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LAUNCESTON FLOOD RISK MITIGATION - JUNE 2016 FLOODS

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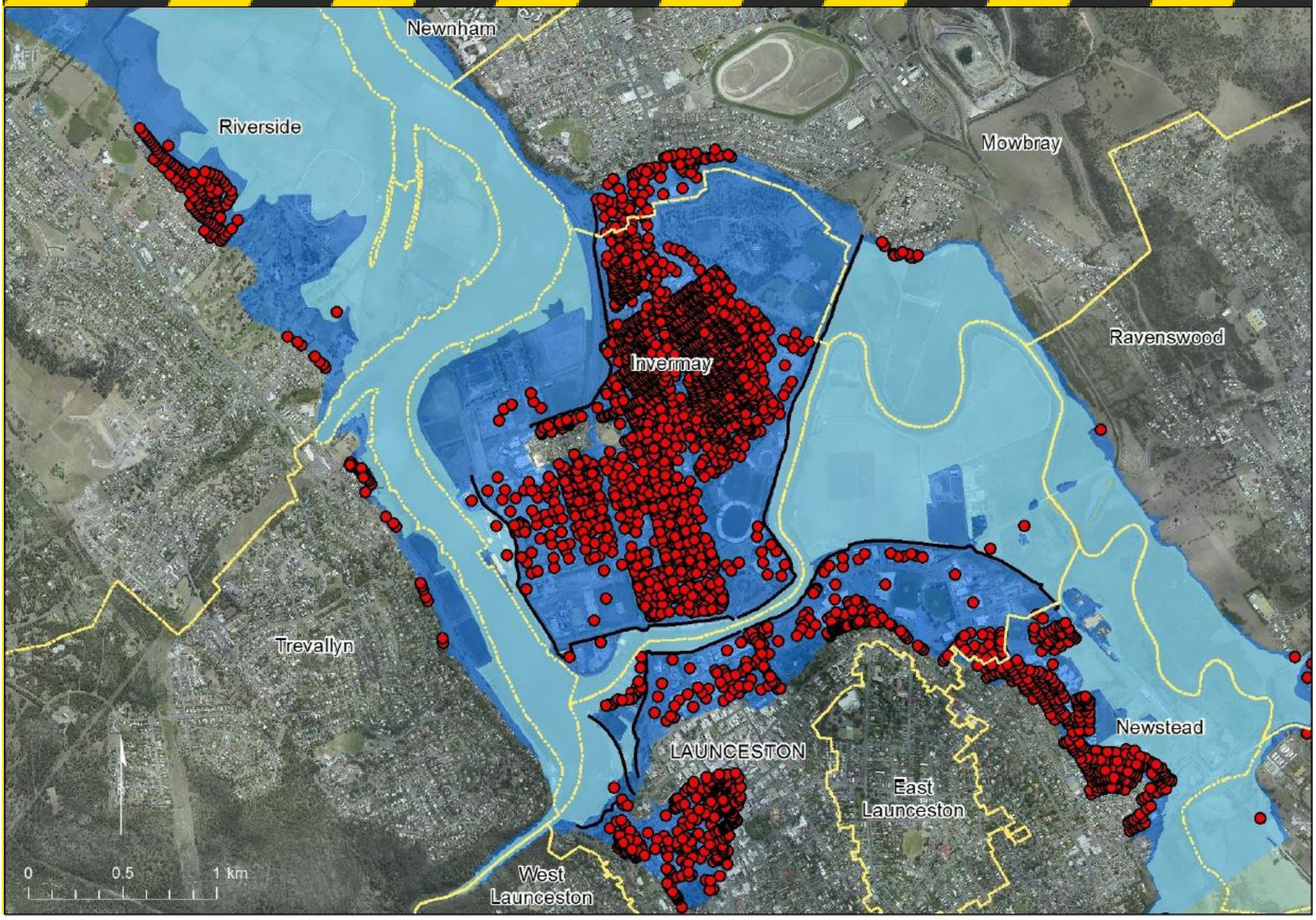

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Cover: June 2016 and probability maximum flood extent map (Geoscience Australia)

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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

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). The devastation caused by the 1929 flood and several smaller floods prompted the construction in the 1960s of a ten kilometre flood levee system to mitigate the flood risk. However, by 2005, the effects of ground settlement and insufficient maintenance resulted in the levee system being considered substandard and providing a lower level of protection than required (Fullard, 2013).

Therefore, a new Launceston Flood Authority was established in 2008 to design, construct and maintain the new and existing flood levees. To replace the existing deteriorated levees a new flood mitigation initiative was commenced in 2010 to provide Launceston with reliable flood protection up to the 200 year Annual Recurrence Interval (ARI) event (Fullard, 2013). The initial project cost (mitigation investment) was estimated to be $22 million in 2006, however, the final project cost was assessed to be $58 million (in 2016 dollars) due to increase in cost of construction and land acquisition. The project was funded by the Federal, State and Local Governments. The completed project comprises a levee and flood gate system which includes 12 kilometers of earth levee, 700 metres of concrete levee and 16 floodgates (National Precast Concrete Association, 2015).

Geoscience Australia (GA) was funded to undertake a project to conduct a Cost Benefit Analysis (CBA) of the Launceston flood mitigation initiative described above as 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.

FIGURE 1: STUDY AREA

AIMS AND OBJECTIVES

The study aimed to assess:

- The avoided damage cost to Launceston in the June 2016 floods as a result of the new mitigation works.
- 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.
- Avoided residential and non-residential building damage for flood events ranging from the 20 year ARI up to the PMF due to the new mitigation works.
- The long term cost to Launceston from flood hazard prior to the new mitigation works.
- The long term cost to Launceston from flood hazard following the new mitigation works.
- A CBA of the new flood mitigation investment.

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.

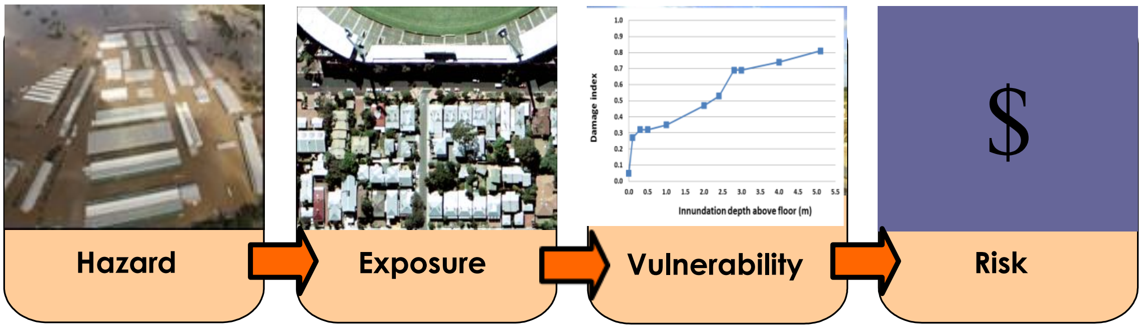


FIGURE 2: FLOOD RISK ASSESSMENT FRAMEWORK

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) at the junction of Lindsay Street and E Tamar Highway. Figure 3 shows 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 LAUNCESTON

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	4.98
200	0.005	4.24
100	0.01	3.84
50	0.02	3.38
20	0.05	2.82
June 2016 event	~0.02	3.30

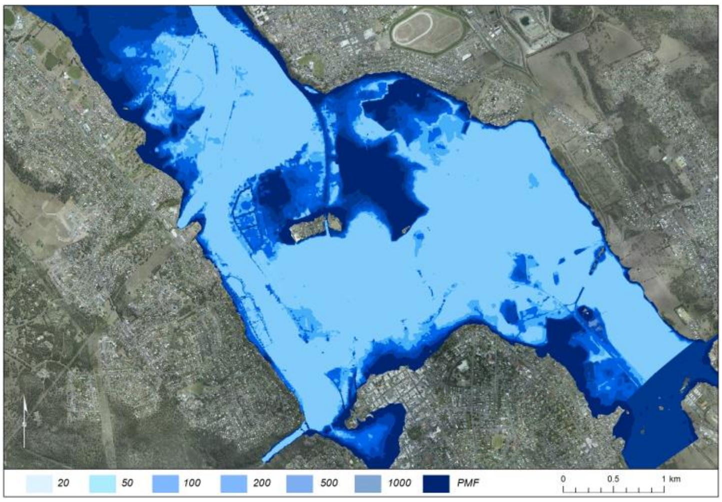


FIGURE 3: MODELLED FLOOD EXTENTS FOR SELECTED RECURRENCE INTERVALS

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 (2,656 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 4 shows the buildings within the PMF flood extent map for which building level attributes were compiled in the exposure database. Figure 5 presents the spatial distribution of buildings within the PMF extent for selected attributes.

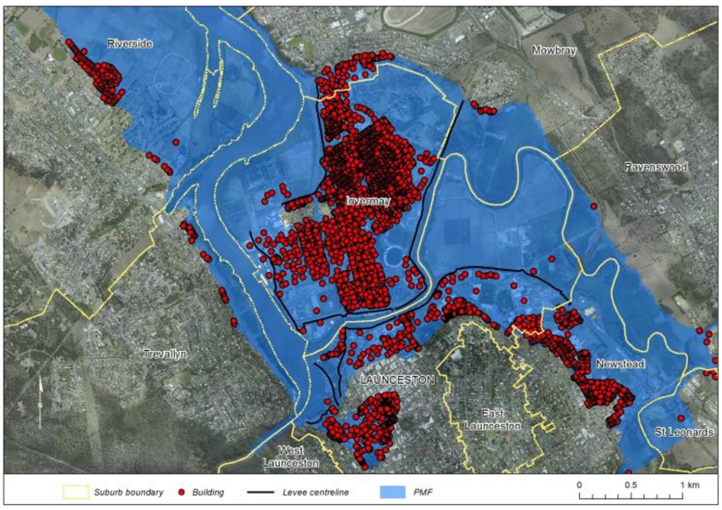
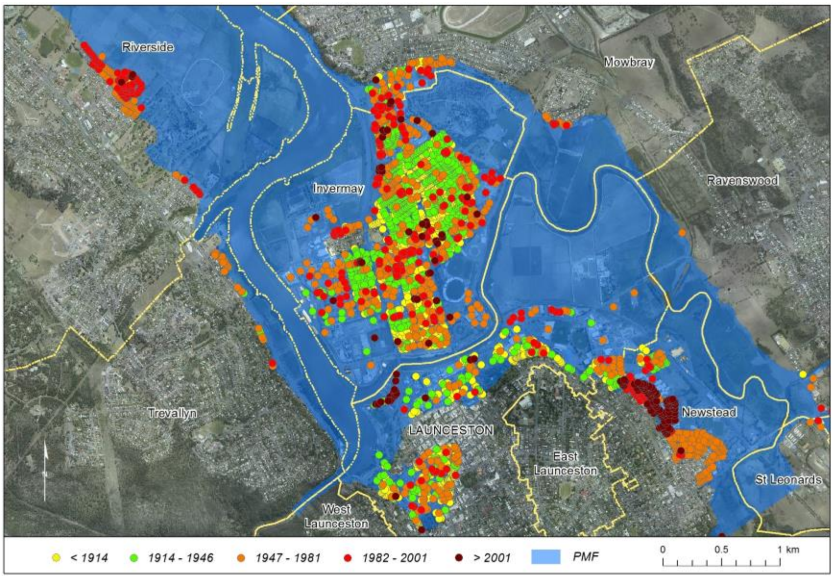
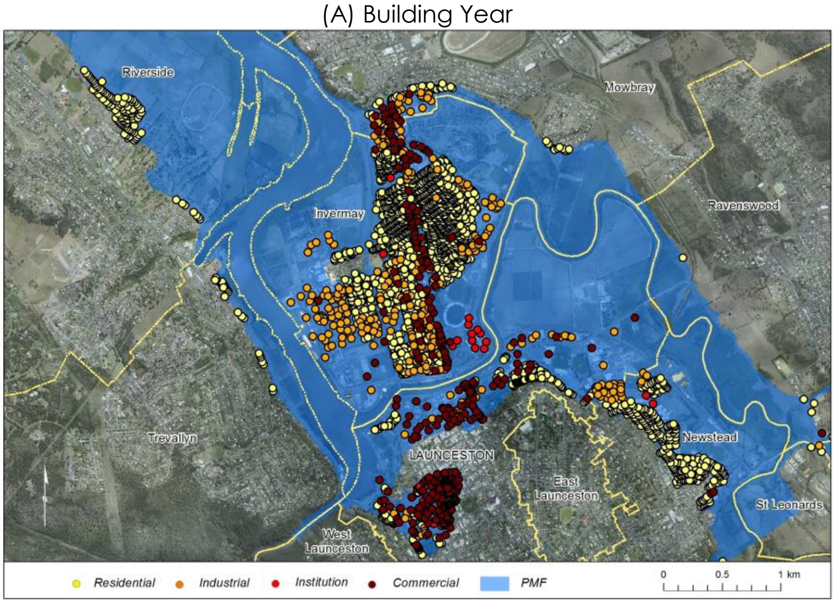


