2. BACKGROUND

2.1. Manly Lagoon Catchment

2.1.1. Flooding Behaviour

Flooding in the Manly Lagoon catchment is dominated by catchment flooding, although elevated ocean conditions can also cause flooding and contribute to catchment driven events. The entrance conditions have an influence on flood behaviour, with higher entrance berm levels leading to higher peak flood levels. The Lagoon is managed by Council, who undertake mechanical opening of the Lagoon entrance in times of heavy rain at defined trigger levels. Short duration events

2 hour duration storms typically provide for the worst case flooding conditions in Manly Lagoon, with a level of 3.0 mAHD at Pittwater Bridge in the 1% AEP event. The rise in flood waters can be relatively fast: Peak flood levels in Manly Lagoon are recorded less than 30 minutes after the flood peaks at Brookvale and in the Burnt Creek deviation. Four hotspot locations have been identified including Kenneth and Balgowlah Roads, Balgowlah, Manly Lagoon North Bank and Brookvale. Further detail regarding flood behaviour in these locations is provided in Section 5.

2.1.2. Land Use

Figure 2 shows the land use within the Manly Lagoon catchment, as defined in the relevant Local Environment Plans. The catchment is predominantly urbanised with industrial, commercial and residential development. There are three major commercial centres within the catchment – Warringah Mall, Balgowlah Industrial Estate, and Stockland Balgowlah. The floodplain of the lagoon itself is primarily open space, comprising of golf courses, parks and reserves. Manly Dam is located in the upper catchment, and has a catchment area of approximately 500 ha comprising predominantly bushland. This accounts for approximately one quarter of the total Manly Lagoon catchment area.

2.1.3. Manly Lagoon Entrance

The entrance to Manly Lagoon is located at the northern end of Queenscliff beach, bounded to the north by a rocky headland and urban development to the south. There are two low flow pipes, each with 1.8 m diameter, and a concrete channel. Stuart Somerville Bridge crosses the Lagoon at Queenscliff beach. The rate of discharge into the ocean from the lagoon is controlled at this point by a rock bar (at approximately 0.2 mAHD) and the bridge abutments.

During a significant flood event, a secondary relief channel is cut through the sand berm at Queenscliff Beach which allows water to discharge directly into the ocean from downstream of the Bridge, rather than via the concrete channel. The opening regime of the relief channel is controlled by Council and based on actual and predicted lagoon water levels, and the observed

hydraulic, weather and ocean conditions. The Manly Lagoon Emergency Flood Channel Protocol (2000) dictates that cutting of the relief channel should begin once water levels in the Lagoon rise above *1.0-1.4 mAHD* as a result of rainfall, and a head difference of 0.6 m exists between the lagoon and the ocean.

The beach berm at the entrance of the Lagoon will naturally build up over time, and breakouts will occur without intervention during high lagoon levels and/or wave processes at the entrance.

2.1.4. Manly Dam

Manly Dam has a storage capacity of approximately 2,000 ML, with the crest of the Dam at 35.84 mAHD. The water level in the Dam is maintained at 34.1 mAHD (1.7 m below the crest). The Dam has a fixed crest continuous spillway approximately 250 m long. The water levels in the Dam are controlled and monitored by Sydney Water and Northern Beaches Council, with Sydney Water primarily releasing water for dam safety control, and Council for flood mitigation. Water in the Dam is also extracted by the two hydraulics laboratories located in Manly Vale for testing of physical models. The water is later released into Manly Creek. Scour valves are used to regulate the water level in the Dam, with a combined discharge capacity of 2.6 m^3/s.
Previous investigations estimated that initial water levels in the Dam impact peak design flood levels in the Manly Lagoon catchment by 0.1 m to 0.2 m.

The current operating procedure for the opening and closing of the scour valves are:

- Water level is to be maintained at 34.1 mAHD (1.7 m below crest level);
- At 1.0 m below crest level, Council is notified to open the scour valves operated by Council;
- At 0.5 m below crest level, Sydney Water are notified to open the scour values operated by Sydney Water; and
- At 1.6 m below crest level, Council and Sydney Water are notified to close the scour valves if they have been opened.

