Hydrological Mitigation Report





Windsor Bridge Replacement

Hydrological Mitigation Report

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Executive Summary

The NSW Government is replacing Windsor Bridge with a new bridge to provide a safe and reliable crossing of the Hawkesbury River at Windsor. The existing bridge is deteriorating due to age and heavy usage and has reached the end of its economic life. It no longer meets the demands of current traffic volumes or current road standards and requires significant on-going maintenance. The existing bridge (with exception of the first southern span) will be demolished and removed after the replacement bridge has been opened to traffic. This Hydrological Mitigation Report has been prepared to address the NSW Minister for Planning and Infrastructure's Conditions of Approval (CoA) for Hydrology and Flooding aspects of the Windsor Bridge Replacement Project.

The project is located in a flood prone area. The behaviour of flooding at Windsor is largely affected by its varying topography, consisting of the low lying floodplains around Windsor and the narrow winding gorge from Wilberforce down to Sackville. The narrow constriction of the gorge controls outflow from the Hawkesbury River system, which in large flood events causes floodwaters to flow out slower than the rate at which they flow in. This results in relatively large increases in flood levels for small decreases in flood frequency. For example, the difference in flood levels between the 100 year and 5 year average recurrence interval (ARI) events at Windsor Bridge is approximately 6.2m. The large flood height range at Windsor sets it apart from other locations in NSW.

In light of the significant flood risk at Windsor, the potential impact of the project on flooding has been considered at all design stages of the project. Features of the replacement bridge which have been incorporated into the final design to mitigate flood impacts includes:

- Oval shaped piers with a 1.85m width measured perpendicular to the flow direction of flow.
- Minimal number of piers within the river.
- Inclusion of hand rails which are designed to collapse in a flood event.
- Bridge abutments set back from the channel banks.

It is impossible to exactly replicate the existing flood behaviour when replacing the existing bridge with a significantly different replacement bridge. In order to test the flood impacts of the project, a detailed two dimensional (2D) hydrodynamic model of the Hawkesbury River and floodplains at Windsor was developed. The hydrodynamic model was calibrated and validated against observed peak flood levels and recorded stage hydrographs for three historical flood events. The calibrated hydrodynamic model was used to simulate existing flood behaviour and flood behaviour under construction and operation phases of the project. The flood behaviour was assessed for the 5, 10, 20, 50, 100 and 2000 year ARI events and probable maximum flood (PMF). A comparison between the model results for the existing flood behaviour and construction and operation phase flood behaviour as a result of the project.

The comparison of model results indicates that there are negligible flood level impacts during the construction and operation phase for the PMF event, 2000 r, 100, 50 and 20 year ARI events, with minor flood level impacts for the 10 and 5 year ARI events. The effect of the minor change in flooding to properties, access routes and infrastructure has been assessed to determine if mitigation is required.

For the operational phase, the model results indicate that there is one dwelling in the 10 year ARI event and one farm shed in the 5 year ARI event which were not previously flooded and would experience above floor level flooding. Both buildings are at the threshold of flooding under existing conditions and a minor change in flood levels results in above floor level flooding with depths of 10mm and 20mm for the 10 year and 5 year ARI events respectively. Both buildings are inundated for all design flood events rarer than the 10 year and 5 year ARI events with flood depths up to 6.35m in a 100 year ARI event. In the context of the minor change in flood levels and significant flood risk at these buildings, it is considered that no reasonable and feasible flood mitigation measures should be implemented for these buildings.

The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to access and infrastructure. Access routes and infrastructure assets within the areas of flood level changes are currently inundated by flooding with model results indicating current flood depths typically in the range of 1m to 9m for the



10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, minor changes in flood levels will have a negligible impact on access routes and infrastructure and no reasonable and feasible flood mitigation measures are required.

Construction phase flood impacts are marginally greater than the operational phase impacts as both the existing bridge and replacement bridge have a greater impact on flooding. To reduce the potential flood impacts, the construction phase of the project should be programmed to ensure the minimum possible period when both the existing bridge and replacement bridge are in place at the same time. The construction program should consider phasing the period where both bridges are fully in place at the same time to periods of the year where the likelihood of flooding is reduced. A review of the gauged water level record on the Hawkesbury River at Windsor indicates that flooding at Windsor is more likely to occur in winter (44% of events) with the least likelihood of floods occurring during the spring months (10%).



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1. Introduction

1.1 Purpose

This Hydrological Mitigation Report (Report) has been prepared to address the NSW Minister for Planning and Infrastructure's Conditions of Approval (CoA) for Hydrology and Flooding aspects of the Windsor Bridge Replacement Project. This report is supported by a detailed hydrological and hydraulic assessment which is presented in the Windsor Bridge Replacement Hydrology and Hydraulics Report (Jacobs, 2017) and attached as **Appendix A. Table 1-1** below, provides a summary of where each CoA has been addressed within this Report.

Table 1-1 : Minister's Conditions of Approval for Hydrology and Flooding

Condition	Description	Condition Addressed	Reference
B5	The Applicant shall not commence construction of the project on or within those areas likely to alter flood conditions until such time as works identified in the Hydrological Mitigation Report, required under condition C27, have been completed, unless otherwise agreed by the Director-General	Yes	Refer to Condition of Approval No. C27 in this table.
C26	The Applicant shall ensure, where feasible and reasonable, that the project is designed to not exceed the afflux and other flooding criteria within the vicinity of the project as identified or predicted in the documents listed under condition A2.	Yes	Refer to Section 3 . While there is no specific flooding criteria defined for this project, the revised detailed design resulted in a reduction of flood impacts from the concept design and what is reported in the EIS for the project.
	The Applicant shall develop a Hydrological Mitigation Report for properties in the Hawkesbury River floodplain areas where flood impacts are predicted to increase as a result of the project. The Report shall be based on detailed floor level survey and associated assessment of potentially flood affected properties in those areas. The Report shall:	Yes	Hydrological Mitigation Report (this report). Predicted flood impacts (refer to Section 2) Detailed floor level survey (refer to Section 2.1.3.1)
	a) Identify properties in those areas likely to have an increased flooding impact and detail the predicted increased flooding impact.	Yes	Refer to Section 2.1.3.1 and Section 2.2.3.1
C27	 Identify mitigation measures to be implemented where increased flooding is predicted to adversely affect access, property or infrastructure. 	Yes	Refer to Section 3
	c) Identify measures to be implemented to minimise scour and dissipate energy at locations where flood velocities are predicted to increase as a result of the project and cause localised soil erosion and/or pasture damage.	Yes	Refer to Section 3
	d) Be developed in consultation with the relevant Council, NSW State Emergency Service and directly- affected property owners.	Yes	Refer to Section 4
	e) Identify operational and maintenance	Yes	Refer to Section 3



Condition	Description	Condition Addressed	Reference
	responsibilities for items (a) to (c) inclusive.		
C28	Based on the mitigation measures identified in this consent, the Applicant shall prepare a final schedule of feasible and reasonable flood mitigation measures proposed at each directly-affected property in consultation with the property owner. The schedule shall be provided to the relevant property owner(s) prior to the implementation/ construction of the mitigation works, unless otherwise agreed by the Director-General. A copy of each schedule of flood mitigation measures shall be provided to the Department and the relevant Council prior to the implementation/ construction of the mitigation measures on the property.	Yes.	Refer to Section 3 No reasonable and feasible flood mitigation measures have been identified at individual properties due to negligible impacts on flood planning levels adopted by Councils and minor flood impacts (up to a maximum 40mm increase in flood level) for 5 and 10 year average recurrence interval (ARI) events.
C29	In the event that the Applicant and the relevant property owner cannot agree on feasible and reasonable flood mitigation measures to be applied to a property within one month of the first consultation on the measures (as required by this consent), the Applicant shall employ a suitably qualified and experienced independent hydrological engineer, who has been approved by the Director-General, to resolve this dispute prior to the commencement of construction in the floodplain areas affected by increased afflux from the project. The independent hydrological engineer shall advise and assist affected property owners in negotiating feasible and reasonable mitigation measures.	Not applicable	Refer to "Requirement Addressed" comment under Condition of Approval No. C28 in this table.
C30	The Applicant shall provide assistance to the relevant council and/ or NSW State Emergency Service, to assist in the preparation of any new or necessary update(s) to the relevant plans and documents in relation to flooding, to reflect changes in flooding levels, flows and characteristics as a result of the project.	Yes	Refer to Section 4

1.2 Background

The existing Hawkesbury River Bridge at Windsor was opened in 1874. The existing bridge is the oldest existing crossing of the Hawkesbury River and parts of the bridge are now over 130 years old. Windsor Bridge is deteriorating due to age and heavy usage and has reached the end of its economic life. It no longer meets the demands of current traffic volumes or current road standards and requires significant on-going maintenance. The bridge is regularly inspected to ensure safety for use and heavy vehicle traffic is now limited to 40km/h. Windsor Bridge is below the 2 year ARI flood event level while the surrounding approach roads provide access closer to the 5 year ARI flood level.

The NSW Government is replacing the existing bridge with a new bridge to provide a safe and reliable crossing of the Hawkesbury River at Windsor. In November 2011, Sinclair Knight Merz Pty Ltd (SKM), now Jacobs, was commissioned by the Roads and Maritime Services (Roads and Maritime) to complete a concept design for a replacement bridge and prepare an Environmental Impact Statement (EIS) which included a detailed Hydrology Study (Working Paper No. 8).



