APPENDIX A

FLOOD PHOTOGRAPHS

APPENDIX A1

SELECTION OF COUNCIL
'FLOOD MARK' PHOTOGRAPHS
FOR NOVEMBER 1984 FLOOD
AT FULLERS BRIDGE AND ALONG SHRIMPTONS CREEK

Photo A1.1: Fullers Bridge across Lane Cove River, looking east, showing debris deposited on bridge columns.

(Ryde City Council photo 'L1')

Photo A1.2: Debris lines in Alma Road, looking upstream and towards Talavera Road and Macquarie Shopping Centre.

(Ryde City Council photo 'S6')

Photo A1.3: Debris caught on fence at Macquarie Shopping Centre's frontage to Talavera Road.

(Ryde City Council photo 'S5')

Photo A1.4: Floodwaters passing through Macquarie Shopping Centre's car park area (looking from near Waterloo Road)

Photo A1.5: Debris line in Waterloo Road property immediately south of Shrimptons Creek.
(Property has since been re-developed).

(Ryde City Council photo 'S14')

Photo A1.6: Debris line on southern bank of Shrimptons Creek just upstream of Epping Road bridge.

(Ryde City Council photo 'S16')

Photo A1.7: Debris deposited at Kent Road culvert crossing, looking downstream.

(Ryde City Council photo ‘S23’)

Photo A1.8: Debris deposited at Kent Road culvert crossing, looking downstream.

(Ryde City Council photo ‘S24’)

Photo A1.9 Photo taken of footbridge with Lucinda Road in background

(Ryde City Council photo 'S26')

Photo A1.10: Debris deposited at property on corner of Herring Road and Lucinda Road, looking east along Herring Road.

(Ryde City Council photo 'S29')

Photo A1.11: Debris deposited against Bridge Road property fence, on south bank of Shrimptons Creek. (Property has since been purchased and house, etc demolished).

(Ryde City Council photo 'S32')

Photo A1.12: Photo taken of Bridge Road bridge, looking downstream from Santa Rosa Park.

(Ryde City Council photo 'S32').

APPENDIX A2

PHOTOGRAPHS IN THE VICINITY OF FORD STREET, NORTH RYDE FOR NOVEMBER 1984 FLOOD (SHRIMPTONS CREEK CATCHMENT)

Photo A2.1: Looking at North Ryde Golf Course from Lane Cove Road.

(Photo provided by J. Murrey, used by permission)

Photo A2.2: Looking east at Lane Cove Road, near the intersection with Ford Street

(Photo provided by J. Murrey, used by permission)

Photo A2.3: Looking south up Ford Street towards Lane Cove Road

(Photo provided by J. Murrey, used by permission)

Photo A2.4: Looking south up Ford Street towards Lane Cove Road

(Photo provided by J. Murrey, used by permission)

Photo A2.5: Looking north down Eastview Avenue from the intersection with Ford Street

(Photo provided by J. Murrey, used by permission)

APPENDIX B

RESPONSES FROM PUBLIC EXHIBITION OF HISTORIC FLOOD MAPS

City of Ryde | SES State Emergency Service | Department of Environment & Climate Change NSW | Bewsher

MACQUARIE PARK FLOODPLAIN RISK MANAGEMENT STUDY & PLAN

FLOOD MODEL FEEDBACK FORM

NOVEMBER 1984 FLOOD

1) Do you have information about the 1984 flood in the Macquarie Park catchment?

☐ Yes ☐ No (If "no", go to Q7)

2) What are your observations based on?

☐ I saw the flood myself
☐ I did not see the flood but I saw the effects afterwards
☐ Others told me about the flood

3) What location or locations do your comments relate to? (Please be as specific as possible)

4) Have you seen the map of the "Simulation of the November 1984 Flood" produced by the computer model?

☐ Yes ☐ No

5) How well does the model's representation of the flood match with your experience? (Please refer to the extent and depth of flooding).

6) What is your overall assessment of the accuracy of the model's representation of the 1984 flood?

☐ Accurate match ☐ Reasonable match
☐ Poor match ☐ Don't know

FEBRUARY 1990 FLOOD

7) Do you have information about the 1990 flood in the Macquarie Park catchment?

☐ Yes ☐ No (If "no", go to Q13)

8) What are your observations based on?

☐ I saw the flood myself
☐ I did not see the flood but I saw the effects afterwards
☐ Others told me about the flood

9) What location or locations do your comments relate to? (Please be as specific as possible)

10) Have you seen the map of the "Simulation of the February 1990 Flood" produced by the computer model?

☐ Yes ☐ No

11) How well does the model's representation of the flood match with your experience? (Please refer to the extent and depth of flooding).

12) What is your overall assessment of the accuracy of the model's representation of the 1990 flood?

☐ Accurate match ☐ Reasonable match
☐ Poor match ☐ Don't know

13) Please record any other comments you would like to make (and continue on back if required)

14) Your contact details (optional)

Name:
Address:
Telephone: Email:

Please complete this form and leave it in the box provided, or post your reply (no stamp required) to:

Bewsher Consulting
Reply Paid 352
EPPING NSW 1710

Thank you for your assistance!

