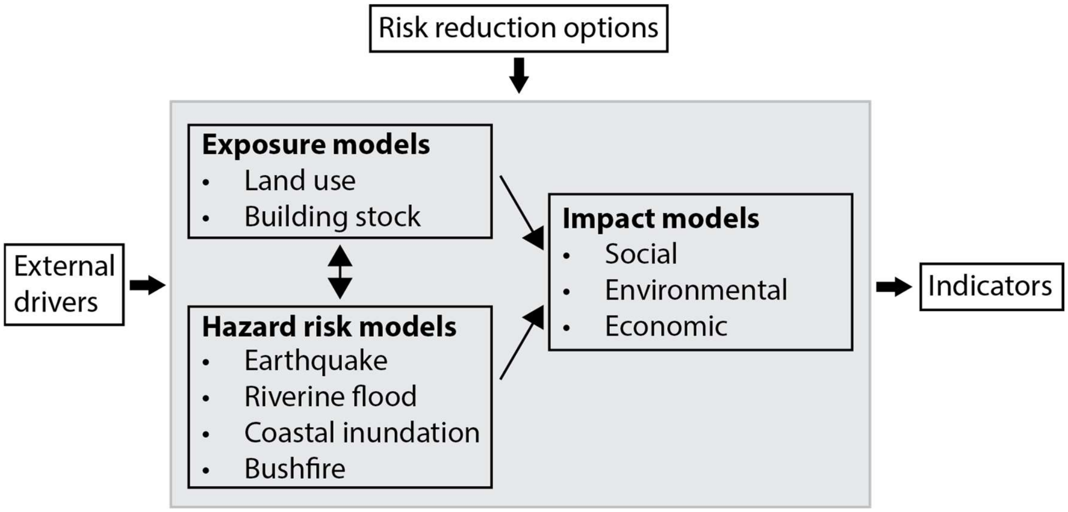

FIGURE 1: MODELLING COMPONENTS FOR INCLUSION WITHIN THE INTEGRATED MODELLING FRAMEWORK OF UNHARMED.

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 2 of this project, as shown in Figure 2. The report details the approach undertaken within the project including integrated assessment of flood risk management options and how these can be combined to a strategic floodplain management pathway. Critically this report provides:

- An overview of the assessment approach, including the outcomes of this section of the process leading to the integrated and participatory development of flood risk management pathways;
- Specific results on the performance of identified risk management options that will subsequently be integrated into the developed portfolios and pathways.

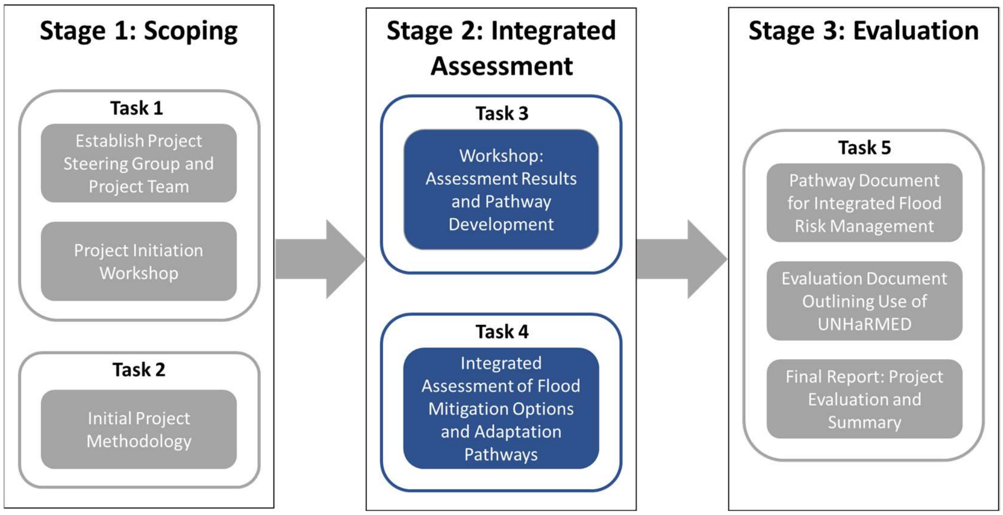

FIGURE 2 PROJECT STAGES (BLUE REFERS TO THE STAGE THIS REPORT ALIGNS TO).

2 OVERVIEW OF ASSESSMENT APPROACH

The flood risk management options are tested against metrics and scenarios individually. The figure below outlines how the assessment was undertaken and summarises the types of results as presented in Section 5. At the end of this section an overview is provided of the mitigation options that have been tested under the various scenarios, and these are subsequently detailed in Sections 3 and 4.

The initial stage of the assessment explores how the flood risk is impacted by changes over time for different future scenarios. A baseline and four exploratory scenarios have been developed in a participatory setting to test the future resilience of the Gawler Floodplain community and effectiveness of actions. These temporal risk profiles assist in understanding the impact of mitigation options under various future conditions and thus assist in dealing with future uncertainties. The assessment of different scenarios against time, and a common metric is provided in Figure 3.

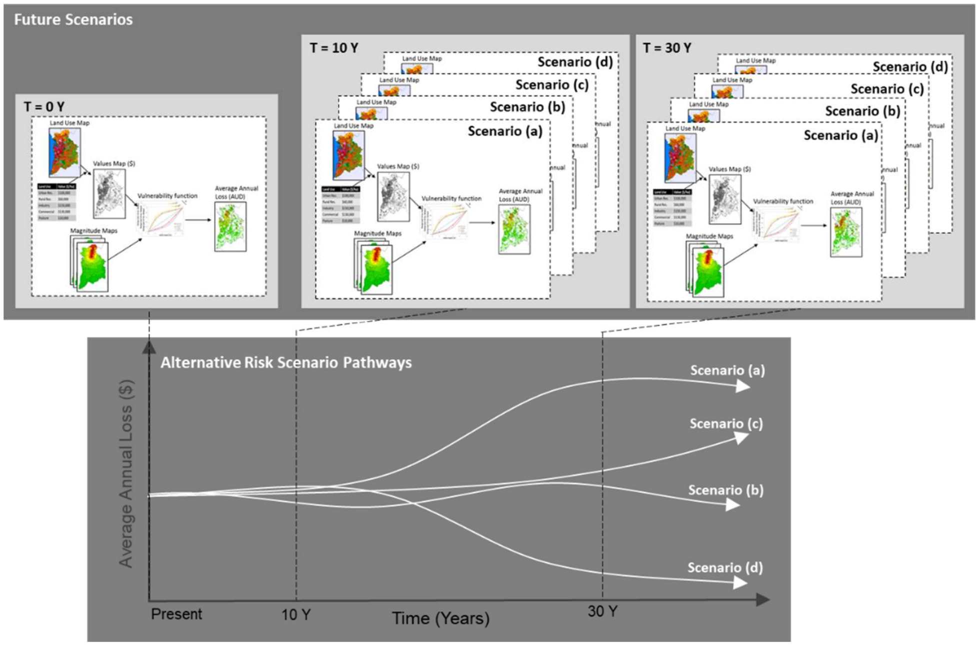

FIGURE 3: OVERVIEW OF RISK ASSESSMENT PROCESS AGAINST TIME

Key risk metrics used in the flood risk assessment are:

- 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;
- Direct damage per ARI: direct 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 direct 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): indirect damages due to productivity losses associated with direct damage to capital loss.

The first three risk metrics are calculated on an annual basis from 2018 – 2060, the latter is provided for 2018, 2040 and 2060 for the baseline scenario, including the mitigation options tested under this scenario. We have selected 2018, 2040 and 2060 as the years to report on, although intermediate information is available upon request. All risk reduction options included in this report are implemented from 2018 onwards.

The assessment presented in this report is based on 30 m resolution inundation maps for a range of ARIs (i.e. 1/20, 1/50, 1/100, 1/200, 1/500 year flood events), together with 100 m resolution land use maps. As no climate change impacts are included, inundation maps do not change over time. Socio-economic developments over roughly a 40-year period, lead 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 include the area inundated of each land use cell as the sum of the areas inundated in the underlying, more detailed, inundation map.

Risk modelling is 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. The determination of the asset value and the vulnerability functions are critical components of quantitative risk assessments. Vulnerability functions were derived based on the building and infrastructure type, and the type of agriculture. Functions were sourced from the European Union Joint Research Centre (Huizinga et al, 2017) who has provided these functions for different regions in the world including Oceania. They have been adapted to better suit the current South Australian conditions. Details about the vulnerability functions can be found in Annex 1. Details about the asset value van be found in Annex 2.

Direct damages are calculated at the grid level (i.e., 100 m 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].

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 the flood. 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.

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

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. Durations are based on expert judgement.

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 set of (initial) mitigation options was tested against the above-mentioned scenarios (see Figure 4 for an overview). More information on the scenarios is provided in Section 3, more information about the mitigation options in Section 4.

3 SCENARIOS

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 4: OVERVIEW OF EXPLORATORY SCENARIOS

3.1 BASELINE

The baseline scenario used residential land use demands based on the Australian Bureau of Statistics (ABS) Population Projections by Region, 2017 - 2066 for the Greater Adelaide Capital City Statistical Area – Series B (middle trend).

Along with population change, economic projections were used for functional land uses. ABS Projected employment growth five years to May 2023 for the Greater Adelaide Capital City Statistical area were projected beyond 5 years to cover the model period – 2018 – 2060. Functional land uses modelled in this way included commercial, public institutions (including education), recreation, industry, agriculture, horticulture and livestock. To translate from employment change to land use, demand assumptions were made about the density of employees / ha and whether intensification would occur i.e. increasing number of employees per area.

