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COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR FLOOD PRONE BUILDINGS

Report on benefit versus cost analysis and optimal cost effective mitigation strategies

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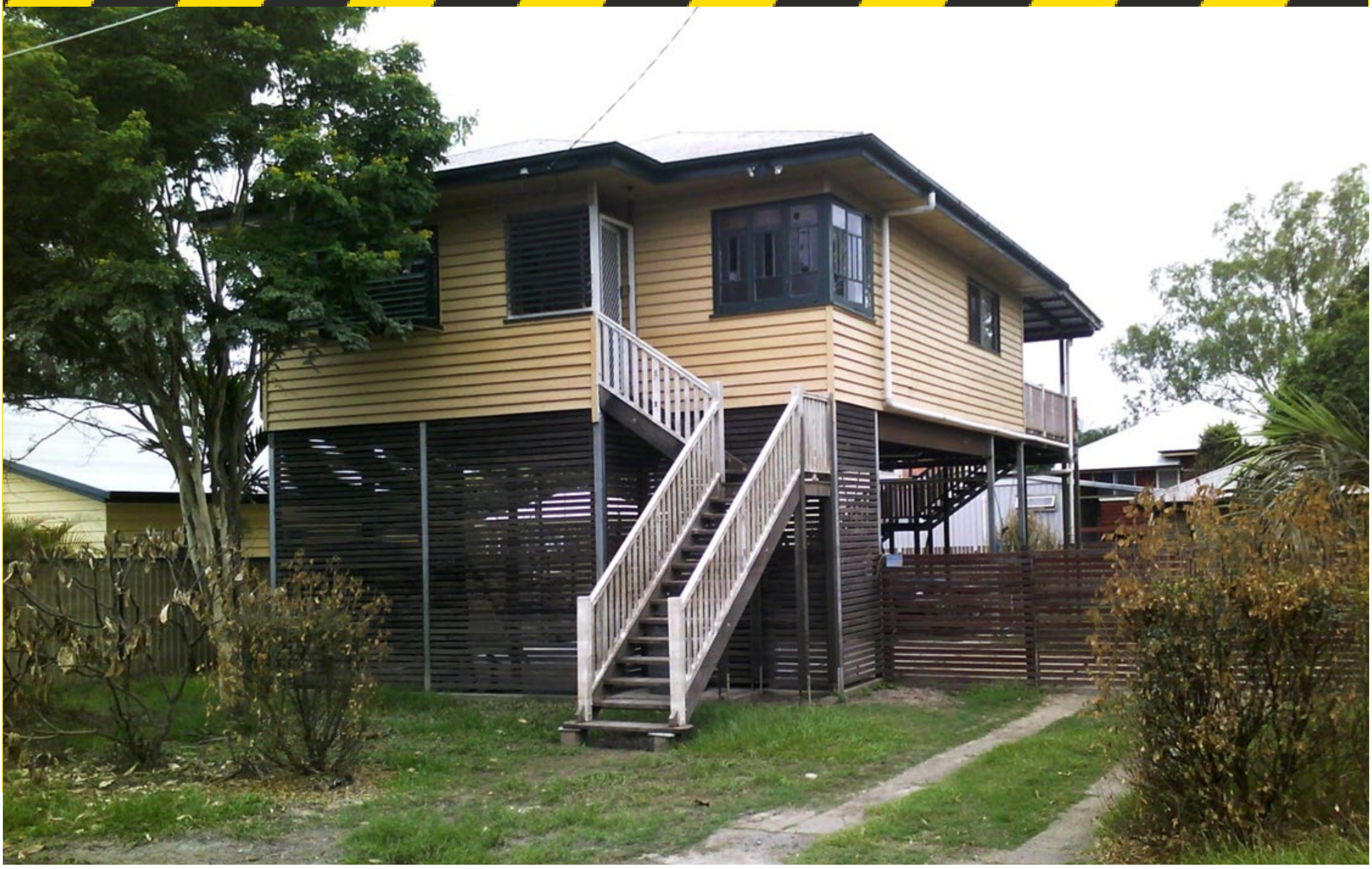

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Cover: Flood mitigation strategy: elevating floor level. Photo: Geoscience Australia

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EXECUTIVE SUMMARY

This report forms part of the output to a research project entitled 'Cost effective mitigation strategy development for flood prone buildings' within the Bushfire and Natural Hazards Cooperative Research Centre. The motivation for this project arises from the experience and observations during the recent flooding in Australia in 2011, 2013 and 2015, which caused widespread devastation in Queensland. A fundamental reason for this damage was inappropriate development in floodplains and a legacy of high risk building stock in flood prone areas. The BNHCRC project aims to address this issue and is targeted at assessing mitigation strategies to reduce the vulnerability of existing residential building stock in Australian floodplains.

Previous project steps towards achieving this goal have included the development of a building schema to categorise the Australian residential building stock and a literature review of mitigation strategies developed nationally and internationally. The review categorised strategies into elevation, relocation, dry floodproofing, wet floodproofing and the use of flood barriers. Five typical storey types which represent the most common residential buildings in Australia have been selected to evaluate the above mentioned mitigation strategies.

Each mitigation strategy has been costed through engagement of a professional quantity surveyor and the application of the mitigation strategies and resultant reduction in susceptibility of damage has been quantified in the form of vulnerability models for mitigated storey types.

This report presents an assessment of the cost-effectiveness of flood mitigation strategies to residential buildings in Launceston Tasmania through a benefit versus cost analysis. The benefit versus cost analysis requires assessing loss both pre-and post-mitigation for a range of flood likelihoods with the difference being the benefit. The costs of the applied mitigation are then compared to the benefits with a benefit versus cost ratio of greater than 1.0 indicating an economically viable decision.

In the research presented here the mitigation options were typically assessed as cost-effective when considering damage to the rersidential buildings with the probable maximum flood extent. An important modelling assumption was to assume that the existing levee system that does provide a level of flood protection to Launceston was not in place (i.e. the City was unprotected). The results here are also only for one catchment and its behavior and also for the building stock in Launceston. The use of temporary flood barriers around the area with the highest flood hazard was the most cost-effective measure.

Work will continue with cost versus benefit analyses planned for other locations with different building stock configuarations and different catchment type behaviours. The result will be an evidence base to inform decision making by government and property owners on the mitigation of flood risk. The evidence base will feature information on the cost effectiveness of different mitigation strategies and optimal solutions for different cases of building and catchment types.

INTRODUCTION

In Australia, floods cause more damage on an average annual cost basis than any other natural hazard. Figure 1 shows the Average Annual Losses (AAL) by disaster type in Australia from 2007 to 2016 (Deloitte Access Economics [DAE], 2017). The fundamental causes of this level of damage and the key factor contributing to flood risk, in general, is the presence of vulnerable buildings constructed within floodplains due to ineffective land use planning.

The increasing trend of flood damage to residential buildings can only be mitigated through better flood risk management by government authorities and also by improvements and mitigation efforts adopted by private households (Kreibich et al. 2010; Productivity Commission, 2014).

The Bushfire and Natural Hazards Collaborative Research Centre project entitled 'Cost-effective mitigation strategy development for flood prone buildings' (BNHCRC, 2020) examines the opportunities for reducing the vulnerability of Australian residential buildings to flood. It addresses the need for an evidence base to inform decision making on the mitigation of the flood risk posed by the most vulnerable Australian building types and complements parallel BNHCRC projects for earthquake and severe wind.

This project investigates methods for the upgrading of existing residential building stock in floodplains to increase its resilience in future flood events. It aims to identify economically optimal mitigation solutions so the finite resources available can be best used to minimise losses, decrease human suffering, improve safety and ensure amenity for communities. This report presents an assessment of the cost-effectiveness of flood mitigation strategies to residential buildings in Launceston Tasmania through a benefit versus cost analysis.

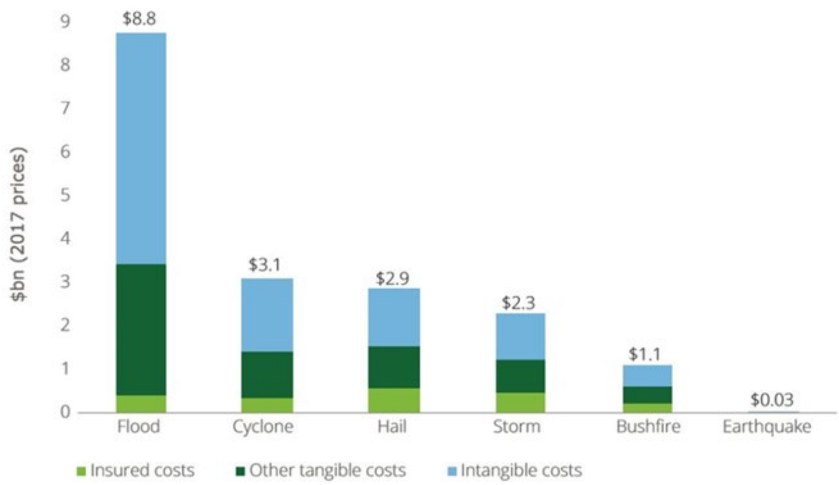

FIGURE 1: AVERAGE ANNUAL LOSSES BY DISASTER TYPE IN AUSTRALIA FROM 2007 T0 2016 (DAE, 2017)

BACKGROUND

A number of project activities required for the cost-benefit analysis have been completed in previous years. These are summarised in the following sections.

DEVELOPMENT OF BUILDING CLASSIFICATION SCHEMA

A schema was proposed in this project to categorise Australian residential building stock into a limited number of typical storey types. It was a fundamental shift from describing the complete building as an entity to one that focuses on sub-components. The proposed schema divided each building into the sub-elements of foundations, bottom floor, upper floors (if any) and roof to describe its vulnerability (see Figure 2).

Through this approach it was possible to assess the vulnerability of structures with different usage and/or construction materials used in different floors, and also to assess the vulnerability of tall structures with basements where only basements and/or bottom floors are expected to be inundated (Maqsood et al. 2015a). The schema classified each storey type based on six attributes: construction period, fit-out quality, storey height, bottom floor, internal wall material and external wall material.

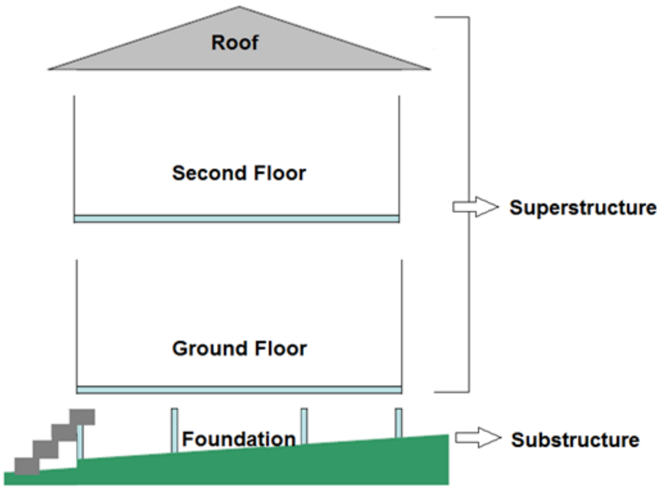

FIGURE 2: SCHEMATIC DIAGRAM OF BUILDING COMPONENTS USED IN SCHEMA (MAQSOOD ET AL., 2015A)

LITERATURE REVIEW OF FLOOD MITIGATION STRATEGIES

A literature review of mitigation strategies developed nationally and internationally was undertaken to evaluate the strategies that suit Australian building types and typical catchment behaviours. The review categorised mitigation strategies into five categories: elevation, relocation, dry floodproofing, wet floodproofing and flood barriers. These options are described briefly below with further detail on each provided in reporting by Maqsood et al. (2015b).

Elevation

Elevation of a structure is one of the more common mitigation strategies which aims to raise the lowest habitable floor of a building above the expected level of flooding. This can be achieved, for example, by (i) raising the whole structure on new foundations (walls, piers or columns); (ii) changing the ground floor usage and constructing a new floor above the existing one and, (iii) extending the walls of an existing structure and raising the floor level.

Relocation

Relocation of a building is the most dependable technique in mitigation of flood risk. However, it is generally the most expensive as well (USACE, 1993). Relocation involves moving a structure to a location that is less prone to flooding or exposed to flood-related hazards such as erosion or scouring. Relocation normally involves placing the structure on a wheeled vehicle. The structure is then transported to a new location and set on a new foundation (FEMA, 2012).