Surv. No.	**1984 FLOOD COMMENTS**							**1990 FLOOD COMMENTS**							Additional feedback?
	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	
I1	Yes	Saw flood	23 Napier Crescent	Yes	Completely wrong: water did not cover his side of	Poor	Conflicting information at Napier/David. One report	Yes	Saw flood	Napier Crescent	Yes	Does not reflect true position	Poor		The mapping does not truly reflect water in the dip in
I2	Yes	Saw flood	70 David Avenue NORTH RYDE	Yes	Matches the extent and depth.	Accurate	Conflicting information at Napier/David. One report says good match, one says too extensive, one says generally good but too deep at one location (likely topography change since 1984).	No							No floods since 1984. That flood caused by rubber trees' roots growing into the water channels that go through backyards.
I3	Yes	Saw flood	Near 64 David Avenue	Yes	Nothing above 100mm on 64 David Street. About 300mm flooding in 6 Paul Street, where ground level is below road level (but houses rebuilt now). Not in house at 6 Paul Street. Shops at corner David/Holt not flooded. Low point in David near Holt flooded to at least 0.5m and one house flooded there.	Poor	Conflicting information at Napier/David. One report says good match, one says too extensive, one says generally good but too deep at one location (likely topography change since 1984).	No							Attributes flooding to blockage of Council drains by an accumulation of local newspapers. Concerned that a non-repeatable event (since practices have improved) will be used as a basis for flood risk mapping.
I4	No						N/a								
L1	No						N/a	Yes	Saw flood	National Park		National Park too high. The flood around the weir in the NP extended along Little Blue Gum Creek beyond the Naamaroo Entrance. Sections along a number of the picnic areas show the water going up too far. The picnic areas at the end of Max Allen Drive were not completely inundated as your model indicates - came only half way up those picnic areas except for the low lying section (then known as area no 32) of the road near the first picnic area after the admin office. Fullers Bridge and Delhi Road and Millwood Ave remained open. The section near Fiddens Wharf Rd does not accurately represent where the water reached. There are two plaques fixed to the piers of the house at 15(?) River Ave Chatswood with the actual depths that the river reached on them.	Reasonable	Little Blue Gum Creek is outside of study area and therefore not included in flood model or mapping. Fullers Bridge is not overtopped in model. Satisfactory fit obtained at Fullers Bridge and along River Avenue.	
L2	Yes	Saw effects	River Avenue and parkland directly in front of 112-120 River Avenue	Yes	Good, estimate flood depth of approx. 0.5m in front of 114 River Ave.	Reasonable		No			Yes	Cannot recall 1990 flood.	Don't know		May 1988 would probably have equalled Nov 1984 had tide reached its predicted height.
L3	Yes	Heard	11 River Avenue CHATSWOOD WEST	Yes		Accurate		No							The property at 11 River Avenue has two plaques that represent flood levels in 1984 and 1986.
M1	Yes	Saw flood	211-213 Waterloo Road	Yes	Doesn't show the flooding in that area. During 1984, courtyard & carpark & garages flooded 400mm depth. Duration of flooding about 1 hour. All 48 garages flooded up to 400mm.	Don't know	Location outside study area.	No							

Surv. No.	1984 FLOOD COMMENTS							1990 FLOOD COMMENTS							Additional feedback?
	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	
M2	Yes	Saw flood	Libya Place MARSFIELD	Yes	Accurate. Libya Place flooded in 1984, with floating wheelie bins in the cul-de-sac.	Accurate									Flooding in August 2003 and about 2005.
M3	Yes	Saw flood	Taranto Road	Yes	The lowest part of Taranto Road was flooded, cars could not pass.	Accurate									
N/a							N/a								
P1	Yes	Heard	Corner of Cam St/Avon Rd NORTH RYDE	Yes	Good match. Water came down Cam Street up to footpath of 4 Avon.	Accurate		No							
P2	No						N/a	No							No flooding since arrived in Dec 2001
P3	Yes	Saw flood	11 Rowell Street NORTH RYDE	Yes	Completely incorrect: Rowell Street was flooded, water came through my back fence almost a metre high washed out passing gates, water was over 60cm high in my backyard and the street was the same.	Poor	Based on reported flood behaviour and depths, model appears to be a reasonable match with resident's observations - depths of 0.4-0.6m are described in backyard and street.	No							
P4							N/a								Only floods in our street were over 40 years ago and the main reason was the lack of drainage outlets on the way down the streets from Cox's and Blenheim Rds.
P5	No		27 Morshead Street NORTH RYDE				N/a								27 Morshead Street flooded in past according to elderly resident
S01	Yes	Saw flood	14 Herring Road MARSFIELD and surrounds	Yes	Good match showing flooding between Agincourt and Lucinda on Herring Road (and almost came up to his fence); poor match around his house (although he said water almost came up to door, he attributes this somehow to a fence on the Gasworks site).	Poor	Model is showing inundation adjacent to house (as observed by resident) however it is noted that historical topography different to today. In 1984, open channel, but today, covered box culvert.	No							A large truck tyre was stuck at the 1.8x0.9m pipe culvert entrance in 1984. Need to assess whether the 2x1m culvert feeding into the smaller culvert under Herring Road is suitable.
S02	Yes	Saw effects	1-3 Lucinda Road on corner Herring Road	Yes	Picture of our then property is accurate but taken after water of around a foot [ie 300mm] subsided.		Resident's recollection of depth is unclear. Map of No. 3 shows depth in property varying between 100 and 1000mm.	No							Found it difficult to read the map, what looked like an areal view
S03	Yes	Saw flood	6 Lyle Street RYDE	Yes	Good match. The deepest water was at the back fence - 2 feet [ie 600mm].	Accurate		No							

