40 YEARS OF FLOODPLAIN MANAGEMENT IN PERTH : A REPORT CARD

S Rodgers[1], M Bretnall[1]
[1] Department of Water, Perth, Western Australia

Abstract

Perth, like many coastal cities, is situated on the banks of a major river system, at the interface between a river catchment and tidal estuary. As a result it is potentially susceptible to both riverine and storm surge flooding.

In recognising the need to mitigate potential flood damages, the WA State Government began a State-wide floodplain mapping programme in 1975, commencing with the Swan and Canning Rivers. The Swan River floodplain covers a reach of approximately 70 kilometres from Fremantle to Upper Swan and includes 17 local government areas. The floodplain mapping dataset is used to advise planners and local government authorities on development strategies for ensuring appropriate building controls for proposed development. The mapping has been reviewed as new flood and land surface elevation information became available.

Over the last thirty years there has been a lack of major flood events in the Swan River. This has resulted in a limited availability of detailed flood intelligence information on the expected effects of flooding on existing developments, which increases the potential risk to life, health and safety of people working and living on the floodplain.

In addressing this issue, a GIS database of flood affected infrastructure has been developed that details information pertaining to residential and commercial buildings, major sheds and public facilities located on the floodplain. Determining potential flood affected infrastructure and potential damage for varying magnitude flood events provides key information for targeted flood emergency response planning and increases the understanding of local governments' individual flood risk profiles.

The relatively low number of properties directly affected by major flooding and the expected low flood damage costs are considered to be good overall performance measure of the State Government's floodplain management program.

Study area

Situated on the south-west coast of Western Australia, the Perth metropolitan region covers an area of approximately 5,400 km^2 with a population in excess of 1.7 million people. Perth is experiencing significant population growth, 18% over the past decade, and is the fourth most highly populated city in Australia (ABS, 2008).

The Swan River, extending approximately 70kms from the Indian Ocean at Fremantle to Upper Swan, is the major river flowing through Perth. The Swan River floodplain passes through 17 local government areas (Figure 1).

Like many coastal cities and towns in Australia, Perth is located on the fringe of the floodplain of a major river system, at the interface between a river catchment and a tidal estuary. As a result, it is potentially susceptible to two different flooding regimes: riverine and storm surge. The dominant flooding regime of the lower estuarine reaches of the Swan River is storm surge / tidal. Riverine flooding becomes the dominant regime upstream of the Causeway (Swan River) and Kent Street Weir (Canning River).

Figure 1. Study area

Continuous recorded flow data for the Swan River commenced in 1970 but knowledge of the flood history of the Swan River through Perth dates back to the early 1800s. The earliest anecdotal reference to major flooding was in 1830 (Public Works Department, 1985), when the River peaked at 6.1 metres above the normal level; residential properties near the Causeway were inundated with water for weeks and the bridge over the Canning River was washed away (Bureau of Meteorology 1929). The largest flood on record dates back to 1872 which was estimated to be equivalent to the peak level for the 1 % annual exceedence probability (AEP) design event.

The number and severity of major flood events have declined since the early 1970s, (Figure 2). Consequently, flood damage losses in Perth over the past forty years have been minimal along the Swan River, with the last major river flow in 1983 being estimated at approximately a 10 % AEP event.

