APPENDIX B
BACKGROUND TO DEVELOPMENT AND TESTING OF LOWER COOKS RIVER FLOOD MODELS

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FIGURES
(BOUND IN VOLUME 2)

B1. SYNOPSIS

This Appendix provides background to the development of the hydrologic and hydraulic computer models that were developed to define flooding behaviour in the lower reaches of the Cooks River upstream of its point of discharge to Botany Bay.

The hydrologic and hydraulic models relied upon for the present investigation were originally developed on behalf of the Roads and Maritime Services as part of the early planning for the Project (*M5 East Upgrade – Marsh Street to Sydney Park Road – Flooding and Drainage Studies* - Lyall & Associates (L&A), 2010). More recently, the flood models have undergone refinement as part of several studies, which included investigations into the impact the proposed upgrade of Marsh Street west of the Cooks River (*Drainage and Flooding Investigation – Marsh Street Widening – M5 East Motorway to Giovanni Brunnetti Bridge* - L&A, 2015) and also the impact several preliminary concepts for the Eastern Surface Works will have on flooding behaviour.

The hydrologic models that were developed as part of these earlier investigations include a RAFTS model of the Cooks River catchment and a DRAINS model of the Alexandra Canal catchment. The hydraulic model was developed using the TUFLOW software.

This Appendix also includes a comparison of the results from the present investigation with those of previous studies.

B2. COOKS RIVER RAFTS MODEL

B2.1 Background to Hydrologic Model Development

The Cooks River catchment was divided into 44 sub-catchments as part of L&A, 2010 using ortho-photomaps with two metre contour intervals. Data such as sub-catchment land use and percentage imperviousness of the surfaces due to urbanisation, were developed from the underlying aerial photography. **Figure B2.1** shows the sub-catchments which comprised the RAFTS model that was developed as part of L&A, 2010 (**Cooks River RAFTS Model**).

B2.2 Design Storms

B2.2.1 Rainfall Intensity

Design storms for frequencies between 1 in 20 and 1 in 200 years were derived from *Australian Rainfall and Runoff – A Guide to Flood Estimation* (Institution of Engineers of Australia (IEAust), 1998) for storm durations ranging between 1 hour and 6 hours.

B2.2.2 Areal Reduction Factors

The rainfalls derived using the processes outlined in IEAust, 1998 are applicable strictly to a point. In the case of a large catchment of over tens of square kilometres, it is not realistic to assume that the same rainfall intensity can be maintained over a large area, an areal reduction factor (ARF) is typically applied to obtain an intensity that is applicable over the entire area.

The rainfall intensity data contained in IEAust, 1998 were originally published by the US National Weather Service in 1980 and were derived from recorded storm data in the Chicago area. The Cooperative Research Centre for Catchment Hydrology (CRCCH) undertook a program of deriving ARF's in an Australian setting. Siriwardena and Weinmann, 1996 undertook this analysis for Victorian catchments for a range of catchments from 1 to 10,000 square kilometres in area and storm durations from 18 to 120 hours. The conclusion of this investigation was that ARF's were related to rainfall frequency and that the values in ARR should be reduced by 5-8 per cent for storm durations in this range.

Catchlove and Ball, 2003 undertook a study on the 112 square kilometres catchment of the Upper Parramatta River where the records at 8 pluviometers were analysed. The key finding of this investigation was that for storm durations in excess of 2 hours, the best estimate of ARF for this catchment was 1.0. Application of relationships derived by ARR and CRCCH gave similar results for the Upper Parramatta River catchment, because the variations for different exceedance probabilities for a small catchment of this size are minimal. In practice, adoption of a single ARF unrelated to frequency is more appropriate.

For this present study, ARR indicates that a value of 0.85 could have been adopted for the ARF on the Cooks River catchment as an appropriate value for the 2 hour storm duration found to be critical on this catchment. However, a value of 1 was selected for design purposes, in keeping with the more recent results of Catchlove and Ball.

B2.2.3 Temporal Patterns

Temporal patterns for various zones in Australia are presented in IEAust, 1998. These patterns are used in the conversion of a design rainfall depth with a specific ARI into a design flood of the same frequency. Patterns of average variability are assumed to provide the desired conversion. The patterns may be used for ARIs up to 500 years where the design rainfall data is extrapolated to this ARI.

B2.3 RAFTS Model Parameters

B2.3.1 Rainfall Losses

RAFTS requires losses to be applied to storm rainfall to determine the depth of surface runoff, as well as information on the time of travel of the flood wave through the catchment.

Infiltration losses are of two types: initial loss arising from water which is held in depressions which must be filled before runoff commences, and a continuing loss rate which depends on the type of soil and the duration of the storm event. The split catchment option was used for estimating hydrographs from each sub-catchment. This option separately models runoff from the pervious and impervious portions.

Losses from the impervious portion of the catchment are subject to less uncertainty resulting from antecedent rainfall conditions than from the pervious portion. Values of 2 millimetres for initial loss and zero continuing loss were adopted for impervious surfaces. The response of the model to initial losses from the pervious portion ranging between zero and 20 millimetres was tested for the 100 year ARI 2 hour critical storm (**Figure B2.2**). The results showed that the peak discharge was not particularly sensitive to pervious initial loss, because about 50 per cent of the total catchment surface was impervious. Loss values adopted for design flood estimation are shown in **Table B2.1**.

TABLE B2.1
DESIGN LOSS VALUES

Type of Surface	Initial Loss mm	Continuing Loss mm/h
Pervious Areas	10	2.5
Impervious Areas	2	0

B2.3.2 Travel Time of Floodwave

A simple lagging of the ordinates was adopted to describe the translation of the hydrograph generated at each sub-catchment outlet along the various links to the next downstream sub-catchment. This approach required specifying a velocity of the flow along the link. The sensitivity of the results to assumed velocities ranging between 1 and 3 metres per second was tested for the 100 year ARI critical storm (**Figure B2.2**). The 1 metre per second velocity resulted in peak discharges that were much smaller than peaks estimated in any of the other studies of flooding on the Cooks River (**Table B2.2** over the page). After consideration a velocity of 2 metres per second was adopted for design.

B2.4 Probable Maximum Precipitation

Estimates of probable maximum precipitation were made using the GSDM as described in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method* (Bureau of Meteorology (BoM), 2003). This method is appropriate for estimating extreme rainfall depths for catchments up to 1000 km^2 in area and storm durations up to 6 hours.
The steps involved in assessing PMP for the Cooks River catchment are briefly as follows:

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.
- Adjust the PMP estimate according to the percentages of the catchment which are meteorologically rough and smooth, and also according to elevation adjustment and moisture adjustment factors.
- Assess the design spatial distribution of rainfall using the distribution for convective storms based on US and world data, but modified in the light of Australian experience.
- Derive storm hyetographs using the temporal distribution contained in Bulletin 53, which is based on pluviographic traces recorded in major Australian storms.

B2.5 Design Discharge Hydrographs

Figure B2.3 shows design discharge hydrographs that were adopted for input at the upstream boundaries of the TUFLOW model. The peaks of the PMF are between two and four times those of the 100 year ARI flood, depending on location. The PMF is the largest flood that could reasonably be expected to occur and is generally considered to have a return period between 1 in 10^5 and 1 in 10^6 years.

Table B2.2 over the page compares peak discharges derived from the present and previous investigations. The peak discharges derived from the Cooks River RAFTS Model as part of the present investigation are given in column B of the table. The peaks derived from TUFLOW are given in column C. The differences between the peak flows at each of the locations represent the routing effects of channel and floodplain storage which are incorporated in the TUFLOW analysis but which are not modelled by RAFTS. The effects of storage are represented by a reduction in peak flow at the outlet for TUFLOW when compared with the RAFTS result.

Both of the *Cooks River Flood Study* (Sydney Water Corporation (SWC), 2009) and the Cooks River Floodplain Management Study (Webb, McKeown and Associates (WMA), 1994) (refer peak flows given in columns D and E of **Table B2.2**, respectively) used the WBNM system for hydrologic modelling. WBNM is a rainfall runoff hydrologic model similar to RAFTS and would be expected to give similar results, provided that the model layout and adopted parameters were similar.

TABLE B2.2
PEAK DISCHARGES
100 YEAR ARI
(cubic metres per second)

Location [A]	Cooks River RAFTS Model [B]	Lower Cooks River TUFLOW Model [C]	Cooks River Flood Study (SWC, 2009) [D]	Cooks River Floodplain Management Study (WMA, 1994) [E]
Wolli Creek at SWSOOS Crossing	431	430	348	290
Alexandra Canal Discharge to Cooks River	353	203	286	160
Muddy Creek Discharge to Cooks River	262	178	145	150
Cooks River Outfall to Botany Bay	1440	1145	1596	1010

B3. ALEXANDRA CANAL DRAINS MODEL

B3.1 Background to Hydrologic Model Development

Investigations into several of the early concept designs for the Project required an understanding of the magnitude of flow in Sheas Creek (the major contributor to flow in Alexandra Canal), as well as the minor lateral drainage lines which discharge to the canal along its length. Rather than further sub-divide the Cooks River RAFTS Model, a separate DRAINS model was developed of the catchments which contribute flow to Alexandra Canal (**Alexandra Canal DRAINS Model**). **Figure B3.1** shows the sub-catchments which comprised the Alexandra Canal DRAINS Model.

B3.2 DRAINS Model Parameters

Adopted DRAINS model parameters comprised initial losses of 2 and 20 millimetres for paved and grassed areas, respectively. An antecedent moisture condition of 3 was adopted, reflecting rather wet conditions prior to the occurrence of storm events and the soil type was set equal to 2, which corresponds with a soil of comparatively low runoff potential.

Rainfall intensities for design storms of 20. 100 and 200 year ARI, and for storm durations ranging between 30 minutes and 3 hours, were derived using procedures outlined in IEAust, 1998.