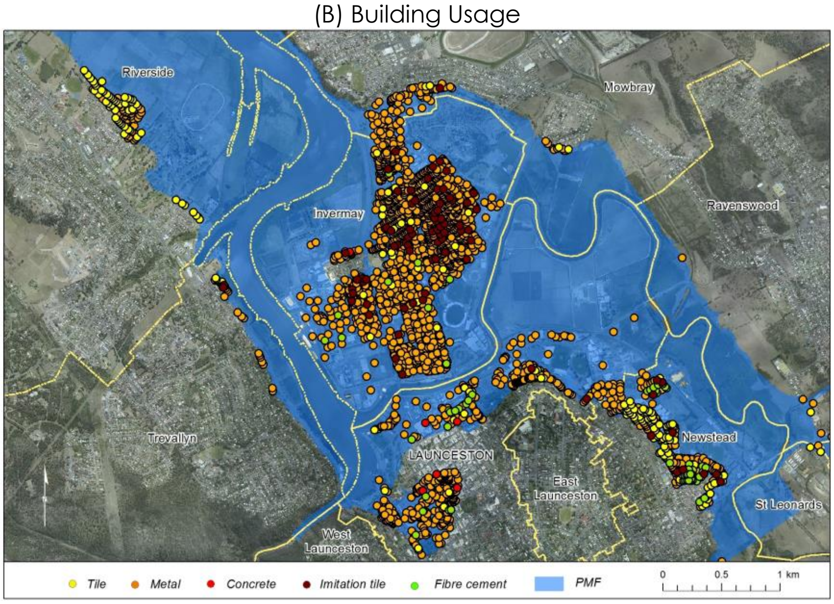
FIGURE 4: AFFECTED BUILDINGS IN THE STUDY AREA AND THE PMF FLOOD EXTENT MAP



(A) Building Year

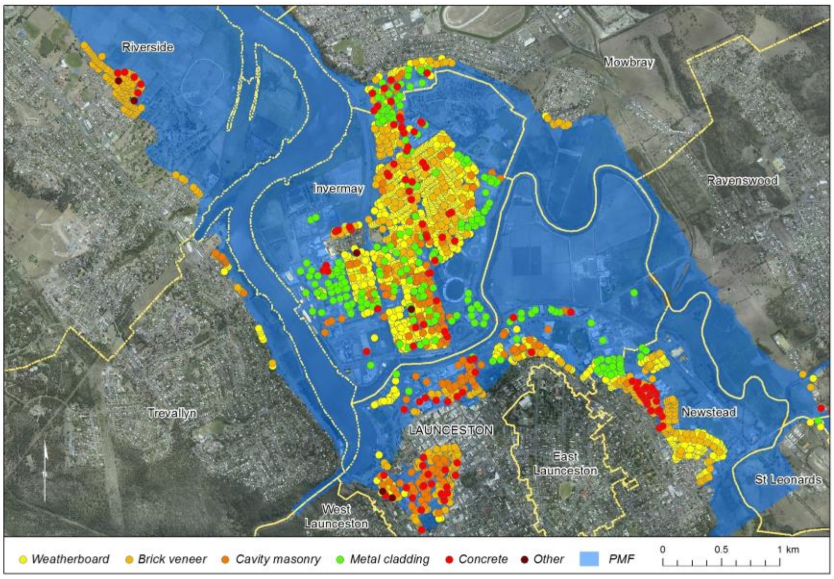


(B) Building Usage

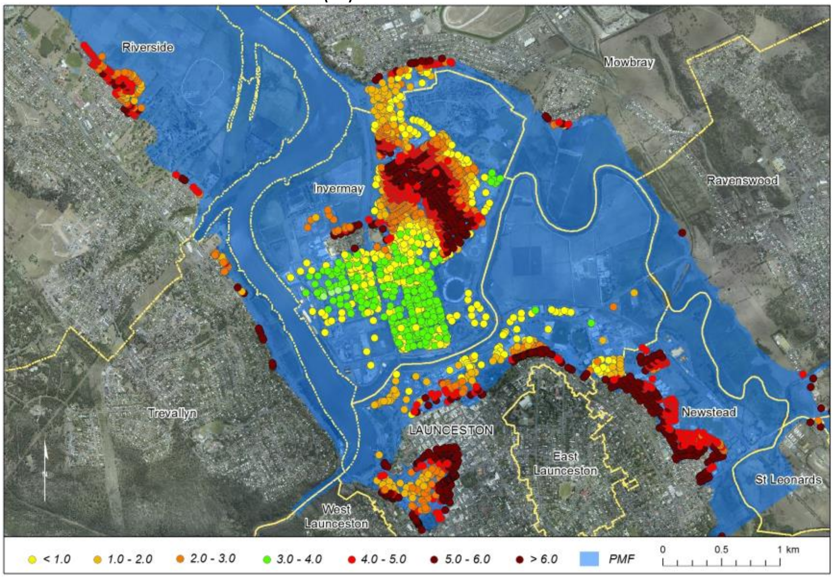


(C) Roof Material

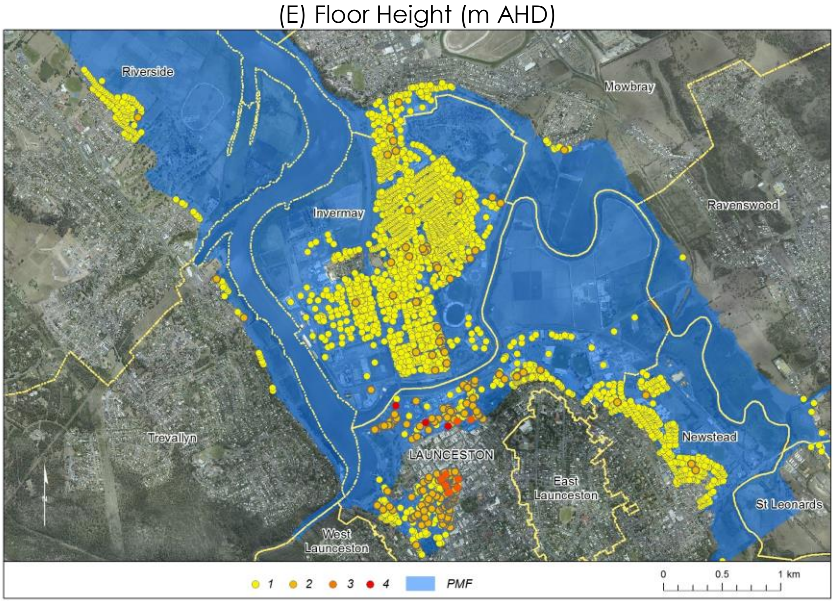
Figure 5: BUILDING ATTRIBUTES AND THEIR Spatial DISTRIBUTION IN THE STUDY AREA



(D) Wall Material



(E) Floor Height (m AHD)



(F) Number of Storeys

FIGURE 5: BUILDING ATTRIBUTES AND THEIR SPATIAL DISTRIBUTION IN THE STUDY AREA (CONT.)

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 6 shows the spatial distribution of vulnerability models assigned to the building stock in the study area.

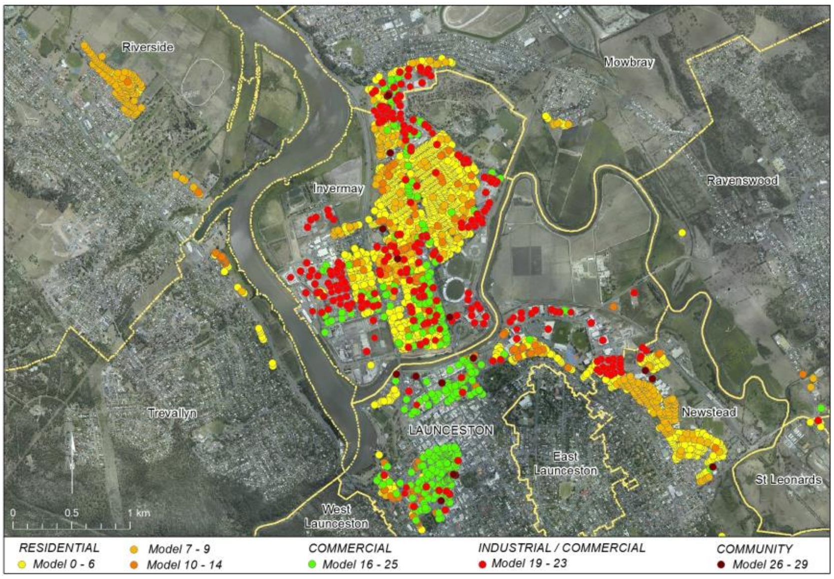


FIGURE 6: FLOOD VULNERABILITY MODELS ASSIGNED TO BUILDINGS IN LAUNCESTO

Risk

Risk can be measured as the aggregated annualised dollar loss due to building damage, essential service disruption, injury/fatality, community disruption, business inventory loss or economic activity disruption caused by hazard events over the full range of event likelihoods. For this study, risk has been assessed in terms of economic loss (or costs) from building damage, contents damage, clean-up cost, rental income loss, cost of business interruption and fatalities due to inundation. Table 2 lists the components for which losses have been estimated in this study in 2016 dollar values for the residential and non-residential sectors.

TABLE 2: SOURCES OF ESTIMATED LOSS FOR THE RESIDENTIAL AND NON-RESIDENTIAL SECTORS

Residential Sector	Non-residential Sector
Building repair/rebuild cost	Building repair/rebuild cost
Contents damage cost	Clean-up cost
Loss of rental income	Loss of Inventory/equipment
Clean-up cost	Loss of stock
Loss due to fatalities	Loss of income: proprietor's income
	Loss of income: turnover
	Loss of income: wage/salary

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, 2016a). The outcomes of business survey conducted after the 2013 floods in Bundaberg were utilised to assess duration of interruption, average loss of income, average loss of stock, average loss of inventory and average loss of turnover for the non-residential sector (Canterford, 2016b). 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 Launceston. 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).

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 7 and described below.