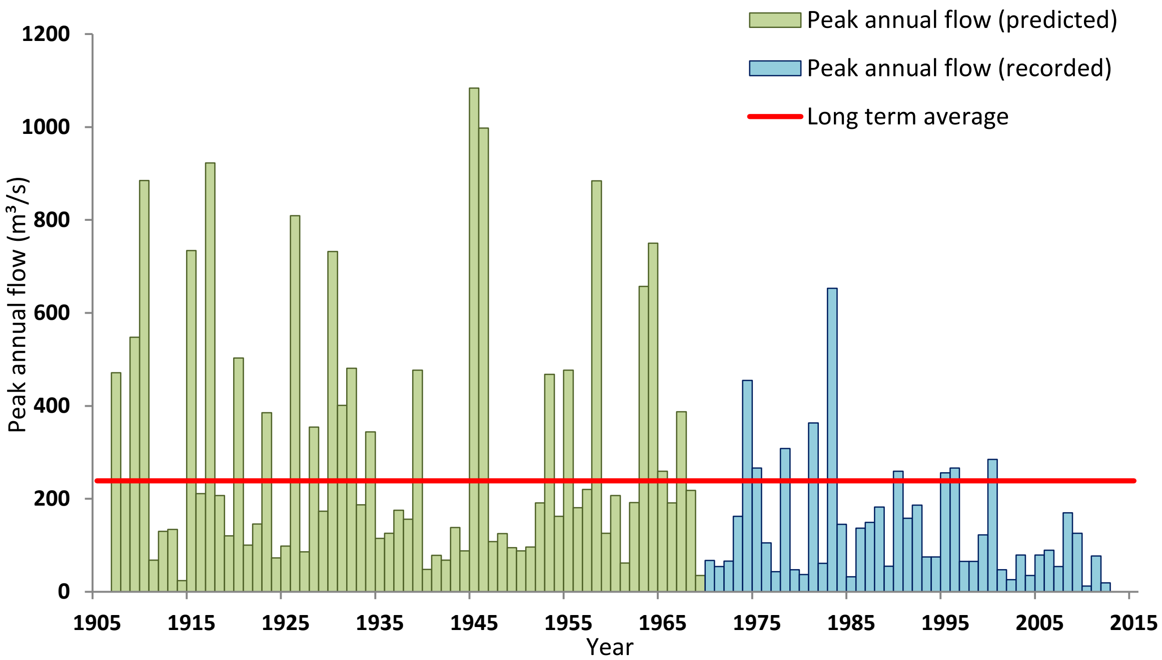


Figure 2. Peak annual flow in the Swan River at Walyunga (Upper Swan)

History of floodplain management in Perth

In recognising the need to mitigate potential flood damages, the WA State Government began a State-wide floodplain mapping programme in 1975, commencing with the Swan and Canning Rivers (Public Works Department, 1978a, PWD, 1978b).

These original flood studies for the Swan River were reviewed and updated following a major flood event in 1983 (Public Works Department, 1985, Water Authority of Western Australia, 1987). More recently, water level estimates for tidal and storm surge events, including the incorporation of potential sea level rise over the next century, have been updated (URS, 2013).

The floodplain extent mapping has been refined by the Department of Water (DoW) as more accurate contour information has become available.

In addition to mapping the design flood extent, the flood studies include a recommended floodplain development strategy to guide planning bodies and local government decision makers. The strategy is based on designating a portion of the floodplain as suitable for further development (referred to as the flood fringe) based on an hydraulic assessment of the impact of this development on upstream flood levels during the design 1% AEP event. In determining the location of this potential developable area factors that are considered include, existing development within the floodplain, cadastral boundaries, topography (flood depth), existing and possible future land use / zoning and expansion and contraction of flow at bridges. An example of this mapping and a diagrammatic representation of the recommended floodplain development strategy is provided in Figures 3 and 4.

