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DARLING HARBOUR CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY (DRAFT REPORT)

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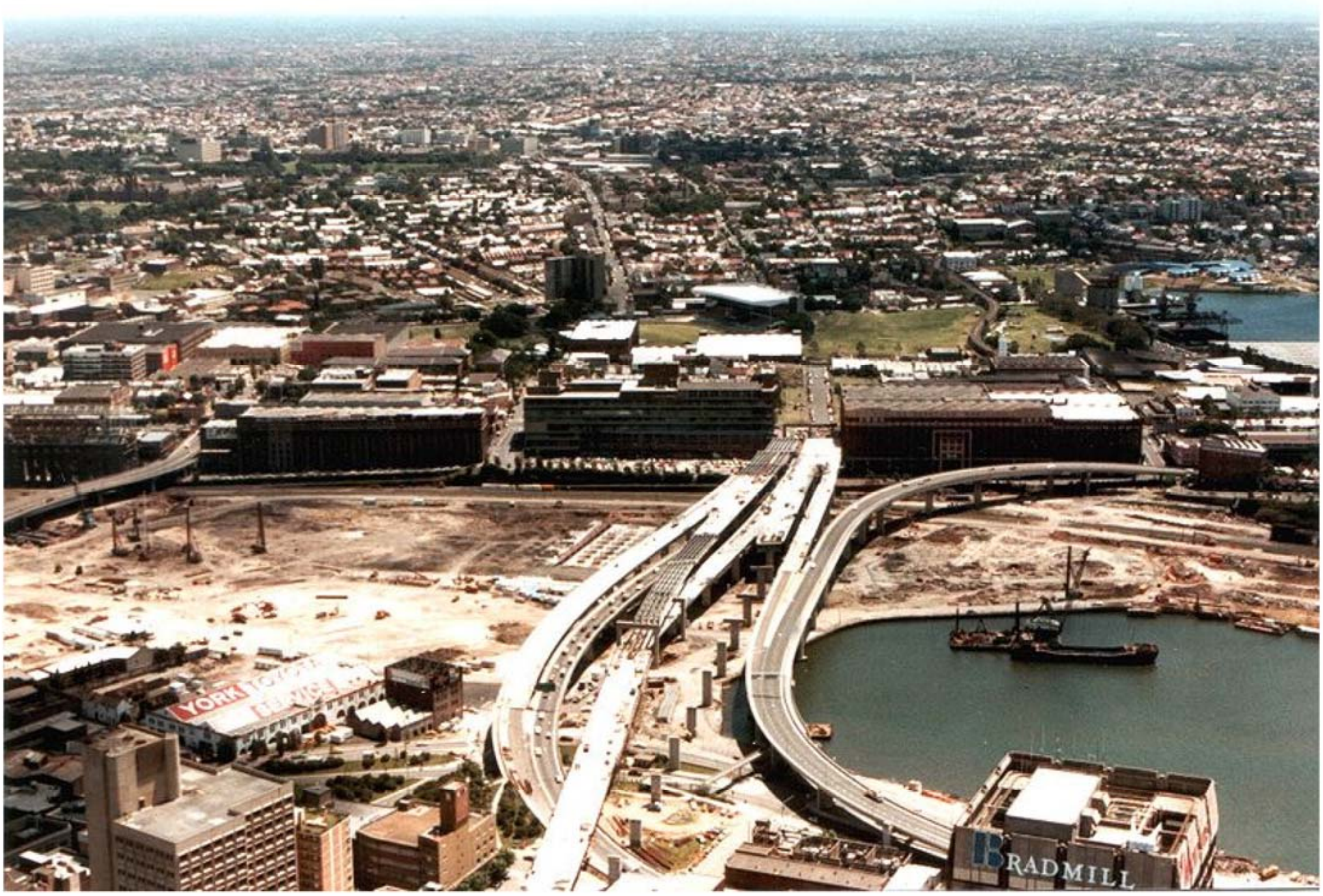
DRAFT



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DARLING HARBOUR CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

DRAFT REPORT

JANUARY 2016

Project Darling Harbour Catchment Floodplain Risk Management Study	**Project Number** 114095
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Date 12 January 2016	**Verified by** TO BE SIGNED FOR FINAL REPORT

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FOREWORD

The NSW State Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Flood Prone Land Policy, the management of flood liable land remains the responsibility of local government. The NSW Government, administered through the Office of Environment and Heritage (OEH), provides financial assistance and specialist technical advice to assist councils in the discharge of their floodplain management responsibilities. The Australian Government may also provide financial assistance in some circumstances.

The Flood Prone Land Policy provides for specialist technical and financial support to Councils by the NSW Government through the stages set out in the "Floodplain Development Manual – the management of flood liable land, NSW Government, 2005". This Manual is provided to assist Councils to meet their obligations and responsibilities in managing flood liable land. These stages are:

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management Study***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Darling Harbour Catchment Floodplain Risk Management Study and Draft Plan constitute the second and third stages of this management process. This study has been prepared by WMAwater for the City of Sydney (Council) under the guidance of Council's floodplain management committee (Committee). This study provides the basis for the future management of those parts of the catchments which are flood liable and within the City of Sydney local government area.

EXECUTIVE SUMMARY

This Floodplain Risk Management Study assesses floodplain management issues in the Darling Harbour catchment, and investigates potential management options for the area. The study, which follows on from the draft Darling Harbour Catchment Flood Study (Reference 2), has been undertaken in accordance with the NSW Government's Flood Policy. A full assessment of the existing flood risk in the catchment has been carried out, including flood hazard across the catchment, overfloor flooding of residential, commercial and industrial properties, road flooding and emergency response during a flood event. A range of measures aimed at managing this flood risk were also assessed for their efficacy across a range of criteria, which allowed certain options to be recommended, forming the basis of the Floodplain Risk Management Plan for the area. Assessed measures included upgraded pit and pipe networks, detention basins, emergency management measures and various property modification measures.

Background

The Darling Harbour catchment is located in Sydney's inner city suburbs of Haymarket, Surry Hills and parts of Pyrmont, Ultimo and Sydney, and has an area of 307 hectares. The area has been extensively developed for urban usage. Land use is predominantly high-density commercial and residential developments. The catchment experiences overland flooding, with some tidal influence in the vicinity of Darling Harbour.

