

IMPROVED ASSESSMENT OF FLOOD IMPACT: AN URBAN STORMWATER CASE STUDY OF A CITY OF SYDNEY CATCHMENT

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Abstract

The flood risk in many urban catchments is poorly understood. Legacy stormwater infrastructure is often substandard and anticipated climate change induced sea level rise and increased rainfall intensity will typically exacerbate present risk. In a Department of Climate Change and Energy Efficiency (DCCEE) funded collaboration between Geoscience Australia (GA) and the City of Sydney, the impacts on the Alexandra Canal catchment in the City of Sydney local government area have been studied. This work has built upon detailed flood hazard analyses by Cardno Pty Ltd commissioned by the City of Sydney and has entailed the development of exposure and vulnerability information. Significantly, the case study has highlighted the value of robust exposure attributes and vulnerability models in the development of flood risk knowledge.

The paper describes how vulnerability knowledge developed following the 2011 Brisbane floods was extended to include key building types found in the inner suburbs of Sydney. It also describes the systematic field capture of building exposure information in the catchment area and its categorisation into 19 generic building types. The assessment of ground floor heights from street view imagery using the Field Data Analysis Tool (FiDAT) developed at Geoscience Australia is also presented.

The selected hazard scenario was a 100 year Annual Recurrence Interval (ARI) event with 20% increased rainfall intensity accompanied by a 0.55m sea level rise in Botany Bay. The impact from the selected scenario was assessed in terms of monetary loss for four combinations. The combinations consist of two vulnerability model suites (GA and NSW Government) and two floor height attribution methods (assumed 0.15m uniformly and evaluated from street view imagery).

It was observed that the total loss is higher in the case of assumed floor heights compared to FiDAT processed floor heights as the former failed to capture increased floor heights for newer construction. However, the loss is lower when only two vulnerability models developed by NSW Government are applied for the entire building stock in the region as two models produced a coarser modelling of the variety in the whole building stock.

Introduction

Climate change is expected to exacerbate a range of natural hazards in Australia leading to more severe community impacts in the future. Flood hazard is one of these as some catchments are expected to experience more severe rainfall and increased tail-water levels at the coast due to sea level rise. Legacy stormwater systems in the urban catchments of some coastal cities may be particularly compromised by these effects. The need to begin to adapt to this changing hazard environment is generally accepted but the evidence base is lacking to inform this. Knowledge of future hazard,

building exposure and vulnerability to flood should be brought together to permit flood risk to be understood and for the best options for community adaptation to be identified in quantitative terms.

As a strategy for addressing this need, Geoscience Australia (GA) collaborated with the Department of Climate Change and Energy Efficiency (DCCEE) and the City of Sydney to develop and demonstrate key risk components that will enable the production of quantitative impact information. It includes the demonstration of flood impact assessment for an urban stormwater system in the Alexandra Canal Catchment area (Botany Bay) in economic terms using improved risk modelling components developed through an overarching DCCEE/GA project and the engagement of a large local government, i.e., the City of Sydney.

In this paper the research methodology is outlined, the development of exposure and vulnerability information is described, and the building damage outcomes for a single flood scenario are presented.

City of Sydney flood risk context

Sydney is Australia's oldest settlement and has grown steadily since settlement in 1788 to a present day population exceeding 4.5 million (ABS, 2012). The burgeoning size of the city has encouraged urban redevelopment in the inner suburbs which has led to the central city having a collection of community infrastructure of various ages. The development and later redevelopment of this area has also contributed to changes in catchment characteristics. These have transitioned from lower density development with greater retention and percolation of rainfall to denser and more impervious catchments having more rapid run-off. Consequently, the present day performance of urban stormwater systems is often substandard and this is true of the Alexandra Canal Catchment in the City of Sydney local government area. The area is low lying, densely urbanised with a range of building stock and is prone to flooding under present climate. The Alexandra Canal Catchment includes the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park (see Figure 1).