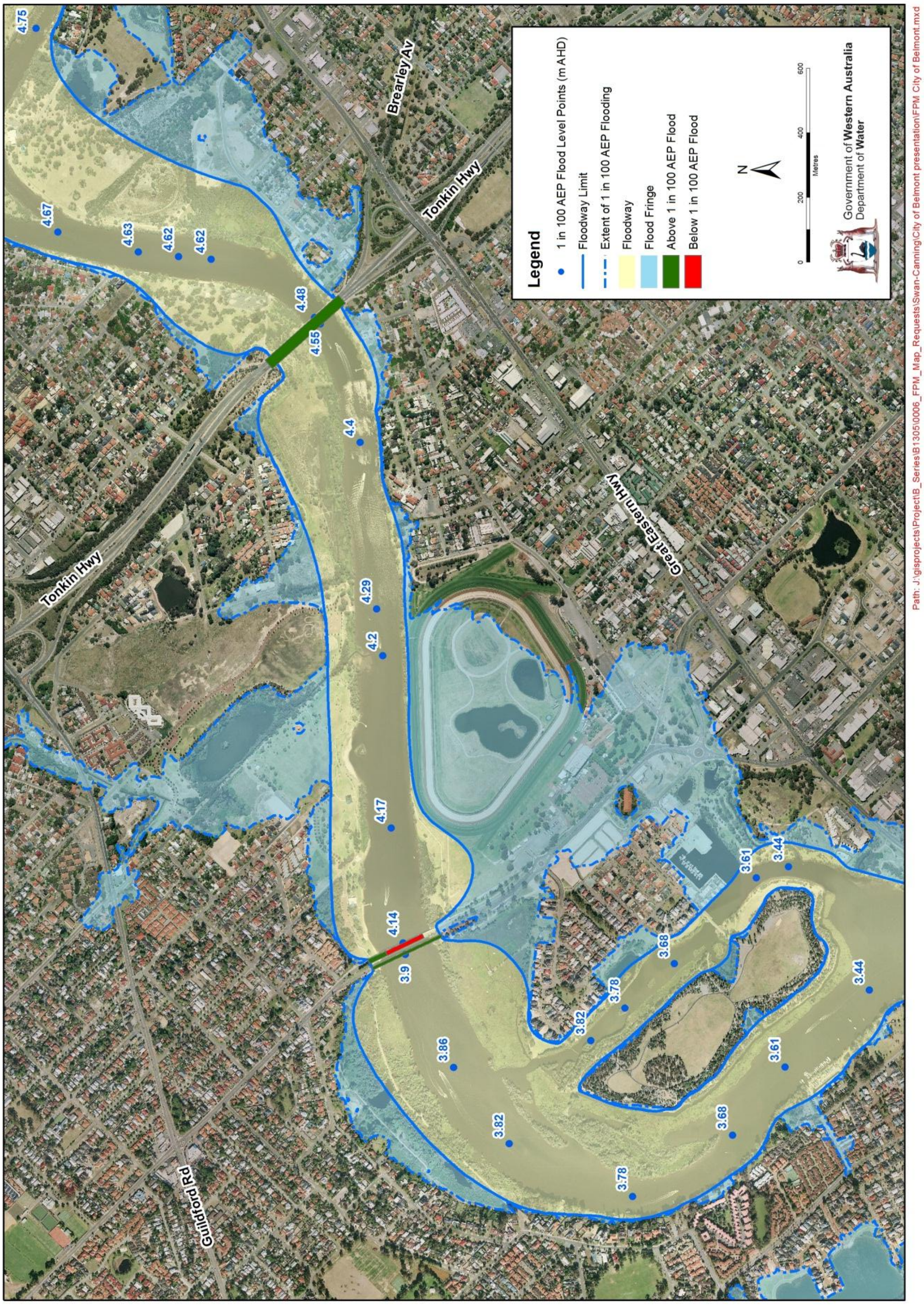
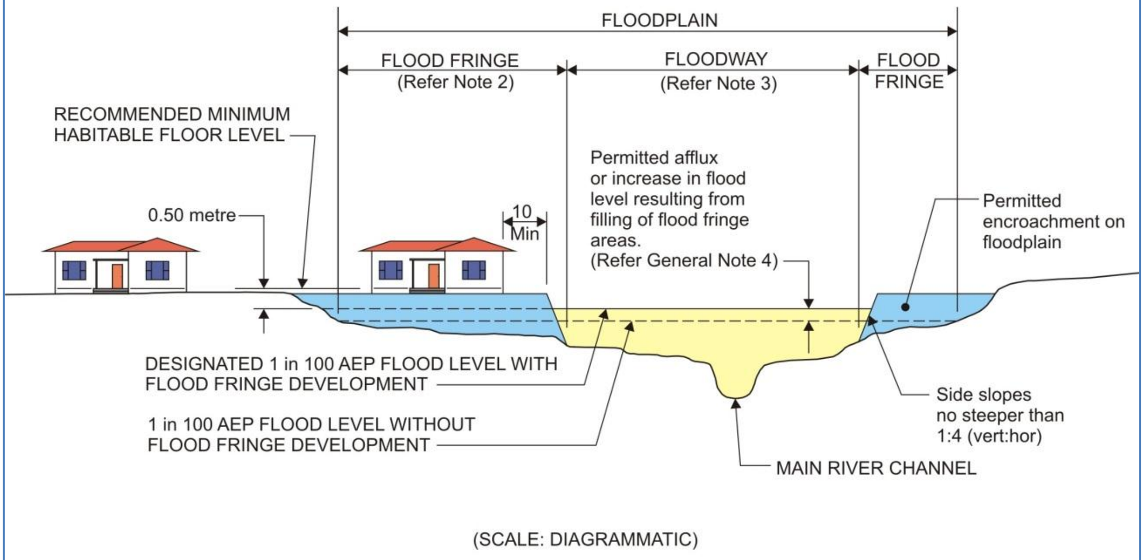


Figure 3. Example of existing Swan River 1 in 100 AEP floodplain mapping

RECOMMENDED FLOODPLAIN DEVELOPMENT STRATEGY



GENERAL NOTES

1. The 1 in 100 Annual Exceedance Probability (AEP) flood level has a 1% probability of being observed or exceeded in any given year. Floods higher than this level will occur but, on probability, will have a lower likelihood of occurrence.