The EIS *Windsor Bridge Replacement Project Environmental Impact Statement* was on public exhibition from November 2012 until December 17th 2012. Following completion of the EIS and concept design, Roads and Maritime commissioned Jacobs to undertake detailed design documentation for the replacement bridge project.

A submissions report (and preferred infrastructure report) was finalised in May 2013 which addressed stakeholder submissions received during the EIS exhibition period. Following this, in December 2013, the Project was approved by the Minister for Planning and Infrastructure with Conditions of Approval (CoA) issued.

The project was placed on hold for a period of time with Jacobs' re-engaged in December 2015 to complete the detailed design in accordance with CoA and prepare tender documents for a RMS construct only contract. At the time of preparation of this report, the detailed design was 100% complete.

The proposed upgrade involves the following works:

- Construction of a replacement bridge over the Hawkesbury River at Windsor, approximately 35 metres downstream of the existing Windsor Bridge.
- Reconstruction of existing intersections and bridge approach roads to accommodate the replacement bridge, including changes to the Macquarie Park access.
- Construction of a shared pedestrian/cycle pathway for access to and across the replacement bridge.
- Removal, backfill and landscaping of the existing bridge approach roads.
- Demolition and removal of the existing Windsor Bridge with the exception of abutments and the southern first span.
- Landscaping works within the open space area of Thompson Square and adjacent to the northern intersection of Bridge Street, Wilberforce Road, Freemans Reach Road and the access to Macquarie Park.
- Connection of The Terrace to provide continuous access along the southern bank of the river.
- Completion of bridge scour protection works.
- Construction of a permanent water quality basin to capture and treat stormwater runoff from the bridge and northern intersection prior to stormwater being discharged to the Hawkesbury River.
- Ancillary works necessary for construction, including:
 - Adjustment, relocation and/or protection of utilities and services, as required.
 - Construction and operation of temporary construction and compound sites.

The bridge replacement will be approximately 158m long, separated into five spans, and have design surface levels of about 12.0m AHD at the southern end and 10.0m AHD at the northern end. The bridge deck is 15.24m wide with a 1.5% cross fall and comprises 1850mm deep box girders with a 75mm thick asphalt layer. The minimum bottom levels of the bridge soffit will be about 9.3m AHD at the southern end and 7.3m AHD at the northern end.

The bridge superstructure will be supported by four piers located in the river. The piers are oval in shape with a 1.85m width measured perpendicular to the flow direction. The piers will be connected to 2.4m wide pile caps near the upper tidal limit, which in turn will be connected to a single row of 4 x 1500mm diameter piles.

The replacement bridge has been designed with improved flood immunity. The replacement bridge has a sloping deck and is 1.9m higher than the existing bridge at its lowest point (northern end). This increase in bridge levels reduces the frequency of flooding of the bridge and increases access to Windsor from areas north of the Hawkesbury River during floods.

During the construction of the replacement bridge, the existing bridge will remain in place. The existing bridge (with exception of the first southern span) will be demolished and removed after the replacement bridge has been opened to traffic, and therefore both bridges will be fully in place for a period of approximately 3 months.



1.3 Study Area

The study area for the hydrology and hydraulic assessment extends from Agnes Banks (just downstream of the Grose River confluence) to Sackville, a distance of about 50km along the Hawkesbury River. The extent of the study area was chosen to consider the complex nature of flooding around Windsor, and the extent of potential impacts identified in the EIS prepared for the Concept Design (Roads and Maritime, 2012).

The study area includes the urban centres of Windsor, Richmond, McGraths Hill, Pitt Town and Wilberforce, and the low-lying floodplain areas of Richmond lowlands, Freemans Reach, and Pitt Town Bottoms that are predominantly used for horticulture, cropping, and grazing.

Further information on the catchment, flood behaviour and historic flood events is provided in the Windsor Bridge Replacement Hydrology and Hydraulics Report (Jacobs, 2017) in **Appendix B**.

1.4 Flood model

In order to assess the existing flood conditions and the impacts of the project on flood behaviour, Jacobs developed a two dimensional hydrodynamic model of the river and floodplain within the study area, extending from Agnes Banks to Sackville. The hydrodynamic model was developed using TUFLOW modelling software. The hydrodynamic model was established using digital terrain data developed from ALS and bathymetric surveys and inputs from previous modelling. Hydrologic and tailwater level boundary conditions for the hydrodynamic model were obtained from WMAwater. Hydrographs of the main upstream inflow and downstream tailwater levels were obtained from WMAwater's latest RUBICON hydraulic model. Inflow hydrographs for local creeks within the study area were obtained from WMAwater's calibrated RORB hydrologic model.

The hydrodynamic model was calibrated and validated against observed peak flood levels and recorded stage hydrographs for three historical flood events. Parameter values in the hydrodynamic model were adjusted so that a satisfactory fit to the peak flood levels observed at Windsor was achieved. The calibrated hydrodynamic model was used to simulate existing flood behaviour for a range of design flood events. The selected design events included the 5, 10, 20, 50, 100 and 2000 year ARI events and PMF event.

Further details on the development of the hydrodynamic model are contained in Appendix B.



2. Flood Impacts

The hydrodynamic model of the river and floodplain developed as part of the Windsor Bridge Replacement Hydrology and Hydraulics Report (Jacobs, 2017) has been utilised to assess the potential flood impacts during both the construction and operational phases of the project.

2.1 Operational phase

2.1.1 Introduction

The hydrodynamic model was modified by removing the existing bridge and adding the replacement bridge, viewing platform, scour protection and road embankments into the model. The replacement bridge and associated works has been based on the 100% detailed design documentation.

The flood modelling results have been used to identify the potential changes in flood behaviour as a result of the operational phase of the project at both a regional and property level for the modelled design flood events.

2.1.2 Changes in flood behaviour

2.1.2.1 Flood levels

Changes in the flood levels during the operational phase of the project for the modelled design flood events are summarised in **Table 2-1**.

Table 2-1 : Changes in flood level during the operational phase of the project

Design flood event	Change in flood level
PMF	Negligible
200 year ARI	Negligible
100 year ARI	Negligible
50 year ARI	Negligible
20 year ARI	Negligible
10 year ARI	Minor
5 year ARI	Minor

There are negligible changes in flood levels for the PMF event and the 200 year, 100 year, 50 year and 20 year ARI events. There are potential minor changes in flood levels for the 10 year and 5 year ARI events. No flood modelling has been undertaken for events more frequent than the 5 year ARI event.

The flood level for the 2 year ARI event at Windsor Bridge has been estimated from the Flood Frequency Analysis (FFA) undertaken for the Windsor gauge (WMAwater, 1994). This gauge is located around 50 metres upstream of Windsor Bridge and the FFA shows a 2 year ARI flood level of 8.7m AHD. Based on a comparison between the 2 year ARI flood level and bridge design levels, the replacement bridge will allow greater conveyance of smaller events, i.e. events less than the 2 year ARI event, while there will be additional obstruction to flows for events just impeded by the new bridge, i.e. the 2 year ARI event and events rarer than the 2 year ARI event. The flow area for the replacement bridge structure is greater than the existing bridge structure at the 2 year ARI flood level, therefore, there is likely to be a reduction in flood levels for events more frequent than the 2 year ARI.

Flood maps (Figure 2-1 to Figure 2-3) have been prepared to show the potential spatial extent of changes in peak water levels.







Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 2-1 | Windsor Bridge Replacement 20 year ARI Flood Level and Building Impacts



 Locality 	Change in flood level	10 to 10	Properties impacted by	+15mm to +20mm
Rail	(mm)	10 to 20	change in flood level	•
Main roads	-50 to -20	20 to 50	+10mm to +15mm	+20mm to +40mm
LGA boundary	-20 to -10	50 to 100	•	•



Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 2-2 | Windsor Bridge Replacement 10 year ARI Flood Level and Building Impacts



 Locality 	Change in flood level	10 to 10	Buildings impacted by	+15mm to +20mm
Rail	(mm)	📃 10 to 20	change in flood level	•
Main roads	-50 to -20	📃 20 to 50	+10mm to +15mm	+20mm to +40mm
LGA boundary	-20 to -10	50 to 100	•	•



Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 2-3 | Windsor Bridge Replacement 5 year ARI impact to properties



Changes in flood level have been categorised into value ranges (i.e. 10mm to 20mm). Changes in flood levels up to 10mm are within the accuracy of the hydrodynamic model and have not been mapped. **Figure 2-1** indicates that there are no changes in flood level for the 20 year ARI event. Flood maps for the PMF, 200 year, 100 year and 50 year ARI events are the same as the 20 year ARI event and individual maps for these design flood events have therefore not been included in this report.

The maps indicate that regional changes in flood levels for the 10 year and 5 year ARI events extend upstream and downstream of the replacement bridge. For the 5 year ARI event, decreases in flood levels extend downstream of Windsor Bridge and are generally in the range of 10mm to 20mm. Flood level increases are generally in the range of 10mm to 20mm for the 10 year ARI event and 10mm to 50mm for the 5 year ARI event. For the 10 year ARI event, localised areas of flood level increases up to 100mm occur directly upstream of the new bridge. For the 5 year ARI event, the majority of the flood level increases are 20mm, however, there are localised areas of flood level increases up to 50mm directly upstream of the replacement bridge.