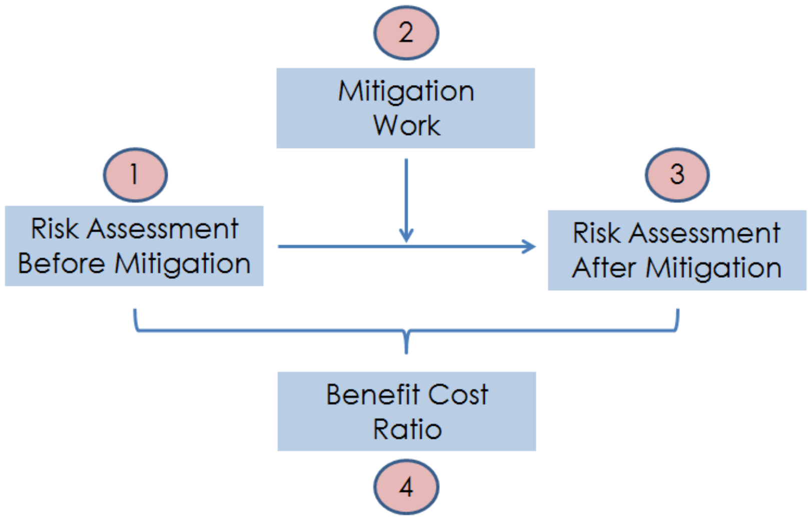


FIGURE 7: COST BENEFIT ANALYSIS FRAMEWORK (ADAPTED FROM MECHLER, 2005)

1. Risk Assessment before mitigation: at this step risk was calculated in terms of conditional loss ($) associated with the older levee system in place.
2. Mitigation work: this was the investment ($) 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 new levee system from 2010 to 2016, which consisted of construction and land acquisition costs.
3. Risk Assessment after mitigation: at this step risk was again calculated in terms of conditional loss of levee failure ($) by incorporating the effects of the mitigation investment. Usually there was a reduction of loss ($) 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 realized 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 new mitigation initiative, conditional probabilities of levee failure with increasing flood depth were used to replicate the deteriorated condition of pre-existing levees. The assessed likelihood of failure due to overtopping of the new levee system if subjected to extreme flood loads was also considered. The conditional probabilities of failure for existing levees were based on GHD (2006). The conditional probabilities after mitigation were based on the assumption that the new levee system 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 existing and new levee system.

TABLE 3: ADOPTED CONDITIONAL PROBABLITY OF FAILURE FOR EXISTING AND NEW LEVEES

ARI (years)	Conditional Probability of Failure of Existing Levees	Conditional Probability of Failure/Overtopping of New Levees
100,000	100%	100%
1,000	100%	100%
500	100%	10%
200	75%	0%
100	40%	0%
50	5%	0%
20	0.05%	0%

AFFECTED POPULATION

Table 4 presents the number of affected residential properties 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 levees (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	1,853	4,262	4,262
1,000	0.001	989	2,275	2,275
500	0.002	864	1,987	199
200	0.005	786	1,356	0
100	0.01	707	650	0
50	0.02	627	72	0
20	0.05	551	1	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	0
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

RESIDENTIAL LOSSES

The losses in the residential sector were comprised of the building repair cost, loss of contents, rental income loss, clean-up cost and cost of fatalities.

Building Repair Cost

The building repair cost was estimated at building level by using 15 vulnerability models for the residential buildings developed by GA, presented in the Appendix B. Each residential building (1,980 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 presence of garage. Losses to ancillary structures such as fences, swimming pools, garden sheds and detached garages were not considered.

The unit replacement rates for each GA residential 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 residential building was provided by the LCC.

The Damage Index (ratio of repair cost to replacement cost) was then assessed for each residential 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 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 residential 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 existing (before mitigation investment) and new levee system (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 new levee system reduced the AAL due to the repair costs for the residential buildings by $1.28 million as shown in Table 6.

TABLE 6: ESTIMATED BUILDING REPAIR COST (RESIDENTIAL SECTOR)

ARI (Years)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	466.06	1	1	466.06	466.06	1.769	0.486
1,000	218.23	1	1	218.23	218.23		
500	192.27	1	0.1	192.27	19.23		
200	149.53	0.75	0	112.15	0		
100	127.35	0.4	0	50.94	0		
50	106.23	0.05	0	5.31	0		
20	75.39	0.0005	0	0.04	0		

Loss of Contents

In a similar approach as used to estimate the building repair costs, the loss of contents in the residential sector was estimated for each affected building by using 11 vulnerability models developed by GA. Each residential building (1,980 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 were also updated to account for location and inflation to assess the contents replacement cost. 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 the mitigation. It was estimated that the mitigation investment in the new levee system reduced the AAL to the residential contents by $0.40 million.

TABLE 7: ESTIMATED LOSS OF CONTENTS (RESIDENTIAL SECTOR)

ARI (Years)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	132.34	1	1	137.05	137.05	0.556	0.143
1,000	63.29	1	1	65.00	65.00		
500	55.64	1	0.1	57.02	5.70		
200	47.48	0.75	0	36.36	0		
100	41.65	0.4	0	16.95	0		
50	36.45	0.05	0	1.84	0		
20	28.01	0.0005	0	0.01	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 from the ABS census data for Launceston.

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).

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

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 new levee system reduced the AAL to the rental income by $0.013 million as shown in Table 8.

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

ARI (Years)	Potential Loss ($ M)	Conditional Probability of Failure	Conditional Loss ($ M)	Average Annual Loss ($ M)

		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	3.48	1	1	3.48	3.48		
1,000	1.87	1	1	1.87	1.87		
500	1.72	1	0.1	1.72	0.17		
200	1.11	0.75	0	0.83	0	0.0136	0.0003
100	0.85	0.4	0	0.34	0		
50	0.75	0.05	0	0.04	0		
20	0.56	0.0005	0	0	0		

Cost of Clean-up

The cost of clean-up was estimated for the residential properties by using per unit area clean-up cost recorded by the Bundaberg Regional Council during the 2013 Bundaberg floods. The clean-up cost during the Bundaberg floods to residential sector was reported to be $5.12 per square meter (Honor, 2017). The total residential ground floor area affected by each hazard event was calculated by overlaying the flood footprint of each event on the building footprints.

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

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

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 new levee system reduced the AAL due to clean-up by $0.006 million.

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

ARI (Years)	Residential Floor Area (m^2)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
			Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	278,571	1.43	1	1	1.43	1.43		
1,000	131,295	0.67	1	1	0.67	0.67		
500	112,435	0.58	1	0.1	0.58	0.06		
200	104,455	0.53	0.75	0	0.40	0	0.0060	0.0001
100	97,321	0.49	0.4	0	0.19	0		
50	81,427	0.42	0.05	0	0.02	0		
20	73,473	0.38	0.0005	0	0	0		

Cost of Fatalities

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 8.

For this study the fatality rate function described in Figure 8 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 7m^2/s.

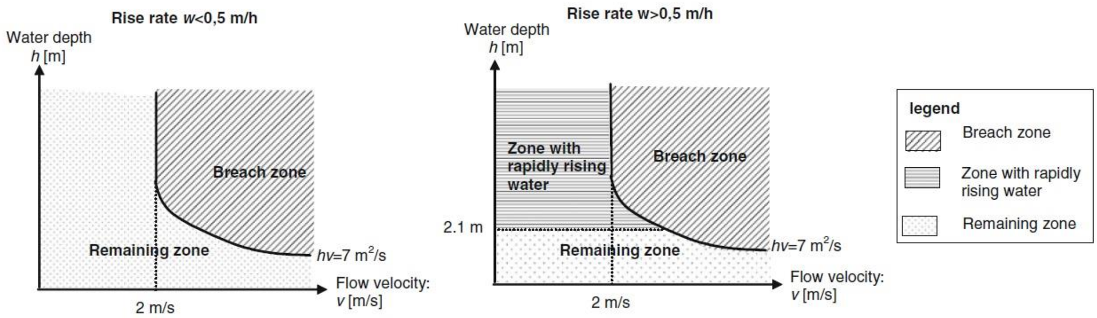


Figure 8: AREA OF APPLICATION OF FATALITY FUNCTIONS (JONKMAN ET AL., 2007)

The fatality rate selected is given by Equation (5).

$$Fatality\ Rate = \varphi\ (\frac{(\ln(h) - \mu)}{\sigma}) \qquad (5)$$

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 exposed human population was subdivided in to three age categories i.e. under 20 years, 20-60 years and more than 60 years to differentiate the vulnerability of various age groups. The proportion of fatalities in these age groups was estimated from the database developed by Haynes et al., (2016) which included fatalities due to floods since 1900 in Australia. The fatality rates for each event were then proportionally applied to these age categories.

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 (6).

$$Lf = \sum_{i=1}^{n} (Number\ of\ Affected\ People\ x\ Fatality\ Rate\ x\ Value\ of\ Life) \tag{6}$$

Table 10 and Table 11 present the number and cost of fatalities before and after mitigation for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the new levee system reduced the AAL due to fatalities by $0.14 million.

TABLE 10: ESTIMATED COST OF FATALITIES BEFORE MITIGATION (RESIDENTIAL SECTOR)

ARI (Years)	Conditional Number of Affected people	Age (0-19 yrs)	Age (20-59 yrs)	Age (60+ yrs)	Average Fatality Rate	Fatality Rate (0-19 yrs)	Fatality Rate (20-59 yrs)	Fatality Rate (60+ yrs)	Fatalities (0-59 yrs)	Fatalities (60+ yrs)	Total Fatalities	Value of Life $M (40 years)	Value of Life $M (60 years)	$ Loss ($ M)	Average Annual Loss ($ M)
100,000	4,262	1,096	2,487	680	0.0085	0.0031	0.0039	0.0015	13.17	1.00	14.17			59.96	
1,000	2,275	585	1,327	363	0.0074	0.0027	0.0034	0.0013	6.12	0.46	6.59			27.86	
500	1,987	511	1,159	317	0.0080	0.0029	0.0037	0.0014	5.78	0.44	6.22			26.31	
200	1,356	349	791	216	0.0057	0.0021	0.0026	0.0010	2.81	0.21	3.02	4.34	2.78	12.79	0.20
100	650	167	379	104	0.0045	0.0016	0.0021	0.0008	1.06	0.08	1.15			4.84	
50	72	19	42	12	0.0030	0.0011	0.0014	0.0005	0.08	0.01	0.08			0.36	
20	1	0	0	0	0.0013	0.0005	0.0006	0.0002	0	0	0			0	

TABLE 11: ESTIMATED COST OF FATALITIES AFTER MITIGATION (RESIDENTIAL SECTOR)

ARI (Years)	Conditional Number of Affected people	Age (0-19 yrs)	Age (20-59 yrs)	Age (60+ yrs)	Average Fatality Rate	Fatality Rate (0-19 yrs)	Fatality Rate (20-59 yrs)	Fatality Rate (60+ yrs)	Fatalities (0-59 yrs)	Fatalities (60+ yrs)	Total Fatalities	Value of Life $M (40 years)	Value of Life $M (60 years)	$ Loss ($ M)	Average Annual Loss ($ M)
100,000	4,262	1,096	2,487	680	0.0085	0.0031	0.0039	0.0015	13.17	1.00	14.17			59.96	
1,000	2,275	585	1,327	363	0.0074	0.0027	0.0034	0.0013	6.12	0.46	6.59			27.86	
500	1,99	51	116	32	0.0080	0.0029	0.0037	0.0014	0.58	0.04	0.62			2.63	
200	0	0	0	0	0	0	0	0	0	0	0	4.34	2.78	0	0.06
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	

Total Residential Costs

The losses to the residential sector (*Lres*) were contributed by the building repair cost (*Lbr*), loss of contents (*Lc*), rental income loss (*Lren*), clean-up cost (*Lcr*) and cost of fatalities (*Lf*), as shown in Equation (7).