2. The flood fringe is an area affected by a 1 in 100 AEP flood. Development (ie, filling, building, etc) that is located within the *flood fringe* is considered acceptable with respect to major flooding. However, a minimum habitable floor level of 0.50 metre above the adjacent 1 in 100 AEP flood level is recommended to ensure adequate flood protection.

3. Development (ie, filling, building, etc) that is located within the *floodway* and is considered obstructive to major flows is not acceptable as it would increase flood levels upstream. No new dwellings are acceptable within the floodway.

4. The increase in flood level that will result from total development of flood fringe areas has been calculated to be no greater than 0.15 metre.

5. A failure to properly adhere to these recommendations will result in a greater exposure to risks of flood damage. This advice is related to major flooding only and other planning issues, such as environmental

Figure 4. Recommended floodplain development strategy for the Swan River

The hydraulic assessment illustrated that complete development within the area shaded blue in Figure 3 (ie, filling the entire area to above 1 % AEP flood level), and for similar areas along the entire river, did not significantly increase flood levels. Consequently, proposed development in these areas is considered acceptable subject to appropriate building controls and emergency response planning to ensure adequate flood protection is provided. However, proposed development that is located within the yellow shaded area in Figure 3 and considered obstructive to major flows are not supported. Such proposals result in unacceptable increases in upstream flood levels.

Figure 3 also shows that the Tonkin Highway road bridge remains above flood level during the 1 % AEP event, whilst one of the duplicated bridges further downstream at Garratt Road is below the 1 % AEP flood level and would be overtopped. A duplicate bridge at Garratt Road remains above flood level.

The DoW uses floodplain mapping and recommended floodplain development strategies as part of its land use planning advisory role. The DoW itself is not a decision making authority. To this end, the floodplain development strategies are implemented through Department of Planning and local government authorities incorporating the information into regional and local floodplain development policy and within planning schemes.

Floodplain mapping and recommended development strategies have been used to guide land use planning and development decision making for a number of decades but the effectiveness of these tools to assist flood emergency response planning is limited due to the lack of information on impacts to infrastructure. Intelligence on the magnitude of flood events that isolate and/ or inundate buildings allows emergency response groups to appropriately plan and respond during flood emergencies. Information on building floor levels also enables an evaluation of the effectiveness of the four decades of floodplain management in Perth.

Defining the flood risk to buildings

The DoW's existing floodplain mapping datasets for the 10 % AEP, 4 % AEP, 2 % AEP and 1 % AEP events were used to identify the expected flood extents and peak flood heights. Additional floodplain mapping for design events larger than the 1 % AEP was desired but was not available, as there is no hydraulic model covering the entire Swan River currently available. To illustrate the possible flood extent of larger events, 1.0 metre was added to the peak flood levels predicted for the 1 % AEP event (1 in 100 AEP event + 1.0 metre) and the resulting extent was mapped. The corresponding flow and expected AEP for this event have not been determined and would vary for different locations along the river.

In addition, a flood scenario that reflects the impact of a 0.9 metre increase in mean sea level on the design 1 % AEP event was prepared (1 in 100 AEP + Sea Level Rise (SLR)). Hydraulic modelling of the estuarine section of the river (URS 2014) was used to prepare mapping for this scenario and showed that the impact of sea level rise is negligible by Garratt Road Bridge at Ascot.

A third additional scenario, 1 in 100 AEP event + 0.5 metre , was also analysed as this is consistent with the current recommended minimum habitable floor level set for new development on the floodplain. However, no floodplain mapping dataset was created for this flood scenario.

The floodplain mapping datasets were overlaid on 2008 and 2013 aerial imagery using ArcGIS version 10.0 (ESRI, 2010) to identify potentially flood affected infrastructure. Infrastructure was defined as flood affected if it was located within and/or intersected the flood extent boundary. The visible roof area within the aerial imagery was used to estimate the floor area of affected buildings and prepare polygon shapefiles of the affected buildings. Buildings with a roof area less than $40m^2$ were not included within the flood affected infrastructure database. Flood affected infrastructure was categorised into 4 main building types, namely: residential; commercial; major sheds; and public facilities.

The flood affected infrastructure database was developed in ArcGIS using cadastral and topographical information, building type, floor levels and flood levels. In total, more than 4000 buildings were identified to be located within the land area defined by 1 in 100 AEP + 1.0 metre scenario.