Surv. No.	1984 FLOOD COMMENTS							1990 FLOOD COMMENTS							Additional feedback?
	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	Consultant evaluation	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	Consultant evaluation	
S04	Yes	Saw flood	27 Ellen Street RYDE	Yes	Yard has never been flooded. There was flooding on Ronald Street as shown.	Reasonable	Based on information, accurate match. Resident concerned about possible flood notification.	No							
S05	No						1984 TUFLOW model shows inundation regime similar to resident's 'general' comment.	No							Flooding at rear of 16 Lyle Street with water from Brian Street - almost in house on two occasions - once 18 months ago(?)
S06	No						N/a	Yes	Saw flood	Cecil Street	Yes	Flooding on back of our lot not shown on model.	Reasonable	It appears that resident is referring to just very localised property overland flow.	Flooding also in direction between Birdwood and Cecil Streets.
S07	Yes	Saw flood	111 North Road RYDE		Water entered car in garage requiring repairs esp. with water in oil.		Consistent with model.	Yes	Saw flood	111 North Road RYDE		Fence between house and garage and the back fence (neighbour in Quarry Road) damaged.		Model shows property is lying within overland flow path.	Council put a drain in back of property after 1990 flood. Concerned about drain level.
S08	Yes	Saw flood	30 Fawcett Street RYDE	Yes	0.7m outside garage, backyard flooded. Water came from 28 Fawcett Street (under fence) and from 241 Quarry Road. Deeper than what is shown. 38 & 40 Fawcett were badly affected esp. 38.	Reasonable	Model predicting about 400mm deep at garage (ie less than reported by resident). Model shows Nos. 38 and 40 were badly affected.	Yes	Saw flood	30 Fawcett Street RYDE	Yes	Not as deep as 1984, son flooded to knees.		Model shows less water depth in 1990 compared with 1984 event.	Looking for photos.
S09	Yes	Saw flood	35 Christine Avenue RYDE	Yes	There was shallow flooding across whole western side of park at rear. Water came up to back of garage (which hasn't moved).	Reasonable	Model possibly under-representing flood depth.	No							Only event of such a magnitude in her experience.
S10	Yes	Saw flood	49 Fawcett Street RYDE	Yes	At 5 am was flowing across Fawcett St from gutter to gutter and running down Warren through front yard. Went over 1m high wall between his house and 20 Warren St. Pooled around house but not in back of house or inside garage or house (4 steps up). Possibly more water in Fawcett than is shown.	Reasonable	Model appears to be generally consistent with resident's observations.	No							Contact Bill Lalor in Warren Street for historical flood photos.
S11	Yes	Saw flood	34 Zola Avenue RYDE	Yes	Dog kennel floated in 1 ft of water; garage and house not affected.	Reasonable		No							Contractors removed too many trees when clearing Shrimptons Creek floodplain 18 months ago. No. 62 Bridge Road often flooded but recently built a brick wall that acts as levee.

Surv. No.	**1984 FLOOD COMMENTS**							**1990 FLOOD COMMENTS**							Additional feedback?
	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	
S12	Yes	Heard	Cook Street and Ford Street @ the cul-de-sac next to Shrimptons Creek	Yes	Reasonably accurate - although it is hard to interpret from an aerial view to what we know of the flood.	Reasonable		Yes	Saw flood	Cook Street and Ford Street @ the cul-de-sac next to Shrimptons Creek; also Flinders Park	Yes	Could not tell if there was any difference - maybe the water rise was not as high as the 1984 flood.	Reasonable	Noted.	As the water level in Shrimpton's Creek rose our drains backed up causing flooding into our property. The common drain that runs thru the back of the properties on our side of Cook St had enough water pressure to lift the concrete inspection slab off the inspection pit in 36 Cook Street. Water then sheeted across from there into our property, flooding my backyard and entered my shed.
S13	Yes	Saw flood	In the vicinity of Lucinda Road footbridge over Shrimptons Creek	Yes	2.1m from the creek bed is fair, however, I got only 1m on my block.	Reasonable	Model is generally consistent with resident's observations.	Yes	Saw flood		Yes	Only about 10cm on my block	Don't know		
S14	Yes	Saw flood	Shrimptons Creek - Tindara Reserve - Kent Road and Ford Street	Yes	Depth on Kent Road was as high as middle grill of my car. Several cars didn't make it. In Tindari Reserve, flooding only 1m at its very worst.	Reasonable	Model is consistent with resident's obseravtions.	Yes	Saw flood		Yes	Depth no more than 1 metre	Reasonable	Model shows shallower depths than in 1984 event.	The severity of the 1990 flood was made worse by overgrown and choked creek bed and banks. Flood frequency increasing due to degradation of creek with noxious weeds e.g. elephant ears.
S15			Junction Twin and Goulding Roads, near North Ryde Golf Course	Yes	Did not see any flooding in 1984.						Yes	Did not see any flooding in 1990.			
S16	Yes	Saw flood	Lane Cove Road and Ford Street	Yes	Ford Street was a lake. I saw a Mini Minor floating along on the water. Depth of water was at least 8 inches.	Don't know		Yes	Saw flood	North Ryde	Yes	A lot of this water caused by runoff from golf links.	Don't know		
S17	Yes	Saw flood	Ford Street and Eastview Avenue	No	Photos provided.		Photos of Lane Cove Road, Ford Street, Eastview Ave show good match with model.	No							
S18	No				Water could not pool to a depth of 0.2-0.4m on Epping Road between Herring Road and Shrimptons Creek. Water could not pool on Parklands Road west of Whiteside Street to a depth of 0.1-0.2m with patches 0.2-0.4m.		It is noted that the resident did not see the flood. Both Epping Road and Parklands Road are acting as de facto flow paths and these are reflected in the model.	No							
S19	No														