Dry floodproofing

In dry floodproofing the portion of a structure that is below the expected flood level is sealed to make it substantially impermeable to floodwaters. Such an outcome is achieved by using sealant systems which include wall coatings, waterproofing compounds, impervious sheeting over doors and windows and a supplementary leaf of masonry (FEMA, 2012). Preventing sewer backflow by using backwater valves is also important in making dry floodproofing effective (Kreibich et al. 2005; FEMA, 2007). Sump pumps are also used to drain out the water which may leak through small openings or due to exterior wall permeability (FEMA, 2013).

Wet floodproofing

In this measure the building is modified and floodwater is allowed to enter into the building to equalise the hydrostatic pressure on the interior and exterior of the building, thus reducing the chance of building failure (USACE, 1993; FEMA, 2007). As this technique entails all the building components below the flood level being wetted, all construction material and fit-outs should be water-resistant and/or can be easily cleaned following a flood. Wet floodproofing involves raising utilities and important contents above the expected flood level and installing flood openings (FEMA, 1999). This strategy can be implemented during two different construction regimes i.e. existing state before any event and substantial renovation or reconstruction after an event. Both regimes have been considered in this project.

Flood barriers

ICPR (2002) states that flood damage can potentially be reduced by 80-100% if water barriers provided are not over-topped. Flood barriers considered here are those built around a single building and are normally placed some distance (usually 3.0m) away from it to avoid any structural modifications to the building. There are two kinds of barriers: permanent and temporary. An example of a permanent barrier is a floodwall which is quite effective because it requires little maintenance and can be easily constructed and inspected. Generally, it is made of reinforced masonry or concrete (in rare instances glass) and has one or more passageways through it that are closed by gates during a flood and require periodic maintenance. The options considered here for permanent flood barriers were:

1. 300mm thick and 1500mm high core filled reinforced block walls and 1000mm high self-closing gate
2. 300mm thick and 2300mm high core filled reinforced block walls and 1800mm high self-closing gate

There are also several types of temporary flood barriers available on the market which can be moved, stored and reused. A number of vendors make temporary flood barriers that can be assembled relatively easily, moved into place, anchored and filled with water (if required). Examples of some of the flood barrier options are sandbags, tubes, fences and box wall. The options considered here for temporary flood barriers were provided by FSAG (2016):

1. 900mm high Floodstop barrier system including removable keys
2. 1200mm high Floodplank system including removable posts and planks
3. 1800mm high Floodplank system including removable posts and planks

DEVELOPMENT OF COSTING MODULES FOR SELECTED MITIGATION OPTIONS

Predominant construction materials and storey types used in Australia were identified and used to inform the development of costing modules. Five typical residential storey types were selected for detailed study in this research. Key characteristics of these storey types are presented in Table 1.

TABLE 1: CHARACTERISTICS OF SELECTED STOREY TYPES

Storey Type	Construction period	Bottom floor system	Fit-out quality	Storey height	Internal wall material	External wall material	Photo
1	Pre-1960	Raised Timber	Low	2.7m	Timber	Weather-board	
2	Pre-1960	Raised Timber	Low	3.0m	Masonry	Cavity masonry	

3	Pre-1960	Raised Timber	Low	2.4m	Masonry	Cavity masonry	
4	Post-1960	Raised Timber	Standard	2.4m	Plasterboard	Brick veneer	
5	Post-1960	Slab-on-grade	Standard	2.4m	Plasterboard	Brick veneer	

Based on the characteristics of the selected storey types a flood protection matrix was developed which excluded mitigation options that were invalid in the Australian context. Costing modules (see Table 2) were developed by quantity surveying specialists to estimate the cost of implementing all appropriate mitigation strategies for the five storey types (Maqsood et al., 2016).

TABLE 2: COST OF IMPLEMENTING FLOOD MITIGATION STRATEGISES TO EXISTING BUILDINGS FOR SELECTED STOREY TYPES (MAQSOOD ET AL., 2016)

Storey Type	Elevation-Extending the walls ($)	Elevation-Building a second storey ($)	Elevation-Raising the whole house ($)	Relocation ($)	Flood Barriers (Permanent) ($)		Flood Barriers (Temporary) ($)			Dry Flood-proofing ($)	Wet Flood-proofing ($)	
					1.0m high	1.8m high	0.9m high	1.2m high	1.8m high		Existing structure	Substantial Renovation
1	N/A	N/A	78,200	58,000	N/A	N/A	N/A	N/A	N/A	N/A	10,600	68,000
2	N/A	213,500	N/A	N/A	133,500	177,600	62,500	111,800	136,300	N/A	15,400	56,600
3	397,700	429,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17,400	104,300
4	N/A	405,200	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	15,500	140,000
5	N/A	431,000	N/A	N/A	154,300	208,300	164,600	144,100	176,200	124,000	17,900	149,800

VULNERABILITY ASSESSMENT FOR CURRENT AND MITIGATED BUILDING TYPES

The vulnerability of the selected building types to a wide range of inundation depths was assessed and supplemented by a significant body of flood vulnerability research by Geoscience Australia. An example of implementing appropriate mitigation measures considered for the slab-on-grade brick veneer (Storey Type 5) and resulting vulnerability models is shown in Figure 3.

This activity considered appropriate strategies for five selected storey types during two construction regimes: existing state (pre-event) and during substantial renovation or post-event reconstruction. Detailed outcomes were reported by Maqsood et al (2018).

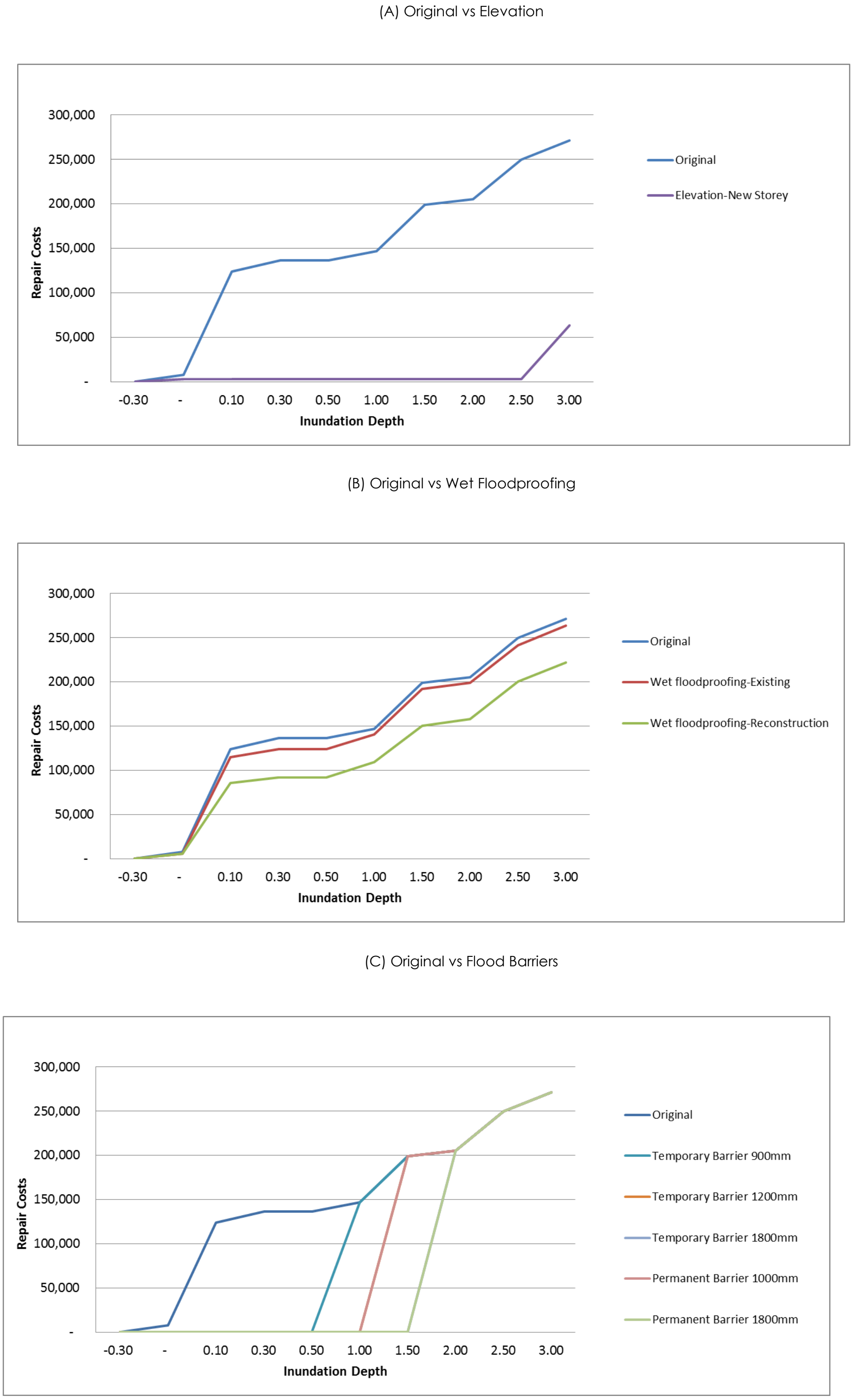

FIGURE 3: VULNERABILITY MODELS FOR STOREY TYPE 5: BRICK VENEER (SLAB-ON-GRADE)

CATCHMENT TYPE DEFINITION

The project team has investigated ways of defining catchment behavior in an attempt to cover as many situations as possible (ie catchment behavior and building stock variation) in the benefit versus cost analyses. Through a collaboration agreement between IAG and Geoscience Australia the team has been able to access flood studies held in IAG's database.

Two methods were considered for categorising flood hazard for different catchments:

- Assess flood depths for a range of average recurrence intervals (ARIs) at selected reference points for each flood study area. The number of reference points required in each study area depends on the size of catchment, level of exposure and topographic differences within the catchment (along with other possible factors). Reference point selection would be a time consuming process.
- Use flood depths for a range of ARIs for all residential buildings within the 100 year ARI flood extent map and fit a curve through all the points. In this process the 100 year ARI depth at each property was adjusted to 0.0m and all other water depths at the site adjusted relative to it. The slope of the curves from a number of flood studies could be used to characterise catchments into three typical types (low, medium, high) based on selected definition/criteria. High corresponds with flood depth that increases greatly with lengthening ARI.

The second method was selected for use as it was assessed as capturing a better overall picture of the hazard and also permitted the assessment of variation and/or uncertainty of hazard within a flood study area. As an example Figure 4 shows results from a number of different catchments with average flood depth plotted against ARI. The 'steepness' of the regressed line will be used in defining catchments into three types as discussed in the point above.

Four locations have been identified for study at this time: Murwillumbah (NSW), Tweed Heads (NSW), Wagga Wagga (NSW), and Launceston (Tasmania). The focus of this report is Launceston.

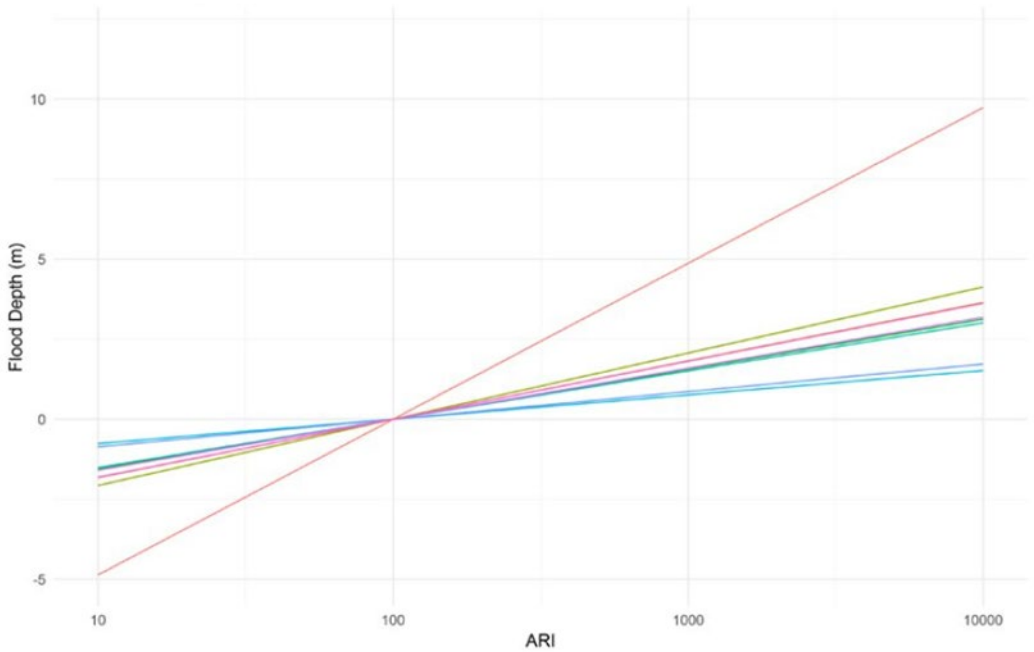

FIGURE 4: EXAMPLES OF CATCHMENT 'STEEPNESS' USING IAG FLOOD DATABASE. LINEAR REGRESSION FITS FOR DEPTH PROFILE IN SELECTED AREAS NORMALISED WITH D100=0M.