The Darling Harbour Catchment Flood Study (2014) was carried out to define existing flood behaviour for the Darling Harbour catchment in terms of flood levels, depth, velocities, flows, hydraulic categories and provisional hazard. A 1D/2D TUFLOW hydraulic model was established and verified by a calibration/verification process. Following this, the model was used to define flood liability for the range of design flood events. Several flooding hotspots were also identified in the study. In addition, a floor level survey and damages assessment were undertaken to identify properties that are liable to over floor inundation.

Existing Flood Environment

A number of locations within the catchment are flood liable. This flood liability mainly relates to the nature of the topography within the study area as well as the capacity of service provided by drainage assets. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 19th century and many buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths. Sub-surface drainage is not able to route flow from these ground depressions unrelieved by overland flow paths, as the majority of the drainage network reaches capacity during small events (i.e. 0.5 EY).

193 properties within the catchment are liable to over floor inundation in the 1% AEP event, while 86 properties are liable in the 0.2 EY event. A flood damages assessment for existing development was undertaken, with the average annual damage estimated to be approximately

$3.7 million for the catchment.

Flooding hotspots in the catchment were identified at the following locations: Commonwealth Street near Ann Street, Pyrmont Street near Jones Bay Road, Elizabeth Street near Belmore park, Hay Street from Elizabeth Street to Haymarket and Darling Harbour near Tumbalong Park, Chinese Gardens and King Street Wharf. The study identified that effective warning time is zero and that evacuation in place is therefore the default response to extreme floods.

Flood Risk Management Options

A range of floodplain risk management options were investigated as part of the study.

Fourteen options were considered in detail, as shown in the below table, which ranks them according to the results of the multi-criteria assessment. The assessment of management options involved gathering feedback from the community on the options, who were informed about the study and the various options via a brochure and questionnaire, as well as an information session. Options were also considered in the context of relevant policies and planning controls, including City of Sydney's Interim Floodplain Management Policy.

Rank	Ref	Option	Score
1	PM-DH02	Property Modification - Development Control Planning	10
2	PM-DH01	Property Modification - Flood Planning Levels	9
3=	PM-DH04	Property Modification - Feasibility Study for City of Sydney Flood Proofing	8
3=	RM-DH01	Response Modification - Flood Warning and Evacuation	8
3=	RM-DH03	Response Modification - Community Awareness Programme	8
6	RM-DH02	Response Modification - Flood Emergency Management	7
7	FM-DH01	Drainage Upgrade – Commonwealth Street	6
8	PM-DH03	Property Modification - Flood Proofing	5
9	FM-DH05	Drainage Upgrade – Elizabeth Street to Outlet	2
10	FM-DH07	Drainage Upgrade – Black Wattle Place	1
11	FM-DH02	Drainage Upgrade – Elizabeth Street	0
12=	FM-DH04	Park Adjustment – Belmore Park	-1
12=	FM-DH06	Drainage Upgrade – Pyrmont Street to Outlet	-1
14	FM-DH03	Road Adjustment – Elizabeth Street	-2

A summary of the options, including their time-frame, priority and responsibility, is given in the draft Darling Harbour Floodplain Risk Management Plan. Three of the assessed options were not recommended in the plan as they were assessed to be unviable.

1. INTRODUCTION

1.1. Study Area

The Darling Harbour catchment is located in Sydney's inner city suburbs of Haymarket, Surry Hills and parts of Pyrmont, Ultimo and Sydney (refer Figure 1: Study Area – Darling Harbour Catchment). This region lies within the City of Sydney Local Government Area (LGA) and has been fully developed for urban and commercial usage which provides little opportunity for water to infiltrate due to the high degree of impervious surfaces. Land use is predominantly high-density housing and commercial development, with some areas of open space including parts of Hyde Park. The catchment also includes the large development sites of the Sydney Entertainment Centre, Sydney Exhibition Centre and University of Technology, Sydney.

The catchment covers an area of approximately 307 hectares which drains into Sydney Harbour at various locations, with the main drainage outlets at Darling Harbour. The drainage network includes open channels, covered channels, in-ground pipes, culverts and pits. The majority of the trunk drainage is owned by Sydney Water Corporation (SWC) and City of Sydney.

The topography within Darling Harbour catchment varies from steep surface slopes in excess of 10% in the upper catchment to the near flat lower catchment adjacent to the Sydney Harbour shoreline. Within the catchment there are various excavations and cuttings, resulting in some vertical drops of over 10 m. The catchment therefore has regions where surface water runoff within the road network has high velocity and shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points with lower velocities. The lower reaches of the catchment fringing the Sydney Harbour are potentially affected by elevated water levels within the Harbour.

A number of locations within the catchment are flood liable, and flooding is known to occur in some areas for all rainfall events greater than the 0.5 EY. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 19th century and many buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths where sub-surface systems are running at capacity. This creates a significant drainage/flooding problem in many areas throughout the catchment, with roads and pedestrian areas forming major flow paths, with associated high velocities and flood depths.

1.2. The Floodplain Risk Management Process

As described in the Floodplain Development Manual (Reference 1), the floodplain risk management process is formed of sequential stages:

- Data Collection;
- Flood Study;
- Floodplain Risk Management Study;

- Draft Floodplain Risk Management Plan; and
- Plan Implementation.

The first key stage of the process has been undertaken with the completion of the Darling Harbour Catchment Flood Study (Reference 2). Following this, the Floodplain Risk Management Study and Plan (FRMS&P) are undertaken for the catchment in two phases:

Phase I – Floodplain Risk Management Study in which the floodplain management issues confronting the study areas are assessed, management options investigated and recommendations made. The objectives for this phase include:

- Review the current Darling Harbour Catchment Flood Study (2014) and update hydraulic model were necessary to ensure it is fit for purpose;
- Engage community and key stakeholders throughout the project;
- Review Council's existing environmental planning policies and instruments, identify modifications required to current policies;
- Identify residential flood planning levels and flood planning area;
- Identify and assess works, measures and restrictions aimed at reducing the impacts and losses caused by flooding and consider their impacts if implemented, taking into account the potential impacts of climate change; and
- Review the local flood plan, examine the present flood warning system, community flood awareness and emergency response measures (involvement with the NSW State Emergency Service).

As well as considering measures appropriate to the catchment as a whole, specific measures were investigated for the hotspots' identified in the Flood Study. These 'hotspots' are:

- Commonwealth Street between Ann Street and Reservoir Street
- Pyrmont Street between Jones Bay Road and Union Street
- Elizabeth Street between Reservoir Street and Campbell Street
- Hay Street between Elizabeth Street and Quay Street
- Darling Harbour near Tumbalong Park and Chinese Gardens.