Table 12 and Table 13 present the estimated conditional losses to the residential sector before and after mitigation (i.e. the construction of the new levee system), respectively. It was estimated that the mitigation investment in the new levee system reduced the AAL in the residential sector by $1.77 million.

$$Lres = Lbr + Lc + Lren + Lcr + Lf \qquad (7)$$

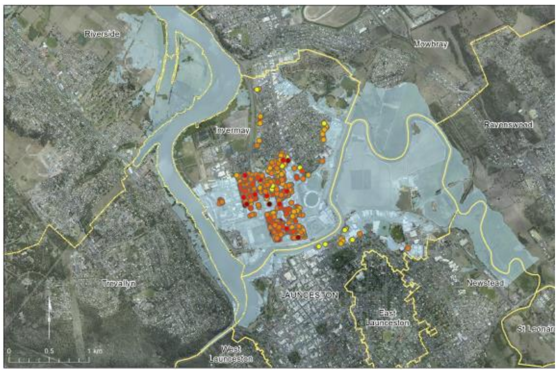
TABLE 12: ESTIMATED CONDITIONAL LOSS ($) IN RESIDENTIAL SECTOR - BEFORE MITIGATION

ARI (Years)	Annual Probability of Exceedance	Building Repair Cost ($ M)	Contents Loss ($ M)	Rental Income Loss ($ M)	Clean-up Cost ($ M)	Cost of fatalities ($ M)	Total ($ M)	Average Annual Loss ($ M)
100,000	0.00001	466.1	137.0	3.5	1.4	59.9	667.9	2.46
1,000	0.001	218.2	65.0	1.9	0.7	27.9	313.6	
500	0.002	192.3	57.0	1.7	0.6	26.3	277.9	
200	0.005	112.1	36.4	0.8	0.4	12.8	149.7	
100	0.01	50.9	16.9	0.3	0.2	4.8	68.4	
50	0.02	5.3	1.8	0	0	0.4	7.2	
20	0.05	0	0	0	0	0	0.1	

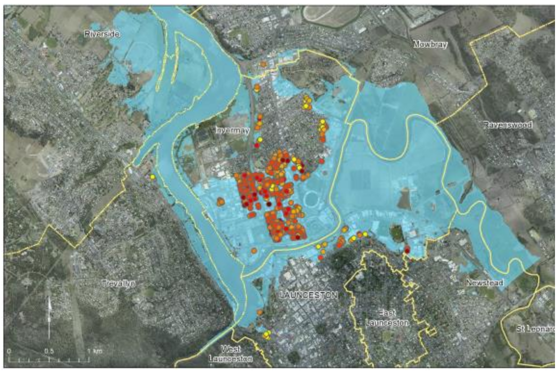
TABLE 13: ESTIMATED CONDITIONAL LOSS ($) IN RESIDENTIAL SECTOR - AFTER MITIGATION

ARI (Years)	Annual Probability of Exceedance	Building Repair Cost ($ M)	Contents Loss ($ M)	Rental Income Loss ($ M)	Clean-up Cost ($ M)	Cost of fatalities ($ M)	Total ($ M)	Average Annual Loss ($ M)
100,000	0.00001	466.1	137.0	3.5	1.4	59.9	663.3	0.69
1,000	0.001	218.2	65.0	1.9	0.7	27.9	313.6	
500	0.002	19.2	57.0	0.2	0.1	2.6	27.8	
200	0.005	0	0	0	0	0	0	
100	0.01	0	0	0	0	0	0	
50	0.02	0	0	0	0	0	0	
20	0.05	0	0	0	0	0	0	

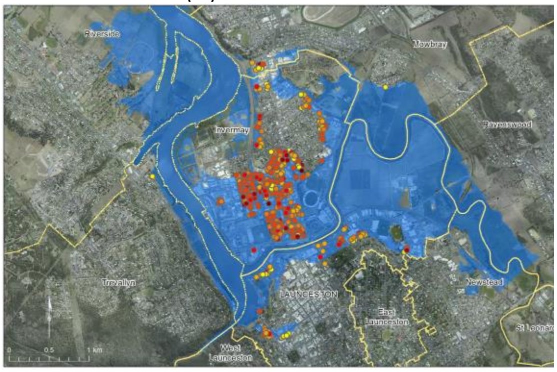
Figure 9 and Figure 10 show the spatial distribution of potential loss of contents and cost of building repair for each residential property in each hazard event without any flood protection.



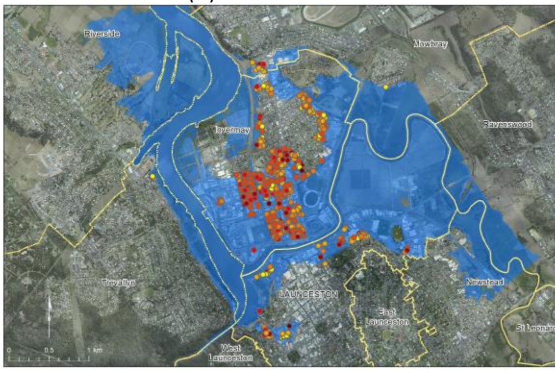
(A) 20 Year ARI



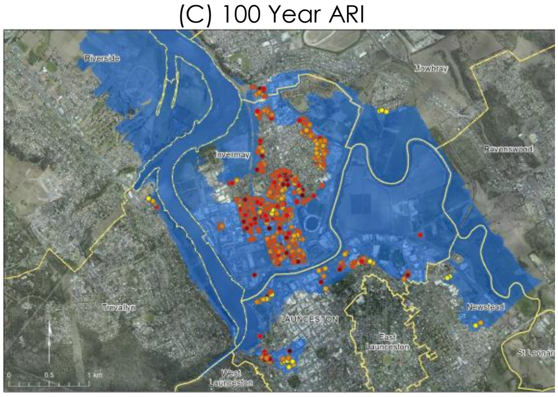
(B) 50 Year ARI



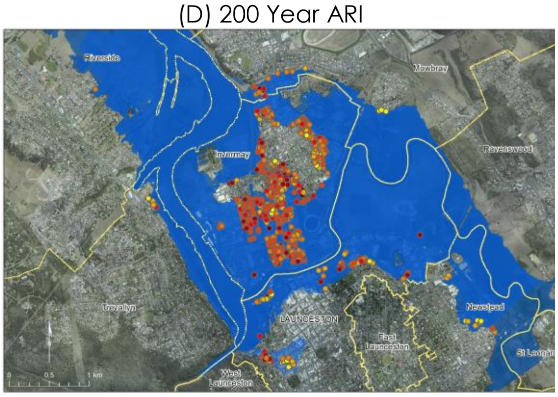
(C) 100 Year ARI



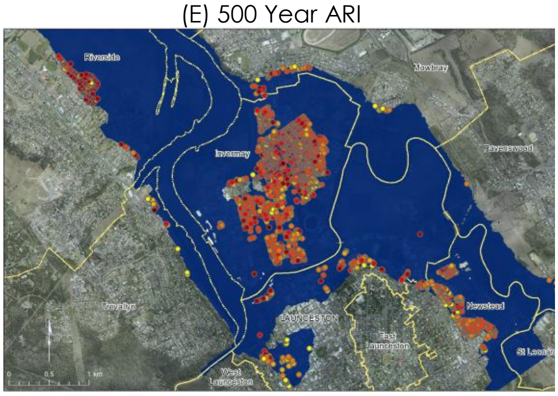
(D) 200 Year ARI



(E) 500 Year ARI



(F) 1,000 Year ARI



(G) PMF

(H) Legend

FIGURE 9: POTENTIAL LOSS OF CONTENTS FOR THE RESIDENTIAL SECTOR

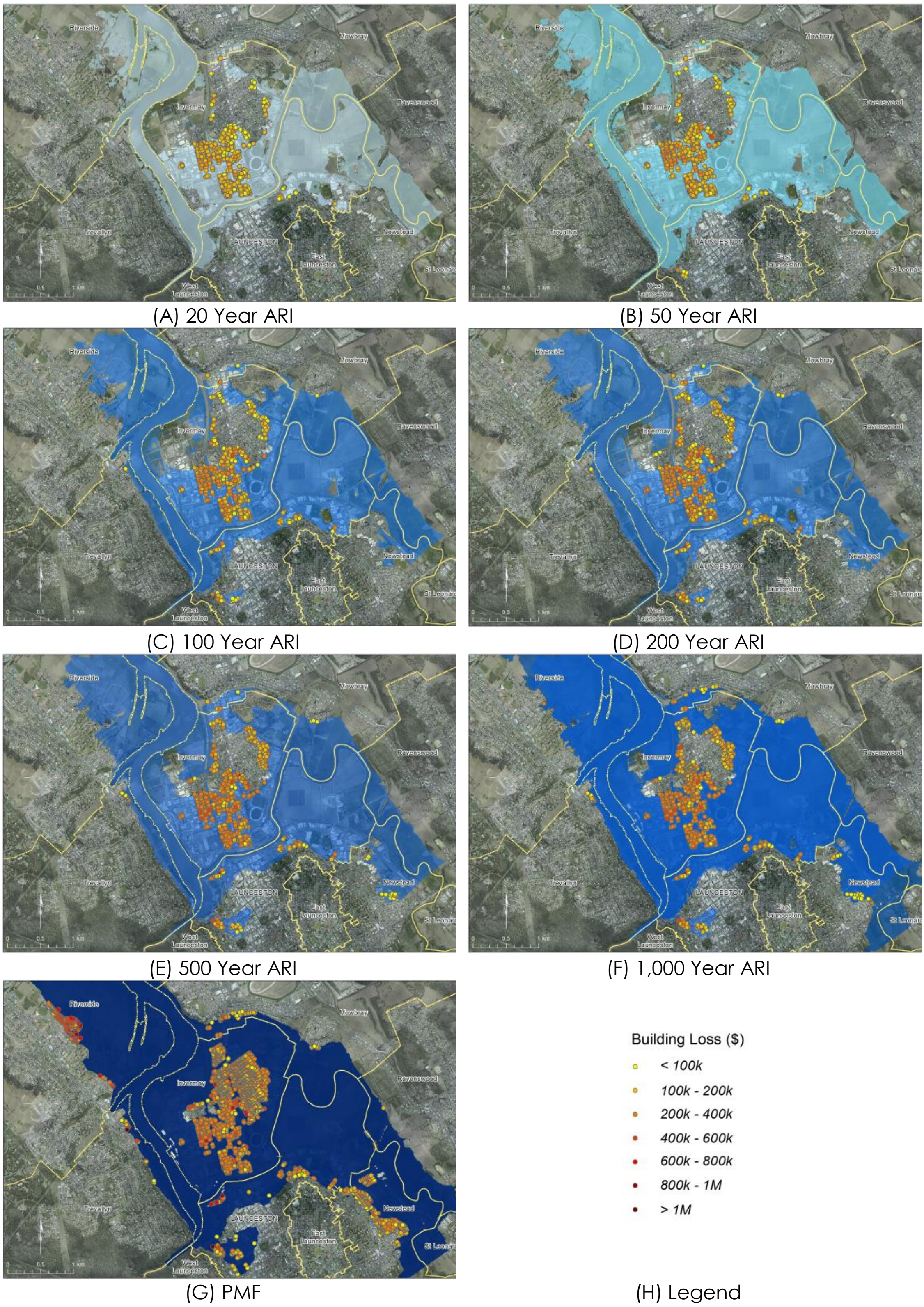


FIGURE 10: POTENTIAL BUILDING REPAIR COSTS FOR THE RESIDENTIAL SECTOR

NON-RESIDENTIAL LOSSES

The losses to the non-residential sector were contributed by the building repair cost, loss of stock, loss of inventory, loss of income, clean-up cost, and loss of turnover. The number of affected non-residential buildings was estimated by overlaying the flood footprint maps for each hazard event on building footprint maps. There were 676 non-residential buildings which were affected by the PMF.

Building Repair Cost

In a similar approach as used to estimate the residential building repair cost, the building repair cost in the non-residential sector was estimated at building level by using 14 vulnerability models developed by GA (see Appendix B). Each affected non-residential building was assigned an appropriate vulnerability model based on the building attributes: usage (commercial, industrial institutional and mixed use), wall material, size and age.

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

The Damage Index was then assessed for each non-residential 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 repair cost (*Lbnr*) for each hazard event for the non-residential buildings 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 non-residential building as shown in Equation (8).

$$Lbnr = \sum_{i=1}^{n}(Ground\ Floor\ Area\ x\ Number\ of\ Storeys\ x\ Reconstruction\ Rate\ x\ Damage\ Index) \quad (8)$$

Table 14 presents the total potential and conditional costs of building repair for each hazard event. Finally, the 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 new levee system reduced the AAL due to the repair cost for non-residential buildings by $0.74 million.