The outlets of the sub-catchments were linked using a trapezoidal channel arrangement which reflected prototype conditions (e.g. the concrete lined section of Sheas Creek and the man-made canal). The length of the channels was taken from the available aerial photography. Each reach of channel was assigned a Manning's n value of 0.03.

B3.3 Probable Maximum Precipitation

Estimates of PMP for the Alexandra Canal catchment were derived using the method described in **Section B2.3**.

B3.4 Design Discharge Hydrographs

Figure B2.3 shows the design discharge hydrographs that were applied to the upstream boundary of the TUFLOW model on Sheas Creek. The peak 100 year ARI flow generated by the Alexandra Canal DRAINS model at the location where Sheas Creek discharges to Alexandra Canal of 162 cubic metres per second compares closely with the peak flow of 160 cubic metres per second given in *Sheas Creek Flood Study* (Webb, McKeown and Associates (WMA), 1991) at the same location.

B4. LOWER COOKS RIVER TUFLOW MODEL

B4.1 Background to Hydraulic Model Development

A TUFLOW model of the Lower Cooks River (**Lower Cooks River TUFLOW Model**) was originally developed as part of L&A, 2010 to assess the impact an early concept design for the Project would have on flooding behaviour. The model was also used to assess the height to which flood protection walls needed to be set in order to prevent the ingress of floodwater to the then proposed tunnel portals.

The Lower Cooks River TUFLOW Model was subsequently updated as part of a number of more recent studies which included investigations into the impact the proposed upgrade of Marsh Street west of the Cooks River (L&A, 2015) and also the impact several preliminary concepts for the Eastern Surface Works will have on flooding behaviour.

B4.2 Sources of Topographic Data

Figure B4.1 shows the various sources of topographic data available to construct the model. The data included:

- Cross sections of the streams which had been included in the TUFLOW model developed for SWC by the PB-WMH Joint Venture study of Cooks River catchment in 2009 (SWC, 2009).
- A hydrographic survey of the lower reaches of Cooks River and the confluence with Alexandra Canal, including several isolated sections of the canal; provided by Roads and Maritime.
- Detailed ground survey along the road reserve of Marsh Street west of the Cooks River.
- Details of the various bridge crossings provided by Roads and Maritime, which were later included in the model.
- LiDAR survey data provided by Roads and Maritime to define natural surface levels on the floodplain.
- Levels along the shoreline based on LiDAR survey provided by Roads and Maritime which were used in conjunction with estimated depths of Botany Bay to extend the model into the bay below the Cooks River outlet.

B4.3 TUFLOW Model Layout

The layout of the TUFLOW model is shown on **Figure B4.1**. Both the floodplain and stream beds were modelled as a grid of two-dimensional elements. The grid levels comprising the stream beds were interpolated from the cross sections shown on **Figure B3.1** in areas where there was no hydrographic survey. The model includes nine road and rail crossings on the main arms, as well as the SWSOOS crossing.

All of the features which influence the passage of flow on the floodplain were included in the model. An important consideration of two-dimensional modelling is how best to represent the roads, fences, buildings and other features which influence the passage of flow over the natural surface. Two-dimensional modelling is very computationally intensive and it is not practicable to use a mesh of very fine elements without incurring very long times to complete the simulation,

particularly for long duration flood events. The requirement for a reasonable simulation time influences the way in which these features are represented in the model.
Earlier versions of the Cooks River TUFLOW Model incorporated a 5 metre grid. However, later studies required a nested grid to be developed which covered the Alexandra Canal. The latest version of the model comprises a 2 metre grid which covers areas that are affected by flooding along Alexandra Canal and a 6 m grid which covers the remainder of the two-dimensional model domain. Ridge and gully lines were added to the model where the grid spacing was considered too coarse to accurately represent important topographic features which influence the passage of overland flow, such as road centrelines and footpaths. It was important that the model recognised the ability of roads to capture overland flow and act as floodways.

The footprints of a large number of individual buildings were digitised and assigned a high hydraulic roughness value relative to the more hydraulically efficient roads and flow paths through allotments. This accounted for their blocking effect on flow whilst maintaining a correct estimate of floodplain storage in the model. It was not practicable to model the individual fences surrounding the many allotments in the study area. They comprised many varieties (brick, paling colorbond, etc) of various degrees of permeability and resistance to flow. It was assumed that there would be sufficient openings in the fences to allow water to enter the properties, whether as flow under or through fences and via openings at driveways.

B4.4 TUFLOW Model Boundary Conditions

B4.4.1 Upstream Boundary

Discharge hydrographs generated by both the Cooks River RAFTS Model and Alexandra Canal DRAINS Model were applied at the inflow boundaries of the Lower Cooks River TUFLOW Model.

B4.4.2 Storm Tides at Botany Bay

The NSW Government's guideline entitled "*Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments*" (Department of Environment, Climate Change and Water (DECCW), 2010) was prepared to assist councils, the development industry and consultants to incorporate the sea level rise planning benchmarks in floodplain risk management planning for new development. The guideline contains an appendix on modelling the interaction of catchment and coastal flooding for different classes of tidal waterway. The appendix may be used to derive scenarios for coincident flooding from those two sources for both *present day conditions* and conditions associated with *future climate change*.

For a catchment draining directly to the ocean via trained or otherwise stable entrances such as is the case for the Cooks River at Botany Bay, the guideline offers the following alternative approaches for selecting storm tidal conditions under *present day conditions*. In order of increasing sophistication they are:

- A default tidal hydrograph which has a peak of RL 2.6 metres AHD for the 1 in 100 year event; or 2.3 metres AHD for the 1 in 20 year event. This default option is acknowledged by DECCW as providing a *conservatively high estimate* of tides for these types of entrances. Results achieved with these levels have been determined in the present investigation, but are only presented as a *sensitivity study*.

- A detailed site-specific analysis of elevated water levels at the ocean boundary. The analysis should include contributions to the water levels such as tides, storm surge wind and wave set up. The analysis should examine the duration of high tidal levels, as well as their potential coincidence with catchment flooding. This approach requires a more detailed consideration of historic tides and the entrance characteristics, but provides information which is more directly relevant to a particular entrance. It has been adopted for *design purposes* in the present investigation.

B4.4.3 Consideration of Historic Storm Tides

The Highest Astronomical Tide (HAT) level recorded in Botany Bay was 1.45 metres AHD on 25 May 1974. This level was recorded at Kurnell and was considered to have a return period of 1 in 100 years. In the WMA, 1994 investigation an allowance of 0.25 metres was adopted for additional storm related components such as wind stress and wave action, yielding a peak of 1.7 metres AHD at the Cooks River entrance. By comparison the High High Water Solstice Spring (HHWSS) tide which occurs once or twice a year has a peak of about RL 1.02 metres AHD.

Peak storm tide levels for events with ARI's of 5 and 20 years were derived by adding 0.25 metres to design still water levels for Fort Denison which are given in *Fort Denison Sea Level Rise Vulnerability Study* (Department of Environment and Climate Change (DECC), 2008), while the upper limit of ocean flooding (referred to herein as an "extreme ocean flood event" and assigned a probability of 10,000 year ARI) was determined by extrapolation of the data presented in DECC, 2008.

Table B4.1 sets out the peak tide levels that were adopted for design flood modelling. Tidal hydrographs were generated with the peak levels for application to the downstream boundary of the TUFLOW model. They are plotted on **Figure B4.2**.

TABLE B4.1
ADOPTED PEAK STORM TIDE LEVELS IN BOTANY BAY

Condition	Storm Frequency	Peak Storm Tide Level (metres AHD)
Present Day	1 in 5 years	1.57
	1 in 20 years	1.63
	1 in 100 years	1.70
	Extreme	1.85
Sensitivity Analysis	Normal Tide	0.63
	HHWSS	1.02
	DECCW 20 year ARI	2.25[1]
	DECCW 100 year ARI	2.60[1]
2050 SLR	1 in 20 years	2.03
	1 in 100 years	2.10
	Extreme	2.25
2100 SLR	1 in 20 years	2.53
	1 in 100 years	2.60
	Extreme	2.75

1. Source: DECCW, 2010

B4.4.4 Envelope Scenarios for Determining Flood Levels in Cooks River

According to DECCW, 2010, determining 100 year ARI flood levels in tidal waterways requires consideration of the interaction of catchment and ocean flooding from the following scenarios:

- 20 year ARI catchment flooding, with 1 in 100 year ocean flooding and coincident peaks.
- 100 year ARI catchment flooding, with 1 in 20 year ocean flooding and coincident peaks.
- 100 year ARI catchment flooding, with normal tidal cycle and coincident peaks.

Table B4.2 over the page sets out the coincident catchment and ocean flooding conditions which were used to define the design flood envelopes.

B4.5 TUFLOW Model Parameters

B4.5.1 General

The main physical parameter for TUFLOW is the hydraulic roughness, which is required for each of the various types of surfaces comprising the overland flow paths, as well as for the streams. In addition to the energy lost by bed friction, obstructions to flow also dissipate energy by forcing water to change direction and velocity, and by forming eddies. Hydraulic modelling traditionally represents all of these effects via the surface roughness parameter known as “Manning’s n”.

B4.5.2 Channel Roughness

There are very limited historic flood level data available in the lower reaches of the Cooks River to assist with the calibration of the model for roughness. Channel roughness values were estimated from site inspection, past experience and values contained in the engineering literature.

Initial runs of the TUFLOW model were carried out with channel roughness values of 0.025 and 0.03, with the latter value resulting in peak flood levels about 200 mm higher than the former. After consideration a value of 0.025 was adopted for design purposes.