Site investigations were carried out between June and December 2013 to verify the existence of flood affected infrastructure identified from the aerial imagery.

During site inspections the floor levels for all residential and commercial properties were visually estimated based on available LiDAR spot levels. The expected vertical accuracy of the LiDAR spot levels is +/- 0.15 metre. The floor levels for residences were estimated to be the habitable floor level of the building (ie, excludes carports, garages, etc). In situations where the residence had multiple floor levels the lowest floor level was assumed for the whole building. The accuracy of the estimated floor levels was considered adequate for this study as estimates were typically within 0.2 metre of known surveyed floor levels. Surveyed floor levels were used in the flood affected infrastructure database where available.

A standard floor level of 0.1 metre above the adjacent natural surface was assumed for major sheds and public facilities that were not inspected.

Care was required to ensure that the 2008 LiDAR topography provided an accurate reflection of building floor levels for new development areas identified in the 2013 aerial imagery.

The depth of flooding through flood affected infrastructure for each flood scenario was calculated as the difference between the floor level and flood level. Infrastructure was deemed to be flood affected when the depth of flooding was greater than 0.1 metre.

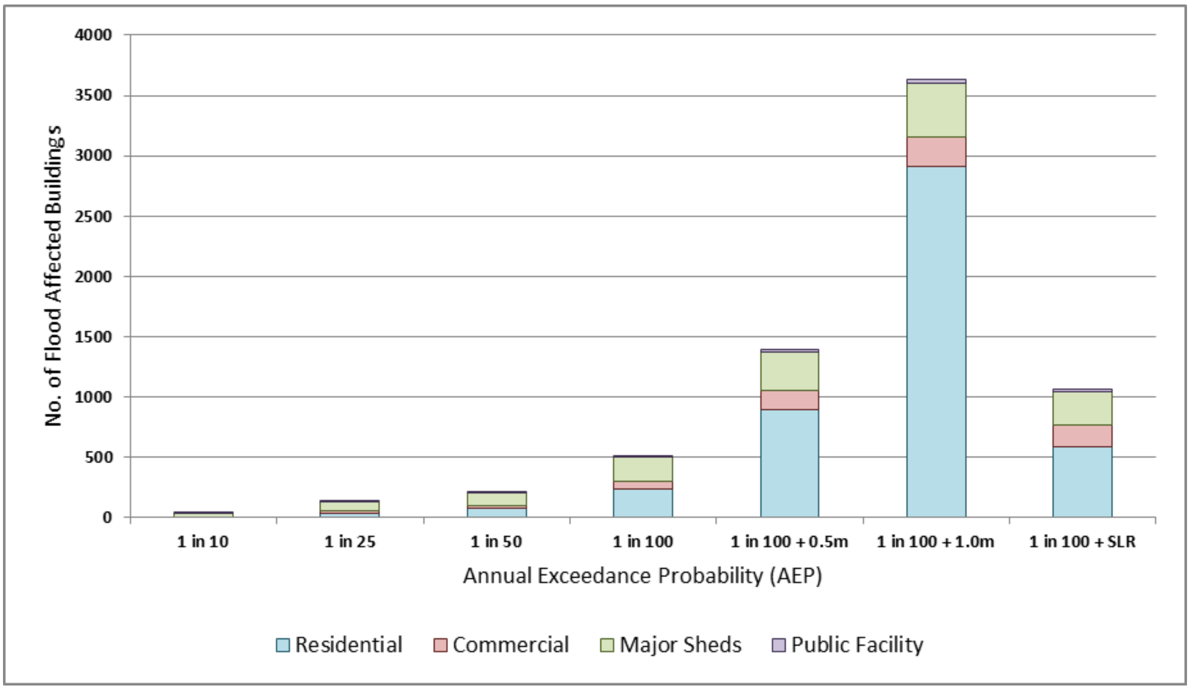
Vulnerability of built infrastructure : The report card

In a 10 % AEP event, there is a total of 39 buildings located on the Swan River floodplain that are inundated above floor (Figure 5). The majority are large sheds and only 1 residence that is inundated. This figure increases to 235 residences, of a total of 510 buildings, in the 1 % AEP event. These 235 flood affected residences are predominantly located in the older settled areas of Perth where many of the houses have been historically built lower than the 1 % AEP flood level. The majority of these flood affected residences tend to have a depth of flooding of less than 1.0 metre.

