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LAUNCESTON FLOOD RISK MITIGATION ASSESSMENT - JUNE 2016 FLOODS

Suburb of Newstead

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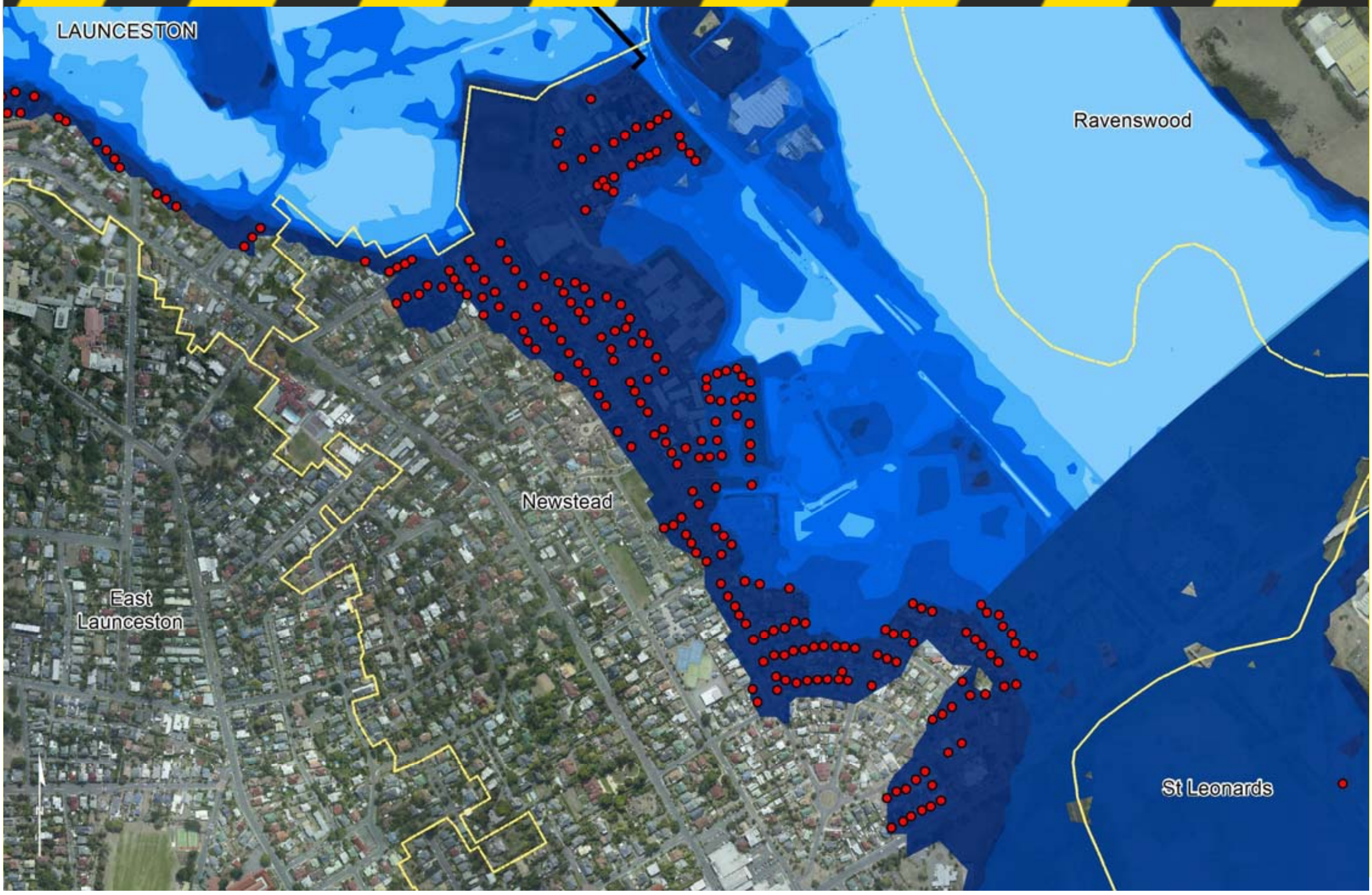

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Cover: Newstead flood extent map (Geoscience Australia)

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ABBREVIATIONS

Acronym	Full Name
AAL	Average Annual Loss
AHD	Australian Height Datum
ARI	Average Recurrence Interval
BCR	Benefit Cost Ratio
BNHCRC	Bushfire and Natural Hazards Cooperative Research Centre
CBA	Cost Benefit Analysis
GA	Geoscience Australia
LCC	Launceston City Council
NEXIS	National Exposure Information System
PMF	Probable Maximum Flood
WTP	Willingness to pay
PTSD	Post-traumatic Stress Disorder

INTRODUCTION

Launceston is floodprone and located within the Tamar River floodplain at the confluence of the Tamar, North Esk and South Esk Rivers in Tasmania (see Figure 1). Launceston has been subjected to 35 significant floods since records began, with the 1929 flood considered to be the worst (Fullard, 2013). A new Launceston Flood Authority was established in 2008 to design, construct and maintain existing and new flood levees. To replace the existing deteriorated levees a flood mitigation initiative was completed in 2016 to provide Launceston with reliable flood protection up to the 200 year Annual Recurrence Interval (ARI) event (Fullard, 2013).

However, this flood mitigation initiative did not extend to Newstead, a suburb in the east of Launceston, with the suburb consequently not protected from floods. Therefore, a new levee was proposed to protect the properties in Newstead from future floods. The cost of the proposed levee was estimated to be $580,000 along with an annual maintenance cost of $10,000 (Fullard, 2016).

Geoscience Australia (GA) was funded to undertake a project to conduct a Cost Benefit Analysis (CBA) of the proposed flood levee in Newstead as a variation to its current project (BNHCRC, 2017a) within the Bushfire and Natural Hazards CRC (BNHCRC). The project stakeholders included the BNHCRC, Tasmanian Department of Premier and Cabinet, Tasmanian State Emergency Service, Launceston City Council (LCC), Launceston Flood Authority and Northern Midlands Council.

This report provides the details of the CBA of the proposed flood levee along with consideration of several other mitigation options as researched within the BNHCRC flood mitigation project.

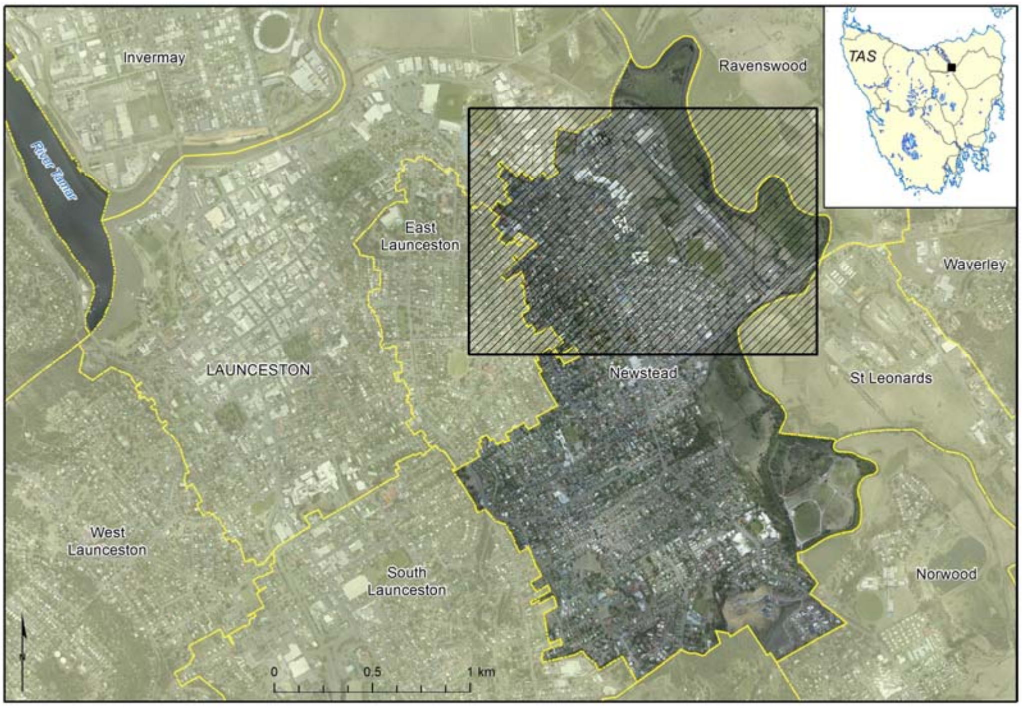


FIGURE 1: STUDY AREA

AIMS AND OBJECTIVES

The study aimed to assess:

- The number of people displaced due to inundation of homes for flood events ranging from the 20 year Annual Recurrence Interval (ARI) up to the Probable Maximum Flood (PMF) and the expected time for them to return before and after the new mitigation works.
- The avoided building damage for flood events ranging from the 20 year ARI up to the PMF due to the new mitigation works.
- The quantification of intangible losses for flood events ranging from the 20 year ARI up to the PMF.
- The long term cost to Newstead from flood hazard prior to the proposed mitigation works.
- The long term cost to Newstead from flood hazard following the proposed mitigation works.
- A CBA of the proposed flood mitigation investment in Newstead.

RESEARCH FRAMEWORK

FLOOD RISK ASSESSMENT FRAMEWORK

To accomplish these aims this study followed the traditional concept of risk which is the combination of hazard, exposure and vulnerability. Flood risk assessment requires knowledge of the hazard severity, the elements exposed to the hazard and their vulnerability to flood damage as presented in Figure 2. For each component this study utilised data from a number of sources.

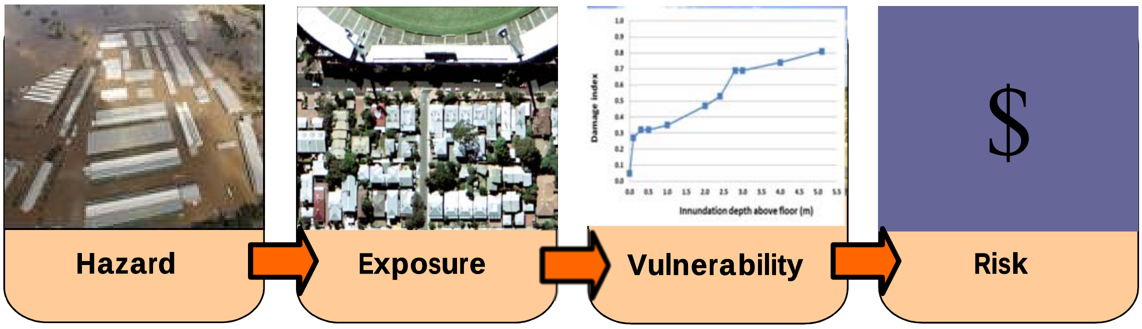


FIGURE 2: FLOOD RISK ASSESSMENT FRAMEWORK

Hazard

Hazard describes the severity and associated likelihood of a hazard at a locality of interest. In this study the hazard is defined in terms of flood depth above ground floor level. The hazard information for 20 to 500 year ARIs was provided by the LCC (2011). To make this study more rigorous and to include rarer events in the analysis the same consultant was engaged which produced the 20 to 500 year ARI hazard to develop the hazard maps for the 1,000 year ARI and PMF events (BMT WBM, 2016). The hazard information utilised in the study included the flood extents and peak flood levels for all the ARIs up to the PMF (100,000 year ARI). Table 1 shows the modelled peak flood depths associated with a range of ARIs in terms of the Australian Height Datum (AHD) on Hart Street. Figure 3A to Figure 3C show the modelled flood extents for the events from the 20 year ARI to the PMF. The number of affected properties grouped in selected categories of inundation depth in each hazard event is presented in Table A1 to Table A4 (Appendix A).