B4.5.3 Floodplain Roughness

The adoption of a value of 0.02 for the surfaces of roads, along with an adequate description of their widths and centreline and kerb elevations, allowed an accurate assessment of their conveyance capacity to be made. Similarly the high value of roughness adopted for buildings recognised that they completely blocked the flow but were capable of storing water when flooded.

B4.5.4 Design Roughness Values

Table B4.3 on page B14 summarises the hydraulic roughness values adopted for design purposes.

TABLE B4.2
ADOPTED COINCIDENT CATCHMENT AND OCEAN FLOODING CONDITIONS

Condition	Design Flood Envelope	Catchment Flood	Ocean Flood[1]
Present Day	20 year ARI	20 year ARI	1 in 5 years [1.57]
		5 year ARI	1 in 20 years [1.63]
	100 year ARI	100 year ARI	1 in 20 years [1.63]
		20 year ARI	1 in 100 years [1.70]
	200 year ARI	200 year ARI	1 in 20 years [1.63]
		20 year ARI	1 in 100 years [1.70][3]
	PMF	CR-PMF[2]	1 in 100 years [1.70]
		AC-PMF[2]	1 in 20 years [1.63]
		100 year ARI	Extreme [1.85]
Sensitivity Analysis	20 year ARI	20 year ARI	HHWSS [1.02]
		5 year ARI	DECCW 1 in 20 years [2.25]
	100 year ARI	100 year ARI	Normal Tide [0.63]
		100 year ARI	HHWSS [1.02]
		100 year ARI	DECCW 1 in 20 years [2.25]
		20 year ARI	DECCW 1 in 100 years [2.60]
	PMF	CR-PMF[2]	DECCW 1 in 100 years [2.60]
		AC-PMF[2]	DECCW 1 in 20 years [2.25]
2050 SLR	100 year ARI	100 year ARI	1 in 20 years [2.03]
		20 year ARI	1 in 100 years [2.10]
	PMF	CR-PMF[2]	1 in 100 years [2.10]
		AC-PMF[2]	1 in 20 years [2.03]
		100 year ARI	Extreme [2.25]
2100 SLR	100 year ARI	100 year ARI	1 in 20 years [2.53]
		20 year ARI	1 in 100 years [2.60]
	PMF	CR-PMF[2]	1 in 100 years [2.60]
		AC-PMF[2]	1 in 20 years [2.53]
		100 year ARI	Extreme [2.75]

1. Values in [ ] relate to adopted peak storm tide level in metres AHD. Refer **Table B4.1** for details.
2. CR-PMF = Cooks River Probable Maximum Flood. AC-PMF = Alexandra Canal Probable Maximum Flood.
3. 1 in 100 year storm tide adopted for modelling purposes as peak 1 in 200 year storm tide level is only 0.02 m higher.

TABLE B4.3
"BEST ESTIMATE" OF HYDRAULIC ROUGHNESS VALUES
ADOPTED FOR TUFLOW MODELLING

Surface Treatment	Manning's n Value
Asphalt or concrete road surface	0.02
Well Maintained Grassed Cover e.g. sporting oval	0.03
Grass or Lawns	0.045
Trees	0.08
Concrete lined channels	0.015
River bed	0.025
Macrophytes (river bank)	0.06
Fenced Properties	1.0
Buildings	10

B4.6 Sensitivity Analyses

B4.6.1 Sensitivity of Flood Behaviour to Increase in Hydraulic Roughness

Figure B4.3 shows the difference in peak flood levels (i.e. the "afflux") for the 100 year ARI storm resulting from an assumed 20 per cent increase in hydraulic roughness compared to the "best estimate" values given in **Table B4.3**. The afflux is given in colour coded increments in metres. The figure also identifies areas where land is rendered flood free, or where additional areas of land are flooded.

Peak 100 year ARI flood levels are generally increased in the range 50-100 mm along Alexandra Canal and in the range 100-200 millimetres along the Cooks River upstream of its confluence with the canal. Peak 100 year ARI flood levels in the northern portion of the Kogarah Golf Course are also increased in the range 100-200 millimetres.

B4.6.2 Sensitivity of Flood Behaviour to Varying Tailwater Conditions

Figures B4.4 and **B4.5** show the impact the adoption of varying coincident tailwater conditions will have on peak 100 year ARI and PMF flood levels along the lower Cooks River and Alexandra Canal, respectively.

Application of the default OEH storm tide hydrographs at the downstream boundary of the Lower Cooks River TUFLOW Model results in significantly higher peak 100 year ARI and PMF flood levels in the Lower Cooks River. Peak flood levels are also increased along Alexandra Canal, although only as far upstream as the Unnamed Bridge Crossing No. 1 in the case of the PMF event. The resulting peak flood levels are considered to provide conservative upper limits to design flood levels and hence have not been used in the derivation of the design flood envelopes.

B4.7 Comparison with Results of Previous Studies

Table B4.4 compares 100 year ARI peak flood levels derived using the Lower Cooks River TUFLOW Model developed as part of the present investigation with levels presented in the *Cooks River Flood Study* (Sydney Water Corporation (SWC), 2009). The latter study also adopted an envelope approach when determining peak flood levels, but adopted a slightly different set of catchment flooding–storm tide combinations, namely:

- A 2 year ARI catchment flood coincident with a 1 in 100 year storm tide of 1.7 metres AHD.
- A 100 year ARI catchment flood coincident with a HHWSS tide of 1.1 metres AHD.

Consequently, the results are not directly comparable. However, it appears that upstream of the crossover point near Marsh Street, where catchment flooding controls peak flood levels, the current set of results give peak flood levels which are considerably higher than the *Cooks River Flood Study* values. The reason appears to be due to the different approaches which were adopted in modelling the conveyance capacity of the inbank areas of the Cooks River and Alexandra Canal.

TABLE B4.4
100 YEAR ARI PEAK FLOOD LEVELS
COMPARISON WITH PREVIOUS STUDY
(metres AHD)

Location on Cooks River	Lower Cooks River TUFLOW Model	Cooks River Flood Study (SWC, 2009)
General Holmes Drive	1.78	1.73
Marsh Street	2.34	2.0
Princes Highway	2.95	2.16
Illawarra Railway	3.14	2.3

The *Cooks River Flood Study* modelled the channels as one-dimensional elements, the hydraulic characteristics of which are described by cross sections taken at right angles to the assumed direction of flow. Only the floodplain was modelled as a two-dimensional grid. The assumption inherent in the one-dimensional approach is that water surface levels for a particular discharge are constant across the section.

The present investigation on the other hand modelled both the channels and floodplains as a grid, ensuring that the two dimensional effects associated with bends in the stream are incorporated in the analysis. By inspection of flooding patterns between Marsh Street and the Illawarra Railway there is a superelevation of up to 600 millimetres across the channel due to bends in Cooks River over this reach (refer **Figure 4.8**, sheet 2).

There is also the tendency for flow to be directed towards the outer side of the bend so that not all of the cross section is effective for the conveyance of flow. This effect occurs at the bend downstream of the Princes Highway bridge, where flow is directed towards the eastern bank and the western side of the river is in a relatively quiescent zone. As a consequence, the Cooks River channel is less efficient than one-dimensional modelling would indicate and peak water levels are higher than those derived using that modelling approach.

Table B4.5 compares peak 100 year ARI and PMF flows derived by the flood models which were developed as part of the present investigation with those of the *Cooks River Flood Study*. While both hydrologic models generate similar peak flows, there is a notable difference in the peak flows generated by the hydraulic models at the location of the Botany Bay outfall. While the structure of the flood models which were development as part of the *Cooks River Flood Study* has not been reviewed as part of the present investigation, the difference in the peak flow estimates may be a function of the previous study incorporating a greater length of the drainage system upstream of the Princes Highway which has resulted in a greater attenuation of flood flows. During detailed design it would be necessary to assess the effects of incorporating a greater length of the drainage system on flooding behaviour in the vicinity of the project.

TABLE B4.5
COMPARISON OF PEAK FLOWS AT BOTANY BAY OUTFALL
WITH PREVIOUS STUDY
(m^3/s)

100 year ARI				PMF			
SWC, 2009		Present Investigation		SWC, 2009		Present Investigation	
Hydrologic Model (WBNM)	Hydraulic Model (TUFLOW)	Hydrologic Model (RAFTS)	Hydraulic Model (TUFLOW)	Hydrologic Model (WBNM)	Hydraulic Model (TUFLOW)	Hydrologic Model (RAFTS)	Hydraulic Model (TUFLOW)
1596	930	1440	1145	5049	1759	5143	3094

B4.8 Adjustments made to the structure of the Cooks River TUFLOW Model to reflect post-project conditions

The following adjustments were made to the structure of the Cooks River TUFLOW Model in order to assess the impact the project would have on flooding behaviour and to also assess the flood risks to the project:

- The 3D concept design model for the project was spliced with the available LiDAR survey data.
- The key features of the two new bridges over Alexandra Canal (e.g. deck and soffit levels, pier widths, abutment locations) were incorporated in the model.
- The blocking effects of the Arncliffe, St Peters and Burrows Road motorway operations complexes were incorporated in the model by raising natural surface levels above the peak PMF level.
- Finished surface levels were raised around the perimeter of the St Peters interchange to prevent the ingress of floodwater to the new tunnel portals.

Figure 1.3 (Sheets 1 and 2) show the key features of the project which were incorporated in the TUFLOW model representing post-project conditions.

B5. REFERENCES

Bureau of Meteorology (BoM), 2003. *"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"*.

Catchlove R H and Ball J E, 2003. *"A Hydroinformatic Approach to the Development of Areal Reduction Factors"* 28th International Hydrology and Water Resources Symposium, Institution of Engrs. Aust.

Department of Environment & Climate Change (DECC), 2008. *"Fort Denison Sea Level Rise Vulnerability Study"*

Department of Environment, Climate Change and Water (DECCW), 2009. *"Derivation of the NSW Government's Sea Level Rise Planning Benchmarks. Technical Note"*.

