Understanding Complexities in Overland Flood Behaviour in Coastal Urbanised Catchment using 2D Hydraulic Models

Comprendre la complexité des phénomènes d'inondations dans des bassins cotiers urbanisés en utilisant des modèles hydrauliques 2D

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RÉSUMÉ

Les « Baies Moyennes » (Middle Bays) sont situées dans la zone de gouvernement local Kogarah à environ 14 km au sud du centre-ville de Sydney. Elles comprennent des bassins résiduels – Connells Bay, Kyle Bay et Shipwrights Bay – qui se déversent dans la rivière Georges. Dans le passé, les inondations dans le bassin des Middle Bays ont causé des dommages matériels et constituaient un danger pour les habitants vivant à proximité du principal bassin versant et des chemins d'écoulement. La tempête historique la plus importante pour le bassin versant a eu lieu en Mars 1975, lorsque 28 propriétés ont été inondées principalement en raison de l'insuffisance des capacités de drainage, une obstruction des chemins d'écoulement terrestres, et des inondations localisées dans la rue. Le Conseil Kogarah a entrepris une étude sur la gestion de l'écoulement de surface en 2008 pour modéliser le comportement des crues dans le bassin versant. L'étude a été menée en interne en utilisant le modèle 2D XP-Storm afin de comprendre le comportement d'inondation pour une gamme complète de tempêtes, jusqu'à et y compris la crue maximale probable (CMP). La modélisation 2D a donné un aperçu de la complexité du comportement des inondations terrestres validées par des inondations historiques de blocage et de bâtiments sur les voies d'écoulement de drainage. La modélisation 2D a indiqué que les impacts de l'urbanisation, les bâtiments et le blocage des réserves de drainage et des voies d'écoulement terrestre, ont conduit à la redistribution du ruissellement en surface dans le bassin versant. Avec la réduction de la capacité du système au fil des ans, cela a entraîné d'importants problèmes d'inondations localisées dans le bassin versant.

ABSTRACT

The Middle Bays are located within the Kogarah Local Government Area approximately 14 km to the south of the Sydney City centre. The Middle Bays are comprised of the residual catchments which are Connells Bay, Kyle Bay and Shipwrights Bay, which discharges into the Georges River. In the past, flooding in the Middle Bays catchment caused property damage and posed a hazard to the residents living close to the major drainage and flow paths. The most significant historical storm event for the catchment was in March 1975 when 28 properties were flooded mostly due to inadequate drainage capacity, obstruction to overland flow paths, and localised flooding from the street. Kogarah Council undertook an overland flow management study in 2008 to model the flood behaviour in the catchment. The study was undertaken in-house using XP-Storm 2D model to understand flood behaviour for a full range of design storm events up to and including the Probable Maximum Flood (PMF). 2D modelling gave insights into the complexities in overland flood behaviour validated by historical flooding from blockage and buildings on the drainage flow paths. 2D modelling indicated that the impacts of urbanisation, buildings and blockage of drainage reserves and overland flow paths, have led to re-distribution of overland flows within the catchment. With the reduction in system capacity over the years, this has resulted in significant localised flooding issues within the catchment.

KEYWORDS

2D Stormwater Modelling, Average Recurrence Interval (ARI), Overland Flows Study.

1 INTRODUCTION

The Middle Bays are located within the Kogarah Local Government Area approximately 14 km to the south of Sydney City centre (see Figure 1). The Middle Bays comprise of catchments Connells Bay (Catchments 10,11), Kyle Bay (Catchment 9) and Shipwrights Bay (Catchment 7) that discharge into the Georges River. The study area extends from Tom Ugly's Bridge in the east to Connells Point in the west, and is bounded by 6.5 kilometres of foreshore.

Figure 1 Catchment Location (left) and Digital Elevation Map (right) showing topography

The elevation of the catchment varies from 44m AHD in the north to 0m AHD at the bays. The western part of the catchment rise up to 23m AHD at Connells Point and 10m AHD in the east, near Ton Ugly's bridge. The catchment slopes range from 10-22 % in the upper reaches to 1% in the foreshore areas (see Figure 1).

In the past, flooding in the Middle Bays catchment caused property damage and posed hazard to the residents living close to the major drainage/ flowpaths. The most significant historical storm event for the catchment was the March 1975 event. Council has a good record of flooding of properties for this storm event. The flooding was mostly due to inadequate drainage capacity and more so because of obstruction to overland flow paths and localised flooding from the street.