Surv. No.	**1984 FLOOD COMMENTS**							**1990 FLOOD COMMENTS**							Additional feedback?
	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	Information?	Basis?	Location	Viewed display?	Evaluation	Overall assessment	**Consultant evaluation**	
S20	Yes		9 Peachtree Road MACQUARIE PARK	Yes	Water came up to SE boundary fence and extended 15m from NE corner boundary towards SW. Water did not come onto the site. No garage inundation in 1984.		For the Shrimptons Creek flood regime, the flood model achieves a similar flood extent picture to that reported. Model prediction of 'garage inundation' is related to present day local area topography differing from historic flood scenario. On-site discussions were subsequently held with resident and design flood model has been adjusted based on additional data.	Yes		9 Peachtree Road MACQUARIE PARK		No flooding of site.		For the Shrimptons Creek flood regime, the flood model shows the site is not inundated. Model prediction of some site inundation from local runoff is related to present day local area topography differing from historic flood scenario.	Attributes magnitude of 1984 flood to blockage of Shrimptons Creek with tree limbs and other debris. Land not at risk if Council properly cares for and maintains the creek. Calculations to determine 1 in 100 year line should assume free flow of water in the now channelised Shrimptons Creek.
S21	No		175 Herring Road MACQUARIE PARK												Water rushes from steep driveway into garages and foyer.
S22	Yes	Saw flood	17 Cottonwood Crescent MACQUARIE PARK	Yes	Doesn't recall flooding on the street or on NW side (high side) of street. Expect SE (creek) side of road might be affected since lower there. Recalls spill across Waterloo Road at least knee-high - a car was washed through Macquarie Centre. Possibly slightly more across oval u/s [Wilga Park] than what is shown was affected.	Accurate	Model may be over-representing flood depth in Cottonwood Crescent. Wilga Park is shown in model results as shallow flooding (but displayed map does not include flood depths of less than 0.1 metres).	No							
S23	Yes	Saw flood	Macquarie Centre	Yes	Macquarie Centre was flooded to the loading area of the loading docks.	Accurate									
S24	Yes	Heard	13,15,17 Willow Crescent RYDE	Yes	No ponding at any of these properties.		Model shows very shallow inundation in properties. It is noted respondent did not see flood.	Yes	Heard	13,15,17 Willow Crescent RYDE	Yes	No ponding at any of these properties.		Model shows very shallow inundation in properties. It is noted respondent did not see flood.	Not sure about lowpoint in Willow Crescent. Expect to hear from 14 Willow. Survey of No. 15 Willow attached.

APPENDIX C

DESCRIPTION OF TUFLOW MODEL SOFTWARE

C1 BACKGROUND

C1.1 Introduction to Floodplain Modelling

Floodplains are hosts to industrial sites, urban and rural communities, and environmentally sensitive areas. During periods of flooding, most damage and disruption will occur on the floodplains – not in the creeks and rivers. Therefore, correctly modelling floodplains and their interaction with rivers is very important.

Different modelling methods can be applied according to the floodplain's hydraulic characteristics and the study objectives and resources. The simpler methods lump the left and right bank floodplains with the river in a one-dimensional (1D) representation. This computation approach is fast, however, there are limitations such as the floodplain flood level being always assumed to be the same level as the river level.

Alternatively, there is the more detailed approach of modelling the river and adjacent floodplains as separate flow paths. This method increases model complexity, development and running time, and requires greater human and computer resource. The currently most advanced, yet still economical, method to undertake floodplain modelling is using two-dimensional (2D) discretisation.

A detailed 2D approach is recommended in areas where significant differences between river and floodplain flood levels and separate flow paths occur, especially if these differences result from a management option. Therefore a 2D detailed approach is particularly relevant for the Macquarie Park Catchment, which incorporates many overland flowpaths and floodplain flows.

C1.2 Macquarie Park Model Configuration

The modelling software TUFLOW was used to set up a hydrodynamic, dynamically linked 2D/1D hydraulic model of the catchment. The model is a mixture of 1D and 2D domains with the 2D domain covering the whole catchment for predicting floodplain and overland flowpath flow behaviour in floods. The 1D domain is suited for pipe flow modelling where the flow is unidirectional. Dynamic links exist between the 2D domain and the 1D domain at the location of the stormwater drainage pits and between the 2D domain and the 1D open channel sections of the lower reaches of each watercourse.

C2 TUFLOW

C2.1 Overview

TUFLOW solves the full 2D shallow water equations based on the scheme developed by Stelling (1984). The solution is based around the well-known ADI (alternating direction implicit) finite difference method. A square grid is used to define the discretisation of the computational domain. TUFLOW also has the ability to be dynamically linked to 1D models and have 1D models dynamically nested inside or through the 2D domain.

Improvements to the Stelling 1984 scheme, including a robust wetting and drying algorithm and greater stability at oblique boundaries, and the ability to dynamically link a quasi-2D model were developed by Syme (1991). Further improvements including the insertion of 1D elements (channel, pipe, weir) inside a 2D model and the modelling of constrictions on flow such as bridges and large culverts, and automatic switching into and out of upstream controlled weir flow have been developed subsequently (WBM, 2000).

Hydraulic structure flows through large culverts and bridges are modelled in 2D and include the effects of bridge decks and submerged culvert flow. Flow over roads, levees, bunds, etc is modelled using the broad-crested weir formula when the flow is upstream controlled. For smaller hydraulic structures such as pipes or for weir flow over a bridge, 1D models can be inserted at any points inside the 2D model area.

C2.2 Floodplain Modelling Equations

The shallow water equations are the equations of fluid motion used for modelling long waves such as floods, ocean tides and storm surges. They are derived using the hypotheses of vertically uniform horizontal velocity and negligible vertical acceleration (i.e. a hydrostatic pressure distribution). These assumptions are valid where the wave length is much greater than the depth of water.