Table 6 (Section 3.3) details the land use demands calculated for residential and other function land uses across scenarios.

Given the uncertainties in these projections, the exploratory scenarios mentioned above, and described in more detail in Section 3.2, are also included in the risk assessment and pathways development process following this initial options analysis.

3.2 EXPLORATORY SCENARIOS

Tables 2 – 5 outline the overarching drivers for the four exploratory scenarios summarised in Figure 4.

These scenarios will be modelled in subsequent stages to outline how the effectiveness of risk management options varies under critical uncertainties.

TABLE 2 - OVERVIEW OF SILICON HILLS

Factor	Description
Motivating factors	*Growing valuation of nature and stimulation of tech industries see increase in skills for technology, innovation and R&D.*
Population & Urbanisation	*Growing population driven by immigration. Increase in higher density city living and developments in the Adelaide Hills.*
Community profile	*Multi-cultural community grows with an emphasis on integration. Leads to increased interest in public schooling, decreasing inequality.*
Economy & Lifestyle	*The next 15 years see small investments in tech start-ups and innovative small-scale manufacturing begins to take effect. 'Tech-hubs' take form with high intensity commercial and industrial areas. Focus on tech and innovation sees Adelaide as a significant technology centre in the Asia Pacific.*
Politics and institutions	*State government policies grow in influence due to an emphasis on consultation and engagement. This results in more effective and better-implemented policies.*
Technology & Infrastructure	*Technology drives a decrease in community vulnerability due to improved education programs and decreased building vulnerability. Adelaide begins to build a reputation as the leader in technological solutions to risk reduction.*

TABLE 3 OVERVIEW OF CYNICAL VILLAGES

Factor	Description
Motivating factors	Downturn in mining and ageing population, shift towards nature and high quality agricultural society.
Population & Urbanisation	Experiences a slowing in population, particularly because of a lack of younger, skilled immigrants. Urban sprawl increases through an increase of rural residential development. Interwoven patchwork of land uses in the Adelaide Hills, increasing the hazard interface.
Community profile	Growing rural residential lifestyle increases local understanding. Some communities have greater skills and resources; others don't (less financial flexibility, the elderly and less socially connected).
Economy & Lifestyle	Downturn in mining and manufacturing, and subsequent impact on government revenue. No replacement activity to the same scale, instead the economy becomes more locally based. Reduced export due to decreased workforce, which also becomes more self-sufficient.
Politics and institutions	Tight-knit local communities, protective over their property and individual freedom. Opposition to government intervention and increased pressure on public funds due to health and aged-care costs.
Technology & Infrastructure	People are empowered by access to data. Community groups are increasingly able to challenge in courts. Decline in innovation investment in science and research with a return to cottage industries.

TABLE 4 - OVERVIEW OF IGNORANCE OF THE LAMBS

Factor	Description
Motivating factors	Large immigration to SA from various global areas of unrest. Increasing reliance on Federal Government for funding.
Population & Urbanisation	Significant population growth due to increased immigration and birth-rates. Large, dense new developments in low cost land far from employment centres.
Community profile	Work-life balance pressures increased by growing travel distances places pressure on communities. Decline in local knowledge, understanding and connectedness.
Economy & Lifestyle	Sudden collapse of manufacturing, growing unemployment and increased reliance on government for social support. Those who can leave for work on the Eastern Seaboard.
Politics and institutions	Economic climate and increased emphasis on large infrastructure projects sees Commonwealth growing in influence. State becomes service provider with little planning or decision-making power.
Technology & Infrastructure	Significant structural mitigation measures put in place by Commonwealth. State privatises all infrastructure but finds itself inheriting poorly maintained assets once private companies can no longer make a profit.

TABLE 5 - OVERVIEW OF INTERNET OF RISK

Factor	Description
Motivating factors	Increasing reliance on the internet for social and work-related activities decreases community connectedness and resilience.
Population & Urbanisation	Population growth is low due to low immigration, and migration from SA by those who have the capacity and skills to leave. Pressures placed on urban landscape due to dispersed residential living and minimal strategic planning.
Community profile	Inequality is rife; especially post 2035, where the differences between an individuals' ability to work grows increasingly large. Those trapped in traditional economies struggle to re-train and require financial support from State Government.
Economy & Lifestyle	Significant loss of intensive industry and commercial sectors. Large employment sectors for those skilled for digital economy and software development.
Politics and institutions	Government struggles to raise revenue due to high levels of free enterprise and global work practices. Residents grow increasingly individualistic.
Technology & Infrastructure	Every home is wired to the web but State owned infrastructure is creaking under the strain of dispersed residential centres.

3.3 COMPARISON ACROSS SCENARIOS

Table 6 highlights the key land use demands for each of the scenarios, including the baseline or business as usual (BAU) scenario. The modelled area is shown in Figure 4. Although calculations are carried out for the entire Extended Adelaide region, results are provided for the 6 councils within the Gawler river basin.

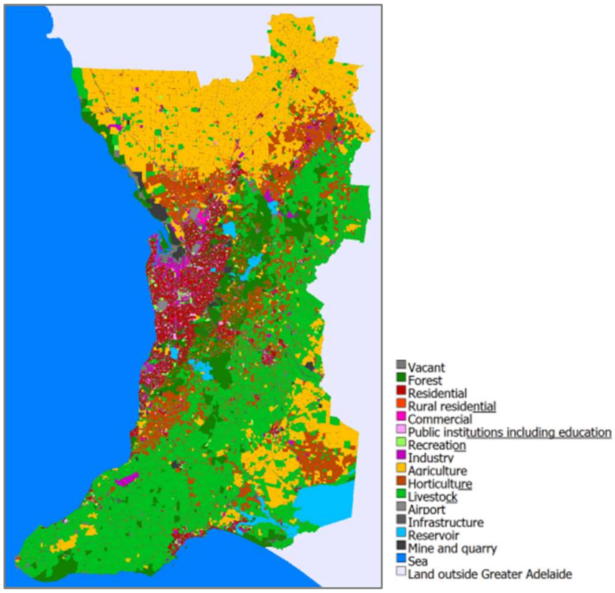


FIGURE 5: OVERVIEW OF MODELLED AREA

TABLE 6: LAND USE DEMANDS PER SCENARIO APPLIED TO THE GREATER ADELAIDE AREA SHOWN IN FIGURE 4.

	2018	Baseline 2060	Silicon Hills 2060	Cynical Villagers 2060	Ignorance of the Lambs 2060	Internet of Risk 2060
Urban residential area (ha)	39,523	53,054	56,767	37,056	72,021	46,321
Rural residential area (ha)	26,479	35,544	50,747	34,157	46,133	35,544
Commercial (ha)	5,311	5,847	9,664	5,576	6,213	6,903
Public institutions (ha)	9,040	15,459	16,449	8,676	15,459	8,676
Recreation (ha)	7,069	7,932	8,478	8,478	7,932	7,932
Industry (ha)	11,760	12,702	20,454	9,639	9,639	10,697
Agriculture (ha)	239,645	239,645	239,645	235,123	261,247	239,645
Horticulture (ha)	79,959	79,959	87,954	71,962	85,456	79,959
Livestock (ha)	309,314	309,314	269,403	309,314	309,314	309,314

4 FLOOD RISK MANAGEMENT OPTIONS

4.1 STRUCTURAL OPTIONS

4.1.1 Northern Floodway

The Northern Floodway project includes several modifications to the river channel including the construction of a new levee and floodway – spill area. Figure 5 documents the scheme. For more information we refer to AWE (2016).

The scheme includes:

- Levee improvements
- River channel works
- New levee and Northern Floodway system downstream of Old Port Wakefield Road.

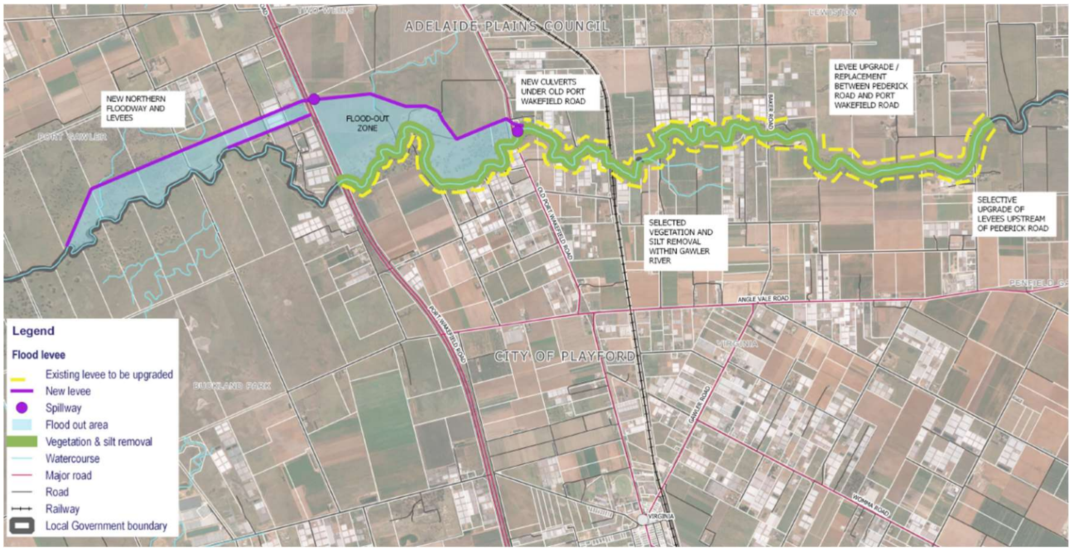


FIGURE 6: PROPOSED NORTHERN FLOODWAY SCHEME

The floodway is designed to offer protection for the 1 in 20 year flood hazard, and is thought to offer protection beyond that including the 1 in 50 year event and to some extent even the 1 in 100 year event. The floodway is implemented to offer protection up to the 1 in 50 year event, however, sensitivity testing is possible to compare the implication of this assumption. Figure 6 and 7 show the impact the floodway has on the 1 in 20 year event across the floodplain (AWE, 2016).