Department of Environment, Climate Change and Water (DECCW), 2010. *"Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments"*.

Institution of Engineers, Australia (IEAust), 1998. *"Australian Rainfall and Runoff – A Guide to Flood Estimation"*, Volumes 1 and 2.

Lyall & Associates (L&A), 2010. *"M5 East Upgrade – Marsh Street to Sydney Park Road – Flooding and Drainage Studies"* Progress Report dated December 2010.

Lyall & Associates (L&A), 2015. *"Drainage and Flooding Investigation – Marsh Street Widening – M5 East Motorway to Giovanni Brunnetti Bridge"*

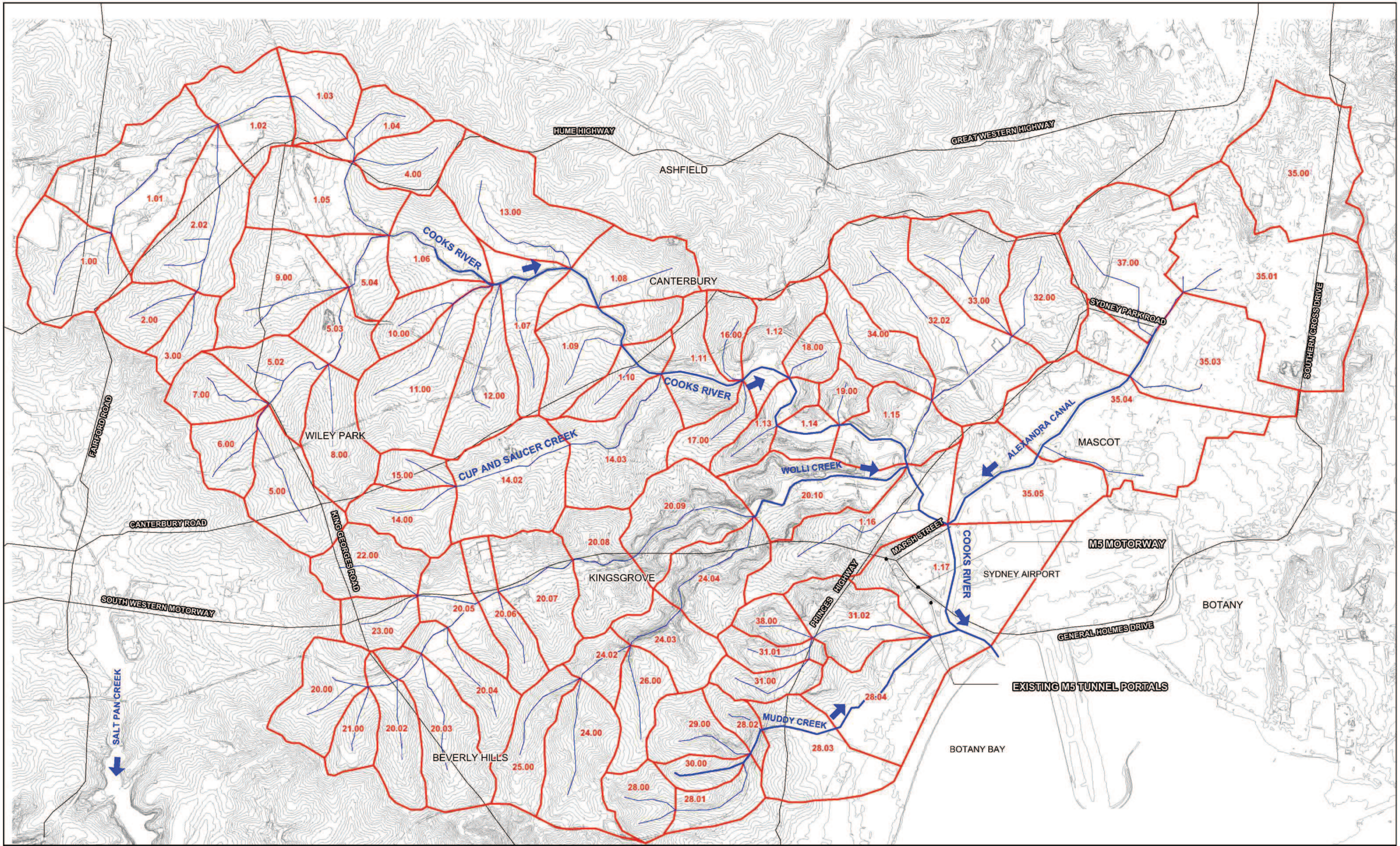
Siriwardene L and Weinmann P E, 1996. *"Derivation of Areal Reduction Factors for Design Rainfalls in Victoria"*. Cooperative Research Centre for Catchment Hydrology Report 96/4.

Sydney Water Corporation (SWC), 2009. *"Cooks River Flood Study".* Report prepared by PB-MWH Joint Venture.

Webb, McKeown and Associates (WMA), 1991. *"Sheas Creek Flood Study"*

Webb, McKeown and Associates (WMA), 1994. "Cooks River Floodplain Management Study". Report prepared for Marrickville and Canterbury City Councils.

FIGURES



N

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Scale: 1:50,000

LEGEND

1.06 RAFTS Node Number and Catchment Boundary

Watercourse/Flowpath

Lyall & Associates

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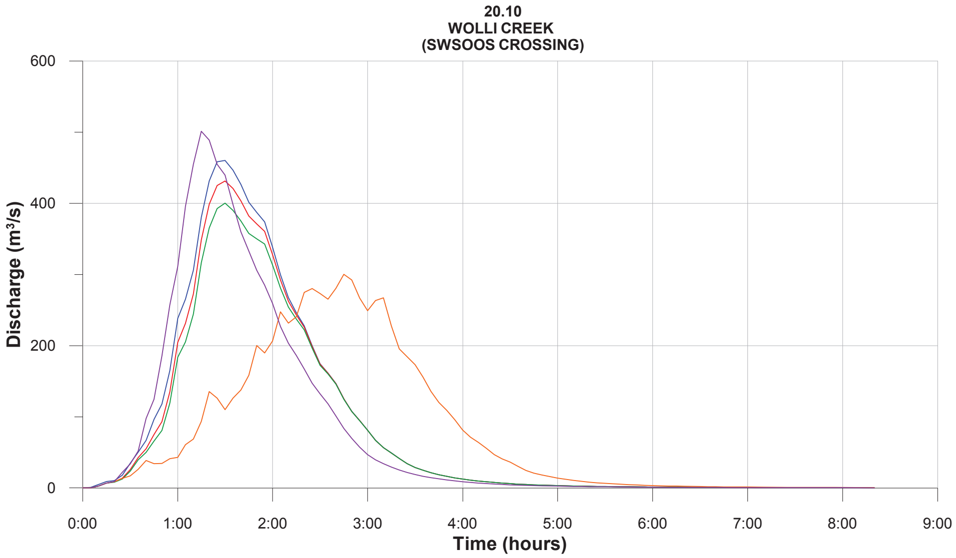
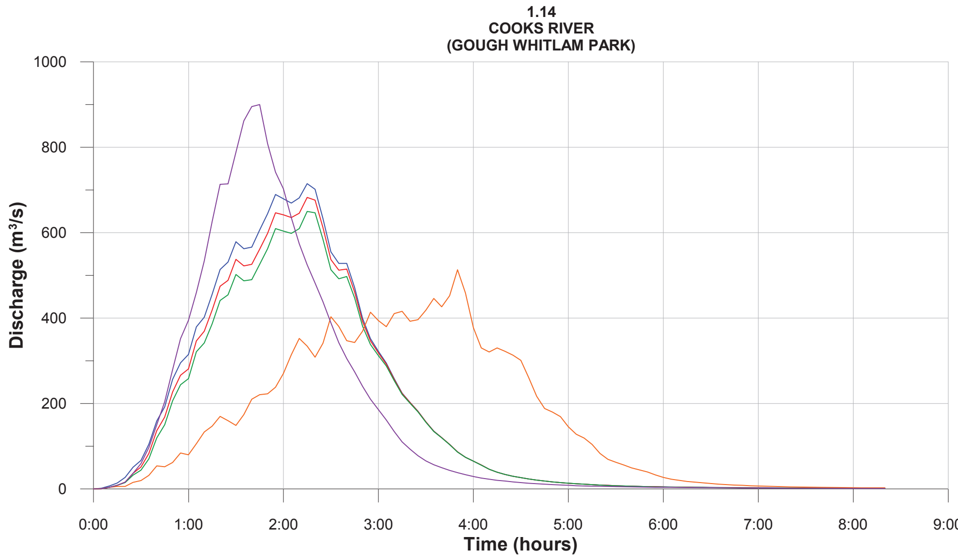
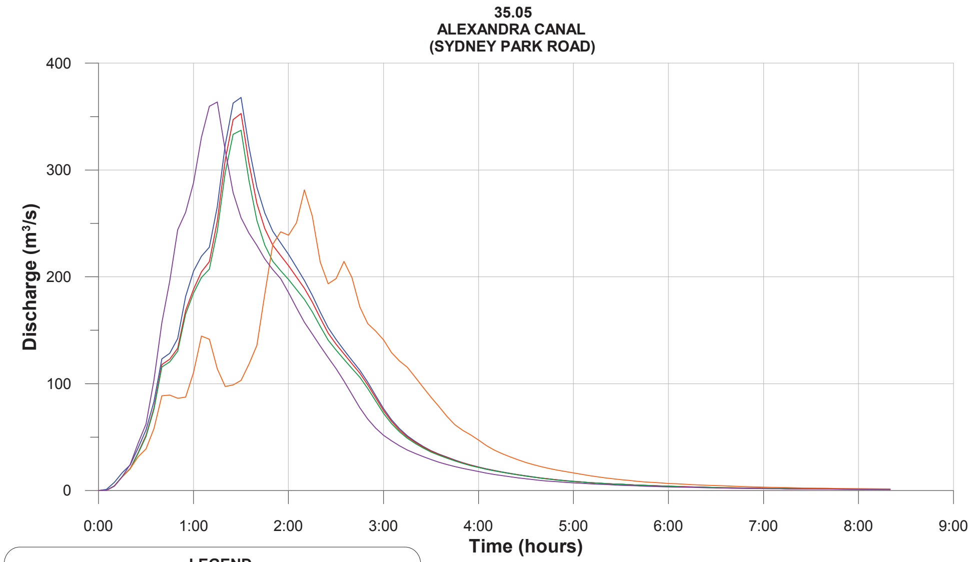
TECHNICAL WORKING PAPER: FLOODING