Phase II – Draft Floodplain Risk Management Plan which is developed from the floodplain risk management study and details how flood prone land within the study areas is to be managed moving forward. The primary aim of the Plan is to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk at this time and ensuring that such plans are informed to a degree by climate change sensitivity. The Plan consists of prioritised and costed measures for implementation.

2. BACKGROUND

2.1. Darling Harbour Catchment

2.1.1. Land Use

The land use zones as identified in the Sydney LEP 2012 are shown as Figure 2. The majority of the catchment is classed as either *Metropolitan Centre, Mixed Use* or *DH Development Plan*. The remainder of the catchment is a mixture of *Public Recreation, General Residential* and *Infrastructure* as well as a small area classed *Neighbourhood Centre* in the western part of the catchment.

2.1.2. Social Characteristics

Information is available from the 2011 census (http://www.abs.gov.au/) to understand the social characteristics of this study area which includes the suburbs of Haymarket, Surry Hills and parts of Ultimo, Pyrmont and Sydney. Understanding the social characteristics of the area can help in ensuring that the right floodplain risk management practices are adopted. Table 1 below shows some selected characteristics for suburbs in the catchment area.

Table 1: 2011 Census data by location

	NSW	Haymarket	Surry Hills	Ultimo*	Pyrmont*	Sydney*
Population Age: **0 – 14 years** **15 - 64 years** **> 65 years**	 19.2% 66.1% 14.7%	 4.5% 92.3% 3.1%	 5.1% 86.6% 8.3%	 5.8% 89.9% 4.1%	 8.7% 85.1% 6.1%	 4.1% 91.1% 4.8%
Average people per dwelling	2.6	2.6	1.8	2.0	2.1	2.1
Own/mortgage property **Rent property**	66.6% 30.1%	31.5% 63.5%	34.9% 62.0%	29.7% 67.6%	37.3% 60.7%	33.7% 63.4%
Moved into are: **- within last year** **- within last five years**	 - -	 37% 73%	 28% 65%	 38% 73%	 28% 65%	 34% 74%
No cars at dwelling	10.9%	63.6%	47.0%	53.7%	28.0%	59.2%
Speak only English at home	72.5%	15.9%	61.2%	29.0%	53.3%	26.4%
Other languages spoken		Mandarin (17%), Thai (14.4%), Indonesian (9.6%), Cantonese (7.6%), Korean (6.4%)	Cantonese (2.9%), Mandarin (2.3%), Thai (2.2%), Greek (1.4%), French (1.3%)	Mandarin (15.5%), Cantonese (9.4%), Indonesian (2.5%), Thai (2.4%	Mandarin (6.7%), Cantonese (5.2%), Korean (2.8%), Thai (1.8%), Japanese (1.6%)	Mandarin (12.5%), Indonesian (7.9%), Thai (6.9%), Cantonese (6.3%), Korean (5.6%)

* only parts of these suburbs are located within the Darling Harbour catchment however statistics are provided for the entire suburb.

From this data it is apparent that the Darling Harbour comprises a much higher portion of 15 – 64 year olds than the state average. There is a marginally lower average number of people per dwelling compared to the state average. There is also a particularly high proportion of households without access to cars, which should be taken into account when considering evacuation and access routes and flood depths which remain safely traversable.

The high proportion of renters and the large number of languages spoken by residents will need to be considered in any flood awareness/education programmes. Renters are typically more transient than owner-occupiers, and therefore it is likely the turnover of residents within the catchment is high, meaning a more frequent program may be required in order to retain an acceptable level of flood awareness. Furthermore, it is likely that communication material will need to be provided in languages other than English, as a high proportion of residents speak languages other than English at home.

2.1.3. Local Environment

The Darling Harbour catchment is completely urbanised and has no remnant vegetation. Areas of parkland exist at Belmore Park, Darling Harbour and in various small pockets of land, and some streets are lined with mature trees. The limited natural environment means that flooding does not play any role environmentally, and that impact of possible mitigation works on the local environment is minimal.

City of Sydney aspires to protect and expand the LGA's urban forest. This includes a list of protected Significant Trees, of which a number of trees in the catchment are listed. Mitigation measures assessed by this study will consider the value that is placed upon trees in the catchment when there is a potential impact.

Other environmental features of interest in the catchment are;

- Parts of the catchment are classified as general conservation areas with a number of conservation buildings identified.
- There are no currently listed contaminated sites in the catchment.
- The majority of the Darling Harbour catchment has an Acid Sulphate Soils classification of 5 (works within 500m adjacent of an area classified 1 -4 and likely to reduced groundwater levels by 1m or more are likely to present an environmental risk). Areas of Class 1 (any works undertaken in this area are likely to present an environmental risk) are located around Darling Harbour, and Class 2 in the Barangaroo development site (any works undertaken in this area below ground level or which lower the water table are likely to present an environmental risk).

2.1.4. Drainage System

The original natural drainage system comprised rock gullies draining to small pockets of mangroves along the shoreline. As development proceeded within the catchment, the land use changed to a higher proportion of impervious surfaces leading to increased runoff volumes and peak flows. It followed that the natural drainage lines were incorporated into the constructed drainage system of open channels. By the late 19th century much of the channel system was progressively covered over and piped, with much of the original system forming the backbone of the drainage system in place today. There are no open channels within the study area.

An extensive network of stormwater infrastructure exists in the study area to provide drainage to the Darling Harbour catchment. This infrastructure primarily comprises of a ‘pit and pipe’ stormwater network and does not include open channels as part of the trunk drainage system. City of Sydney own and manage the smaller upper catchment elements, and SWC the trunk drainage assets.

Pit types within the study area include circular, rectangular and oviform pipes. Circular and rectangular pipes are modern extruded concrete, whereas oviform and clay pipes are very old, built in the late 1800’s, with irregular dimensions. Figure 3 shows the location and type of pipe across the study area.

The study area also contains the Hay Street Stormwater Channel which has been listed on the Heritage and Conservation Register as maintained by SWC. The channel is one of the first five original combined sewers constructed in Sydney around the 1860 period. This feature now only conveys stormwater, giving the pipe a relatively higher flow conveyance compared with newer drainage elements.