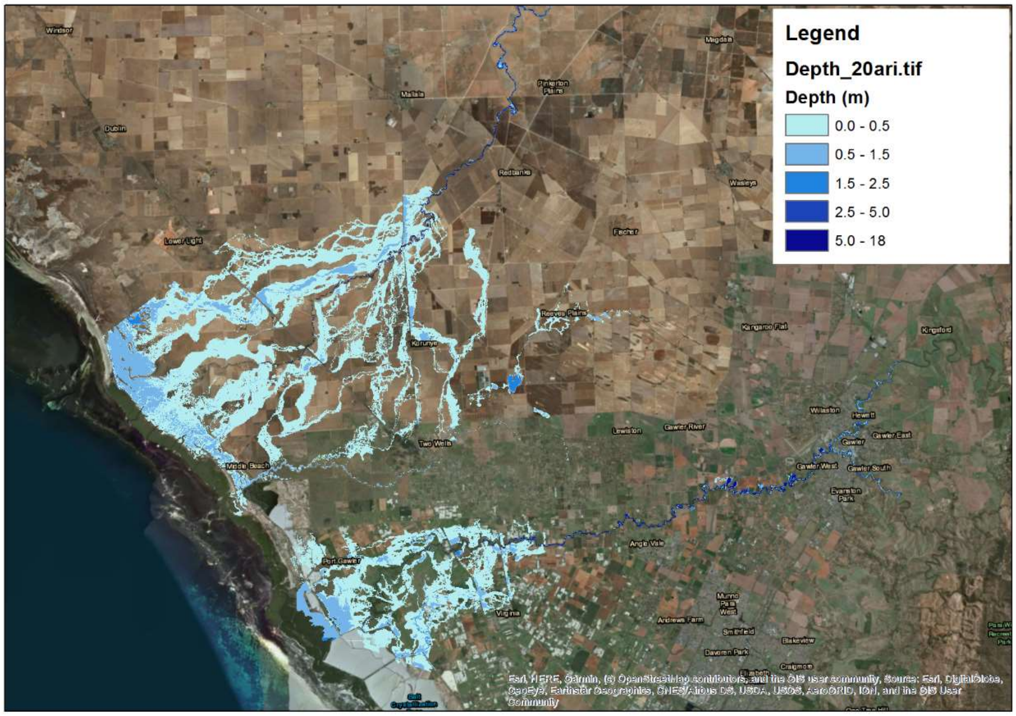


FIGURE 7: 1 IN 20 YEAR FLOOD HAZARD MAP - BASELINE

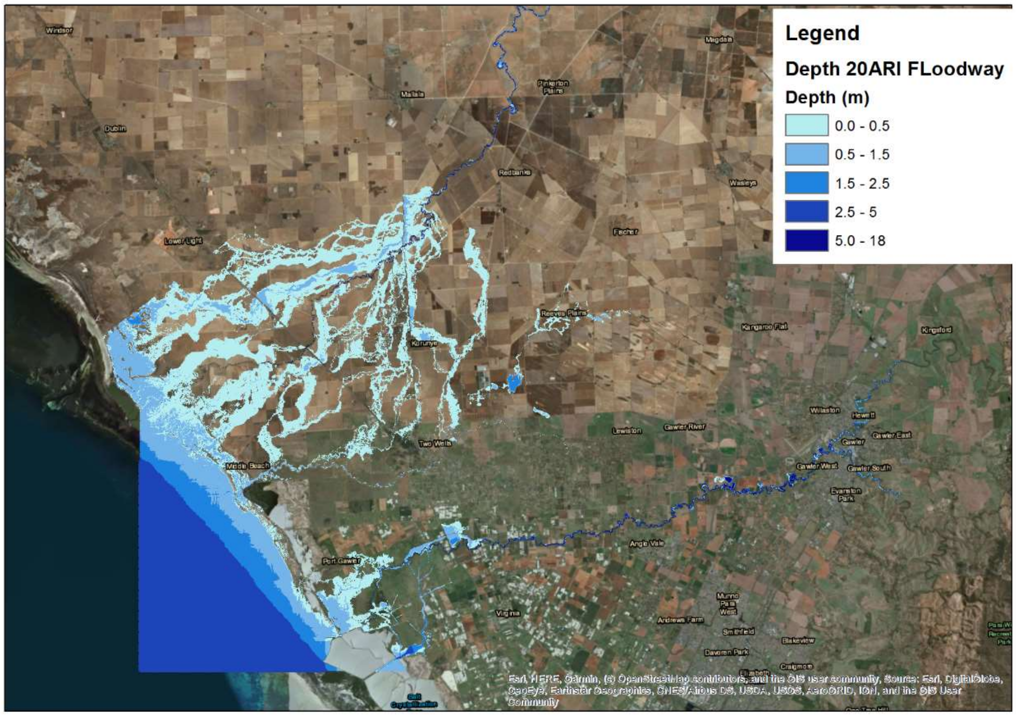
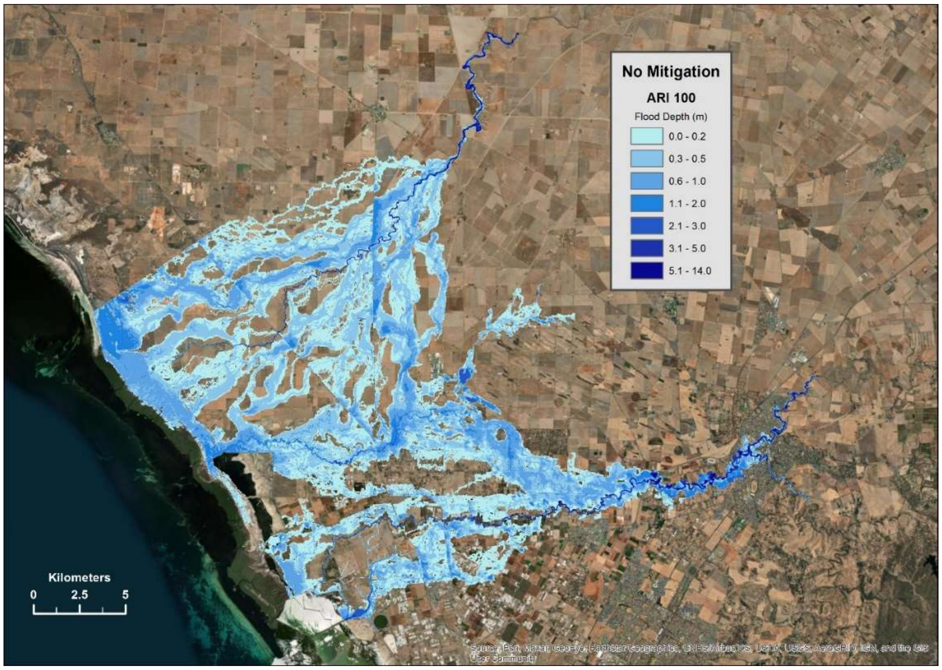


FIGURE 8: 1 IN 20 YEAR FLOOD HAZARD MAP – NORTHERN FLOODWAY SCHEME

4.1.2 Bruce Eastick Dam Raise

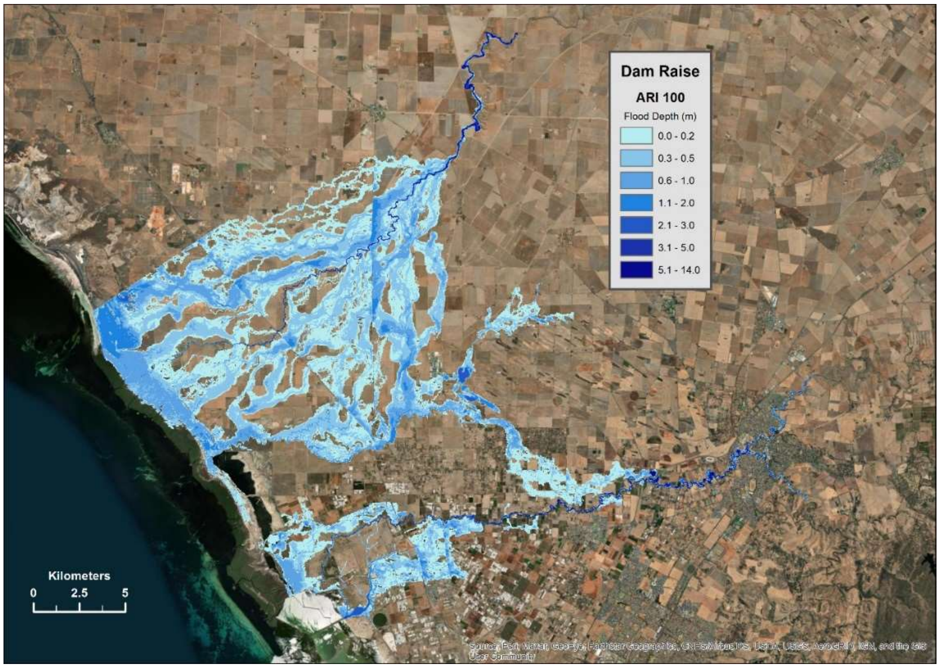
Raising the existing Bruce Eastick Dam by approximately 10m for flood protection is another of the risk management options considered. The proposal would offer protection in the Gawler River floodplain up to a 1 in 200 year flood event. Figures 8 and 9 highlight the performance of the dam for a 1 in 100 year flood event.