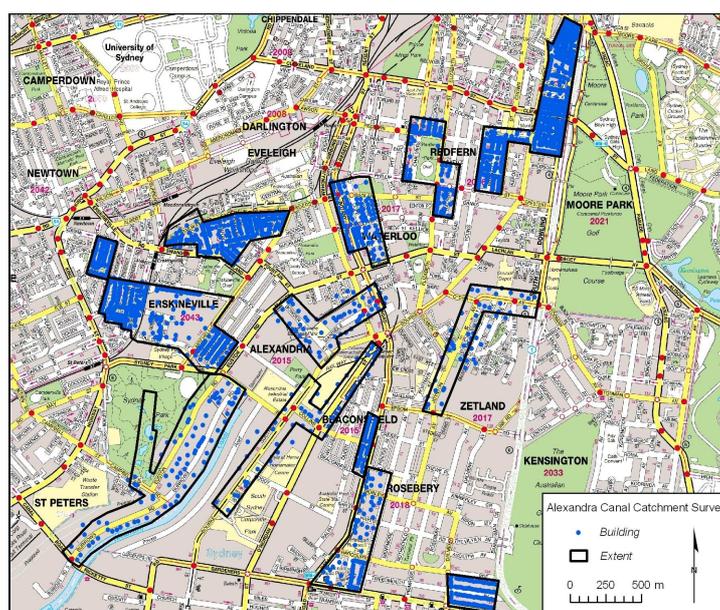


Figure 1: Alexandra Canal catchment area with polygons show the extent of the Rapid Inventory Capture System (RICS) survey activity

Cardno hazard study

Cardno Pty Ltd was commissioned by the City of Sydney to undertake a flood study for the entire Alexandra Canal Catchment. The primary objective of the study was to define the flood behaviour in the catchment, along with a review of previous studies and available data. The study utilised a detailed asset survey undertaken by the City of Sydney to build a complex hydraulic model of the stormwater system and the overland flow paths that would come into play in a severe flood event. The study produced information on flood levels for different Average Recurrence Interval (ARI) events (1 year, 2 year, 5 year, 10 year, 20 year, and 100 year) together with the Probable Maximum Flood (PMF) event. The flood output used for this research was local water depth above ground (Cardno Pty Ltd, 2010).

The effect of climate change was also assessed in the hazard study which included sea level rise and increases in rainfall intensity. Three simulations were run for the 100 year ARI 90 minute storm for increases in rainfall intensity of 10%, 20% and 30%, each with a concurrent elevated tail water level of 2.9m AHD resulting from mid-range sea level rise of 0.55m (Cardno Pty Ltd, 2010).

Research methodology

The research methodology involved the development of the primary inputs to the impact framework. Flood impact assessment requires knowledge of the hazard, the number and nature of properties exposed and their vulnerability to flood damage. It also requires a computational framework for bringing the three elements together. The impact assessment framework presented by Edwards (2012) was adopted for severe flood impact assessment which is the combination of the elements illustrated in Figure 2. In this research the impact assessment framework was used for a single deterministic scenario to provide an estimation of the level of damage and loss associated with the hazard exposure. Each of the elements in Figure 2 is described briefly:

Hazard describes the severity and associated likelihood of a rapid onset hazard at a locality of interest. In this study, the hazard is defined in terms of flood depth above ground floor level.

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. The present study focuses on buildings only.

Vulnerability describes the susceptibility of assets to hazard exposure and is the likelihood of a building being damaged due to a given severity of hazard exposure, i.e., inundation.

Impact describes the economic losses resulted from the building damage during an event. The key elements of the research methodology were:-

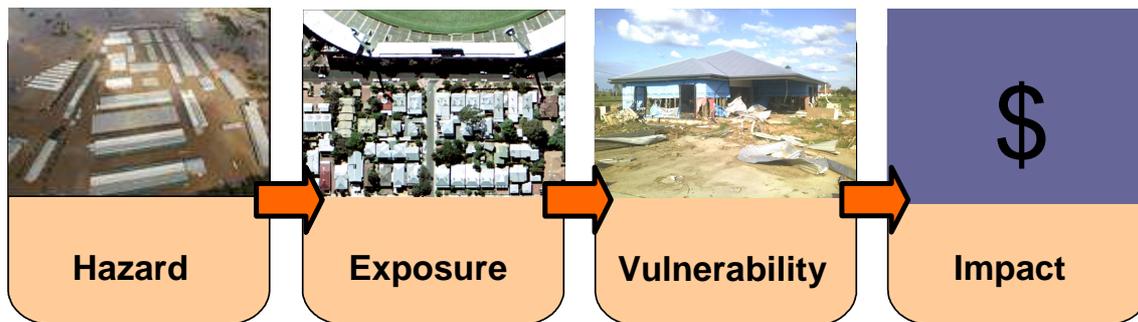


Figure 2: Impact assessment framework that describes schematically the translation of severe hazard through exposure and vulnerability to give impact