An earlier flood damage assessment (Middlemann, 2008) predicted that 150 residential properties were affected by flooding in a 10 % AEP event and 650 residential properties in a 1 % AEP event. This discrepancy can be attributed to the assumption in the Middelmann (2008) study that residential properties had floor levels of 0.1 metre above natural surface, resulting in an over-estimate of the number of flood affected residences.

Currently there are no residential dwellings inundated in the lower estuarine section of the River between Fremantle and the Causeway during events up to the 1 % AEP event. However should mean sea level rise by 0.9 metre, then 340 residences in this section of the River are expected to become inundated during a design 1 % AEP event. A further 16 residences located upstream of the Causeway are also expected to become affected during this scenario bringing the total number of residences affected to 591.

For the most extreme scenario analysed (ie, 1 in 100 AEP event + 1.0 metre), 3631 flood affected buildings (2913 residences) were identified between Fremantle and Upper Swan. The increase in properties subject to above floor inundation is largely in areas of recent greenfield and in-fill development within 10 kilometres of the Perth CBD. The significant increase in number of buildings affected can be partially attributed to the successful implementation of DoW’s floodplain development strategy that recommends minimum residential floor levels of 0.5 metre above the 1 % AEP flood level.



	1 in 10	1 in 25	1 in 50	1 in 100	1 in 100 + 0.5m	1 in 100 + 1.0m	1 in 100 + SLR
Residential	1	38	73	235	899	2,913	591
Commercial	5	15	27	70	153	238	171
Major Sheds	32	79	109	198	320	454	283
Public Facility	1	1	3	7	18	26	17
TOTAL	**39**	**133**	**212**	**510**	**1,390**	**3,631**	**1,062**

Figure 5. Number of flood affected buildings for seven flood scenarios

Comparison of the peak flood levels and the available survey information for the main access roads and rail bridges showed the majority were above flood level and would remain serviceable during major flooding. The Garratt Road Bridge at Ascot and the Meadow Street Bridge at Guildford, which both become impassable in 2 % AEP events and larger, were the two exceptions.

Estimated Flood Damages

Estimation of potential direct flood damages to infrastructure were calculated using stage-damage curves. Due to the lack of historical flood damage information of the Swan River area, synthetic stage-damage curves were formulated based on the single parameter, depth of flooding (Figures 6 & 7).

Synthetic stage-damage curves are hypothetical curves developed independently from historical flood information for a specific area (Middelmann-Fernandes, 2010). They represent the full extent of damage or loss that may be sustained, assuming that no preventative measures, such as raising contents above the flood level, are taken to reduce the loss of contents.