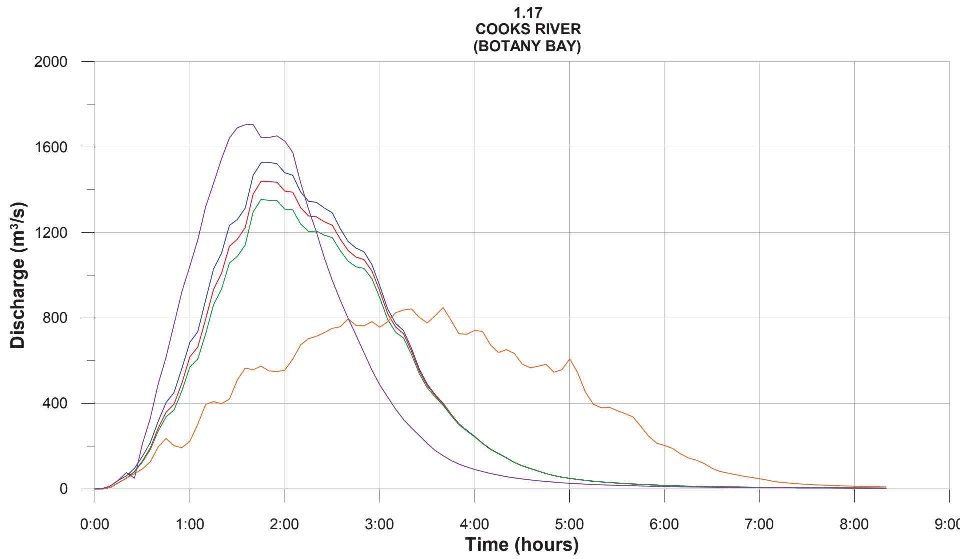
Figure B2.1

COOKS RIVER RAFTS MODEL LAYOUT









LEGEND

	INITIAL LOSS (mm)	VELOCITY (m/s)
(blue)	0	2
(red)	10	2
(green)	20	2
(orange)	10	1
(purple)	10	3

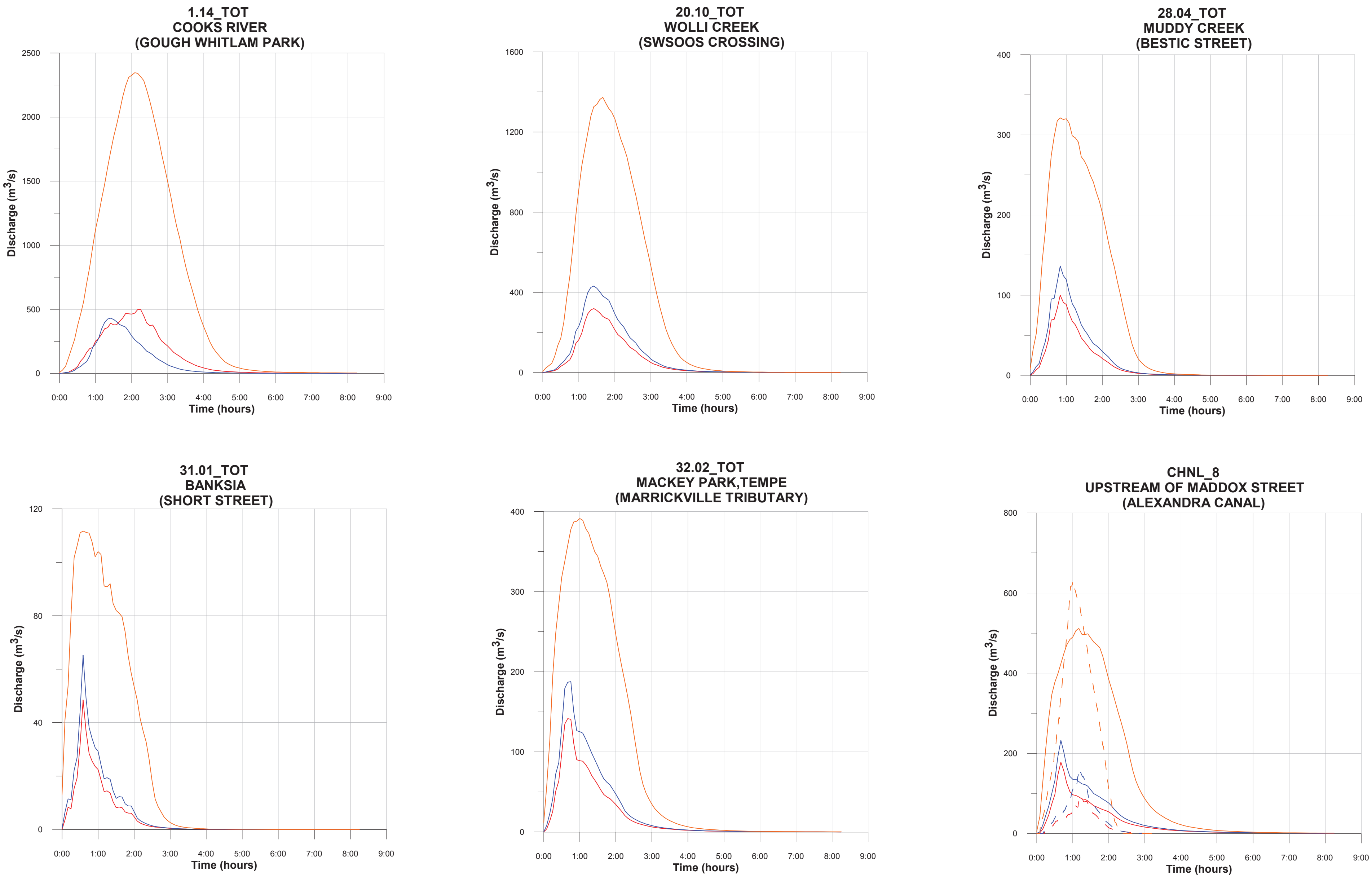
NOTE:

RESULTS APPLY FOR 2 HOUR CRITICAL STORM.

WESTCONNEX NEW M5 EIS
TECHNICAL WORKING PAPER: FLOODING

Figure B2.2

SENSITIVITY STUDY - 100 YEAR ARI
RAFTS DISCHARGE HYDROGRAPHS



LEGEND

Cooks River RAFTS Model	Alexandra Canal DRAINS Model	
solid orange line	dashed orange line	PMF
solid blue line	dashed blue line	100 Year ARI
solid red line	dashed red line	20 Year ARI

NOTE:

UNLESS OTHERWISE NOTED, FLOWS WERE DERIVED BY RAFTS AND APPLIED AS BOUNDARY CONITIONS TO TUFLOW.

CRITICAL DURATION FOR 20, 100, 200, 500 YEAR ARI STORMS IS 2 HOURS. CRITICAL DURATION FOR PMF IS 2.5 HOURS.

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TECHNICAL WORKING PAPER: FLOODING