Note: the hydrology shown below needs to be further studied as to where spill would occur with the raised dam. For more information we refer to AWE (2016).



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 9: 1 IN 100 YEAR FLOOD HAZARD – BASELINE



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 10: 1 IN 100 YEAR FLOOD HAZARD - BRUCE EASTISK DAM RAISE

4.2 LAND USE PLANNING OPTIONS

Land use planning was also included as a modelled risk management option. In comparison to structural options which manage existing risk, land use planning manages future risks in the floodplain.

Two options were considered and implemented through a development exclusion overlay. The overlays considered the 1 in 100 year and 1 in 200 year flood extents. These are shown in Figure 10. In the modelling, this overlay would effectively restrict any future urban development – residential, rural residential, commercial and industrial, in new locations within the overlay extent. Existing development and redevelopment and infill at existing urban locations would still be possible.

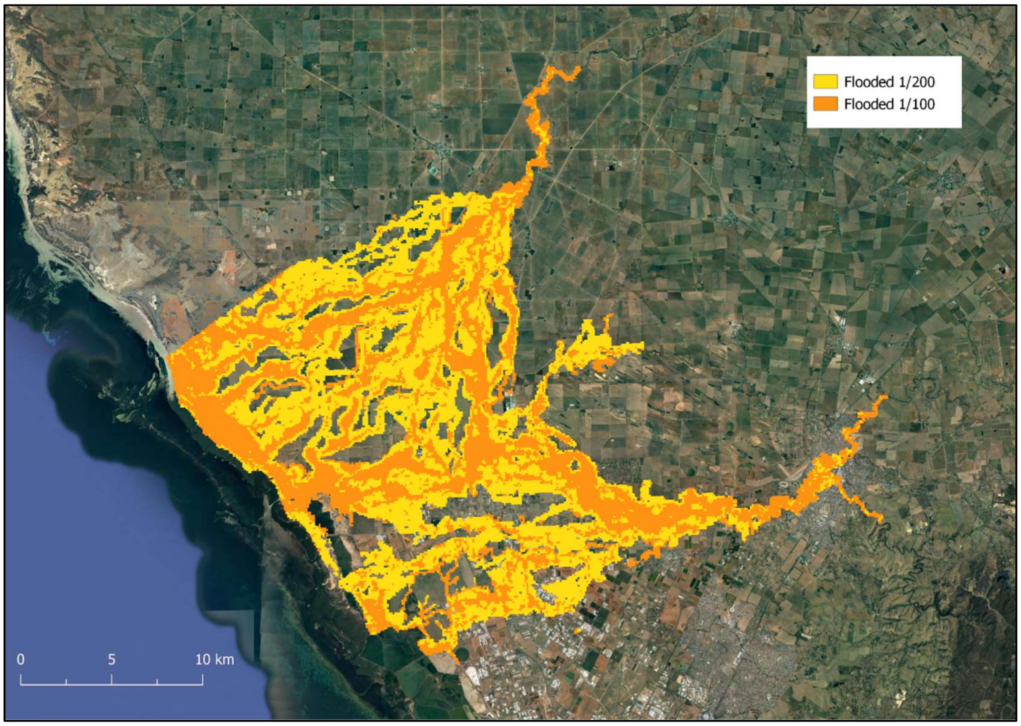


FIGURE 11: RESTRICTED DEVELOPMENT OVERLAYS 1 IN 100 YEAR (ORANGE) AND 1 IN 200 YEAR (YELLOW)

4.3 RESILIENT BUILDING OPTIONS

The resilient building options considered include raising floor levels, including protection for horticulture where appropriate. For the current options assessment we assessed the situation in which damage to buildings and horticulture would only occur beyond 30 cm. of inundation depth, compared to 15 cm. for buildings and 10 cm. for horticulture in a scenario without mitigation. The remainder of the vulnerability function was also shifted in this option by 15 cm. Details about the baseline and adapted vulnerability functions can be found in Annex 1.

5 FLOOD RISK ASSESSMENT RESULTS

5.1 RISK ASSESSMENT RESULTS WITHOUT MITIGATION

To understand current and potential future risk without mitigation, the risk across the floodplain without the implementation of risk management strategies was modelled for the baseline (socio-economic) scenario as well as the 4 alternative plausible future scenarios.

Land use demands for the five scenarios were implemented as described in Section 3.1. Zoning policies were assumed equal across all scenarios, while the interaction between economic activities and residential actors was simulated to reflect the various scenarios.

Results are presented for direct and indirect damages for 2018, 2040 and 2060 based on the changes to exposure[3]. Direct damages are calculated per ARI for buildings, crops and infrastructure. In addition, the Average Annual Damage (AAL), the expected (direct) damages per year accounting for the range of ARIs considered, is calculated, as well as the Average Annual Output Loss (AAOL), the indirect damage resulting from productivity losses associated with direct damage to capital loss. Further details about the metrics are provided in Section 2.

5.1.1 Risk change

The results below show baseline risks in 2018 and how direct and indirect damages change from 2018 to 2060.

Figures 11-13 show the distribution of damages across the floodplain with total Average Annual Damages from direct damages **(AAD) in 2018 of $9.8 million** and Average Annual Output Losses from indirect damages **(AAOL) of $2.4– $9.8 million**, dependent on production loss duration assumptions. This shows the clear risk within the floodplain, especially how it is concentrated in more urban and developed areas in the Gawler River floodplain. Table 7 documents the damages across the floodplain.

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[3] Additional information on land use impacted and direct damages to buildings and agricultural land use is also available in supplementary Excel files. Note that these Excel files do not include information on infrastructure damages or indirect damages as these are not calculated per LGA. Totals in the Excel files and the tables in this report therefore do not align.

TABLE 7: SUMMARY OF DAMAGES – BASELINE, NO MITIGATION 2018

ARI	Direct Damage ($)	Indirect Damage - Low ($)	Indirect Damage – Med. ($)	Indirect Damage - High ($)	Total Damage: direct + indirect medium ($)
20	62,226,750	2,240,000	4,480,000	8,950,000	66,706,750
50	163,891,950	12,570,000	25,130,000	50,260,000	189,021,950
100	355,423,560	41,890,000	83,780,000	167,560,000	439,203,560
200	437,528,800	94,810,000	189,620,000	379,250,000	627,148,800
500	696,793,300	263,980,000	527,960,000	1,055,920,000	1,224,753,300
AAD / AAOL*	**9,818,164**	**2,440,000**	**4,880,000**	**9,750,000**	**14,698,164**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

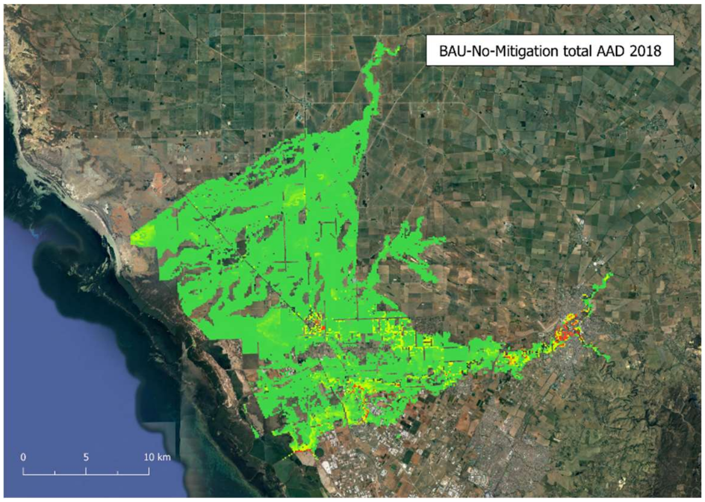

FIGURE 12 - AAD DISTRIBUTION ACROSS THE FLOODPLAIN – BASELINE (BAU) SCENARIO IN 2018

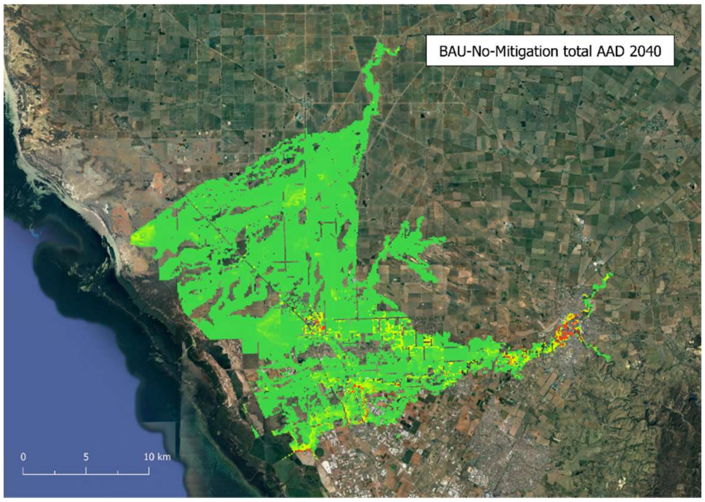

FIGURE 13 - AAD DISTRIBUTION ACROSS THE FLOODPLAIN – BASELINE (BAU) SCENARIO IN 2040

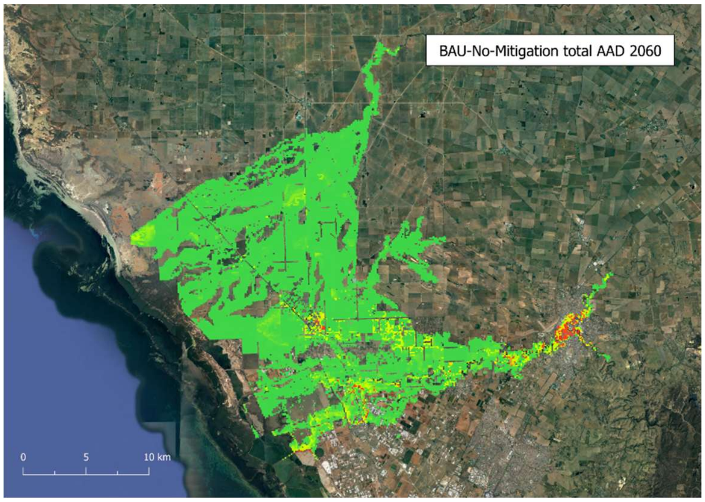

FIGURE 14 - AAD DISTRIBUTION ACROSS THE FLOODPLAIN – BASELINE (BAU) SCENARIO IN 2060

Based on assumptions as outlined in previous sections, and modelling of future growth in the region, these damages are also projected to increase into the future. AAD in 2040 is modelled to be approximately $12.7 million and in 2060 $15.1 million, while total damages as the sum of the AAD and the AAOL are expected to increase from $14.7 million in 2018 to $19.9 million in 2040 and $27.1 million in 2060 (see Tables 7-9). In addition to the expected direct damage presented in the second column, Tables 8 and 9 also show the damage range across the alternative socio-economic scenarios in the third column expressed as a percentage of the damage in the baseline scenario.