BENEFIT VERSUS COST ANALYSIS

Retrofit options entail an investment that will realise a benefit over future years through reduced average annualised loss caused by severe flood exposure. Decisions to invest in reducing building vulnerability, either through asset owner initiatives or the provision by government or insurance industry incentives, will depend upon the benefit versus cost of the retrofit.

In this research, retrofit options were assessed through a consideration of a range of severity and likelihood of flood hazard covering a selection of catchment types. The work provides information on the optimal retrofit types and design levels in the context of Australian construction costs and catchment behaviours.

BENEFIT VERSUS COST ANALYSIS FRAMEWORK

The application of the benefit versus cost analysis in this study was to evaluate the cost-efficiency of flood risk mitigation investment for a variety of mitigation options for typical Australian residential buildings. The benefit versus cost analysis comprised four steps as presented in Figure 4 and described below.

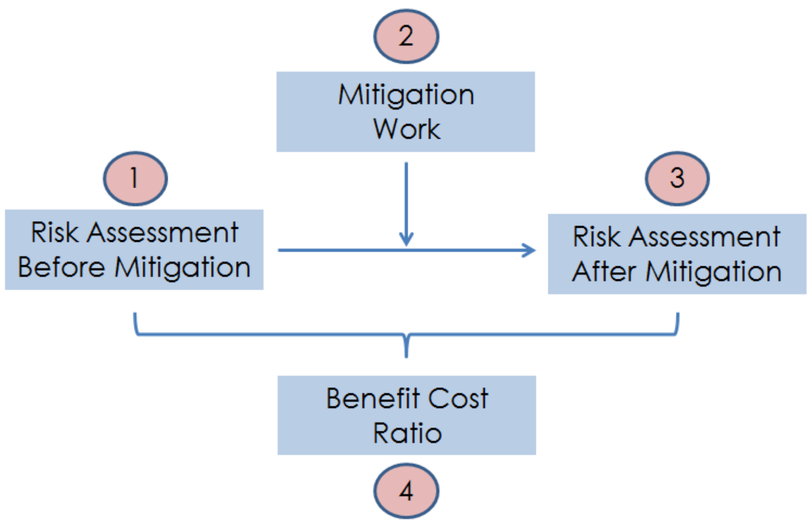

FIGURE 5: COST BENEFIT ANALYSIS FRAMEWORK (ADAPTED FROM MECHLER, 2005)

1. Risk Assessment before mitigation: at this step risk was calculated in terms of conditional loss ($) based on existing building stock (unretrofitted).
2. Mitigation work: this was the investment ($) to reduce potential impacts assessed in the first step. It was comprised of the costs of conducting the mitigation work on the relevant properties.
3. Risk Assessment after mitigation: at this step risk was again calculated incorporating the effects of the mitigation investment. There is typically a reduction of loss ($) compared to the pre-mitigation state. This reduction in loss ($) 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 need 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.

BENEFIT VERSUS COST ANALYSIS – LAUNCESTON, TASMANIA

The city of Launceston in Tasmania was chosen as the first study region for a benefit versus cost analysis of mitigation options in this project. 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 5). 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).

In this risk context, 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 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).

The project team was funded to undertake work to conduct a benefit versus cost of the Launceston flood mitigation initiative described above in 2016/17 (Maqsood et al, 2017). This current study of Launceston utilises some of the material developed for the previous work, but there are a number of significant differences. The current program of work:

- Assumes that the levee system does not exist.
- Considers only residential buildings and loss due to damage to those buildings. Contents losses and business interruption losses are not considered, nor are rental income losses or the cost of injuries or fatalities.

FIGURE 6: LAUNCESTON STUDY AREA

Flood 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 Launceston City Council (2011). To make the original study more rigorous and to include rarer events in the analysis the same consultant engaged to produce the 20 to 500 year ARI hazard was engaged to develop the hazard maps for the 1,000 year ARI and probable maximum flood (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 3 presents 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 the East Tamar Highway. Figure 7 shows the modelled flood extents for the events from the 20 year ARI to the PMF.

TABLE 3: 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

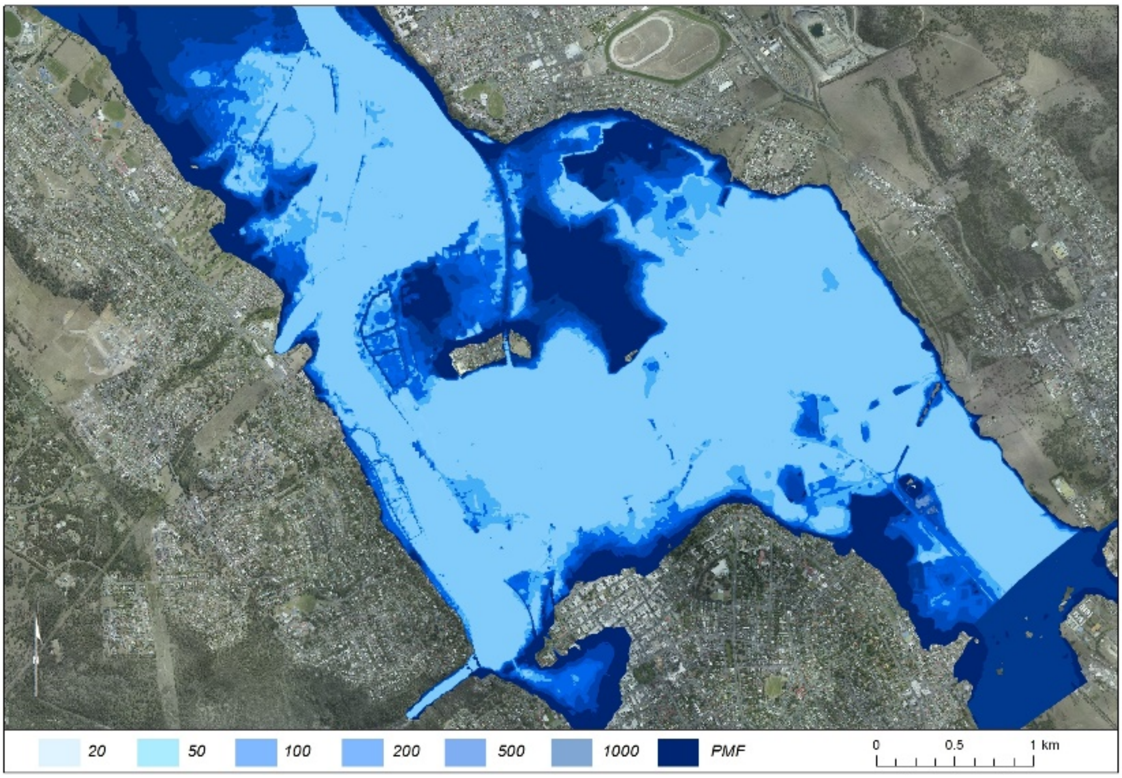

FIGURE 7: MODELLED FLOOD EXTENTS FOR SELECTED RECURRENCE INTERVALS

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 was focused on assessing impacts of floods on residential buildings only.

The exposure database was compiled for all residential buildings (820 in total) within the mapped PMF extent by sourcing building attributes from GA's National Exposure Information System - NEXIS (Geoscience Australia, 2020). This database was supplemented, where necessary, by a desktop study utilising Google street view imagery to record additional building attributes. Floor height information was provided by the Launceston City Council 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.

The 820 residential buildings within the PMF flood extent for which building level attributes were compiled in the exposure database are included in Figure 8 by the depth of water above floor in the modelled 100 year ARI flood. Other building attributes such as wall material, roof material, number of storeys and age are shown distributed in the subsequent figures.

