Development and evaluation of FLFA$_{cs}$ - a new Flood Loss Function for Australian commercial structures

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Abstract

Commercial building flood losses significantly affect the Australian economy; however, there are not many models for commercial flood damage estimation and their results are not reliable. This study has attempted to derive and develop a new model (FLFA$_{cs}$) for estimating the magnitude of direct damage on commercial structures. The FLFA$_{cs}$ - Flood Loss Function for Australian commercial structures, was calibrated using empirical data collected from the 2013 flood in Bundaberg, Australia, and considering the inherent uncertainty in the data sample. In addition, the newly derived model has been validated using a K-fold cross-validation procedure. The model performance has also been compared with the Flood Loss Estimation MOdel for the commercial sector (FLEMO$_{cs}$) and the Federal Emergency Management Agency (FEMA) damage functions from overseas, as well as the ANUFLOOD damage model from Australia.

The validation procedure shows very good results for FLFA$_{cs}$ performance (no bias and only five per cent mean absolute error). It also shows that ANUFLOOD, as Australia's most prevalently used commercial loss estimation model, is still subject to very high uncertainty.

Hence, there is an immediate need for a project to build new depth-damage functions for commercial and industrial properties.

Awareness of these issues is important for strategic decision-making in flood risk reduction and it could amplify the cognition of decision-makers and insurance companies about flood risk assessment in Australia.

Keywords: Flood damage assessment, commercial structures, risk reduction, flood loss function, flood risk assessment.

1 Introduction

Statistical analyses shows the considerable impacts of flood risk compared to other types of natural hazards (André et al., 2013; Kourgialas and Karatzas, 2012; Llasat et al., 2014; UNISDR, 2009). In Australia, floods are the most costly of all disaster types, contributing 29 % of the total cost for the nation's economy and the built environment (Bureau of Transport Economics, 2001; Khalili et al., 2015). Unfortunately, unsustainable developments and global warming are increasing the risk of flood (Elmer et al., 2012; Kundzewicz et al., 2005; McGrath et al., 2015). Consequently, flood risk assessment and flood risk mitigation are gaining more attention (André et al., 2013; Kreibich et al., 2010; Othman et al., 2014).

Flood risk can be defined as the probability and magnitude of expected losses (André et al., 2013; Elmer et al., 2010; Kaplan and Garrick, 1981; Kreibich et al., 2010; Mouri et al., 2013; Neale and Weir, 2015; UNISDR, 2004). Therefore, loss estimation and consequence assessment is an indispensable part of flood risk assessment, and the results will provide decision-makers with an essential tool for planning better risk reduction strategies (Emanuelsson et al., 2014; Gissing and Blong, 2004; McGrath et al., 2015; Merz et al., 2010).

In general, flood losses can be categorised into direct or indirect (Meyer et al., 2013; Molinari et al., 2014a; Thieken et al., 2005); and marketable (tangible) or non-marketable (intangible) values (André et al., 2013; Kreibich et al., 2010; Molinari et al., 2014a). Direct damages take place due to physical contact between the floodwater and inundated structures (Hasanzadeh Nafari et al., 2016; McGrath et al., 2015; Morrison and Mollino, 2012). This study is limited to direct, tangible damages of commercial structures due to a short duration of riverine (low velocity) inundation.

In Australia, direct tangible damages of commercial buildings could be estimated by the Rapid Appraisal Method (RAM) or by function approaches (e.g. ANUFLOOD). Function approaches are the most common and internationally accepted methodology (Hasanzadeh Nafari et al., 2016). They make a causal relationship between the magnitude of the hazard and resistance of flooded objects, and can estimate the extent of losses for each stage of water (Dewals et al., 2008; Grahn and Nyberg, 2014; Jongman et al., 2012; Kreibich and Thieken, 2008; Molinari et al., 2014b; Smith, 1994; Thieken et al., 2006). Function approaches can be categorised into absolute and relative types. Absolute functions express the magnitude of damages in monetary values; while relative types estimate the dimension of losses as a ratio of the total value, i.e. replacement value or depreciated value (Kreibich et al., 2010). Relative loss functions in contrast to absolute loss functions have better transferability in space and time since they are independent of changes in market values (Merz et al., 2010). However, both types are restricted to the area of origin in terms of geographical conditions, i.e. building characteristics and flood specifications (Cammerer et al., 2013; McGrath et al., 2015; Proverbs and Soetanto, 2004). Therefore, the results of transferred models contain a high level of uncertainty if they have not been calibrated with the empirical data sets collected from the new region of study (Cammerer et al., 2013; Molinari et al., 2014b).

Commercial sector flood losses significantly contribute to the economy and to societal welfare. Hence, any disruptions in their activities due to direct damages might cause indirect and induced long-term losses (Haque and Jahan, 2015; Haraguchi and Lall, 2014). Also, inaccurate loss estimation for commercial buildings leads to wasted effort, money and resources for insurance companies and organisations involved in risk mitigation (McBean et al., 1986; McGrath et al., 2015). In spite of these facts, available approaches have concentrated on residential building losses, and they are still subjected to a considerable level of uncertainty for commercial building flood loss estimation (Gissing and Blong, 2004; Kreibich et al., 2010).

This study has derived a new Flood Loss Function for Australian commercial structures (FLFA$_{cs}$). The newly derived model is a general methodology for swiftly describing the extent of losses for each level of flood, and suggests a simple and flexible curve with regards to the variability in characteristics of structures. The FLFA$_{cs}$ has been calibrated for Australian geographical conditions by using an empirical data set collected from the 2013 flood in Bundaberg, Queensland, Australia. Uncertainties pertaining to the newly derived function have been considered as well. In addition, performance of this function has been compared with an Australian methodology as well as two well-known overseas methodologies. Accordingly, the accuracy and validation of each model compared to the empirical data set has been evaluated and examined.

On the whole, the results of flood damage models provide the input data for subsequent damage reduction, vulnerability mitigation and Disaster Risk Reduction (DRR). Therefore, it is very important to be aware of associated uncertainties.

2 Background

In Australia, RAM and ANUFLOOD are the most common models for the estimation of direct losses of commercial structures. The RAM, developed by Sturgess and Associates (2000), considers some mean values of damage for all flooded buildings, including those inundated above and below floor level, and estimates the magnitude of potential losses. Potential losses are the maximum possible value of losses without considering any mitigation measures (Bureau of Transport Economics, 2001; Hasanzadeh Nafari et al., 2016; Molinari, 2011; Molinari et al., 2013). This methodology allocates a damage value of AUD20,500 to inundated businesses less than 1000 m^2 in size, and some individual damage values (in dollars per square metre) for businesses larger than 1000 m^2 in size (Gissing and Blong, 2004; Sturgess and Associates, 2000). The value of estimated damages includes losses to building structures and contents (Kreibich et al., 2010) and could be converted to actual values by using some ratios, suggested based on the previous flood experiences and early warning time (Gissing and Blong, 2004; Molinari, 2011; Sturgess and Associates, 2000).

Although this methodology for initial rapid assessment is useful and inexpensive, the results are considerably inaccurate and uncertain (Barton et al., 2003; Gissing and Blong, 2004). In addition, this averaging method has not precisely considered the variability of commercial buildings with regard to building characteristics, building materials, and building exposure values (Handmer et al., 2002). Also, propagation of water depth and different magnitudes of flood impacts have been neglected in this approach. Consequently, this model only calculates an accumulated value of the total damages occurred, without considering its distribution over the inundated area. It is also noted that due to economic inflation, the potential damage values of the RAM methodology need regular recalibration. Under other circumstances, this method might underestimate the value of losses considerably (Merz et al., 2010). Furthermore, because RAM does not separate the magnitude of structural damage from contents losses, the conversion of potential damage to actual damage, due to the different nature of movable inventories from non-movable components with lead-time, is problematic (Gissing and Blong, 2004).