2.1.2.2 Flow velocities

Changes to flood velocities are limited to the channel and channel banks in the vicinity of the existing and replacement bridge. Model results indicate increases and decreases in flood velocities for the full range of design flood events. Flow velocities along the southern side of the river are observed to increase by the greatest amount with peak flow velocity increases of up to 0.6m/s in the 100 year ARI event. Changes in flow velocities for the study area are negligible. The changes in velocity occur as a result of:

- Relocating the bridge constriction and the concentration of flow from the existing bridge to the replacement bridge. This causes velocities at the existing bridge to reduce and velocities at the new bridge to increase.
- The increased waterway area provided by the replacement bridge compared to the existing bridge allows more flow through the bridge opening when flood levels are below 10.5m AHD. This causes a general increase in flow velocity through the bridge opening.
- The sloping deck configuration of the replacement bridge forms a preferential flow path along the southern side of the river since the bridge deck is higher on this side. This generally causes velocities on the southern side of the channel to increase and velocities on the northern side of the channel to decrease.

2.1.3 Impacts of changes in flood behaviour

2.1.3.1 Properties

To identify buildings impacted by the change in flood levels during the operational phase, a property database was developed. The database was developed using property data from the Windsor Bridge Environmental Impact Statement (SKM, 2012) and 2016 Land Property Information (LPI) property data. The property database provides information on the location and floor level of buildings within areas impacted by the project. Detailed floor levels were determined from threshold level survey data captured by Roads and Maritime for the Windsor Bridge Environmental Impact Statement (EIS) and elevations extracted from a digital elevation model (DEM) generated from aerial laser scanning (ALS) data. The floor level survey was undertaken for buildings generally within the 5 year ARI event extent maps used in the development of the Windsor Bridge EIS. The remaining building levels were determined from the DEM data. A comparison between the surveyed floor levels and the DEM data. On average, the surveyed floor levels are 17mm higher than the levels in the DEM data.

The flood level results from the hydrodynamic model have been compared to the building floor levels to determine the depth of flooding above floor level and the change in flood levels at buildings during the operational phase. The results have been mapped in **Figure 2-2** and **Figure 2-3** and indicate minor changes in flood levels at properties for the 5 and 10 year ARI events respectively. As discussed in **Section 2.1.2.1** there are negligible changes in flood levels for the 20 year ARI and rarer events.

Tabulated results detailing the change in flood levels at each building are provided in **Appendix A**. The tabulated results show that the majority of buildings with changes in flood levels are already flooded above floor level. For the 10 year ARI event, 96% of buildings have above floor level flooding with the average depth of



flooding equal to 1.26m. For the 5 year ARI event, 44% of buildings have above floor flooding with average depths of flooding equal to 0.6m. A summary of the buildings with changes in flood levels are summarised in **Table 2-2**.

Design Event ARI	Number o levels fo	f buildings v or various flo	with change bod level in	es in flood creases	Total number of	Total number of	Number of building	Comment
	<10mm	10 mm to 15 mm increase	15mm to 20 mm increase	20mm to 40 mm increase	buildings with flood level increases >10 mm	already flooded above floor level	which ald not previously flood)	
10 year	Within the accuracy	72	12	2	86	85	1	Maximum increase in flood level of 26mm
5 year	of the TUFLOW model	0	3	37	40	39	1	Maximum increase in flood level of 40mm

Table 2-2 : List of buildings with changes in flood levels during the operational phase

Table 2-2 indicates that there is one building in the 10 year ARI event and one building in the 5 year ARI event which was not previously flooded (for that particular event) and which experiences above floor level flooding as a result of the replacement bridge for the assessed design flood events. Details of changes in flood levels at these two buildings are summarised in **Table 2-3**.

Table 2-3 : List of buildings which did not previously flood for assessed design flood events

Property Address	Floor Level (m AHD)	Existing flood level (m AHD) for range of ARI events				Flood level during operational phase (m AHD) for range of ARI events			
		100 year ARI	20 year ARI	10 year ARI	5 year ARI	100 year ARI	20 year ARI	10 year ARI	5 year ARI
	12.35**	17.77	13.81	12.34	NA	17.77	13.81	12.35	NA
	11.42*	17.77	13.81	12.34	11.42	17.77	13.81	12.35	11.44

*Surveyed floor level

**Floor level from DEM

The building at **a second seco**

The building at the flood level under existing conditions is equal to the building floor level for the 5 year ARI event and that the building would be inundated for all design flood events rarer than the 5 year ARI. The depth of flooding above floor level for the 100 year, 20 year and 10 year ARI events are 6.35m, 2.39m and 0.93m respectively for the existing and



proposed conditions. Under proposed conditions, the building is subject to 20mm above floor flood depths in the 5year ARI event. Given the degree of flood risk at this building, this small increase in flood level (20mm) is considered to have a negligible impact on the building.

A qualitative assessment has been undertaken to consider potential impacts to property land uses including:

- Grazing.
- Horticulture orchards and vegetables.
- Horticulture turf farming.
- Intensive animal production.
- Native forest and waterways.

The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to property land uses. The flood maps show that approximately 2800 hectares and 2600 hectares of land are affected by changes in flood levels for the 10 year and 5 year ARI events respectively. Model results indicate that current flood depths in these areas are typically in the range of 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, minor changes in flood levels will have negligible impacts on property land use. The flood maps also indicate that there is a negligible increase in the extent of flooding during the operational phase.

The replacement bridge is likely to result in a minor decrease in flood levels for events equivalent to or more frequent than the 2 year ARI event which is likely to result in a minor reduction in flood levels to property land uses for frequent flood events.

As discussed in **Section 2.1.2.2**, changes in velocity are limited to the channel and channel banks in the vicinity of the existing and replacement bridge and there are negligible changes in velocity at properties.

2.1.3.2 Access

The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to property access within the areas of flood level changes. The areas where changes in flood level occur are currently inundated for the 10 year and 5 year ARI events. Model results indicate that current flood depths are typically in the range of 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, access routes will not be passable and minor changes in flood levels has no impact on property access. The flood maps also indicate that there are negligible increases in the extent of flooding during the operational phase and no additional access issues have been generated by the replacement bridge. The replacement bridge is likely to result in a minor decrease in flood levels for events equivalent to or more frequent than the 2 year ARI event. It is expected that these minor decreases in peak flood levels would have a negligible change to regional access.

The replacement bridge has been designed with improved flood immunity reducing the frequency of flooding of the bridge and increasing access to Windsor from areas north of the Hawkesbury River during more frequent floods.

As discussed in **Section 2.1.2.2**, changes in velocity are limited to the channel and channel banks in the vicinity of the existing and replacement bridge and there are negligible velocity impacts to access.

2.1.3.3 Infrastructure

The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to infrastructure. Infrastructure assets within the areas of flood level changes include roads and bridges. The infrastructure assets within these areas of flood level change are currently inundated by flooding with model results indicating current flood depths typically in the range of 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, minor changes in flood levels will have a negligible impact on infrastructure. The replacement bridge is likely to result in a minor decrease in flood levels for events equivalent to or more



frequent than the 2 year ARI event. These minor changes in flood levels may reduce the frequency of flooding of infrastructure assets and improve both access and maintenance costs.

The impact of velocity changes to infrastructure is limited to the vicinity of the existing and replacement bridge. Increases in velocities along the southern foreshore have the potential to impact the gabion scour retaining wall located on the southern foreshore. The increase in flow velocities may increase the risk of scour and erosion occurring at the base of the retaining wall during a flood, potentially causing undermining and structural collapse. A separate investigation is currently in progress as part of this project to review the current gabion wall suitability.

2.1.4 Flood Plans

The Hawkesbury Nepean Flood Emergency Sub Plan (SES, 2015) has been prepared to cover prevention and preparedness measures, the conduct of flood operations and the transition to recovery for floods in the Hawkesbury Nepean Valley. The plan has been prepared by NSW State Emergency Services (SES) and covers the area between Wallacia to downstream of Spencer. The Plan notes that the gauge at Windsor (reference 212426) is used for emergency planning. Windsor's flood evacuation routes include the Windsor Road at South Creek (closed at 13.5 metres AHD at Windsor Bridge gauge).

Both the Hawkesbury City Local Flood Plan (NSW SES, 2010) and the Penrith City Local Flood Plan are subordinate plans to the Hawkesbury Nepean Flood Emergency Sub Plan. Both plans provide localised emergency response procedures during a flood event.

The changes in flood levels extend to areas covered by the Hawkesbury Nepean Flood Emergency Sub Plan and both Hawkesbury City Local Flood Plan and Penrith City Local Flood Plan. Changes in flood levels for the 10 and 5 year ARI events during the operational phase are considered minor and do not warrant any updating of the Flood Plans.

2.1.5 Development Control Plans

The 100 year ARI flood level is used by both Hawkesbury and Penrith City Councils as a development control. Since the project does not impact on flood levels for the 100 year ARI event there is no impact on development control levels.

2.2 Construction phase

2.2.1 Introduction

This assessment has focussed on the period during the construction phase of the project when both bridges are expected to be fully in place for a period of approximately 3 months. Changes in flood behaviour have been assessed at a regional level for the modelled design flood events.