The flooding history prompted Kogarah Council in 2008 to commence preparation of an Overland flows study as Stage 1 of Floodplain Management Plan. An Overland flows study is a comprehensive technical investigation of flood behaviour. It defines the nature of flood risk by providing information on the extent, level and velocity of floodwaters and on the distribution of flood flows across various sections of the catchment for the full range of design flood events up to and including the PMF. The overland flows study was undertaken in-house using XP-Storm 2D model (XP-Storm 2008).

The objective of the Overland flows study was

- To determine the existing flood behaviour of flood prone areas for a range of flood risk levels from the 5 year Average Recurrence Interval (ARI) through to the Probable Maximum Flood (PMF).
- To determine water levels and velocities (hydraulic and hazard aspects), and
- To form the basis for the development of Overland Flows Risk Management Study and Plan (Stage 2) for this catchment.

The purpose of this paper is to present results from Overland flows study using XP-Storm 2D models and provide overview of the complexities in overland flood behaviour in a typical old urbanised catchment. The study indicated that urbanisation has significant impact in altering the flood behaviour and distribution of velocities within the catchment. The 2D models not only validated historical flood behaviour but provided knowledge on complex flood behaviour as consequence of interactions between the overland and underground drainage in a highly urbanised catchment. The impacts of urbanisation, buildings and blockage of drainage reserves and overland flow paths, have led to complexities in flood behaviour within the catchment. With the reduction in system capacity over the years, re-distribution of overland flows has resulted in significant localised flooding issues within the catchment.

2 CATCHMENT DESCRIPTION

The Middle Bays catchments are typical coastal catchment with ground slopes ranging from mild slopes (1-10%) and steep slopes (>10%) in few areas of the catchment. Figure 1 illustrates the topography of this coastal catchment.

Land uses vary from 57% to 66% residential, 4% to 11% open spaces and remaining other uses for the three Catchments. The catchments are highly urbanised coastal fringes of Georges River.

Figure 2 Drainage System (left) and Digital Elevation Map (right) showing naturalised streams

The catchments are a typical "old" urban catchment with an extensive stormwater pipe drainage network (See Figure 2). The majority of the drainage runs under roads and properties within the catchment. The drainage system of this catchment has been built over with pipes constructed to carry flows for all major storm events.

The catchment is service by formalised kerb and gutter connecting to a sub surface piped stormwater system. Statistics of drainage elements for Kyle Bay catchment (see Figure 3) show the general age and stormwater pipes. Majority of the pipes are less than 600 mm in diameter with average age greater than 50 years.

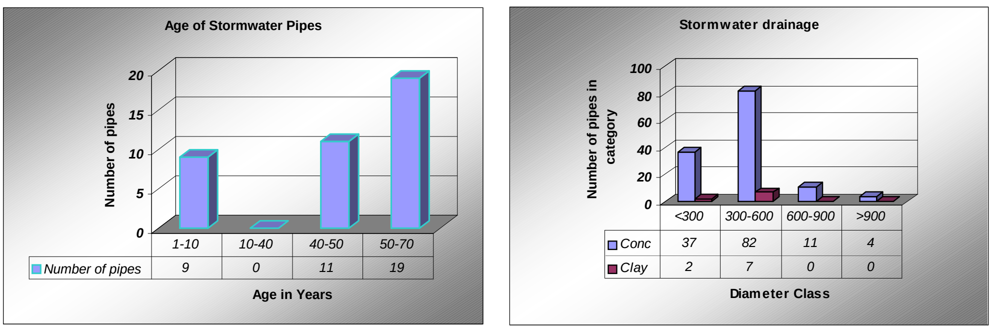

Figure 3 Statistics of Drainage elements for Kyle Bay Catchment

The drainage system was laid in the early 1930s. The overland flow paths generally follow the natural watercourses that were classified as drainage reserves or easements. The digitally synthesised naturalised stream network (Figure 2) provides a good snapshot of the natural drainage in the area and where the major drainage paths follow the terrain. These were the paths that were formal drainage easements to convey the overland flows in the catchment. The flooding generally occurs at sag points on the road when the road drainage capacity is exceeded and overland flows enters properties/or there is restriction or blockage in conveyance of flows on designated overland flow paths.