TABLE 1: MODELLED PEAK FLOOD LEVELS IN NEWSTEAD

ARI Events (years)	Annual Probability of Exceedance	Peak Flood Level (m AHD)
100,000	0.00001	7.52
1,000	0.001	5.16
500	0.002	5.06
200	0.005	4.34
100	0.01	3.93
50	0.02	3.47
20	0.05	2.93

(i) 20 Year ARI

(ii) 50 Year ARI

(iii) 100 Year ARI

FIGURE 3A: MODELLED FLOOD EXTENTS FOR 20 TO 100 YEAR AVERAGE RECURRENCE INTERVALS

(i) 200 Year ARI

(ii) 500 Year ARI

(iii) 1,000 Year ARI

FIGURE 3B: MODELLED FLOOD EXTENTS FOR 200 TO 1,000 YEAR AVERAGE RECURRENCE INTERVALS

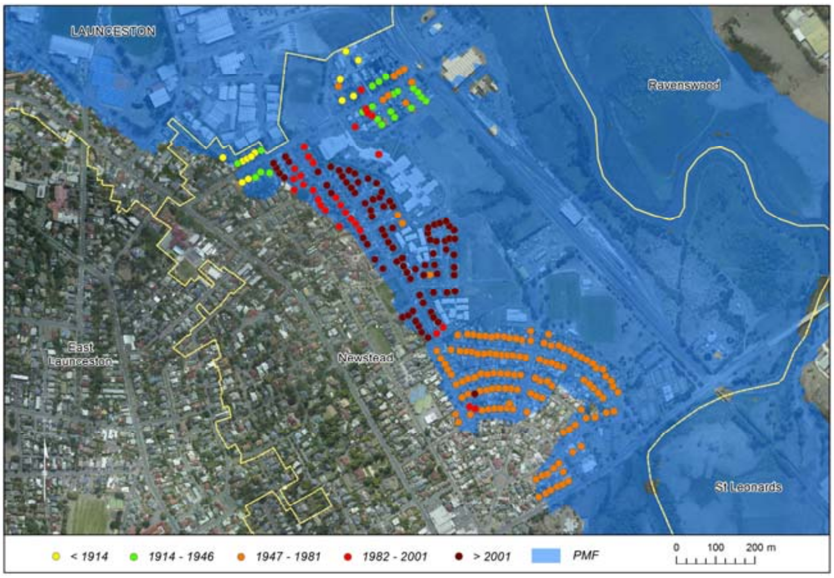
FIGURE 3C: MODELLED FLOOD EXTENTS FOR THE PMF

Exposure

Exposure describes the assets of value that are potentially exposed to the hazard. These assets can be physical (buildings, contents, essential infrastructure), social (populations and social systems), economic (businesses and regional scale economic activity) and environmental. This study is focused on assessing impacts of floods on buildings, businesses and people only.

The exposure database was compiled for all buildings in Newstead (272 in total) within the mapped PMF extent by sourcing building attributes from GA's National Exposure Information System - NEXIS (GA, 2017). This database was supplemented by a desktop study utilising Google street view imagery to record additional building attributes. Floor height information was provided by the LCC for all buildings within the 500 ARI extent map. For all the remaining buildings exposed to rarer events a desktop study was conducted to assess floor height for each building.

Figure 4A and Figure 4B present the spatial distribution of buildings within the PMF extent for selected attributes.

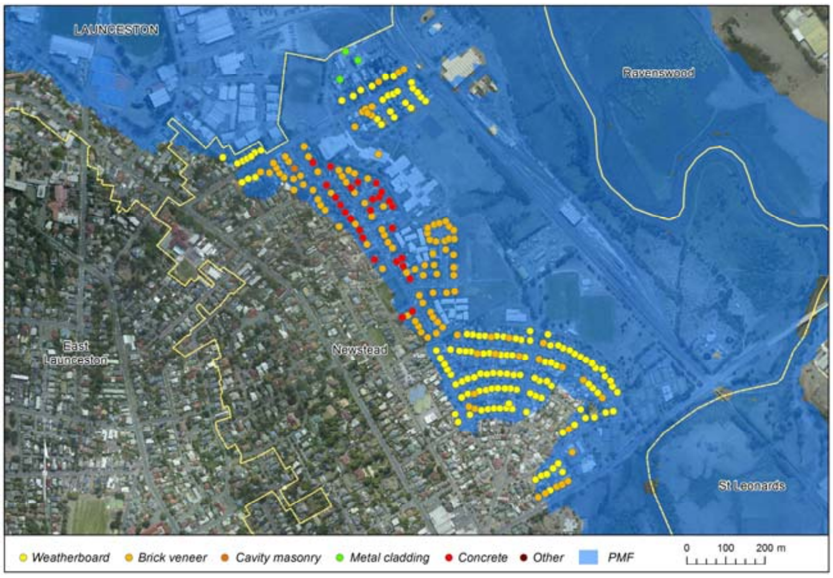


(i) Building Year

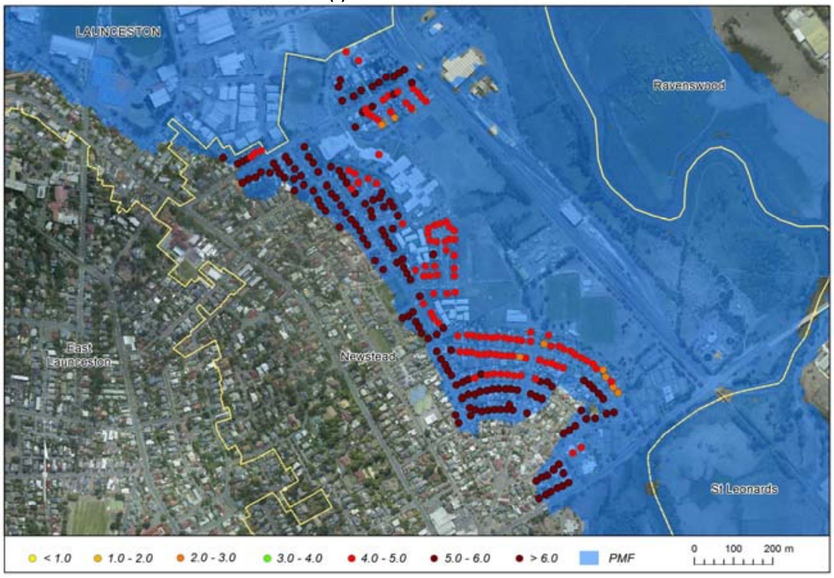
(ii) Building Usage

(iii) Roof Material

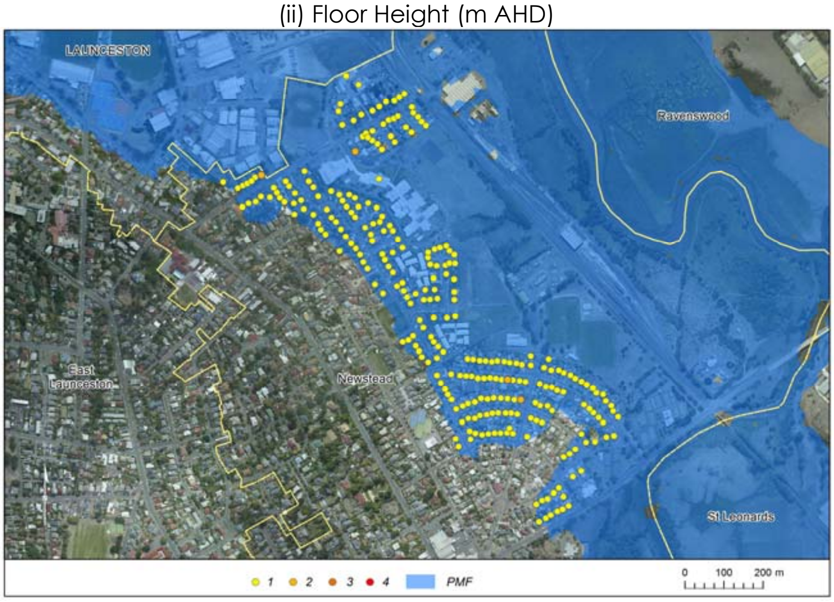
Figure 4A: BUILDING ATTRIBUTES AND THEIR SPATIAL DISTRIBUTION IN THE STUDY AREA



(i) Wall Material



(ii) Floor Height (m AHD)



(iii) Number of Storeys

FIGURE 4B: BUILDING ATTRIBUTES AND THEIR SPATIAL DISTRIBUTION IN THE STUDY AREA

Vulnerability

Vulnerability describes the susceptibility of assets to damage when exposed to a hazard. It provides a relationship between loss and the severity of hazard (flood depth above ground floor level). Vulnerability models (also known as stage-damage curves) were sourced from the outcomes of a number of research projects that GA has undertaken in the last six years to facilitate flood risk assessment. The outcomes of these projects included flood vulnerability models for residential, commercial, industrial and community building types (29 models in total). Moreover, they also included vulnerability models for contents of residential buildings (11 models in total). Appendix B lists the building types for which vulnerability models were used in this project.

Figure 5 shows the spatial distribution of vulnerability model types based on building use assigned to the building stock in the study area.

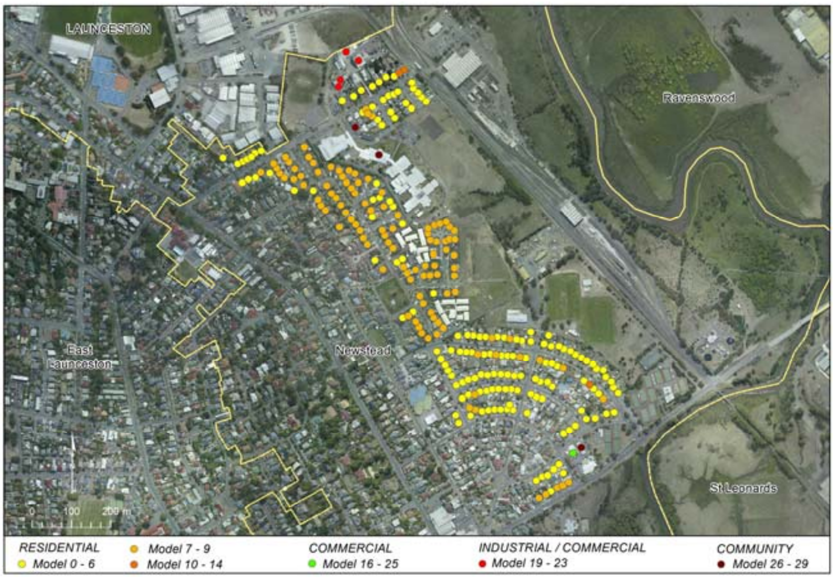


FIGURE 5: FLOOD VULNERABILITY MODEL TYPES ASSIGNED TO BUILDINGS IN NEWSTEAD

Risk

Risk can be measured as the aggregated annualised dollar loss due to tangible and intangible impacts such as building damage, contents loss, economic activity disruption, fatalities and social disruption caused by hazard events over the full range of event likelihoods. Although in economic terms the quantified intangible impacts are not strictly additional to the direct financial losses quantified in this study, these are taken into account for illustrative purpose. Table 2 lists the components for which losses have been estimated in this study in 2016 dollar values.

TABLE 2: SOURCES OF TANGIBLE AND INTANGIBLE LOSSES

Tangible	Intangible
Building repair/rebuild cost	Physical health
Contents damage cost	Mental health
Loss of rental income	Social Disruption – Electricity Outage
Clean-up cost	Social Disruption – Traffic Delays
	Social Disruption - Displacement
	Amenity
	Safety

Information related to the duration of household interruption was sourced from the 2011 post-flood household surveys conducted by GA in Brisbane and Ipswich (Canterford, 2016). The household survey outcomes were used to assess the rental income loss for the residential sector.

In addition, Bundaberg Regional Council provided estimates of clean-up cost based on the Council's experience after the 2013 Bundaberg floods in Queensland (Honor, 2017). These cost estimates, based on per unit area of residential and non-residential buildings, were used to assess the likely clean-up cost in Newstead. These costs did not include clean-up associated with critical infrastructure.

Likelihood of fatalities was based on the fatality model developed by Jonkman (2007) and was estimated for night time population exposure in the residential sector (worst case scenario). The value of statistical life was based on the updated value determined in the parallel BNHCRC earthquake mitigation project (BNHCRC, 2017b) which, in turn, was based on Abelson (2007).

For the assessment of all other intangible impacts listed in Table 2, Gibson (2017) provided the willingness to pay (WTP) estimates to avoid flood impacts on the community. These WTP values were then used to quantify the intangible impacts.

COST BENEFIT ANALYSIS FRAMEWORK

The main application of the CBA in this study was to evaluate the efficiency of flood risk mitigation investment. The CBA comprised four steps as presented in Figure 6 and described below.