The 2D shallow water equations in the horizontal plane are described by the following partial differential equations of mass continuity (Equation B.1) and momentum conservation in the X and Y directions (Equations B.2a and b) for an in-plan cartesian coordinate frame of reference.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (Hu)}{\partial x} + \frac{\partial (Hv)}{\partial y} = 0 \qquad \mathbf{(B.1)}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - c_f v + g\frac{\partial \zeta}{\partial x} + g u\frac{\sqrt{u^2+v^2}}{C^2 H} - \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = F_x \qquad \mathbf{(B.2a)}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + c_f u + g\frac{\partial \zeta}{\partial y} + g v\frac{\sqrt{u^2+v^2}}{C^2 H} - \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = F_y \qquad \mathbf{(B.2b)}$$

$where$

$\zeta = Water\ surface\ elevation$

$u\ and\ v = Depth\ averaged\ velocity\ components\ in\ X\ and\ Y\ directions$

$H = Depth\ of\ water$

$t = Time$

$x\ and\ y = Distance\ in\ X\ and\ Y\ directions$

$c_f = Coriolis\ force\ coefficient$

$C = ChÇzy\ coefficient$

$\mu = Horizontal\ diffusion\ of\ momentum\ coefficient$

$F_x\ and\ F_y = Sum\ of\ components\ of\ external\ forces\ in\ X\ and\ Y\ directions$

The terms of the equations can be attributed to different physical phenomena. These are propagation of the wave due to gravitational forces, the transport of momentum by advection, the horizontal diffusion of momentum, and external forces such as bed friction, rotation of the earth, wind, wave radiation stresses, and barometric pressure.

The 2D shallow water equation scheme adopted incorporates all of the above physical processes. External forces such as wind, wave radiation stresses, and barometric pressure are incorporated into the code but are not used in this study.

For further information on the 2D solutions, refer to Syme 1991.

C2.3 Open Channel Flow 1D Modelling Equations

TUFLOW uses an explicit finite difference, second-order, Runge-Kutta solution technique (Morrison and Smith, 1978) for the 1D equations of continuity and momentum as given by Equations B3 and B.4. The equations contain the essential terms for modelling periodic long waves in open channels, that is: wave propagation; advection of momentum (inertia terms) and bed friction (Manning's equation).

$$\frac{\partial (uA)}{\partial x} + B\frac{\partial \zeta}{\partial t} = 0 \qquad \textbf{(B.3)}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} + k\,|\,u\,|\,u = 0 \qquad \textbf{(B.4)}$$

$where$

$u = depth\ and\ width\ averaged\ velocity$

$\zeta = water\ level$

$t = time$

$x = distance$

$A = cross\ sectional\ area$

$B = width\ of\ \ flow$

$k = energy\ loss\ coefficient = \frac{gn^2}{R^{4/3}}$

$n = M'annings\ n$

$R = Hydraulic\ Radius$

$g = acceleration\ due\ to\ gravity$

The spatial discretisation of an area of interest is carried out as a network of interconnected nodes and channels. The nodes represent the storage characteristics of the open channel, while the channels model the hydraulic conveyance characteristics.

The continuity equation is solved at the nodes, while the momentum equation is solved for the channels. The output consists of water levels at the nodes, and flows, velocities and integral flows (flow integrated over time) at the channels.

For further information on the 1D solutions, refer to Syme 1991.

C2.4 Pipe Flow Modelling Equations

In pipe flows, the area of flow is fixed, and for a known flow in a given size of conduit the velocity can be calculated directly. The energy equation for the total flow in a pipe can be expressed as:

$$\frac{V_1^2}{2g} + h_1 + z_1 = \frac{V_2^2}{2g} + h_2 + z_2 + \Delta H$$

where ΔH is the energy loss in the pipeline between the two sections 1 and 2. The energy lost through turbulence is caused by two mechanisms:

- The drag of the pipe walls on the flow. This mechanism is known as the ‘friction’ loss; and
- Turbulence generated wherever there is a change to the direction and/or magnitude of flow. This mechanism is known as the ‘form’ loss.

The friction losses are continuous over the length of a pipeline; the form losses are localised in the immediate vicinity of the element causing the energy loss.

The loss of energy due to hydraulic resistance of a pipe is a function of the velocity of the flow, *V*, the internal pipe diameter, *D*, the length of the pipe, *L*, and the roughness of the pipe internal surface. There are several empirical formulae for the calculation of friction losses in pipes that have been derived through research. The Manning's equation is appropriate for use when the flow is in the fully-turbulent range, which is the case in rough conduits and at high flows in stormwater mains.

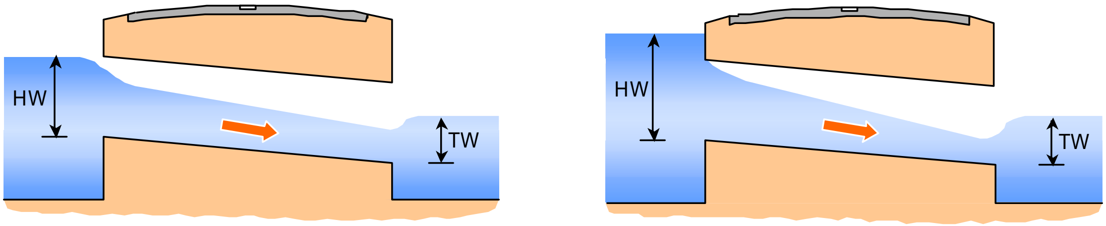
TUFLOW uses the Manning's equation to model pipe flows. For circular pipe, the equation can be written as follow:

$$V = \frac{0.397 D^{2/3} \sqrt{S_f}}{n}$$

where S_f is the hydraulic gradient and *n* is the roughness parameter. Although *n* is a function of the conduit size, it is relatively insensitive to the pipe diameter and is assumed constant in the TUFLOW calculations.

