PHYSICAL AND NUMERICAL MODELLING OF A MAJOR STORMWATER CHAMBER AND ARTERIAL ROAD CROSSING IN SYDNEY, NSW

B. C. PHILLIPS
S. YU
D. ATKINSON
Cardno (NSW/ACT) Pty. Ltd, Level 9, 203 Pacific Highway,
St Leonards NSW 2065, Australia,

N.S. GUERRY
B. MILLER
UNSW Water Research Laboratory, 110 King St,
Manly Vale NSW 2093, Australia

Warringah Mall is a regional shopping centre located within the Brookvale Creek catchment in the Sydney's northern suburbs. Currently stormwater is conveyed by 1 x 4.2 m (W) x 1.8 m (H) + 2 x 1350 mm diameter conduits + 1 x 1500 mm diameter conduit + 3 x 1.8 m diameter conduits + 1 x 900 mm diameter conduit discharges into a large chamber (Chamber C6) which in turn discharges into 4 x 2.8 m (W) x 1.8 m (H) culverts which convey stormwater under Condamine Street and into the Brookvale Creek GPT. As part of planned augmentation works it is proposed to connect two new 3.3 m (W) x 1.8 m (H) culverts into a re-constructed chamber (Chamber C6) and lowering the two central culverts under Condamine Street by up to 1.0 m. One of the conditions of consent required a physical model study of the large chamber and Condamine Street crossing to confirm the hydraulic losses which were assumed in the computer model studies and to provide advice on how the hydraulic losses in each junction box can be minimized. This physical model study is described and a comparison of the hydraulic performance of the chamber and crossing predicted by the numerical model and observed hydraulic losses and flood levels is presented.

1 INTRODUCTION

As discussed by Phillips and Yu, 2011 [1], Warringah Mall is a major regional shopping centre located within the Brookvale Creek catchment in the Sydney's northern suburbs. The land uses within the Brookvale Creek catchment include residential and industrial/commercial developments as well as a significant area of bushland known as Allenby Reserve.

Prior to 2004 it was identified that under existing conditions Warringah Mall is flooded by overland flows and overflows from Brookvale Creek in major storms. By 2006 the Peninsula Industrial Estate Floodplain Management Study was released [2]. This study assessed flooding under existing conditions and the merits of a number of structural management options that could achieve a balance between reducing flood hazard and flood damages and protecting the environment of the Brookvale Creek floodplain. Subsequently in 2007, the assessment of four schemes [3] led to the adoption of a scheme of works within Warringah Mall that reduce 100 yr Average Recurrence Interval (ARI) overland flooding through the site to a Low Hazard without any upstream works.

In December 2008 the Warringah Mall Flood Impact Assessment [4] was submitted to Warringah Council supporting two Development Applications which covered the proposed stormwater augmentation works within the Warringah Mall site and various works to be implemented as part of Stage 1 Retail development.

In 2009 the floodplain model was updated based on discussions with Warringah Council and its Peer Reviewer. The final values of floodplain model parameters were agreed as part of the peer review process. The final model was then run to identify final amendments to the augmentation works to meet Council's requirements and documented in a 2010 Flood Impact Assessment Addendum report [5].

2 FLOODING AT WARRINGAH MALL

As discussed by [2], [4] there are no recorded streamflow data for Brookvale Creek. Likewise there are no water level recorders within the study area. A very limited number of observed flood levels were available for historical major rainfall events in March 1975, March 1977, February 1986, January 1989 and April 1992.

Almost all of the historical flood levels were observed at a single location within the Harrison Group property located at 71-79 Old Pittwater Road located immediately upstream of Warringah Mall.

2.1 Hydrology and Hydraulics

The hydrological analyses of historical storms including March 1975 (20 yr ARI), March 1977 (2 yr ARI), February 1986 (5 yr ARI), January 1989 (20 yr ARI) and April 1992 (10 yr ARI) and a range of design storms are discussed in [1], [2] and [3].

A unified 1D and 2D xpswmm2D model of the Brookvale Creek floodplain, including the drainage systems and overland flowpaths between Kentwell Road (located around 800 m downstream of Condamine Street) and Allenby Reserve (upstream), was assembled. The Brookvale Creek channel between Old Pittwater Road and Warringah Mall through the Harrison Group property (refer Figure 1) was also modelled as a 1D section linked to the 2D floodplain to provide better definition of the channel geometry.