TABLE 14: ESTIMATED COST OF BUILDING REPAIR (NON-RESIDENTIAL SECTOR)

ARI (Year)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	244.79	1	1	244.79	244.79	0.998	0.263
1,000	120.00	1	1	120.00	120.00		
500	111.84	1	0.1	111.84	11.18		
200	87.28	0.75	0	65.46	0		
100	71.61	0.4	0	28.64	0		
50	56.98	0.05	0	2.85	0		
20	37.51	0.0005	0	0.02	0		

Loss of Inventory

The inventory included furniture, fittings, plant and equipment that were not intended for sale in a business. The affected businesses in the study were first classified according to the Australian and New Zealand Standard Industrial Classification (ABS, 2006). Each affected business was then catogorised into three major industry types i.e. primary, secondary and tertiary. The primary industry category included agriculture, fishing, forestry and mining. Secondary industry category included manufacturing and construction. The tertiary industry category included retail trade, wholesale trade and other services. Transportation, health care, food, advertising, entertainment, tourism, banking and law are all examples of tertiary sector businesses.

None of the businesses exposed to flooding in the study area were primary industries. The number of affected businesses in the secondary and tertiary categories in each hazard event is presented in Table 15.

Average inventory loss to an industry category was based on the outcomes of GA's Bundaberg business survey conducted after the January 2013 flood and was inflated to 2016 values. The average loss of inventory to a business in secondary and tertiary categories was estimated by using the business survey to be $35,978 and $32,350, respectively.

The potential loss of inventory (*Linv*) for each hazard event is calculated as the summation of the product of the number of affected businesses in each industry category in the study area and the average inventory loss to a business, and shown in Equation (9).

$$Linv = \sum_{i=1}^{n}(Number\ of\ Affected\ Properties\ x\ Average\ Loss) \quad (9)$$

Table 15 presents the potential and conditional loss of inventory for secondary and tertiary industry sectors for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the new levee system reduced the AAL of inventory by $0.11 million.

TABLE 15: ESTIMATED LOSS OF INVENTORY (NON-RESIDENTIAL SECTOR)

ARI (Years)	Number of Affected Secondary Businesses	Number of Affected Tertiary Businesses	Potential Loss - Secondary Sector ($ M)	Potential - Tertiary Sector ($ M)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
						Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	4	642	0.14	20.76	20.91	1	1	20.91	20.91	0.142	0.028
1,000	4	462	0.14	14.94	15.09	1	1	15.09	15.09		
500	4	436	0.14	14.10	14.25	1	0.1	14.25	1.42		
200	4	408	0.14	13.19	13.34	0.75	0	10.01	0		
100	3	384	0.11	12.42	12.53	0.4	0	5.01	0		
50	2	337	0.07	10.90	10.97	0.05	0	0.55	0		
20	1	256	0.04	8.28	8.32	0.0005	0	0.004	0		

Loss of Stock

The stock included raw materials, work in progress and finished goods that were for sale in a business. In a similar approach as used to estimate the loss of inventory, the loss of stock in the non-residential sector was estimated for each business by utilising the outcomes of the GA's Bundaberg business survey conducted after the January 2013 flood and was inflated to 2016 values. The average loss of stock in a business in secondary and tertiary categories was estimated to be $2,081 and $18,509, respectively.

The total potential loss of stock (*Ls*) for each hazard event was calculated as the summation of the product of the number of affected businesses in each industry category in the study area and the average loss of stock in a business, as shown in Equation (10).

$$Ls = \sum_{i=1}^{n}(Number\ of\ Affected\ Properties\ x\ Average\ Loss) \qquad (10)$$

Table 16 presents the potential and conditional loss of stock for secondary and tertiary industry categories for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the new levee system reduced the AAL of stock by $0.06 million.

TABLE 16: ESTIMATED LOSS OF STOCK (NON-RESIDENTIAL SECTOR)

ARI (Year)	Number of Affected Tertiary Businesses	Number of Affected Secondary Businesses	Potential Loss - Secondary Sector ($ M)	Potential - Tertiary Sector ($ M)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
						Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	642	4	0.008	11.88	11.89	1	1	11.89	11.89	0.080	0.016
1,000	462	4	0.008	8.55	8.56	1	1	8.56	8.56		
500	436	4	0.008	8.07	8.08	1	0.1	8.08	0.81		
200	408	4	0.008	7.55	7.56	0.75	0	5,67	0		
100	384	3	0.006	7.11	7.11	0.4	0	2,84	0		
50	337	2	0.004	6.24	6.24	0.05	0	0.31	0		
20	256	1	0.002	4.74	4.74	0.0005	0	0.002	0		

Loss of Income

The loss of income in the non-residential sector was estimated for three employment categories:

- Owners and managers of incorporated enterprises,
- Owners and managers of unincorporated enterprises, and
- Employees not owning a business.

The first two employment categories represented the loss in proprietary income and third sub-category represented the loss in wage/salary income. Data from a number of sources were collected to estimate the loss of income in the three major industry categories (primary, secondary and tertiary) for each hazard event. The sources included:

- Australian Bureau of Statistics census database (ABS, 2011) accessed through the Census Table Builder to estimate the total number of employed persons and owners of unincorporated and incorporated businesses by Place of Work and to obtain their average weekly income,
- National Regional Profile database (ABS, 2014) to estimate the number of businesses in the three industry sectors in the study area,
- GA's Bundaberg business survey (Canterford, 2016b) to estimate the duration of business interruption for each industry category.

As stated earlier, none of the primary industry was exposed to flooding in the study area. The proportion of businesses affected in secondary and tertiary industry categories was estimated by dividing the number of affected businesses by the total number of businesses in the study area. This proportion was then applied to the number of employees, owners and managers of unincorporated and incorporated businesses to estimate the number of employees and owners affected by the flood for each hazard event.

The potential loss of income (*Li*) in secondary and tertiary industry categories for each hazard event was calculated as the summation of the product of the number of affected employees and owners in each employment category, the duration of disruption and the average weekly income, as shown in Equation (11).

$$Li = \sum_{i=1}^{n}(Number\ of\ Affected\ Employees\ or\ Owners\ x\ Duration\ of\ Disruption\ x\ Average\ Income\ Loss) \quad (11)$$

Table 17 presents the potential loss of income in the three employment categories in secondary and tertiary industry categories for each hazard event.

TABLE 17: ESTIMATED POTENTIAL LOSS OF INCOME BY EMPLOYMENT CATEGORY

ARI (Year)	Number of Affected Secondary Businesses	Number of Affected Tertiary Businesses	Estimated Potential Loss in Wage/Salary Income ($ M)		Estimated Potential Loss in Owner's Income of Unincorporated Business ($ M)		Estimated Potential Loss in Owner's Income of Incorporated Business ($ M)	
			Secondary Businesses	Tertiary Businesses	Secondary Businesses	Tertiary Businesses	Secondary Businesses	Tertiary Businesses
100,000	4	642	0.037	22.66	0.004	1.44	0.005	1.76
1,000	4	462	0.037	16.32	0.004	1.04	0.005	1.27
500	4	436	0.037	15.41	0.004	0.98	0.005	1.20
200	4	408	0.037	14.41	0.004	0.92	0.005	1.12
100	3	384	0.028	13.59	0.003	0.87	0.004	1.06
50	2	337	0.019	11.88	0.002	0.76	0.002	0.92
20	1	256	0.009	9.06	0.001	0.58	0.001	0.71

Table 18 presents the potential and conditional losses of income for secondary and tertiary industry categories for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the new levee system reduced the AAL of income by $0.14 million.

TABLE 18: ESTIMATED LOSS OF INCOME (NON-RESIDENTIAL SECTOR)

ARI (Year)	Number of Affected Secondary Businesses	Number of Affected Tertiary Businesses	Potential Loss - Secondary Sector ($ M)	Potential - Tertiary Sector ($ M)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
						Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	4	642	0.05	25.87	25.92	1	1	25.92	25.92	0.176	0.035
1,000	4	462	0.05	18.63	18.68	1	1	18.68	18.68		
500	4	436	0.05	17.59	17.64	1	0.1	17.64	1.76		
200	4	408	0.05	16.46	16.50	0.75	0	12.38	0		
100	3	384	0.03	15.52	15.56	0.4	0	6.22	0		
50	2	337	0.02	13.56	13.58	0.05	0	0.68	0		
20	1	256	0.01	10.35	10.36	0.0005	0	0.005	0		

Cost of Clean-up

In a similar approach as used to estimate the cost of clean-up in the residential sector, the clean-up cost for the non-residential properties was estimated by using per unit area cost recorded by the Bundaberg Regional Council during the 2013 Bundaberg floods.

The non-residential buildings were categorised into three major categories i.e. commercial, industrial and institutions. The ground floor area affected by each flood event in these categories was calculated by overlaying the flood footprint of each event on the building footprints. The unit clean-up costs during the Bundaberg floods to commercial, industrial and institutions were reported to be $1.52, $1.30 and $3.28 per square meter, respectively (Honor, 2017).

The total cost of clean-up (*Lcnr*) in each industry category for each hazard event was then assessed as the summation of the product of total affected ground floor area and the average clean-up cost per unit area, and shown in Equation (12).

$$Lcnr = \sum_{i=1}^{n}(Ground\ Floor\ Area\ x\ Clean\ up\ Cost\ per\ unit\ area) \quad (12)$$

Table 19 presents the total potential and conditional clean-up costs for each hazard event. It was estimated that the mitigation investment in the new levee system reduced the AAL due to clean-up cost by $0.004 million.

TABLE 19: ESTIMATED COST OF CLEAN-UP (NON-RESIDENTIAL SECTOR)

ARI (Year)	Floor Area (m²)			Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
	Commercial	Industrial	Institutions		Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	179,616	220,851	42,875	0.70	1	1	0.70	0.70	0.0053	0.0009
1,000	124,415	200,596	28,259	0.54	1	1	0.54	0.54		
500	120,432	193,715	26,990	0.52	1	0.1	0.52	0.05		
200	110,974	188,200	26,990	0.50	0.75	0	0.38	0		
100	104,274	181,832	26,990	0.48	0.4	0	0.19	0		
50	84,045	166,255	24,580	0.42	0.05	0	0.02	0		
20	70,366	122,473	15,809	0.32	0.0005	0	0.00	0		

Loss of Turnover

In a similar approach as used to estimate the loss of inventory, the loss of turnover in the non-residential sector was estimated for each business by utilising the outcomes of the GA's Bundaberg business survey conducted after the January 2013 flood and was inflated to 2016 values. The average loss of turnover in a business in secondary and tertiary sectors was estimated to be $137,324 and $95,640, respectively.

The total potential loss of turnover (*Lt*) for each hazard event was calculated as the summation of the product of the number of affected businesses in each industry sector and the average loss of turnover in a business as assessed above, and shown in Equation (13).

$$Lt = \sum_{i=1}^{n}(Number\ of\ Affected\ Properties\ x\ Average\ Loss) \qquad (13)$$

Table 20 presents the potential and conditional loss of turnover for secondary and tertiary industry sectors for each hazard event along with the AAL before and after the mitigation. It was estimated that the mitigation investment in the new levee system reduced the AAL due to loss of turnover by $0.34 million.

TABLE 20: ESTIMATED LOSS OF TURNOVER (NON-RESIDENTIAL SECTOR)

ARI (Year)	Number of Affected Secondary Businesses	Number of Affected Tertiary Businesses	Potential Loss - Secondary Sector ($ M)	Potential - Tertiary Sector ($ M)	Total Potential Loss ($ M)	Conditional Probability of Failure		Conditional Loss ($ M)		Average Annual Loss ($ M)	
						Before Mitigation	After Mitigation	Before Mitigation	After Mitigation	Before Mitigation	After Mitigation
100,000	4	642	0.55	61.40	61.95	1	1	61.95	61.95	0.422	0.084
1,000	4	462	0.55	44.18	44,.73	1	1	44,.73	44,.73		
500	4	436	0.55	41.69	42.25	1	0.1	42.25	4.22		
200	4	408	0.55	39.02	39.57	0.75	0	29.67	0		
100	3	384	0.41	36.72	37.14	0.4	0	14.86	0		
50	2	337	0.27	32.23	32.50	0.05	0	1.62	0		
20	1	256	0.14	24.48	24.62	0.0005	0	0.01	0		

Total Non-residential Costs

The total non-residential losses (L*nres*) were comprised of the building repair cost (L*bnr*), loss of stock (L*s*), loss of inventory (L*inv*), clean-up cost (L*cnr*) and loss of income (L*i*) due to business disruption (loss of wages and proprietor's income), as shown in Equation (14).

$$Lnres = Lbnr + Ls + Linv + Lcnr + Li \tag{14}$$

Table 21 and Table 22 present the estimated conditional losses to the non-residential sector before and after construction of the new levee system, respectively. It was estimated that the mitigation investment reduced the AAL in the non-residential sector by $1.06 million.