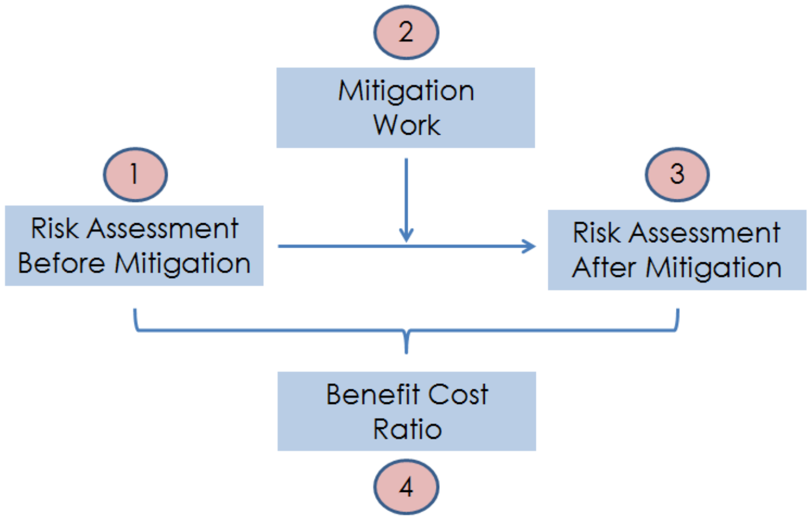


FIGURE 6: COST BENEFIT ANALYSIS FRAMEWORK (ADAPTED FROM MECHLER, 2005)

1. Risk Assessment before mitigation: at this step risk was calculated in terms of conditional loss ($) associated with the existing situation i.e. without any flood protection.
2. Mitigation work: this was the investment ($) to reduce potential impacts assessed in the first step. It was comprised of the costs of conducting the mitigation work i.e. construction of the proposed levee, which consisted of construction and ongoing maintenance costs.
3. Risk Assessment after mitigation: at this step risk was again calculated in terms of conditional loss ($) by incorporating the effects of the mitigation investment and conditional probability of the levee failure. Usually there was a reduction of loss ($) as compared to the before mitigation state. This reduction in loss ($) was considered to be the benefit arising from the investment.
4. Benefit Cost Ratio: finally, economic effectiveness of the mitigation investment was evaluated by comparing benefits and costs. Costs and benefits accumulating over time needed to be discounted to make current and future effects comparable as any money spent or saved today has more value than that realised from expenditure and benefits in the future. This concept is termed Time Value of Money. Thus future values also needed to be discounted by a discount rate representing the loss in value over time. A Benefit Cost Ratio of 1.0 or more suggests the mitigation investment was an economically viable decision.

METHODOLOGY AND RESULTS

For the assessment of direct losses before and after the proposed mitigation initiative, conditional probabilities of levee failure with increasing flood depth were used to replicate the capacity of the proposed levee. The assessed likelihood of failure due to overtopping of the proposed levee if subjected to extreme flood loads was also considered. The conditional probabilities after mitigation were based on the assumption that the proposed levee would be able to protect the community up to the 200 ARI event and hence the community will not be affected by floods having an ARI of 200 years or less. Furthermore, it was estimated that there was a 90% chance of protection during the 500 year ARI event based on the freeboard provided on top of the 200 ARI peak flood level. Table 3 shows the adopted conditional probabilities of failure for the proposed levee.

TABLE 3: ADOPTED CONDITIONAL PROBABLITY OF FAILURE FOR THE PROPOSED LEVEE

ARI (years)	Conditional Probability of Failure/Overtopping of the Proposed Levee
100,000	100%
1,000	100%
500	10%
200	0%
100	0%
50	0%
20	0%

AFFECTED POPULATION

Table 4 presents the number of affected residential properties with inundation above ground floor level for selected ARIs. The number of people before and after mitigation work that would be displaced due to inundation of homes for each hazard event was based on the number of affected properties, the conditional probability of failure of the levee (Table 3) and an average household size of 2.3 as determined from the census data (ABS, 2011).

TABLE 4: ESTIMATED AFFECTED NUMBER OF PEOPLE IN RESIDENTIAL SECTOR

ARI (Years)	Annual Probability of Exceedance	Number of affected residential properties	Number of Affected People – Before Mitigation	Number of Affected People – After Mitigation
100,000	0.00001	234	538	538
1,000	0.001	14	32	32
500	0.002	11	25	3
200	0.005	0	0	0
100	0.01	0	0	0
50	0.02	0	0	0
20	0.05	0	0	0

Table 5 presents the average number of days for which alternative accommodation was required for the affected population in the residential sector. These values were also used to estimate the rental income loss for the proportion of rented properties.

TABLE 5: AVERAGE DURATION OF INTERRUPTION TO RESIDENTIAL SECTOR (CANTERFORD, 2016)

Flood Depth Above Floor Level (m)	Average Number of Days
0.01 to 0.15	41
0.16 to 0.70	56
0.71 to 1.20	92
1.20 to 2.40	106
2.41 and more	205

TANGIBLE LOSSES

The tangible losses were comprised of the building repair cost, loss of contents, rental income loss and cost of clean-up.

Building Repair Cost

The building repair cost was estimated at building level by using appropriate vulnerability models from the suite of 29 building vulnerability models developed by GA presented in the Appendix B. Each building (272 in total) was assigned an appropriate vulnerability model based on the building attributes such as the type of foundation, wall material, age, number of storeys and usage. Losses to ancillary structures such as fences, swimming pools, garden sheds and detached garages were not considered.

The unit replacement rates for each GA vulnerability model were updated to account for change in location and inflation by using Construction Price Indices (Rawlinsons, 2017). The ground floor area for each building was provided by the LCC.

The Damage Index (ratio of repair cost to replacement cost) was then assessed for each building in the study area for each hazard event ranging from the 20 year ARI up to the PMF based on the inundation depth above ground floor level.

The total building repair cost (*Lbr*) for each hazard event was calculated as the summation of the product of the Damage Index, the updated unit replacement rate, the number of storeys and the ground floor area of each affected building as shown in Equation (1):-

$$Lbr = \sum_{i=1}^{n}(Ground\ Floor\ Area\ x\ Number\ of\ Storeys\ x\ Replacement\ Rate\ x\ Damage\ Index) \quad (1)$$

Table 6 presents the total potential cost of building repair for each hazard event which was the expected loss without any flood protection system. The conditional loss for each hazard event was then assessed by using potential loss and conditional probabilities of failure of the proposed levee (after mitigation investment) as presented in the Table 3.

Finally, the Average Annual Loss (AAL) was assessed based on the conditional losses and the probabilities of occurrence of the hazard events. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to the building repair cost by $2.52 thousand as shown in Table 6.

TABLE 6: ESTIMATED BUILDING REPAIR COST

ARI (Years)	Potential Loss ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	56,565	56,565	56,565	32.71	30.19
1,000	1,925	1,925	1,925		
500	1,368	1,368	137		
200	14	14	0		
100	0	0	0		
50	0	0	0		
20	0	0	0		

Loss of Contents

In a similar approach as used to estimate the building repair cost, the loss of contents in the residential sector was estimated for each affected building by using a selection from the 11 vulnerability models developed by GA. Each residential building (264 in total) was assigned an appropriate content vulnerability model based on the building typology. Building contents were defined here as occupants' belongings that might be removed from the house. Items such as kitchen built-in appliances, window furnishings and floor coverings were considered part of the building fabric and hence included in building repair costs above.

The unit replacement rates for each GA content vulnerability model to assess the contents replacement cost were updated to account for location and inflation. The Damage Index was then assessed for each residential building by using GA's contents vulnerability models for each hazard event.

The total loss of contents (*Lc*) for each hazard event was calculated as the summation of the product of the Damage Index, the updated unit replacement rate, the number of storeys and the ground floor area of each affected residential building as shown in Equation (2):-

$$Lc = \sum_{i=1}^{n}(Ground\ Floor\ Area\ x\ Number\ of\ Storeys\ x\ Replacement\ Rate\ x\ Damage\ Index) \quad (2)$$

Table 7 presents the total potential and conditional loss of contents for each hazard event along with the AAL before and after mitigation. It was estimated that the mitigation investment in the proposed levee reduced the AAL to the residential contents by $0.57 thousand.

TABLE 7: ESTIMATED LOSS OF RESIDENTIAL CONTENTS

ARI (Years)	Potential Loss ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	13,911	13,911	13,911	7.98	7.41
1,000	467	467	467		
500	313	313	31		
200	0	0	0		
100	0	0	0		
50	0	0	0		
20	0	0	0		

Loss of Rental Income

The loss of rental income was estimated for the rented residential properties which could not be rented out due to the disruption and damage caused by the floods. The proportion of rental properties was assessed to be 36.7% of total privately occupied residential buildings by using census data (ABS, 2011). Similarly the average weekly rent was assessed to be $238 per property for Newstead. The duration of disruption or the time the properties could not be rented out was considered to be dependent on the severity of the flood which was measured as the inundation depth above ground floor. The duration of disruption for six categories of flood severity (or inundation depths) has been presented earlier in Table 5.

The loss of rental income (*Lren*) for each hazard event was assessed as the summation of the product of the duration of disruption and the average rent of each affected rented property, as shown in Equation (3):-

$$Lren = \sum_{i=1}^{n}(Duration\ of\ Disruption\ x\ Average\ Rent) \quad (3)$$

Table 8 presents the total potential and conditional loss of rental income for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the proposed levee reduced the AAL to the rental income by $0.01 thousand as shown in Table 8.

TABLE 8: ESTIMATED LOSS OF RENTAL INCOME (RESIDENTIAL SECTOR)

ARI (Years)	Potential Loss ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	284	284	284	0.16	0.15
1,000	9	9	9		
500	6	6	1		
200	0	0	0		
100	0	0	0		
50	0	0	0		
20	0	0	0		

Cost of Clean-up

The cost of clean-up was estimated for the residential and non-residential properties by using per unit area clean-up cost recorded by the Bundaberg Regional Council during the 2013 Bundaberg floods. The average clean-up costs during the Bundaberg floods for exposed residential, commercial, industrial and institutions sectors were reported to be $5.12, $1.52, $1.30 and $3.28 per square meter, respectively (Honor, 2017). The total ground floor area affected by each hazard event for each sector was calculated by overlaying the flood footprint of each event on the building footprints.

The cost of clean-up (*Lcl*) for each hazard event for each sector was assessed as the summation of the product of ground floor area of each affected building and the average clean-up cost per unit area, as shown in Equation (4):-

$$Lcl = \sum_{i=1}^{n}(Ground\ Floor\ Area\ x\ Clean\ up\ Cost\ per\ unit\ area) \quad (4)$$

Table 9 presents the potential and conditional clean-up costs for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to clean-up by $0.03 thousand.

TABLE 9: ESTIMATED COST OF CLEAN-UP (RESIDENTIAL SECTOR)

ARI (Years)	Total Floor Area (m²)	Total Potential Loss ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
			Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	62,132	279	279	279	0.19	0.16
1,000	4,010	21	21	21		
500	3,376	17	17	2		
200	0	0	0	0		
100	0	0	0	0		
50	0	0	0	0		
20	0	0	0	0		

Total Tangible Losses

The tangible losses (*Ltan*) were contributed by the building repair cost (*Lbr*), loss of contents (*Lc*), rental income loss (*Lren*) and clean-up cost (*Lcl*), as shown in Equation (5):-

$$Ltan = Lbr + Lc + Lren + Lcl \quad (5)$$

Table 10 and Table 11 present the estimated conditional tangible losses before and after mitigation (i.e. the construction of the proposed levee), respectively. It was estimated that the mitigation investment in the proposed levee reduced the tangible AAL by $3.13 thousand.

TABLE 10: ESTIMATED TANGIBLE LOSS ($) - BEFORE MITIGATION

ARI (Years)	Annual Probability of Exceedance	Building Repair Cost ($ 000s)	Contents Loss ($ 000s)	Rental Income Loss ($ 000s)	Clean-up Cost ($ 000s)	Total ($ 000s)	Average Annual Loss ($ 000s)
100,000	0.00001	56,565	13,911	284	279	71,039	41.04
1,000	0.001	1,925	467	9	21	2,421	
500	0.002	1,368	313	6	17	1,705	
200	0.005	0	0	0	0	0	
100	0.01	0	0	0	0	0	
50	0.02	0	0	0	0	0	
20	0.05	0	0	0	0	0	

TABLE 11: ESTIMATED TANGIBLE LOSS ($) - AFTER PROPOSED LEVEE

ARI (Years)	Annual Probability of Exceedance	Building Repair Cost ($ 000s)	Contents Loss ($ 000s)	Rental Income Loss ($ 000s)	Clean-up Cost ($ 000s)	Total ($ 000s)	Average Annual Loss ($ 000s)
100,000	0.00001	56,565	13,911	284	279	71,039	37.91
1,000	0.001	1,925	467	9	21	2,421	
500	0.002	137	31	1	2	171	
200	0.005	0	0	0	0	0	
100	0.01	0	0	0	0	0	
50	0.02	0	0	0	0	0	
20	0.05	0	0	0	0	0	

Figure 7 and Figure 8 show the spatial distribution of potential loss of contents and cost of building repair for each property in each hazard event without any flood protection.