1. Preliminary survey of building stock in the flood prone areas of the Alexandra Canal catchment;
2. Association of the surveyed building types with building types for which vulnerability relationships are presented in Wehner *et al.* (2012) and identification of additional building types necessary to describe the surveyed building stock;
3. Survey of the building stock in the flood prone areas of the catchment utilising a street view image capturing system known as RICS;
4. Development of an exposure database including the assessment of ground floor height;
5. Review of the typical damage sustained to the range of additional building types of interest when exposed to flooding;
6. Development of repair scenarios for each additional building type;
7. Costing of the repair scenarios using quantity surveying professionals;
8. Development of building vulnerability curves;
9. Assessment of flood hazard in terms of water depth above ground floor for each building in the study area;
10. Calculation of the Damage Index from the appropriate vulnerability model for each building; and,
11. Estimation of economic loss by multiplying the Damage Index with average cost per square metre and total floor area of each building type.

Step 4 above was undertaken using two methods for floor height determination. Steps 5 to 8 were undertaken to extend the suite of available vulnerability curves developed. These were then used in parallel to a vulnerability model suite from the NSW government for steps 9 to 11. In total four combinations of floor height and vulnerability model suite were considered in assessing the climate change scenario loss.

Exposure definition

The asset exposure definition was primarily based on a database developed utilising street view image capture and augmented by NEXIS, the National Exposure Information System developed by GA (Nadimpalli, 2009). The extent of the survey areas were defined with reference to the flood hazard data contained in the Cardno Pty Ltd (2010) report and consisted of about 3,500 buildings. The exposure was refined by street view imagery capture through the Rapid Inventory Capture System (RICS), image interrogation and building footprint information provided by the City of Sydney. The process is described in greater detail below.



Figure 3: The Rapid Inventory Collection System (RICS) mounted on a car

RICS survey

The street view imagery capture was undertaken using the Rapid Inventory Capture System (RICS) developed by GA. RICS is a vehicle borne camera system that takes geo-located images from a moving vehicle and is available as open source software (Habibi *et al.* 2011). The equipment is shown in Figure 3. RICS comprises two cameras, associated tripods, GPS receiver, hazard light and a laptop computer. Images taken by RICS were automatically attached to survey database entries by post-survey processing that selects the nearest RICS image to each building location.

FiDAT processing

The interrogation of images was undertaken using the Field Data Analysis Tool (FiDAT) shown in Figure 4. This tool was developed by Geoscience Australia to enable the interpretation of data to develop a building inventory and to assess damage. The tool can use data from several sources including RICS imagery, Google street view imagery, aerial imagery, information captured in the field using hand held computers and NEXIS. It also allows exporting information in ESRI shapefile format. From the FiDAT processing building characteristics were defined which included the attributes of building age, usage, wall and roof material, ground floor height, presence of basement and garage etc. The information captured was fundamental for assigning an appropriate vulnerability model to each building in the study area.

It is observed that average ground floor heights have increased gradually over a period of time and considerably since the 1960s. The trend is predominant in residential and commercial buildings; however, the same trend is not observed for industrial buildings, as shown in Figure 5. The increase in ground floor height may have been a result of change in land use regulations and may also have been influenced by an increased level of flood awareness and experience of residents.

Building stock categorisation

A preliminary foot survey of buildings was conducted in the study area prior to the RICS activity to establish the predominant building types. The survey helped to ascertain how the categorisation of generic building types developed by Wehner *et al.* (2012) may need to be extended. Eight additional building types were selected that included residential structures along with mixed-use, commercial and industrial buildings. The augmented categorisation of building types is presented in Table 1 (ACFS1a to ACFS6). The generic building types listed were chosen, not only to represent the most common building types, but also to capture the variety of construction typologies and usages that would require specific repair works after inundation.