3 FLOODING HISTORY

The 10th - 11th March 1975 storm was a significant rainfall event throughout the Sydney/Wollongong region with the meteorological conditions documented (Armstrong et. al). This reference indicates that pluviometer at Miranda received 435 mm of rain in the 48 hours to 9:00am on 11th March 1975 (10% greater than at pluviometer at Sans Souci). The rain started at 8:00pm on 9th March 1975 with the peak burst occurring at around 6:00am on 10th March 1975. The rain ceased around 4:00pm on 10th March 1975. Figure 4 shows the rainfall intensity recorded at Sydney Airport that was used in the models.

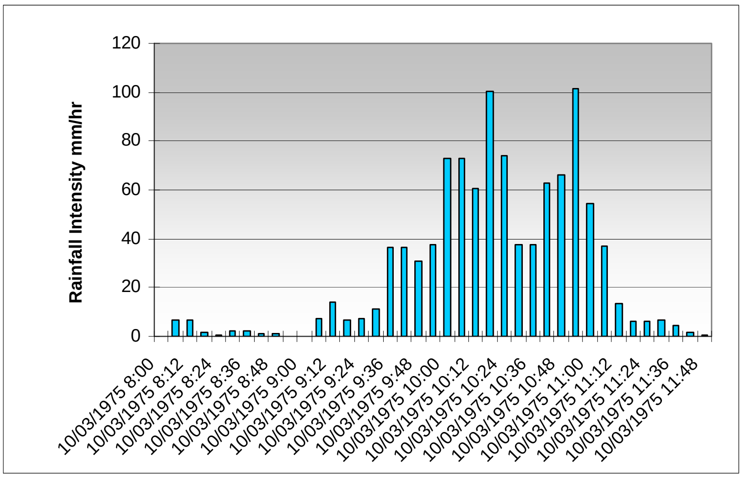

Figure 4 Rainfall distribution for 1975 Storm event

The Average Recurrence Interval (ARI) for this storm event as sourced from varied records is estimated to between 50 and 100 year ARI.

Following the March 1975 flood Council undertook a detailed inspection of all areas of flood damage within their local government area. Over 200 locations were inspected, photographed and compiled into a folder. A large number relate to fences collapsing or scouring which provide insight into the depth of floodwaters. Approximately 28 of the 200 locations are within the Middle Bays catchment (sub-catchments 7,9,10 and 11); however, only 20 related to issues with overland flooding were used for calibration/validation of the hydraulic models. The flooding was mainly due to inadequate road drainage and issues with overland flooding from flows entering the properties from overland flow paths.

4 2D HYDRAULIC MODEL

Modelling was carried in-house using stormwater modelling program XP-Storm developed by XP-Software, Australia (XP-Storm, 2008). XP-Storm is a link-node model that performs hydrology and hydraulics of stormwater drainage systems including automatic pipe design for the entire system or just a portion of the network. The 2D modelling add-on in XP-Storm utilizes the TUFLOW program developed by WBM Oceanics Australia and The University of Queensland (Syme W.J., 2001).

A variety of data were collected, collated and used to develop the 2D model. The main sources of data included Airborne Laser Survey (ALS), Aerial photography, Historic flood records, Rainfall data for historical events, Flood level data for historical events from previous studies, stormwater drainage database, Survey data on overland flow paths and properties, landuse maps for defining 2D imperviousness and Ocean water levels. Model details are not provided due to limitations in length of this paper but brief overview of modelled drainage elements and derivation of roughness parameter for two dimensional model has been discussed. The stormwater elements as modelled are shown in Table 1. The modelled drainage network comprised of 223 stormwater pits and 287 stormwater pipes covering a total length of 65 km.

Table 1 Details of Modelled Drainage Elements

Stormwater Pits

	Grate	Sealed	Kerb Inlet	Sag	Total	Modelled
Connells Bay	17	21	44	14	96	96
Shipwrights Bay	1	22	73	10	106	91
Kyle Bay	6	39	66	7	118	106

Stormwater Drains

	Total	Modelled
Connells Bay	94	94
Shipwrights Bay	104	89
Kyle Bay	110	104

2D roughness parameters were derived using combination of landuse maps, building polygons, roads and fences and other built up areas. Building polygons together with road polygons were used to derive base map of impervious areas in the catchment. The maps were used for historical level of development for calibration/validation and ultimate level of development for design flood events. The ground and non-ground data was used to derive the roughness for the 2D models. The tailwater levels were based on ocean water levels for the recorded 1975 flood event and recommended levels for the design flood events.