TABLE 8: SUMMARY OF DAMAGES – BASELINE, NO MITIGATION 2040

ARI	Direct Damage ($)	Direct damage range across scenarios**	Indirect Damage - Low ($)	Indirect Damage – Med. ($)	Indirect Damage - High ($)	Total Damage: direct + indirect medium ($)
20	81,325,250	-25%, +78%	2,820,000	5,630,000	11,270,000	86,955,250
50	209,062,950	-18%, +51%	18,680,000	37,370,000	74,740,000	246,432,950
100	444,001,560	-15%, +29%	74,230,000	148,460,000	296,920,000	592,461,560
200	547,914,800	-14%, +26%	163,660,000	327,330,000	654,650,000	875,244,800
500	874,142,300	-12%, +22%	415,120,000	830,240,000	1.660,490,000	1,704,382,300
AAD / AAOL*	**12,710,740**	**-17%, +41%**	**3,590,000**	**7,180,000**	**14,350,000**	**19,890,740**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES. **DIRECT DAMAGE RANGE ACROSS SCENARIOS IS CALCULATED BY TAKING THE MINIMUM AND MAXIMUM DIRECT DAMAGE ACROSS ALL SCENARIOS AND COMPARING THIS TO THE DIRECT DAMAGE OF THE BASELINE SCENARIO (2ND COLUMN).

TABLE 9: SUMMARY OF DAMAGES – BASELINE, NO MITIGATION 2060

ARI	Direct Damage ($)	Direct damage range across scenarios**	Indirect Damage - Low ($)	Indirect Damage – Med. ($)	Indirect Damage - High ($)	Total Damage: direct + indirect medium ($)
20	112,402,150	-49%, +35%	4,240,000	8,480,000	16,950,000	120,882,150
50	253,241,950	-37%, +30%	31,040,000	62,080,000	124,017,000	315,321,950
100	505,212,560	-25%, +19%	128,620,000	257,240,000	514,480,000	762,452,560
200	616,783,800	-24%, +17%	290,050,000	580,100,000	1160,210,000	1,196,883,800
500	988,134,300	-22%, +13%	774,830,000	1,549,660,000	3,099,320,000	2,537,794,300
AAD / AAOL*	**15,128,731**	-31%, +24%	**5,980,000**	**11,970,000**	**23,940,000**	**27,098,731**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES. **DIRECT DAMAGE RANGE ACROSS SCENARIOS IS CALCULATED BY TAKING THE MINIMUM AND MAXIMUM DIRECT DAMAGE ACROSS ALL SCENARIOS AND COMPARING THIS TO THE DIRECT DAMAGE OF THE BASELINE SCENARIO (2^{ND} COLUMN).

5.2 NORTHERN FLOODWAY IMPLEMENTATION

This scenario considered the baseline exposure and vulnerability changes, as outlined in Section 5.1 along with changes to the hazard layers based on implementation of the floodway.

The Northern Floodway (Section 4.1.1) reduces flooding for return periods up to and including the 1 in 20 year flood, and likely to the 1 in 50 year flood and potentially the 1 in 100 year flood for the bottom section of the Gawler River.

5.2.1 Risk change

Comparing risk at the initial year (2018), the floodway performs well against direct and indirect losses. Figure 14 in comparison to Figure 11 of the baseline scenario clearly shows a reduction in AAD concentration in the lower reaches of the Gawler River – where the floodway should reduce the risk. The floodway transfers risk away from the southern banks of the Gawler River where spill was occurring in the baseline.

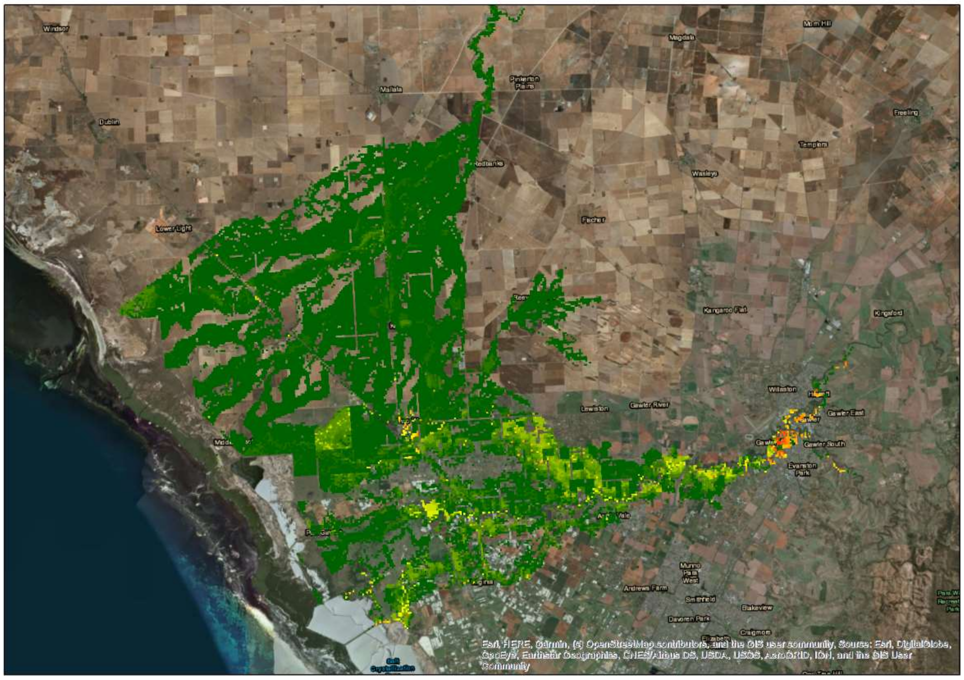

FIGURE 15: AAD DISTRIBUTION ACROSS THE FLOODPLAIN - NORTHERN FLOODWAY IN 2018. AREAS IN GREEN INDICATE LOW DAMAGES, WHILE AREAS IN YELLOW, ORANGE AND RED INDICATE HIGHER DAMAGES.

Table 10 summarises the damages, both direct and indirect, across return periods for the mitigated scenario. Here it is shown that the floodway is performing as expected in reducing the impacts significantly for smaller, more frequent floods. This has substantial positive benefits when considering the indirect damages with reductions of around 20% for a 1 in 20 year event – or between $10-16 million. Total damage as the sum of the Average annual damage and the Average annual output losses has a reduction of close to $1 million.

These results are repeated in Tables 11 and 12 for the years 2040 and 2060, where similar patterns are observed, in that decreases in the damages are only seen for the lower ARIs.

Table 10: Summary of damages - Northern Floodway 2018. percentages in brackets represent changes from baSeline scenario values without mitigation in table 7.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	51,128,010 (-18%)	3,800,000 (-15%)	54,928,010 (-18%)
50	155,856,830 (-5%)	22,520,000 (-10%)	178,376,830 (-6%)
100	349,591,410 (-2%)	79,430,000 (-5%)	429,021,410 (-2%)
200	437,528,800 (0%)	189,620,000 (0%)	627,148,800 (0%)
500	696,793,300 (0%)	527,960,000 (0%)	1,224,753,300 (0%)
AAD / AAOL*	**9,384,829 (-4%)**	**4,460,000 (-9%)**	**13,844,829 (-6%)**

TABLE 11: SUMMARY OF DAMAGES - NORTHERN FLOODWAY 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 8.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	61,657,610 (-24%)	4,430,000 (-21%)	66,087,610 (-24%)
50	185,476,830 (-11%)	34,010,000 (-9%)	219,486,830 (-10%)
100	421,144,410 (-5%)	143,090,000 (-4%)	564,234,410 (-5%)
200	547,914,800 (0%)	327,330,000 (0%)	875,244,800 (0%)
500	874,142,300 (0%)	830,240,000 (0%)	1,704,382,300 (0%)
AAD / AAOL*	**11,680,358 (-8%)**	**6,480,000 (-10%)**	**18,160,358 (-9%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

TABLE 12: SUMMARY OF DAMAGES - NORTHERN FLOODWAY 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 9.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	89,455,610 (-%20)	5,900,000 (-30%)	95,355,610 (-21%)
50	228,095,830 (-%10)	39,510,000 (-36%)	267,605,830 (-15%)
100	482,731,410 (-4%)	242,660,000 (-7%)	725,391,410 (-5%)
200	616,783,800 (0%)	580,100,000 (0%)	1,196,883,800 (0%)
500	988,134,300 (0%)	1,549,660,000 (0%)	2,537,794,300 (0%)
AAD / AAOL*	**14,009,772 (-7%)**	**10,150,000 (-15%)**	**24,159,772 (-11%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

5.3 BRUCE EASTICK DAM RAISE IMPLEMENTATION

This scenario considered the baseline exposure and vulnerability changes, as outlined in Section 5.1 along with changes to the hazard layers based on implementation of the dam raise project.