2.2 Calibration

The hydrological model was not calibrated directly against historical flow data but was instead compared with historical flood estimates. Similarly the hydraulic model was only calibrated against flood levels observed at a single location. Where appropriate the models were configured so as to be consistent with previous models. Similar model parameters and values were adopted where appropriate.

2.3 Design Floods

Within the limits of the available information the model was calibrated using available historical flood levels. This model was then run to estimate the flood levels and flow velocities at key locations on the Brookvale Creek floodplain for the 20 yr ARI, 50 yr ARI, 100 yr ARI, 10,000 yr ARI, 100,000 yr ARI and PMF design storms design storms under existing conditions and 20 yr ARI, 50 yr ARI, 100 yr ARI design storms with various flood mitigation measures in place.

The estimated 100 yr ARI design flood depths under existing conditions are presented in Figure 1.

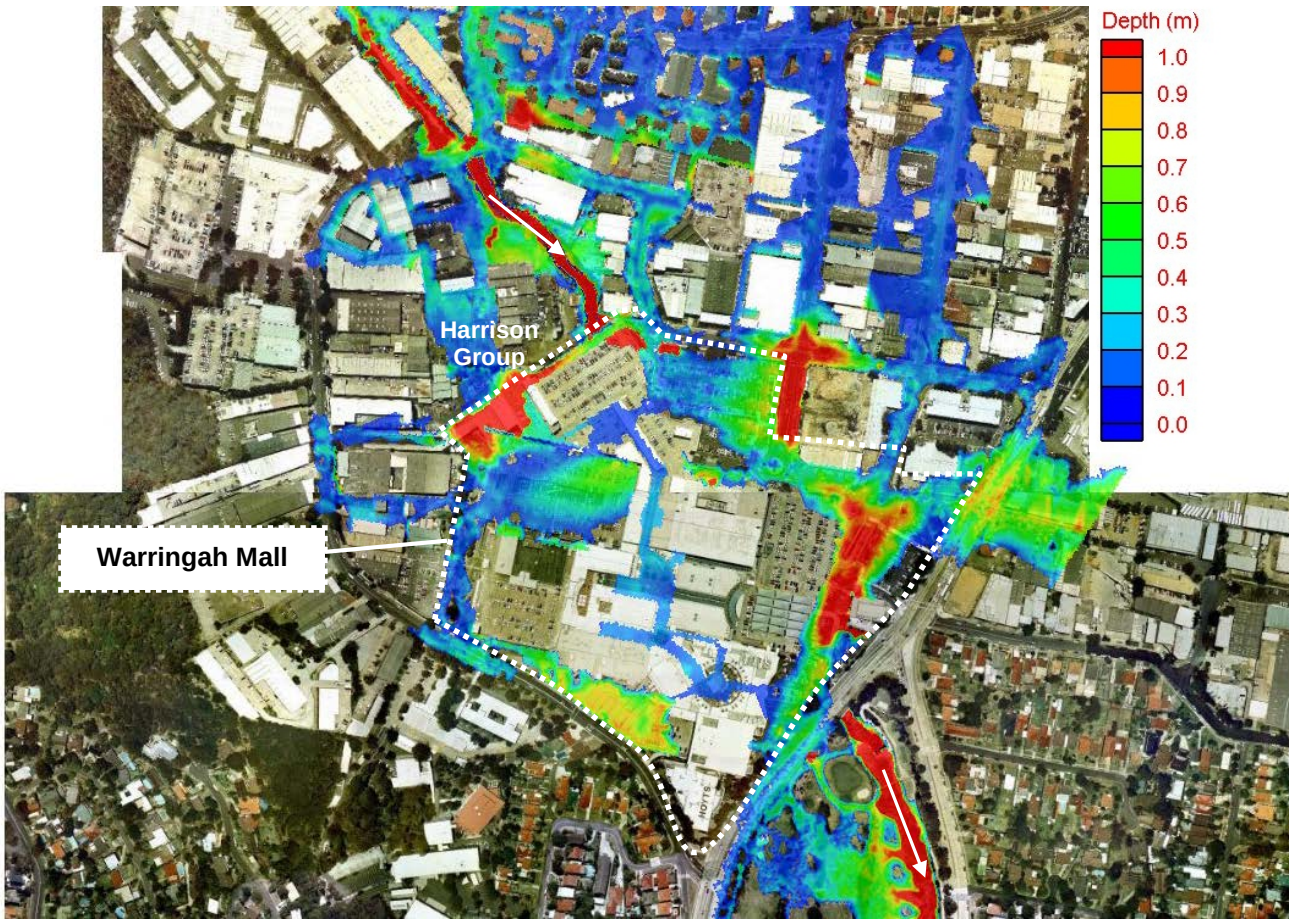


Figure 1. 100 yr ARI Flood Depths at Warringah Mall under Existing Conditions

2.4 Augmentation Scheme

In 2008 an augmentation scheme was proposed and is described in [4]. The 2008 scheme evolved based on the needs to minimise flood impacts on the land adjoining the upstream boundary of Warringah Mall (the Harrison Group property) and to minimise, or if possible eliminate, the need for any augmentation works on the adjoining upstream property to divert overflows from Brookvale Creek into the augmentation scheme.