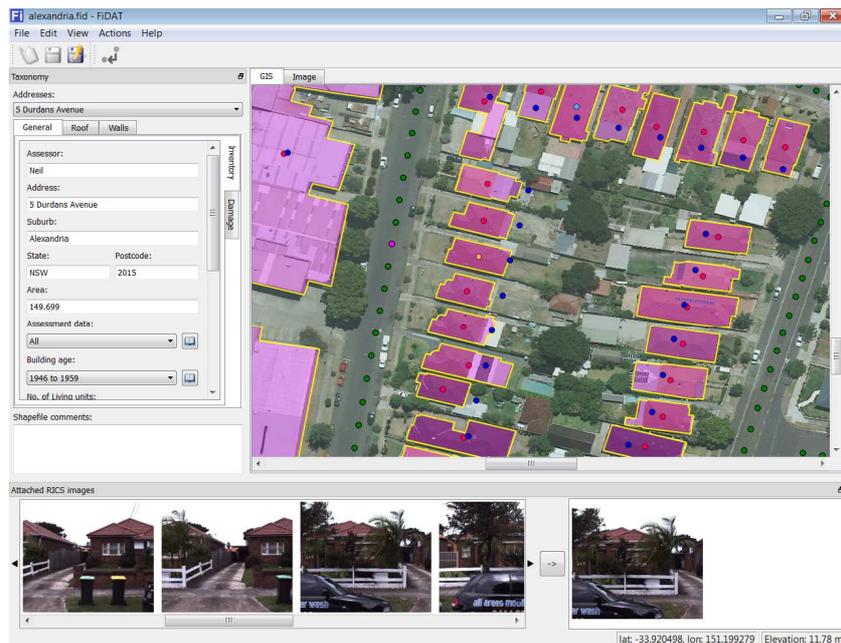


Figure 4: Interface of the Field Data Analysis Tool (FiDAT) developed by Geoscience Australia

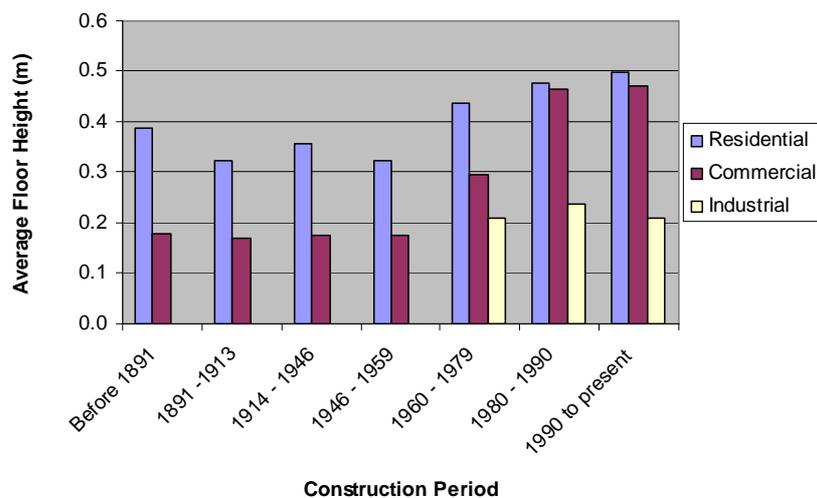


Figure 5: Average floor heights for different age categories

Vulnerability model development

Vulnerability models were developed in the present study for the eight additional categorised building types. They were similar to those developed earlier by Wehner *et al.* (2012) for Southeast Queensland residential buildings in that they related to inundation only, with no account made of flow velocities. Flow velocities in the Alexandra Canal catchment were assumed to be insufficient to cause local structural damage or transport buildings. As water enters into a building and the depth increases above floor level the impact increases as more internal building components are exposed. The exposure sequence include floor material and coverings, lower electrical sockets and associated circuits, lower cabinetry, higher cabinetry, electrical switch boards, ceilings and roof structure etc.

For each selected building type an example building was documented and the building fabric was divided into components (e.g., substructure, floor covering, light switches, window dressing, and ceilings). For each component of each generic building type repair work was identified at ten selected inundation depths, thus enabling repair costing to be based on a detailed break-down of repair work. Damage is expressed as a Damage Index (ratio of repair cost to replacement cost) and also as a dollar repair sum. All the costing work was undertaken by a quantity surveying consultant.