The hydrodynamic model was modified to include both the existing bridge and the replacement bridge and associated works. The replacement bridge and associated works has been based on the 100% detailed design documentation and does not include formworks and other site works which may be present close to completion of the construction phase. The modified model was run for a range of design flood events to quantify the potential changes in flood behaviour for the full range of design flood events.

2.2.2 Changes in flood behaviour

2.2.2.1 Flood levels

Potential changes in flood levels during the construction phase are summarised in **Table 2-4** for the modelled design flood events.



Design flood event	Change in flood level
PMF	Negligible
200 year ARI	Negligible
100 year ARI	Negligible
50 year ARI	Negligible
20 year ARI	Negligible
10 year ARI	Minor
5 year ARI	Minor

Table 2-4 : Changes in flood level during the construction phase of the project for modelled design flood events

There are negligible changes in flood levels for the PMF event and the 200 year, 100 year, 50 year and 20 year ARI events. There are potential minor changes in flood levels for the 10 year and 5 year ARI events. No flood modelling has been undertaken for events more frequent than the 5 year ARI event. The 2 year ARI flood level has been determined from a FFA and indicates that the existing bridge would be inundated in a 2 year ARI event.

Flood maps (Figure 2-4, Figure 2-5 and Figure 2-6) have been prepared to show the potential spatial extent of changes in peak water levels. Figure 2-4 indicates that there are no changes in flood level for the 20 year ARI event. Flood maps for the PMF, 200 year, 100 year and 50 year ARI events are the same as the 20 year ARI event and individual maps for these design flood events have therefore not been included in this report. Figure 2-5 and Figure 2-6 indicates that potential changes in flood level during the construction phase extend upstream and downstream of the replacement bridge. For the 10 year ARI event, minor flood level increases are generally in the range of 20mm to 50mm. For the 5 year ARI event, potential flood level increases are generally in the range of 50mm to 100mm, with some localised changes in levels up to 110mm directly upstream of the existing Windsor Bridge.

2.2.2.2 Flow velocities

Changes in velocities are limited to the channel and channel banks in the vicinity of the existing and replacement bridges. Model results indicate potential flood velocity increases up to 1.0m/s and maximum decreases of 0.1m/s for the modelled design flood events. Flow velocities along the southern side of the river are observed to increase by the greatest amount during the construction phase with peak flow velocity increases occurring in the 10 year ARI event.

2.2.3 Impacts of changes in flood behaviour

2.2.3.1 Properties

A qualitative assessment of the potential changes in flood levels at buildings has been undertaken based on changes in flood behaviour outlined in **Section 2.2.2.1**. There are minor changes in flood levels at properties for the 5 and 10 year ARI events and negligible flood impacts for the 20 year ARI and rarer events. For the 10 year ARI event, potential flood level increases at buildings are in the range of 10mm to 50mm and extend upstream and downstream of Windsor Bridge. For the 5 year ARI event, the majority of the potential flood level increases at buildings are in the range of 50mm to 100mm.

The majority of the buildings with potential changes in flood levels are already flooded during the 10 year and 5 year ARI events. The model results indicate that flood depths across the floodplain range from 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, the potential increase in flood levels at buildings is considered to have a negligible impact.





0 1 2km N 1:90,000 @ A4

> Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 2-4 | Windsor Bridge Replacement 20 year ARI temporary flood impact for combined bridge scenario



 Locality 	Change in flood level	10 to 10
Rail	(mm)	10 to 20
Main roads	-50 to -20	20 to 50
LGA boundary	20 to -10	50 to 100



Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 2-5 | Windsor Bridge Replacement 10 year ARI temporary flood impact for combined bridge scenario





0 1 2km N 1:90,000 @ A4

> Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 2-6 | Windsor Bridge Replacement 5 year ARI temorary flood impact for combined bridge scenario



A qualitative assessment has been undertaken to consider potential impacts to property land use such as grazing and horticulture. The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to property land use. The flood maps show that approximately 11,000 hectares and 3,000 hectares of land have changes in flood levels for the 10 year and 5 year ARI events respectively. The model results indicate that flood depths across the floodplain range from 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event and the potential increases in flood levels are considered negligible. The flood maps also indicate that there are negligible increases in the extent of flooding during the construction phase.

As discussed in **Section 2.2.2.2**, changes in velocity are limited to the channel and channel banks in the vicinity of the existing and replacement bridge and there are negligible velocity impacts to properties.

2.2.3.2 Access

The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to access. The areas shown to have changes in flood level are currently inundated with flood depths typically in the range of 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, access routes will not be passable and the potential change in flood levels has no impact on property access. The model results indicate that there are negligible increases in the extent of flooding during the construction phase and no additional access issues have been generated during the construction phase.

As discussed in **Section 2.2.2.2**, changes in velocity are limited to the channel and channel banks in the vicinity of the existing and replacement bridge and there are negligible velocity impacts to access.

2.2.3.3 Infrastructure

The flood level changes for the 10 year and 5 year ARI events will have a negligible impact to infrastructure assets. The infrastructure assets within these areas of flood level changes are currently inundated by flooding with model results indicating current flood depths typically in the range of 1m to 9m for the 10 year ARI event and 1m to 8m for the 5 year ARI event. At these depths, minor changes in flood levels will have a negligible impact on infrastructure.

The impact to infrastructure of changes in velocities is limited to the vicinity of the existing and replacement bridge. Increases in velocities along the southern foreshore have the potential to impact the gabion scour retaining wall located on the southern foreshore. A separate investigation is currently in progress to review the current gabion wall suitability.



3. Mitigation Measures

The project is located in an area of significant flood risk. A unique feature of flooding in the Hawkesbury River at Windsor is the relatively large increase in flood levels for small decreases in frequency. For example, the difference in flood levels between the 100 year and 5 year ARI events at Windsor Bridge is approximately 6.2m. The large flood height range at Windsor sets it apart from other locations in NSW.

The potential impact of the project on flooding has therefore been considered at all design stages. Design improvements since the concept design, assessed as part of the Windsor Bridge EIS, have resulted in a reduction in flood impacts for the final design. Features of the replacement bridge which have been incorporated into the final design to mitigate flood impacts includes:

- Oval shaped piers with a 1.85m width measured perpendicular to the flow direction of flow.
- Minimal number of piers within the river.
- Inclusion of hand rails which are designed to collapse in a flood event.
- Bridge abutments set back from the channel banks.

As discussed in **Section 2**, there are negligible changes in flood behaviour during the construction and operation phase for the PMF, 2000 year, 100 year, 50 year and 20 year ARI events with minor changes in flood behaviour for the 10 year and 5 year ARI events. Changes in flood behaviour with the new bridge are primarily due to the different number and location of piers, increased height of the bridge deck plus increased thickness of the bridge superstructure including barriers. The removal of the existing bridge also changes flood behaviour through the removal of the deck and bridge piers. It is impossible to exactly replicate the existing flood behaviour when replacing the existing bridge with a significantly different replacement bridge.

3.1 Operational Phase

3.1.1 Properties

There are negligible changes in flood levels at buildings during the operational phase for the following design flood events: PMF event, 2000 year, 100 year, 50 year and 20 year ARI events. The model results indicate that the replacement bridge results in minor changes in flood levels at properties in both the 10 and 5 year ARI events. The average increase in above floor level flooding is 10mm and the maximum increase in above floor level is 40mm. The majority of buildings where flood level changes occur are already flood affected with flood depths up to 12.4m in a 100 year ARI event. The minor increase in levels during the operational phase has no discernible impact on the frequency of flooding of these buildings.

As discussed in **Section 2.1.3.1** there is one dwelling in the 10 year ARI event and one farm shed in the 5 year ARI event which were not previously flooded and would experience above floor level flooding during the operational phase. Both buildings are at the threshold of flooding having 10mm and nil freeboard above building floor level for the 10 year and 5 year ARI events respectively. Both buildings are also inundated for all design flood events rarer than the 10 year and 5 year ARI events respectively. It is considered that no reasonable and feasible flood mitigation measures should be implemented for these two buildings as increases to flood levels are negligible and these buildings are already subject to significant above floor level flooding for events rarer than the 10 year ARI events respectively.

Minor increases in flood levels will not adversely affect property land uses. Therefore it is considered that no mitigation measures would be required to manage the minor changes in flood levels for the 10 year and 5 year ARI events.



3.1.2 Access

Access routes within areas with minor changes in flood levels are already inundated by flooding. The flood depths under existing conditions make these access routes impassable. Minor increases in flood levels have no impact on property access and mitigation measures would not be required.

3.1.3 Infrastructure

Infrastructures assets within areas with minor changes in flood levels are already inundated by flooding. Minor increases in flood levels have no impact on infrastructure and mitigation measures to manage this change in flood levels would not be required.

The impact to infrastructure due to changes in velocities is limited to the vicinity of the existing and replacement bridge. A comprehensive assessment of the potential scour impacts on both banks of the river has been undertaken and the findings are documented the following reports:

- Northern bank scour protection detailed design report (Royal Haskoning DHV, 5 April 2017)
- Gabion wall visual inspection and stability assessment (Jacobs, March 2017)
- Southern river bank stability and scour protection design report (Jacobs, 13 April 2017)

The project will provide scour protection works on both banks of the river (upstream and downstream of the new bridge) to mitigate any potential scour impacts as a result of the proposed works. The proposed scour protection works is comprehensibly documented in Volume 9 – Scour Protection of the detailed design documentation.