In rainfall events where flows exceed the minor system (i.e. pit/pipe system) capacity, surface water runoff is generally conveyed as uncontrolled flow via the major drainage system which consists of an unplanned network of roads and pedestrian (etc.). When this occurs, there is potential for high hazard flood conditions resulting from flow velocities and depths. Further, under Council policy resultant 1% AEP levels inform required commercial flood levels.

2.1.4.1. Darling Harbour Live Development

The catchment’s drainage system is currently undergoing large-scale changes as part of the Darling Harbour Live development. The development is located between the west end of Hay Street and the catchment outlet, and consists of large-scale re-development of part of the Darling Harbour area for commercial and residential use. Recent plans of the ongoing development show significant changes to the sub-surface drainage, including additional feeder pipes on Darling Drive, between Pier Street and the Western Distributor, between Hay Street and Pier Street, and on Hay Street near Harbour Street. New or modified drainage elements have not been included in the current study’s ‘existing’ catchment conditions, as they are still under construction. However, the impact of the proposed drainage has been tested and has been shown to increase drainage flow rates and benefit Darling Harbour’s flood affectation. Mitigation options tested as part of the current study have also been assessed with consideration of the proposed changes.

2.1.5. Historical Floods

Major historical storm events are known to have occurred on June 1949, November 1961, March 1973, November 1984, January 1991 and February 2001, although Council indicates that flooding can occur at various locations across the catchment in events starting from the 0.5 EY. The 2014 Flood Study analysed rainfall records from the Observatory Hill gauge for these events an estimated the design frequency of these events, as shown in Table 2.

A more recent event occurred on 24 August 2015, with heavy rainfall over a short duration (approx. 10 min) resulting in flooding in the neighbouring catchment on Pitt Street Mall, King Street between Pitt and George Streets, and at Circular Quay. There is anecdotal evidence of flooding in parts of the Darling Harbour catchment. Rainfall data indicates that for a 10 minute duration, the intensity was between a 20% and 10% AEP event.

Table 2: Historical Flood Events

Event	Equivalent Design Frequency
15 June 1949	~ 0.2 EY
18 – 19 November 1961	~5% AEP
March 1973	Gauge failed
9 November 1984	> 0.2% AEP
27 January 1991	~2% AEP
February 2001	Gauge failed
24 August 2015	~10% AEP

2.2. Previous Studies

A limited number of previous studies have been undertaken for the Darling Harbour catchment, as summarised below.

2.2.1. Darling Harbour Flood Study, BMT-WBM, October 2014 (Reference 2)

This flood study was carried out as part of the Floodplain Risk Management Programme to define existing flood behaviour in the Darling Harbour catchment through the establishment of appropriate numerical models. The study produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment conditions.

Community consultation was undertaken as part of the study which aimed to inform the community about the study and its likely outcome as a precursor to floodplain management activities.

The hydrologic and hydraulic modelling was combined in a TUFLOW 1D/2D model, using the "direct rainfall" approach. The entire Darling Harbour catchment was modelled in the 2D domain, with approximately 26km of sub-surface pipe network modelled as 1D elements dynamically linked to the 2D domain.

Two historical flood events (8 November 1984 and 26 January 1991) were used for model calibration and verification, and the 8 March 2012 for a general verification of flood behaviour. The model was found to provide a good representation of the observed flood behaviour.

The study defined flood behaviour of the 0.5 EY, 0.2 EY, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP and PMF design events, including peak flood levels, depths and velocities. The study also undertook sensitivity testing and considered the impact of future climate change on design events.

The study identified the following ‘hotspots’:

- Commonwealth Street between Ann Street and Reservoir Street
- Pyrmont Street between Jones Bay Road and Union Street
- Elizabeth Street between Reservoir Street and Campbell Street
- Hay Street between Elizabeth Street and Quay Street
- Darling Harbour near Tumbalong Park and Chinese Gardens.

2.2.2. City Area SWC30 Capacity Assessment, Sydney Water, 1996 (Reference 3)

This report assessed the quantitative performance of stormwater drainage elements within SWC’s City Area SWC30 which covers a greater area than the current study. This report assessed the quantitative performance of stormwater drainage elements within SWC’s City Area SWC30 which covers a greater area than the current study. Details of pipe capacity as well as dimensions and hydraulic parameterisation are extensively detailed within this report.

The performance was assessed by firstly analysing the capacity of various elements of the drainage system. This was determined by defining the storm event which results in a peak flow equal to that of the hydraulic capacity of the drainage element. The catchment was then zoned into one of four categories based on land use – low density residential, business/commercial, highways/freeways and CBD. Each category corresponds with a design standard (in terms of pipe capacity) typically adopted in the past for that particular land use. For example, low density residential corresponds with a 0.2 EY event. The drainage system capacity was then compared to the design standard and results are provided in terms of percentage of the drainage length situated in each of the four categories that is able to satisfactorily handle the range of design events.

The results found that whilst business areas where generally better serviced than residential areas, the overall catchment had a relatively poor performance.

2.1. Flood Study Modelling Review

WMAwater have carried out a review of the Darling Harbour model established as part of the

2014 Flood Study (Reference 2). This was carried out with the aim of establishing that the model developed was suitable for carrying out FRMS&P work. The review consisted of checking the model system and approach, the schematisation of the catchment, including model parameters and the base data, as well as the model results.

The review found that the model was generally of a high standard and produced design flood results for the 1% AEP event in line with best practice. No issues relating to the model stability were identified and the peak flow rates were found to be reasonable based the catchment size and type. The representation of the roads' crown and kerb lines was assessed. Table 3 summarises the findings of the review.

Table 3: Model Review Summary

Model Component	Comment
Model System and Approach	A 2D hydraulic model (TUFLOW) was used with the Direct Rainfall Method in place of a traditional hydrologic model. The model approach is similar to that used in other City of Sydney catchments.
Base Data	The model topography is based on 2007 LiDAR data. Comparison to ground survey and another LiDAR dataset show the data used to be generally accurate.
Model Schematisation	Schematisation of the catchment is sound. It was noted that kerb and crown lines were not 'stamped' into the model grid, but this would only effect representation of minor floods.
Model Parameters	Mannings 'n' values in the model fall within standard ranges. It was noted that conservative pit blockage has been used (pits in sags are 100% blocked) and that a reduced blockage will be used in testing mitigation options.
Model Results	Model results showed no indication of numerical instability. Due to the lack of calibration data, unit flow rates were assessed as an indication of model accuracy. Unit flow rates were satisfactory based on the catchment location and its high imperviousness.