5 MODEL RESULTS AND VALIDATION

There is no flow gauging data available in the catchment to verify the historical flood events. However for the historical March 1975 flood event Council recorded flood marks and levels for varied properties affected by overland flooding compiled in a report. The adopted approach for calibration and verification was to simulate flood levels at the worst flooded area in the catchment (i.e. March 1975 storm event). This area is around the intersection of Kyle Parade and Terry Street. The flood levels of around 3 feet (0.9m) were reported in the garage of properties in Kyle Parade (see Figure 5). Overland flooding was also reported at all other properties (the worst flooded are in light red and minor flooding in pink). The calibrated hydraulic 2D model results mimics closely observed flooding in the area with a simulated flood depth of around 1 m.

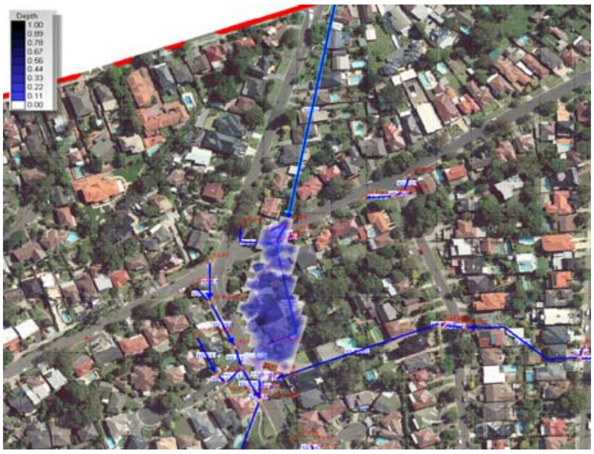

Figure 5 Recorded 1975 Flooding of properties (left) and Simulated 1975 Flood Event (right)

5.1 Description of Overland Flow Paths

Results from 2D hydraulic modelling of Middle Bay catchments indicate the following:

- The incidence of both historical and simulated flooding of properties are generally due to obstruction along the drainage easement. Overland flooding mainly occurs in areas of original watercourses (which have been piped post 1930s) and where drainage easement/reserve were laid out. The flooding occurs as system capacity is exceeded (due to increase flows from development) and overland flows are blocked by buildings/fences along the easement. The flood depths due to blockage can be significant (>0.3 m) in the extreme storm events.
- The blockage of overland flow paths has redistributed the velocities during flood event causing areas or pockets of high hazard.
- The localized flooding of the properties in the catchment are due to low points/internal drainage within the properties or maybe caused by overland flows entering the properties at sag points when road capacity is exceeded. The flood depths are generally less than 0.5 m.
- The drainage of some areas have been upgraded post 1975 storm flooding. In particular, the new drainage along foreshores of Connells point and Kyle Bay had significantly reduced the recurrence of historic flooding in this area of the catchment.

Following describes the overland flow paths in the varied catchments of Middle Bays.

5.1.1 Connells Point (Catchment 11)

There were number of properties that were flooded in the 1975 storm event as shown in Figure 6. The flood depths as recorded in properties ranged from 5 to 33 cm with most of the damage in garage and yard of buildings. The flooding was mostly from stormwater entering the properties at sag point in the road and also from overland flows entering from rear of properties. Summary of the major overland flow paths as indentified from 2D modelling are shown in Table 2.

Table 2 Summary of Overland flow paths for Connells Point (Catchment 11)

11-A	There is a sag pit in front of property at Connells Point road. A drainage easement was in place to convey overland flows from this point to Terry Street. This area has been completely blocked by developments. There are also fences that have blocked the conveyance of overland flows resulting in flooding of property at the location.
11-B	This area is at the lower end of Murdoch Crescent. This is the lowest point of the road and located in a cul-de-sac. The overland flows have restricted conveyance of flows to the bays due to blockage by buildings in front.
11-C	The area shown has a history of overland flooding. This is due to absence of inadequate drainage and restriction of flow conveyance by buildings.
General	The drainage in the area has significantly improved through stormwater upgrade works undertaken in 2006.

The results from 2D model (see Figure 6) validate the overland flooding as recorded for the 1975 flood events. There were three flow paths (11-A, 11-B and 11-C) that followed the natural drainage paths. These have been significantly altered by blockage and developments. The reduced system capacity and altered flow path led to significant flooding of properties as recorded in the 1975 Storm events.