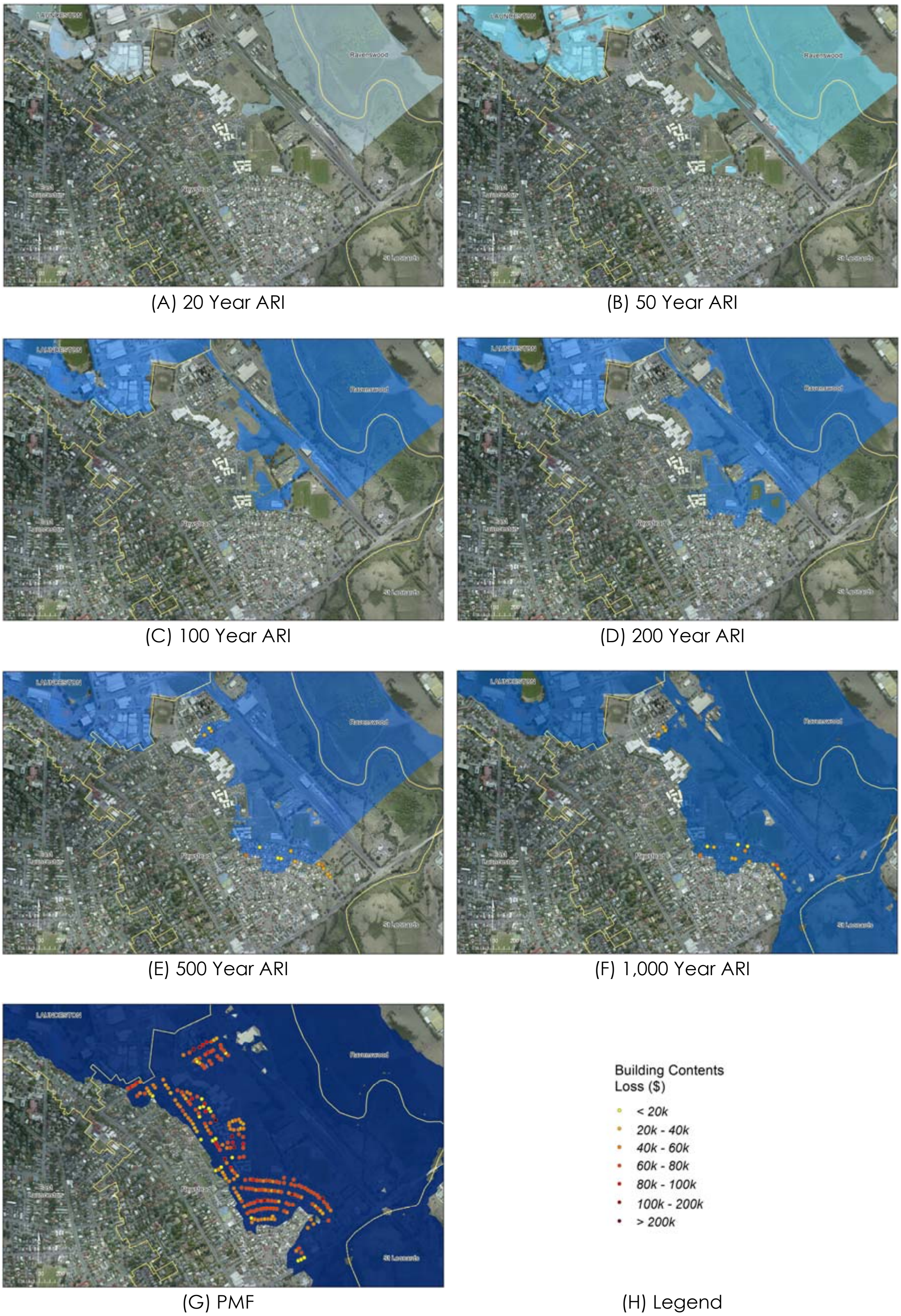


FIGURE 7: POTENTIAL LOSS OF CONTENTS FOR THE RESIDENTIAL SECTOR WITHOUT FLOOD PROTECTION

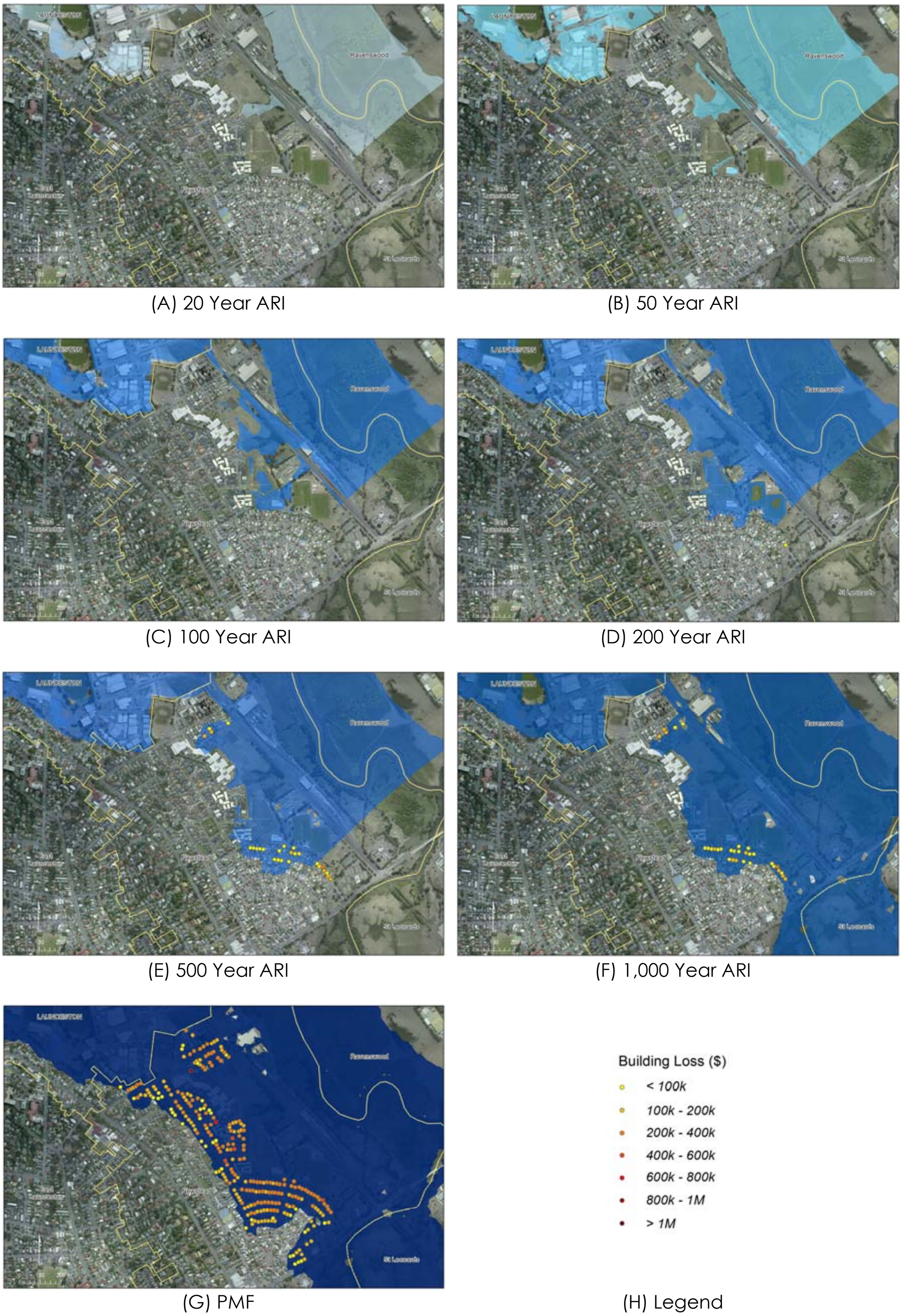


FIGURE 8: POTENTIAL BUILDING REPAIR COSTS WITHOUT FLOOD PROTECTION

INTANGIBLE LOSSES

The intangible losses (except the cost of fatalities) were assessed by the WTP assessed by Gibson (2017) for the affected residents of Newstead to minimise the impacts of floods on the wellbeing of the community and environment.

Fatalities (Physical Health)

The number and cost of fatalities was estimated at midnight as the worst case scenario when the entire population in the study area was assumed to be at home and exposed to the potential danger of flooding. Table 4 presents the exposed population for each hazard event.

The number of fatalities was estimated by using the fatality rate functions developed by Jonkman (2007). The fatality rate is defined as the probability of a person dying in a house due to an inundation depth of *h* meters. The functions were developed for three different zones due to breaching of flood defences for two rise rates as shown in Figure 9.

For this study the fatality rate function described in Figure 9 as the remaining zone was selected to assess the fatality rate in slow rising condition (rise rate is less than 0.5m/h) where the product of flood depth and velocity (*hv*) was assumed to be less than $7 m^2/s$.

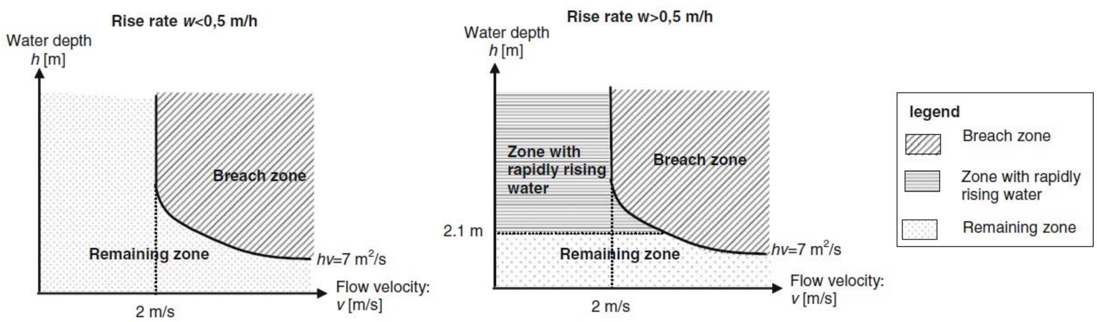


Figure 9: AREA OF APPLICATION OF FATALITY FUNCTIONS (JONKMAN ET AL., 2007)

The fatality rate selected is given by Equation (6):-

$$Fatality\ Rate = \varphi\left(\frac{(\ln(h) - \mu)}{\sigma}\right) \quad (6)$$

μ=7.60, σ=2.75 (sourced from Jonkman et al., 2007)

Where *h* was inundation depth (in metres), μ was the mean of the normal distribution, σ was the standard deviation of the normal distribution and φ was the cumulative normal distribution function.

The fatality rate was based on the median inundation depth for all the affected residential properties. The fatality rate is negligible for all the hazard events up to the 1,000 year ARI due to very shallow inundation depths above ground floor. The median inundation depth for the PMF was assessed to be 1.29m which resulted in the fatality rate of 0.0038.

The value of a statistical life was assessed in 2016 dollar values to be $4.3 million for the first two age categories and $2.8 million for the third age category. This figure was based on Abelson (2007) and was updated for inflation.

Finally, the total cost of fatalities (*Lf*) for each hazard event was assessed as the summation of the product of number of persons affected, the fatality rate and the value of a statistical life for each age category, as shown in Equation (7):-

$$Lf = \sum_{i=1}^{n}(Number\ of\ Affected\ People\ x\ Fatality\ Rate\ x\ Value\ of\ Life) \quad (7)$$

Table 12 presents the number and cost of fatalities for each hazard event along with the AAL before and after the proposed mitigation. It was estimated that the mitigation investment in the proposed levee would not reduce the AAL due to fatalities as there is no additional benefit associated with the levee construction and fatality reduction.

TABLE 12: ESTIMATED COST OF FATALITIES BEFORE AND AFTER MITIGATION (RESIDENTIAL SECTOR)

ARI (Years)	Conditional Number of Affected people		Fatality Rate	Total Fatalities		$ Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	538	538	0.0038	0.80	0.80	3,384	3,384	1.67	1.67
1,000	32	32	0	0	0	0	0		
500	25	3	0	0	0	0	0		
200	0	0	0	0	0	0	0		
100	0	0	0	0	0	0	0		
50	0	0	0	0	0	0	0		
20	0	0	0	0	0	0	0		

Mental Health (Stress and Anxiety)

The psychological effects from floods can be extensive and long lasting. Gibson (2017) provided a methodology to assess the impacts of floods on mental health of the community in Newstead. To estimate the mental health value from building a flood levee in Newstead following information was required:

- The change in mental health benefits of avoiding flood damage,
- The number of people affected,
- The length of time the mental health change persists for, and,
- The value of a quality adjusted life year (QALY).