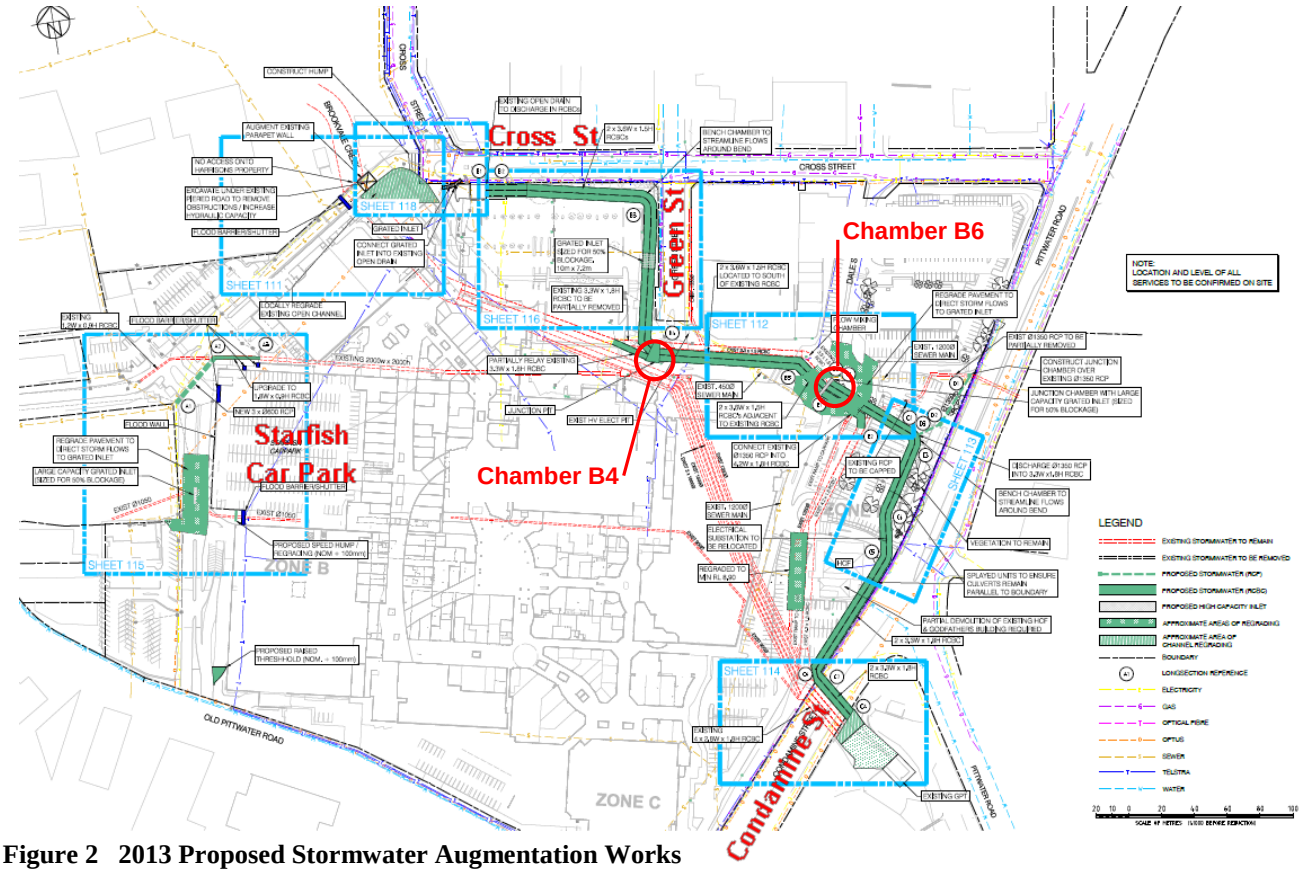


Figure 2 2013 Proposed Stormwater Augmentation Works

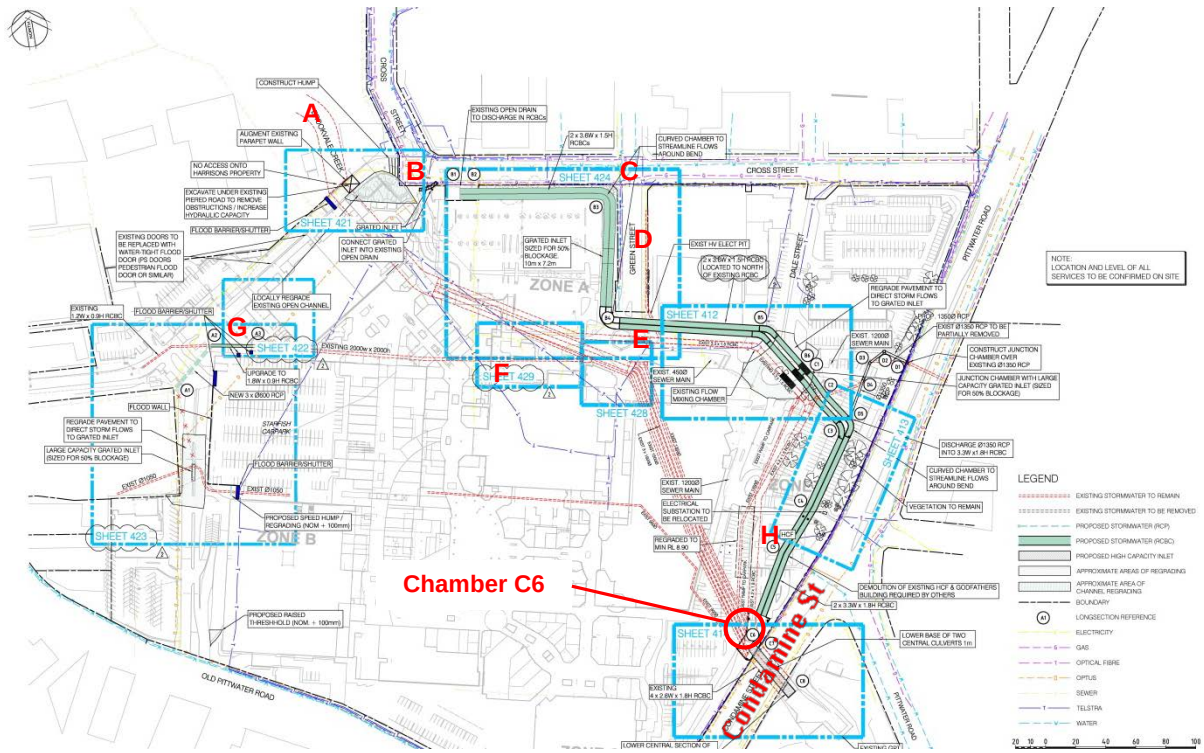


Figure 3 2014 Proposed Stormwater Augmentation Works (shown in green)

This scheme further evolved to respond to opportunities presented by subsequent planned development for Warringah Mall and to services constraints identified on the site. The stormwater augmentation scheme proposed in 2013 (shown in green) is presented in Figure 2.

In 2014 detailed consideration of the outcomes of physical modelling of Chambers B4 and B6 [6] and the interaction of the proposed works with other services, the feasibility of relocating services at the southern end of Green Street, traffic management during construction, construction sequencing and potential hydraulic impacts during construction led changes to the 2013 scheme, including changes to the Condamine Street crossing and re-alignment of the new stormwater culverts through the Bing Lee site. The 2014 stormwater augmentation scheme is presented in Figure 3.

3 CHAMBER C6 PHYSICAL MODEL STUDY

Currently stormwater is conveyed by 1 x 4.2 m (W) x 1.8 m (H) + 2 x 1350 mm diameter conduits + 1 x 1500 mm diameter conduit + 3 x 1.8 m diameter conduits + 1 x 900 mm diameter conduit discharges into a large chamber (Chamber C6) which in turn discharges into 4 x 2.8 m (W) x 1.8 m (H) culverts which convey stormwater under Condamine Street and into the Brookvale Creek GPT. As part of planned augmentation works it is proposed to connect two new 3.3 m (W) x 1.8 m (H) culverts into a re-constructed Chamber C6 and lowering the two central culverts under Condamine Street by up to 1.0 m.