3.2 Construction Phase

3.2.1 Response planning

During the construction phase an emergency management plan will be prepared by the contractor which will detail a proactive approach to planning and responding to a flood event. In the event an ancillary compound is located in a 1 in 20 ARI flood level area a flood management plan will be developed and implemented in accordance CoA 8.

3.2.2 Minimising the period when both bridges are in place

The construction phase of the project should be programmed to ensure the minimum possible period when both the existing bridge and replacement bridge are in place at the same time. This reduces the likelihood of a flood event affecting the construction phase works. The current estimated period when both the existing bridge and replacement bridge are in place at the same time is 3 months.

3.2.3 Scheduling of construction to ensure both bridges are in place during the low flow season

The program works should consider phasing the period where both bridges are fully in place at the same time to times of the year where the likelihood of flooding is reduced. A review of the gauged water level record at Windsor, from 1900 to 1990, has been undertaken to determine the seasonality of flooding at Windsor. A water level threshold value of 8m AHD was set as the basis for the assessment. A water level of 8m AHD is less than the 2 year ARI flood level of 8.7m AHD and corresponds with the minimum soffit level of the proposed bridge structure. **Figure 3-1** shows the results of the analysis of the gauged data based on the above criteria.





Figure 3-1 : Seasonality of flood levels above 8m AHD at Windsor gauge from 1900 to 1990

The gauged record for Windsor indicated that a total of 52 events had a level greater than 8m AHD over this 90 year period. The analysis of this record indicated that flooding at Windsor is more likely to occur in winter (44% of events) with the least likelihood of floods occurring during the spring months (10%).

3.2.4 Properties

There are negligible changes in flood levels at properties during the construction phase of the project for the following design flood events: PMF event, 2000 year, 100 year, 50 year and 20 year ARI events. Minor flood level changes at buildings occur for the 10 year and 5 year ARI events. The majority of buildings where flood level changes occur are already flood affected with flood depths up to 12.4m in a 100 year ARI event. The minor increase in levels during the operational phase has no discernible impact on the frequency of flooding of these buildings.

No reasonable and feasible flood mitigation measures have been identified at individual properties for the construction phase of the project. The majority of properties are already flood affected for 10 and 5 year ARI events, therefore, potentially increasing flood levels of the magnitude identified has a negligible affect the degree of flood risk. In addition and as discussed in **Section 3.2.2** and **Section 3.2.3**, the likelihood of a storm event occurring within a 3 months period is reduced.

Potential minor increases in flood levels during the construction phase of the project will not adversely affect property land uses. Therefore no mitigation measures would be required to manage the potential minor changes in flood levels for the 10 year and 5 year ARI events.

3.2.5 Access

Access routes within areas impacted by potential minor changes in flood levels are already inundated by flooding. The flood depths under existing conditions make these access routes impassable. Potential minor changes in flood levels will have no impact on property access and mitigation measures would not be required.

3.2.6 Infrastructure

Infrastructures assets impacted by potential minor changes in flood levels are already inundated by flooding. Minor increases in flood levels have no impact on infrastructure and mitigation measures would not be required.



The increase in flow velocities as described in **Section 2.2.2.2** may increase the risk of scour and erosion along both banks of the river (in the vicinity of the new bridge) during the construction phase. The contractor would manage this risk by constructing the scour protection works required for the project (as described in **Section 3.1.3**) as soon as the new bridge piers and abutments are completed.



4. Consultation

4.1 Hawkesbury City Council

RMS has met with Hawkesbury City Council on 22 September 2016 where a briefing of the hydrological and hydraulic analysis undertaken was given to Council representatives. At this meeting, Council verbally expressed that they generally had no objection to the project and flooding outcomes given there are only minor increases and decreases in events less than the 20 year ARI event, and there is nil impact to their development controls or flood plans which are primarily based on the 100 year ARI design flood level.

Consultation with Hawkesbury City Council and the Office of Environment and Heritage is required to determine the design and location of a flood warning sign. The flood warning sign will advise members of the public that the area may be subject to inundation during floods. If a flood event occurs during construction, works on-site shall be suspended and consultation with Hawkesbury City Council will occur to inform of them of the status of works and before recommencing activity after the peak of a flood event.

A copy of version E of this report has been issued to Council for information on 29/6/2017. No comments were received from Council and the final version F of this report has been sent to Council for information purposes.

4.2 Penrith City Council

RMS has sent a draft copy of this report (Revision D) to

on 26 April 2017 RMS.

of Penrith City Council provided comments via email on e bridge so as to ensure that adverse

12 May 2017 requesting "that consideration be given to the design of the bridge so as to ensure that adverse flood impacts to residential properties (within the Penrith LGA) do not occur."

RMS replied to **access to the second second**

RMS contacted and left a voice message to **example to which was followed by an email on 8 June 2017 to** close out the outstanding comment. A further email was sent to **example to the sent to be an email on 18 June 2017 stating RMS** accepts no further comments.

On 19 June 2017, **Control of the second seco**

4.3 NSW State Emergency Services (SES)

RMS has sent a draft copy of this report (Revision D) to a since there on 28 April 2017 which he further forwarded it to since there was no reply from SES within the requested comment period, RMS contacted on 8 June 2017 which it was followed by an email to both since the report on 13 June 2017, replied requesting for the report to be resent to SES. RMS resent the report on 19 June 2017 with an extension of time given till 21 June 2017.

SES sent a letter dated 21 June 2017 to RMS with comments in relation to flood plans, closure of the bridge during flood events, Transport and Traffic Plans and infrastructure impacts. RMS will discuss these matters with SES in due course during the finalisation phase of the project.



4.4 Directly-affected Property Owners

No reasonable and feasible flood mitigation measures have been identified at individual properties due to negligible impacts on flood planning levels adopted by Councils and minor changes in flood levels (up to a maximum 40mm increase in flood level) for 10 and 5 year ARI events. As a result, it was considered that consultation with directly affected owners would not be required.

4.5 Department of Planning and Environment

RMS has sent a draft copy of this report (Revision E) to DPE for review on 30 June 2017 and other reference documents were sent on 21 August 2017. An email was received from **Example 1**

on 28 September 2017 indicating that DPE has no comments on the

report.



5. References

Bewsher (2012), Hawkesbury Floodplain Risk Management Plan Volume 1 Main Report Revised Draft for Public Exhibition, Bewsher Consulting, July 2012

Hawkesbury City Council (2002), Hawkesbury Development Control Plan, Hawkesbury City Council

Jacobs (2017), Windsor Bridge Replacement Hydrology and Hydraulics Report, January 2017

Jacobs (2016), Windsor Bridge Replacement Gabion Wall Visual Inspection and Stability Assessment, 22 December, 2016

NSW SES (2015), Hawkesbury Nepean Flood Emergency Sub Plan. A Sub Plan of the State Emergency Management Plan, September 2015

NSW SES (2010), Hawkesbury City Local Flood Plan, 2010

Penrith City Council (2014), Penrith Development Control Plan Volume 1, Penrith City Council



Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to prepare a hydrological mitigation report to address flood impacts resulting from the 100% detailed design for the replacement of Windsor Bridge over the Hawkesbury River in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was agreed to with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client, third parties, and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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Appendix A. Tabulated changes in flood levels at properties during the operational phase

Property address	Floor level (m AHD)		Estimated flood depth above floor level (m)				Estimated change in flood level (m)			
	Surveyed by RMS	Extracted from DEM	100 year ARI	20 year ARI	10 year ARI	5year ARI	100 year ARI	20 year ARI	10 year ARI	5 year ARI
	#N/A	11.806	5.967	2.005	0.534	0.000	0.001	0.004	0.013	0.000
	#N/A	12.221	5.552	1.590	0.119	0.000	0.001	0.004	0.013	0.000
	#N/A	12.023	5.749	1.788	0.317	0.000	0.001	0.004	0.013	0.000
	#N/A	12.030	5.743	1.782	0.310	0.000	0.001	0.004	0.013	0.000
	#N/A	10.538	7.234	3.273	1.801	0.878	0.001	0.004	0.013	0.022
	#N/A	11.884	5.889	1.928	0.456	0.000	0.001	0.004	0.013	0.000
	#N/A	11.461	6.325	2.354	0.879	0.000	0.001	0.004	0.013	0.000
	#N/A	11.369	6.403	2.442	0.970	0.047	0.001	0.004	0.013	0.022
	#N/A	12.277	5.496	1.534	0.063	0.000	0.001	0.004	0.013	0.000
	#N/A	12.035	5.738	1.777	0.305	0.000	0.001	0.004	0.013	0.000
	#N/A	12.116	5.657	1.696	0.224	0.000	0.001	0.004	0.013	0.000
	#N/A	11.709	6.064	2.102	0.630	0.000	0.001	0.004	0.013	0.000
	#N/A	12.192	5.581	1.619	0.147	0.000	0.001	0.004	0.013	0.000
	#N/A	12.349	5.424	1.463	0.000	0.000	0.001	0.004	0.013	0.000
	#N/A	11.977	5.795	1.834	0.362	0.000	0.001	0.004	0.013	0.000
	#N/A	10.491	7.277	3.313	1.855	1.020	0.001	0.004	0.013	0.019
	#N/A	10.738	7.028	3.065	1.609	0.771	0.001	0.004	0.013	0.021