2.2. Flood Study Model Updates

Updates to the previously established model were made where new data was available and where the model review identified areas of improvement. Overall, the model updates that were made are considered to be small refinements, and there were no major revisions. The following updates were made:

1. The tunnel entrance on Harbour Street was updated to the schematisation of the other tunnels (i.e., runoff was allowed to enter it).
2. Revision to the pit/pipe data based on recent survey from SWC. Survey data was provided that had revised dimensions and alignments of some pits and pipes. Changes were minimal and there were no widespread effects on design flood behaviour.

3. EXISTING FLOOD ENVIRONMENT

3.1. Overview of Flood Behaviour

The topography within the Darling Harbour catchment varies from steep surface slopes in excess of 10% in the upper catchment to the near flat lower catchment adjacent to the Sydney Harbour shoreline. The catchment therefore has regions where surface water runoff within the road network has high velocity with shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points with typically lower flow velocities. The lower reaches of the catchment fringing Sydney Harbour are potentially affected by elevated water levels within the Harbour.

The entire catchment is highly developed with little opportunity for water to infiltrate due to the high degree of impervious surfaces. Most residential properties are brick or sandstone construction with common walls to neighbours. There are very few opportunities to flow to pass through or between properties and as a result the roads form the primary overland flow paths (major drainage system) and the areas of highest risk in a flood. Ground floors of some buildings are flood affected; however, flow velocities will be much lower than on the roads and evacuation to a higher level is usually possible.

The catchment is serviced by entirely by a piped network system and there are no open channels within the area. In rainfall events where flow exceed the piped system capacity, surface water runoff is generally conveyed within the road system as uncontrolled flow. When this occurs, there is potential for high hazard flood conditions resulting from combined high flow velocities and depths.

The catchment is divided into two distinct areas by the Western Distributor. Flows underneath the Western Distributor arrive from the Surry Hills area to the south-east. North of the Western-Distributor, flood waters have very small catchment areas and flow quickly to Cockle Bay/Sydney Harbour by the shortest distance. High in the catchment, upstream of the Western Distributor (in south-east Surry Hills), steep streets quickly convey flows downstream to the Darling Harbour area. Downstream of Elizabeth Street and the railway line, the catchment slope starts to reduce. Sub-surface conduits become very important in relieving flood waters. North of the Western Distributor, flooding is from localised catchments with small upstream areas. These catchments may drain to trapped low points such as Pyrmont Road where piped infrastructure is critical in relieving flooding.

The catchment's small size results in a small degree of 'scaling' between small and large flood events. That is, the depth of inundation across the catchment is similar in flood events of different frequency, for example, the 10% and 1% AEP event. For example, at Mary Street near Foveaux Street, there is around 0.2 m of depth in a 10% AEP and 0.3 m in the 1% AEP. There is slightly more scaling in the downstream areas of the catchment, for example the 1% AEP depth is 0.2 m higher than the 10% AEP on Hay Street. The small scaling results in affectation being quite similar across the range of design flood events (excluding very rare events).

The capacity of the existing stormwater network is exceeded in most flood events, with around half of the area's drainage full in a 0.5 EY event, and around 80% full in a 10% AEP event. It should be noted that the network's function is largely determined by the degree of blockage in a particular event, with regards to both the pits (particularly in topographic sags) and pipes. Table 4 lists the peak flow in various stormwater pipes for the 20% AEP and 1% AEP design events, as well as an estimate of the pipe's approximate capacity. The locations are shown in Figure 3. As shown in the table, upper sections of the main trunk line have quite large capacity (approximately 1% AEP), despite most of the catchment's drainage being full in a frequent event.

Table 4: Pipe Peak Flow and Approximate Capacity

Stormwater Drain Location	Peak flows (m^3/s)- 20%AEP	Peak flow (m^3/s) - 1%AEP	Approx. Capacity
1. Reservoir Street upstream of Elizabeth Street	2.8	5.3	1% AEP
2. Elizabeth Street near Belmore Park	3.5	6.0	10% AEP
3. Hay Street near Belmore Park	15.9	21.3	1% AEP
4. Hay Street at George Street	18.8	24.5	<20% AEP
5. Darling Harbour near Tumbalong Park (6 parallel pipes)	35.4	45.6	<20% AEP
6. Pyrmont Street near Star City	1.6	2.7	<20% AEP

3.2. Hydraulic Categories

The 2005 NSW Government's Floodplain Development Manual (Reference 6) defines three hydraulic categories which can be applied to different areas of the floodplain; namely floodway, flood storage or flood fringe. Floodway describes areas of significant discharge during floods, which, if partially blocked, would cause a significant redistribution of flood flow. Flood storage areas are used for temporary storage of floodwaters during a flood, while flood fringe is all other flood prone land.

There is no single definition of these three categories or a prescribed method to allocate the flood prone land into them. Rather, their categorisation is based on knowledge of the study area, hydraulic modelling and previous experiences. Based on analysis of similar catchments, as well as literature review (Reference 6), the Flood Study (Reference 2) defined hydraulic categories as:

Floodway:		Velocity x Depth > 0.25 m^2/s AND Velocity >0.25 m/s
	OR	Velocity > 1 m/s
Flood Storage:		Land outside the floodway where Depth > 0.2m
Flood Fringe		Land outside the floodway where Depth < 0.2m

The hydraulic categories for the 5% AEP, 1% AEP and PMF events are shown on Figure 6 to Figure 8. In the 5% AEP event there is a well-defined floodway along the length of Hay Street, while flood storage areas exist around the downstream end of Hay Street and in various isolated areas in Pyrmont. In the 1% AEP event these features are more pronounced, with more prominent floodways in Ann Street and Reservoir Street in Surry Hills, and through parts of Darling Harbour. In the PMF event, floodways exist in the same areas, as well as on George Street, Eddy Avenue and through most of Darling Harbour.

3.3. Flood Hazard Classification

Flood hazard is a measure of the overall adverse effects of flooding and the risks they pose. The 2005 NSW Government's Floodplain Development Manual (Reference 1) describes two *provisional flood hazard* categories; High and Low, based on the product of the depth and velocity of floodwaters. These hazard categories do not consider other factors which may influence the flood hazard (Figure L2 of the Floodplain Development Manual); hence they are provisional estimates only with "true" hazard to be defined through the process of the current study. The boundary of the provisional High and Low hazard classification will change according to the magnitude of the flood in question.