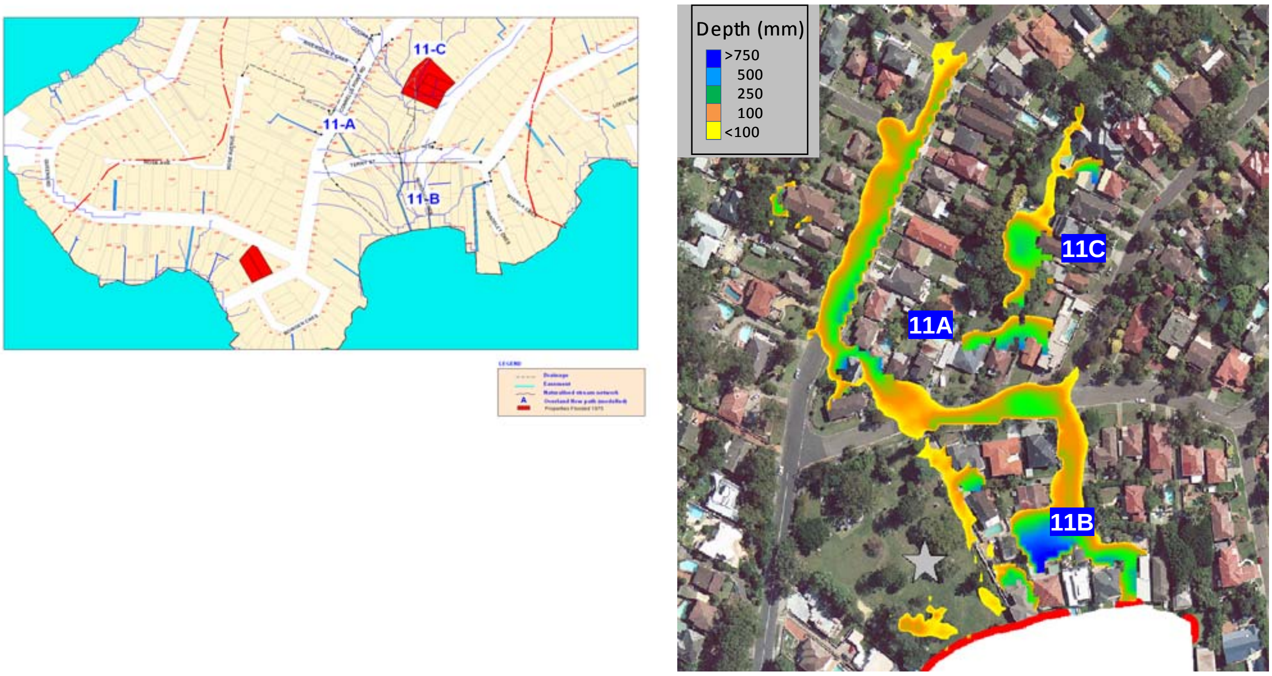

Figure 6 Recorded 1975 flooding of properties (left) and Simulated 1975 Flood event (right)

5.1.2 Connells Point (Catchment 10)

There were around 7 properties that were flooded in the 1975 storm event as shown in Figure 7. The flood depths as recorded in properties ranged from 0.45 – 1.0 m with most of the damage in garage, backyard and ground floor of buildings. The flooding was mostly due to obstruction from blockage of drainage easements. Summary of the major overland flow paths as indentified from 2D modelling are shown in Table 3.

Table 3 Summary of Overland flow paths for Connells Point (Catchment 10)

10-A	The area shown has a history of overland flooding. There is a sag pit in front of property at Terry Street. A drainage easement was in place to convey overland flows from this point to Kyle Parade. This area has been completely blocked by building. Also, the properties along Kyle Parade (140-142) gets flooded due to overland flows entering the properties.
10-B	There is a sag pit in front of property at Boronia street. A drainage easement was in place to convey overland flows from this point to Kyle Parade. This area has been completely blocked by building. The overland flows have restricted conveyance of flows through to the bays due to blockage by buildings.
10-C	There is a sag pit in front of property at Boronia Street. A drainage easement is in place to convey overland flows from this point to Kyle Parade. The easement is a 2 m wide footpath that connect Boronia Street to Kyle Parade.

The results from 2D model (see Figure 7) validate the overland flooding as recorded for the 1975 flood events. There were three flow paths (10-A, 10-B and 10-C) that followed the natural drainage paths. These have been significantly altered by blockage and developments. The reduced system capacity and altered overland flow paths led to significant flooding of properties as recorded in the 1975 Storm events.