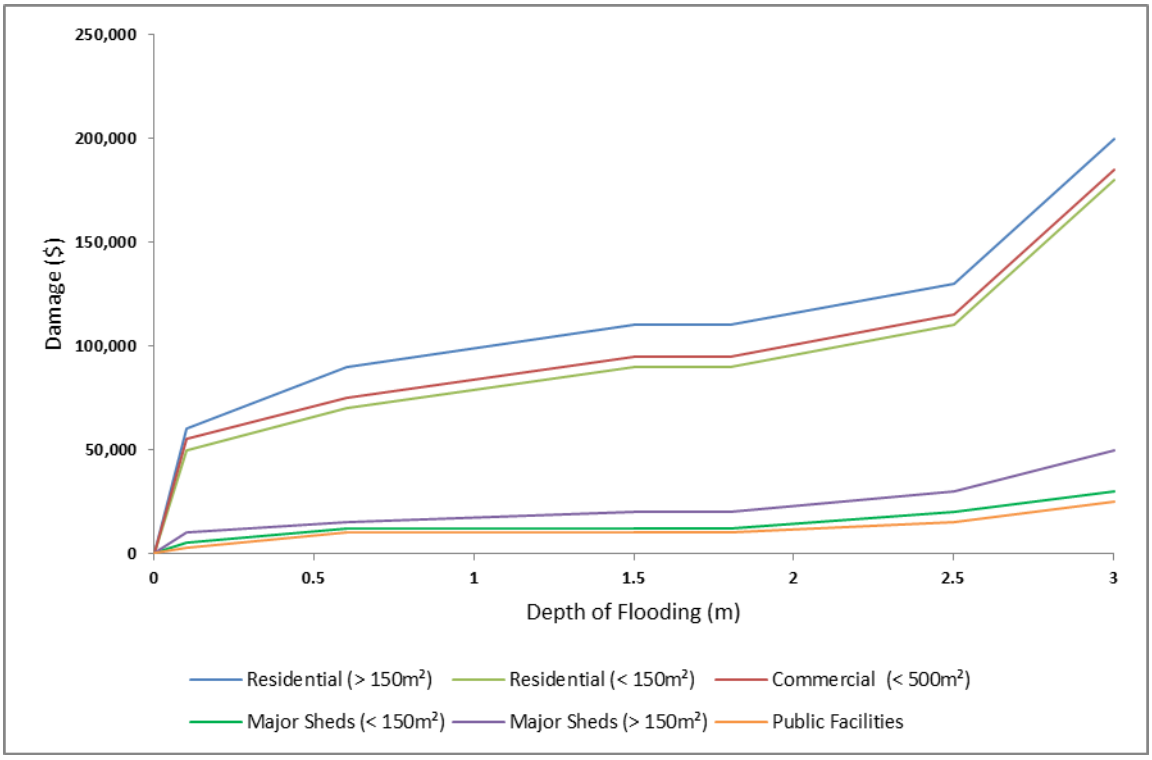


Figure 6. Stage-damage curves for residential, commercial (area <500m2), major sheds and public facilities

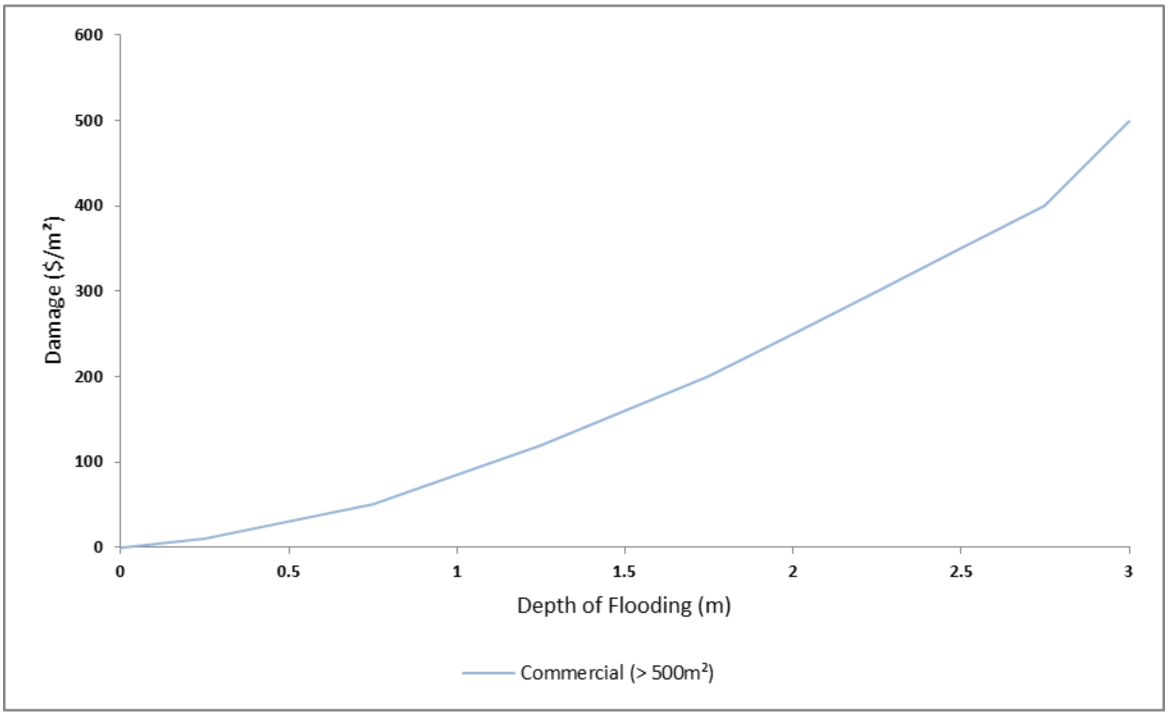


Figure 7. Stage-damage curve for commercial (area >500m2) infrastructure

The residential and commercial stage-damage curves are based on critical water depths and structure costs provided by the Queensland Government's Natural Resources and Mines (2002). The structural costs were adjusted to current monetary value using a CPI of 10 %. Also considered was advice from the Insurance Council Australia (ICA) that suggested a typical residential property with 0.1 metre depth of flooding would expect to have ~$60,000 flood damage.

Stage-damage curves for major sheds and public facilities were developed using the information from the residential and commercial curves.