A health status survey conducted by the Queensland Government after the 2011 floods (a 100 year ARI event) was used to estimate the likely change in mental health from flooding in Newstead (Queensland Government, 2011). The Queensland Government (2011) report used the EQ-5D scores developed by the European Quality of Life Group which had been validated internationally, to assess health quality of life across five dimensions (mobility, self-care, usual activities, pain/discomfort and anxiety/depression) with respondents ranking their current health state on a three point scale (no problems, some problems, or severe problems). EQ5D measures were then converted into a score ranging from 0-1, where 1 was full health and zero represented death: effectively defining a Quality Adjusted Life Year (QALY). The EQ-5D score for the population affected by the flood was 0.03 less than those not affected by the flood i.e. having one's home or income generating property affected by flood lead to a 0.03 point reduction in quality of life due to mental distress.

The Queensland government (2011) also provided evidence on the length of time the mental health impact persists: the survey was conducted up to 5 months after the event. This was a conservative estimate of the time of persistence, since other studies indicated that mental health impacts could last up to several years. For example, Bryant et al. (2014) reported that a minority of people in the high-affected communities of the Black Saturday Victorian bushfires reported persistent Post-traumatic Stress Disorder (PTSD), depression and psychological distress several years after the event.

Shiroiwa et al. (2010) examined the WTP for QALY in a number of countries, including Australia, reported the WTP for an Australian QALY to be $64,000 in 2007 dollar values. Based on this study, the CPI adjusted Australian average QALY was assessed to be $79,376.

The WTP to avoid a mental health affect from the flood (WTP_{MH}) was calculated as the change in EQ-5D between the affected and unaffected population (ΔEQ5D) multiplied by the willingness to pay for a change in QALY for the 5 month time period (WTP_{QALY} x $T_{MHaffect}$), as presented in Equation (8):-

$$WTP_{MH} = \Delta EQ5D \times (WTP_{QALY} \times T_{MH\ affect}) \quad (8)$$

For the figures presented above, this calculation would generate a value of $1,000 per person, as presented in Equation (9):-

$$WTP_{MH} = 0.03 \times (79{,}376 \times 0.42) = \$1{,}000 \quad (9)$$

Table 13 presents the estimated cost of impact of flooding on the mental health of the affected population for each hazard event. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to mental health by $0.05 thousand.

TABLE 13: ESTIMATED COST OF MENTAL HEALTH

ARI (Years)	Number of Affected People		Willingness to Pay ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	538	538	1	538	538	0.35	0.30
1,000	32	32	1	32	32		
500	25	3	1	25	3		
200	0	0	1	0	0		
100	0	0	1	0	0		
50	0	0	1	0	0		
20	0	0	1	0	0		

Social Disruption

Three types of social disruptions were examined for different flood events i.e. disruption caused by electricity outage, traffic delays and displacement of people.

Electricity Outage

It was assumed that electric power supply would be disrupted in the case of flooding above ground floor level. Hensher et al. (2014) used a survey of Canberra residents to estimate of residential customers' WTP to avoid an electricity outage (per customer, per outage event). The WTP estimate to avoid a 24 hour electricity outage was found to be $104 in 2016 dollars.

Table 14 presents the estimated cost of impact of flooding on the social disruption caused by electricity outage for each hazard event. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to social disruption caused by electricity outage by $0.01 thousand.

TABLE 14: ESTIMATED COST OF SOCIAL DISRUPTION - ELECTRICITY OUTAGE

ARI (Years)	Number of Affected People		Willingness to Pay ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	538	538	0.104	56	56	0.04	0.03
1,000	32	32	0.104	3	3		
500	25	3	0.104	3	0		
200	0	0	0.104	0	0		
100	0	0	0.104	0	0		
50	0	0	0.104	0	0		
20	0	0	0.104	0	0		

Road Traffic Delay

Two of the most important values obtained from travel demand studies were the value of travel time and the value of travel time reliability. The former linked the monetary values travelers (or consumers) placed on reducing their travel time (i.e. savings). The latter connected the monetary values travelers placed on improving the predictability (i.e. reducing the variability) of their travel time.

Li et al. (2010) provided estimates from an Australian study in 2008. In 2016 dollars, the value of expected schedule delay late (ESDL) was $46.19 per hour and the mean of value of travel time saving (VTTS) was $35.70 per hour.

Table 15 presents the estimated cost of impact of flooding on the social disruption caused by one day of traffic delay for each hazard event. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to social disruption caused by traffic delay by $0.1 thousand.

TABLE 15: ESTIMATED COST OF SOCIAL DISRUPTION - TRAFFIC DELAY

ARI (Years)	Number of Affected People		Willingness to Pay ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	538	538	2	1,057	1,057	0.69	0.59
1,000	32	32	2	63	63		
500	25	3	2	50	5		
200	0	0	2	0	0		
100	0	0	2	0	0		
50	0	0	2	0	0		
20	0	0	2	0	0		

Displacement of People

The WTP estimate to return home by individuals was based on Laundry et al. (2007) study following hurricane Katrina. The WTP to avoid displacement was assessed to be $7,083 per household per year in 2016 dollars. GA survey data from 2011 Queensland floods provided estimates for the average number of days of a household to return home for selected categories of the inundation depth (see Table 5). Table 16 provides the aggregate WTP estimate to avoid displacement for each ARI and the number of affected properties with above ground floor inundation.

Table 17 presents the estimated cost of flooding on the social disruption caused by displacement for each hazard event. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to social disruption caused by displacement by $0.02 thousand.

TABLE 16: ESTIMATED NUMBER OF AFFECTED RESIDENTIAL PROPERTIES

Flood Depth Above Floor Level (m)	Average Number of Days	Willingness to Pay ($ 000s)	Number of Affected Properties						
			PMF	1,000 year ARI	500 year ARI	200 year ARI	100 year ARI	50 year ARI	20 year ARI
0.01 to 0.15	41	0.8	6	6	7	0	0	0	0
0.16 to 0.70	56	1.6	44	7	4	0	0	0	0
0.71 to 1.20	92	1.8	45	1	0	0	0	0	0
1.20 to 2.40	106	2.1	127	0	0	0	0	0	0
2.41 and more	205	3.9	12	0	0	0	0	0	0
Total			234	14	11	0	0	0	0

TABLE 17: ESTIMATED COST OF SOCIAL DISRUPTION - DISPLACEMENT

ARI (Years)	Number of Affected Properties		Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	234	234	464	464	0.27	0.25
1,000	14	14	18	18		
500	11	1	12	1		
200	0	0	0	0		
100	0	0	0	0		
50	0	0	0	0		
20	0	0	0	0		

Amenity

Amenity relates to the values associated with the aesthetics of an area. In the event of a flood, debris and pollutants are likely to enter the river system and temporarily degrade the amenity value of the area for residents and recreational users. Ambrey and Fleming (2011) used a scenic amenity scale where individuals in Southeast Queensland rated preferred scenery on a scale from 1 to 10, and were then asked how much they were willing to pay per unit improvement on the scale. Households were willing to pay $15,655 per year for a one unit improvement on the amenity scale (in 2016 dollars). These values could similarly reflect a WTP to avoid a decrease in amenity for each unit on the scale.

It was not possible to exactly match the scenery and unit descriptions from Ambrey and Fleming (2011) to the magnitude of amenity change in Newstead during a flood event. However, by following a conservative approach it was assumed that amenity values were unlikely to be affected significantly for flood events ranging from 20 year ARI to 200 year ARI. For the rarer events, the WTP to avoid impact on amenity was taken to be $15,655 per household.

Table 18 presents the estimated cost of flooding on the amenity of the affected area for each hazard event before and after the proposed mitigation. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to amenity by $0.32 thousand.

TABLE 18: ESTIMATED COST OF AMENITY

ARI (Years)	Number of Affected Properties		Willingness to Pay ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	234	234	16	3,663	3,663	2.38	2.06
1,000	14	14	16	219	219		
500	11	0	16	172	17		
200	0	0	16	0	0		
100	0	0	16	0	0		
50	0	0	16	0	0		
20	0	0	16	0	0		

Safety

Safety values relate to risks associated with living in or close to a flood prone area. These are typically measured using hedonic pricing methods which reflect the premium paid for houses built outside of such areas. Rajapaksa (2015) investigated the difference in property prices in Brisbane following the 2011 flood event, and determined that houses located within the flood zone were worth 6% less for low median income suburbs and 7% less for high median income suburbs. However, there could also be other contributing factors which influence the real estate value. Using the conservative estimate for low income suburbs, the WTP for safety could be estimated by multiplying the 6% figure against the mean sale price of housing in the Newstead area (taken to be $250,000), which equated to $15,000.

Table 19 presents the estimated cost of flooding on the safety of the community for each hazard event before and after the proposed mitigation. It was estimated that the mitigation investment in the proposed levee reduced the AAL due to safety by $0.30 thousand.

TABLE 19: ESTIMATED COST OF SAFETY

ARI (Years)	Number of Affected Properties		Willingness to Pay ($ 000s)	Conditional Loss ($ 000s)		Average Annual Loss ($ 000s)	
	Before Mitigation	After Mitigation		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	234	234	15	3,510	3,510	2.28	1.98
1,000	14	14	15	210	210		
500	11	0	15	165	17		
200	0	0	15	0	0		
100	0	0	15	0	0		
50	0	0	15	0	0		
20	0	0	15	0	0		

Ecosystems

The North Esk River and its riparian corridor provides habitat for a number of flora and fauna species, including threatened species and non-threatened native fish, as well as the platypus. The North Esk River is a known migration route for the Australian grayling (Prototroctes maraena) which is listed as vulnerable under both State and Federal legislation (LCC, 2017).

Hatton-McDonald et al. (2011) estimated the WTP for a 1% improvement in non-threatened native fish population in the Murray River using an Australia-wide sample (including Tasmania). Rolfe et al. (2000) provided the WTP estimate from Brisbane residents for the WTP to maintain endangered species in Desert Uplands in Central Queensland.

However, these WTP values could be not used as the change in impact of flooding before and after the proposed levee could not be assessed.

Water Quality

Flood waters are known to contain contaminants and the presence of faecal contamination in particular is considered to be a significant risk to the community. It was also noticed that the water treatment plant in Newstead would not be protected by the proposed levee based on the current alignment.

However, no suitable studies could be found to provide the WTP estimate to reduce the risk of illness from flood water fecal contamination.

Recreation

There are two soccer grounds that would be protected by the proposed levee. There are nine tennis and netball courts in the suburb but these would not be protected due to the alignment of the levee. However, no suitable studies could be found to provide the WTP estimate to avoid flood impact on recreation facilities. An estimate of the replacement cost of these facilities could be used to provide a proxy measure of non-market value.

Memorability

No suitable studies could be found to provide the WTP estimate to reduce the risk of lost memorabilia from the flood event.

Total Intangible Losses

The total intangible losses (L*int*) were comprised of the cost of fatalities (Lf), cost of mental health (L*mh*), cost of social disruption due to electricity outage (L*sde*), traffic delay (Lsdt) and displacement (Lsdd), amenity cost (Lam) and cost of safety (Lsf), as shown in Equation (10):-

$$Lint = Lf + Lmh + Lsde + Lsdt + Lsdd + Lam + Lsf \qquad (10)$$

Table 20 and Table 21 present the estimated conditional intangible losses before and after construction of the proposed levee, respectively. It was estimated that the mitigation investment reduced the intangible AAL by $0.77 thousand.