In addition to the averaging method, stage damage curves can be used for the estimation of flood losses in commercial sectors. These models estimate the magnitude of losses for different stages of flooding, and the magnitude of damage increases by over-floor water depth increments (Gissing and Blong, 2004). Stage damage curves have been grouped into two different main classifications: empirical and synthetic curves (McBean et al., 1986). Empirical curves build on surveyed damage data. The estimated results are more accurate due to taking into account the effect of mitigation measures and the variability within one category of building (Kreibich et al., 2005; Merz et al., 2010, 2004). However, Smith (1994) discussed that by moving in time and space, mitigation measures, level of preparedness, characteristics of floods, and the attributes of buildings, could alter significantly. Therefore, gathering data from one flood event and using it as a guide for future events prediction, even in the area of origin, requires a complicated process of extrapolation (Gissing and Blong, 2004; McBean et al., 1986; Smith, 1994). As a solution, synthetic curves based on a valuation survey have been created for different types of buildings. Valuation surveys direct attention to the value and level of all components that are situated above the basement (Barton et al., 2003). The extent of potential losses for different stages of flood via "what-if" questions is estimated based on the distribution of components in the height of the building and the degree of fragility of each item (Gissing and Blong, 2004; Merz et al., 2010). In addition to the advantages related to a high degree of standardisation and independency from historic data, a valuation survey, even for one type of building, needs a high level of effort. Also, due to estimating the extent of potential losses, this approach does not take into account the effects of mitigation measures (Hasanzadeh Nafari et al., 2016; Merz et al., 2010; Smith, 1994).

ANUFLOOD commercial damage curves (Smith, 1994) are empirical damage functions that are used commonly in Australia. This methodology expresses the magnitude of losses as a total value including damage to the structure and inventories. Furthermore, this model has presented different depth-damage functions based on the size of the business (i.e. smaller than 186 m^2, between 186 m^2 and 650 m^2, and larger than 650 m^2) and value of buildings (i.e. depends on the vulnerability of contents). The same as RAM, damage for small- and medium-sized classes have been given in absolute values; while for large-sized classes, it has been presented in dollars per square metre (Gissing and Blong, 2004).

Similar to most Australian approaches, this approach expresses the magnitude of damage in absolute fiscal values. As stated earlier, these types of functions, in contrast to relative loss functions, are more rigid for transferring in space or time (Merz et al., 2010). For instance, the RAM report demands that the magnitude of damage estimated by the ANUFLOOD method should be increased by 60 % and its performance is no longer sufficiently accurate (Sargent, 2013; Sturgess and Associates, 2000). The reason for this is related to the fact that these curves are based primarily on a 1986 flood event in Sydney and they need updating due to changes in the value of the dollar compared to today's value. Hence, their results are not reliable unless they have been recalibrated frequently (Merz et al., 2010).

To address these issues, the authors have attempted to develop a new empirical-synthetic model with a better level of accuracy in results and transferability in time and space compared to the available Australian methodologies. Also, this new model is easy enough to understand and generalise for other types of structures and vulnerability classes. Despite the fact that the itemised estimation survey proposed for synthetic damage functions seems a little confusing and takes a long time (Merz et al., 2010), the new model for evaluating the assembly components and tracking the vertical parameters, by considering more general categories, has tried to simplify the process as much as possible.

3 The Newly Derived Function ($FLFA_{cs}$)

For developing an analytical stage damage curve in one area of study, a representative building category is first needed. Next, for the representative classification, an average distribution of the building components in the height of the structure should be taken out. Eventually, the percentage of damage for every stage of water could be estimated based on the average value of fragile items relative to the total value of the structure (Bureau of Transport Economics, 2001). In this study and for developing the newly derived model, these steps have been put well to use.

Firstly, selection of the representative group and the vulnerability class has been made based on the characteristics of existing structures (e.g. material, size and age) collected from the national exposure information system of Australia (Dunford et al., 2014). This data set shows that 70 % of commercial buildings in our areas of study are one-storey buildings with masonry walls and slab-on-ground. Also, these buildings are used for retail trades, repair or personal services, or professional offices; and their size, on average, is 400 square metres. In addition, 75 % of these buildings have been constructed before 1980.

Next, for resolving the stated issues related to the significant efforts required for data gathering and details surveying, some more generic sub-assembly groups have been defined. To be more specific, components of commercial structures based on the sub-assembly approach proposed by the HAZUS technical manual (FEMA, 2012) have been grouped into five main categories, as:

- Foundation and below first floor
- Structure framing
- Roof covering and roof framing
- Exterior walls: includes wall coverings, windows, exterior doors and insulation
- Interiors: includes interior walls and floor framing, drywall, paint, interior trims, floor coverings, cabinets, and mechanical and electrical facilities.

The percentage of damage for every stage of water is a function of fragility and value of flooded categories. Therefore, for pursuing the real behaviour of each category against the impacts of water, and resolving the issue related to ignoring the effect of mitigation measures in synthetic methods (Merz et al., 2010), the shape of the newly derived function has been adjusted and calibrated using a historic data set collected from a recent extreme event. Hence, this approach could be named as an empirical-synthetic model.

The $\mathrm{FLFA_{cs}}$ has been built on a general methodology which attempts to generate a simple and flexible curve to depict the extent of flood losses for every stage of water quickly. The proposed formula can create a flexible curve with regards to variability in the number of storeys, height of storeys, and the distribution of assembly items through the height of the building. Therefore, users can manipulate and calibrate this model easily based on the characteristics, uses and types of structures.

This methodology has been developed by considering the variability of structural components, namely flood vulnerability and exposed value. More specifically, the vulnerabilities of structural components are different from each other, and each assembly category starts damaging after a specific level of total damage and subsequent to different water depths. Also, the exposed value of each category relative to the total value of the structure is different, and the most valuable items (e.g. the interiors and the exterior walls) start damaging from the first few centimetres of water depth (FEMA, 2012). This means that the rate of damage in the first stages of flooding is greater than the remaining stages. Therefore, the slopes of the damage curves might vary based on an exponential equation (Cammerer et al., 2013; Elmer et al., 2010; Hasanzadeh Nafari et al., 2016; Kreibich and Thieken, 2008).

The power (*r*) of Equation (1) controls the rate of alteration in the percentage of damage relative to the growth of water depth. In general, a higher value for "*r*" means a faster rate of damage at the first few metres of building height (Hasanzadeh Nafari et al., 2016). The general formula has been proposed as shown below:

$$d_{hi} = \left(\frac{h_i}{H_i}\right)^{r_i} \times D_{\max i} \qquad (1)$$

where h_i = the depth of water above the i_{th} floor, d_{hi} = the percentage of damage corresponding to the depth of water above the i_{th} floor, H_i = the maximum height of i_{th} floor, $D_{\max i}$ = the maximum percentage of damage for the i_{th} floor corresponding to the maximum height of i_{th} floor, and r_i = the rate control for the i_{th} floor (i.e. for the representative group of buildings in this study i =1).

4 Study Areas and Official Data

4.1 Study Areas and Flood Events

The selected area of study is the commercial zone of Bundaberg Council in Queensland, Australia. Bundaberg central city, as illustrated in Figure 1, is part of the Bundaberg region, north of the state's capital, Brisbane. Overall, 549 commercial buildings are situated in this suburb, including wholesale and retail trades; offices; and transport activities. As stated earlier, 75 % of these buildings have been constructed before 1980 (Dunford et al., 2014). As such, the majority of these buildings are old structures and vulnerable against flood impacts. Also, 70 % of the buildings have been constructed with masonry walls (Dunford et al., 2014), which are more vulnerable, compared to concrete and metal walls (Hawkesbury-Nepean Floodplain Management Steering Committee, 2006). From 2010, this city has experienced some extreme flood events due to the fact that it is situated in the vicinity of the Burnett River waterway. The Burnett River catchment and the Bundaberg ground elevation are illustrated in Figures 2 and 3. Empirical data used for this study has been collected after the January 2013 flood.

This flood event was a result of Tropical Cyclone Oswald and the associated rainfall. Flooding had a catastrophic effect on the Bundaberg economy, with this event being considered as the worst flood experienced in Bundaberg's recorded history. The observed peak water level along the Burnett River reached 9.53 metres (Queensland Government, 2013). The propagation of the water depth is illustrated in Figure 4. Lifelines and infrastructure were disrupted, agricultural sectors and marine environments were impacted, and usage of coal and insurance claims dramatically increased (Queensland Government, 2013). According to comments from the communications team of the Queensland Reconstruction Authority, Bundaberg Regional Council estimated that the public infrastructure damage from the natural disaster events of 2013 was approximately AUD103 million (Hasanzadeh Nafari et al., 2016).