Figure B2.3

DESIGN DISCHARGE HYDROGRAPHS
COOKS RIVER AND TRIBUTARIES

LEGEND

D_1.13 Sub-Catchment Boundary and Identifier

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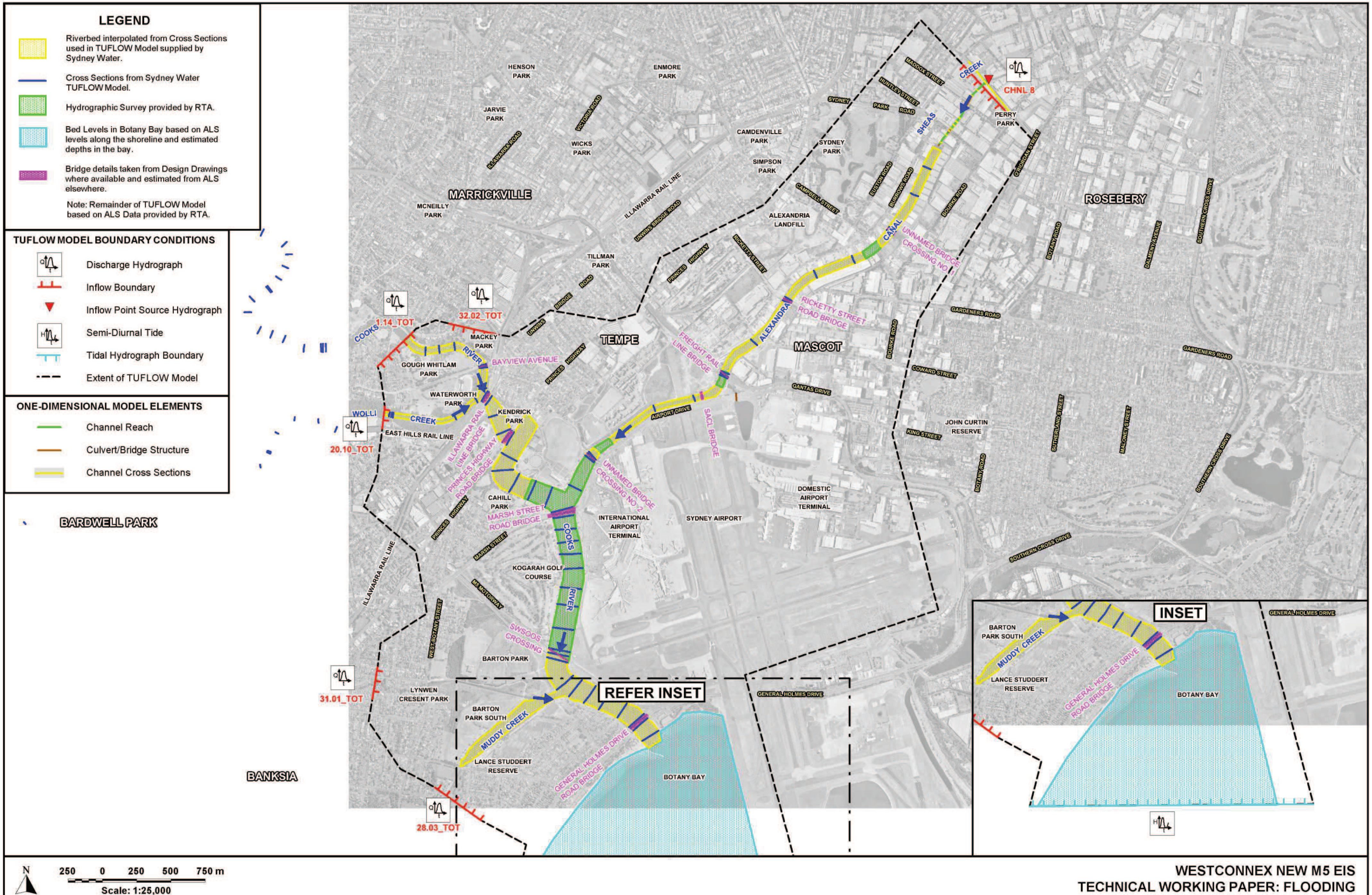
TECHNICAL WORKING PAPER: FLOODING

Figure B3.1

ALEXANDRA CANAL DRAINS MODEL LAYOUT



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NOTE:

TUFLOW MODEL SHOWN ON THIS FIGURE IS REPRESENTATIVE OF PRESENT DAY CONDITIONS

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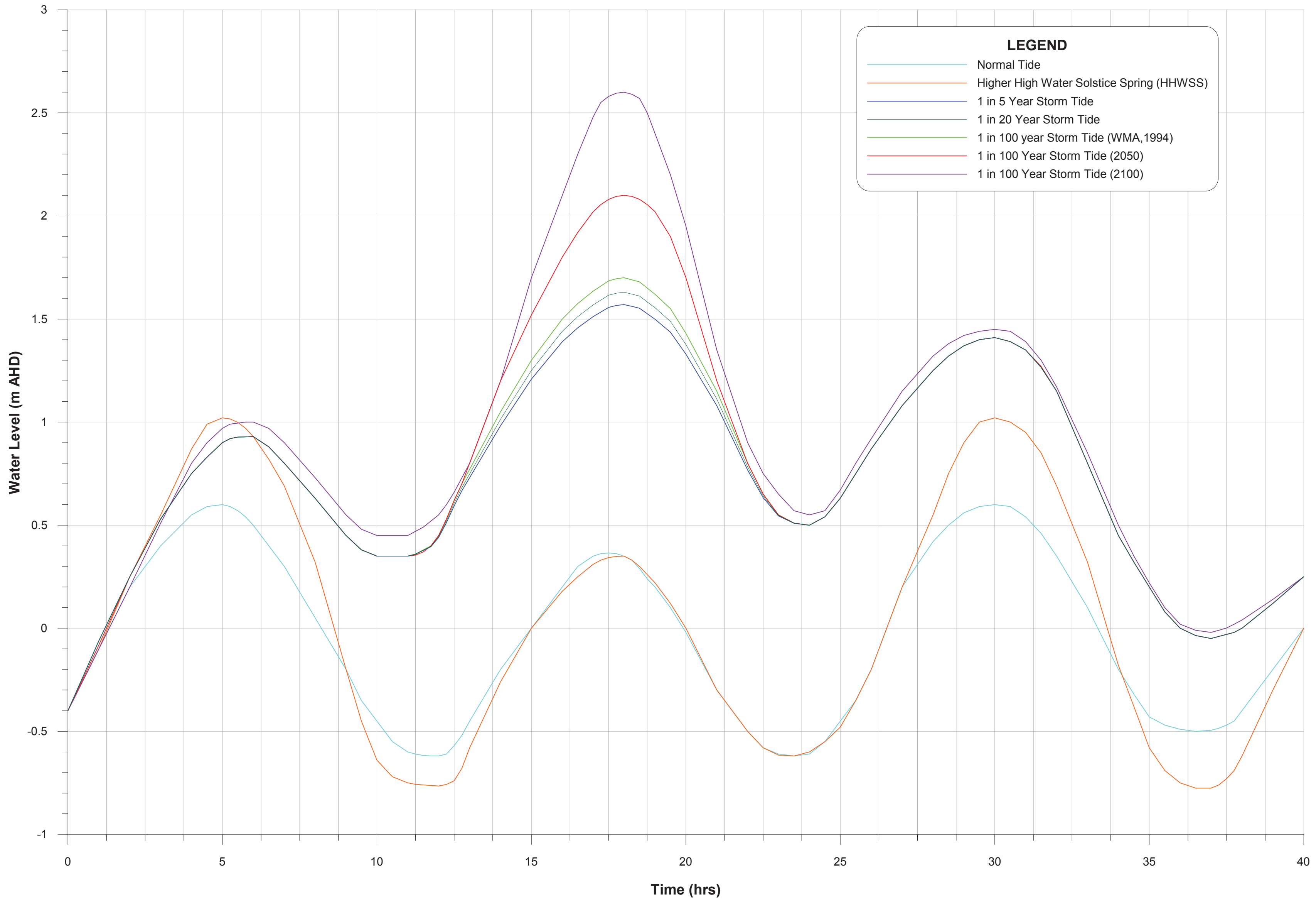
TECHNICAL WORKING PAPER: FLOODING