Figure 11 shows the spatial distribution of potential cost of building repair for each non-residential property in the hazard event without any flood protection.

TABLE 21: ESTIMATED CONDITIONAL LOSS ($) IN NON-RESIDENTIAL SECTOR - BEFORE MITIGATION

ARI (Year)	Annual Probability of Exceedance	Building Repair Cost ($ M)	Clean-up Cost ($ M)	Loss of Inventory ($ M)	Loss of Stock ($ M)	Loss of Income - Incorporated Business ($ M)	Loss of Income - Unincorporated Business ($ M)	Loss of Wage or Salary ($ M)	Total ($ M)	Average Annual Loss – Before Mitigation ($ M)
100,000	0.00001	244.8	0.7	20.9	11.9	1.8	1.5	22.7	304.2	1.40
1,000	0.001	120.0	0.5	15.1	8.6	1.3	1.0	16.3	162.9	
500	0.002	111.8	0.5	14.2	8.1	1.2	1.0	15.4	152.3	
200	0.005	65.5	0.3	10.0	5.7	0.8	0.7	10.8	93.9	
100	0.01	28.6	0.2	5.0	2.8	0.4	0.3	5.4	42.9	
50	0.02	2.8	0.02	0.5	0.3	0.05	0.04	0.6	4.4	
20	0.05	0.02	0	0	0	0	0	0	0.03	

TABLE 22: ESTIMATED CONDITIONAL LOSS ($) IN NON-RESIDENTIAL SECTOR - AFTER MITIGATION

ARI (Year)	Annual Probability of Exceedance	Building Repair Cost ($ M)	Clean-up Cost ($ M)	Loss of Inventory ($ M)	Loss of Stock ($ M)	Loss of Income - Incorporated Business ($ M)	Loss of Income - Unincorporated Business ($ M)	Loss of Wage or Salary ($ M)	Total ($ M)	Average Annual Loss – After Mitigation ($ M)
100,000	0.00001	244.8	0.7	20.9	11.9	1.8	1.5	22.7	304.2	0.34
1,000	0.001	120.0	0.5	15.1	8.6	1.3	1.0	16.3	162.9	
500	0.002	11.2	0	1.4	0.8	0.1	0.1	1.5	15.2	
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	

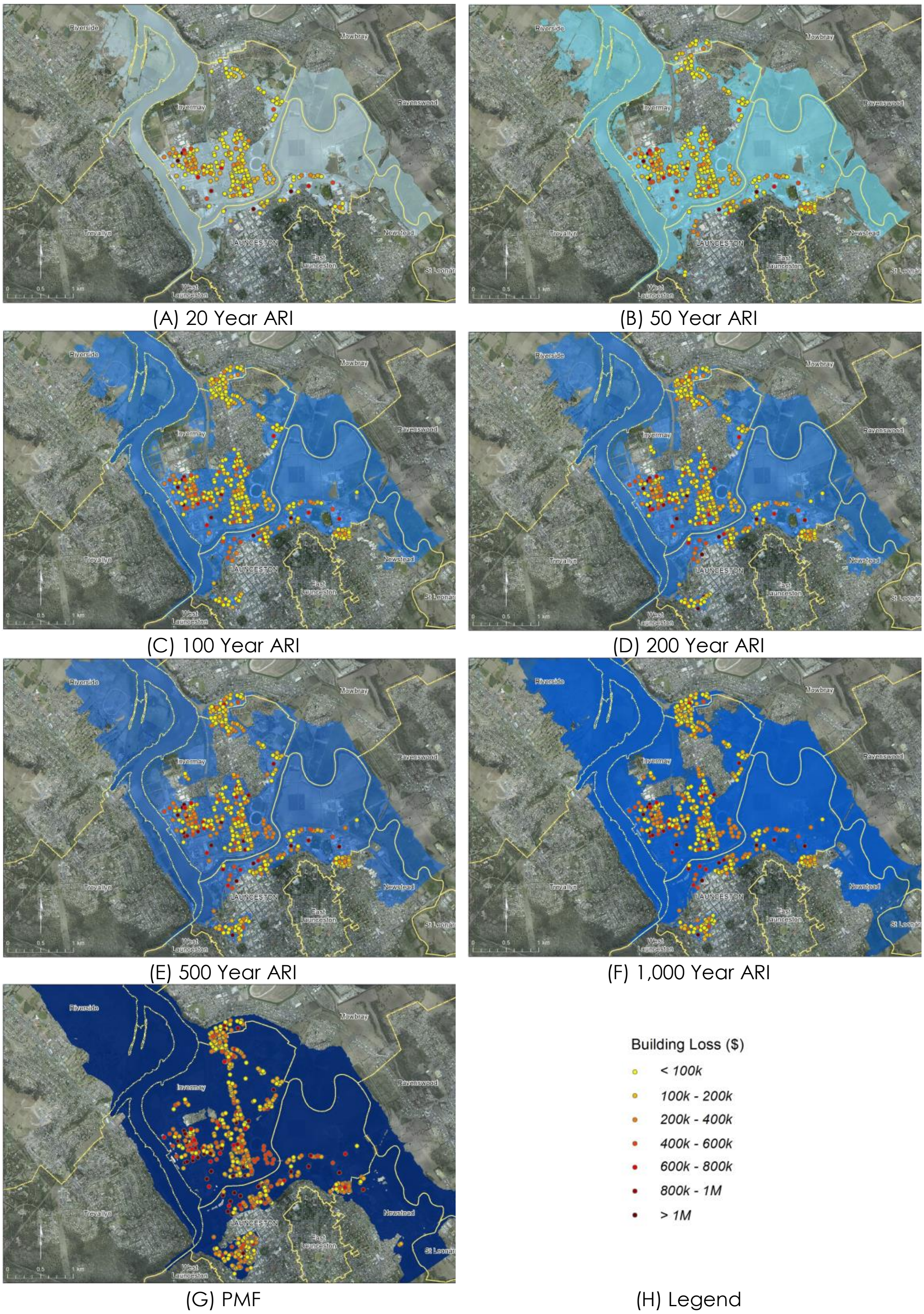


FIGURE 11: POTENTIAL BUILDING REPAIR COSTS FOR THE NON-RESIDENTIAL SECTOR

LONG-TERM COST

Table 23 presents the estimated total losses to the residential and non-residential sector before and after construction of the new levee system. 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 $2.91 million in the AAL which reflects the savings made by the investment in mitigation.

Figure 12 and Figure 13 show the loss exceedance curves for residential and non-residential sectors for the components listed in Table 2.

TABLE 23: ESTIMATED TOTAL LOSS ($) BEFORE AND AFTER MITIGATION

ARI (Years)	Annual Probability of Exceedance	Potential Loss ($ M)	Conditional Loss – Before Mitigation ($ M)	Conditional Loss – After Mitigation ($ M)	Average Annual Loss – Before Mitigation ($ M)	Average Annual Loss – After Mitigation ($ M)
100,000	0.00001	972.2	972.2	972.2		
1,000	0.001	476.5	476.5	476.5		
500	0.002	430.2	430.2	43.0		
200	0.005	324.8	256.4	0	3.95	1.04
100	0.01	278.4	111.2	0		
50	0.02	232.4	11.9	0		
20	0.05	165.8	0.08	0		

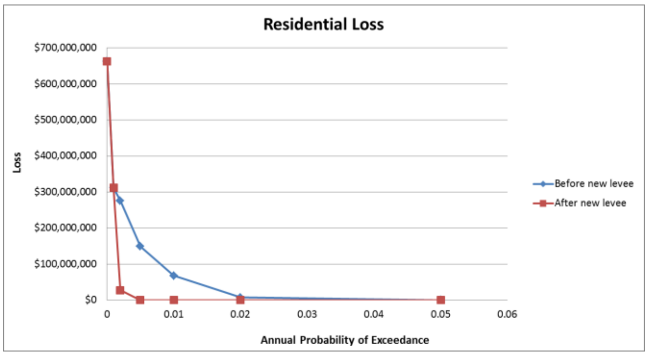


FIGURE 12: LOSS EXCEEDANCE CURVE FOR THE RESIDENTIAL SECTOR

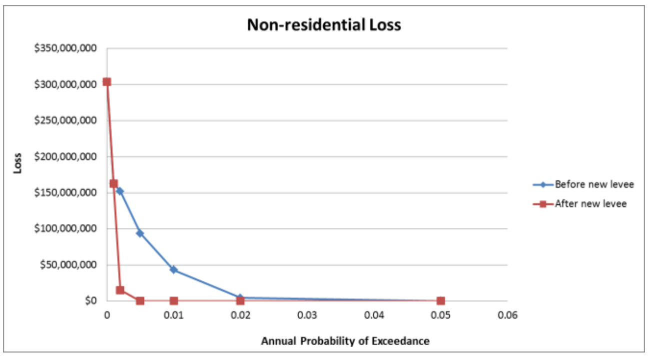


FIGURE 13: LOSS EXCEEDANCE CURVE FOR THE NON-RESIDENTIAL SECTOR

COST BENEFIT ANALYSIS

Typically, in Australia, a 7% discount rate has 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 as the future climate related impacts and benefits tend to disappear in economic assessments when high discount rates are used (Chigama, 2017).

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 actual investment cost of the project comprised an initial construction and land acquisition cost of $58 million in 2016 dollars.

The ongoing maintenance cost consists of $181,000 annually and an additional $250,000 dollars every five years for the first twenty years of the project (Fullard, 2016). However, it was assumed that the maintenance cost would be same for both the existing and new levee, and therefore, was not included in the CBA.

The CBA shows that the BCR remained less than 1.0 for the discounted rates of 5% to 7% when the actual project costs were used (see Table 24). However, the BCR improved considerably if the original estimated cost of the project used for decision making was used. This was assessed to be $22 million in 2006 ($28 million in 2016 dollars) by GHD (2006) but was exacerbated later due to increases in the cost of construction and land acquisition (Fullard, 2013). The original estimated cost yielded BCR greater than 1.0 for all discount rates.

TABLE 24: COST BENEFIT ANALYSIS FOR SELECTED DISCOUNT RATES

Cost Basis	Total Investment (2016 $ M)	Avoided Losses (2016 $ M)					Benefit Cost Ratio (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
Actual Cost	58.4*	88.0	69.7	57.1	48.1	41.4	1.51	1.19	0.98	0.82	0.71
Estimated Cost	27.9	88.0	69.7	57.1	48.1	41.4	3.15	2.49	2.04	1.72	1.48

*The final investment cost is expected to increase further as total relocation cost has not finalised yet (Roberts, 2017).

EFFECT OF SEA LEVEL RISE

This study also reviewed the impact of predicted sea level rise on the total cost of building repair by incorporating two scenarios of 0.5m and 0.8m rise for selected ARI events. The resulting increase in the peak flood level due to sea level rise was provided by Fullard (2013) as shown in Table 25.

It was found that sea level rise scenarios had a limited impact (3% to 12% increase in conditional loss). Furthermore, as the sea level rise is a future scenario the influence it would have on economic assessment would be small as the conditional losses are discounted.

Had the required information been available, it would be of great interest to assess the combined impact of sea level rise and increased rainfall intensity due to climate change on the total losses. A similar study conducted by GA in the Alexandra Canal catchment area in Sydney assessed potential flood losses based on the impacts of sea level rise and increased rainfall intensity due to climate change (Maqsood et al. 2013). Potentially the combined effects may influence mitigation investment decisions made today.