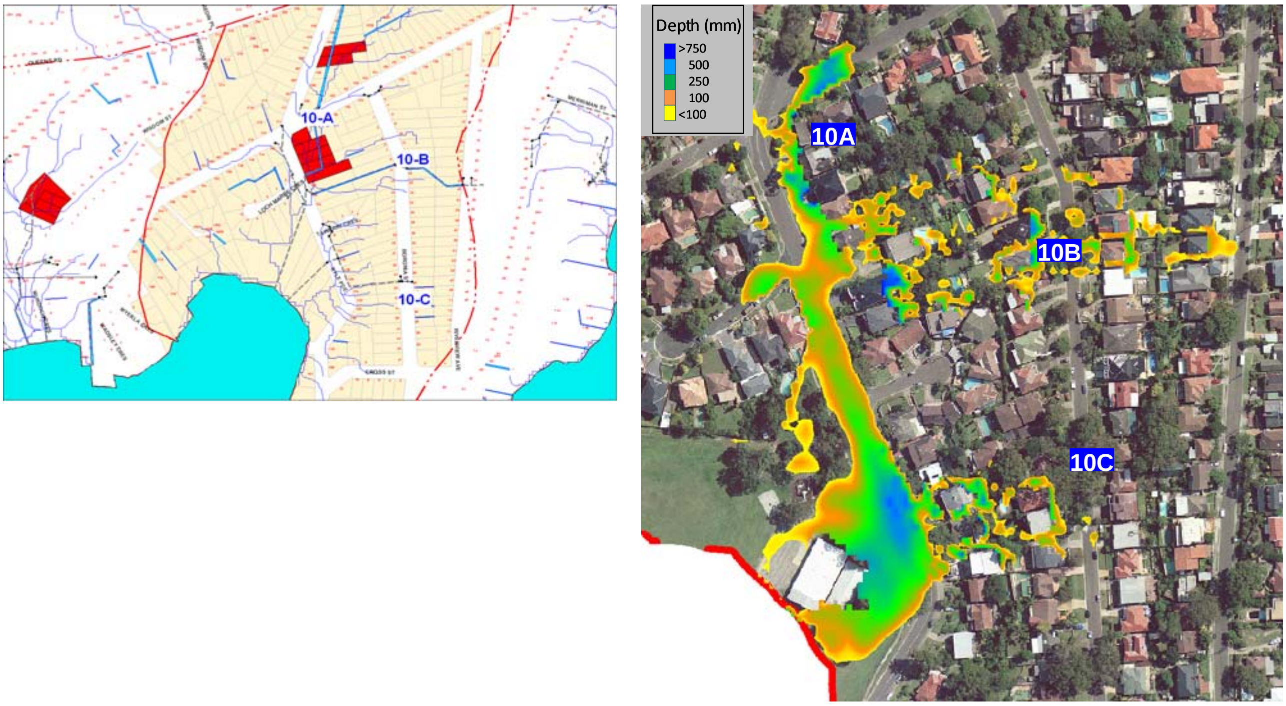

Figure 7 Recorded 1975 flooding of properties (left) and Simulated 1975 Flood event (right)

5.1.3 Kyle Bay (Catchment 9)

There were around 6 properties that were flooded in the 1975 storm event as shown in Figure 8. The flood depths as recorded in properties ranged from 0.38- 0.5 m with most of the damage in garage, lower ground floor and fences of buildings. The flooding was mostly due to obstruction from blockage of drainage easements. Summary of the major overland flow paths as indentified from 2D modelling are shown in Table 4.

Table 4 Summary of Overland flooding and flow paths for Kyle Bay (Catchment 9)

9-A	There is a sag pit in front of property. A drainage easement was in place to convey flows from this point to Kyle Parade. This area has been completely blocked by building. The overland flows have restricted conveyance of flows through to the bays due to blockage by buildings.
9-B	There is a sag pit in front of property. A drainage easement was in place to convey overland flows from this point to Kyle Parade. This area has been completely blocked by building. The overland flows have restricted conveyance of flows through to the bays due to blockage by buildings.
9-C	There is a sag pit in front of property. A drainage easement was in place to convey flows from this point to Kyle Parade. This area has been completely blocked by building.
9-D	There is a sag pit in front of property. A drainage easement was in place to convey flows from this point to Kyle Parade. This area has been completely blocked by buildings.
General	There has been significant improvements in system capacity from Kyle Bay Foreshore Improvement works undertaken in 2007.The area around the Merriman Reserve has been designed as detention basin and reduces the peak flows.