2.1.5. 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 French's Forest, Allambie Heights, Freshwater, North Manly, Manly Vale, Manly, Brookvale, Seaforth, North Balgowlah, Beacon Hills, Balgowlah, Fairlight and Queenscliff. Understanding the social characteristics of the area can help in ensuring that the right floodplain risk management practices are adopted. Table 2 below shows some selected characteristics.

Table 2: 2011 Census data

	NSW	Northern Beaches South	Northern Beaches Central
Population Age:			
0 – 14 years	19.2%	18.9%	20.1%
15 - 64 years	66.1%	67.6%	64.5%
> 65 years	14.7%	13.5%	15.5%
Average people per dwelling	2.6	2.5	2.7
Own/mortgage property	66.6%	61.6%	66.6%
Rent property	30.1%	36.5%	25.9%
Moved into area:			
- within last year	-	20%	14.7%
- within last five years	-	50%	39.7%
No cars at dwelling	10.9%	12.3%	7.9%
Speak only English at home	72.5%	81.9%	80.1%

Based on these statistics the area aligns fairly consistently with the state average. Approximately half the residents have lived in the area for more than 5 years, combined with a high proportion of home owners, suggests there is likely to be some familiarity with flooding amongst the community.

2.1.6. Drainage System and Structures

The Manly Lagoon catchment comprises a substantial pit and pipe network, with pipes ranging in size from 0.3 m diameter to large 10 m by 5 m structures (Burnt Bridge Creek beneath Condamine Street), as shown in Figure 3. In addition, there are three main creek systems which flow into the Lagoon; Burnt Bridge Creek, Manly Creek and Brookvale Creek, and they comprise a mixture of natural channels and culverted sections. There are two bridges, Pittwater Road Bridge and Stuart Somerville Bridge. Manly Dam is also located within the Lagoon's catchment area.

2.2. Previous Studies

A number of studies have previously been undertaken for the Manly Lagoon catchment, as listed below. A brief summary of those in bold is provided in the following sections.

- Manly Lagoon Flood Study, BMT-WBM, 2013;
- Bangaroo Street Flood Investigation, Cardno Lawson Treloar, 2006;
- Ryan Place Overland Flood Study, Webb, McKeown & Associates, 2007;
- Brookvale Bus Depot Flood Study, Arup, 2007; and
- Manly Lagoon Flood Study, MHL, 1992.

A brief overview of the two flood studies (2013 and 1992) is provided below, with further information regarding the other studies summarised within the 2013 Flood Study Report.

2.2.1. Manly Lagoon Flood Study, BMT-WBM, 2013

The primary objective of this Flood Study was to define the flood behaviour under historical, existing and future conditions (incorporating potential impacts of climate change), for the full range of design flood events. The study provided information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. It also identified the impacts future climate change and potential changes in the catchment and lagoon entrance could have on flood behaviour.

Key findings from the flood study are:

- Longer duration events (6-9 hours) typically provide for the worst case flooding conditions in Manly Lagoon. In the lower reaches of all of the tributary catchments, flood levels are dominated by the Lagoon flooding conditions. The peak flood water level in the Lagoon extends a significant distance up the tributary channels. In the upper reaches of the tributary catchments, shorter duration events in the order of 2-hours provide the critical flood condition in terms of peak flood water level;
- The rise of flood water levels can be relatively fast. The potentially rapid inundation has implications for flood warning and emergency response;
- Catchment derived flood events represent the dominant flooding mechanism. The entrance condition has some influence on catchment flood behaviour with higher entrance berm levels providing for higher peak flood levels. The existing entrance management policy provides for manual breakout of the Lagoon entrance at defined trigger levels in preparation for imminent flooding. Irrespective of the successful implementation of a manual entrance breakout, significant flood inundation may be expected during major catchment flood events;
- The worst flood affected areas are typically in the lower parts of the catchment. These areas include the foreshore of the Lagoon around Riverview Parade. Much of the lower floodplain area is however, occupied by park lands/golf courses such that flood risk exposure to existing property is limited. Elsewhere, the Warringah Mall and Balgowlah Industrial Estate are located on the alignments of Brookvale Creek and Burnt Bridge Creek respectively. When drainage system capacities in these areas are exceeded, there is potential for overland flow through these areas;
- Peak design flood water levels are expected to progressively increase as the impacts of climate change manifest. Potential sea level rise will provide for a worsening of existing flood conditions in the Manly Lagoon catchment through higher ocean water levels (tide and storm surge), higher entrance berm and higher water levels in the Lagoon; and
- With potential sea level rise, normal tide levels in the Lagoon will approach and eventually exceed the current trigger levels for manual entrance management of the Lagoon. Future openings would need to be at significantly higher trigger levels to be effective. Low-lying land currently impacted by flooding may also be subject to regular, or permanent, tidal inundation at some time in the future.