TABLE 20: ESTIMATED CONDITIONAL INTANGIBLE LOSS ($) - BEFORE MITIGATION

ARI (Year)	Annual Probability of Exceedance	Fatalities ($ 000s)	Mental Health ($ 000s)	Social Disruption – Electricity Outage ($ 000s)	Social Disruption – Traffic Delay ($ 000s)	Social Disruption – Displacement ($ 000s)	Amenity ($ 000s)	Safety ($ 000s)	Total ($ 000s)	Average Annual Loss – Before Mitigation ($ 000s)
100,000	0.00001	3,384	538	56	1,058	464	3,663	3,510	12,673	7.67
1,000	0.001	0	32	4	63	18	219	210	546	
500	0.002	0	25	3	50	12	172	165	427	
200	0.005	0	0	0	0	0	0	0	0	
100	0.01	0	0	0	0	0	0	0	0	
50	0.02	0	0	0	0	0	0	0	0	
20	0.05	0	0	0	0	0	0	0	0	

TABLE 21: ESTIMATED CONDITIONAL INTANGIBLE LOSS ($) - AFTER MITIGATION

ARI (Year)	Annual Probability of Exceedance	Fatalities ($ 000s)	Mental Health ($ 000s)	Social Disruption – Electricity Outage ($ 000s)	Social Disruption – Traffic Delay ($ 000s)	Social Disruption – Displacement ($ 000s)	Amenity ($ 000s)	Safety ($ 000s)	Total ($ 000s)	Average Annual Loss – After Mitigation ($ 000s)
100,000	0.00001	3,384	538	56	1,058	464	3,663	3,510	12,673	6.90
1,000	0.001	0	32	4	63	18	219	210	546	
500	0.002	0	3	0	5	1	17	17	43	
200	0.005	0	0	0	0	0	0	0	0	
100	0.01	0	0	0	0	0	0	0	0	
50	0.02	0	0	0	0	0	0	0	0	
20	0.05	0	0	0	0	0	0	0	0	

LONG-TERM COST

Table 22 presents the estimated total losses (tangible and intangible) before and after construction of the proposed levee. The potential loss is the loss without any flood protection system. The conditional loss is the expected loss with a levee system in place considering the likelihood that the levee would fail in the flood.

Using these conditional losses, the AAL was calculated for both before and after mitigation. It was found that there is a reduction of $3.9 thousand in the AAL which reflects the savings made by the investment in mitigation.

Figure 10 and Figure 11 show the loss exceedance curves for the tangible and intangible losses before and after the proposed mitigation. Figure 12 shows the combined loss exceedance curve for total conditional losses listed in Table 22.

TABLE 22: ESTIMATED TOTAL LOSS ($) BEFORE AND AFTER MITIGATION

ARI (Years)	Annual Probability of Exceedance	Potential Loss ($ 000s)	Conditional Loss – Before Mitigation ($ 000s)	Conditional Loss – After Mitigation ($ 000s)	Average Annual Loss – Before Mitigation ($ 000s)	Average Annual Loss – After Mitigation ($ 000s)
100,000	0.00001	83,712	83,712	83,712	48.71	44.82
1,000	0.001	2,967	2,967	2,967		
500	0.002	2,132	2,132	213		
200	0.005	14	14	0		
100	0.01	0	0	0		
50	0.02	0	0	0		
20	0.05	0	0	0		

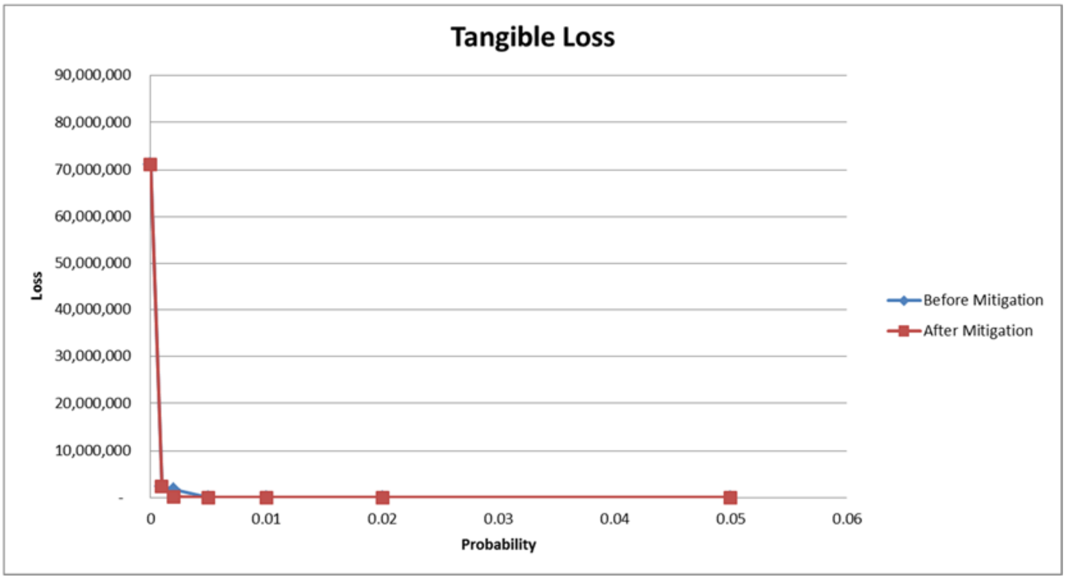


FIGURE 10: LOSS EXCEEDANCE CURVE FOR THE TANGIBLE LOSSES

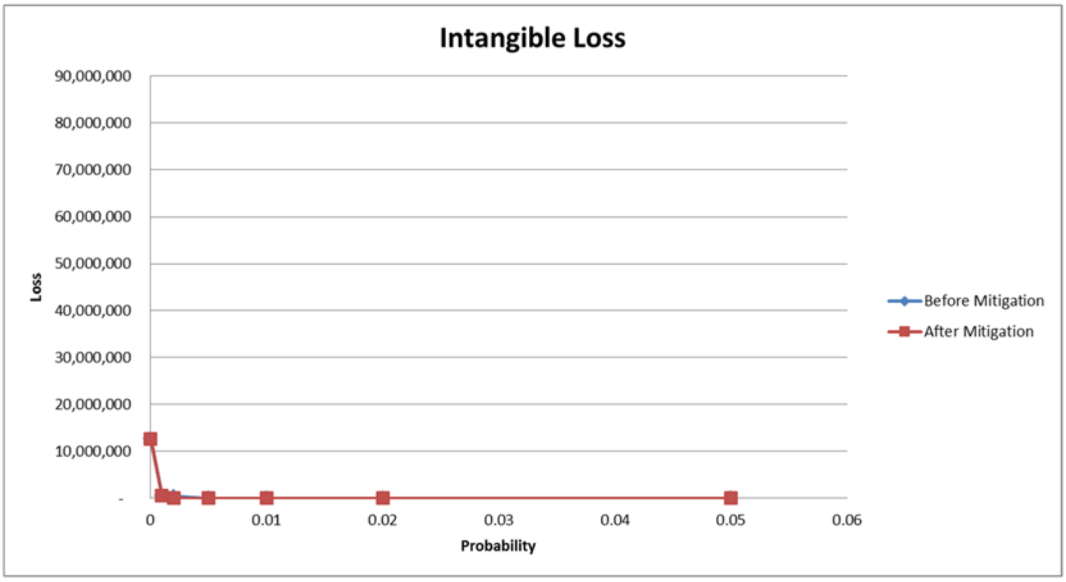


FIGURE 11: LOSS EXCEEDANCE CURVE FOR THE INTANGIBLE LOSSES

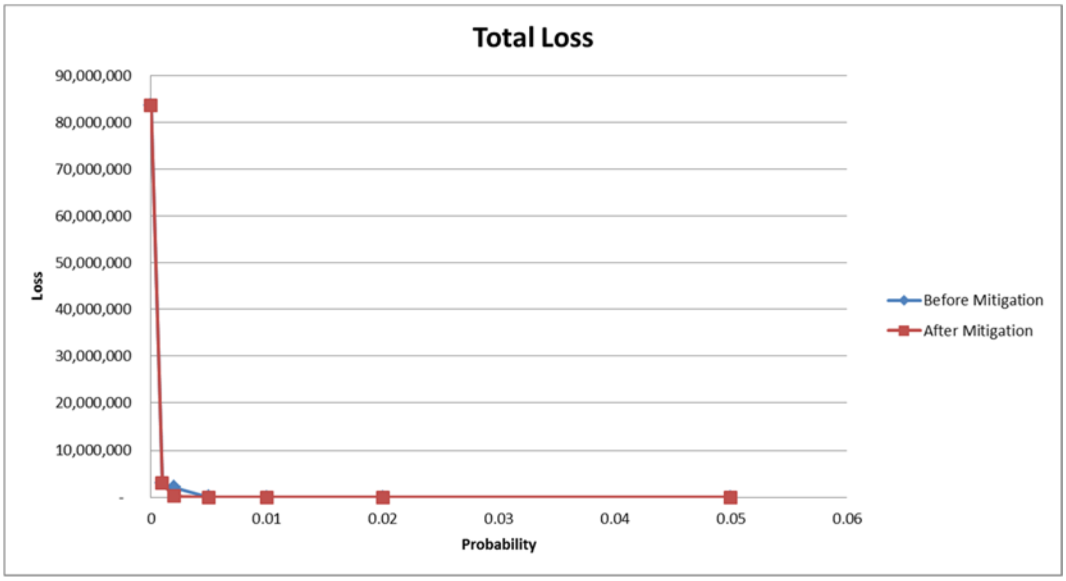


FIGURE 12: LOSS EXCEEDANCE CURVE FOR THE TOTAL LOSSES

OTHER MITIGATION OPTIONS

Outcomes of the flood mitigation project within the BNHCRC were utilised for buildings in Newstead to assess alternative mitigation options. The study represented a preliminary assessment of options to further reduce flood risk by reducing building vulnerability or exposure to flood. The mitigation options (see Figure 13) other than the proposed flood levee include:

- House raising
- House retirement (buy out)
- Temporary flood barrier
- Permanent flood barrier

There were 7 residential properties within the 200 year ARI flood footprint and 41 within the 500 year ARI flood footprint which would have restricted access during these events. Moreover, eleven of these properties would be flooded above finished floor level in the 500 year ARI event as the expected flood level was below the floor levels of other properties in the flood footprint.

House raising would be appropriate for four timber frame residential properties on the Hart Street which were at high risk due to their low ground floor height. The cost of raising these four houses above the PMF level would be approximately $313,000 with no ongoing costs. Table 23 presents the benefits (avoided losses) resulting from raising these four houses. It was estimated that the investment in raising the four houses reduced the AAL by $3.71 thousand.

House retirement (buying out of properties by the Council) would be an alternative strategy for the last five neighboring/adjacent high risk properties on Hart Street that would eliminate future flood risk for them entirely. The cost of buying out these five houses would be approximately $1.25 million with no ongoing costs. Retirement of these houses would provide land which would be available for social, recreational or other purposes bringing benefits to the Council and to the local community. Table 24 presents the benefits (avoided losses) resulting from buying out these five houses. It was estimated that the investment in buying out the five houses reduced the tangible AAL by $4.03 thousand.

Flood barriers (with temporary or permanent) would be the other options and would require ongoing maintenance cost. The cost of temporary flood barrier and permanent flood barrier would be approximately $647,000 and $897,000, respectively. Maintenance cost of temporary and permanent flood barriers would be approximately $10,000 and $2,000 per annum, respectively. Table 25 presents the avoided losses and BCR for the above mentioned mitigation options.

(A) House Raising

(B) Temporary Flood barrier

(C) Permanent Flood barrier

FIGURE 13: EXAMPLES OF OTHER MITIGATION OPTIONS

TABLE 23: ESTIMATED BENEFITS (AVOIDED LOSSES) DUE TO HOUSE RAISING

ARI (Year)	Building Repair Cost ($ 000s)	Contents Loss ($ 000s)	Rental Income Loss ($ 000s)	Clean-up Cost ($ 000s)	Fatalities ($ 000s)	Mental Health ($ 000s)	Social Disruption – Electricity Outage ($ 000s)	Social Disruption – Traffic Delay ($ 000s)	Social Disruption – Displacement ($ 000s)	Amenity ($ 000s)	Safety ($ 000s)	Total ($ 000s)
100,000	1,217	344	10	3	57	9	0.4	18	16	63	60	1,797
1,000	634	190	3	3	0	9	0.4	18	16	63	60	987
500	564	162	3	3	0	9	0.4	18	16	63	60	888
200	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 24: ESTIMATED BENEFITS (AVOIDED LOSSES) DUE TO HOUSE BUY OUT

ARI (Year)	Building Repair Cost ($ 000s)	Contents Loss ($ 000s)	Rental Income Loss ($ 000s)	Clean-up Cost ($ 000s)	Fatalities ($ 000s)	Mental Health ($ 000s)	Social Disruption – Electricity Outage ($ 000s)	Social Disruption – Traffic Delay ($ 000s)	Social Disruption – Displacement ($ 000s)	Amenity ($ 000s)	Safety ($ 000s)	Total ($ 000s)
100,000	1,433	411	13	4	69	12	0.5	22	18	78	75	2,136
1,000	652	190	3	4	0	12	0.5	22	7	78	75	1,043
500	578	162	3	4	0	12	0.5	22	6	78	75	940
200	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0

COST BENEFIT ANALYSIS

In Australia a 7% discount rate has typically been used within government for investment decisions as it represents the longer term opportunity cost of capital. However, for climate change studies discount rates as a low as 3.5% have been used (e.g. in the UK) to assess long-term benefits of adaptation the future climate related impacts (Chigama, 2017). Benefits tend to disappear in economic assessments when high discount rates are used.