The accumulation of losses is very non-linear and is represented by a flood damage function, often described as a stage-damage or vulnerability curve. An example is presented in Figure 6 where the hazard parameter is water depth above ground floor level. Table 1 lists the complete suite of vulnerability models developed by Geoscience Australia.

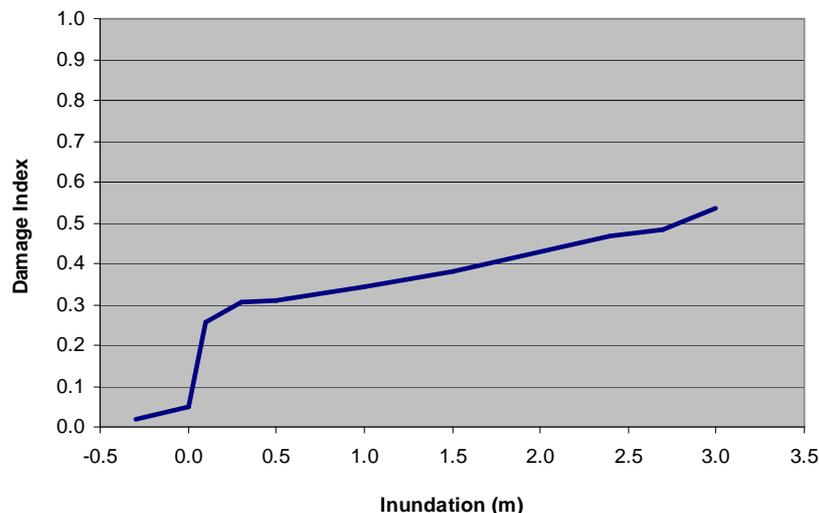


Figure 6: Vulnerability curve for ACFS1a

NEXIS integration

Several building attributes (e.g., address, building area, building value) were acquired from NEXIS for each property to support the development of the building database. With NEXIS integration, the property reconstruction value could be calculated by multiplying a unit area cost for a model building type with total building area.

Table 1: Generic building types selected for inundation damage costing

No.	Vulnerability Model	Region	Type	Description
1	ACFS1a	Sydney	Residential	Victorian terrace, 1 storey, without basement
2	ACFS1b	Sydney	Residential	Victorian terrace, 1 storey, with basement
3	ACFS2a	Sydney	Residential	Victorian terrace, 2 storey, without basement
4	ACFS2b	Sydney	Residential	Victorian terrace, 2 storey, with basement
5	ACFS3	Sydney	Mixed use	Retail/residential, 2 storey, without basement
6	ACFS4	Sydney	Commercial	Showroom/office, 2 storey, without basement
7	ACFS5	Sydney	Commercial	Warehouse/garage, 2 storey, without basement
8	ACFS6	Sydney	Industrial	Factory, 1 storey, without basement
9	FCM1	Brisbane	Residential	1 storey, raised floor, weatherboard cladding, plaster board lining, no integral garage
10	FCM2	Brisbane	Residential	1 storey, raised floor, weather board or panel cladding, timber lining, no integral garage
11	FCM3	Brisbane	Residential	2 storey, slab-on-grade, cavity masonry lower storey, weatherboard upper storey, metal roof, no integral garage
12	FCM4	Brisbane	Residential	2 storey, slab-on-grade, cavity masonry lower storey, weatherboard upper storey, metal roof, integral garage
13	FCM5	Brisbane	Residential	2 storey, slab-on-grade, weatherboard cladding, plaster board lining, partial lower floor, integral garage
14	FCM6	Brisbane	Residential	2 storey, raised floor, weatherboard cladding, plaster board lining, no integral garage
15	FCM7	Brisbane	Residential	1 storey, slab-on-grade, masonry veneer, plaster board lining, integral garage
16	FCM8	Brisbane	Residential	1 storey, slab-on-grade, masonry veneer, plaster board lining, no garage
17	FCM9	Brisbane	Residential	1 storey, raised floor, masonry veneer, plaster board lining, no garage
18	FCM10	Brisbane	Residential	1 storey, slab-on-grade, cavity masonry, no garage
19	FCM11	Brisbane	Residential	1 storey, raised floor, cavity masonry, no garage

Flood impact assessment

Flood impact was assessed and tabulated for each building with the respective inundation depth in the flood scenario. Impacts are assessed in terms of numbers of buildings impacted and the economic loss in terms of direct reparation cost. This is done using the total reconstruction values and stage damage curves attributed to each building asset. The Alexandra Canal Catchment study area is shown in Figure 1 with the locations of the individual flood prone buildings for which flood damage was calculated.