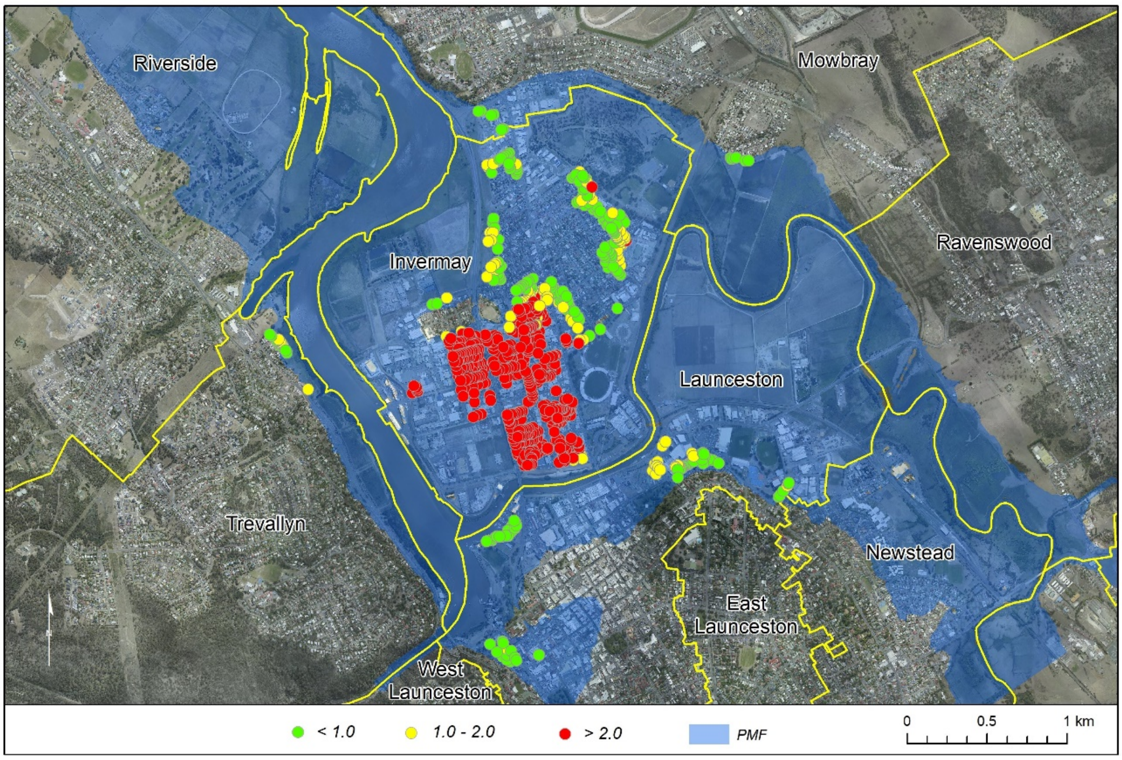

FIGURE 8: RESIDENTIAL BUILDINGS WITHIN PMF EXTENT BY WATER DEPTH OVER FLOOR IN 100 YEAR ARI EVENT

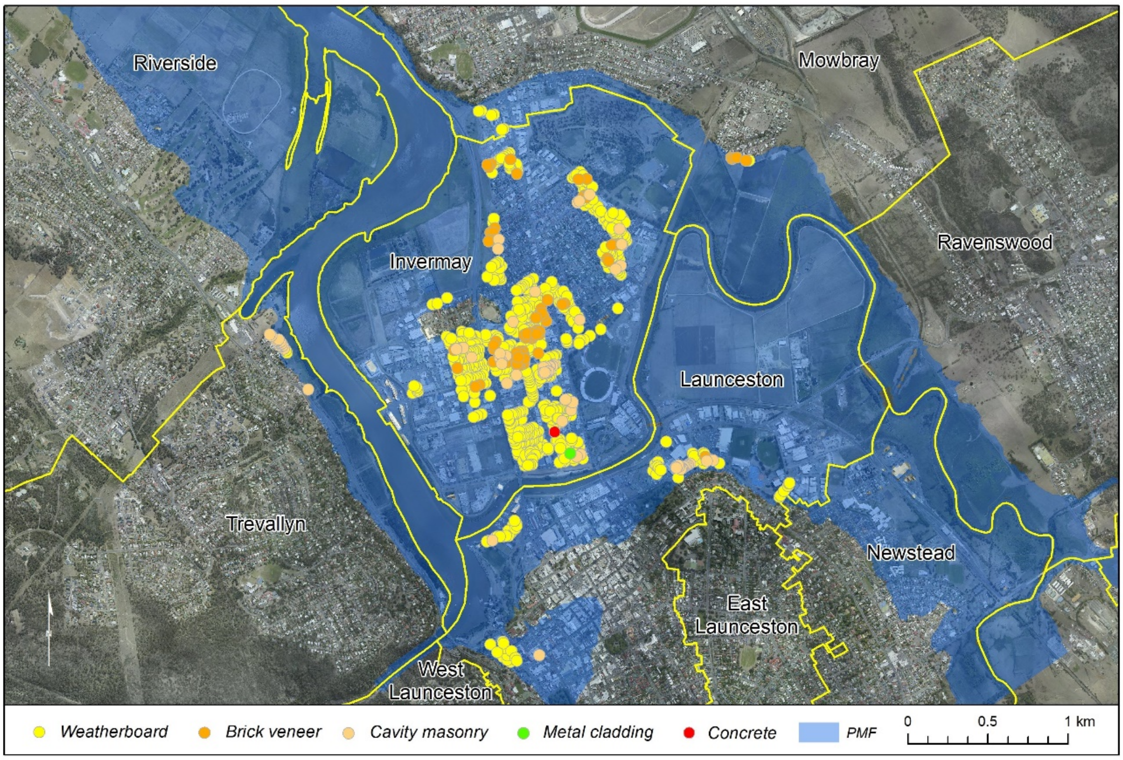

FIGURE 9: RESIDENTIAL BUILDINGS WITHIN PMF EXTENT BY WALL TYPE

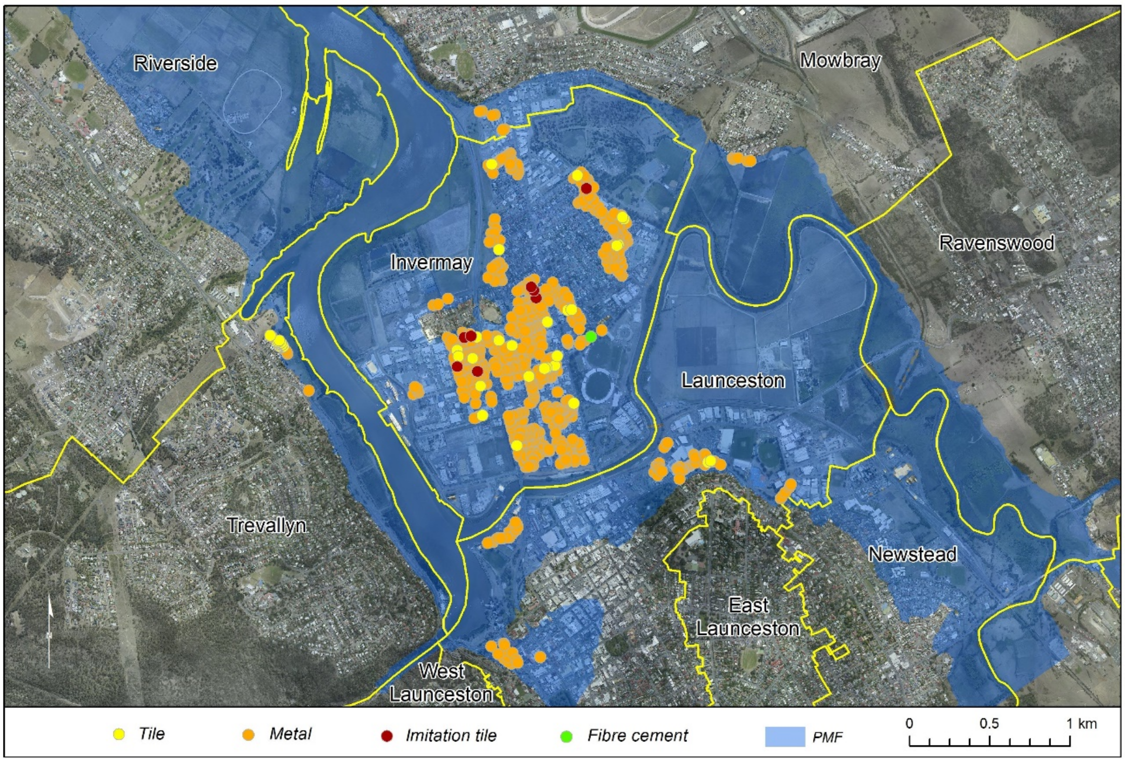

FIGURE 10: RESIDENTIAL BUILDINGS WITHIN PMF EXTENT BY ROOF TYPE

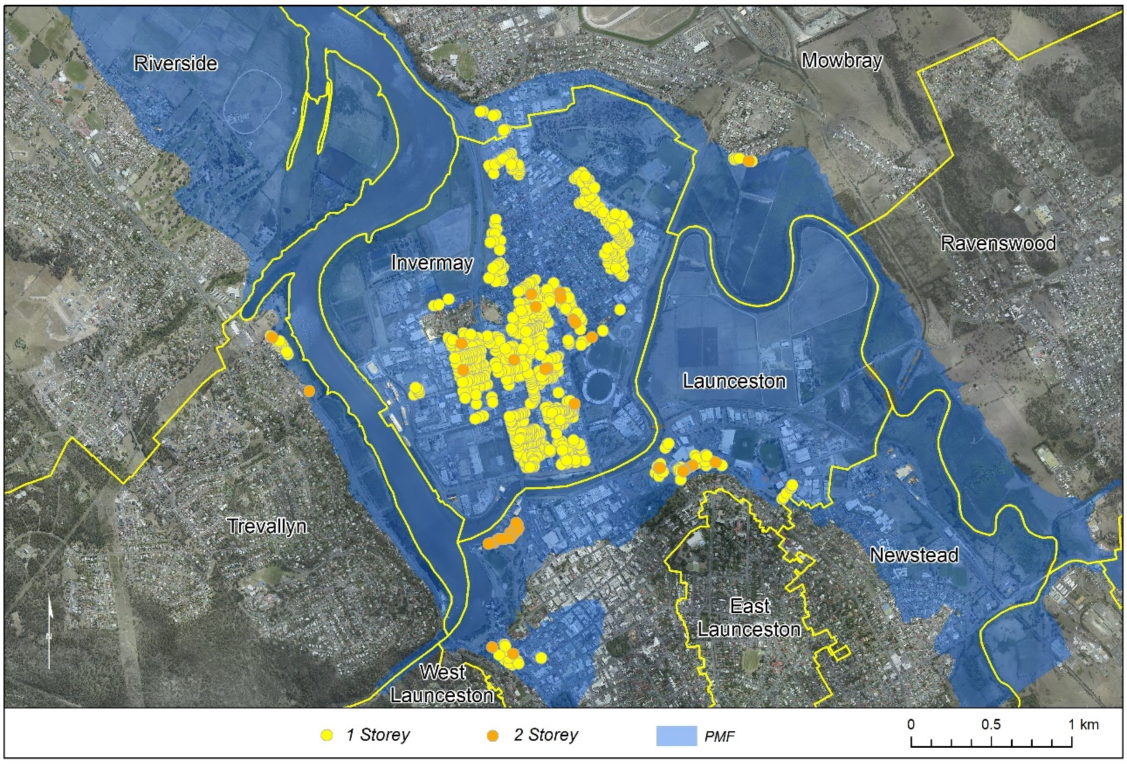

FIGURE 11: RESIDENTIAL BUILDINGS WITHIN PMF EXTENT BY NUMBER OF STOREYS

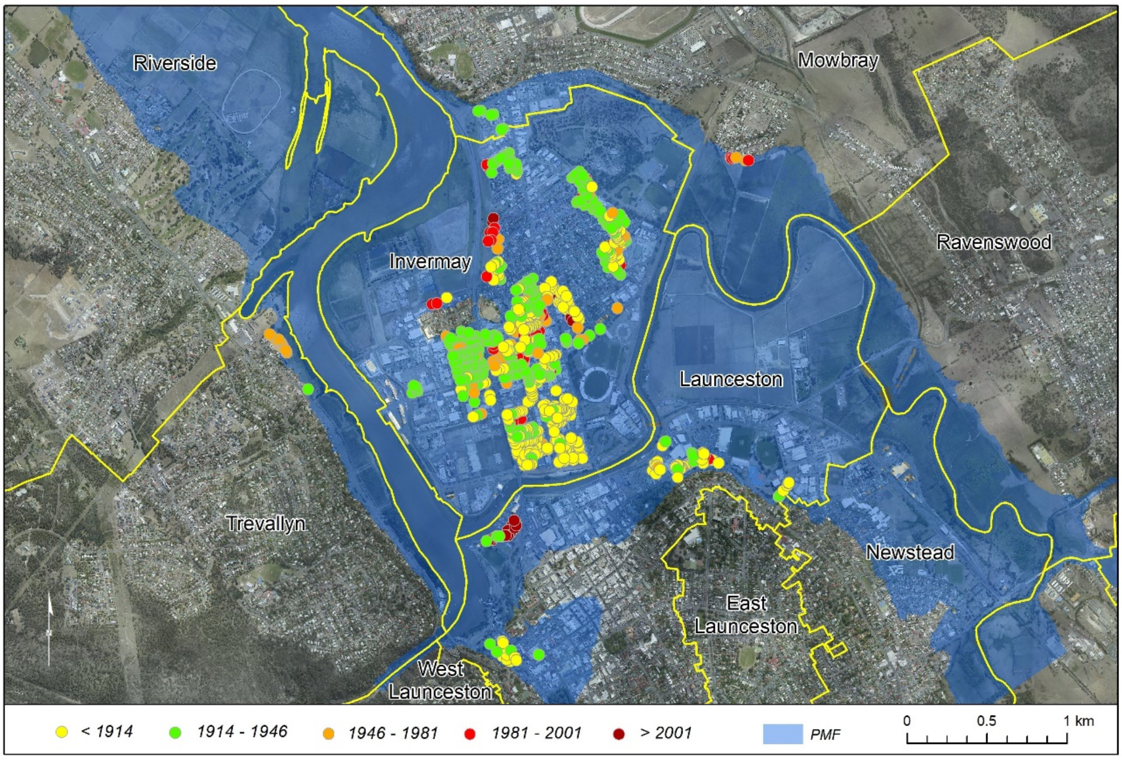

FIGURE 12: RESIDENTIAL BUILDINGS WITHIN PMF EXTENT BY YEAR BUILT

Vulnerability and Mitigated Vulnerability Models

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). They also included vulnerability models for contents of residential buildings (11 models in total). Appendix A presents the vulnerability curves (mitigated and unmitigated) used in the benefit versus cost analysis undertaken here.

Application of Mitigation Options through the Floodplain

Assuming no existing flood protection works in Launceston, a number of options related to mitigation were explored through this work. Firstly not all mitigation options are appropriate for all the considered residential building types. A summary of wall types applicable to the different retrofit options is presented in Table 4.

TABLE 4: SUMMARY OF MITIGATION OPTIONS AND APPLICABLE WALL TYPES

Mitigation Options	Applicable Wall Types
House raising (3m)	Weatherboard, metal sheeting
House raising (2m)	Weatherboard, metal sheeting
Relocation	Weatherboard, metal sheeting
Dry floodproofing	Veneer masonry, cavity brick, precast concrete, fibre cement
Wet floodproofing - Existing	Veneer masonry, cavity brick, precast concrete, fibre cement
Wet floodproofing - Renovation	Veneer masonry, cavity brick, precast concrete, fibre cement
Barriers	All

Consideration was also given to the uptake of mitigation options within the floodplain. The 'ideal' mitigation results are based on every building for which a mitigation option is appropriate being virtually retrofitted (i.e. 100% of the applicable building stock have been modified to reduce their vulnerability). This is not a realistic outcome so a number of other scenarios with lower percentages of retrofit uptake have also been modelled. Three retrofit zones were defined based on their hazard related to the 100 year ARI. The extents of the zones are shown in Figure 13 with definitions as follows:

- Retrofit Zone 1 Red: High risk, 488 properties, inundation greater than 2m in the 100 year ARI event
- Retrofit Zone 2 Yellow: Medium risk, 111 properties, inundation between 1m and 2m in the 100 year ARI event
- Retrofit Zone 3 Green: Low risk, 221 properties, inundation less than 1m in the 100 year ARI event.