Provisional hazard was established as part of the Flood Study (Reference 2) based on the Floodplain Development Manual criteria (Appendix L of the Floodplain Development Manual). Due to the combination of high flood depths and velocities, many regions of the catchment are affected by high hazard flows. Figure 9 to Figure 16 show the flow hazard classification throughout the catchment for the 50%, 20% 10%, 5%, 2%, 1%, 0.2% AEP and PMF events. As shown in the figures, high hazard inundation is concentrated on Hay Street, with small localised areas in trapped depressions and gutters. As with inundation in general, high hazard occurs almost exclusively on roadways, with no flowpaths passing through buildings. Vehicles and pedestrians are therefore most vulnerable to the hazardous flow, and not buildings and structures.

To assess the true flood hazard, all adverse effects of flooding have to be considered. This includes the provisional (hydraulic) hazard, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors are considered under a qualitative assessment, as described in Table 5.

Table 5: Hazard Classification

Criteria	Weight [1]	Comment
Size of the Flood	Medium	Relatively low flood hazard is associated with more frequent minor floods while the less frequent major floods are more likely to present a high hazard situation.
Depth & Velocity of Floodwaters	High	The provisional hazard is the product of depths and velocity of flood waters. These can be influenced by the magnitude of the flood event.
Rate of Rise of Floodwaters	High	Rate of rise of floodwaters is relative to catchment size, soil type, slope and land use cover. It is also influenced by the spatial and temporal pattern of rainfall during events.
Duration of Flooding	Low	The greater the duration of flooding the more disruption to the community and potential flood damages. Permanent inundation due to sea level rise is of indefinite duration.
Flood Awareness and Readiness of the Community	High	General community awareness tends to reduce as the time between flood events lengthens and people become less prepared for the next flood event. Even a flood aware community is unlikely to be wise to the impacts of a larger, less frequent, event.
Effective Warning & Evacuation Time	Medium	This is dependent on rate at which waters rise, an effective flood warning system and the awareness and readiness of the community to act.
Effective Flood Access	Medium	Access is affected by the depths and velocities of flood waters, the distance to higher ground, the number of people using and the capacity of evacuation routes and good communication.
Evacuation Problems	Medium	The number of people to be evacuated and limited resources of the SES and other rescue services can make evacuation difficult. Mobility of people, such as the elderly, children or disabled, who are less likely to be able to move through floodwaters and ongoing bad weather conditions is a consideration.
Provision of Services	Low	In a large flood it is likely that services will be cut (sewer and possibly others). There is also the likelihood that the storm may affect power and telephones. Permanent inundation from sea level rise may lead to permanent loss of services.
Additional Concerns	Low	Floating debris, vehicles or other items can increase hazard. Sewerage overflows can occur when river levels are high preventing effective discharge of the sewerage system.

(1) Relative weighting in assessing the hazard for the Darling Harbour catchment

Larger flood events in the catchment are associated with increased depths and velocities; however, this is largely accounted for by the provisional hazard criteria being considered over a range of events. Furthermore, the nature of flooding in the catchment results in only small increases in flood levels between design events.

Floodwaters have hazardous depth and velocity in frequent flood events, with overland flow passing down several roads in the catchment. The main risk associated with the flowpaths is that pedestrians or vehicles will attempt to cross a flowpath (for example, when crossing Hay Street) and will be de-stabilised. Pedestrians can injure themselves when falling over, and cars can lose power and become stranded, or lose traction and be carried downstream. The areas of risk are well-described by the maps of hydraulic hazard, which show areas of high hazard in each event.

The concept of rate of rise of flood waters is more applicable to mainstream flooding scenarios, where a fast rate of rise can leave residents unaware of the flood event, and they can become stranded. However, the rate of rise in this catchment is very fast (up to 1-2 m/hour in the 5% AEP and 2-2.5 m/hour in the 1% AEP – both 90 minute storm duration) and flood prone areas will become inundated soon after the rainfall event begins.

Flood awareness in the community appears to be low, with 40% of questionnaire respondents aware of flooding in the catchment (Reference 2). As described in the flood study, the area's residential population is largely transient, with only 25% of residents living in the same address 5 years prior when surveyed for the 2011 census. Experience in similar urban catchments indicates residents, people who work in the area and in this case tourists are all generally sceptical of the possibility of large floods and therefore may not ascribe the appropriate level of risk to floodwaters when they are encountered. This is especially true in this area where there is no resemblance to a natural catchment, that is, it is completely urbanised.

Effective warning and evacuation time in the catchment is very low, as the flooding is likely to be sudden, with a fast rate of rise. For a person in the area without additional warning or forecast, flood events will initially resemble more benign (but still heavy) storms, with awareness of the flood coming from direct experience of it. However, effective access, which refers to an exit route that remains trafficable for sufficient time to evacuate people and possessions, is likely to be available to the majority of affected residents, as the flood extents are not wide. The areas where access is an issue are those areas identified as having high hydraulic hazard, shown on Figure 14 for the 1% AEP event. The vehicular and pedestrian access routes are all along sealed roads and present no unexpected hazards if the roads have been adequately maintained.

At depths of 0.3 m wading should be possible for most mobile adults, but could be problematic for children, elderly or disabled people. The majority of flood prone properties in the catchment do have access with flood depths of 0.3 m or less. Areas that do have depths of 300 mm or more in the 1% AEP include:

- Commonwealth Street near Reservoir Street
- Parts of Elizabeth Street near Hay Street
- Hay Street between Belmore Park and Darling Drive
- Large parts of Darling Harbour between Hay Street and the waterfront.
- Sections of Darling Drive
- Pyrmont Street near Jones Bay Road
- Harris Street near Allen Street

At depths of 300 mm, larger vehicles can easily travel through water at this depth and aid evacuation. Nevertheless, for areas within the catchment without effective flood access, evacuation is generally not recommended considering the short duration of flooding experienced as residents are more likely to put themselves in harm's way by evacuating.

The impact of debris is unlikely to be a significant factor due to the low flood depths and/or velocities for large parts of the catchment. It would impact the time of inundation as waters would take longer to recede, however as the duration of the flooding is generally short across the catchment this is not considered significant. Figure 17 shows the length of inundation taken at each of the drainage pit inlets in the 1% AEP, 1.5 hour event. This shows that the duration of flooding is typically less than 1 hour except in the low points of Darling Harbour, on Commonwealth Street and near the west end of Hay Street, where it may take up to four hours to drain, assuming the piped network is operating efficiently (i.e. without blockages).