Table A.1 : Tabulated changes in flood levels at properties during the operational phase



Property address	Floor level (m AHD)		Estimated flood depth above floor level (m)				Estimated change in flood level (m)			
	Surveyed by RMS	Extracted from DEM	100 year ARI	20 year ARI	10 year ARI	5year ARI	100 year ARI	20 year ARI	10 year ARI	5 year ARI
	11.69	11.649	6.076	2.113	0.653	0.000	0.001	0.004	0.013	0.000
	#N/A	10.443	7.324	3.361	1.899	1.038	0.001	0.004	0.013	0.020
	#N/A	11.672	6.094	2.131	0.671	0.000	0.001	0.004	0.013	0.000
	#N/A	11.761	6.006	2.044	0.628	0.000	0.001	0.004	0.010	0.000
	#N/A	12.294	5.472	1.509	0.061	0.000	0.001	0.004	0.012	0.000
	#N/A	10.362	7.407	3.442	1.975	1.054	0.001	0.004	0.014	0.022
	#N/A	10.872	6.895	2.933	1.467	0.546	0.001	0.004	0.013	0.022
	#N/A	8.432	9.340	5.378	3.908	2.984	0.001	0.004	0.013	0.022
	#N/A	9.500	8.270	4.308	2.838	1.915	0.001	0.004	0.014	0.022
	#N/A	10.149	7.622	3.657	2.185	1.252	0.001	0.004	0.014	0.023
	#N/A	9.160	8.612	4.648	3.179	2.256	0.001	0.004	0.014	0.022
	#N/A	10.804	6.967	3.007	1.536	0.613	0.001	0.004	0.013	0.022
	#N/A	10.887	6.881	2.916	1.451	0.532	0.001	0.004	0.014	0.022
	#N/A	7.871	9.911	5.944	4.469	3.546	0.001	0.004	0.013	0.022
	#N/A	12.034	5.741	1.779	0.410	0.000	0.001	0.004	0.014	0.000
	#N/A	11.887	5.879	1.914	0.453	0.000	0.001	0.004	0.014	0.000
	10.51	10.438	7.258	3.293	1.827	0.906	0.001	0.004	0.014	0.022
	9.42	9.448	8.348	4.383	2.917	1.996	0.001	0.004	0.014	0.022
	11.42	11.470	6.353	2.394	0.920	0.000	0.001	0.004	0.014	0.022



Property address	Floor level (m AHD)		Estimated flood depth above floor level (m)				Estimated change in flood level (m)			
	Surveyed by RMS	Extracted from DEM	100 year ARI	20 year ARI	10 year ARI	5year ARI	100 year ARI	20 year ARI	10 year ARI	5 year ARI
	11.17	11.137	6.602	2.643	1.170	0.247	0.001	0.004	0.014	0.022
	11.63	11.591	6.144	2.185	0.708	0.000	0.001	0.004	0.013	0.000
	#N/A	10.003	7.766	3.800	2.334	1.413	0.001	0.004	0.014	0.022
	#N/A	10.421	7.347	3.384	1.920	1.013	0.001	0.004	0.014	0.021
	#N/A	11.514	6.254	2.292	0.851	0.236	0.001	0.004	0.011	0.017
	#N/A	11.880	5.895	1.929	0.493	0.000	0.001	0.004	0.014	0.000
	#N/A	12.337	5.434	1.476	0.037	0.000	0.001	0.004	0.015	0.000
	#N/A	6.838	10.94	6.977	5.502	4.579	0.001	0.004	0.013	0.022
	#N/A	10.010	7.763	3.801	2.330	1.407	0.001	0.004	0.013	0.022
	#N/A	10.015	7.776	3.800	2.325	1.402	0.001	0.004	0.013	0.022
	11.52	11.558	6.246	2.273	0.736	0.000	0.001	0.004	0.011	0.000
	#N/A	11.971	5.800	1.833	0.549	0.000	0.001	0.004	0.027	0.000
	#N/A	11.889	5.875	1.908	0.447	0.000	0.001	0.003	0.012	0.000
	#N/A	12.178	5.587	1.613	0.144	0.000	0.001	0.003	0.015	0.000
	#N/A	12,309	5 459	1 488	0.216	0.000	0.001	0.003	0.024	0.000
		12.000	0.400	1.400	0.210	0.000	0.001	0.000	0.024	0.000
	#N/A	12.284	5.489	1.527	0.056	0.000	0.001	0.004	0.013	0.000
	#N/A	12.306	5.467	1.505	0.034	0.000	0.001	0.004	0.013	0.000



Property address	Floor level (m AHD)		Estimated flood depth above floor level (m)				Estimated change in flood level (m)			
	Surveyed by RMS	Extracted from DEM	100 year ARI	20 year ARI	10 year ARI	5year ARI	100 year ARI	20 year ARI	10 year ARI	5 year ARI
	9.23	9.251	8.540	4.578	3.109	2.186	0.001	0.004	0.013	0.022
	9.36	9.318	8.411	4.448	2.979	2.056	0.001	0.004	0.013	0.022
	#N/A	12.079	5.723	1.741	0.261	0.000	0.001	0.004	0.013	0.000
	#N/A	11.385	6.414	2.433	0.955	0.033	0.001	0.004	0.013	0.022
	#N/A	11.775	5.998	2.037	0.565	0.000	0.001	0.004	0.013	0.000
	#N/A	11.824	5.975	1.992	0.516	0.000	0.001	0.004	0.013	0.000
	#N/A	11.186	6.611	2.630	1.154	0.232	0.001	0.004	0.013	0.022
	#N/A	11.768	6.028	2.047	0.572	0.000	0.001	0.004	0.013	0.000
	#N/A	6.814	10.95	6.997	5.526	4.602	0.001	0.004	0.014	0.022
	#N/A	11.771	6.001	2.040	0.568	0.000	0.001	0.004	0.013	0.000
	#N/A	12.321	5.452	1.490	0.019	0.000	0.001	0.004	0.013	0.000
	#N/A	7.620	10.15	6.191	4.720	3.797	0.001	0.004	0.013	0.022
	#N/A	11.521	6.251	2.290	0.818	0.000	0.001	0.004	0.013	0.000
	#N/A	11.714	6.058	2.097	0.625	0.000	0.001	0.004	0.013	0.000
	#N/A	12.097	5.675	1.714	0.243	0.000	0.001	0.004	0.013	0.000
	#N/A	10.872	6.923	2.944	1.468	0.546	0.001	0.004	0.013	0.022
	#N/A	11.558	6.231	2.257	0.782	0.000	0.001	0.004	0.013	0.000
	#N/A	11.425	6.367	2.390	0.915	0.000	0.001	0.004	0.013	0.000
	#N/A	10.318	7.476	3.497	2.021	1.099	0.001	0.004	0.013	0.022



Property address	Floor level (m AHD)		Estimated flood depth above floor level (m)				Estimated change in flood level (m)			
	Surveyed by RMS	Extracted from DEM	100 year ARI	20 year ARI	10 year ARI	5year ARI	100 year ARI	20 year ARI	10 year ARI	5 year ARI
	#N/A	12.147	5.623	1.654	0.154	0.000	0.001	0.004	0.017	0.000
	#N/A	12.295	5.475	1.506	0.002	0.000	0.001	0.004	0.017	0.000
	#N/A	11.536	6.260	2.280	0.804	0.000	0.001	0.004	0.013	0.000
	#N/A	10.629	7.139	3.169	1.646	0.434	0.001	0.004	0.019	0.048
	#N/A	10.920	6.849	2.878	1.351	0.150	0.001	0.005	0.019	0.024
	#N/A	5.411	12.36	8.392	6.902	5.849	0.001	0.004	0.016	0.029
	11.17	10.819	6.596	2.624	1.073	0.000	0.001	0.004	0.017	0.000
	10.88	10.795	6.886	2.915	1.379	0.158	0.001	0.005	0.020	0.033
	10.86	10.334	6.908	2.937	1.408	0.195	0.001	0.004	0.019	0.031
	10.88	10.814	6.888	2.918	1.391	0.179	0.001	0.004	0.019	0.028
	10.86	10.843	6.908	2.938	1.410	0.198	0.001	0.004	0.019	0.025
	11.11	11.017	6.657	2.686	1.155	0.000	0.001	0.004	0.019	0.000
	10.93	10.990	5.967	2.866	1.334	0.149	0.001	0.004	0.019	0.026
	#N/A	12.208	5.552	1.616	0.134	0.000	0.001	0.004	0.013	0.000



Appendix B. Windsor Bridge Replacement Hydrology and Hydraulics Report



Windsor Bridge Replacement Project

Roads & Maritime Services

Hydrology and Hydraulics Report

NB98005-NHY-RP-0052 | C

02 February 2017




Executive Summary

Overview

This report outlines the hydrology and hydraulic assessment undertaken for the detailed design of the proposed replacement of the existing Windsor Bridge over the Hawkesbury River at Windsor, NSW. The objective of the hydrology and hydraulic assessment is to:

- Provide design flood level and flow velocity information required for the detailed design of the bridge structure and scour protection measures.
- Determine and assess the bridge replacement's impact on existing flood behaviour.