The Bruce Eastick Dam Raise (Section 4.1.2) reduces flooding for the 1 in 100 year and 1 in 200 year flood extent, however more examination of hydrology is required to understand its impact on spill for smaller events.

5.3.1 Risk change

Similar to the floodway, the dam raise performs well against baseline risk in 2018. The dam however has greater impact on rarer, large events at the upper end of the Gawler River.

Table 13 summarise the direct and indirect damages with the dam raise implemented. The dam protects more residential properties in and around Gawler which sees substantial decreases in direct damages in comparison to the baseline, and floodway scenario.

Total damage as the sum of the Average annual damage and the Average annual output losses has a reduction of close to $4 million compared to no mitigation options in 2018, $5 million in 2040 and $7 million in 2060.

TABLE 13: SUMMARY OF DAMAGES - BRUCE EASTICK DAM RAISE IN 2018. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 7.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	54,123,430 (-13%)	4,230,000 (-6%)	58,353,430 (-13%)
50	76,639,760(-53%)	17,030,000 (-32%)	93,669,760 (-50%)
100	126,373,580 (-64%)	55,420,000 (-34%)	181,793,580 (-59%)
200	169,376,440 (-61%)	135,420,000 (-29%)	304,796,440 (-51%)
500	696,793,300 (0%)	527,960,000 (0%)	1,224,753,300 (0%)
AAD / AAOL*	**6,177,172 (-37%)**	**4,160,000 (-15%)**	**10,337,172 (-30%)**

TABLE 14: SUMMARY OF DAMAGES - BRUCE EASTICK DAM RAISE IN 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 8.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	67,825,330 (-17%)	5,320,000 (-6%)	73,145,330 (-16%)
50	98,045,860 (-53%)	27,290,000 (-27%)	125,335,860 (-49%)
100	174,122,580 (-61%)	110,080,000 (-26%)	284,202,580 (-52%)
200	235,680,440 (-57%)	247,560,000 (-24%)	483,240,440 (-45%)
500	874,142,300 (0%)	830,240,000 (0%)	1,704,382,300 (-0%)
AAD / AAOL*	**8,158,221 (-36%)**	**6,220,000 (-13%)**	**14,378,221 (-28%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

TABLE 15: SUMMARY OF DAMAGES - BRUCE EASTICK DAM RAISE IN 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 9.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	95,799,430 (-15%)	7,930,000 (-6%)	103,729,430 (-14%)
50	128,349,660 (-49%)	36,410,000 (-41%)	164,759,660 (-48%)
100	208,844,580 (-59%)	186,990,000 (-27%)	395,834,580 (-48%)
200	274,983,440 (-55%)	453,440,000 (-22%)	728,423,440 (-39%)
500	988,134,300 (0%)	1,549,660,000 (0%)	2,537,794,300 (0%)
AAD / AAOL*	**10,026,372 (-34%)**	**10,150,000 (-15%)**	**20,176,372 (-26%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

5.4 LAND USE PLANNING – FLOODING OVERLAYS

The baseline scenario was modelled to assess the risk across the floodplain without the implementation of risk management strategies. To assess the impact of zoning controls in 2020, restrictions to urban development in both the 1 in 100 and 1 in 200 year flood footprint were implemented (see Section 4.2).

Land use demands for the baseline scenario were implemented as described in Section 3.1. Interaction between economic activities and residential actors were not changed compared to previous mitigation options, however an additional zoning layer was included, strictly restricting development of urban and rural residential, commercial, industrial and public services in the floodplains.

Results are presented for direct damages in 2040 and 2060 for both overlays (see Tables 16-19).

5.4.1 Risk change

Table 10 summarises the results of both overlays. Important to note is the significant increase in risk over time, which is especially clear in the scenario without mitigation options (Tables 7-9). This is from urban growth, along with infill and densification of existing urban areas. Treatment of this risk requires alternative strategies such as improved building codes.

Total damage as the sum of the Average annual damage and the Average annual output losses has a reduction of close to $4 million compared to no mitigation options in 2060 for the 1 in 100 year flood overlay and $10 million for the 1 in 200 year flood overlay. Considerable reductions in risk can be found across all ARIs.

TABLE 16: SUMMARY OF DAMAGES – ZONING ARI100 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 8.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	71,865,450 (-12%)	5,020,000 (-11%)	76,885,450 (-12%)
50	186,855,950 (-11%)	34,980,000 (-6%)	211,835,950 (-10%)
100	395,657,560 (-11%)	118,000,000 (-21%)	513,657,560 (-13%)
200	486,661,800 (-11%)	266,440,000 (-19%)	753,101,800 (-14%)
500	771,716,300 (-12%)	723,260,000 (-13%)	1,494,976,300 (-12%)
AAD / AAOL*	**11,240,420 (-12%)**	**6,080,000 (-15%)**	**17,320,420 (-13%)**

TABLE 17: SUMMARY OF DAMAGES - ZONING ARI100 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 9.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	93,609,750 (-17%)	7,290,000 (-14%)	100,899,750 (-17%)
50	210,867,950 (-17%)	58,560,000 (-6%)	269,427,950 (-15%)
100	421,501,560 (-17%)	226,200,000 (-12%)	647,701,560 (-15%)
200	513,620,800 (-17%)	512,200,000 (-12%)	1,025,820,800 (-14%)
500	819,203,300 (-17%)	1,414,750,000 (-8%)	2,233,953,300 (-12%)
AAD / AAOL*	**12,540,932 (-17%)**	**10,610,000 (-11%)**	**23,150,932 (-15%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

TABLE 18: SUMMARY OF DAMAGES - ZONING ARI200 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 8.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	62,593,250 (-23%)	3,630,000 (-36%)	66,223,250 (-24%)
50	171,436,950 (-18%)	19,080,000 (-49%)	190,516,950 (-23%)
100	365,773,560 (-18%)	67,540,000 (-55%)	433,313,560 (-27%)
200	448,364,800 (-18%)	159,550,000 (-51%)	607,914,800 (-31%)
500	720,149,300 (-18%)	458,290,000 (-45%)	1,178,439,300 (-31%)
AAD / AAOL*	**10,292,255 (-19%)**	**3,990,000 (-44%)**	**14,282,255 (-28%)**

TABLE 19: SUMMARY OF DAMAGES - ZONING ARI200 IN 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 9.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	62,591,750 (-44%)	3,370,000 (-60%)	65,961,750 (-45%)
50	171,412,950 (-32%)	25,690,000 (-59%)	197,102,950 (-37%)
100	365,721,560 (-28%)	172,310,000 (-33%)	538,031,560 (-29%)
200	448,300,800 (-27%)	356,990,000 (-38%)	805,290,800 (-33%)
500	731,670,300 (-26%)	1,094,380,000 (-29%)	1,826,050,300 (-28%)
AAD / AAOL*	**10,365,591 (-31%)**	**6,530,000 (-45%)**	**16,895,591 (-38%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

5.5 RESILIENT BUILDING OPTIONS – RAISING FLOOR LEVELS

A final risk reduction option that was explored as part of the initial impact assessment was increasing the resilience of assets by making them less prone to damage due to flooding. For buildings, this means protecting the base of the building (so raising the height from which damage will occur), or placing the entire building at a slightly higher location (so shifting the vulnerability function). As part of this impact assessment, we explored the latter. We assessed the reduction in risk if all buildings within the flood prone area would be raised by 15 cm and damage from floods would only occur from inundation levels above 30 cm.

Due to the high economic value of horticulture, we applied a similar risk reduction to this agricultural practice as we assumed horticulture is protected from inundation depths below 30 cm.

5.5.1 Risk change

As can be seen from Tables 20-22, this option reduces risk from the start (as the assumption is that the current building stock is impacted by the option as well). Although the reduction in risk is not as large as for some of the other options, it is still substantial, with reductions of the total damage (sum of the Average annual damage and the Average annual output losses) of $1-$2 million.

TABLE 20: SUMMARY OF DAMAGES – RAISED FLOOR LEVELS IN 2018. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 7.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	57,021,750 (-8%)	4,480,000 (0%)	61,501,750 (-8%)
50	129,627,950 (-21%)	25,130,000 (0%)	154,757,950 (-18%)
100	281,858,560 (-21%)	83,780,000 (0%)	365,638,560 (-17%)
200	354,224,800 (-19%)	189,620,000 (0%)	543,844,800 (-13%)
500	594,118,300 (-15%)	527,960,000 (0%)	1,122,078,300 (-8%)
AAD / AAOL*	**8,638,633 (-12%)**	**4,880,000 (0%)**	**13,518,633 (-8%)**

TABLE 21: SUMMARY OF DAMAGES - RAISED FLOOR LEVELS IN 2040. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 8.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	70,000,050 (-14%)	5,630,000 (0%)	75,630,050 (-13%)
50	159,748,950 (-24%)	37,370,000 (0%)	197,118,950 (-20%)
100	344,402,560 (-22%)	148,460,000 (0%)	492,862,560 (-17%)
200	433,517,800 (-21%)	327,330,000 (0%)	760,847,800 (-13%)
500	728,749,300 (-17%)	830,240,000 (0%)	1,558,989,300 (-9%)
AAD / AAOL*	**10,862,107 (-14%)**	**7,180,000 (0%)**	**18,042,107 (-9%)**

TABLE 22: SUMMARY OF DAMAGES - RAISED FLOOR LEVELS IN 2060. PERCENTAGES IN BRACKETS REPRESENT CHANGES FROM BASELINE SCENARIO VALUES WITHOUT MITIGATION IN TABLE 9.