3.4. Hotspots

The flood study identified a number of potential flooding problem areas, where flooding is likely to present a significant issue to businesses, residents, pedestrians and/or vehicles. These were reviewed as part of the current study, and used to form a set of flooding hotspots. These areas are shown in Figure 4 and discussed in Table 6. Further to the list of hotspots, flooding exists at various locations in the catchment, but is minor relative to the hotspot flooding. These locations are summarised in Table 7.

Table 6: Hotspots - Darling Harbour Catchment

Location	Description	Flood characteristics	Provisional Hazard (from Flood Study)
Commonwealth Street, near Ann and Reservoir Streets	Trapped low point which is sensitive to pit blockage. Capacity is first exceeded in the 10% AEP event. Mixture of commercial and residential properties. Terrace style.	Peak depths exceed 1.0m in the 1% AEP event and 1.6m in the PMF.	5% AEP: High in sag, other areas Low / Medium 1% AEP: High in sag, other areas Medium
Pyrmont Street, near Jones Bay Road and Union Street	Trapped low point which is sensitive to pit blockage. Capacity is first exceeded in the 10% AEP event	Peak depths exceed 1.1 m in the 1% AEP event, and more than 4.3 m in the PMF.	5% AEP: Medium in sag, other areas Low 1% AEP: High in sag, other areas Low / Medium
Elizabeth Street	The railway line along Elizabeth Street only allows flood water to pass through to the lower catchment at the under bridge crossings at Eddy Ave, Hay Street and to a lesser extent Campbell Street.	In the 1% AEP event a peak flood depth of 0.5m occurs on Elizabeth Street upstream of Hay St and Campbell St, and 0.2m upstream of Eddy Ave. Depths of exceed 1.3 m upstream of Hay St in the PMF event.	5% AEP: Low 1% AEP: Low
Hay Street, from Elizabeth Street to Haymarket	This reach has a provisional high hydraulic hazard for the 1% AEP event and presents a significant potential risk to pedestrians, motorists and property	Peak depths of more than 1.0 m and velocity of almost 3 m/s in the 1% AEP event. Depths reach 2.5 m in sag points in the PMF.	5% AEP: High in sag points, other areas predominantly Low 1% AEP: Predominantly High, some areas Low / Medium
Darling Harbour, near Tumbalong Park, Chinese Gardens and King Street Wharf.	This area is sensitive to sea level rise. It is a highly pedestrianised area with many restaurants and tourist attractions. At the Haymarket Tram Station, the concentrated flow path along Hay Street spreads out and reduces in velocity.	Near Tumbalong Park flooding first occurs in the 5% AEP event with depths greater than 0.3 m and velocities greater than 0.8 m/s. In the PMF depths can exceed 1.8 m. Around King Street Wharf, velocities are generally lower, between 0.1 – 0.3 m/s but depths exceed 1 m in the 1% AEP event. Ponding also occurs around a substation located at Black Wattle Place.	5% AEP: Low 1% AEP: Predominantly Low, some areas Medium

Table 7: Other Flooding Locations

Location	Description	Flood characteristics	Provisional Hazard (from Flood Study)
Chalmers Lane, near Rutland Street and Devonshire Street	Trapped low point which is sensitive to pit blockage. The area is a back lane and has some garage entries and back doors to property. Not a pedestrian or vehicle thoroughfare.	Over 0.5 m depth in the 1% AEP flood.	1% AEP: Low
Ultimo Road, between Harris Street and Darling Drive	Slight topographic sag beneath rail line has high depth of flow in large floods. No property affectation but moderate pedestrian and vehicle traffic.	Over 0.7 m depth at some points below rail line, remaining around 0.5 m or less.	1% AEP: Mix of high and low hazard
Mary Ann Street	Overland flow blocked by rail line, causes ponding at the east end of the street. Minimal use by cars or pedestrians, and minimal property affectation.	Around 0.4 m depth in the 1% AEP at the east end of the street.	1% AEP: Low
Harris Street, near Fig Street and Allen Street	Slight topographic sag in block of Harris Street, causes ponding. Moderate pedestrian and vehicle traffic through the area, minimal property affectation as floor levels raised.	Over 0.5 m depth in the 1% AEP flood.	1% AEP: Low
Sussex Street, north of Druitt Street	Slight topographic sag in block north of Druitt Street causes ponding. Moderate pedestrian and vehicle traffic through the area, minimal property affectation and one underground car park potentially flooded.	Over 0.7 m depth at some points, remaining around 0.5 m or less.	1% AEP: Mostly low, one high hazard section

4. STAKEHOLDER CONSULTATION

4.1. Community Consultation

One of the central objectives of the FRMS process is to actively liaise with the community throughout the process, keep them informed about the current study, identify community concerns and gather information from the community on potential management options for the floodplain. The consultation programme consisted of:

- Distribution of brochure and questionnaire survey;
- Media release; and
- Public meetings.

4.1.1. Previous Consultation

As part of the Flood Study (Reference 2), an extensive community questionnaire survey was undertaken during May 2013 to gather historical data for model calibration. 21,250 surveys were distributed to residents and businesses across both the City Area and Darling Harbour catchments. 244 responses were received, which equates to a return rate of 1.1%, of which 186 were received from the Darling Harbour catchment. The most significant events reported through the consultation were 12 February 2010 (approximately 10% AEP event), 8 March 2012 (approximately 0.5 EY event) and 3 April 2013 (approximately 1.0 EY event).

4.1.2. Consultation as Part of This Study

Further community questionnaire survey was undertaken as part of this study to inform residents of the next stage of the floodplain management process as well as to gather flood information and community's preferred options of managing flood risks within the catchment. With assistance from Council, 2,487 copies of the newsletters and questionnaires were printed and delivered to the owners of properties located within the PMF extents as identified in the 2014 Flood Study (Reference 2). Results are shown in Figure 18, while Appendix B contains the newsletter and questionnaire mailout.

The results show that respondents to date have little experience of flooding and the majority are in residential lots. Of the respondents, thirteen have experienced flooding, with seven of those having floodwaters inside their house/business, four observing road flooding and two observing it in the neighbourhood. There was not a clear trend in what respondents' least preferred management option is, but 'Educated of the community' and 'Improved Flood Flow Paths' were the least preferred. Around a third of residents preferred pit and pipe upgrades (the most favoured type) and 'Flood forecasting, Warnings, Evacuation Planning' was also preferred.