TABLE 25: IMPACT OF SEA LEVEL RISE ON BUILDING REPAIR COST

ARI (Years)	Annual Probability of Exceedance	Peak Flood Level (m AHD)			Building Repair Costs ($ M)			Change in Costs	
		(0.0m Rise)	(0.5m Rise)	(0.8m Rise)	(0.0m Rise)	(0.5m Rise)	(0.8m Rise)	(0.5m Rise)	(0.8m Rise)
200	0.005	4.24	4.31	4.39	177.6	182.2	187.5	3%	6%
100	0.01	3.84	3.95	4.05	79.6	83.8	87.3	5%	10%
50	0.02	3.38	3.49	3.63	8.2	8.6	9.1	6%	12%

AVOIDED LOSSES DURING JUNE 2016 FLOOD

The results indicated that during the June 2016 flood in Launceston (a 50 year ARI event for the South Esk River based on LCC, 2016) the reconstruction of the levee system resulted in avoiding losses of about $216 million had the pre-existing levees failed. The losses that would be experienced with levee failure would be approximately four times the investment in the new levee system.

SENSITIVITY ANALYSIS

The selection of appropriate input values for the following parameters plays an important role in assessing the BCR and selecting the best outcome.

- Maintenance costs.
- Discount rates.
- Conditional probabilities of levee failure.

A sensitivity analysis has been conducted to find out how sensitive the BCR is to any change in these parameters for the actual cost of investment i.e. $58 million.

Table 26 lists the three cases used to assess the impact of changes in the maintenance cost of the old levee system on the BCR of the new mitigation investment for selected discount rates. Case 2 is the base case for which it is assumed that there is no difference in maintenance cost between the new and old levees with its consequential exclusion from the analysis. Case 1 refers to a scenario in which the cost of maintaining the new levee is more than the old levee and therefore incurs extra ongoing maintenance cost. This results in lowering the BCR as shown in Figure 14. Case 3 refers to a scenario in which the cost of maintaining the new levee is less than the old levee and therefore incurs savings which result in improving the BCR (see Figure 14). However, the changes in maintenance cost results in a minor change of about 4% in the BCR, demonstrating that maintenance cost is not a critical input.

TABLE 26: MAINTENANACE COST FOR OLD AND NEW LEVEES

Case	New Levee ($ 000s)	Old Levee ($ 000s)	Difference ($ 000s)
Case 1	180	80	100
Case 2	180	180	0
Case 3	180	280	-100

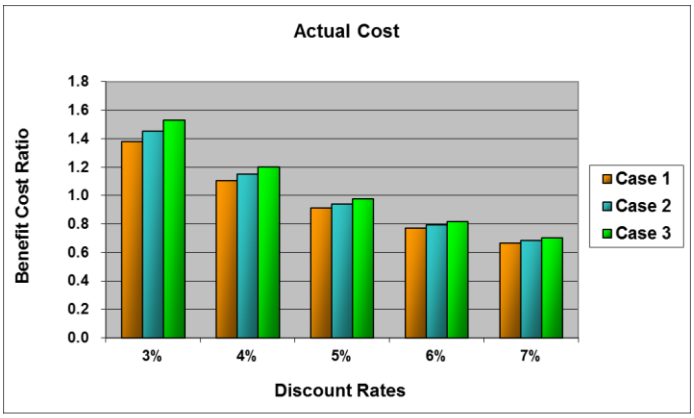


FIGURE 14: EFFECT OF CHANGE IN MAINTENANCE COST TO THE BENEFIT COST RATIO

Table 27 lists the three cases considered to assess the impact of changes to the conditional probability of failure of the new and the old levee systems on the BCR of the new mitigation investment for selected discount rates. Case 2 is the base case for which the results have been presented earlier for selected conditional probabilities of failure for the new and the old levee systems (see Table 3 and Table 24).

TABLE 27: CONDITIONAL PROBABILITY OF FAILURE/OVERTOPPING OF NEW AND OLD LEVEES

ARI (Years)	Case 1		Case 2		Case 3	
	Conditional Probability of Failure of Old Levees	Conditional Probability of Failure of New Levees	Conditional Probability of Failure of Old Levees	Conditional Probability of Failure of New Levees	Conditional Probability of Failure of Old Levees	Conditional Probability of Failure of New Levees
100,000	100%	100%	100%	100%	100%	100%
1,000	100%	100%	100%	100%	100%	100%
500	100%	50%	100%	10%	100%	5%
200	50%	0%	75%	0%	100%	0%
100	30%	0%	40%	0%	50%	0%
50	1%	0%	5%	0%	10%	0%
20	0.01%	0%	0.05%	0%	1%	0%

For the old levee system, Case 1 refers to an optimistic scenario where the old levee system is considered to better protect the community with lower probabilities of failure for all the ARIs below 500 year, whereas Case 3 refers to a pessimistic scenario with high probabilities of failure. The range of conditional probabilities of failure of the old levee system was provided by GHD, 2006.

For the new levee system, Case 1 refers to a pessimistic scenario and Case 3 refers to an optimistic scenario with low probabilities of failure to better protect the community for all the ARIs below 1,000 year.

As shown in Figure 15 the selected changes in conditional probabilities of failure in Case 1 results in a reduction of about 38% in the BCR, demonstrating that the conditional probability of failure is a critical input. In Case 3 the resulted change in the BCR is about 29%. Figure 15 shows that the BCR ranges from as low as 0.4 to as high as 1.8 depending upon the discount rate and the conditional failure probability associated with the levee systems.

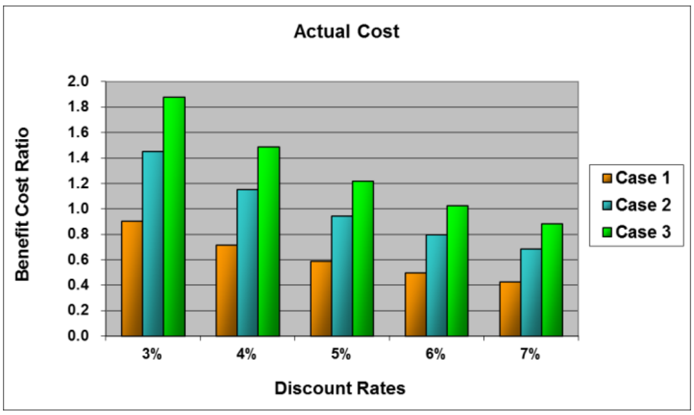


FIGURE 15: EFFECT OF CHANGE IN MAINTENANCE COST TO THE BENEFIT COST RATIO

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. Only the tangible impacts which can be measured or are quantifiable into monetary values can be readily included. These tangible impacts can be catogorised into direct and indirect impacts. Direct impacts refer to the damage caused to people and the built environment which are directly affected by water and are within the flood footprint. Indirect impacts refer to the damage caused to people and the built environment that are outside the flood footprint. Further, there are other forms of impact which are classified as intangibles and therefore cannot be quantified into monetary values. Examples of intangible include stress, trauma, depression, and loss of living environments or social contacts and relationships.

This study has focused on assessing 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, clean-up cost, loss of business stock, loss of inventory, loss of income due to business interruption and loss of life.

The BCR would be increased by taking into account other costs to infrastructure, storm water and sewage systems, damage to vehicles and investment income loss. Furthermore, indirect costs such as the cost of emergency services response, loss of utility of services, other indirect economic costs and the intangible costs mentioned above could also be included to make this analysis more comprehensive. However, lack of data and difficulty in assigning monetary values to intangibles have 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.

FINDINGS

Key findings of this study are summarised below:

- The losses that would have been experienced during the June 2016 floods should the old levee had failed would be approximately four times the total investment in the new levee system.
- The investment in building the new flood levee system in Launceston was found to be a sound economic decision based on the estimated costs at the time of decision making and improved estimates of benefits from this study.
- Actual benefits of the mitigation works to the community are greater than could be assessed economically and would further support the investment in mitigation.
- It is found that sea level rise scenarios have only a limited impact on building losses. However, the combined impact of sea level rise and increased rainfall intensity due to climate change on the total losses may be significantly greater and could be further investigated.

ACKNOWLEDGEMENTS

The authors are grateful to Launceston City Council for providing valuable information to conduct this study. The Council provided the authors with the following datasets which were critical input into the flood risk assessment and the CBA:

- 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).

The authors would like to thank Andrew Fullard (Launceston Flood Authority) for providing construction and maintenance costs for the new levee system in Launceston.

The authors would like to thank Dwayne Honor (Bundaberg Regional Council) for providing estimates of clean-up cost for the residential and non-residential sectors based on the Council's experience after the 2013 floods.

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.

The authors also thank the project stakeholders including the BNHCRC, Tasmanian Department of Premier and Cabinet, Tasmanian State Emergency Service, Launceston Flood Authority and Northern Midlands Council to share their local knowledge and contributing in the scoping of this study.

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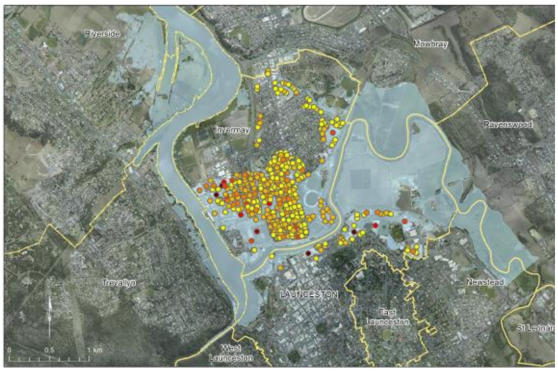
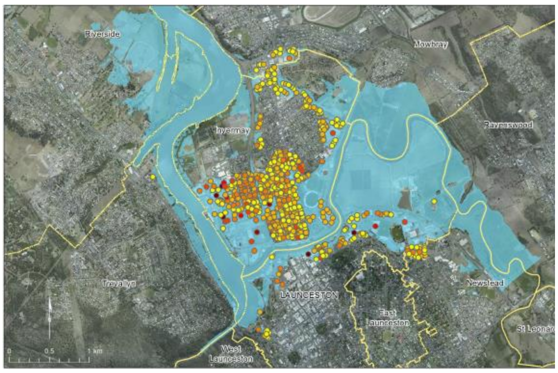
APPENDIX A: RESULTS

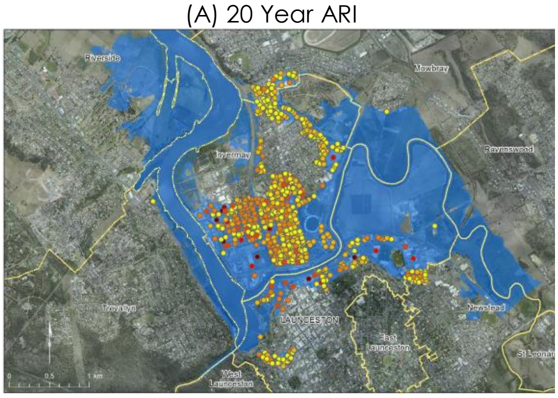
Figure A1 shows the spatial distribution of potential loss due to building repair for each building in the study area for each hazard event.