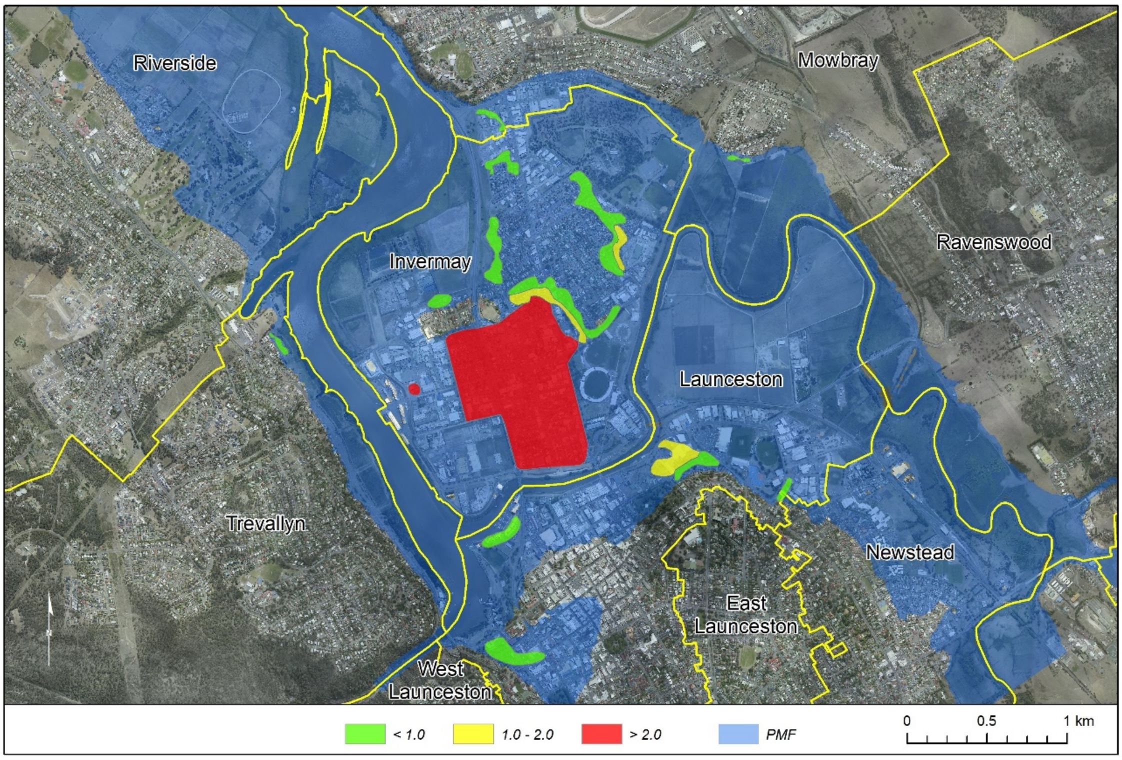

FIGURE 13: EXTENTS OF RETROFIT ZONES

The assumed retrofit percentages for applicable buildings by zone are shown in Table 5. They were chosen to try and reflect the most practical measures to be taken in the different zones. For example dry floodproofing can cause structural instability in deeper inundations and so it is not appropriate in Zones 1 and 2 but may be a reasonable choice in Zone 3. Conversely raising a house by 3m is not a good value proposition when floodwaters are likely to be low, so this option is not appropriate in Zone 3, but has an assumed uptake in appropriate building types of 30% in Zone 1.

The temporary barrier system was chosen to provide coverage as displayed in Figure 14. The barrier placement coincides with sealed roadways that it can be placed upon.

TABLE 5: SUMMARY OF ASSUMED MITIGATION UPTAKE BY ZONE

Mitigation Option	Assumed Mitigation Uptake by Zone (applicable wall types only)		
	Zone 1	Zone 2	Zone 3
House raising (3m)	30%	-	-
House raising (2m)	-	20%	-
Relocation	10%	-	-
Dry floodproofing	-	-	10%
Wet floodproofing - Existing	10%	20%	30%
Wet floodproofing - Reno	10%	20%	30%
Barriers	100%	-	-

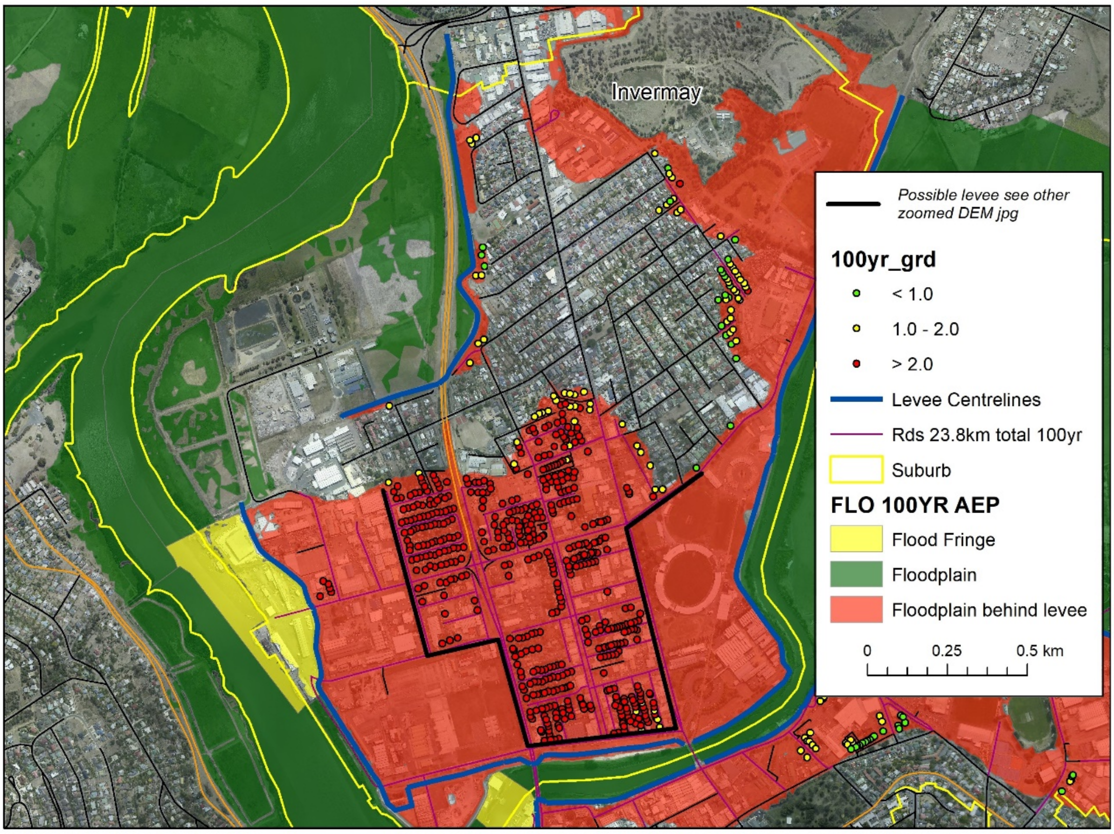

FIGURE 14: ASSUMED TEMPORARY BARRIER SYSTEM

Results

Risk can be measured as the aggregated annualised dollar loss (AAL) 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 residential building damage only.

Long Term Cost

Estimated residential building repair costs (pre-mitigation) by flood event are provided in Table 6. The average annualised loss based on these losses in $6.36M.

TABLE 6: ESTIMATED RESIDENTIAL BUILDING REPAIR COSTS BY FLOOD EVENT

ARI Event (years)	Estimated Residential Building Repair Cost Before Mitigation ($M)	Average Annualised Loss Before Mitigation($M)
100,000	278	6.36
1,000	225	
500	218	
200	171	
100	147	
50	123	
20	87	

Cost vesus Benefit Analysis

The benefit due to mitigation is measured in the reduction in AAL. AALs calculated after mitigation options have been virtually retrofit are shown in Table 7. The results are for the independent application of the mitigation measure in isolation, and not with the concurrent application of other measures.

TABLE 7: ESTIMATED RESIDENTIAL BUILDING REPAIR COSTS FOLLOWING MIMTIGATION

Mitigation Option	Average Annualised Loss After Mitigation (Mitigation uptake in brackets) ($M)			
	Ideal (100%)	Zone 1	Zone 2	Zone 3
House raising (3m)	1.64 (100%)	5.25 (30%)		
House raising (2m)	2.06 (100%)		6.26 (20%)	
Relocation	1.48 (100%)	6.00 (10%)		
Dry floodproofing	5.62 (100%)			6.30 (10%)
Wet floodproofing - Existing	5.22 (100%)	6.08 (10%)	6.32 (20%)	6.35 (30%)
Wet floodproofing - Reno	4.62 (100%)	5.95 (10%)	6.31 (20%)	6.34 (30%)
Barriers	3.84 (100%)	4.69 (100%)		

Investment costs are calculated as unit mitigation costs multiplied by the number of properties mitigated. The barriers are an exception to this with the following assumptions made in assessing the cost of barriers in addition to the initial cost of purchase:

- A storage cost of $25k per year is included
- The cost of installation/removal has been applied 14 times
- The barriers will need replacement after 40 years.

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 impact and benefit tend to disappear in economic assessments when high discount rates are used (Chigama, 2017). For the assessment of the benefit versus cost ratio 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. Investment costs, avoided losses and benefit cost ratios are summarised in Table 8 (ideal case, 100% application), Table 9 (Zone 1 mitigation options), Table 10 (Zone 2 mitigation options), and Table 11 (Zone 3 mitigation options). The benefit versus cost ratios are also shown graphically for the different cases in Figures 15-18.

TABLE 8: AVOIDED LOSSES AND BENEFIT VERSUS COST RATIO FOR 100% APPLICATION IN ALL ZONES

All Applicable Locations	Investment Cost ($M)	Avoided Losses ($M)					Benefit Cost Ratio (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
House raising (3m)	45.83	142.55	112.88	92.50	77.92	67.13	3.11	2.46	2.02	1.70	1.46
House raising (2m)	45.83	129.86	102.84	84.26	70.99	61.15	2.83	2.24	1.84	1.55	1.33
Relocation	33.99	147.38	116.71	95.63	80.56	69.40	4.34	3.43	2.81	2.37	2.04
Dry floodproofing	29.02	22.35	17.70	14.50	12.22	10.52	0.77	0.61	0.50	0.42	0.36
Wet floodproofing - Existing	9.25	34.43	27.26	22.34	18.82	16.21	3.72	2.95	2.42	2.03	1.75
Wet floodproofing - Reno	10.14	52.55	41.61	34.10	28.73	24.75	5.18	4.10	3.36	2.83	2.44
Barriers	10.68	76.11	60.27	49.38	41.60	35.84	8.23	7.11	6.20	5.47	4.86

TABLE 9: AVOIDED LOSSES AND BENEFIT VERSUS COST RATIO FOR ZONE 1

Zone 1	Investment Cost ($M)	Avoided Losses ($M)					Benefit Cost Ratio (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
House raising (3m)	8.68	33.64	26.64	21.83	18.39	15.84	3.88	3.07	2.51	2.12	1.83
Relocation	2.15	10.84	8.59	7.04	5.93	5.11	5.05	4.00	3.28	2.76	2.38
Wet floodproofing - Existing	1.70	8.37	6.62	5.43	4.57	3.94	4.92	3.89	3.19	2.69	2.32
Wet floodproofing - Reno	1.80	12.35	9.78	8.01	6.75	5.82	6.85	5.43	4.45	3.75	3.23
Barriers	6.16	50.44	39.94	32.73	27.57	23.75	8.18	7.10	6.22	5.50	4.90