Selected scenario

The selected hazard scenario is the peak flood depths for the 100 year Annual Recurrence Interval (ARI) event with a 20% rainfall increase and 0.55m sea level rise taken from Alexandra canal catchment flood study conducted by Cardno Pty Ltd (2010). Hazard distribution in terms of water depths in the catchment area for the selected scenario is shown in Figure 7. The depth of flood water over the land surface appears to be highest in areas of high building density which predominantly comprise Victorian era houses.

Building age

The spatial distribution of building age is shown in Figure 8 which ranged from pre 1890 to the present. It is apparent from the figure that there is a large concentration of older residential building stock in the north-eastern part of the study area where single and double storey Victorian terrace houses were constructed. Some of these Victorian terraces have partial basements as well. Newer residential construction is predominant in the south-eastern part of the study area which was of slab-on-grade construction. In the south there are also numerous newly constructed industrial buildings clustered together.

Floor height assessment

Two approaches were used to attribute floor heights to each building. The first one was to assume a uniform ground floor height of 0.15m for each building representing a case where no detailed study is undertaken to measure the floor heights of each building.

The second approach was to determine the ground floor height of each building as part of the desktop study using FiDAT after the RICS survey activity. This approach was undertaken using a visual assessment entailing the counting of steps to front door thresholds or by counting the number of brick layers above ground to the ground floor level and then multiplying this by the nominal step or brick course height. The spatial distribution of floor heights attributed to each building through FiDAT is presented in Figure 9A. Detailed examination indicates that the newer residential construction in the southern part had higher ground floor heights compared to the old residential construction in the northern part. However, the industrial buildings which were constructed in the 80s have quite low ground floor heights thus increasing the likelihood of inundation.

Hazard attribution

For each surveyed property a hazard value in terms of flood inundation height above ground floor was attributed from the selected scenario. The inundation height at each property location was calculated by subtracting ground floor height of the particular building from water depth. As two approaches have been followed to assess the floor heights of each building, there are two hazard levels (water level above ground floor height) representing both floor height assessment approaches.