The study area for the hydrology and hydraulic assessment extends from Agnes Banks (just downstream of the Grose River confluence) to Sackville, a distance of about 50km along the Hawkesbury River. The extent of the study area was chosen to consider the complex nature of flooding around Windsor, and the extent of potential impacts identified in the Environmental Impact Statement prepared for the Concept Design (Roads and Maritime, 2012).

Flood behaviour

The flood behaviour through the study area is affected by its varying topography, consisting of the low lying floodplains around Windsor and the narrow winding gorge from Wilberforce down to Sackville. During a flood, floodwaters can spread out across the floodplains inundating extensive areas around Richmond, Windsor and Pitt Town Bottoms. The floodwaters must then pass through a narrow gorge that begins downstream of Wilberforce and continues to Sackville and further downstream. The narrow constriction of the gorge controls outflow from the system, which in large flood events causes floodwaters to flow out slower than the rate at which they flow in. This causes backwater flooding in the tributaries of the Hawkesbury River, in particular, Rickabys Creek, South Creek, and Eastern Creek. The backwater flooding causes extensive inundation around Richmond and Windsor.

The Hawkesbury River has a long history of flooding. From historical records extending from 1791 to 1990, a total of 44 floods have been identified which exceeded 10m Australian Height Datum (AHD) at Windsor (WMA, 1994). The largest flood on record occurred in June 1867 and reached a peak level of 19.7m AHD at Windsor and has been estimated to have an average recurrence interval (ARI) of between 200 and 300 years (Bewsher, 2012).

Hydraulic modelling

To achieve the objectives of the study, Jacobs developed a new two dimensional hydrodynamic model of the river and floodplain within the study area, extending from Agnes Banks to Sackville. The hydrodynamic model was developed using TUFLOW modelling software. The hydrodynamic model was established using digital terrain data and inputs from previous modelling. Hydrologic and tail water level boundary conditions for the hydrodynamic model were obtained from WMAwater. Hydrographs of the main upstream inflow and downstream tail water levels were obtained from WMAwater's latest RUBICON hydraulic model. Inflow hydrographs for local creeks within the study area were obtained from WMAwater's calibrated RORB hydrologic model.

The hydrodynamic model was calibrated and validated against observed peak flood levels and recorded stage hydrographs for three historical flood events. Parameter values in the hydrodynamic model were adjusted so that a satisfactory fit to the peak flood levels observed at Windsor was achieved. Calibration and validation results indicate that the hydrodynamic model provided a good fit to observed peak levels at Windsor for the August 1986 and April 1988 events, producing modelled levels 0.05m and 0.06m higher than those observed. A poorer fit was achieved for the April 1989 event with a modelled level 0.37m lower than that observed. The poorer fit is consistent with the RUBICON model (WMA, 1994) where the modelled calibration level was 0.65m below the observed level.

Design flood event

The calibrated hydrodynamic model was used to simulate existing flood behaviour for a range of design flood events. The selected design events for this study include the 5, 10, 20, 50, 100 and 2000 year ARI events and



PMF event. The design flood event results have been presented in a series of flood depth maps for the study area which show the extent and peak depths for each design event simulated. Design peak flood levels and extents from the model were verified against those obtained from previous modelling and the design flood levels adopted by Hawkesbury City Council.

Flood impact assessment

In order to assess the impacts of the new bridge on flooding, the calibrated hydrodynamic model was modified by removing the existing bridge and adding the new bridge, viewing platform, scour protection and road embankments into the model. The proposed scenario conditions have been based on the 100% detailed design documentation and were modelled for a range of design flood events so that the change in existing flood behaviour could be quantified. The new bridge causes changes to flood behaviour due to the different number and location of piers, increased height of the deck plus increased thickness of the bridge superstructure including road barriers. The new bridge will allow greater conveyance of smaller events, i.e. less than the 2 year ARI, while there will be additional obstruction to flows for events just impeded by the new bridge, i.e. 2 year ARI event and events greater than the 2 year ARI. As the new bridge becomes more deeply submerged with larger events, the model results show that the impact on flooding decreases to a nil impact.

Flood level impact maps have been prepared to show the extent of changes in flood levels as a result of the new bridge and associated works. The maps indicate that the flood level impacts for the 5 year and 10 year ARI events extend to a large area upstream and downstream of the new bridge. For the 5 year ARI event, the majority of the flood level increases is 0.02m and extends upstream of the replacement bridge to near Inalls Lane, Richmond, on the Hawkesbury River and Carrington Road, Londonderry on Rickabys Creek. There are also localised areas of flood level increases in the range of 0.03m to 0.05m directly upstream of the replacement bridge. The maps indicate a decrease in flood levels downstream of the new bridge in the range of 0.01m to 0.02m extending from Windsor to Cattai. For the 10 year ARI event, flood level increases are generally in the range of 0.01m to 0.02m and extend upstream to Inalls Lane, Richmond, on the Hawkesbury River and Carrington Road, Localised impacts up to 0.1m occur directly upstream of the new bridge. There are localised increases in levels up to 0.025m along Freemans Reach Road and occur where there is a large change in ground elevations (approximately 5m difference) between Freemans Reach Road and the adjoining farm land to the south of the road.

Flood velocity impact maps have also been prepared to show the extent of impacts on flow velocities with the new bridge in place. Changes in flow velocities are localised to upstream and downstream of the existing and new bridges. Flow velocities along the southern side of the river change by the greatest amount with increases up 0.6m/s at the location of the new bridge. Velocities increases at this location are due to the changed bridge configuration, including the increased waterway opening and the pier configuration.



Glossary of terms and abbreviations

Term	Meaning				
afflux	Increase in flood level as a result of obstruction to flow				
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.				
average recurrence interval (ARI)	he long-term average number of years between the occurrence of a flood as big as (or arger than) the selected event. For example, floods with a discharge as great as (or reater than) the 20 year ARI design flood will occur on average once every 20 years. RI is another way of expressing the likelihood of occurrence of a flood event. (see also nnual exceedance probability)				
catchment	The area of land draining to a particular site. It is related to a specific location, and includes the catchment of the main waterway as well and any tributary streams.				
conveyance	The transport of flood water downstream				
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m ³ /s). Discharge is different from speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).				
flood	Relatively high stream flow which overtops the natural of artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super- elevated seal levels and/or waves overtopping coastline defences excluding tsunami.				
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood (PMF) event, that is, flood prone land.				
flood prone land	Land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.				
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods.				
HEC-RAS	Hydraulic Engineering Centre River Analysis System, developed by the US Army Corps of Engineers. Models the hydraulics of water flow through natural channels.				
hydraulics	The study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.				
hydrograph	A graph which shows how the discharge or stage/flood level at a particular location varies with time during a flood.				
hydrology	The study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.				
Intensity Frequency Duration (IFD)	Describes rainfall in terms of intensity (typically mm/hr), frequency (e.g. ARI) and duration of the storm.				
probable maximum flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain.				
RUBICON	A non-commercial hydrodynamic model				
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.				
scour	Erosion by mechanical action of water, typically of soil.				



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1. Introduction

1.1 Purpose

This report outlines the hydrology and hydraulic assessment undertaken for the detailed design of the proposed replacement of the existing Windsor Bridge over the Hawkesbury River at Windsor, NSW. The objective of the hydrology and hydraulic assessment is to:

- Provide design flood level and flow velocity information required for the detailed design of the bridge structure and scour protection measures.
- Determine and assess the bridge replacement's impact on existing flood behaviour.

1.2 Background

The existing Hawkesbury River Bridge at Windsor was opened in 1874. The existing bridge is the oldest existing crossing of the Hawkesbury River and parts of the bridge are now over 130 years old. Windsor Bridge is deteriorating due to age and heavy usage and has reached the end of its economic life. It no longer meets the demands of current traffic volumes or current road standards and requires significant on-going maintenance. The bridge is regularly inspected to ensure safety for use and heavy vehicle traffic is now limited to 40km/h. Windsor Bridge is below the 2 year average recurrence interval (ARI) flood event level while the surrounding approach roads provide access closer to the 5 year ARI flood level.

The NSW Government is replacing the existing bridge with a new bridge to provide a safe and reliable crossing of the Hawkesbury River at Windsor. In November 2011, Sinclair Knight Merz Pty Ltd (SKM), now Jacobs, was commissioned by the Roads and Maritime Services (Roads and Maritime) to complete a concept design for a replacement bridge and prepare an Environmental Impact Statement (EIS) which included a detailed Hydrology Study (Working Paper No. 8).

Following the completion of the concept design in December 2012, Roads and Maritime commissioned Jacobs to undertake detailed design documentation for the replacement bridge project.

The NSW Minister for Planning and Infrastructure's Conditions of Approval (MCoA) was provided in December 2013 but were then appealed at the NSW Land and Environmental Court on the grounds that it would impact on Thompson Square. However, in 2015 the appeal was denied and the court allowed the project to proceed. Jacobs' engagement was extended in December 2015 to complete the detailed design in accordance with MCoA and prepare tender documents for a RMS construct only contract.