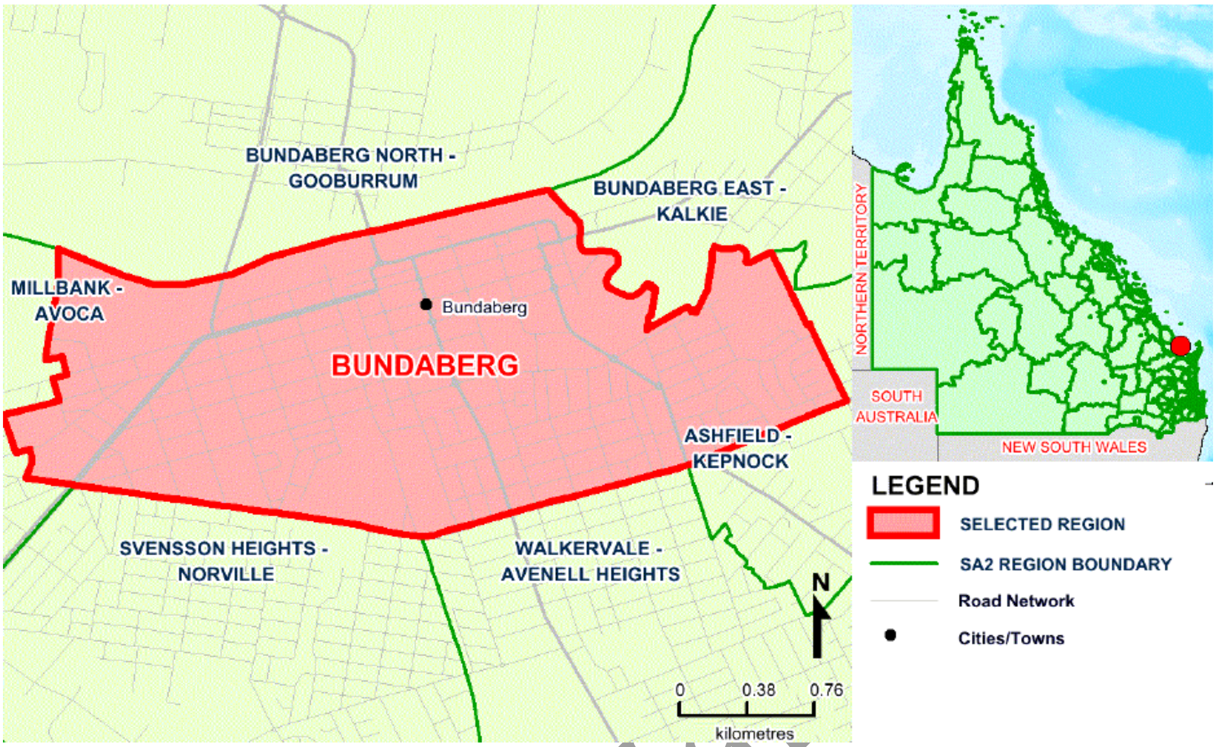

Figure 1: Map of Bundaberg City (Queensland Government, 2011)

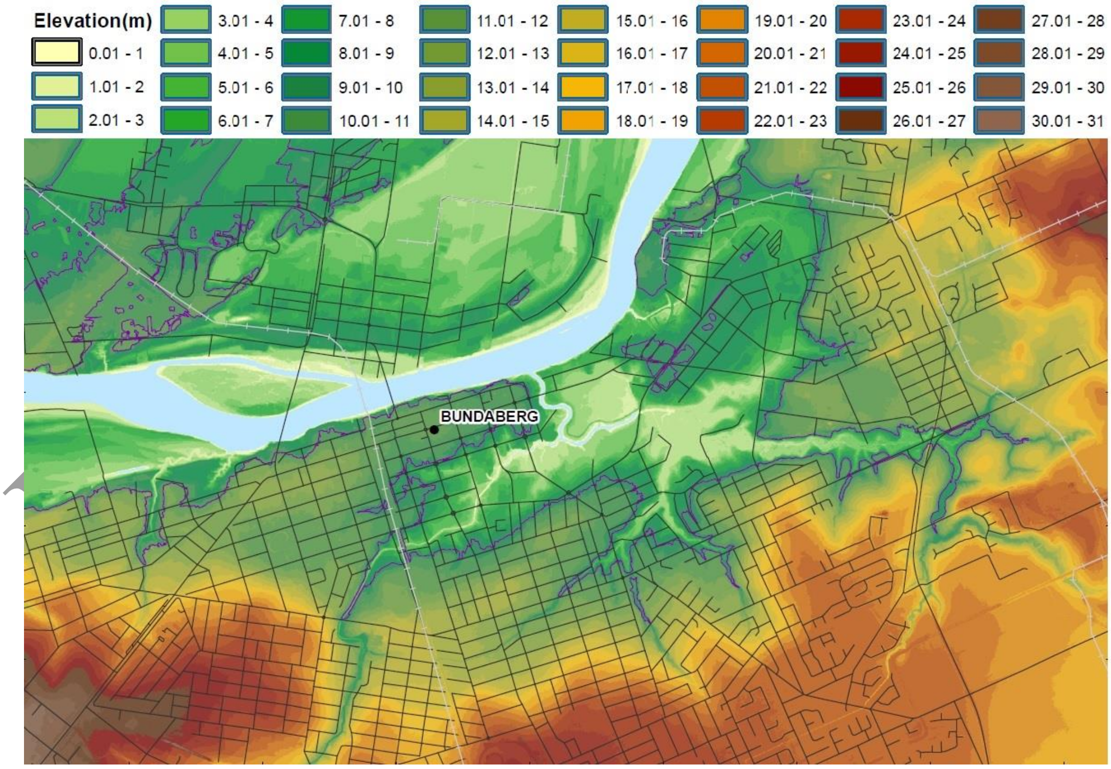

Figure 2: Bundaberg ground elevation (Bundaberg Regional Council, 2013a)

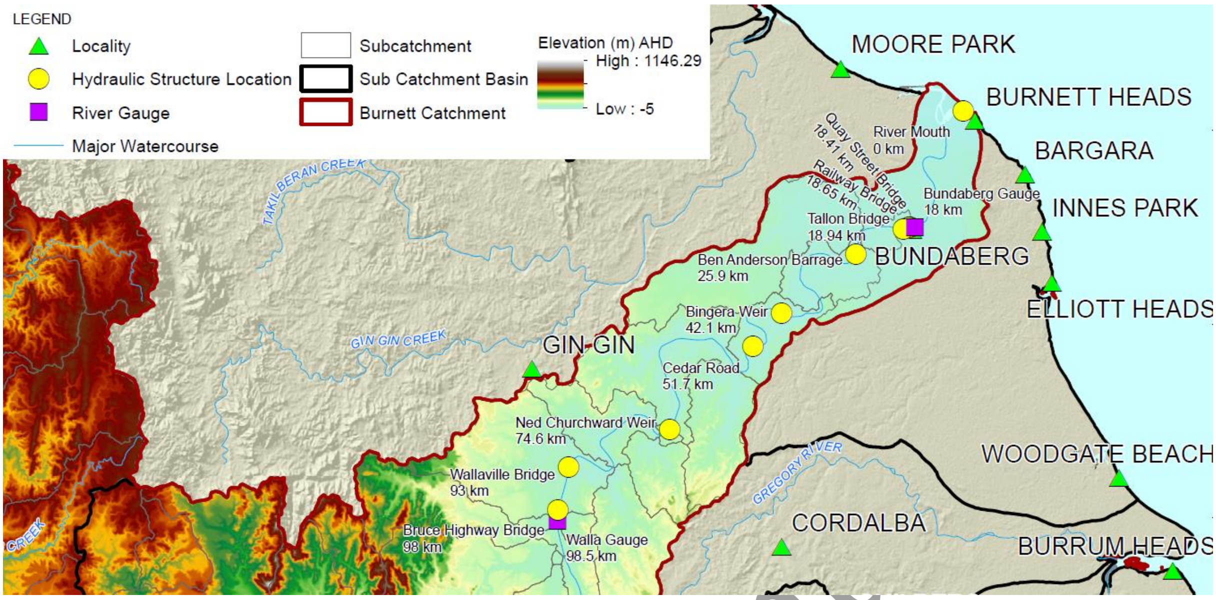

Figure 3: Burnett River catchment map (Bundaberg Regional Council, 2013b)