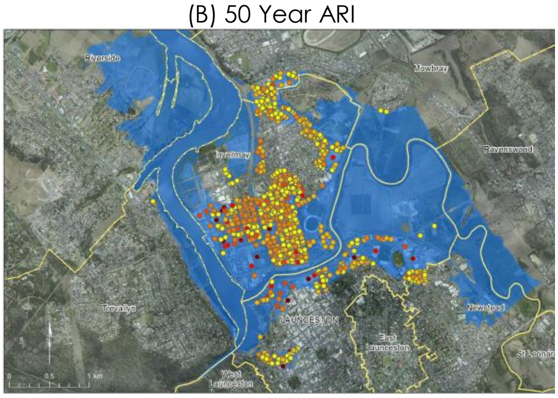
(A) 20 Year ARI



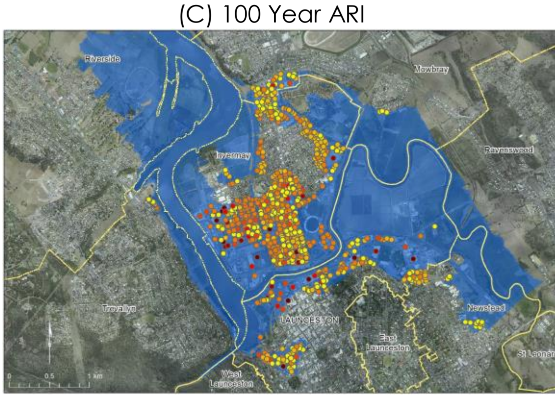
(B) 50 Year ARI



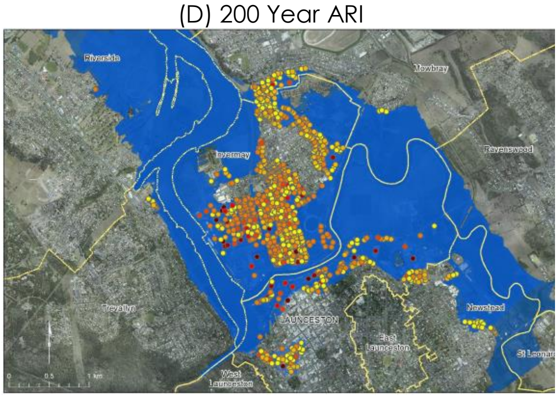
(C) 100 Year ARI



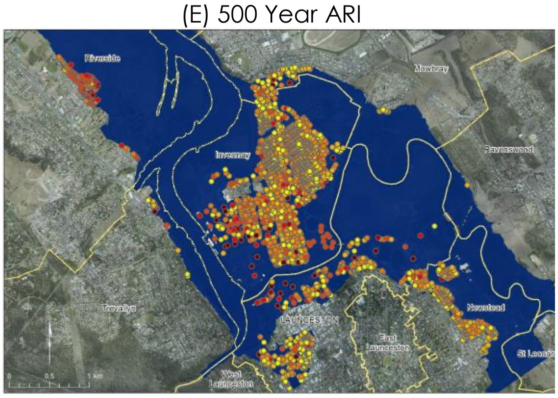
(D) 200 Year ARI



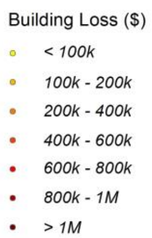
(E) 500 Year ARI



(F) 1,000 Year ARI



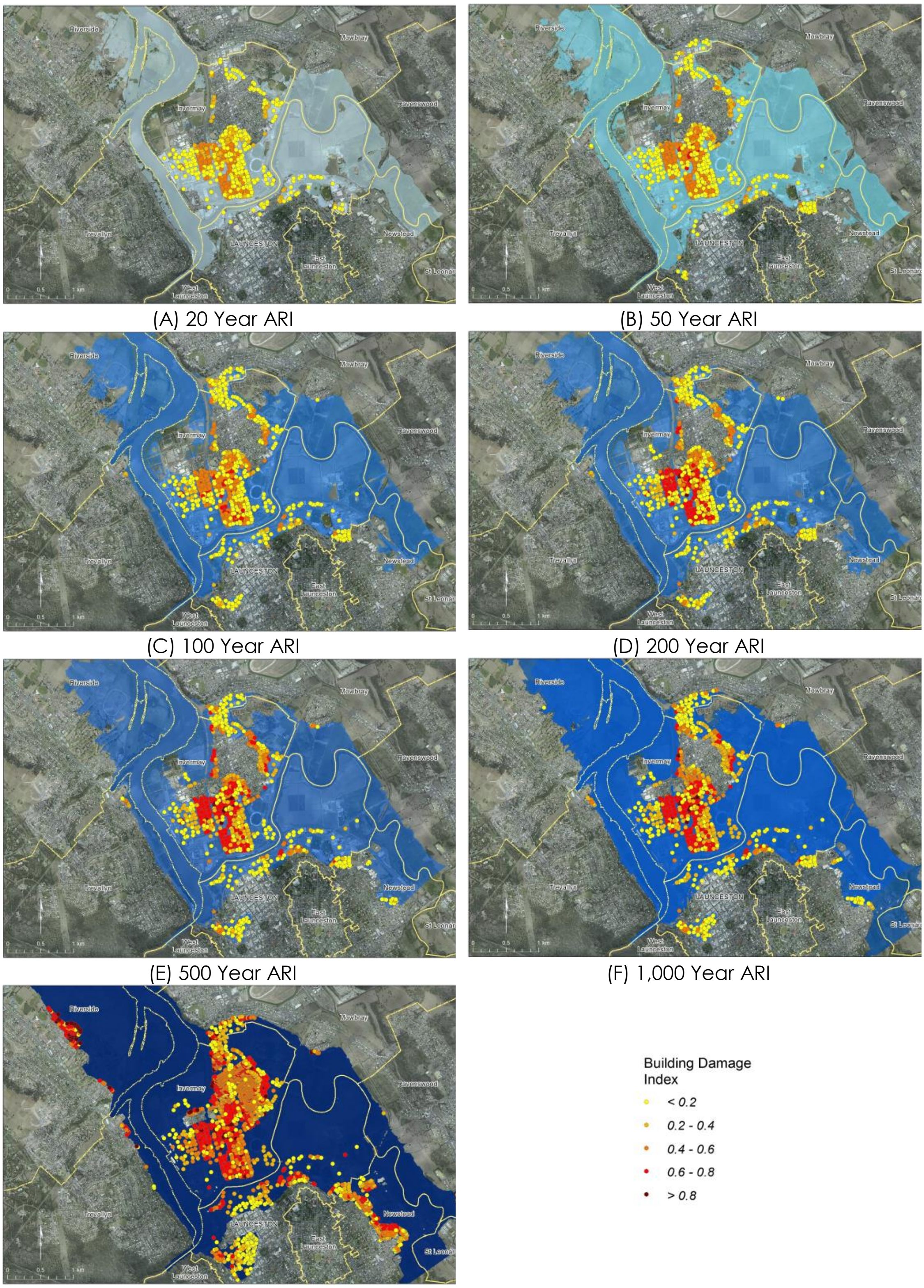
(G) PMF



(H) Legend

FIGURE A1: SPATIAL DISTRIBUTION OF BUILDING REAPIR LOSS ($) FOR ALL BUILDINGS

Figure A2 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

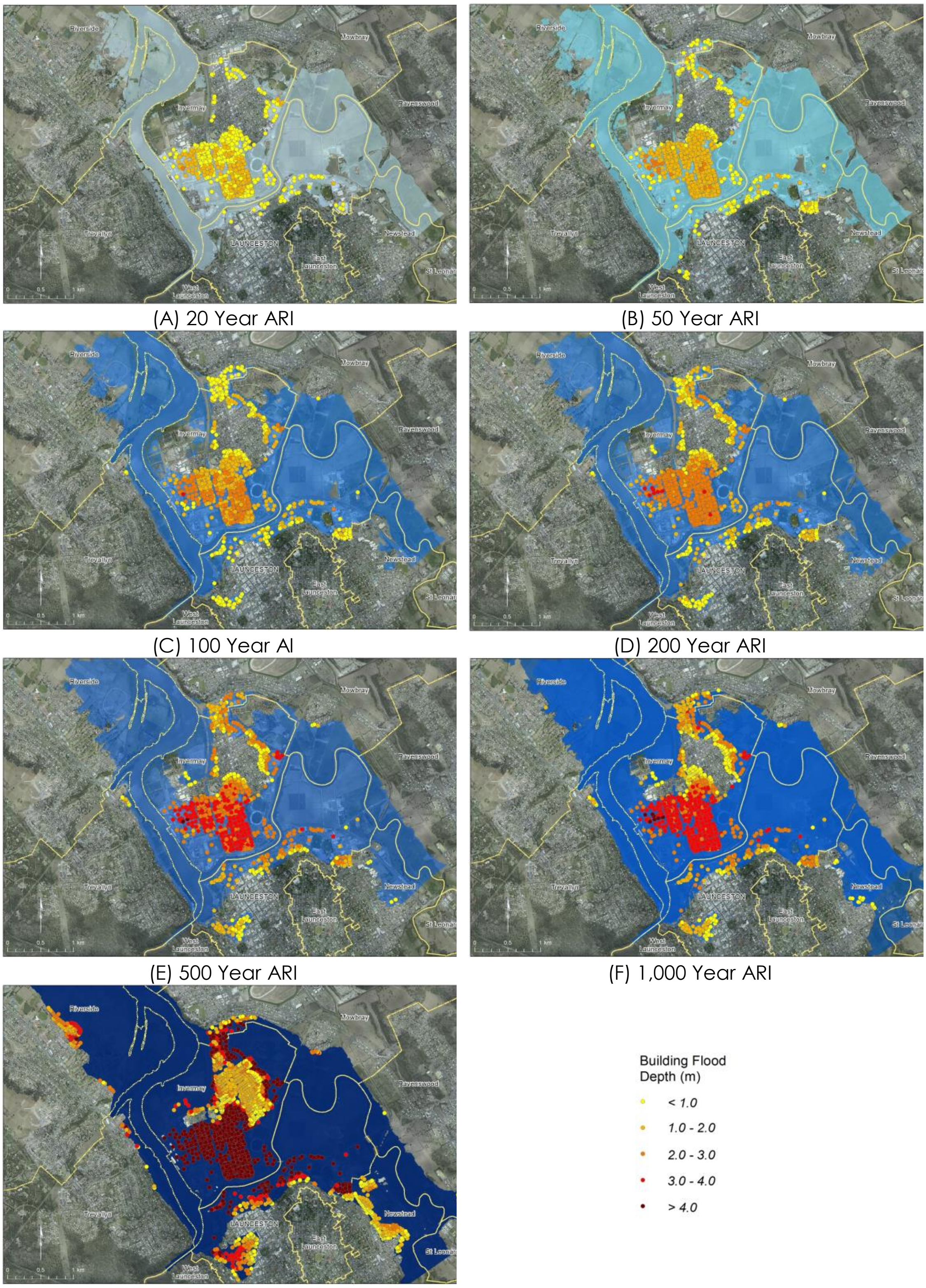
(F) 1,000 Year ARI

(G) PMF

(H) Legend

FIGURE A2: SPATIAL DISTRIBUTION OF BUILDING INDEX FOR ALL BUILDINGS

Figure A3 shows the spatial distribution of inundation depth above ground floor for each building for each hazard event.



(A) 20 Year ARI (B) 50 Year ARI

(C) 100 Year AI (D) 200 Year ARI

(E) 500 Year ARI (F) 1,000 Year ARI

(G) PMF (H) Legend

FIGURE A3: SPATIAL DISTRIBUTION OF INUNDATION DEPTH ABOVE GROUND FLOOR (m AHD)

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	127	89	52	130	209	289	365
0.01 to 0.15	23	13	7	34	37	19	20
0.16 to 0.70	149	123	69	96	73	77	134
0.71 to 1.20	213	123	101	72	70	103	364
1.21 to 2.4	508	186	163	448	521	428	33
More than 2.4	960	544	524	136	6	0	0
Total	1,980	1,078	916	916	916	916	916

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	26	14	17	38	52	80	110
0.01 to 0.15	3	3	0	4	12	9	10
0.16 to 0.70	37	22	21	29	31	31	29
0.71 to 1.20	36	14	19	27	26	22	34
1.21 to 2.4	61	70	68	67	72	56	15
More than 2.4	194	84	73	33	5	0	0
Total	357	207	198	198	198	198	198

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	4	7	4	13	23	43	92
0.01 to 0.15	1	1	0	5	8	9	5
0.16 to 0.70	3	8	9	20	23	43	31
0.71 to 1.20	13	17	14	25	43	30	66
1.21 to 2.4	20	76	73	89	132	126	59
More than 2.4	259	158	151	101	24	2	0
Total	300	267	251	253	253	253	253

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	0	1	2	2	3	3	6
0.01 to 0.15	1	1	0	0	0	0	3
0.16 to 0.70	0	0	0	1	1	6	3
0.71 to 1.20	1	1	1	2	5	3	2
1.21 to 2.4	4	5	6	9	5	2	0
More than 2.4	13	6	5	0	0	0	0
Total	19	14	14	14	14	14	14

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.

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 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.