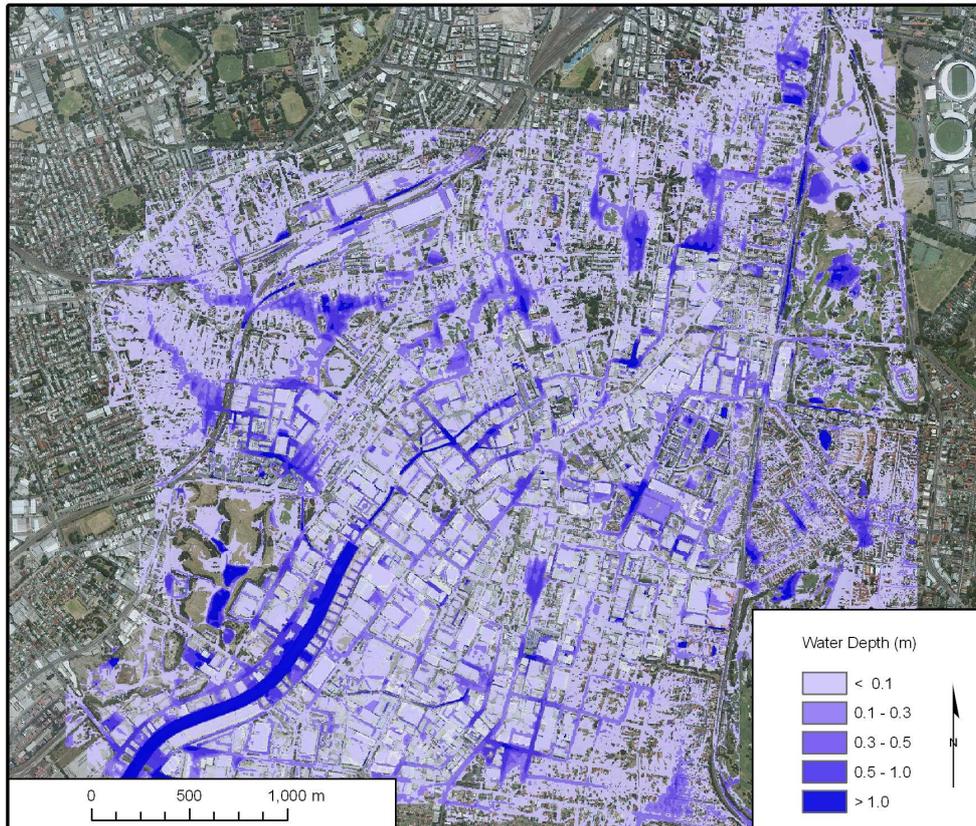


Figure 7: Selected scenario showing water depths, taken from Cardno Pty Ltd, 2010

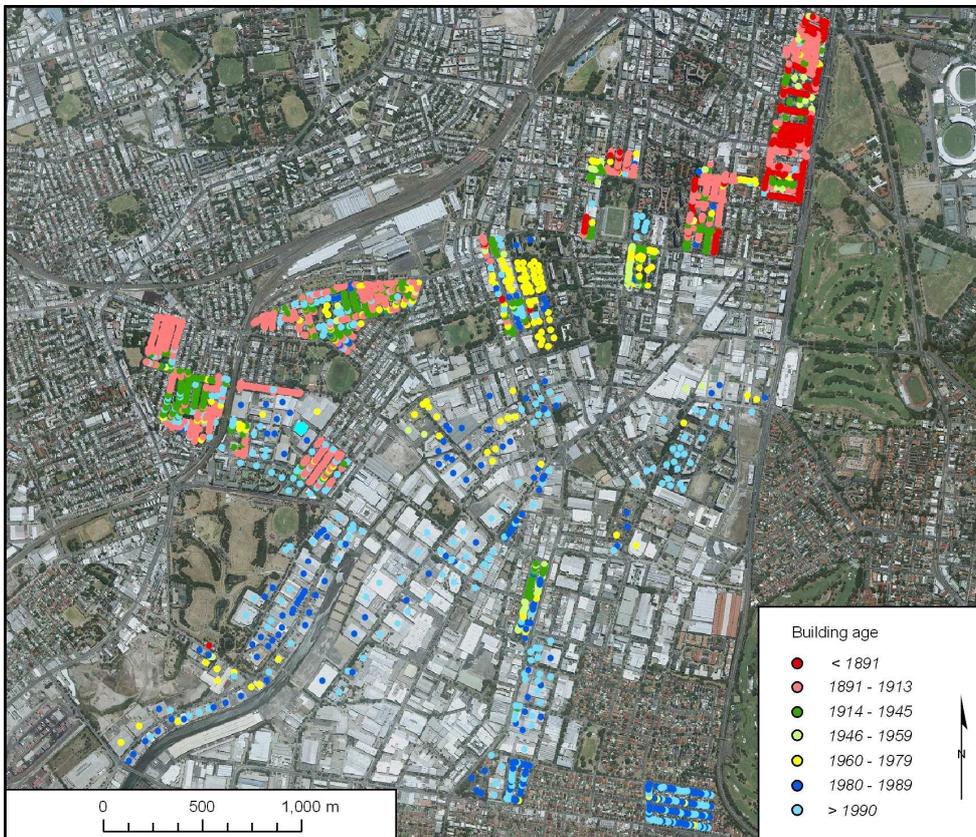


Figure 8: Spatial distribution of building age in the study area



(A) Ground floor height distribution



(B) Vulnerability model distribution

Figure 9: Spatial distribution of ground floor heights assessed through FiDAT and major vulnerability models

Vulnerability attribution

Two sets of vulnerability models were attributed to each building in the present study. The first set comprised two vulnerability models developed by NSW Government (McLuckie, 2007) which corresponded to two residential building types, i.e., single storey house with slab-on-grade/low-set construction and a two storey house. The models provide loss estimates for a given level of inundation for the two typical constructions. However, the NSW vulnerability models do not address non-residential structures and do not distinguish between different construction materials.