TABLE 10: AVOIDED LOSSES AND BENEFIT VERSUS COST RATIO FOR ZONE 2

Credible Zone 2	Investment Cost ($M)	Avoided Losses ($M)					Benefit Cost Ratio (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
House raising (2m)	1.09	3.14	2.49	2.04	1.72	1.48	2.87	2.27	1.86	1.57	1.35
Wet floodproofing - Existing	0.28	1.15	0.91	0.74	0.63	0.54	4.03	3.19	2.62	2.20	1.90
Wet floodproofing - Reno	0.35	1.60	1.27	1.04	0.87	0.75	4.54	3.60	2.95	2.48	2.14

TABLE 11: AVOIDED LOSSES AND BENEFIT VERSUS COST RATIO FOR ZONE 3

Credible Zone 3	Investment Cost ($M)	Avoided Losses ($M)					Benefit Cost Ratio (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
Dry floodproofing	1.74	1.96	1.55	1.27	1.07	0.92	1.13	0.90	0.73	0.62	0.53
Wet floodproofing - Existing	0.24	0.45	0.36	0.29	0.25	0.21	1.85	1.46	1.20	1.01	0.78
Wet floodproofing - Reno	0.29	0.60	0.48	0.39	0.33	0.28	2.09	1.65	1.35	1.14	0.98

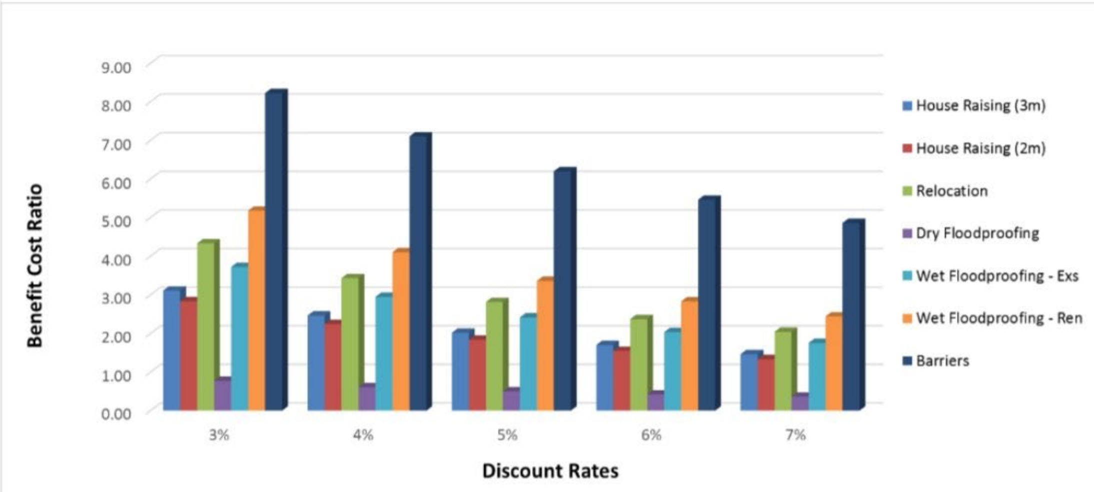

FIGURE 15: BENEFIT VERSUS COST RATIOS FOR VARIED DISCOUNT RATES AND IDEAL UPTAKE

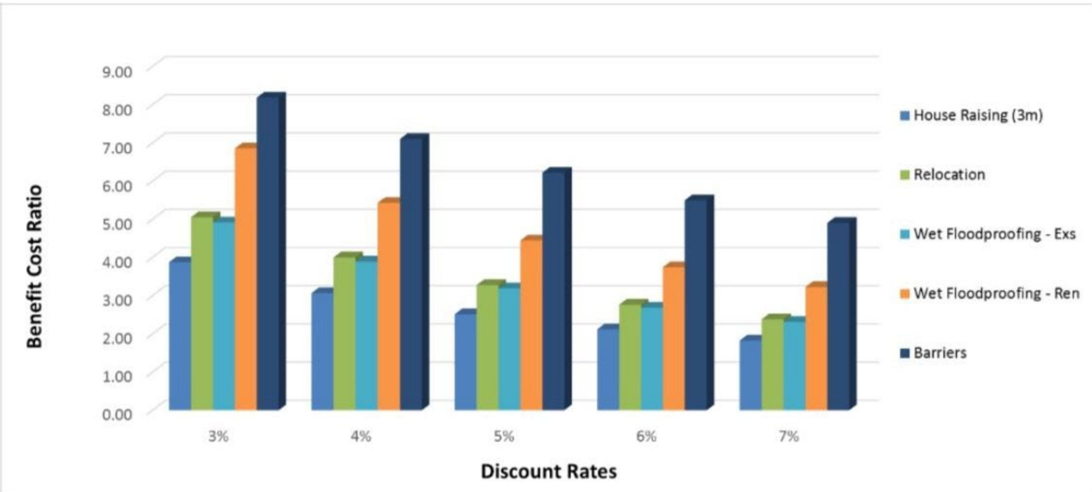

FIGURE 16: BENEFIT VERSUS COST RATIOS FOR VARIED DISCOUNT RATES (ZONE 1)

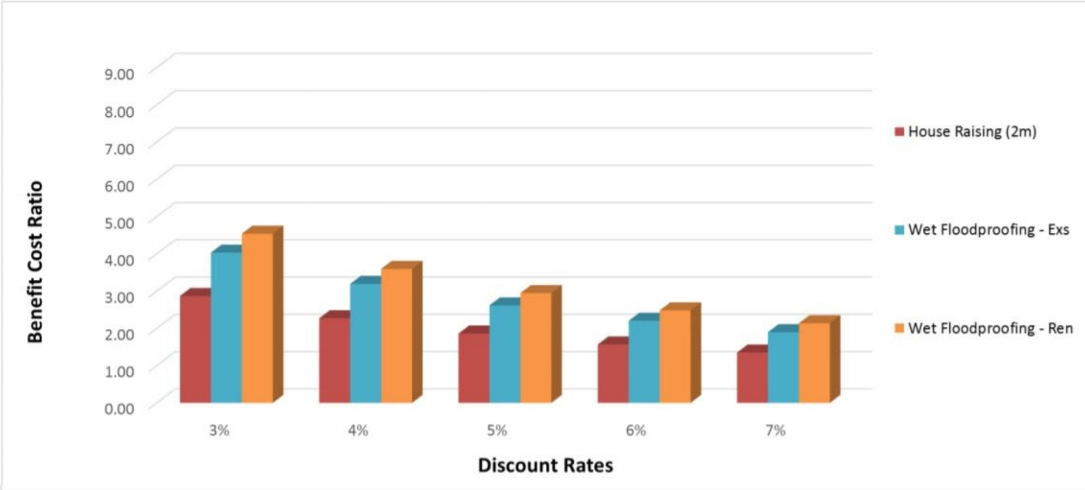

FIGURE 17: BENEFIT VERSUS COST RATIOS FOR VARIED DISCOUNT RATES (ZONE 2)

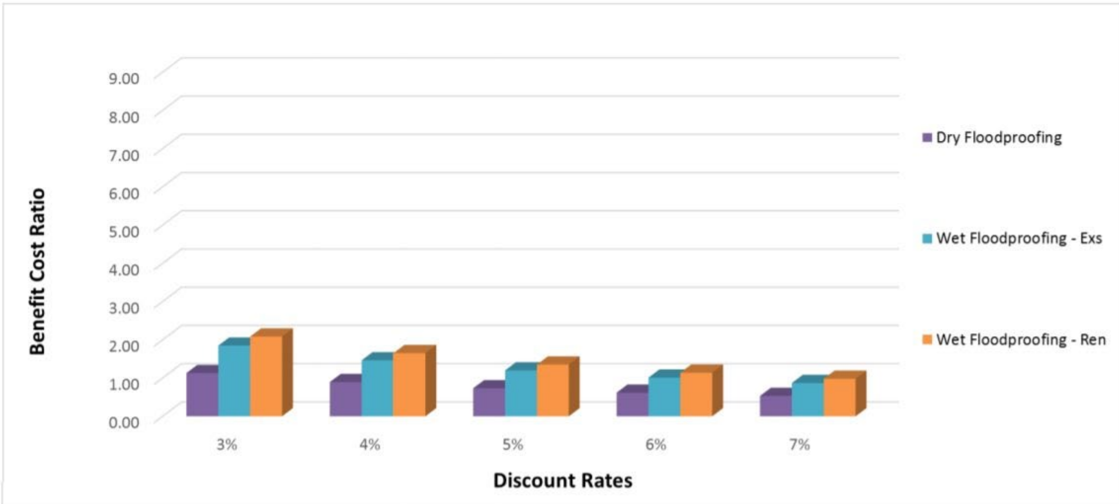

FIGURE 18: BENEFIT VERSUS COST RATIOS FOR VARIED DISCOUNT RATES (ZONE 3)

For this study of Launceston without existing flood protection levees, nearly all of the mitigation options analysed yield a benefit versus cost ratio of greater than 1.0, signifying a good investment decision. Exceptions (BCR less than 1.0) occur in Zone 3 for dry floodproofing (4%-7% discount) and wet floodproofing (7% discount). The use of temporary barriers in the high hazard Zone 1 is the most cost-effective of all the measures with a BCR ranging between 5 and 8 depending on the discount rate used. Wet floodproofing at renovation stage in Zone 1 is the next best investment option with BCR from 3 to almost 7. The three other options considered in Zone 1 (raising by 3m, wet floodproofing from existing and relocation) are more closely grouped with BCRs ranging from approximately 2 up to 4-5. House raising was the least cost-effective measure modelled in Zone 1.

In Zone 2 the cost-effectiveness of the three measures assessed is slightly lower however they all result in BCRs of greater than 1.0. Wet floodproofing at renovation (2-4.5) is followed by wet floodproofing (existing) with BCRs ranging from 1.9 to 4 and finally house raising by two metres with BCRs between 1.35 and 2.9. The floodproofing measure considered for the low hazard Zone 3 are less cost-effective as already discussed with wet floodproofing at renovation stage the best option.

DISCUSSION

Cost versus benfit analysis 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).

This study has focused on assessing the impacts of floods of varying severity to the residential sector at building level. It has only included estimates of building repair cost, and does not consider 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. As contents losses and rental income losses are applicable to the residential sector it can be taken as a lower bound to the benefits.

The use of temporary barriers in protecting the relatively high hazard Zone 1 appears the best return on investment of all the options investigated. It should be noted that this option also requires the most assumptions, particularly on optimal placement, frequency of use, cost of storage, and the useful life of the barriers (i.e. how often do they require replacement). The barrier option was also the only 'community' type mitigation measure explored with all other options being applied at the individual property level.

Of the individual property-based mitigation options wet floodproofing during renovation or reconstruction was the most cost-effective. Interestingly the benefits of this measure were not very large compared to some other options but the expenditure was also very modest. House raising was the least cost effective of the options considered in Zone1 and Zone 2 but managed a BCR significantly greater than 1.0 for all discount rates.

Options in Zone 1 were all very effective with the cost versus benefit dropping in the other zones as the relative hazard decreased, resulting in very little cost-effective benefit in Zone 3. The assignment of the three hazard zones and the assumed uptake of mitigation measures within those zones were based on the assumptions of the project team and could be the subject of further sensitivity work and reassessment. The application of the measure within the zones was also 'random'; for example if the mitigation measure was to be applied to 10% of relevant properties then it would simply be every tenth house of the type being considered. It may be that Local Government incentives may target the 'worst' impacted areas seeing clusters of properties retrofitted rather than the assumed random spread.

Importantly, the outcomes reported here are based on one city and its building stock and one catchment behavior. Further work is planned in other locations and is described in the following section.

Not all forms of impact can be practically quantified and incorporated into a cost versus benefit analysis. 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 has particular reference to mitigation measures that may be cost-effective, but entail more frequent household disruption. Flood barriers in Zone 1 and wet floodproofing in Zones 2 and 3 are examples of this.

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 these tangibles and intangibles have precluded the inclusion of these costs into the analysis.

The benefit to cost ratios for the reduction of flood losses through building level mitigation strategies have been shown to be typically high through this research. However, it should be noted that the study suburb of Invermay in Launceston is hypothetical in that the existing levees that protect this community have been virtually removed. Without levees the high flood hazard has resulted in high avoided losses and return on investment. This observations is further supported by the reducing benefit versus cost ratios zones 2 and 3 which has lower hazard. The study does illustrate the use of these measures to reduce risk but returns will be lower where the more likely flood events have been mitigated and the measures are seeking to reduce residual risk. This will be illustrated further in the balance of this project which will examine the building level investment in flood mitigation for flood hazard in three flood catchment types.