ARI	Direct Damage – BAU scenario ($)	Indirect Damage – Med. ($)	Total Damage: direct + indirect medium ($)
20	98,937,850 (-12%)	8,480,000 (0%)	107,417,850 (-11%)
50	199,148,950 (-21%)	62,080,000 (0%)	261,228,950 (-17%)
100	397,614,560 (-21%)	257,240,000 (0%)	654,854,560 (-14%)
200	493,098,800 (-20%)	580,100,000 (0%)	1,073,198,800 (-10%)
500	823,657,300 (-17%)	1,549,660,000 (0%)	2,373,317,300 (-6%)
AAD / AAOL*	**13,082,469 (-14%)**	**11,970,000 (0%)**	**25,052,469 (-8%)**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

5.6 RISK REDUCTION ACROSS OPTIONS AND SOCIO-ECONOMIC SCENARIOS

Information from the individual risk reduction options from the previous sections is summarized in Tables 23-25 to provide an overview of the impact of each option compared to not applying any mitigation. Each of the tables therefore provides the damage per ARI (sum of direct and indirect damages) and the combined AAD and AAOL for a specific year (2018, 2040, 2060) without any mitigation options. For each of the mitigation options the risk reduction is then provided as a percentage reduction compared to the damage without mitigation.

The tables show that some options (Floodway, Dam raise, Raised floor levels) have a very consistent risk reduction impact over time, while other options (both flood overlay options), do not have any impact in 2018, but an increasing impact over time. While the Dam raise is overall very effective in reducing risk, and even more so during large flood events, 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 reduce impacts of smaller floods and outperforms other options in doing so initially. Although it remains equally effective in reducing risk over time, the impact in risk reduction of the ARI 200 flood overlay is so dominant in 2060 that it outperforms all other options for all ARIs.

TABLE 23: COMPARISON OF RISK REDUCTION OPTIONS AGAINST THE NO MITIGATION OPTION FOR 2018 FOR THE BASELINE SOCIO-ECONOMIC SCENARIO. RISK REDUCTION IS COMPARED TO THE NO MITIGATION OPTION (COLUMN 2) FOR DAMAGES PER ARI AS WELL AS THE SUM OF THE AAL AND AAOL, AND EXPRESSED AS A PERCENTAGE REDUCTION.

ARI	Total Damage ($)	Floodway	Dam raise	Zoning ARI 100	Zoning ARI 200	Raised floor levels
20	66,706,750	-18%	-13%	0%	0%	-8%
50	189,021,950	-6%	-50%	0%	0%	-18%
100	439,203,560	-2%	-59%	0%	0%	-17%
200	627,148,800	0%	-51%	0%	0%	-13%
500	1,224,753,300	0%	0%	0%	0%	-8%
AAD & AAOL*	**14,698,164**	**-6%**	**-30%**	**0%**	**0%**	**-8%**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

TABLE 24: COMPARISON OF RISK REDUCTION OPTIONS AGAINST THE NO MITIGATION OPTION FOR 2040 FOR THE BASELINE SOCIO-ECONOMIC SCENARIO. RISK REDUCTION IS COMPARED TO THE NO MITIGATION OPTION (COLUMN 2) FOR DAMAGES PER ARI AS WELL AS THE SUM OF THE AAL AND AAOL, AND EXPRESSED AS A PERCENTAGE REDUCTION.

ARI	**Total Damage ($)**	**Floodway**	**Dam raise**	**Zoning ARI 100**	**Zoning ARI 200**	**Raised floor levels**
20	86,955,250	-24%	-16%	-12%	-24%	-13%
50	246,432,950	-11%	-49%	-10%	-23%	-20%
100	592,461,560	-5%	-52%	-13%	-27%	-17%
200	875,244,800	0%	-45%	-14%	-31%	-13%
500	1,704,382,300	0%	0%	-12%	-31%	-9%
AAD & AAOL*	**19,890,740**	**-9%**	**-28%**	**-13%**	**-28%**	**-9%**

TABLE 25: COMPARISON OF RISK REDUCTION OPTIONS AGAINST THE NO MITIGATION OPTION FOR 2060 FOR THE BASELINE SOCIO-ECONOMIC SCENARIO. RISK REDUCTION IS COMPARED TO THE NO MITIGATION OPTION (COLUMN 2) FOR DAMAGES PER ARI AS WELL AS THE SUM OF THE AAL AND AAOL, AND EXPRESSED AS A PERCENTAGE REDUCTION.

ARI	**Total Damage ($)**	**Floodway**	**Dam raise**	**Zoning ARI 100**	**Zoning ARI 200**	**Raised floor levels**
20	120,882,150	-21%	-14%	-17%	-45%	-11%
50	315,321,950	-15%	-48%	-15%	-37%	-17%
100	762,452,560	-5%	-48%	-15%	-29%	-14%
200	1,196,883,800	0%	-39%	-14%	-33%	-10%
500	2,537,794,300	0%	0%	-12%	-28%	-6%
AAD & AAOL*	**27,098,731**	**-11%**	**-26%**	**-15%**	**-38%**	**-8%**

*AAD IS AVERAGE ANNUAL DAMAGE FROM DIRECT DAMAGES, AAOL IS AVERAGE ANNUAL OUTPUT LOSSES FROM INDIRECT DAMAGES.

We have used a set of 4 alternative socio-economic scenarios in addition to a baseline scenario to better understand the performance of each risk reduction option under a range of plausible future socio-economic conditions, and hence the robustness of the various mitigation strategies (see Section 3). Table 26 shows the % risk reduction in average annual damage (AAD) of each option under each scenario for three points in time: 2018, 2040 and 2060, which are subsequently listed top, middle, and bottom in each cell.

The table shows that for some options, risk reduction is immediate (starting from 2018 in our study). 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.

From the table, it can also be concluded that 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, such as the Ignorance of the Lambs scenario.

TABLE 26: SUMMARY OF REDUCTION OF AVERAGE ANNUAL DAMAGES (AAD) UNDER DIFFERENT SOCIO-ECONOMIC SCENARIO FOR DIFFERENT RISK REDUCTION OPTIONS UNDER CONSIDERATION. THE THREE ROWS FOR EACH MITIGATION OPTIONS REPRESENT REDUCTION IN DIRECT DAMAGE VALUES FOR 2018 (TOP ROW), 2040 (MIDDLE ROW) AND 2060 (THIRD ROW).

Option	**Year**	**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)**
Floodway	2018	-4	-4	-4	-4	-4
	2040	-8	-7	-8	-7	-8
	2060	-7	-7	-8	-7	-8
Dam raise	2018	-37	-37	-37	-37	-37
	2040	-36	-35	-38	-34	-37
	2060	-34	-35	-39	-34	-35
Zoning ARI 100	2018	0	0	0	0	0
	2040	-12	-12	-7	-23	-8
	2060	-17	-15	-12	-26	-17
Zoning ARI 200	2018	0	0	0	0	0
	2040	-19	-26	-8	-53	-11
	2060	-31	-29	-13	-56	-23
Raised floor levels	2018	-12	-12	-12	-12	-12
	2040	-15	-14	-15	-12	-15
	2060	-14	-14	-16	-12	-15

6 CONCLUSIONS

This report is part of the Gawler River UNHaRMED Mitigation Project (GRUMP) and demonstrates the role of UNHaRMED in assessing mitigation options against each other with consistent metrics, and their performance over time.

As part of this report, a distinct set of 5 mitigation options is assessed on their ability to reduce risk under different plausible futures. While some options score well under all scenarios, other options perform especially well under specific scenarios. Some options take effect immediately and hence protect the current assets, while other options avoid the increase of risk over time by limiting exposure.

In addition to exploring the impact of an option on the Average annual damages or Average annual output losses across ARIs, it is also relevant to assess if certain options address particular types of events well. For example, the impact assessment shows that the floodway is performing as expected in reducing impacts significantly for smaller, more frequent floods, while the dam raise has greater impact on rarer, large events at the upper end of the Gawler River.

The options assessed in this report are deliberately quite extreme (e.g. strict zoning for new development within all 1/200 flood areas, or raising floor levels of all buildings in flood prone areas) to better understand how effective different option *could* be. In the pathways report less extreme versions of the measures will be included as well, in addition to combinations of measures and a temporal differentiation of the measures. This will further support the development of the flood management plan for the Gawler River Basin.

REFERENCES

Australian Institute for Disaster Resilience (2015). Australian Disaster Resilience Handbook - 10 National Emergency Risk Assessment Guidelines.

Australian Institute for Disaster Resilience (2017). Australian Disaster Resilience Handbook 7 - Managing the floodplain: A guide to best practice in flood risk management in Australia.

Australian Water Environments (AWE) and Water Technology (2016). Mitigations Options Review. A Findings Report for the Gawler River Flood Mitigation Scheme. Prepared for Gawler River Floodplain Management Authority.

Burns G., Adams, L., Buckley, G. (2017). Independent review of the extreme weather event South Australia 28 September – 5 October 2016. Presented to the Government of South Australia).

Crichton, D. (1999). The Risk Triangle. In: Natural Disaster Management. Ingleton J., (Eds.). London, UK: Tudor Rose. pp. 102–103.

Deloitte Access Economics (2017). Building resilience to natural disaster in our states and territories. Report for the Australian Business Roundtable for Disaster Resilience and Safer Communities.