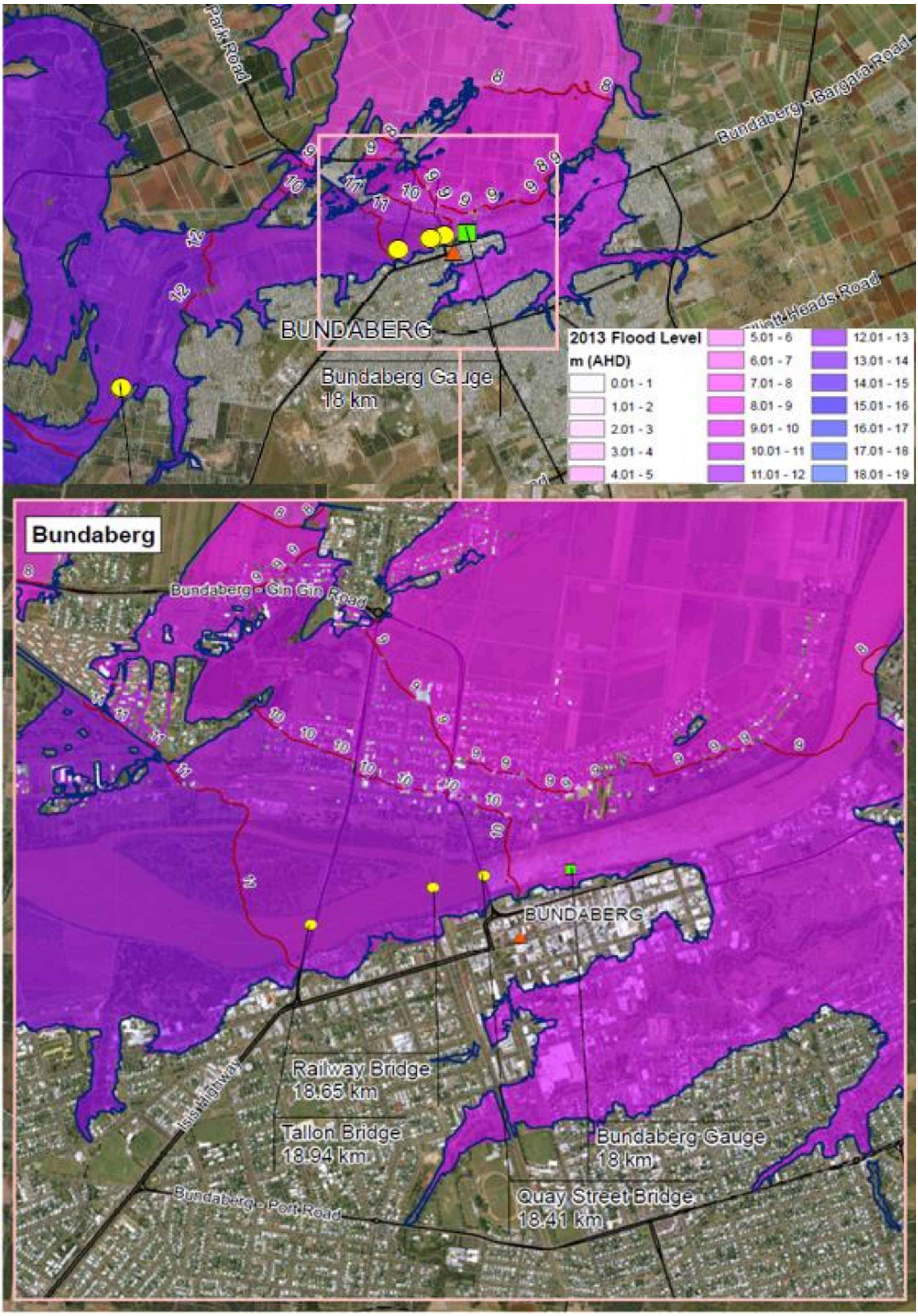

Figure 4: Inundation map of 2013 flood (Bundaberg Regional Council, 2013c)

4.2 Official Flood Data set

Damage surveys after floods are not a common activity for Australian governments, and most states have not dedicated any organisations to perform post-disaster data collection and surveys. Therefore, similar to many other countries, there is a high reliance on insurance company reports (Bureau of Transport Economics, 2001; Merz et al., 2010; Smith, 1994). Insurance company data sets are not generally accessible to the public, and due to confidentiality policies, companies do not release detailed records for communal use (Grahn and Nyberg, 2014). On the other hand, company methods of data gathering and collection are extremely dependent on their internal standards and policies. Therefore, the data sets may not be appropriate for deriving loss estimation models (Hasanzadeh Nafari et al., 2016; Thieken et al., 2009).

Between November 2010 and April 2011, Queensland was struck by a series of natural disasters such as extensive flooding (e.g. Maranoa and Bundaberg floods) and destructive storms. In response to the disaster events, the Queensland Government established the Queensland Reconstruction Authority. This government organisation has provided the confidential data set used for this study and employed for model calibration. As mentioned before, this data set is related to the Bundaberg central region flood in 2013 and represents the magnitude of hazard (i.e. over-floor water depth) and the extent of damages for 155 masonry wall commercial buildings.

The extent of structural damages has been collected by two post-disaster surveys and expresses the condition of flooded buildings by some descriptive terms such as: undamaged, minor, moderate, severe, and total damaged. An attached guideline explains these terms based on the affected structural components. Specifically, for each condition, the survey indicates which groups of sub-assemblies (e.g. foundation, below first floor, structure, interiors or exterior walls) start to become damaged, or become partially or entirely damaged.

Consequently, based on the average value of damaged items relative to the total value of the structure and the sub-assembly approach proposed by the HAZUS technical manual (FEMA, 2012), the description of damages have been exchanged into percentage of damages. In this regard, the replacement value of each set of building sub-assembly compared with the total value of the building has been estimated with the help of the Australian construction cost guide (Rawlinsons, 2014) and cost estimation bills generated by local construction companies (e.g.

Organized Builders' cost estimation[1]). Table 1 summarises the average contribution of sub-assembly replacement values as a percentage of the total building replacement value. Eventually, for every building, based on the estimated percentage of damage and the recorded depth of water, the percentage of damage vs. depth of water was extracted.

Table 1: Sub-assembly replacement values for the common types of commercial buildings (one-storey retail trade buildings and office buildings with masonry walls and slab-on-ground) as a percentage of the total building replacement value

Assembly Components	Relative Value
Foundation and below first floor	12%
Structure framing	8%
Roof covering and roof framing	7%
Exterior walls	13%
Interiors	60%
Total	100%

5 Derivation and Calibration of the New Model

For the newly derived model in this work, the extent of damage (d_h) in each level of water (h) is a function of two parameters: maximum percentage of damage D_{max}, and the rate control of function r. These two parameters, with reference to the empirical data, should be stabilised to the most appropriate values. However, because of the inherent uncertainty in the data sample and great inhomogeneity of the commercial sector (Gissing and Blong, 2004; Seifert et al., 2010), a range of estimates for the r factor and D_{max} have been provided. With this objective,

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[1] http://organizedbuilders.com.au

this section of the study has illustrated a bootstrapping approach to the empirical data to assist in describing confidence limits around the parameters of the depth-damage function. The following steps have been accomplished in this regard:

- The range of maximum percentage of damage (D_{max}) has been selected. This choice has been made established upon the scatter of empirical data; structural characteristics (e.g. age and material); the Australian building guidelines for flood prone areas (Hawkesbury-Nepean Floodplain Management Steering Committee, 2006); and some comparable relative flood loss models.
- Based on the defined range of D_{max}, different damage functions by different r values have been generated. Afterwards, by visual comparison among damage functions and the empirical data set, 210 different damage functions with the most appropriate values of r and D_{max} have been picked out. These curves have been created by changing the r value between 1.1 and 2, and D_{max} between 40% and 60%.
- Subsequently, resampling of empirical loss values by means of bootstrapping was carried out, and with the help of chi-square test of goodness of fit, the best fitted value of r and D_{max} were extracted.
- Resampling of building loss values was continued up to 1000 times and for each bootstrap, the previous stage and goodness of fit test was fulfilled. By this iteration, the average of fitted values of r and D_{max} converged to the final values used for the most-likely damage curve. Furthermore, the range of D_{max} and r parameters, which were utilised for creating the minimum and maximum damage curves, were taken out from the population of fitted values.

The range of estimates we are depicting with the D_{max} and r values express the lack of confidence in the damage depth samples in representing the true uncertainty that exists in the population. Variability of these two parameters might be related to variation in characteristics of companies, change in characteristics of flood, and alteration of mitigation measures undertaken (Kreibich et al., 2010; McGrath et al., 2015). Results of the model calibration are summarised in Table 2. Also, the final damage functions have been depicted in Figure 5.

The authors have tried to select a trend with a slight difference relative to the empirical data set. In that connection and as stated before, the most accurate values of parameters have been selected by the chi-square test of goodness of fit. As discussed further below, this matter has minimised the errors of the new model estimates relative to the observed loss records.