Figure B4.1

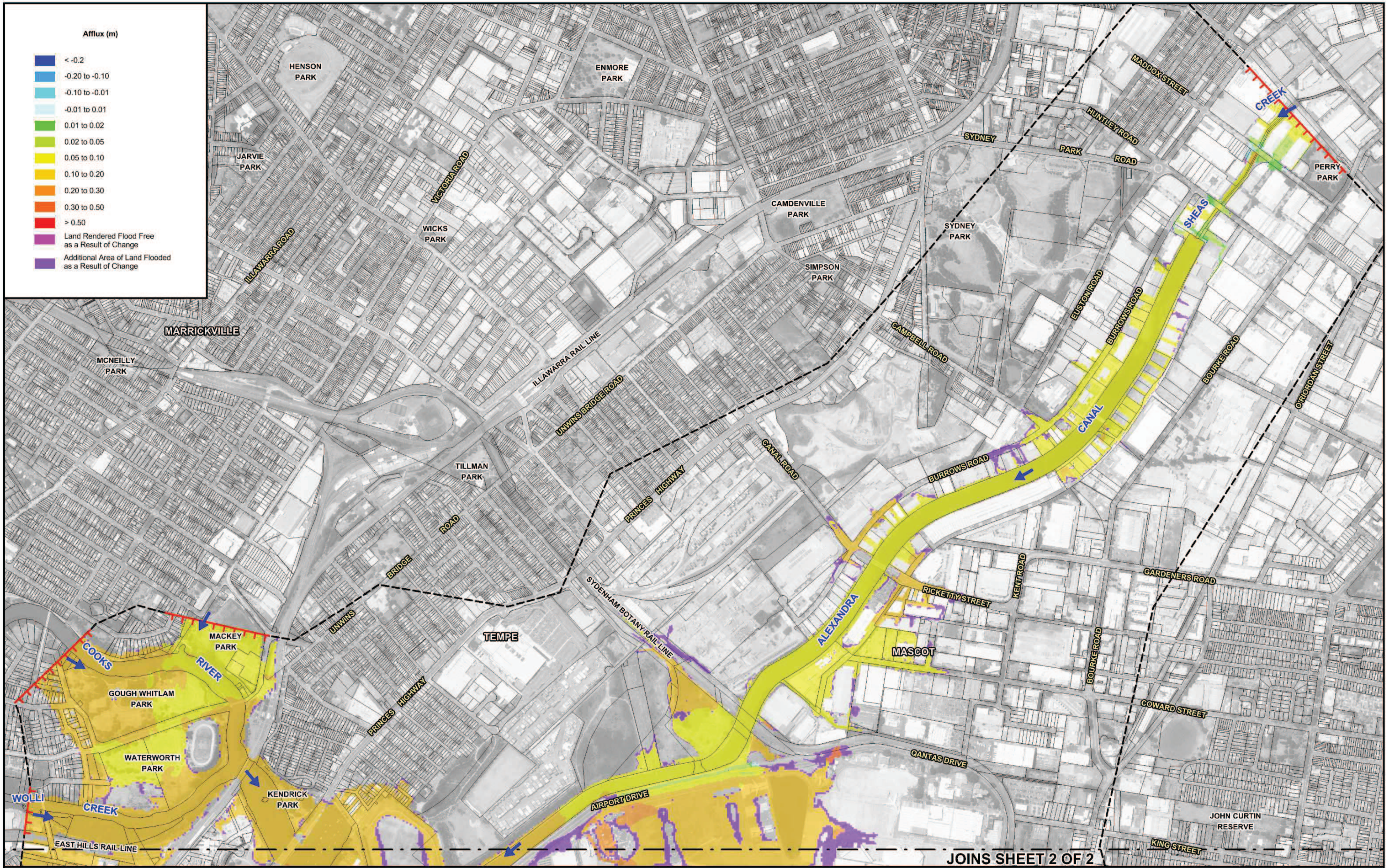
LOWER COOKS RIVER TUFLOW MODEL LAYOUT



WESTCONNEX NEW M5 EIS
TECHNICAL WORKING PAPER: FLOODING

Figure B4.2

TIDAL HYDROGRAPHS AT BOTANY BAY



N

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Scale: 1:12,000

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LEGEND

TUFLOW Model Extent

Inflow Boundary

WESTCONNEX NEW M5 EIS
TECHNICAL WORKING PAPER: FLOODING

Figure B4.3
Sheet 1 of 2

SENSITIVITY OF FLOOD BEHAVIOUR TO 20% INCREASE IN HYDRAULIC ROUGHNESS VALUES
100 YEAR ARI

N

120 0 120 240 360 m

Scale: 1:12,000

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LEGEND

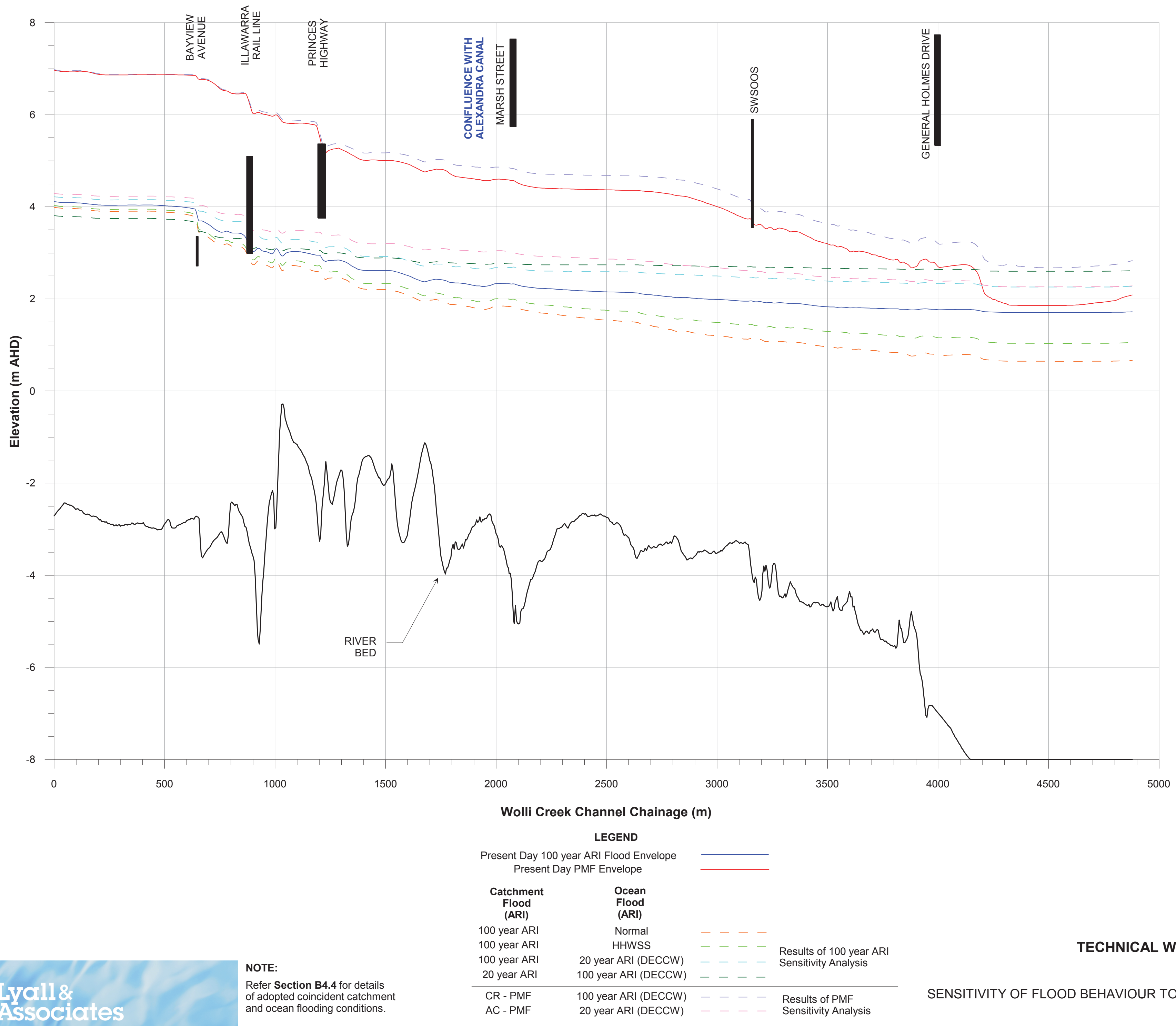
TUFLOW Model Extent

Inflow Boundary

WESTCONNEX NEW M5 EIS
TECHNICAL WORKING PAPER: FLOODING

Figure B4.3
Sheet 2 of 2

SENSITIVITY OF FLOOD BEHAVIOUR TO 20% INCREASE IN HYDRAULIC ROUGHNESS VALUES
100 YEAR ARI



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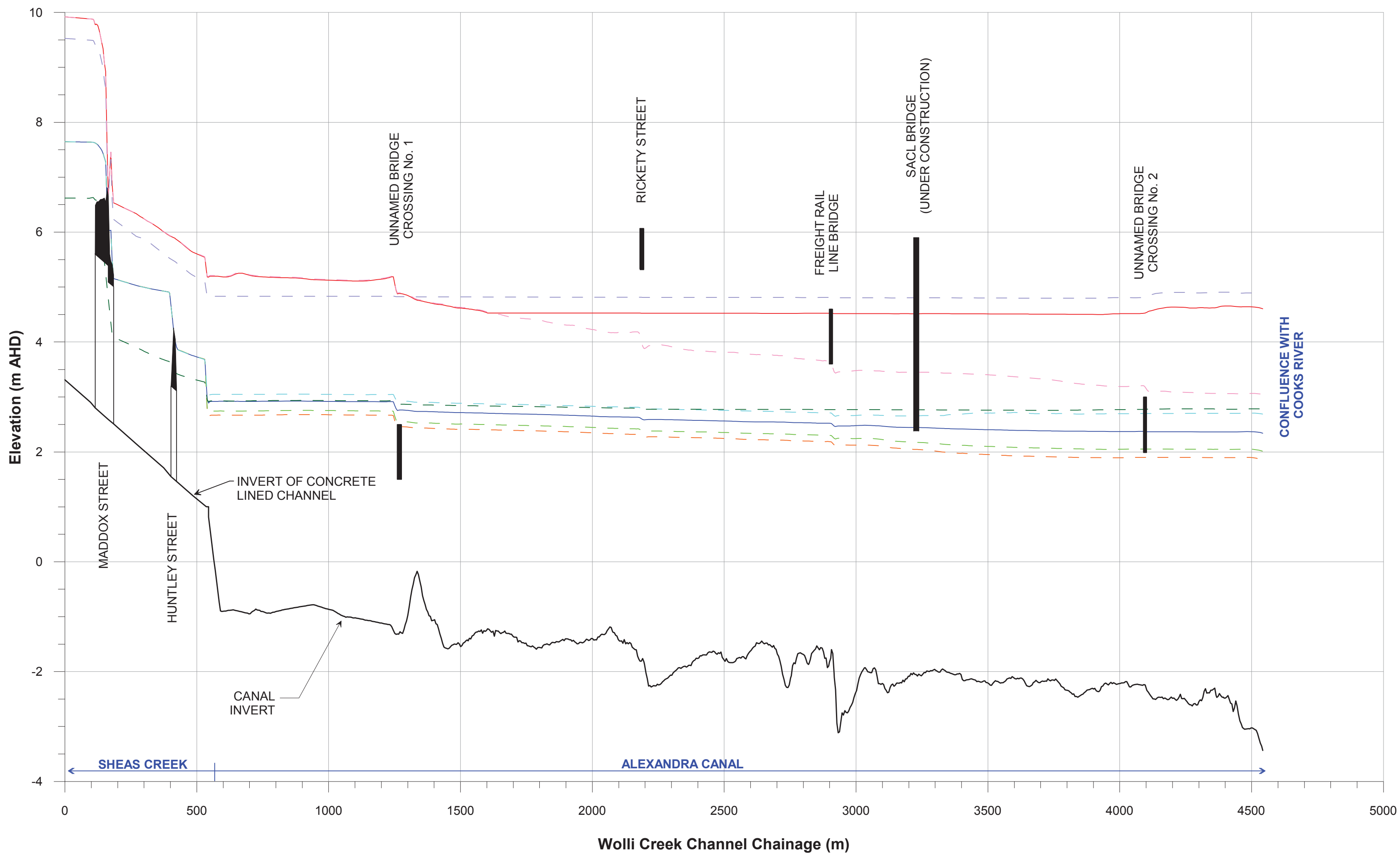
NOTE:
Refer **Section B4.4** for details of adopted coincident catchment and ocean flooding conditions.

WESTCONNEX NEW M5 EIS
TECHNICAL WORKING PAPER: FLOODING

Figure B4.4

SENSITIVITY OF FLOOD BEHAVIOUR TO VARYING TAILWATER LEVELS
COOKS RIVER



LEGEND

Present Day 100 year ARI Flood Envelope
Present Day PMF Envelope

Catchment Flood (ARI)	Ocean Flood (ARI)	
100 year ARI	Normal	Results of 100 year ARI Sensitivity Analysis
100 year ARI	HHWSS	
100 year ARI	20 year ARI (DECCW)	
20 year ARI	100 year ARI (DECCW)	
CR - PMF	100 year ARI (DECCW)	Results of PMF Sensitivity Analysis
AC - PMF	20 year ARI (DECCW)	

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NOTE:
Refer **Section B4.4** for details of adopted coincident catchment and ocean flooding conditions.