One of the conditions of consent required a physical model study of Chamber C6 and the Condamine Street crossing to confirm the hydraulic losses which were assumed in the computer model studies and to provide advice on how the hydraulic losses in Chamber C6 can be minimized.

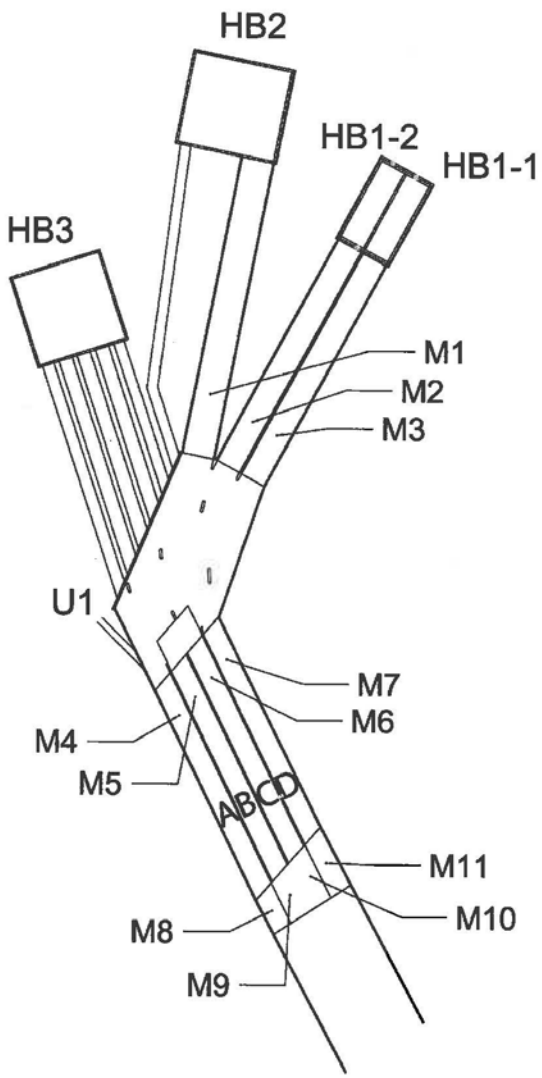


Figure 4 Chamber C6 Physical Model Layout and Location of Manometer Tapping Points (after [7])

3.1 Objectives

The objectives of the study were to undertake a physical model study to:

- Quantify the flow capacity and hydraulic losses in the modified Chamber C6 and through the modified Condamine Street culverts; and
- Assess the sensitivity or otherwise of the capacity of the modified culverts to the downstream tailwater level;
- Identify any opportunities to hydraulically improve the proposed works and test proposed modifications as appropriate.

3.2 The Physical Model

Prior to constructing the physical model the layout of Chamber C6 was reviewed and adjusted to further streamline flows through the chamber and to reduce hydraulic losses.
The model layout is given in Figure 1.

A Froude scale of 16.3: 1 was used for this model and Table 1 summarises the various scaling ratios. This precise scale was adopted to best match the prototype pipes to available acrylic pipe diameters. The scale provided flow depths that could be accurately measured and ensured that head losses had suitable resolution. The culverts have a relatively flat grade in some parts and the scale ensured that frictional and surface tension effects did not become dominant. At this scale, the form losses and turbulence were accurately represented. This scale ensured that maximum prototype flow rates were achievable, with total prototype flow of 70.3 m^3/s being represented by 65.5 L/s in the model.

Table 1 Model Scaling Ratios

Ratio	Symbol	Formula	Value
Length ratio	L_R	16.3	16.3
Time ratio	T_R	$L_R^{0.5}$	*4.04*
Velocity ratio	V_R	$L_R^{0.5}$	*4.04*
Flow ratio	Q_R	$L_R^{2.5}$	*1072.67*

The model was constructed with a marine plywood base and acrylic walls and roofs for culverts and the chamber. Acrylic pipes were used for all pipe inlets. In parts of the model an expanded PVC base was used in order to allow for raising and lowering of the invert level for design modifications.

Five separate water supplies were applied to the model to supply the ten separate inflows to chamber C6. Two head boxes (HB1-1 and HBl-2) were constructed to control the flow into the proposed twin culverts (U9 and Ul0) upstream of chamber C6 with one head box for each culvert. One head box (HB2) was constructed to control the flow into the existing culvert (US) and the easternmost pipe (U7). One head box was constructed to control the flow into the five central pipes (U2-U6).Inflow into the westernmost pipe (Ul) was not controlled with a head box and was piped directly into the model.