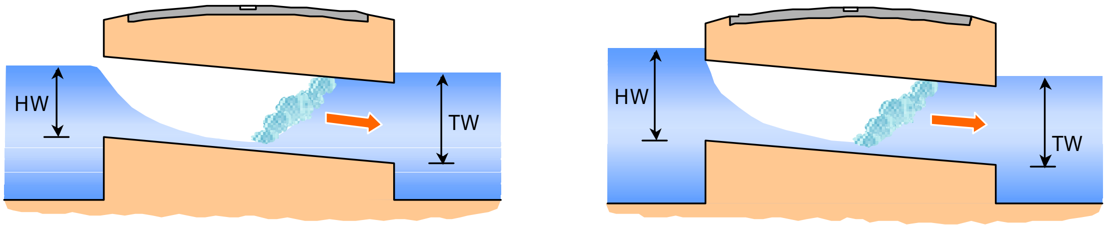
When the pipes are not flowing full, ten flow regimes are possible within the TUFLOW software as illustrated in Figure C1 and Figure C2. Upstream water levels are calculated from the 1D equations and/or standard culvert discharge relationships.

INLET CONTROL FLOW REGIMES



A: Unsubmerged Entrance,
Supercritical Slope

B: Submerged Entrance,
Supercritical Slope

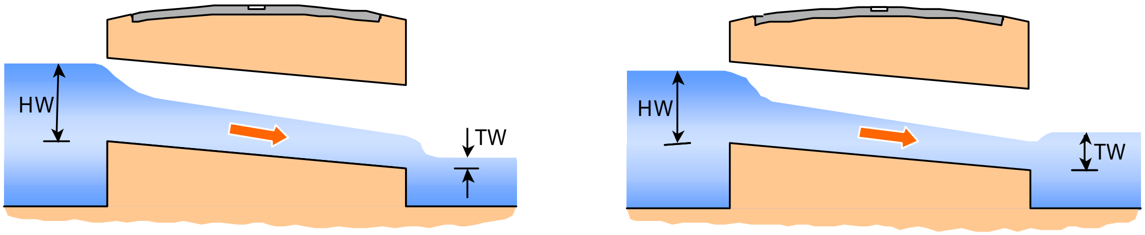


K: Unsubmerged Entrance,
Submerged Exit
Critical at Entrance

L: Submerged Entrance,
Submerged Exit
Orifice Flow at Entrance

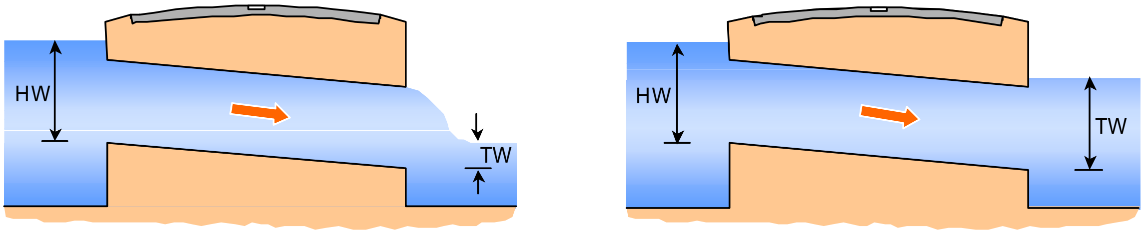
Figure C1 1D Inlet Control Culvert Flow Regimes in TUFLOW

OUTLET CONTROL FLOW REGIMES



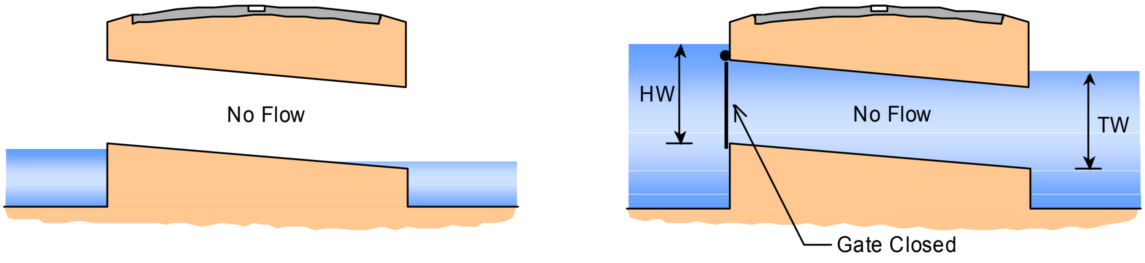
**C: Unsubmerged Entrance,
Critical Exit**