NEXT STEPS

The current project continues to the end of 2020 and the next steps include the application of benefit versus cost analyses to other towns. Likely options include Murwillumbah, Tweed Heads, and Wagga. This will broaden the evidence base of building stock configurations and the most cost-effective mitigation measures. Similarly, the other towns will enable further catchment types to also be analysed, again adding to the evidence base being developed through the project outcomes.

Further work could potentially be done looking at the realistic uptake of mitigation options. The uptake modelled here was based on what the project team considered realistic. Further, the benefits to the avoidance of losses to the population of buildings represent the end point of a local program that could span a decade or longer.

Finally, the work could include residential contents losses and intangible values associated with household disruption and emotional distress due to flood impact.

ACKNOWLEDGMENTS

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 cost versus benefit analysis:

- 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 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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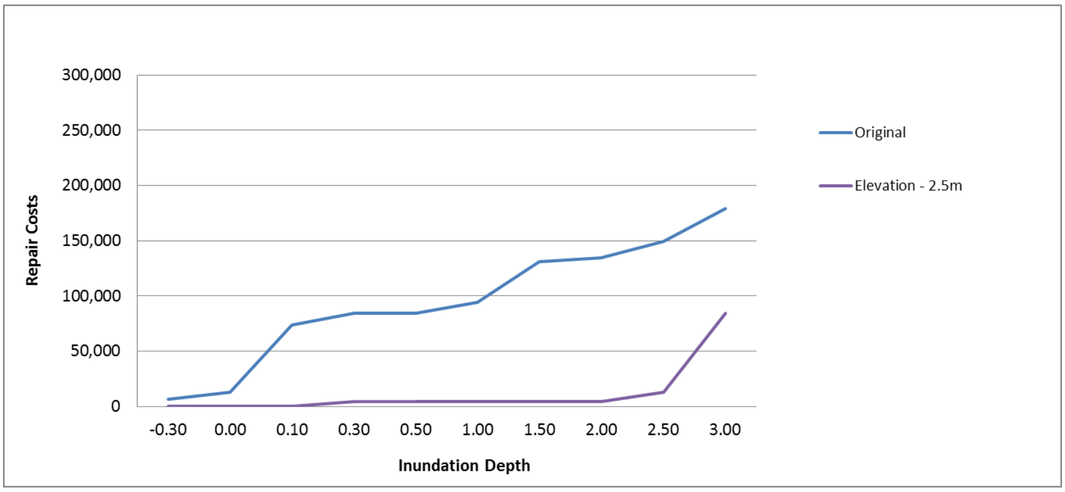
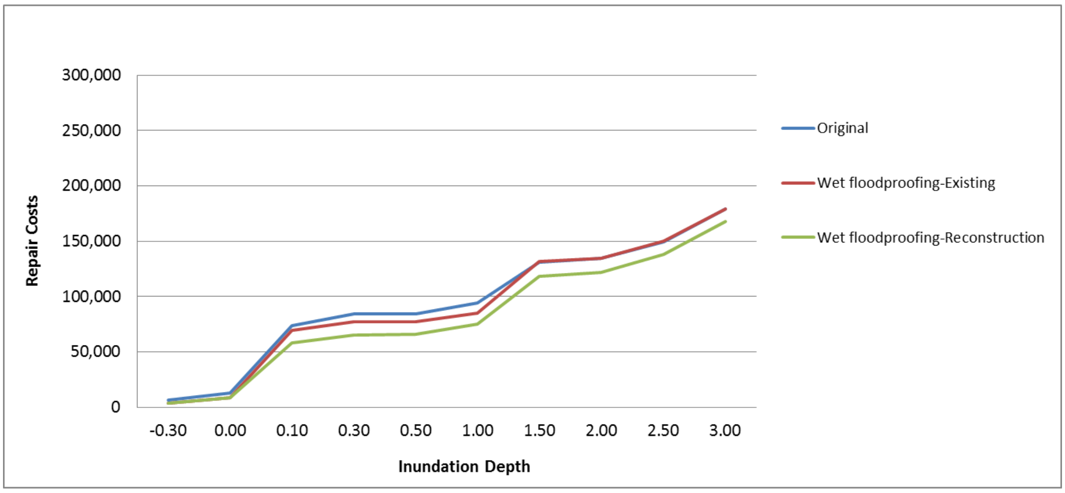
APPENDIX A: VULNERABILITY MODELS

TIMBER FRAME (RAISED FLOOR)

(A) Original vs Elevation

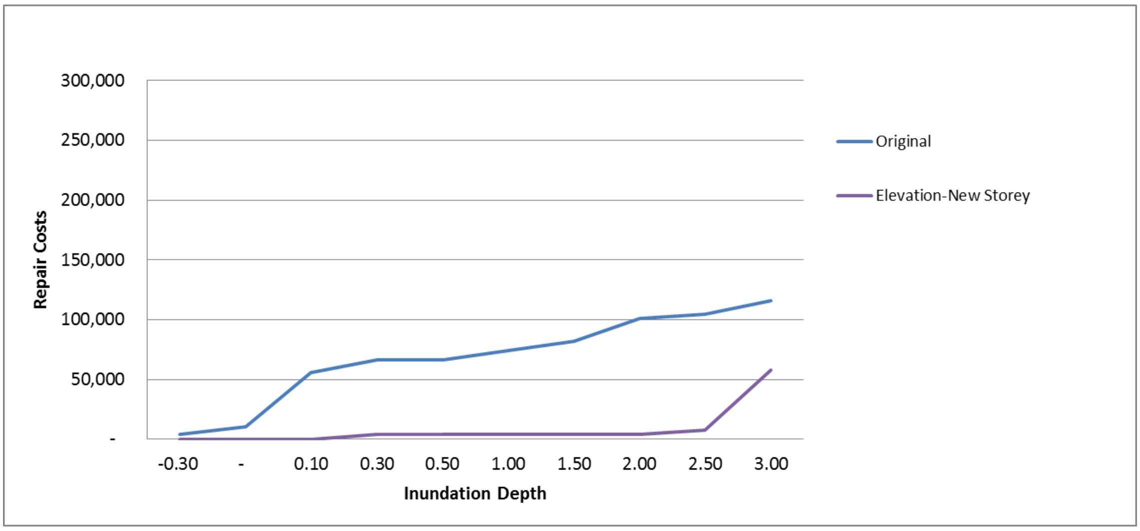


(B) Original vs Wet Floodproofing

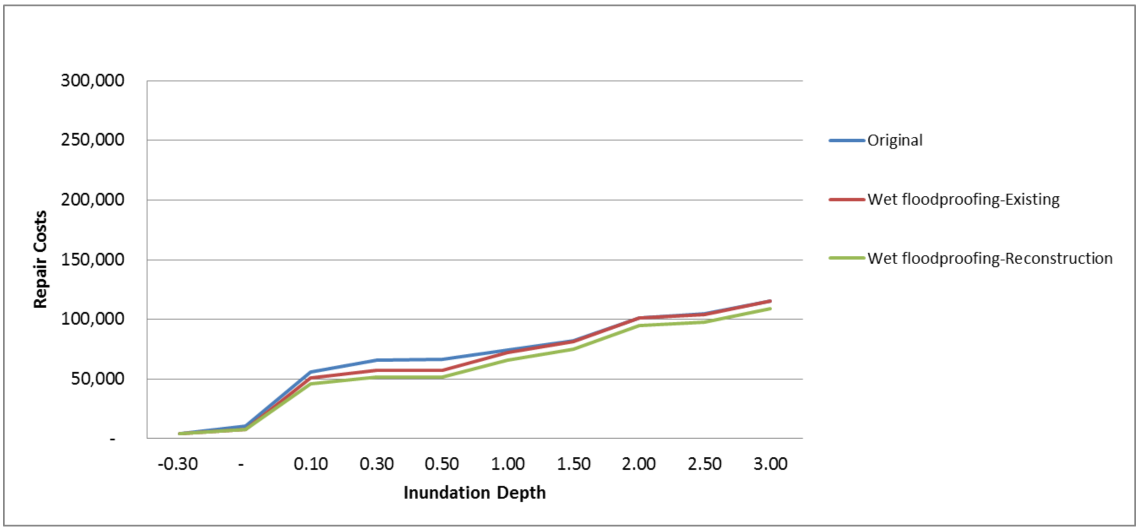


CAVITY MASONRY – VICTORIAN TERRACE (RAISED FLOOR)