Testing was carried out under five different steady state inlet boundary conditions and two different tailwater boundary conditions, based on hydrograph data provided by Cardno.

3.3 Physical Model Cases

Four design configurations were tested, starting with Cardno's proposed alternative to the DA approved scheme and proceeding with three successive modifications to this design. The designs are outlined as follows.

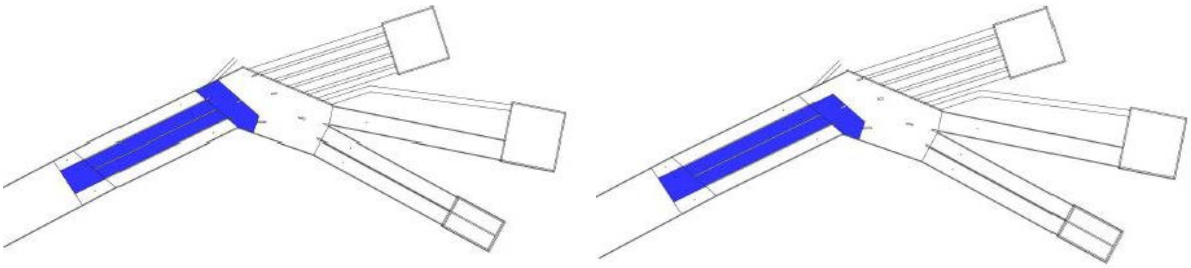
The Case 1 model was constructed as per the initial designs provided by Cardno, being the initial proposed alternative to the DA approved design. It involved a reconstructed C6 chamber and the lowering by 1.0 m of: the invert level of the two central culverts under Condamine Street; a small section upstream of these culverts inside C6; and downstream of these culverts on the apron.

Case 2 tested lowering the same area as in Case 1 by 740 mm (as opposed to 1.0 m in Case 1) to allow for a blinding slab to cover construction joints in the lowered culverts.

Case 3 considered increasing the size of the lowered section inside chamber C6, including the area upstream of the two outer culverts (the culverts themselves were not lowered). The extent of lowering remained 1.0 m, as in Case 1. Figure 5a presents the Case 3 flow conditions observed under peak flow conditions at the tailwater level WL1.

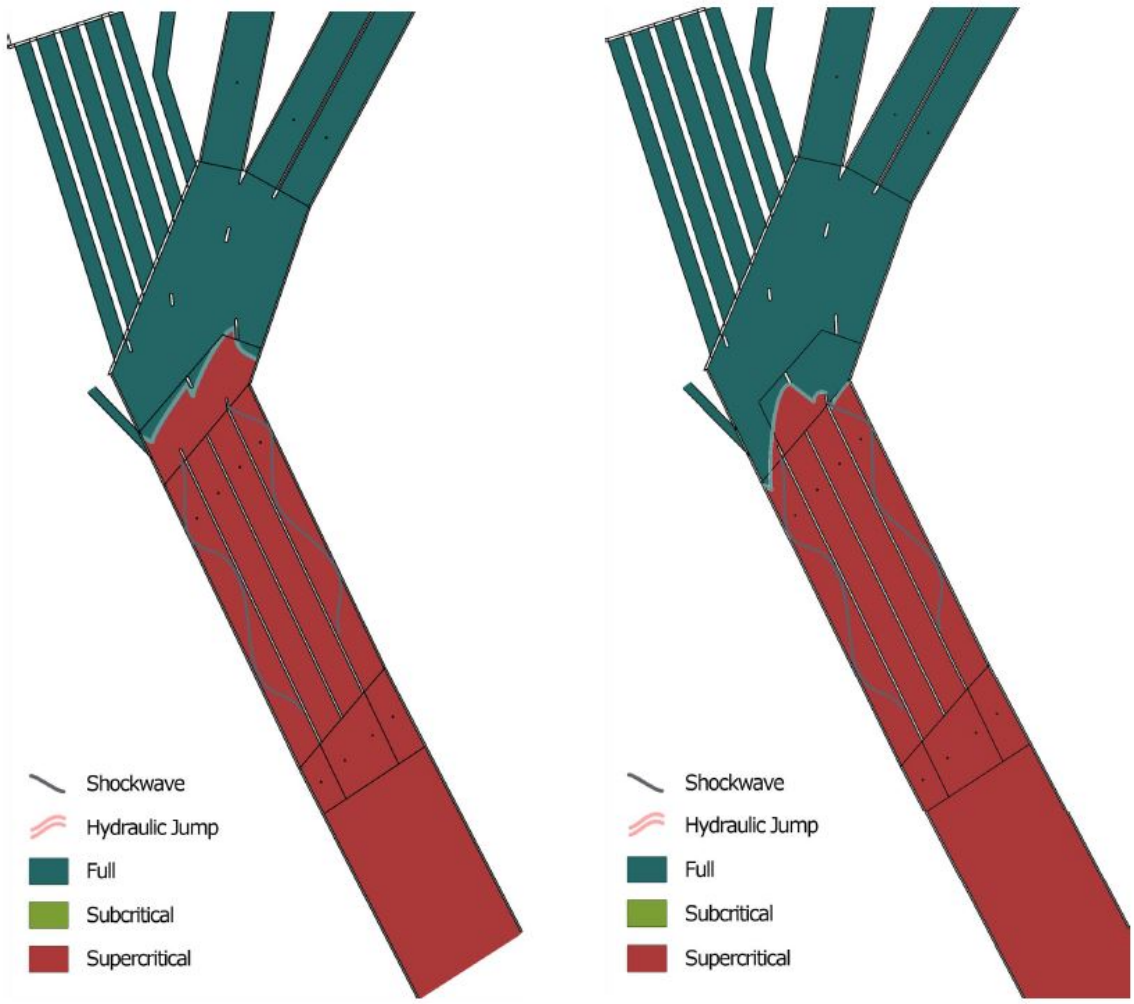
Case 4 was a final option where the size of the lowered section inside chamber C6 was between that of Case 1 and Case 3. The depth of lowering was 740 mm. Figure 5b presents the Case 4 flow conditions observed under peak flow conditions at the tailwater level WL1