For the assessment of the Benefit Cost Ratio (BCR) the project life was considered to be 80 years and five annual discount rates (3% to 7%) were used to assess the sensitivity of the results to the investment capital cost. The estimated investment cost of the proposed levee in Newstead was $580,000 in 2016 dollars. The ongoing maintenance cost was estimated to be $10,000 annually (Fullard, 2016). The benefits were the combination of both tangible and intangible, with the latter strictly not usually added in a CBA.

The investment and maintenance costs of other flood mitigation options (house raising, house buy out, temporary and permanent flood barriers) is presented in Table 25.

The CBA shows that the BCR remained less than 1.0 for all the discounted rates from 3% to 7% (see Table 25). This is because the mitigation investment costs are far greater than the discounted avoided losses which are realised only in flood events with more than 200 year ARI. However, the BCR improved slightly for house raising option but still found not to be a cost-effective strategy.

TABLE 25: COST BENEFIT ANALYSIS FOR SELECTED DISCOUNT RATES

Mitigation Option	Initial Investment Cost (2016 $000s)	Maintenance Cost (2016 $000s)					Avoided Losses (2016 $000s)					Benefit Cost Ratio (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
Permanent: New Levee	580	302	239	196	165	142	118	93	76	64	55	0.13	0.11	0.10	0.09	0.08
Permanent: House Raising	313	-	-	-	-	-	112	89	73	61	53	0.36	0.28	0.23	0.20	0.17
Permanent: House Buy-out	1,250	-	-	-	-	-	122	96	79	67	57	0.10	0.08	0.06	0.05	0.05
Temporary: Barrier 0.9m high	647	302	239	196	165	142	118	93	76	64	55	0.12	0.11	0.09	0.08	0.07
Permanent: Barrier 1.5m high	897	60	48	39	33	28	118	93	76	64	55	0.12	0.10	0.08	0.07	0.06

DISCUSSION

CBA is a tool that is commonly used to estimate the economic effectiveness of a given project by comprehending the costs and benefits of the investment. The cost-effectiveness of a flood risk mitigation measure depends upon a number of factors. These include the frequency and severity of flood hazard in the area of interest, the type and value of elements exposed to the hazard, the degree to which the communities are impacted and the cost of the mitigation measure (White and Rorick, 2010).

Not all forms of impact can be practically quantified and incorporated into a CBA. However, an effort was made to quantify not only the tangible but also the intangible impacts of flooding in Newstead. Strictly, in economic terms, the quantified intangible impacts are not additional to the direct financial losses quantified in this study. However, these are taken into account only to explore broader benefits.

This study has assessed the tangible impacts of floods of varying severity to the residential and non-residential sector at building level. It included estimates of building repair cost, loss of building contents, loss of rental income and cost of clean-up cost. Moreover, the intangible losses quantified in this study included the impact of flooding on the physical health, mental health, social disruption, amenity and safety of the community in Newstead.

The BCR would be increased by taking into account other costs to infrastructure, storm water and sewage systems, and damage to vehicles. Furthermore, indirect costs such as the cost of emergency services response and other indirect economic costs could also be included to make this analysis more comprehensive. However, lack of data has precluded the inclusion of these costs into the analysis.

The benefit of increased land utility and value as experienced in Launceston could also be considered in assessing the effectiveness of such a measure, though the latter may not be realised by the community as a whole and can lead to increased risk due to increased human exposure in a large flood event which overtops the new levee.

Feedback has been received from the Launceston Flood Authority on the outcomes of this study. Its view is that the humanitarian and mitigation needs of the residents and businesses of Newstead are the same as those in other parts of Launceston. For this reason the Newstead and the Launceston Flood Protection System should be considered as a whole, which would result in a more positive BCR conclusion for Newstead.

FINDINGS

Key findings of this study are summarised below:

- This preliminary research indicates that none of the mitigation options (house raising, house retirement, flood barriers or a new levee) are shown to be cost-effective based solely on the economics of avoided losses. This is because the mitigation investment is far greater than the discounted avoided losses. However, there could be other social and political reasons that may provide justification for these options. For example, retirement of houses would provide land which would be available for social, recreational or other purposes bringing benefits to the Council and to the local community.
- Raising four high risk properties on the Hart Street is found to be an alternative strategy with the greatest BCR, though still economically unviable.
- Temporary mitigation options such as placing flood barriers only prior to forecast flooding (if they can be sourced and placed at short notice) could be a solution. Moreover, opportunities could be explored for a centralised facility in Tasmania to store the temporary barriers which would be transported and placed in other catchments at short notice to maximise the use and benefits of the investment.
- The above Newstead study is of a preliminary nature which has illustrated the utility of the BNHCRC research. More detailed investigation of the costs and the benefits resulting from different mitigation strategies is recommended to enable a final assessment of the most cost-effective option.
- It is noted that if the Newstead mitigation works were considered as part of the combined Launceston levee upgrade, instead of in isolation, the overall BCR would be positive.

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- Flood hazard maps for 20 to 500 year ARIs,
- Building floor height data,
- Flood levee heights,
- Tamar River discharge and flood level map,
- June 2016 flood investigation report,
- History of flooding in Launceston,
- Previous studies conducted by GHD (2006) and Frontiers (2006), and
- Trevallyn flood frequency review conducted by Hydro Tasmania (2008).

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The authors thank BMT WBM for providing the River Tamar and North Esk River flood study report and developing flood hazard maps for the 1,000 year ARI and the PMF events.

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REFERENCES

Abelson, P. 2007. Establishing a monetary value of lives saved: issues and controversies. Proc. Delivering better quality regulatory proposals through better cost-benefit analysis. Department of Finance and Deregulation. Australia.

ABS. 2006. Australian and New Zealand Standard Industrial Classification. Australian Bureau of Statistics. www.abs.gov.au.

ABS. 2011. Cenus- counting dwellings, population, age, place of enumeration. Australian Bureau of Statistics. www.abs.gov.au.

Ambrey, C.L. and Fleming, C.M. 2011. Valuing scenic amenity using life satisfaction data. *Ecological Economics*. **72**, 106-115.

BMT WBM. 2016. Tamar river extreme event flood height contours. BMT WBM Pty Ltd. Melbourne.

BNHCRC. 2017a. Cost-effective mitigation strategy development for flood prone buildings. http://www.bnhcrc.com.au/research/resilient-people-infrastructure-and-institutions/243.

BNHCRC. 2017b. Cost-effective mitigation strategy development for building related earthquake risk. http://www.bnhcrc.com.au/research/resilient-people-infrastructure-and-institutions/244.

Bryant, R.A., Waters, E., Gibbs, L., Gallagher, H.C., Pattison, P., Lusher, D., MacDougall, C., Harms, L., Block, K., Snowdon, E., Sinnott, V., Ireton, G., Richardson, J. and Forbes, D. 2014. Psychological outcomes following the Victorian Black Saturday bushfires. *Australian & New Zealand Journal of Psychiatry*. **48**, 634–643

Canterford, S. 2016. Personal communication: estimated time out of home based on household survey conducted by Geoscience Australia in Brisbane and Ipswich. 8 November 2016.

Chigama, F. 2017. Personal communication: Discount rates used in the UK for climate change studies. Launceston City Council, Launceston, Australia. 27 February 2017.

Hatton-MacDonald, D. and Morrison, M.D. 2010. Valuing biodiversity using habitat types. *Australasian Journal of Environmental Management*. **17**, 235-243.

Haynes, K., Coates, L., Dimer de Oliveira, F., Gissing, A., Bird, D., van den Honert, R., Radford, D., D'Arcy, R, Smith, C. 2016. An analysis of human fatalities from floods in Australia 1900-2015. Report for the Bushfire and Natural Hazards CRC. May 2016.

Hensher, D., Shore, N. and Train, K. 2014. Willingness to pay for residential electricity supply quality and reliability. *Applied Energy*. **115**, 280-292.

Honor, D. 2017. Personal communication: cost of clean-up due to 2013 Bundaberg floods. 4 January 2017.

Hydro Tasmania. 2008. River Tamar & North Esk River Flood Study, Final report. BMT WBM Pty Ltd. Melbourne, Australia.

Frontier. 2006. Flood risk mitigation in the Invermay floodplain. Frontier Economics Pty Ltd. Melbourne. Australia.

Fullard, A. 2013. Launceston - a city on a floodplain protecting Launceston from a 1 in 200 ARI flood. Floodplain Management Association National Conference; 19pp.

Fullard, A. 2016. Personal communication: Initial cost of new levee construction and ongoing maintenance costs. 6 February 2016.

GA. 2017. National Exposure Information System (NEXIS). Geoscience Australia. Canberra. http://www.ga.gov.au/scientific-topics/hazards/ risk-impact/nexis.

Gibson, F. 2017. Benefit transfer data for BCA of flood levee for Newstead. Centre for Environmental Economics & Policy. University of Western Australia.

GHD. 2006. Invermay floodplain: a social, economic, Infrastructure and risk evaluation study. GHD Pty Ltd.

Jonkman, S. 2007. Loss of life estimation in flood risk assessment - theory and applications. PhD dissertation, Technical University of Delft, The Netherlands.

LCC. 2011. Tamar River flood water surface profiles for multiple discharge emergency management flood level map. Launceston City Council. Tasmania.

LCC. 2017. Personal communication: Impacts of floods on ecosystem and environment in Newstead. Launceston City Council. Tasmania. 2 June 2017.

Mechler, R. 2005. Cost-benefit analysis of natural disaster risk management in developing countries. GTZ GmbH. Commissioned by the Federal Ministry for Economic Cooperation and Development, Germany.

Queensland Government. 2011. Self-reported Health Status 2011: Natural disasters and health. Queensland Health.

Rajapaksa, D.P. 2015. Floods and Property Values: A Hedonic Property and Efficiency Analysis. PhD Thesis. School of Economics and Finance, Faculty of Business, Queensland University of Technology. Australia.

Rawlinsons. 2017. Australian Construction Handbook. Edition 35. Rawlinsons Publishing. Perth, Australia.