Table 2: Number of samples and range of "*r*" and *Dmax* values, calculated by the bootstrap and chi-square test goodness of fit

Commercial Structures with masonry walls and slab-on-ground				
Number of Samples	Parameters	Range of parameters		
		Minimum	Most-likely	Maximum
155	r	1.1	1.85	2
	D_{max}	48%	50%	60%

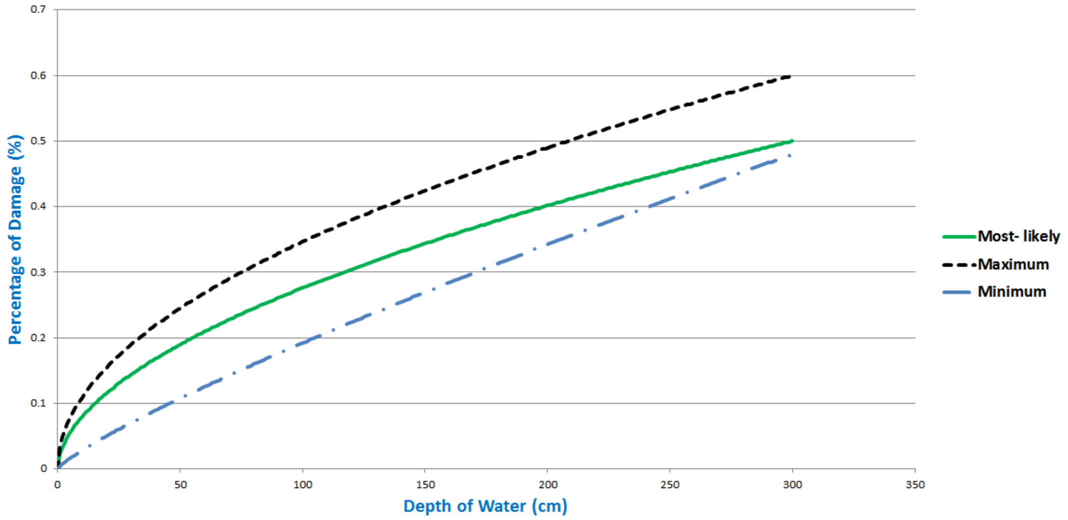

Figure 5: Visualisation of minimum, most-likely and maximum damage functions, calculated by bootstrap and chi-square test goodness of fit

6 Models Comparison

6.1 Applied Damage Models

Besides FLFA$_{cs}$, three more damage models (one local and two from overseas) have been selected for comparison in this study.

6.1.1 ANUFLOOD

One of the models which have been selected for this study is the ANAFLOOD commercial stage damage curves. As discussed previously, ANUFLOOD curves are presented as absolute losses and should be indexed to the most current dollar value. In this context, the performance of ANUFLOOD curves represented by the BMT WBM report (Huxley, 2011) have been examined and evaluated. The ANUFLOOD methodology is considered as Australia's most commonly used commercial loss estimation model (Gissing and Blong, 2004). Therefore, awareness about the level of uncertainty compared to the real-world damage data will amplify the cognition of decision-makers for flood risk reduction strategies in Australia.

As stated earlier, this methodology (as opposed to other applied models) expresses the magnitude of losses as a total absolute value, which includes damage to the structure and contents. Hence, for deriving the ANUFLOOD methodology, the following steps have been taken. (1) Total value of damage has been estimated by taking water depth as the hydraulic input, and size of business as the vulnerability class. It is worth noting that the majority of the buildings in the area of study are situated in the medium class of the ANUFLOOD building value. (2) In order to facilitate comparison of the ANUFLOOD methodology with other models, the values of structural damage and content damage should be separated from each other. For this matter, on the basis of building use and based on the level of water, the ratios of content losses relative to overall building losses proposed by FEMA have been utilised (FEMA, 2011). (3) For deriving structural loss ratios, the values of structural losses have been divided by the average value of assets, extracted from the national exposure information system of Australia (Dunford et al., 2014).

6.1.2 FLEMO$_{cs}$ Depth-Damage Function

Kreibich et al. (2010) proposed a new model for the estimation of flood losses in commercial sectors. This country-wide model has been prepared based on data collected for 642 flooded companies in Germany, and it is applicable for use in different spatial scales (Kreibich et al., 2010). This model has considered the hydraulic impacts of flood at five intervals (< 21 cm, 21–60 cm, 61–100 cm, 101–150 cm, and > 150 cm) of water depth. The characteristics of companies have been considered by three vulnerability classes related to the size of the company considering the number of employees (1–10, 11–100, > 100 employees); and the use of sectors (public and private sectors; production industry; corporate services and trade). Furthermore, this methodology has proposed some scaling factors to account for the effects of water contamination and level of precaution in the loss ratios (Kreibich et al., 2010). This multi-factorial relative method, which considers more damage influencing factors, has decreased the level of uncertainty in flood damage estimation. Hence, it would be a good example for adapting and deriving for this study area.

According to the defined vulnerability classes by FLEMO$_{cs}$; referring to the national exposure information system of Australia (Dunford et al., 2014); pertaining to the provided data set by the Queensland Reconstruction Authority; and applying to the Census of Population and Housing Destination Zones of Australia (Australian Bureau of Statistics, 2012), the majority and the representative group of commercial buildings are located in the medium-sized class of corporate services and trade, or the small-sized class of industry and public services. An average damage ratio for every interval of water depth has been considered based on this analysis, which gives a better comparison among the aforementioned functions.

6.1.3 FEMA Depth-Damage Function

The United States Federal Emergency Management Agency (FEMA) has proposed some relative stage damage functions in the package of Benefit-Cost Analysis (BCA)[2]. These curves could be utilised for estimating both structural and content losses as a percentage of building replacement value (FEMA, 2011). It is worth noting that this method has considered depth of water as the only influencing factor of flood impacts. Also, based on building use, commercial sectors have been classified into five different categories, i.e. retail and clothing, schools, electronics, office, and light industrial. Due to the flexibility of relative functions in transferring to a new region of study (Cammerer et al., 2013; Merz et al., 2010), this model has been selected

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[2] https://www.fema.gov/benefit-cost-analysis

for the comparison part of this study. From the curves provided by the BCA package and on the basis of the representative group of buildings, the related curve has been utilised.

Visual comparisons of the depth-damage functions provided by the three methods and relative loss ratios estimated by the ANUFLOOD model are shown in Figure 6.

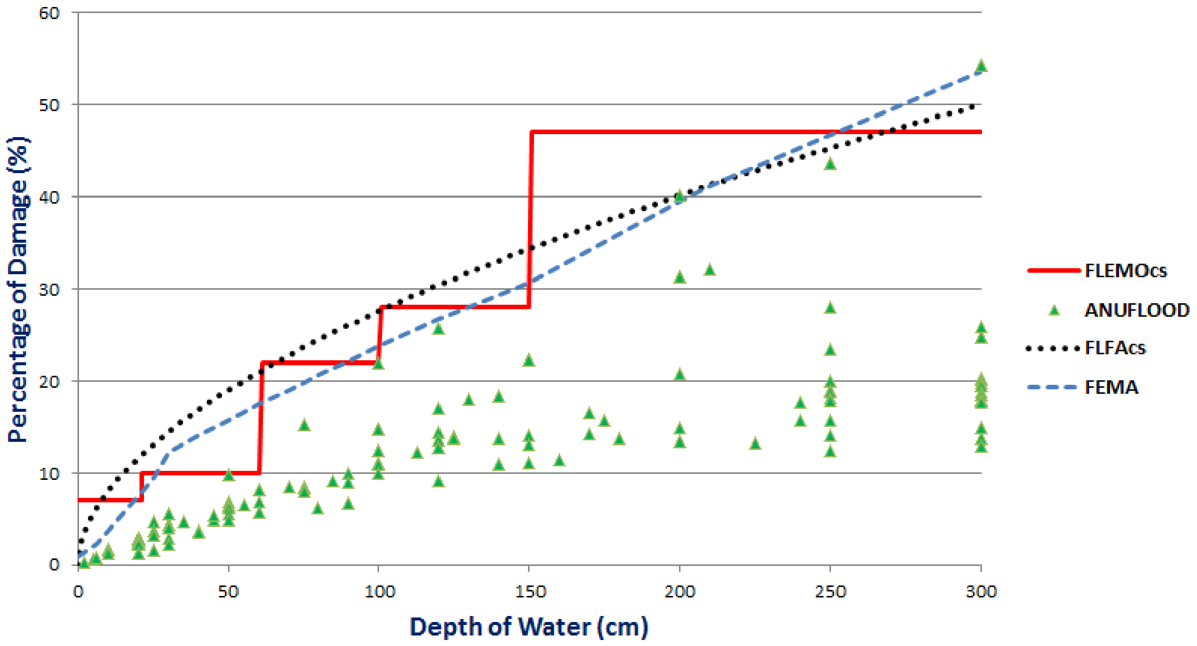

Figure 6: Comparison among applied damage functions from overseas; relative loss ratios estimated by the ANUFLOOD model; and the most-likely function of the newly derived method