It should be noted that no stage-damage curve facilitates estimation of total loss; therefore in flood events where properties are destroyed or deemed irreparable, the use of such curves in isolation under-estimates total damage (Middelmann-Fernandes, 2010).

This assessment has focussed on damage to buildings and property and did not include potential damage to fences, roads, viticulture, power infrastructure and sewerage pump stations.

Analysis of flood damage costs shows that the majority of flood damage occurs in the riverine section of the Swan River between the Causeway and Upper Swan for each of the various flood scenarios (Figure 8).

For example, estimated flood damages for a 10 % AEP event for the section of river from Fremantle to the Causeway was $120,000 compared to $651,000 for the section of river from the Causeway to Upper Swan. Estimated flood damages for the 1 % AEP event are $1.6M and $26.4M for the sections of the of the river from Fremantle to the Causeway and the Causeway to Upper Swan, respectively.

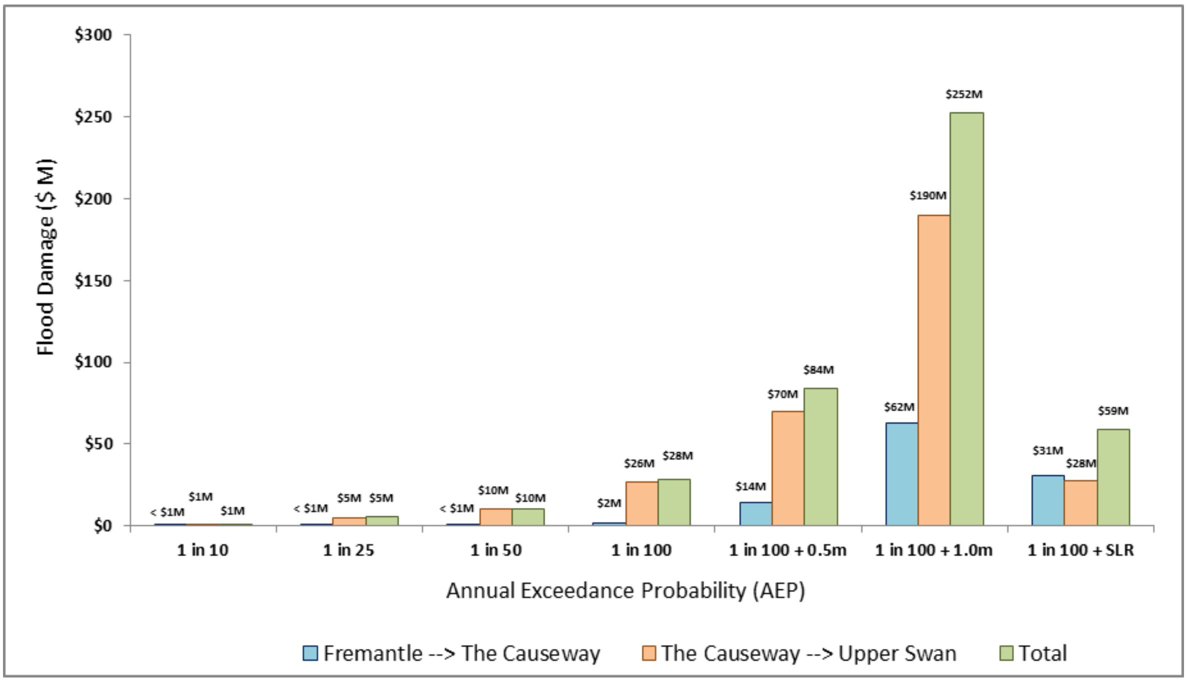


Figure 8. Total estimated flood damages for flood affected infrastructure for 7 major flood scenarios between Fremantle and Upper Swan

Conclusions and Future work

The study identifies critical areas and infrastructure that are expected to be inundated during major flooding. The results of this study will be of great assistance to regional flood emergency response planning and also provides local governments with information to better understand their own individual flood risk profile.

The relatively small number of properties at risk of flooding during events up the 1 in 100 AEP event combined with the significant increase in properties at risk in larger events confirms the ongoing benefits of the State Government's floodplain management program. The expected low flood damage costs are considered to be good overall performance measure of the floodplain management program.

The Department of Water with the support of a number of local and regional councils have commenced a review of the Swan River flood study that will form the basis for the preparation of a Floodplain Management Plan for the entire River.

To better understand the full cost of future flood events would require further information to be collated on other direct costs, such as damage to road, fencing, water and power infrastructure and less tangible costs including social impacts, health, agriculture losses and interruption to business.

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