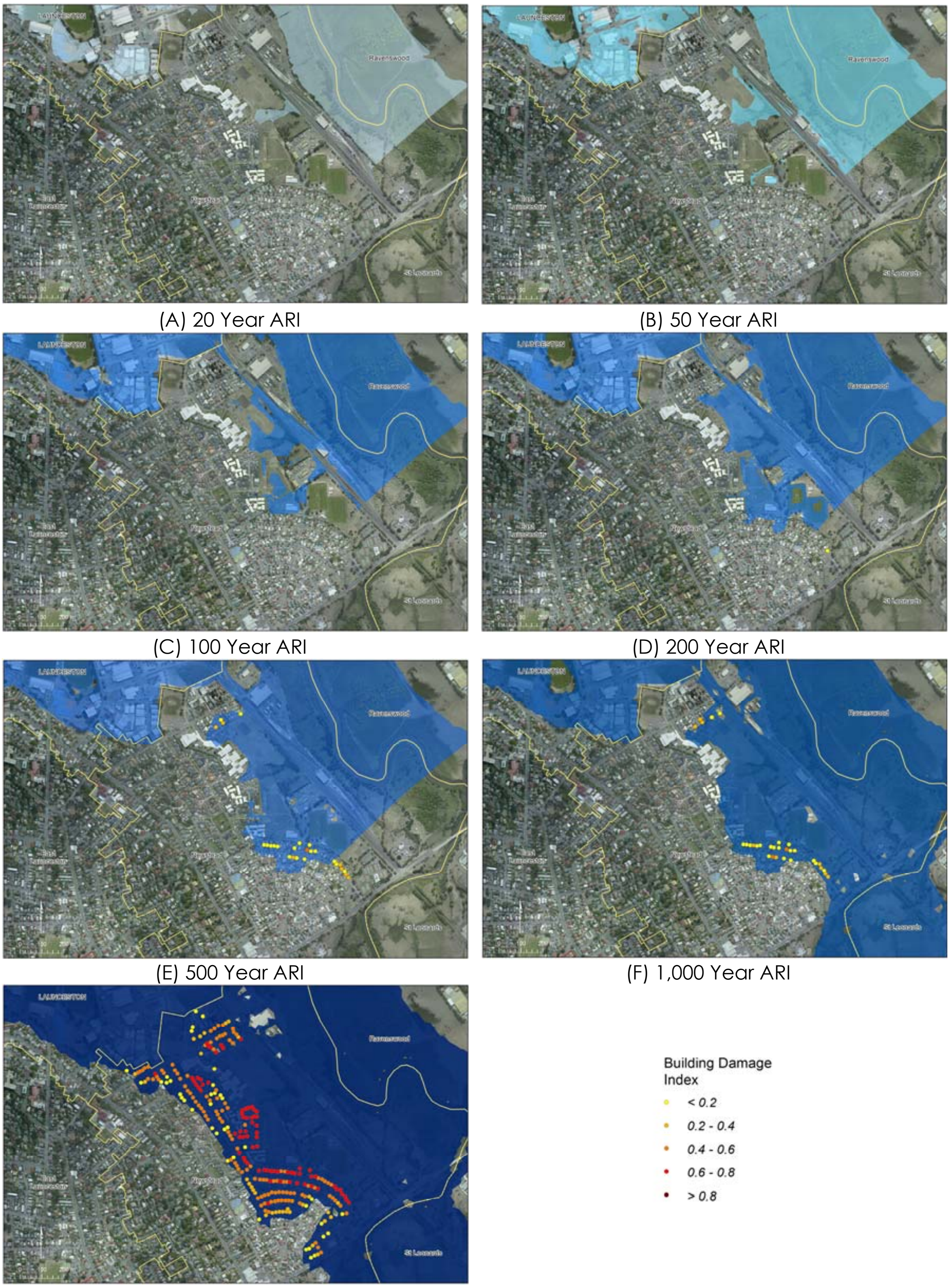
Rolfe, J., Blamey, R. and Bennett, J. 2000. Valuing the preservation of rangelands: Tree clearing in the desert uplands region of Queensland. *The Rangelands Journal*. **22**, 205-219.

Shiroiwa, T., Sung, Y.K., Fukuda, T., Lang, H.C., Bae, S.C. and Tsutani, K. 2010. International survey on willingness-to-pay (WTP) for one additional QALY gained: what is the threshold of cost effectiveness? *Health Economics*. **19,** 422-437.

White, B.A. and Rorick, M.M. 2010. Cost-benefit analysis for community-based disaster risk reduction in Kailali, Nepal. Mercy Corps Nepal. ISBN 978-9937-2-2707-0.

APPENDIX A: RESULTS

Figure A1 shows the spatial distribution of Damage Index to calculate potential loss due to building repair for each building for each hazard event.



(A) 20 Year ARI
(B) 50 Year ARI
(C) 100 Year ARI
(D) 200 Year ARI
(E) 500 Year ARI
(F) 1,000 Year ARI
(G) PMF
(H) Legend

FIGURE A1: SPATIAL DISTRIBUTION OF BUILDING INDEX FOR ALL BUILDINGS

Table A1 to A4 show the number of affected properties in each inundation depth category for each hazard event to calculate potential losses (before mitigation).

TABLE A1: NUMBER OF AFFECTED RESIDENTIAL PROPERTIES

Inundation Depth Above Ground Floor (m)	Average Recurrence Interval (ARI) in years						
	PMF	1,000	500	200	100	50	20
0.01 to 0.15	6	6	7	0	0	0	0
0.16 to 0.70	44	7	4	0	0	0	0
0.71 to 1.20	45	1	0	0	0	0	0
1.21 to 2.4	127	0	0	0	0	0	0
More than 2.4	12	0	0	0	0	0	0
Total	234	14	11	0	0	0	0

TABLE A2: NUMBER OF AFFECTED COMMERCIAL PROPERTIES

Inundation Depth Above Ground Floor (m)	Average Recurrence Interval (ARI) in years						
	PMF	1,000	500	200	100	50	20
0.01 to 0.15	0	0	0	0	0	0	0
0.16 to 0.70	0	0	0	0	0	0	0
0.71 to 1.20	0	0	0	0	0	0	0
1.21 to 2.4	2	0	0	0	0	0	0
More than 2.4	0	0	0	0	0	0	0
Total	2	0	0	0	0	0	0

TABLE A3: NUMBER OF AFFECTED INDUSTRIAL PROPERTIES

Inundation Depth Above Ground Floor (m)	Average Recurrence Interval (ARI) in years						
	PMF	1,000	500	200	100	50	20
0.01 to 0.15	0	0	0	0	0	0	0
0.16 to 0.70	2	0	0	0	0	0	0
0.71 to 1.20	0	0	0	0	0	0	0
1.21 to 2.4	2	0	0	0	0	0	0
More than 2.4	0	0	0	0	0	0	0
Total	4	0	0	0	0	0	0

TABLE A4: NUMBER OF AFFECTED INSITUTIONAL PROPERTIES

Inundation Depth Above Ground Floor (m)	Average Recurrence Interval (ARI) in years						
	PMF	1,000	500	200	100	50	20
0.01 to 0.15	0	0	0	0	0	0	0
0.16 to 0.70	0	0	0	0	0	0	0
0.71 to 1.20	0	0	0	0	0	0	0
1.21 to 2.4	2	0	0	0	0	0	0
More than 2.4	0	0	0	0	0	0	0
Total	2	0	0	0	0	0	0

APPENDIX B: VULNERABILITY MODELS

Below is the list of typical building types for which vulnerability models have been developed by Geoscience Australia. The example photos are intended as a descriptive aid and not indicate individual buildings to which the vulnerability models apply.

TABLE B1: TYPICAL BUILDING TYPES SELECTED TO DEVELOP FLOOD VULNERABILITY MODELS

Model	Description	Vintage	Typical Use	Example Photo
1	One storey, raised timber floor, lightweight cladding, hard board internal lining, no integral garage	Pre 1980	Residential	
2	As for Model 1 but with vertical timber boards internal lining	Pre 1980	Residential	
3	Two storey, slab on grade bottom floor, timber upper floor, lightweight upper floor cladding, no integral garage	Pre 1980	Residential	
4	Two storey, slab on grade bottom floor, timber upper floor, lightweight upper floor cladding, integral garage	Pre 1980	Residential	

5	Two storey, slab on grade lower floor covering only part of the plan area, timber upper floor, integral garage on the lower floor	Pre 1980	Residential	
6	Two storey, raised timber lower floor, timber upper floor, lightweight cladding, no integral garage	Pre 1980	Residential	
7	One storey, slab on grade floor, masonry veneer construction, integral garage	Post 1980	Residential	
8	One storey, slab on grade floor, masonry veneer construction, no integral garage	Post 1980	Residential	
9	One storey, raised timber floor, masonry veneer construction, no integral garage	Pre 1980	Residential	

10	One storey, slab on grade floor, cavity masonry construction, no integral garage	Post 1980	Residential	
11	One storey, raised timber floor, cavity masonry construction, no integral garage	Pre 1980	Residential	
12	Single storey Victorian residential terrace without basement	Pre WW1	Residential	
13	Single storey Victorian residential terrace with basement	Pre WW1	Residential	
14	Two storey Victorian residential terrace without basement	Pre WW1	Residential	

15	Two storey Victorian residential terrace with basement	Pre WW1	Residential	
16	Two storey Mixed use: retail / residential	Pre 1980	Commercial	
17	Two storey Showroom / Office	Pre 1980	Commercial	
18	Two storey Industrial	Post 1980	Industrial	
19	One storey Industrial	Post 1980	Industrial	

20	A single storey older building typical of older inner city light industrial areas. Solid brick walls with a steel framed roof.	Pre WW2	Motor vehicle repair	
21	A single storey portal frame shed cheaply built. Typical of newer light industrial buildings in country towns. Ancillary rooms are demountable sheds external to the main building.	Post 1980	Fabrication shop	
22	A single storey portal frame shed built to a higher standard than LIB2 with integrated bathrooms, offices and a small showroom.	Post 1980	Wholesale business	
23	A large single storey portal frame shed built to a high standard with high clearance designed for truck access. Building subdivided into tenancies.	Post 1980	Warehouse	

24	A smaller single storey warehouse with attached two storey office section typical of inner city light industrial areas. Loadbearing brick structural system, RC suspended floor and steel framed roof.	Pre WW2	Warehouse / variety of business types	
25	A large business park type building consisting of several identical units. Each unit has a high quality amenities and office space housed in a 2 storey section integral with a warehouse. Typical construction is tilt-up RC walls.	Post 1990	Business park	
26	A single storey modern building, brick veneer construction with a structural steel framed roof.	Post 1980	Preschool or childcare centre	
27	A single storey modern building, cavity brickwork construction with a steel framed roof.	Post 1980	Community hall	

28	A single storey modern building, cavity brickwork construction with a timber framed roof.	Post 1980	Aged care facility	
29	A single storey timber framed construction.	Post WW2	Primary school	

APPENDIX C: TEAM MEMBERS

DR TARIQ MAQSOOD

Dr Maqsood is a structural engineer at Geoscience Australia. He is a member of Civil College of Engineers Australia and also a member of the Australian Earthquake Engineering Society (AEES). During the last 14 years Dr Maqsood has focused his research on vulnerability and risk assessment of built environment from natural hazards (earthquakes, floods, tsunami and volcanic ash). He has also been a part of several international initiatives, such as the Global Earthquake Model, the Greater Metro Manila Risk Assessment, the UNISDR Global Assessment Report and the Earthquake Risk Assessment in Pakistan. He has conducted numerous post-disaster surveys after damaging events (earthquakes, floods, cyclones, storm surges) in several countries. He has published several papers in international refereed conferences and reputed journals. Currently he is leading a flood mitigation strategies development project within the Bushfire and Natural Hazards CRC.

MR MARTIN WEHNER

Mr Wehner is a structural engineer at Geoscience Australia. He has 22 years of experience as a practising structural engineer designing buildings of all sizes and types both in Australia and internationally. Since joining Geoscience Australia in 2009 his research work has centred on the vulnerability of structures to flood, wind and earthquake. He has participated in post-disaster damage surveys to Padang (Earthquake), Brisbane (Flood), Kalgoorlie (Earthquake) and Christchurch (Earthquake). In each case he has led the post-survey data analysis to develop vulnerability relationships and calibrate existing relationships. He has led the development of Geoscience Australia's suite of flood and storm surge vulnerability curves. He is a Member of Engineers Australia and IABSE.

DR ITISMITA MOHANTY

Dr Itismita Mohanty is a Research Fellow at the Centre for Research and Action in Public Health (CeRAPH), Health Research Institute, University of Canberra. She has expertise in socio-economic research and modelling in the field of labour economics, health economics, environmental economics and public policy analysis, using applied data analysis, microsimulation modelling, econometric analysis and policy evaluation methods. She has more than 10 years of experience in working on various academic and research assignments in Australia and overseas. She has widely published her research as peer reviewed journals articles, book chapters, conference papers and official and consultancy reports

MR NEIL CORBY

Mr Corby joined Geoscience Australia in 1989 as a cartographer and then moved into Geographic information Systems. He holds a diploma in spatial information systems and has been developing data capture tools within the Vulnerability, Resilience and Mitigation Section over the last decade.

MR MARK EDWARDS

Mr Edwards leads a multi-disciplinary team developing engineering, economic and social vulnerability models at Geoscience Australia. His team undertakes modelling and post-disaster surveys in the development of vulnerability models for natural hazard assessments. He is an engineer with 14 years of industry experience followed by 21 years of risk research.

DR FIONA GIBSON

Dr Gibson received her doctorate from the University of Western Australia in 2011. Since then Dr Gibson has been working on benefit: cost analysis tools for bushfire management, non-market values for natural hazard management and policies for environmental management in agricultural landscapes. Dr Gibson's research aims to provide better advice to decision makers on effective policy design and the factors driving community values of such policies.

DR ABBIE ROGERS

Dr Rogers is a Research Fellow at the Centre for Environmental Economics and Policy, University of Western Australia. Her primary research interest is in the application of non-market valuation to estimate community values and preferences for environmental conservation and management. This includes applications in the context of marine, terrestrial and aquatic environments, and the natural hazards that affect each of these. Dr Rogers' work aims to improve the application, understanding and accessibility of non-market valuation techniques such that they can be used more readily in policy and decision making.