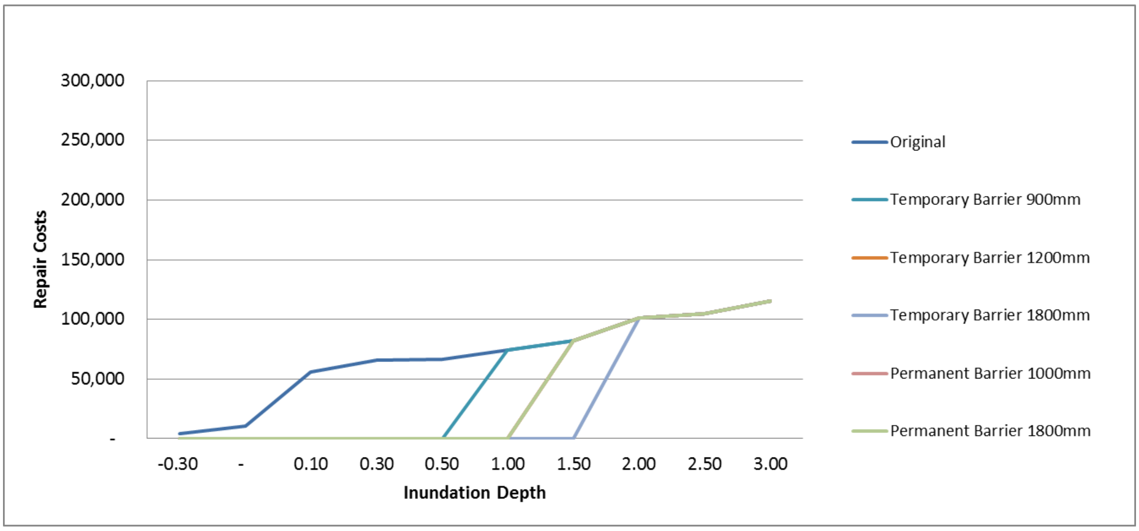
(A) Original vs Elevation



(B) Original vs Wet Floodproofing

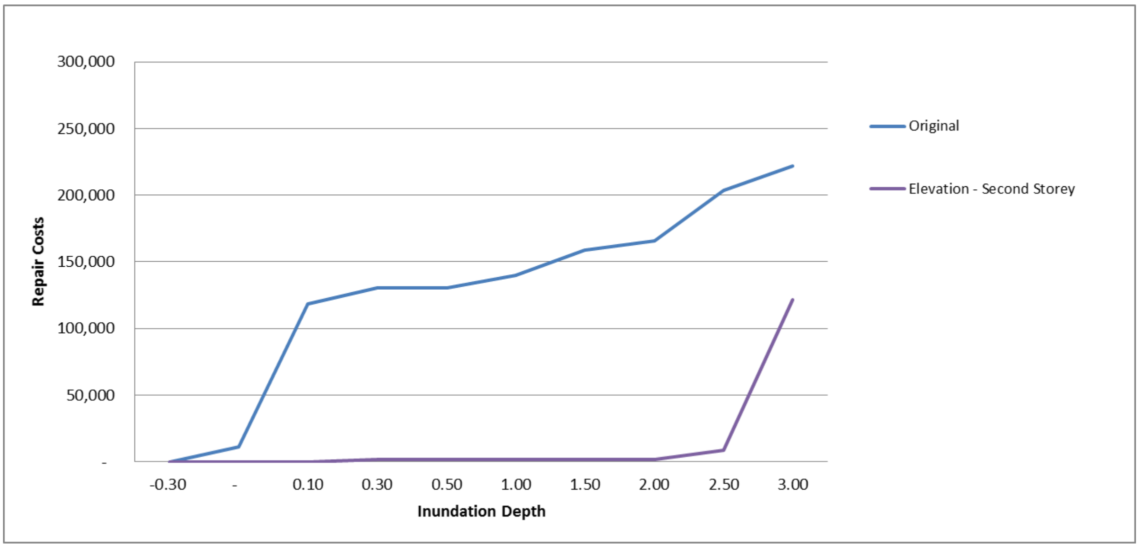


(C) Original vs Flood Barriers

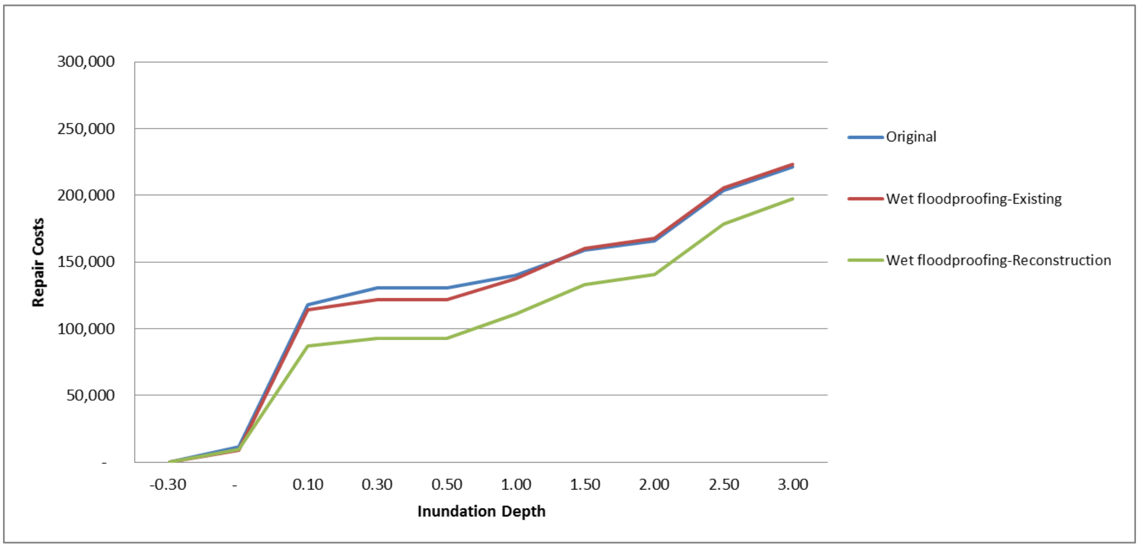


CAVITY MASONRY (RAISED FLOOR)

(A) Original vs Elevation

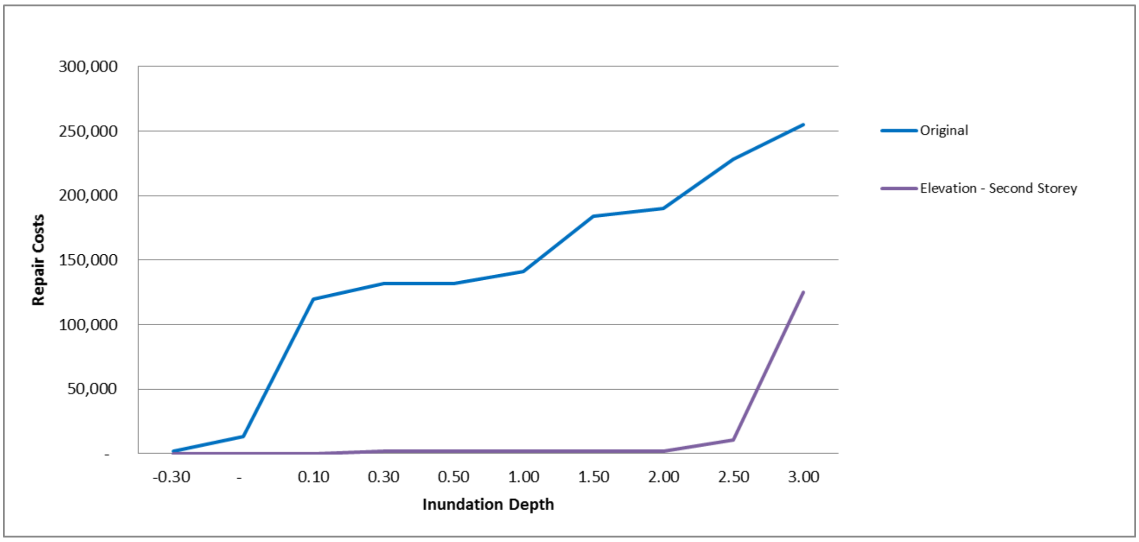


(B) Original vs Wet Floodproofing

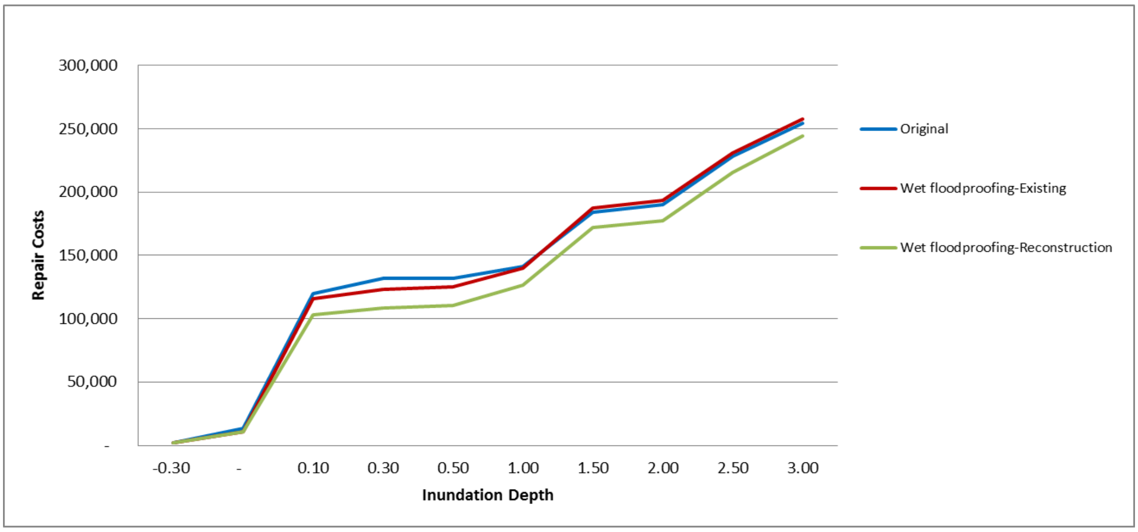


BRICK VENEER (RAISED FLOOR)

(A) Original vs Elevation

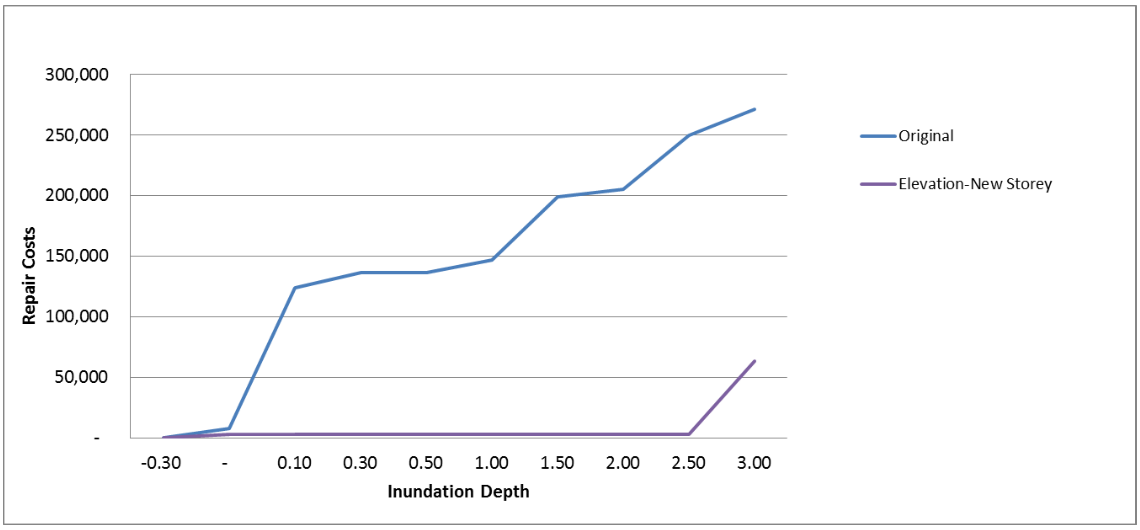


(B) Original vs Wet Floodproofing

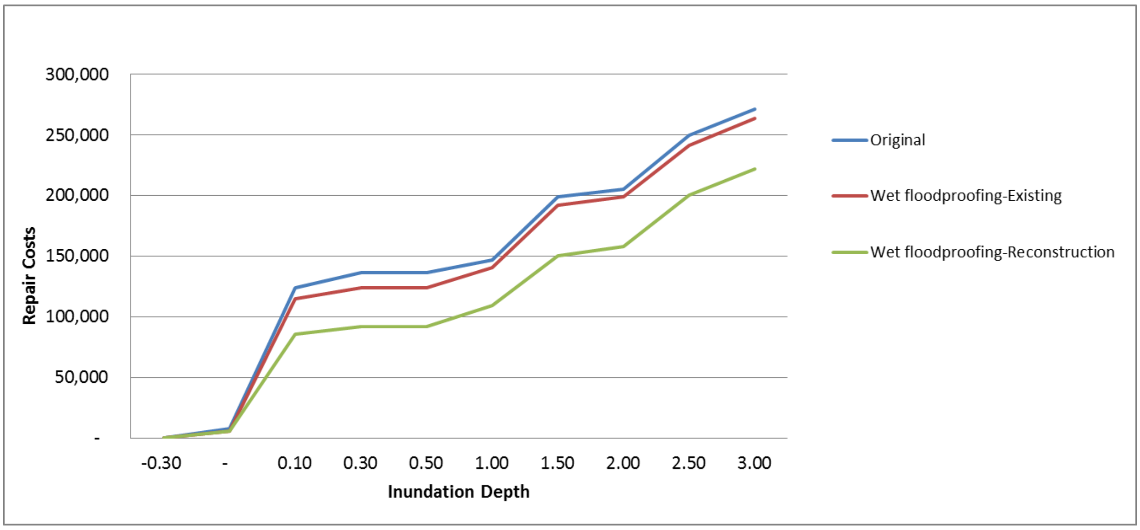


BRICK VENEER (SLAB-ON-GRADE)

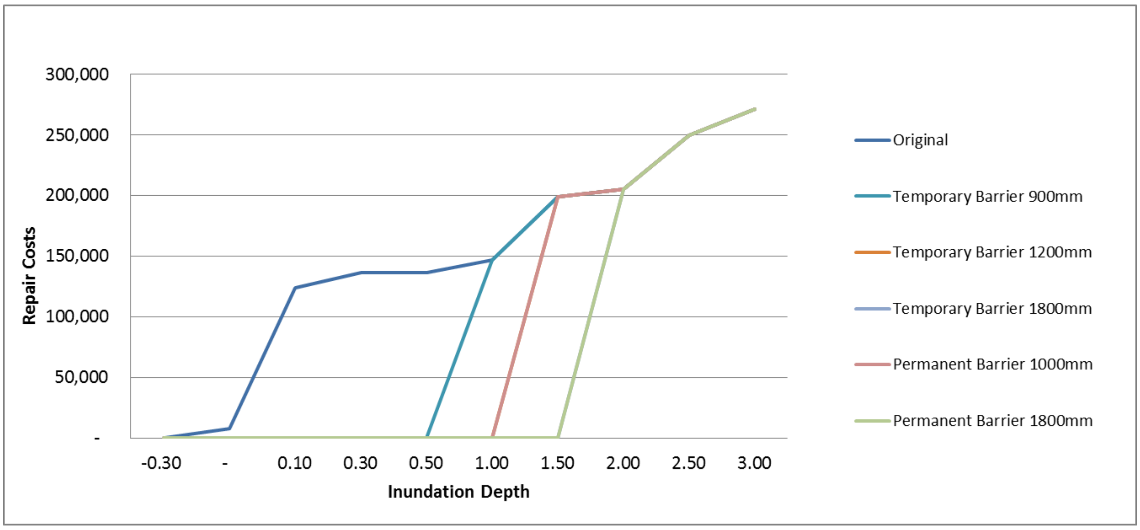
(A) Original vs Elevation



(B) Original vs Wet Floodproofing



(C) Original vs Flood Barriers



(D) Original vs Dry Floodproofing