6.2 Results Comparison and Model Validation

For model validation and error estimation, a three-fold cross-validation procedure was carried out based on the data collected from the 2013 Bundaberg flood event. Due to the lack independent data for model testing, this technique of model validation has been utilized in order to limit problems like overfitting, and to give an insight on how the model will generalize to an independent dataset. The cross-validation method will create some independent data sets for training of the model (model calibration) and testing the performance of the trained model (model validation). In this regard, the shuffled data was first partitioned into three equally sized segments (folds). Subsequently, three iterations of model calibration and model validation were performed; and in each iteration, a different fold of the data was held-out for model validation while the remaining two folds were used for model calibration (Refaeilzadeh et al., 2009). In each iteration, the newly derived model was calibrated on the basis of the general idea explained in Section 5 of this study. This means that the values of rate control r and D_{max}, for the most-likely function, are calculated by means of bootstrapping of data and the chi-square test of goodness of fit. Afterwards, the errors of the new model estimates, compared to the validation fold ratios, were evaluated by the Mean Bias Errors (MBE); the Mean Absolute Error (MAE); and the Root Mean Square Error (RMSE) tests. The MBE provides the average deviation of the estimated ratios from the validation fold ratios, and depict the direction of the error bias. A positive MBE shows an overestimation in the estimated ratios, while a negative value signifies an underestimation. The MAE represents the average absolute deviation of the estimated ratios from the validation fold ratios and is a quantity used to measure how close the estimates are to the empirical data. The RMSE also expressed the variation of the estimated ratios from the validation fold ratios and represents the standard deviation of the differences between the estimated ratios and observed ratios (Chai and Draxler, 2014; Seifert et al., 2010). The MBE, MAE and RMSE are calculated for the data set as follows:

$$MBE = \frac{1}{n}\sum_{i=1}^{n} e_i \qquad (2)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n} \left|e_i\right| \qquad (3)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e_i^2} \qquad (4)$$

where e_i = deviation of the estimated ratios from the validation fold ratios.

By these statistical comparisons, the performance of each newly derived function was assessed with the respective validation fold. In addition to the newly derived model and for each validation fold, errors of the other aforementioned models' estimates were calculated. Eventually, the errors were averaged for every damage model.

Additionally, resampling of observed loss ratios by means of bootstrapping was carried out to obtain a 95 % confidence interval of the mean loss ratios. This was achieved with 10,000 simulated random samples, which were drawn by replacement from the structural loss records.

If the mean loss ratio estimated by the derived models fall within the 95 % interval of the resampled data, their performance is assumed to be accepted, otherwise it can be rejected. By this approach, the performance of the applied damage models in terms of structural damage estimation in the area of study will be evaluated (Cammerer et al., 2013; Seifert et al., 2010; Thieken et al., 2008).

As summarised in Table 3, the K-fold cross-validation procedure shows that the estimates of $FLFA_{cs}$ are good. The MBE values show no bias; the MAE varies between 4 and 5 % (5 % on average); and the RMSE changes between 5 and 8 % (6 % on average). The results of other models show larger average deviations from the validation fold ratios. Also, the other models have larger average values of absolute deviation and greater values of standard deviation. This matter signifies a higher variation in the errors of the $FLEMO_{cs}$, FEMA and ANUFLOOD model estimates. As summarised in Figure 7, the individual differences between the estimated ratios and validation folds ratios (residuals) in $FLFA_{cs}$, in contrast to other models, have less magnitude and variation. The $FLFA_{cs}$ clearly achieves better results than the models that are not calibrated with the local damage data.

In addition, the performance of all flood loss models used to estimate the mean loss ratios is summarised in Table 4. It can be observed that the result of the new model with the most-likely functional parameters, lie within the confidence intervals and its performance is acceptable. However, results of other models do not lie within the confidence intervals of the mean loss ratios and their performance is rejected in this area of study. This issue and the K-fold cross-validation procedure illustrates the importance of model calibration with the empirical local data sets, particularly when the water depth is the only hydraulic factor considered (Cammerer et al., 2013; Chang et al., 2008; McBean et al., 1986). Although the results of the $FLEMO_{cs}$ and FEMA models do not lie within the confidence intervals, errors of their estimates are not too significant and their performances are much better than the ANUFLOOD model.

In this study and for investigating cause-and-effect relations between flooding and damage, water depth is taken into account as the most dominant influencing factor of flood hazard; and the materials of buildings, absence of basement, use of buildings, number of storeys, age of building, and height of storeys have been considered as the vulnerability factors of buildings (Kelman and Spence, 2004; Menoni et al., 2012). Although damage magnitude could be reliant upon more factors (Grahn and Nyberg, 2014), by calibrating the loss function with the empirical data set collected from the real-world and providing an empirically-based curve, the damage model has been validated for use in the conditions of the study area (McBean et al., 1986).

Table 3: Numerical comparison and error estimation for performance of the applied damage functions (MBE: Mean Bias Error; MAE: Mean Absolute Error; RMSE: Root Mean Squared Error)

	MBE				MAE				RMSE			
	FLFAcs	FLEMOcs	FEMA	ANUFLOOD	FLFAcs	FLEMOcs	FEMA	ANUFLOOD	FLFAcs	FLEMOcs	FEMA	ANUFLOOD
Fold 1	0.00	-0.02	-0.01	-0.15	0.05	0.06	0.06	0.15	0.06	0.08	0.08	0.18
Fold 2	0.00	-0.02	-0.01	-0.17	0.04	0.05	0.05	0.17	0.05	0.06	0.07	0.19
Fold 3	0.00	-0.02	-0.01	-0.16	0.05	0.06	0.06	0.17	0.08	0.10	0.09	0.20
Average	0.00	-0.02	-0.01	-0.16	0.05	0.06	0.06	0.16	0.06	0.08	0.08	0.19

Table 4: Comparison of mean loss ratios estimated by the applied damage models with the resampled loss data (95% confidence interval)

	FLFA_{cs}		FLEMO_{cs}		FEMA		ANUFLOOD	
	Mean loss ratios	Within 95% interval	Mean loss ratios	Within 95% interval	Mean loss ratios	Within 95% interval	Mean loss ratios	Within 95% interval
Fold 1	0.313	Yes	0.292	No	0.296	No	0.157	No
		0.306 (2.5th percentile)				0.313 (97.5th percentile)		
Fold 2	0.291	Yes	0.270	No	0.280	No	0.114	No
		0.284 (2.5th percentile)				0.292 (97.5th percentile)		
Fold 3	0.307	Yes	0.281	No	0.296	No	0.149	No
		0.302 (2.5th percentile)				0.308 (97.5th percentile)		
All records	0.304	Yes	0.280	No	0.291	No	0.140	No
		0.297 (2.5th percentile)				0.304 (97.5th percentile)		

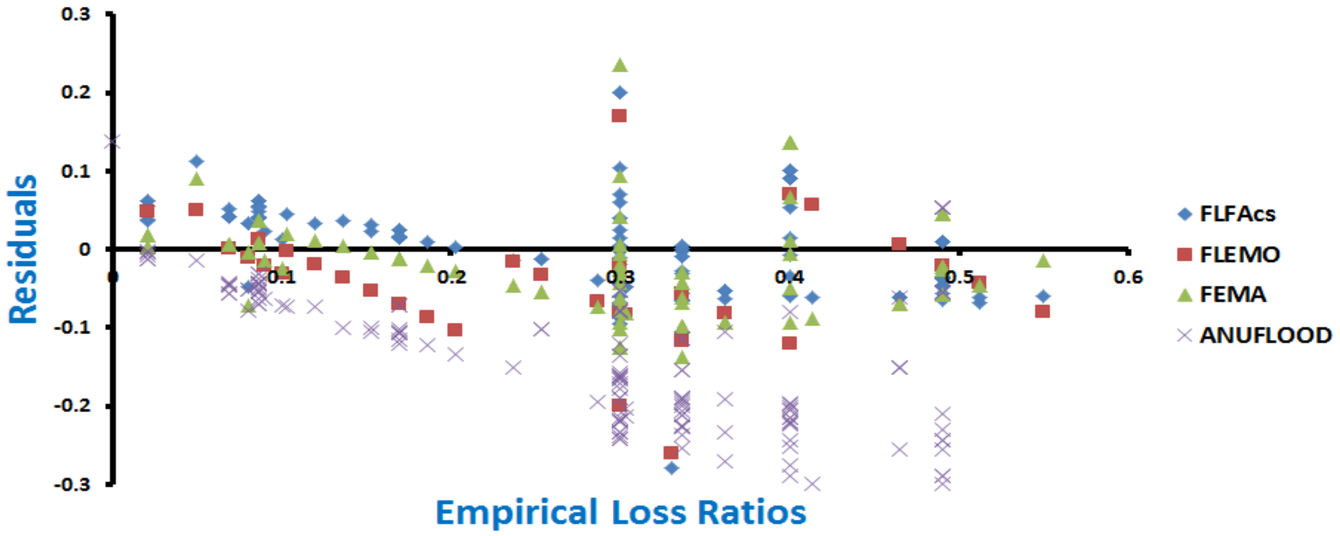

Figure 7: Residual plot used for comparing performance of the selected damage functions relative to the empirical loss ratios

7 Conclusions

Statistical analyses emphasise the significance of commercial building flood losses for the economics of Australia. However, Australian models for commercial loss estimation are still limited and their results are subjected to a high level of uncertainty.