The second set was a selection of 19 vulnerability models from the suite developed by Geoscience Australia discussed earlier in the paper (see Table 1). In this case, for each surveyed property an appropriate vulnerability model was attributed by identifying the building usage and other building characteristics. The major usage categories were residential, mixed, commercial use and industrial. The key building characteristics were number of storeys, floor system, wall material, floor material, basement and presence of garage.

The spatial distribution of some of the vulnerability models associated to the building stock is displayed in Figure 9B. The majority of buildings have been attributed ACFS1a and ACFS2a vulnerability models specifically developed for the old Victorian Terrace single and double storey houses, respectively. The other most used vulnerability model is ACFS5 which is a two storey industrial building common in the southern part of the study area.

Impact assessment

Once each property was assigned an appropriate vulnerability model and a depth of inundation above ground floor level for the particular scenario, impact was computed in terms of Damage Index as well as in monetary values (\$). Monetary loss was calculated by multiplying the Damage Index with average cost per square meter and total floor area of the building type. Total monetary loss from the selected scenario due to water contact with building was estimated by aggregating the loss from all properties in the study area.

Results and implications

As discussed earlier, the majority of the building stock consists of single and double storey Victorian terrace houses represented by ACFS1a and ACFS2a respectively. Consequently, the major proportion of loss is also associated with these two vulnerability models. The other major building types (vulnerability models) which contributed to loss are the commercial (ACFS3) and industrial buildings (ACFS5).

The spatial distribution of estimated monetary loss using the GA vulnerability model suite for buildings attributed with uniform floor heights and buildings attributed with floor heights assessed through FiDAT are shown in Figure 10A and Figure 10B respectively. It can be seen that attributing uniform floor heights results in higher loss values when assessed with GA vulnerability models. However, when the same vulnerability models are used with floor heights assessed through FiDAT, there is a significant decrease in the monetary loss. Also, FiDAT assessed floor height successfully captured the losses to industrial buildings in the south of the study area, while the earlier case failed to do so.



(A) Uniform floor heights



(B) FiDAT assessed floor heights

Figure 10: Spatial distribution of loss using GA vulnerability models



(A) Uniform floor heights



(B) FiDAT assessed floor heights

Figure 11: Spatial distribution of loss using NSW vulnerability models

The spatial distribution of estimated loss using the two NSW vulnerability models for buildings attributed with uniform floor heights and buildings attributed with floor heights assessed through FiDAT are shown in Figure 11A and Figure 11B respectively. In both figures, it is observed that the loss is evenly distributed in the region and does not reflect the different construction materials and building types.

The results related to monetary loss for the four cases from the impact assessment are summarized in Table 2. As discussed earlier, impact is assessed by using two sets of vulnerability models (developed by GA and NSW Government) for two methods of floor height attribution (assumed 0.15m and processed through FiDAT). It is observed that the total loss is higher in the case of assumed floor heights compared to the FiDAT processed floor heights for both sets of vulnerability models.

Considering vulnerability model selection in isolation, the loss is lower when only two residential vulnerability models developed by the NSW Government are used for the whole building stock in the region. The significant difference in loss highlights the importance of using representative vulnerability models for typical residential, commercial and industrial buildings and assessing floor heights more accurately to calculate losses more appropriately.

Table 2: Calculated loss for the selected scenario for selected cases

Floor heights	Loss (\$)	
	NSW Models (000s)	GA Models (000s)
Assumed floor heights (0.15m)	93,854	117,064
FiDAT assessed floor heights	63,117	83,085

Summary

This study has examined some of the key issues associated with flood impact assessment. Through a formal collaboration it has leveraged effectively off a rigorous flood hazard study commissioned by the City of Sydney and has translated the hazard information to quantitative loss measures that can be input into economic assessments of adaptation options.

The study has also developed robust inputs for the assessment of flood scenario losses. A significant exposure database of some 3,500 buildings has been developed. The floor heights for this have been assessed using a new desktop technique that may provide a more affordable approach to the attribution of ground floor height for flood impact assessment. The study has also augmented a flood vulnerability model suite previously developed by GA to include building types present in the older redeveloping parts of Sydney. The application of these models can be extended to other state capitals.

Four combinations of flood impact input information have been explored. It has been found that, while all resolutions of data provided a similar order of magnitude of losses, the loss values are significantly changed by more detailed impact assessment inputs. This has served to examine the incremental benefit of increased investment in modelling rigor.

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