**D: Unsubmerged Entrance,
Subcritical Exit**

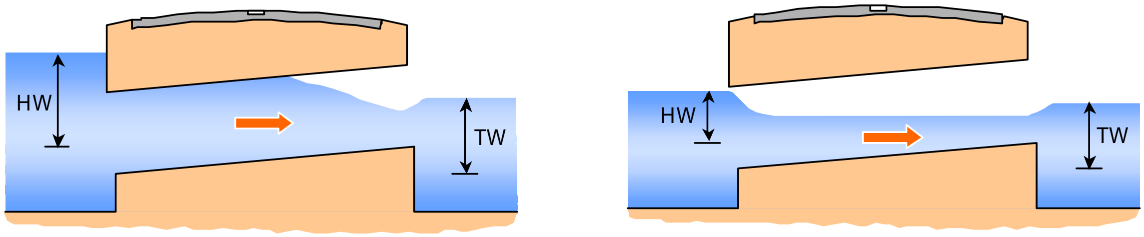


**E: Submerged Entrance,
Unsubmerged Exit**

**F: Submerged Entrance,
Submerged Exit**



**G: No Flow
Dry or Flap-Gate Closed**



**H: Adverse Slope,
Submerged Entrance**

**J: Adverse Slope,
Unsubmerged Entrance
(Critical or Subcritical at Exit)**

Figure C2 1D Outlet Control Culvert Flow Regimes in TUFLOW

C2.5 Stormwater Drainage Network Modelling

The coupling between the floodplain modelling and the pipe flow modelling occurs at the location of the stormwater drainage network pits (see Figure C3). The computation calculates a flow rate between the 2D floodplain cell and the 1D pipe based on:

- Overland water level in the floodplain;
- Energy level in the pipe at the location of the pit; and
- Lintel opening dimensions.

The modelling link representing the pit acts essentially as a zero-length culvert. The actual lintel clear opening dimensions have been used to represent the lintel as a zero-length box culvert with widths equal to the widths of the lintel and a standard height of 0.095m.

Representing the lintels as box culverts allows 11 flow regimes (as coded into TUFLOW) to simulate the culvert flow. The most common flow regimes would be:

- Un-submerged entrance, super critical flow, inlet control;
- Submerged entrance, super critical flow, inlet control; and
- Submerged entrance, submerged outlet, outlet control.

The representation of storage in the pit structure is approximated by the volume of a 1m long box culvert with the lintel opening area cross-section.

The 2D model domain has some limitations in representing the exact depth of flow at a lintel in a kerb. This is principally due to the resolution of the model (3m grid). For the smaller frequent events (e.g. 1 year and 2 year ARI events), this error is likely to be proportionally larger. Hence, the ability of the TUFLOW model to accurately represent the interaction between overland flow and inlet flow is somewhat limited for the smaller events. Therefore, the results for these events are likely to over-estimate the flow along the overland flow system and under-estimate the flow in the pipe system.

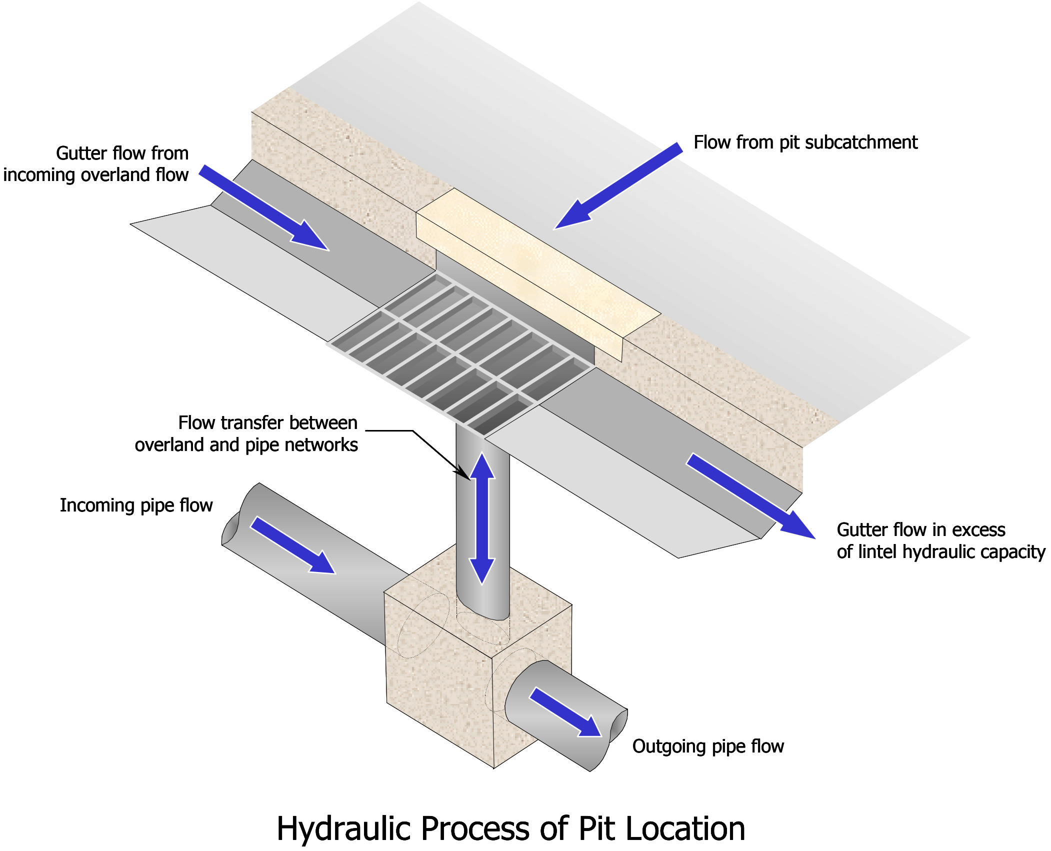


Figure C3: Drainage Pit

C3. TUFLOW Modelling Issues for Macquarie Park

C3.1 2D Domain

The 2D domain of the TUFLOW model is based on a 3m square grid. Each square grid element contains information on ground topography sampled from the DEM at a 1.5m spacing and surface resistance to flow (Manning's *n* value). The 3m grid cell size is adequate for the study area floodplain, as it is sufficiently fine to represent the variations in the floodplain topography and vegetation cover.