4.2. Floodplain Committee Meetings

The Floodplain Management Committee (FMC) oversees and assists with the floodplain risk management process being carried out within the Council LGA. The committee is comprised of representatives from various stakeholders, including local Councillors, emergency services, OEH, SWC and community representatives.

5. ECONOMIC IMPACT OF FLOODING

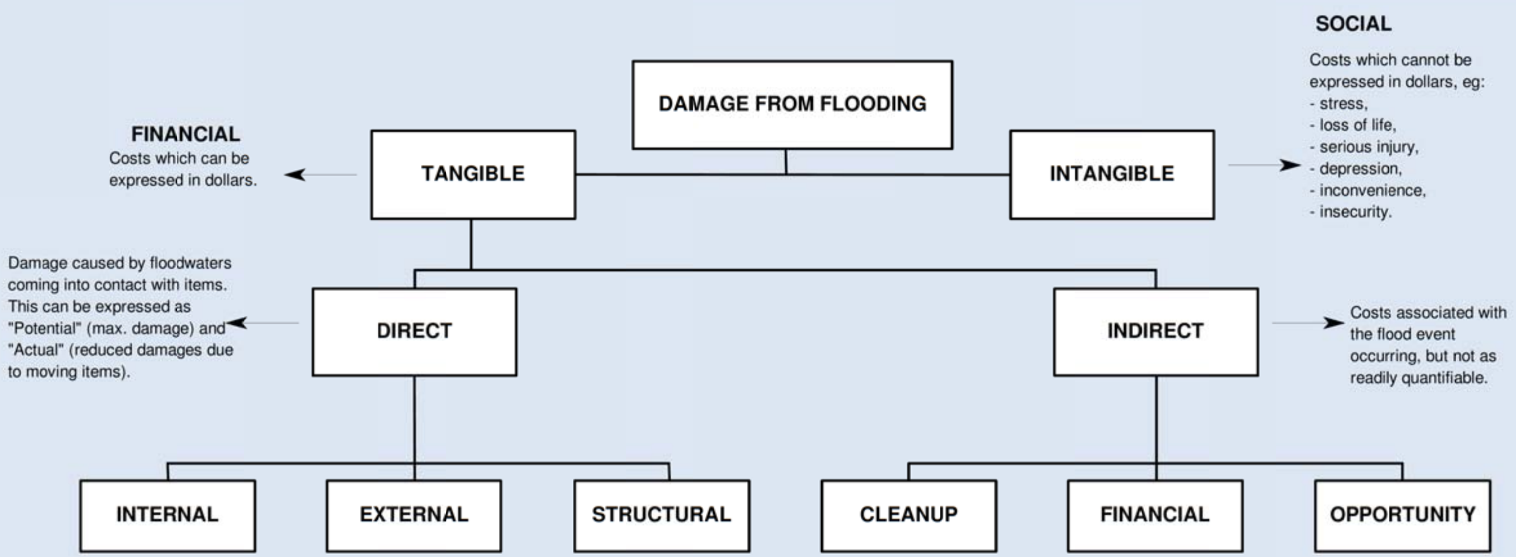
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood mitigation works such as retarding basins, levees, drainage enhancement etc. The quantification of flood damages is an important part of the floodplain risk management process. By quantifying flood damage for a range of design events, appropriate cost effective management measures can be analysed in terms of their benefits (reduction in damages) versus the cost of implementation. The cost of damage and the degree of disruption to the community caused by flooding depends upon many factors including:

- The magnitude (depth, velocity and duration) of the flood;
- Land use and susceptibility to damages;
- Awareness of the community to flooding;
- Effective warning time;
- The availability of an evacuation plan or damage minimisation program;
- Physical factors such failure of services (sewerage), flood borne debris, sedimentation; and
- The types of asset and infrastructure affected.

The estimation of flood damages tends to focus on the physical impact of damages on the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being tangible or intangible. Tangible damages are those for which a monetary value can be easily assigned, while intangible damages are those to which a monetary value cannot easily be attributed. Types of flood damages are shown in Table 8.

The assessment of flood damages not only looks at potential costs due to flooding but also identifies when properties are likely to become flood affected by either flooding on the property or by over floor flooding as shown on Figure 20.

Table 8: Flood Damages Categories (including damage and losses from permanent inundation)



	INTERNAL	EXTERNAL	STRUCTURAL	CLEANUP	FINANCIAL	OPPORTUNITY
RESIDENTIAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Laundries, Caravans, Sheds, Tools, Gardens, Fences	Physical Damage to Buildings: Gyprock, Cupboards, Scour of Footings, Houses becoming buoyant (floating off footings)	Clean Carpets, Walls, Clothes; Re-instate Furniture; Remove Mud and Debris	Loss of wages, Living costs (temporary accomodation and food), Time to repair/replace damaged items	Not Applicable
RURAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Sheds (stables/barns), Machinery, Tools, Fences, Feed storage, Saddles, Crops &/or Stock, Irrigation Systems	Physical Damage to Structures: Damage to Homestead, Sheds, Access tracks, Protection levees	Clean Homestead and Out-buildings; Remove Debris; Dispose of affected crops &/or stock	Loss of Farm Production and Income, Re-instatement of Pastures, Supplementary feeding of stock (by hand or outside agistment), Stock movement/ transport, Living costs (temporary accomodation and food)	Sowing or harvesting of Crops, Sale of Stock (at depreciated value or dependent on market influences)
COMMERCIAL	Contents of Buildings: Products, Stock, Fittings, Tools, Machinery, Raw Materials	External Items: Vehicles, Machinery, Display, Raw Materials/Stockpiles, Fences	Physical Damage to Buildings	Dispose of damaged products, stock, materials; Cleaning and Re-instatement	Loss of Productivity and Income, Bank Interest Charges	Loss of existing &/or Potential Trade
PUBLIC AUTHORITIES	Contents of Public Buildings and Facilities	Public Property and Facilities: Parks, Signs, Machinery, Equipment	Physical Damage to Infrastructure: Electricity, Water, Telephone, Gas, Road & Rail Transport Links	Remove Mud & Debris from Facilities, Public & Private Property Repairs (temporary & permanent)	Disruption of Services, Community Service Relief Grants	Provision of Public Service