2.2.2. Manly Lagoon Flood Study, MHL, 1992

The 1992 Flood Study estimated design flood levels for the PMF, 1% AEP, 5% AEP and 20% AEP flood events. The 1D Mike-11 hydraulic model established for the study was limited to the following areas:

- Manly Lagoon and surrounding parks and golf courses;
- Brookvale Creek down from Warringah Mall;
- Manly Creek down from Manly Dam; and
- Burnt Bridge Creek down from Condamine Street.

The hydraulic model network was defined based on cross-sections at approximately 200 m intervals, and calibrated to the June 1991 rainfall event and tested using the April 1988, March 1975 and May 1974 rainfall events.

This study did not take into account the urban trunk drainage network, and assumed that the entrance would always be mechanically opened at 1.4 mAHD.

2.3. Flood Study Modelling Review and Update

As part of the current study, WMAwater undertook a review of the flood modelling established in the 2013 Flood Study by BMT-WBM. The review established that:

- The model which had been used was a proprietary model developed by BMT-WBM which combines morphological modelling with flood modelling. This model is not available for others to use; and
- The model produced results (flood levels, depths and velocities) in limited locations throughout the study area that were not able to be replicated using the latest commercially available version of TUFLOW (as of August 2015).

Further, BMT-WBM has subsequently advised that the solution scheme used for flood modelling in the Flood Study (pre-2012 version of TUFLOW) could lead to situations in which the capacity of 1D networks could be underestimated (BMT-WBM, 2015).

As such, WMAwater has carried out an assessment of the differences in results produced by existing and revised flood models.

2.3.1. Methodology

The assessment involved the following:

- The flood study TUFLOW model was converted to the most recent TUFLOW version (2013-12 AC);
- All design events and durations were modelled. To achieve this, some alteration of the pipe schematisation and pipe roughness was required in some places to improve the stability of the model. These changes were minor, particularly in the context of a 1%

AEP event, however improved the stability of the model runs. Figure 4 shows an example of some of the changes made;

- An approximation of the variable entrance conditions was required as the morphological module was not used; and
- Impact maps were produced which included a comparison of peak water levels as well as peak flow rates in the 1D network elements. These are shown on Figure 5 and Figure 6 respectively.

2.3.2. Results

Figure 7 shows the flood extents for the PMF, 1% and 20% AEP design events. Generally the impact of the updated modelling work is minimal, particularly in regard to residential flood affectation. However in some commercial areas there are some reductions in peak flood levels and flood extent. The key areas where design flood definition has changed are:

- Brookvale, where levels have been reduced between 0.1 m – 0.5 m;
- Manly Vale, where in specific locations there are reductions of up to 0.5 m in peak water levels, although generally the reduction in levels is less; and
- Various other localised areas where some change has occurred. The most notable being those areas adjoining the northern side of the lagoon where flood extents are reduced.

In all instances, the reduction in flood levels in the revised model is a result of an increase in 1D network flow. The model update also resulted in a reduction in the range of critical durations. The Lagoon previously had a nine-hour critical duration, but this is now two-hour. This is again due to the 1D network more effectively delivering flow downstream when using the updated version of TUFLOW.

The areas impacted by the reduced flood levels mainly include commercial property, although there are some limited areas of residential properties affected by the changes.