The proposed approach presented in this paper has attempted to quantify the magnitude of direct damages of commercial structures. This approach has suggested a damage function for quickly describing the extent of flood losses. The new function ($FLFA_{cs}$) can be utilised for different purposes such as flood management tasks or insurance issues. In this model, water depth is taken into account as the most dominant influencing factor of flood hazard; and materials of buildings, use of buildings, number of storeys, age of building, and height of storeys have been considered as the vulnerability factors. In this regard, the newly derived model has been calibrated for the geographical conditions of Australia by means of empirical data collected from the 2013 flood in Bundaberg, Australia. Also, inherent uncertainty of the new model as a result of insufficient data and the great variation of commercial building structures have been considered. Although non-residential building losses are less about structural damage and more about damage to contents, due to limited availability of data, this model has been built only for structural damages. However, as a result of simplicity and flexibility of the new function, it is possible for it to be developed by future researches, even for using in another region of study.

In addition, the performance of the new model in comparison to the empirical data has been contrasted with two damage functions from overseas and one damage model from Australia. Furthermore, statistical comparison and numerical analysis with regards to estimating the level of uncertainty and validating the applied damage models were conducted. These analyses show that accuracy of results is totally dependent on model calibration. Also, they show that the results of the Australian model are no longer sufficiently accurate. Hence, there is an urgent need for a project to develop new functions for commercial flood damage estimation.

Since the vulnerability of commercial buildings to flood is of particular interest to the insurance industry, databases of insurance claims can benefit this research considerably. Therefore, reconciliation with insurance claims data and consideration of more flood loss events will benefit future works. On the other hand, further research will be aimed at incorporating more influencing factors of hazard, exposure and vulnerability; considering content damages as well as structural damages; taking into account more variations of commercial sectors; and last but not least, enhancing the level of precision in damage documentation procedures.

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References

André, C., Monfort, D., Bouzit, M., Vinchon, C., 2013. Contribution of insurance data to cost assessment of coastal flood damage to residential buildings: Insights gained from Johanna (2008) and Xynthia (2010) storm events. Nat. Hazards Earth Syst. Sci. 13, 2003–2012.

Australian Bureau of Statistics, 2012. Census of Population and Housing Destination Zones , INFORMATION ABOUT DESTINATION ZONES (DZNs) [WWW Document]. URL http://www.abs.gov.au/ausstats/abs@.nsf/mf/8000.0

Barton, C., Viney, E., Heinrich, L., Turnley, M., 2003. The Reality of Determining Urban Flood Damages. In: NSW Floodplain Management Authorities Annual Conference. Sydney.

Bundaberg Regional Council, 2013a. Burnett River Floodplain - Bundaberg Ground Elevations [WWW Document]. URL http://www.bundaberg.qld.gov.au/flood/mapping (accessed 9.30.15).

Bundaberg Regional Council, 2013b. Burnett River Catchment Map [WWW Document]. URL http://www.bundaberg.qld.gov.au/flood/mapping (accessed 9.30.15).

Bundaberg Regional Council, 2013c. 2013 Flood Calibration Map - Paradise Dam to Bundaberg Port [WWW Document]. URL http://www.bundaberg.qld.gov.au/flood/mapping (accessed 9.30.15).

Bureau of Transport Economics, 2001. Economic Costs of Natural Disasters in Australia. Commonwealth of Australia, Canberra.

Cammerer, H., Thieken, a. H., Lammel, J., 2013. Adaptability and transferability of flood loss functions in residential areas. Nat. Hazards Earth Syst. Sci. 13, 3063–3081.

Chai, T., Draxler, R.R., 2014. Root mean square error (RMSE) or mean absolute error (MAE)? -Arguments against avoiding RMSE in the literature. Geosci. Model Dev. 7, 1247–1250.

Chang, L.F., Lin, C.H., Su, M.D., 2008. Application of geographic weighted regression to establish flood-damage functions reflecting spatial variation. Water SA 34, 209–216.

Dewals, B.J., Giron, E., Ernst, J., Hecq, W., Pirotton, M., 2008. Integrated assessment of flood protection measures in the context of climate change: Hydraulic modelling and economic approach. Environ. Econ. Invest. Assess. II 149 108, 149–159.

Dunford, M.A., Power, L., Cook, B., 2014. National Exposure Information System (NEXIS) Building Exposure - Statistical Area Level 1 (SA1) [WWW Document]. Geosci. Aust. Canberra. URL http://dx.doi.org/10.4225/25/5420C7F537B15 (accessed 7.15.15).

Elmer, F., Hoymann, J., Düthmann, D., Vorogushyn, S., Kreibich, H., 2012. Drivers of flood risk change in residential areas. Nat. Hazards Earth Syst. Sci. 12, 1641–1657.

Elmer, F., Thieken, a. H., Pech, I., Kreibich, H., 2010. Influence of flood frequency on residential building losses. Nat. Hazards Earth Syst. Sci. 10, 2145–2159.

Emanuelsson, M. a E., Mcintyre, N., Hunt, C.F., Mawle, R., Kitson, J., Voulvoulis, N., 2014. Flood risk assessment for infrastructure networks. J. Flood Risk Manag. 7, 31–41.

FEMA, 2011. Supplement to the Benefit-Cost Analysis Reference Guide [WWW Document]. Fed. Emerg. Manag. Agency, Dep. Homel. Secur. Washington, DC. URL https://www.fema.gov/benefit-cost-analysis (accessed 7.15.15).

FEMA, 2012. Multi-Hazard Loss Estimation Methodology, Flood Model: Hazus-MH

Technical Manual. Department of Homeland Security,Federal Emergency Management Agency, Mitigation Division, Washington, D.C.

Gissing, A., Blong, R., 2004. Accounting for variability in commercial flood damage estimation. Aust. Geogr. 35, 209–222.

Grahn, T., Nyberg, R., 2014. Damage assessment of lake floods: Insured damage to private property during two lake floods in Sweden 2000/2001. Int. J. Disaster Risk Reduct. 10, 305–314.

Handmer, J.W., Reed, C., Percovich, O., 2002. Disaster loss assessment Guidelines. Queensland Government Department Emergency Services, Queensland and Emergency Management Australia, Australia.

Haque, A., Jahan, S., 2015. Impact of flood disasters in Bangladesh: A multi-sector regional analysis. Int. J. Disaster Risk Reduct. 13, 266–275.

Haraguchi, M., Lall, U., 2014. Flood risks and impacts: A case study of Thailand’s floods in 2011 and research questions for supply chain decision making. Int. J. Disaster Risk Reduct. 1–17.

Hasanzadeh Nafari, R., Ngo, T., Lehman, W., 2016. Calibration and validation of FLFArs -- a new flood loss function for Australian residential structures. Nat. Hazards Earth Syst. Sci. 16, 15–27.

Hawkesbury-Nepean Floodplain Management Steering Committee, 2006. REDUCING VULNERABILITY OF BUILDINGS TO FLOOD DAMAGE; Guidance On Building In Flood Prone Areas. NSW Goverment, Australia.

Huxley, C., 2011. Belongil Creek Floodplain Risk Management Study and Plan; Discussion Paper 2: Flood Damage Assessment [WWW Document]. BMT WBM Pty Ltd. URL http://www.byron.nsw.gov.au/files/committee-meetings/2011/10/04/belongil-creek-flood-risk-management-committee/2011-10-04-.pdf (accessed 7.15.15).