The physical model and the modifications to the initial model which were undertaken and tested are described in the 2015 UNSW WRL Report titled "Warringah Mall Chamber C6 Physical Model Study".



Case 3 Lowered Section in Blue

Case 4 Lowered Section in Blue



(a) Case 3 Peak Flow Conditions

(b) Case 4 Peak Flow Conditions

Figure 5 Observed Peak Flow Conditions in Chamber C6 and in Condamine Street Culverts (after [7])

3.4 Results

The model study concluded (WRL, 2015 [7]):

The best performing options were Case 3 and Case 4. Hydraulic losses in chamber C6 were minimised in Case 3 and flow in the Condamine Street culverts was most evenly distributed in Case 4.

The total inflow cross sectional area was larger than the total outflow cross sectional area for chamber C6 in all cases. However, the physical model has demonstrated that the conveyance under Condamine Street is adequate due to the supercritical flow observed in these culverts. Further, it was found that any blockages downstream of the Condamine Street culverts {which are known to increase downstream levels by up to 0.5m) are unlikely to disrupt the supercritical flow in the culverts.

4 WARRINGAH MALL NUMERICAL MODEL

The Warringah Mall numerical model was modified to include nodes at Locations M1, M2 and M3 in order to compare the recorded and predicted heads (water levels) at these locations. It was found that the predicted heads at M1, M2 and M3 were all lower than observed. The numerical model at Chamber C6 was modified to match the observed flood levels at M1, M2 and M3 for Case 4 with 0% blockage flows which were adopted for the physical model tests.

The comparison of the recorded and predicted heads (water levels) at M1, M2 and M3 are given in Table 1.

It was concluded that the modified model gave excellent agreement with the observed peak water levels and was suitable for estimating 100 yr ARI flood levels upstream and downstream of Chamber C6.

Table 1 Comparison of Peak Water Levels (m AHD) at Locations M1, M2 and M3 under Case 4 Conditions with 0% Blockage

Location	Observed WL (m AHD)	Predicted WL (m AHD)	Difference (cm)
M1	8.13	8.10	-3
M2	8.06	8.04	-2
M3	8.00	8.04	4