The results from 2D model (see Figure 8) validate the overland flooding as recorded for the 1975 flood events. There are four overland flow paths (9-A, 9-B, 9-C and 9-D) that followed the natural drainage paths. These have been significantly altered by blockage and developments. The reduced system capacity and altered overland flow paths led to significant flooding of properties as recorded in the 1975 Storm events.

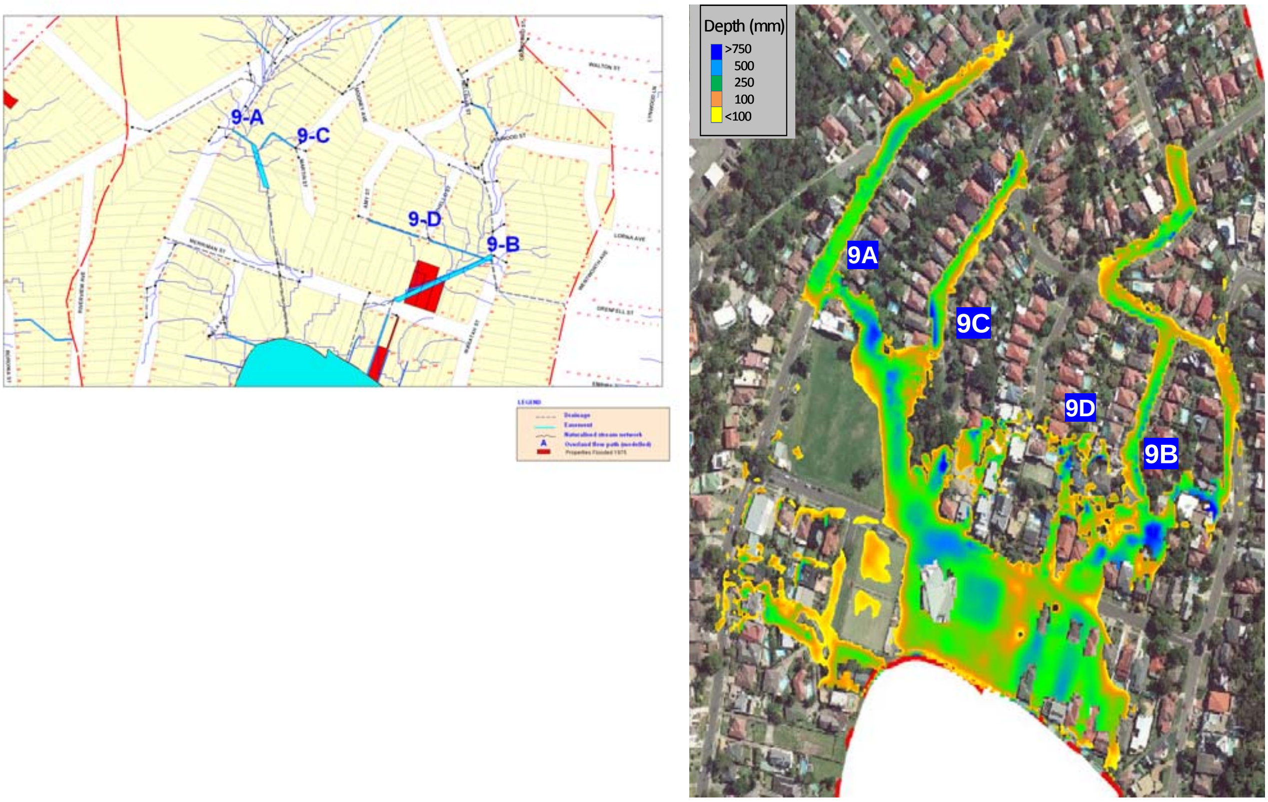

Figure 8 Recorded 1975 flooding of properties (left) and Simulated 1975 Flood event (right)

5.1.4 Shipwrights Bay (Catchment 9)

There were around 10 properties that were flooded in the 1975 storm event as shown in Figure 9. The flood depths as recorded in properties ranged from 0.1- 0.5 m with most of the damage in garage, ground floor, and yards of buildings. The flooding was mostly due to inadequate stormwater drainage and surcharging of sag pits on the roads with resultant overland flows entering the properties below the street level. Summary of the major overland flow paths as indentified from 2D modelling are shown in Table 5. The results from 2D model (see Figure 9) validate the overland flooding as recorded for the 1975 flood events. There are three sag points (7-A, 7-B and 7-C) on road, the houses were built on the natural drainage paths on the premise that underground piped drainage was adequate to convey the stormwater. The reduced system capacity and altered overland flow paths led to significant flooding of properties as recorded in the 1975 Storm events.