Jongman, B., Kreibich, H., Apel, H., Barredo, J.I., Bates, P.D., Feyen, L., Gericke, a., Neal, J., Aerts, J.C.J.H., Ward, P.J., 2012. Comparative flood damage model assessment: Towards a European approach. Nat. Hazards Earth Syst. Sci. 12, 3733–3752.

Kaplan, S., Garrick, B.J., 1981. On the quantitative definition of risk. Risk Anal. 1, 11–27.

Kelman, I., Spence, R., 2004. An overview of flood actions on buildings. Eng. Geol. 73, 297–309.

Khalili, S., Harre, M., Morley, P., 2015. A Temporal Framework Of Social Resilience Indicators of Communities To Flood, Case Studies: Wagga Wagga and Kempsey, NSW, Australia. Int. J. Disaster Risk Reduct. 13, 248–254.

Kourgialas, N.N., Karatzas, G.P., 2012. A hydro-economic modelling framework for flood damage estimation and the role of riparian vegetation. Hydrol. Process. 27, 515–531.

Kreibich, H., Seifert, I., Merz, B., Thieken, A.H., 2010. Development of FLEMOcs – a new model for the estimation of flood losses in the commercial sector. Hydrol. Sci. J. 55, 1302–1314.

Kreibich, H., Thieken, a. H., Petrow, T., Müller, M., Merz, B., 2005. Flood loss reduction of private households due to building precautionary measures – lessons learned from the Elbe flood in August 2002. Nat. Hazards Earth Syst. Sci. 5, 117–126.

Kreibich, H., Thieken, A.H., 2008. Assessment of damage caused by high groundwater inundation. Water Resour. Res. 44, 1–14.

Kundzewicz, Z.W., Ulbrich, U., Brücher, T., Graczyk, D., Krüger, A., Leckebusch, G.C., Menzel, L., Pińskwar, I., Radziejewski, M., Szwed, M., 2005. Summer floods in Central Europe - Climate change track? Nat. Hazards 36, 165–189.

Llasat, M.C., Marcos, R., Llasat-Botija, M., Gilabert, J., Turco, M., Quintana-Seguí, P., 2014. Flash flood evolution in North-Western Mediterranean. Atmos. Res. 149, 230–243.

McBean, E., Fortin, M., Gorrie, J., 1986. A critical analysis of residential flood damage estimation curves. Can. J. Civ. Eng. 13, 86–94.

McGrath, H., Stefanakis, E., Nastev, M., 2015. Sensitivity analysis of flood damage estimates: A case study in Fredericton, New Brunswick. Int. J. Disaster Risk Reduct. 1–9.

Menoni, S., Molinari, D., Parker, D., Ballio, F., Tapsell, S., 2012. Assessing multifaceted vulnerability and resilience in order to design risk-mitigation strategies. Nat. Hazards 64, 2057–2082.

Merz, B., Kreibich, H., Schwarze, R., Thieken, a., 2010. Review article "assessment of economic flood damage." Nat. Hazards Earth Syst. Sci. 10, 1697–1724.

Merz, B., Kreibich, H., Thieken, a., Schmidtke, R., 2004. Estimation uncertainty of direct monetary flood damage to buildings. Nat. Hazards Earth Syst. Sci. 4, 153–163.

Meyer, V., Becker, N., Markantonis, V., Schwarze, R., Van Den Bergh, J.C.J.M., Bouwer, L.M., Bubeck, P., Ciavola, P., Genovese, E., Green, C., Hallegatte, S., Kreibich, H., Lequeux, Q., Logar, I., Papyrakis, E., Pfurtscheller, C., Poussin, J., Przyluski, V., Thieken, a. H., Viavattene, C., 2013. Review article: Assessing the costs of natural hazards-state of the art and knowledge gaps. Nat. Hazards Earth Syst. Sci. 13, 1351–1373.

Molinari, D., 2011. FLOOD EARLY WARNING SYSTEMS PERFORMANCE: an approach at the warning chain perspective. PhD Thesis, Politecnico di Milano.

Molinari, D., Ballio, F., Handmer, H., Menoni, S., 2014a. On the modeling of significance for flood damage assessment. Int. J. Disaster Risk Reduct. 10, 381–391.

Molinari, D., Ballio, F., Menoni, S., 2013. Modelling the benefits of flood emergency management measures in reducing damages: A case study on Sondrio, Italy. Nat. Hazards Earth Syst. Sci. 13, 1913–1927.

Molinari, D., Menoni, S., Aronica, G.T., Ballio, F., Berni, N., Pandolfo, C., Stelluti, M., Minucci, G., 2014b. Ex post damage assessment: an Italian experience. Nat. Hazards Earth Syst. Sci. 14, 901–916.

Morrison, T., Mollino, S., 2012. Hawkesbury-Nepean Flood Damages Assessment: Final Report.

Mouri, G., Minoshima, D., Golosov, V., Chalov, S., Seto, S., Yoshimura, K., Nakamura, S., Oki, T., 2013. Probability assessment of flood and sediment disasters in Japan using the total runoff-integrating pathways model. Int. J. Disaster Risk Reduct. 3, 31–43.

Neale, T., Weir, J.K., 2015. Navigating scientific uncertainty in wildfire and flood risk mitigation: A qualitative review. Int. J. Disaster Risk Reduct. 13, 255–265.

Othman, M., Ahmad, M.N., Suliman, A., Arshad, N.H., Maidin, S.S., 2014. COBIT principles to govern flood management. Int. J. Disaster Risk Reduct. 9, 212–223.

Proverbs, D.G., Soetanto, R., 2004. Flood Damaged Property; A Guide to Repair. Blackwell

Publishing Ltd.

Queensland Government, 2011. Queensland Government Statistician's Office, Queensland Regional Profiles, Bundaberg Statistical Area Level 2 (SA2) [WWW Document]. URL http://statistics.qgso.qld.gov.au/qld-regional-profiles?region-type=SA2_11&region-ids=8075 (accessed 7.15.15).

Queensland Government, 2013. Queensland 2013 Flood Recovery Plan (for the events of January – February 2013) [WWW Document]. URL http://qldreconstruction.org.au/u/lib/cms2/lg-flood-recovery-plan.pdf (accessed 7.15.15).

Rawlinsons, 2014. Australian Construction Cost Guide 2014, 32nd ed. Welshpool Publishing, Western Australia: Rawlinsons.

Refaeilzadeh, P., Tang, L., Liu., H., 2009. "Cross-Validation." In: Encyclopedia of Database Systems. Springer US, pp. 532–538.

Sargent, D.M., 2013. Updating Residential Flood Stage-Damage Curves based on Building Cost Data. In: Reaching out to the Regions - SIAQ Conference. Townsville, pp. 1–10.

Seifert, I., Kreibich, H., Merz, B., Thieken, A.H., 2010. Application and validation of FLEMOcs – a flood-loss estimation model for the commercial sector. Hydrol. Sci. J. 55, 1315–1324.

Smith, D., 1994. Flood damage estimation-A review of urban stage-damage curves and loss function. Water SA 20, 231–238.

Sturgess, R., Associates, 2000. Rapid Appraisal Method (RAM) for Floodplain Management.

Thieken, a. H., Ackermann, V., Elmer, F., Kreibich, H., Kuhlmann, B., Kunert, U., Maiwald, H., Merz, B., Müller, M., Piroth, K., Schwarz, J., Schwarze, R., Seifert, I., Seifert, J., 2009. Methods for the evaluation of direct and indirect flood losses. In: RIMAX Contributions at the 4th International Symposium on Flood Defence (ISFD4). pp. 1–10.

Thieken, A.H., Kreibich, H., Merz, B., 2006. Improved modelling of flood losses in private households. In: German-Polish Seminar "Natural Systems and Global Change." pp. 1–10.

Thieken, A.H., Müller, M., Kreibich, H., Merz, B., 2005. Flood damage and influencing factors: New insights from the August 2002 flood in Germany. Water Resour. Res. 41, 1–16.

Thieken, A.H., Olschewski, A., Kreibich, H., Kobsch, S., Merz, B., 2008. Development and evaluation of FLEMOps – a new Flood Loss Estimation MOdel for the private sector. Flood Recover. Innov. Response, WIT Press 315–324.

UNISDR, 2004. Terminology. Basic terms of disaster risk reduction. United Nations Int. Strateg. Disaster Reduct. (UNISDR), Geneva 1–30.

UNISDR, 2009. UNISDR Terminology on Disaster Risk Reduction [WWW Document]. URL http://www.unisdr.org/eng/terminology/terminology-2009- (accessed 4.30.15).