Table 2 Summary of Impacts of Model Reconfiguration at Chamber C6

Reference Point	**In comparison to Previous DA1742 S96 Results**	**In comparison to Existing Conditions**
Upstream of Warringah Mall (A)	Local increases of up to 7 cm	Still achieves a reduction in flood levels of up to 27 cm.
Cross St Roundabout (B)	No change	Local flood level is 10 cm lower
Intersection of Cross St and Green St (C)	Local increase of 3 cm.	Still achieves a local 73 cm reduction
Green St Low Point (D)	Local increase of 18 cm	Still achieves a local 72 cm reduction
Green St Roundabout (E)	Remains dry if two pit lids outside the Post Office are sealed or are raised to prevent surcharge	Substantial improvement as achieved by the previous DA1742 S96 scheme
DJ Loading Dock (F)	Local increase of 3 cm.	Up to a 58 cm reduction
Woolworths Loading Dock (G)	Local increase of 4 cm.	Substantial improvement as achieved by the previous DA1742 S96 scheme
Near Condamine St (H)	No more than 1 cm difference	Substantial improvement as achieved by the previous DA1742 S96 scheme

4.1 Results

The modified model was then re-run to estimate the 100 yr ARI flood levels under 0% and 50% inlet blockage scenarios. Table 2 summarises the impacts of the model adjustments in the vicinity of Chamber C6 at locations of primary interest (refer Figure 3). While there have been some local increases eg. Green St low point it is our view that the local changes do not adversely impact on any adjoining properties and the Stormwater DA (Stage 2) will deliver significant reductions in 100 yr ARI flood levels in areas of concern eg. Green Street low point.

5 CONCLUSIONS

The Chamber C6 physical model provided an understanding of the flow behavior in Chamber C6 and provided an opportunity to refine the layout of the chamber and the levels of the Condamine St culverts. A key finding of the physical model study was that increases in the flood levels downstream of Condamine St up to 0.5 m higher than estimated by the numerical model are unlikely to disrupt the supercritical flow in the culverts and to have no impact on upstream flood levels.

It was found that the predicted heads at M1, M2 and M3 were all lower than observed in the physical model. The numerical model at Chamber C6 was therefore modified to match the observed flood levels at M1, M2 and M3 for Case 4 with 0% blockage flows which were adopted for the physical model tests.

It was concluded that the modified numerical model gave excellent agreement with the observed peak water levels and was suitable for estimating 100 yr ARI flood levels upstream and downstream of Chamber C6.

The modified model was then re-run to estimate the 100 yr ARI flood levels under 0% and 50% inlet blockage scenarios.

Subject to two stormwater lids near the Green St roundabout being sealed or raised to avoid surcharge during a 100 yr ARI event under 0% blockage, it was concluded from a comparison of the latest estimated 100 yr ARI flood levels and the flood levels estimated prior to the Chamber C6 model study that while there have been some local increases in the peak 100 yr ARI flood levels these local changes do not adversely impact on any adjoining properties and the Stormwater DA (Stage 2) will deliver significant reductions in 100 yr ARI flood levels in areas of concern eg. Green Street low point.

6 ACKNOWLEDGEMENT

The permission of the Scentre Group to outline aspects of the flooding assessments, the drainage augmentation strategy and physical modelling of the proposed Chambers C6 and Condamine Street crossing at Warringah Mall is gratefully acknowledged.

7 REFERENCES

[1] Phillips, B.C. and Yu, S. (2011) “Assessing Flood Risks in a Regional Shopping Centre in Sydney, Australia”, *Proceedings*, 34th IAHR Congress, 26 June -1 1 July, Brisbane

[2] Cardno Willing (2006) “Peninsula Industrial Estate Floodplain Management Study”, *Final Report*, prepared for AMP Capital Investors, November.

[3] Cardno Willing (2007) “Managing Flooding of Warringah Mall”, *Final Report*, prepared for AMP Capital Investors, February.

[4] Cardno Willing (2008) “Warringah Mall Flood Impact Assessment”, *Final Report*, prepared for AMP Capital Investors and Westfield Design & Construction, December.

[5] Cardno Willing (2010) “Warringah Mall Flood Impact Assessment”, *Addendum*, prepared for AMP Capital Investors and Westfield Design & Construction, January.

[6] Phillips, B.C., YU, S., Guerry, N.S. and Miller, B.M. (2015) “Numerical and Physical Modelling of Major Hydraulic Structures in a Regional Shopping Centre in Sydney, Australia”, *E-proceedings* of the 36th IAHR World Congress, 28 June – 3 July, The Hague, The Netherlands.

[7] Water Research Laboratory (2013) “Warringah Mall Chamber C6 Physical Model Study”, *WRL Technical Report 2015/10*, The University of New South Wales, August, 27 pp.