C3.2 1D Channels

The open channels and creeks are modelled using 1D elements. The 1D domain consists of cross-section nodes and channels that calculate the hydraulic conveyance and the storage within the open channels. Dynamic links exist between the 2D domain and the 1D domain along the boundary of the 1D channels. A schematic representation of the linking mechanism between the 1D domain and the 2D domain in the study area is presented in Figure C4.

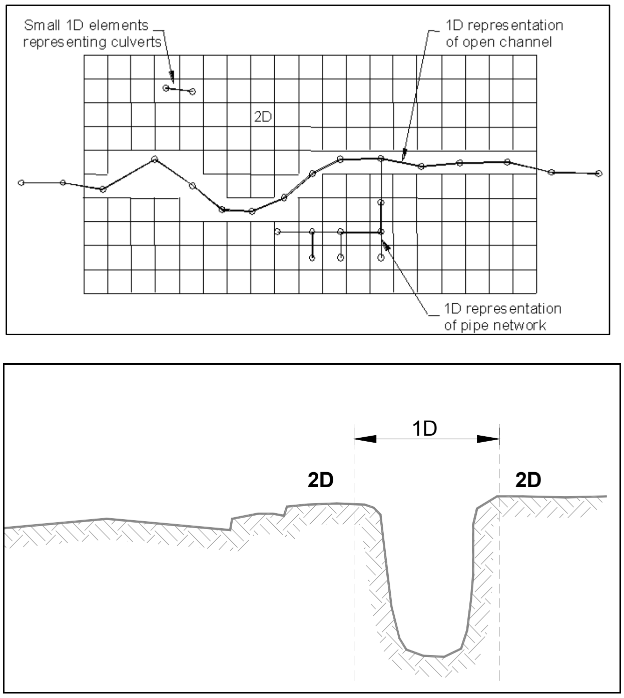


Figure C4 1D/2D Linking Mechanism

The 1D model is based on field data and cross-sections that were extracted from previous models and survey plans of the stormwater open drains (design and/or as constructed). The location and the number of cross-sections provide a sufficient description of the geometric variations of the river channel along its course. Model cross-sections are placed at locations of channel cross-section shape changes, upstream and downstream of flow constrictions and hydraulic structures, and at locations of longitudinal bed slope changes. It is not necessary to input several cross-sections along a uniform straight channel. A 1D channel is associated in the model with each cross-section. The cross-section shape and roughness is processed to determine conveyances with depths. A 1D node is created at each end of the 1D channel to represent the channel storage.

Additional 1D elements represent the bridges crossing the creek. Hydraulic structures in the 1D domain are modelled by replacing the momentum equation with standard equations describing the flow through the structure. The basic structures available are listed below:

- Bridges;
- Culverts; and
- Weirs.

The bridge opening cross section is described in the same manner to a normal channel. The highest level given in the cross-section data table is assumed to be the underside of the bridge deck, enabling the program to compute a correction for submerged decking. Bridge structures are modelled using a height varying form loss coefficient. The coefficients are obtained from publications such as “Hydraulics of Bridge Waterways” (US FHA 1973). They include loss coefficients for bridge opening ratio, for piers, for eccentricity and for skewness and an automated option for applying losses once the deck becomes surcharged.

C3.3 1D Pipes

The pits and pipes network data was provided by the Council and compiled by the consultant. The data is intended to correspond to the entire pipe network. It was compiled from two different sources:

- Council asset database; and
- Site inspections.

Where invert levels of pits and pipes were missing, these levels were estimated based on typical cover types observed n adjacent areas.

C3.4 Roughness of Floodplain and Creek

The roughness of the creek and floodplain is represented in the model using the Manning’s roughness coefficient, *n*. The choice of the Manning’s *n* roughness values is made using engineering standards (e.g. Ven Te Chow, Arcement and Schneider) that have defined empirical values for specific ground cover types.

C3.5 Hydraulic Loss Coefficients at Structures

Pipeline fittings and changes in channel geometry generate head losses along the flowline. The calculation of losses is made as a function of the velocity head:

$$\Delta H = K \frac{V^2}{2g}$$

For pipes, the calculation uses the velocity associated with the flow rate. It is more complicated with open channel losses as it is often not possible to use a single, standard velocity as in the case of a pipe of constant diameter. TUFLOW uses the average velocity inside the structure (bridge, culvert) in the equation.

Values of *K* are almost entirely empirical but there have been extensive experimental measurements on standard fittings and bridges on which estimates can be based. The values adopted for the TUFLOW model follow recommended values. The TUFLOW headloss coefficients are presented in Table C1.

TABLE C1: TUFLOW Model Headloss Coefficients

Coefficient Description		Values
Structure(1) Inlet Control Loss Coefficient	Circular	1.0
	Rectangular – Height	0.6
	Rectangular – Width	0.9
Structure(1) Outlet Control Loss Coefficient	Entry	0.5(2)
	Exit	1(2)

(1): Bridges, culverts or pipes
(2): These are default values only. Actual values used in Macquarie Park were based on site specific assessments.

An additional feature allows the energy losses, associated with the contraction and expansion of flow lines into and out of a structure, to be automatically adjusted according to the approach and departure velocities in the upstream and downstream channels. The entrance and exit losses are adjusted according to the following equations:

$$K_{entrance\_adjusted} = K_{entrance}\left[1 - \frac{V_{approach}}{V_{structure}}\right]$$

$$K_{exit\_adjusted} = K_{exit}\left[1 - \frac{V_{departure}}{V_{structure}}\right]^2$$

TUFLOW can also introduce unadjusted bend or additional losses.