Table 5 Summary of Overland flooding and flow paths for Shipwrights Bay (Catchment 7)

7-A	There is a sag pit in front of property at East Street. A drainage easement was in place to convey overland flows from this point to Kyle Parade. This area has been completely blocked by building. The overland flows have restricted conveyance of flows through to the bays due to blockage by buildings.
7-B	There is a sag pit in front of property at Church street. A drainage easement was in place to convey flows from this point to Raleigh Street. This area has been completely blocked by building. The overland flows have restricted conveyance of flows through to the bays due to blockage by buildings.
7-C	There is a sag pit in front of property at Castle street. The overland flows will build up at this location and will then be conveyed to the reserve area and through to Shipwrights bay.
General	The shipwrights bay wetland constructed in 2006, acts as detention basin for lower ARI events and reduces the peak overland flows in lower part of the catchment.

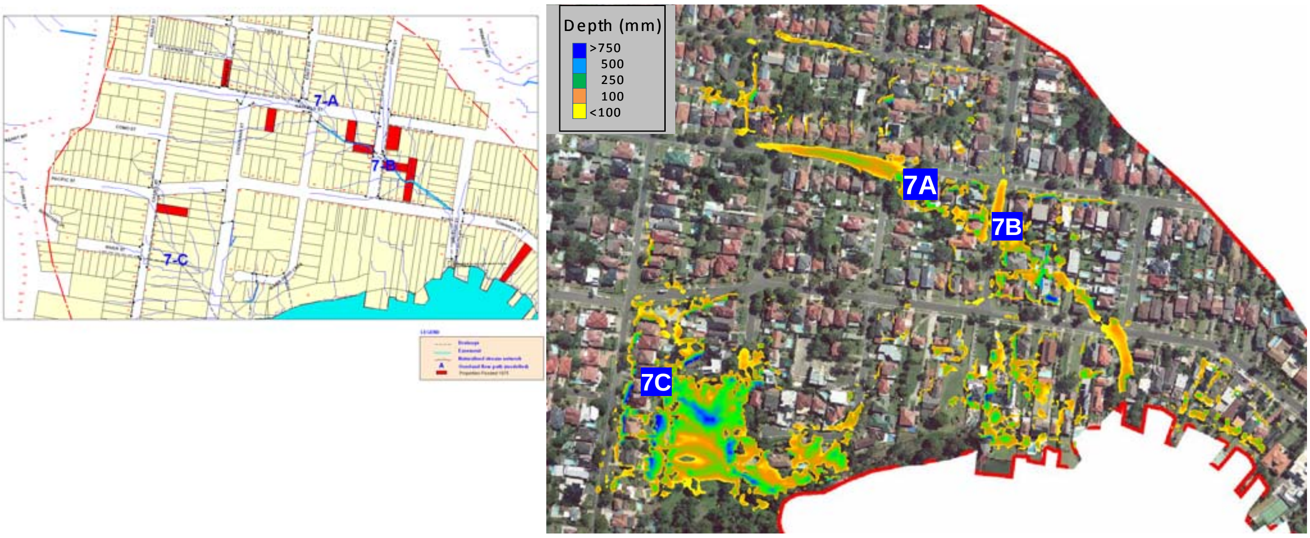

Figure 9 Recorded 1975 flooding of properties (left) and Simulated 1975 Flood event (right)

6 CONCLUSIONS

The results from XP-Storm 2D hydraulic modelling undertaken for Middle Bay Catchments gave insights into complexities in overland flood behaviour, that was validated by historical flooding from blockage and buildings on the drainage flow paths in 1975 storm event. The study also indicated that urbanisation had significant impacts in altering the overland flow distribution within the catchment. The impacts of urbanisation, buildings and blockage of drainage reserves and overland flow paths, have led to complexities in flood behaviour within the catchment. With the reduction in system capacity over the years, re-distribution of overland flows has resulted in significant localised flooding issues within the catchment.

The XP_Storm-2D models developed for Middle Bay Catchments provided a good tool to understand the flood behaviour and identify areas of high hazard for flood risk management and develop solutions for future stormwater drainage improvement works.

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