Huizinga, J., de Moel, H., Szewczyk, W. (2017). Global flood depth-damage functions. Methodology and database with guidelines. EUR 28552 EN. doi: 10.2760/16510.

URS Australia (2010). Goulburn River Environmental Flows Hydraulics Study – Potential Flood Damage Assessment. Final report, prepared for Goulburn Broken Catchment Management Authority, VIC, Australia.

Wehner, M., Canterford, N., Corby, N., Edwards, M, Juskevics, V. (2017). Vulnerability of Australian Houses to Riverine Inundation. Analytical and empirical vulnerability curves. Geoscience Australia.

ANNEX 1: VULNERABILITY CURVES

A literature review was conducted to obtain vulnerability functions for buildings, infrastructure, and crops. From this literature review, vulnerability functions of 2 sources, Geoscience Australia (Wehner et al., 2017) and the European Union Joint Research Centre (Huizinga et al., 2017), have been further explored for building types. Both the shape of the curve and their impact on the regional damage as calculated by UNHARMED was assessed and based on this the vulnerability functions as provided by the JRC report were selected. These curves are provided for different global regions, including Oceania. To align with the local South Australian context, these functions have been slightly adapted to reflect expected damages for low inundation depths. All damage functions for buildings therefore start to calculate damage from an inundation depth of 15cm (see table A.1). In addition, we assume complete destruction for inundation levels above 4 m.

In simulations where floor levels are raised, the vulnerability functions start to calculate damage from an inundation depth of 30 cm. We have assessed the impact of mitigating damages only in the 15-30 cm range (especially relevant when retrofitting existing buildings) (see table A.2), as well as the impact of shifting the entire curve by 15 cm to reflect what would happen if the entire building was raised by 15 cm (hence an option more relevant for new development) (see table A.3).

TABLE A.1: VULNERABILITY FUNCTION FOR RESIDENTIAL BUILDINGS - STANDARD

Water depth (m)	Damage factor
0	0
0.15	0
0.5	0.48
1	0.64
1.5	0.71
2	0.79
3	0.93
4	1

TABLE A.2: VULNERABILITY FUNCTION FOR RESIDENTIAL BUILDINGS – RAISED FLOOR LEVELS

Water depth (m)	**Damage factor**
0	0
0.3	0
0.5	0.48
1	0.64
1.5	0.71
2	0.79
3	0.93
4	1

TABLE A.3: VULNERABILITY FUNCTION FOR RESIDENTIAL BUILDINGS – SHIFTED

Water depth (m)	**Damage factor**
0	0
0.3	0
0.65	0.48
1.15	0.64
1.65	0.71
2.15	0.79
3.15	0.93
4.15	1

For commercial buildings, a similar approach is followed as for residential buildings. Standard functions start to calculate damage from an inundation depth of 15 cm. The raised floor level option provides damages from 30 cm inundation depth, and the option with a shifted function assumes the entire building is raised by 15 cm.

For commercial buildings, we also have information on the number of storeys. We therefore apply different vulnerability functions according to building height. For commercial buildings with 1-3 storeys, we apply the three functions as provided in Tables A.4-A.6. For commercial buildings with 4-7 storeys, we apply the functions as provided in tables A.7-A.9. For buildings with more than 7 storeys, we apply the curves provided in Tables A.10-A.12. The functions for commercial buildings with 1-3 storeys have been sourced from literature (Huizinga et al, 2017), the functions for other commercial buildings are adapted from these.

TABLE A.4: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 1-3 STORIES - STANDARD

Water depth (m)	Damage factor
0	0
0.15	0
0.5	0.24
1	0.48
1.5	0.67
2	0.86
3	1

TABLE A.5: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 1-3 STORIES – RAISED FLOOR LEVELS

Water depth (m)	Damage factor
0	0
0.3	0
0.5	0.24
1	0.48
1.5	0.67
2	0.86
3	1

TABLE A.6: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 1-3 STORIES – SHIFTED

Water depth (m)	Damage factor
0	0
0.3	0
0.65	0.24
1.15	0.48
1.65	0.67
2.15	0.86
3.15	1

TABLE A.7: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 4-7 STORIES - STANDARD

Water depth (m)	Damage factor
0	0
0.15	0
2	0.24
4	0.48
6	0.67

TABLE A.8: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 4-7 STORIES – RAISED FLOOR LEVELS

Water depth (m)	Damage factor
0	0
0.3	0
2	0.24
4	0.48
6	0.67

TABLE A.9: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 4-7 STORIES – SHIFTED

Water depth (m)	Damage factor
0	0
0.3	0
2.15	0.24
4.15	0.48
6.15	0.67

TABLE A10: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 8+ STORIES - STANDARD

Water depth (m)	Damage factor
0	0
0.15	0
6	0.24

TABLE A.11: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 8+ STORIES – RAISED FLOOR LEVELS

Water depth (m)	Damage factor
0	0
0.3	0
6	0.24

TABLE A.12: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 8+ STORIES – SHIFTED

Water depth (m)	Damage factor
0	0
0.3	0
6.15	0.24

In line with the other building types, for industrial buildings, three different vulnerability functions are applied to reflect the standard vulnerability and an improved vulnerability either by raising the floor level or by building the entire building at a higher base level, hence shifting the function. The vulnerability functions for industry are provided in tables A13-A15.

TABLE A.13: VULNERABILITY FUNCTION FOR INDUSTRIAL BUILDINGS - STANDARD

Water depth (m)	**Damage factor**
0	0
0.15	0
0.5	0.31
1	0.48
1.5	0.61
2	0.71
3	0.84
4	0.93
5	0.98
6	1

TABLE A.14: VULNERABILITY FUNCTION FOR INDUSTRIAL BUILDINGS – RAISED FLOOR LEVELS

Water depth (m)	Damage factor
0	0
0.3	0
0.5	0.31
1	0.48
1.5	0.61
2	0.71
3	0.84
4	0.93
5	0.98
6	1

TABLE A.15: VULNERABILITY FUNCTION FOR INDUSTRIAL BUILDINGS - SHIFTED

Water depth (m)	Damage factor
0	0
0.3	0
0.65	0.31
1.15	0.48
1.65	0.61
2.15	0.71
3.15	0.84
4.15	0.93
5.15	0.98
6.15	1

For agricultural damages, functions were also sourced from the European Union Joint Research Centre (Huizinga et al, 2017). To align with the local South Australian context, these functions have been slightly adapted to reflect expected damages for low inundation depths. All damage functions for buildings therefore start to calculate damage from an inundation depth of 10 cm (see table A.4).

TABLE A.16: VULNERABILITY FUNCTION FOR AGRICULTURE - STANDARD

Water depth (m)	Damage factor
0	0
0.10	0
0.5	0.27
1	0.48
1.5	0.56
2	0.61
3	0.76
4	1

TABLE A.17: VULNERABILITY FUNCTION FOR AGRICULTURE – RAISED GROUND LEVEL

Water depth (m)	Damage factor
0	0
0.3	0
0.5	0.27
1	0.48
1.5	0.56
2	0.61
3	0.76
4	1

TABLE A.18: VULNERABILITY FUNCTION FOR AGRICULTURE - SHIFTED

Water depth (m)	**Damage factor**
0	0
0.3	0
0.65	0.27
1.15	0.48
1.65	0.56
2.15	0.61
3.15	0.76
4.15	1

For road infrastructure, vulnerability functions were also sourced from the European Union Joint Research Centre. No specific functions for Oceania were provided, only for Europe and Asia, which are both equal. Consequently, these were adopted.

TABLE A.19: VULNERABILITY FUNCTION FOR ROADS

Water depth (m)	**Damage factor**
0	0
0.5	0.36
1	0.57
1.5	0.73
2	0.85
3	1

ANNEX 2: VALUE AT STAKE

The value at stake for buildings and agriculture has been sourced from NEXIS. Based on the total value per LGA and the number of buildings in each LGA an average value per residential, commercial, and industrial building has been derived, see Table A.20 below. Values for road infrastructure have been derived from a study prepared for the Goulburn Broken Catchment Management Authority (URS Australia, 2010). This report provides values for major and minor floods, while a calculation with vulnerability functions requires a maximum damage. Figures have therefore been slightly raised. Values used in the risk calculations are provided in Table A.21.

TABLE A.20: VALUE AT STAKE PER BUILDING AND AGRICULTURAL AREA, FOR EACH LGA (IN AUD)

Asset	**Adelaide Hills**	**Adelaide Plains**	**Barossa**	**Gawler**	**Light**	**Playford**
Residential building	365,670	401,994	571,684	426,240	402,833	428,434
Commercial building	11,682,660	5,917,880	9,443,230	5,535,347	4,366,392	13,678,560
Industrial building	4,396,668	5,312,800	5,055,299	2,011,404	4,414,080	11,881,129
Crops (ha)	20,847	984	2,035	3,652	987	21,691
Fruit and nuts, grapes and wine production (ha)	6,060	4,814	3,896	16,738	3,975	4,254
Fruit and nuts, excluding grapes (ha)	50,853	1,367	5,046	16,739	4,009	9,391
Nurseries, cut flowers, cultivated turf (ha)	128,494	439,835	128,494	127,649	126,541	264,693
Vegetables for human consumption (ha)	21,138	34,080	71,869	95,417	26,036	42,286
Livestock (ha)	753	15,077	635	6,054	13,903	831

TABLE A.21: DAMAGE VALUE AT STAKE PER ROAD SEGMENT

Asset	Damage value ($/km road)
Freeway	400
Highway	400
Arterial road	100
Sub-arterial road	100
Collector road	50
Local	50
Track 4WD	50
Track 2WD	50
Undetermined	50