WESTCONNEX NEW M5 EIS
TECHNICAL WORKING PAPER: FLOODING

Figure B4.5

SENSITIVITY OF FLOOD BAHAVIOUR TO VARYING TAILWATER LEVELS
ALEXANDRA CANAL

APPENDIX C
TABLES OF PEAK FLOWS

TABLE C1
PEAK FLOWS
UPPER WOLLI CREEK FLOODPLAIN
(cubic metres per second)

Peak flow identifier	Present day conditions(1)				Post-construction conditions(1)				Difference(2)			
	20 year ARI	100 year ARI	200 year ARI	PMF	20 year ARI	100 year ARI	200 year ARI	PMF	20 year ARI	100 year ARI	200 year ARI	PMF
Q1	5.5	7.5	9.0	21.9	5.5	7.5	9.0	21.9	0.0	0.0	0.0	0.0
Q2	7.4	9.1	10.0	24.0	7.4	9.1	10.0	24	0.0	0.0	0.0	0.0
Q3	42.5	56.8	68.0	144.0	42.5	56.8	68.0	131	0.0	0.0	0.0	-13.0
Q4	45.2	55.1	57.3	70.0	43.6	57.6	63.4	57.7	-1.6	2.5	6.1	-12.3
Q5	0.0	1.7	12.2	89.3	0	0.4	2.6	81.8	0.0	-1.3	-9.6	-7.5
Q6	15.4	17.4	17.6	18.2	15	17.8	18.3	16.9	-0.4	0.4	0.7	-1.3
Q7	43.8	55.4	61.1	96.2	43.1	56.2	62.0	85.6	-0.7	0.8	0.9	-10.6
Q8	6.0	7.0	7.3	8.3	6	7	7.3	8.3	0.0	0.0	0.0	0.0
Q9	0.0	-0.2	7.2	95.7	0	0.4	2.1	88	0.0	0.6	-5.1	-7.7
Q10	60.3	75.3	82.1	217.0	59.2	76.4	85.2	198	-1.1	1.1	3.1	-19.0
Q11	111.0	149.0	178.0	557.0	111	149	178.0	557	0.0	0.0	0.0	0.0
Q12	5.6	7.2	7.7	8.5	5.4	7.4	8.9	10.8	-0.2	0.2	1.2	2.3
Q13	4.7	6.6	7.7	12.8	4.7	6.3	7.1	12.7	0.0	-0.3	-0.6	-0.1
Q14	135.0	185.0	223.0	743.0	133	181	218.0	726	-2.0	-4.0	-5.0	-17.0
Q15	0.4	0.6	0.7	4.3	0.4	0.6	0.7	4.3	0.0	0.0	0.0	0.0
Q16	20.9	27.1	32.2	67.3	20.9	27.1	32.2	67.3	0.0	0.0	0.0	0.0
Q17	0.0	-0.1	-0.1	-0.9	-0.1	-0.1	-0.2	-0.9	-0.1	0.0	-0.1	0.0
Q18	0.7	2.0	2.0	2.5	0.7	1.9	2.0	2.4	0.0	-0.1	0.0	-0.1
Q19	0.5	-8.5	-15.9	-92.9	0.5	-8.4	-15.4	-90.9	0.0	0.1	0.5	2.0
Q20	0.3	2.9	3.1	3.4	0.3	2.9	3.0	3.4	0.0	0.0	-0.1	0.0
Q21	17.7	25.1	24.2	30.2	17.2	24.9	24.7	30	-0.5	-0.2	0.5	-0.2

1. A positive value indicates the maximum flow rate is in the direction of the flow arrow shown on the report figure, while conversely a negative value indicates the maximum flow rate is in the opposite direction to the flow arrow shown on the report figure.
2. A positive value represents an increase in peak flow attributable to the project. Conversely, a negative value represents a decrease in peak flow attributable to the project.

TABLE C1 (Cont'd)
PEAK FLOWS
UPPER WOLLI CREEK FLOODPLAIN
(cubic metres per second)

Peak flow identifier	Present day conditions[1]				Post-construction conditions[1]				Difference[2]			
	20 year ARI	100 year ARI	200 year ARI	PMF	20 year ARI	100 year ARI	200 year ARI	PMF	20 year ARI	100 year ARI	200 year ARI	PMF
Q22	103.0	136.0	164.0	629.0	105	136	163.0	623	2.0	0.0	-1.0	-6.0
Q23	9.2	12.7	14.1	20.0	9.2	12.7	14.2	18.3	0.0	0.0	0.1	-1.7
Q24	1.4	6.1	8.1	18.0	1.3	6.1	8.3	23.3	-0.1	0.0	0.2	5.3
Q25	24.4	31.8	38.0	75.8	24.4	31.8	38.0	75.8	0.0	0.0	0.0	0.0
Q26	1.7	2.2	4.1	9.7	1.7	2.2	4.0	9.8	0.0	0.0	-0.1	0.1
Q27	-1.3	-5.2	-9.4	-78.5	-1.3	-5.2	-9.2	-77.1	0.0	0.0	0.2	1.4
Q28	-0.2	-0.3	-0.8	8.6	-0.3	-0.4	0.8	8.6	-0.1	-0.1	1.6	0.0
Q29	3.2	4.2	5.0	9.4	3.2	4.2	5.0	9.4	0.0	0.0	0.0	0.0
Q30	152.0	209.0	250.0	876.0	152	208	249.0	865	0.0	-1.0	-1.0	-11.0
Q31	2.9	3.7	4.4	8.3	2.9	3.7	4.4	8.3	0.0	0.0	0.0	0.0
Q32	0.0	0.0	0.0	0.0	0	0	0.0	0	0.0	0.0	0.0	0.0
Q33	0.9	1.2	1.4	2.3	0.9	1.2	1.4	2.3	0.0	0.0	0.0	0.0
Q34	14.0	18.4	21.9	45.2	14	18.4	21.9	45.2	0.0	0.0	0.0	0.0
Q35	160.0	219.0	262.0	912.0	160	218	261.0	900	0.0	-1.0	-1.0	-12.0
Q36	14.4	19.4	23.3	47.3	14.4	19.4	23.3	47.3	0.0	0.0	0.0	0.0
Q37	10.4	13.2	16.9	30.2	10.6	13.2	16.9	30.2	0.2	0.0	0.0	0.0
Q38	165.0	226.0	271.0	956.0	165	225	270.0	943	0.0	-1.0	-1.0	-13.0
Q39	171.0	236.0	285.0	980.0	171	236	284.0	972	0.0	0.0	-1.0	-8.0

1. A positive value indicates the maximum flow rate is in the direction of the flow arrow shown on the report figure, while conversely a negative value indicates the maximum flow rate is in the opposite direction to the flow arrow shown on the report figure.
2. A positive value represents an increase in peak flow attributable to the project. Conversely, a negative value represents a decrease in peak flow attributable to the project.

TABLE C2
PEAK FLOWS
LOWER COOKS RIVER FLOODPLAIN
(cubic metres per second)

Peak flow identifier	Present day conditions(1)				Post-construction conditions(1)				Difference(2)			
	20 year ARI	100 year ARI	200 year ARI	PMF	20 year ARI	100 year ARI	200 year ARI	PMF	20 year ARI	100 year ARI	200 year ARI	PMF
Q1	88.3	152.5	184.5	602.1	88.3	153	184.5	602	0	0.5	0	-0.1
Q2	84.5	152.2	197.1	650.6	84.5	152	197.1	652	0	-0.2	0	1.4
Q3	89.2	144.2	175.1	627.4	89.2	144	175.1	626	0	-0.2	0	-1.4
Q4	127.2	191.2	227.2	846.4	127	190	227.2	848	-0.2	-1.2	0	1.6
Q5	127.5	190.8	227.4	-	128	191	228.1	-	0.5	0.2	0.7	-
Q6	132.5	200.6	238.5	-	132	201	239.6	-	-0.5	0.4	1.1	-
Q7	143.7	205	237.7	-	144	205	238.7	-	0.3	0	1	-
Q8	148.6	203.5	216.4	-	149	203	216.4	-	0.4	-0.5	0	-
Q9	140.2	187.2	212.2	379.5	140	187	212.2	380	-0.2	-0.2	0	0.5
Q10	453.8	619.5	675	2343.3	454	620	675	2343	0.2	0.5	0	-0.3
Q11	316.9	429.5	480.8	1367.1	317	430	480.9	1367	0.1	0.5	0.1	-0.1
Q12	723.6	954.7	1057.6	-	724	955	1057.4	-	0.4	0.3	-0.2	-
Q13	0	24.8	38.6	-	0	24.8	38.6	-	0	0	0	-
Q14	829.3	1055.5	1160.1	-	830	1055	1160.2	-	0.7	-0.5	0.1	-
Q15	835.9	1059.7	1161.3	2892.1	836	1058	1161.5	2917	0.1	-1.7	0.2	24.9
Q16	45	60.6	71.4	111.5	45	60.6	71.4	112	0	0	0	0.5
Q17	92	127.2	143.4	316.1	92	127	143.4	316	0	-0.2	0	-0.1
Q18	914.9	1145.4	1264.6	3094.2	915	1146	1264.8	3114	0.1	0.6	0.2	19.8

1. A positive value indicates the maximum flow rate is in the direction of the flow arrow shown on the report figure, while conversely a negative value indicates the maximum flow rate is in the opposite direction to the flow arrow shown on the report figure.
2. A positive value represents an increase in peak flow attributable to the project. Conversely, a negative value represents a decrease in peak flow attributable to the project.

WestConnex