At the time of preparation of this report, the detailed design was 100% complete.

The proposed upgrade involves the following works:

- Construction of a replacement bridge over the Hawkesbury River at Windsor, around 35 metres downstream of the existing Windsor Bridge.
- Reconstruction of existing intersections and bridge approach roads to accommodate the replacement bridge, including changes to the Macquarie Park access.
- Construction of a shared pedestrian/cycle pathway for access to and across the replacement bridge.
- Removal, backfill and landscaping of the existing bridge approach roads.
- Demolition and removal of the existing Windsor Bridge with the exception of abutments and the southern first span.
- Landscaping works within the open space area of Thompson Square and adjacent to the northern intersection of Bridge Street, Wilberforce Road, Freemans Reach Road and the access to Macquarie Park.
- Connection of The Terrace to provide continuous access along the southern bank of the river.
- Completion of bridge scour protection works.



- Construction of a permanent water quality basin to capture and treat stormwater runoff from the bridge and northern intersection prior to stormwater being discharged to the Hawkesbury River.
- Ancillary works necessary for construction, including:
 - Adjustment, relocation and/or protection of utilities and services, as required.
 - Construction and operation of temporary construction and compound sites.

A hydrology and hydraulics report was issued in March 2013 to document the hydrological and hydraulic analysis undertaken based on the 20% detailed design bridge drawings. Since the completion of the 2013 report, additional bathymetric data has been captured and the bridge design has been finalised. The finalised bridge design includes a number of changes when compared to the previous design which will potentially impact on the flood regime (refer to Section 2.3 for further information). This includes:

- Lowering of the bridge deck levels by approximately 1m on the southern side of the bridge; and
- Lowering of local road levels along the southern foreshore.

In order to assess the potential impacts of these changes on the flooding regime, the proposed scenario hydraulic model has been updated to include the finalised design details.

1.3 Study Area

1.3.1 Locality

The study area for the hydrology and hydraulic assessment is shown in **Figure 1.1**. The study area extends from Agnes Banks (just downstream of the Grose River confluence) to Sackville, a distance of about 50km along the Hawkesbury River. The extent of the study area was chosen to consider the complex nature of flooding around Windsor, and the extent of potential impacts identified in the Environmental Impact Statement prepared for the Concept Design (Roads and Maritime, 2012).

The study area includes the urban centres of Windsor, Richmond, McGraths Hill, Pitt Town and Wilberforce, and the low-lying floodplain areas of Richmond Iowlands, Freemans Reach, and Pitt Town Bottoms that are predominantly used for horticulture, cropping, and grazing.

1.3.2 Catchment description

The Hawkesbury-Nepean catchment extends from Goulburn in the south to the mouth of the Hawkesbury River at Broken Bay. The catchment covers an area of approximately 22,000km² and includes extensive grazing areas in the south west and large National Parks in the Blue Mountains to the north-west. Urban development in the catchment includes towns such as Goulburn, Lithgow and the outer suburbs of western Sydney (Bewsher, 2012).

There are five major water storages in the Hawkesbury-Nepean catchment including Sydney's main water supply, Warragamba Dam. More than 40% of the total Hawkesbury-Nepean catchment (about 9,000km²) is upstream of Warragamba Dam (Bewsher, 2012). The four other storages of Avon, Cataract, Cordeaux, and Nepean Dams are located in the Upper Nepean catchment.

Grose River is a major tributary that joins the Nepean River just downstream of Yarramundi, after which the Nepean is known as the Hawkesbury. Other major tributaries that join the Hawkesbury River before Sackville include Rickabys Creek, South Creek, and Cattai Creek. The catchment area at Windsor is about 12,800km² (Bewsher, 2012) and the catchment area at Sackville is about 13,500km² (WMA, 1994).



1.3.3 Flood behaviour

The behaviour of flooding through the study area is significantly affected by its varying topography, consisting of the low lying floodplains around Windsor and the narrow winding gorge from Wilberforce down to Sackville. During a flood, floodwaters can spread out across the floodplains inundating extensive areas around Richmond, Windsor and Pitt Town Bottoms. The floodwaters must then pass through a narrow gorge that begins downstream of Wilberforce and continues to Sackville and further downstream.

The narrow constriction of the gorge controls outflow from the system, which in large flood events causes floodwaters to flow out slower than the rate at which they flow in. This causes backwater flooding in the tributaries of the Hawkesbury River, in particular, Rickabys Creek, South Creek, and Eastern Creek. The backwater flooding causes extensive inundation of significant flood depth around Richmond and Windsor.

1.3.4 History of flooding

The Hawkesbury River has a long history of flooding. From historical records extending from 1791 to 1990, a total of 44 floods have been identified which exceeded 10m Australian Height Datum (AHD) at Windsor (WMA, 1994). The largest flood on record occurred in June 1867 and reached a peak level of 19.7m AHD at Windsor. A flood of this magnitude has been estimated to have an average recurrence interval (ARI) of between 200 and 300 years (Bewsher, 2012).

The existing bridge has a road level of 7.15m AHD and provides flood immunity less than the 2 year ARI. The bridge is frequently closed due to flooding, particularly when a spill from Warragamba Dam occurs. As recently as June 2016 the bridge was closed due to flooding.



Legend

Locality — Watercourse

– Rail

Main roads

0 2 4km N 1:110,000 @ A4

> Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure 1-1 | Hydrology and Hydraulic assessment study area



2. Review of Available Data

2.1 Previous Studies and Reports

Jacobs collected and reviewed the following reports that are relevant to the current study.

Warragamba Flood Mitigation Dam EIS Flood Study, October 1994, prepared by Webb McKeown & Associates (WMA) for Sydney Water

This report documents an extensive investigation of flood behaviour in the Hawkesbury-Nepean Valley and the potential impact of raising Warragamba Dam to provide flood mitigation. The investigation involved hydrologic modelling of the Hawkesbury-Nepean catchment using the RORB model and hydraulic modelling of the river and floodplain below Warragamba Dam using RUBICON. The RUBICON model is a one dimensional hydraulic model that was calibrated and verified against 10 historical flood events and was subject to a comprehensive review process.

Of the ten flood events used in model calibration and verification, all were significantly large flood events apart from the October 1987 and April 1989 events. Whilst there was reasonable agreement between recorded and modelled peak water levels for Penrith and Windsor for significantly large flood events, the limited ability of the model to represent minor flood events at Windsor is reflected in the model calibration results for Windsor for the April 1989 event. The model underestimated peak water level at Windsor by 0.65m (observed peak height 9.22 m AHD) for this event. In the absence of recorded peak water level data at Windsor for the flood event of October 1987, the smallest of all flood events used in model calibration/verification, no assurance can be provided on model calibration results for flood events smaller than April 1989.

The flood mitigation dam for which this investigation was undertaken did not proceed; rather an auxiliary spillway was constructed to ensure the dam's structural integrity in large floods.

Windsor Bridge over the Hawkesbury River: Hydraulic analysis, August 2011 prepared by WMAwater for Roads and Maritime

This document outlines the hydraulic assessment of two preliminary options for replacing the existing Windsor Bridge. The assessment was undertaken using the RUBICON hydraulic model, and found that each replacement option would increase the 5 year ARI flood level at Windsor by 50 to 60mm, while there would be negligible change to the 100 year ARI flood level.

Hawkesbury Floodplain Risk Management Study and Plan: Volume 1 – Main Report Revised Draft for Pubic Exhibition, July 2012, prepared by Bewsher Consulting for Hawkesbury City Council

This report is a Floodplain Risk Management Study and Plan for the Hawkesbury River floodplain within the Hawkesbury Local Government Area (LGA), and was prepared in accordance with the NSW Floodplain Development Manual (DIPNR, 2005). The study focused on mapping design flood behaviour and flood hazard for existing conditions, identifying flood risk to property and life, and recommending structural and non-structural measures for managing flood risk at a local scale.

The flood mapping for this study was based on previous investigations and reports, primarily from the RUBICON model developed for the EIS Flood Study described above. The design flood levels and flood extents have been adopted by Hawkesbury City Council for flood planning purposes.

Hawkesbury-Nepean Flood Damages Assessment: Final Report, September 2012, prepared by Molino Stewart for Infrastructure NSW

This report revisits the option of increasing the capacity of Warragamba Dam to provide flood mitigation. It outlines a preliminary investigation into the benefit, in terms of reduced flood damages, of raising the dam wall by 23m. The investigation draws heavily from previous studies, particularly the Warragamba Flood Mitigation Dam EIS from the mid 1990's.



Windsor Bridge Replacement EIS Hydrology Working Paper, November 2012 prepared by SKM for Roads and Maritime

This report was prepared to support the design and approval of the Windsor Bridge replacement, and to address the Director General's Environmental Assessment Requirements (DGRs) related to hydrology and flooding. The report provides an outline of existing flood behaviour and flood risk at Windsor, assesses the impact of the proposed concept design, and identifies potential mitigation measures.

The hydraulic assessment used results from previous RUBICON modelling for establishing existing flooding conditions, and additional HEC-RAS and RUBICON modelling for assessing the impact of the preferred concept design. The HEC-RAS modelling was undertaken to estimate head losses at the new bridge for input to the RUBICON model. The HEC-RAS model was established making conservative assumptions regarding the new bridge's number of piers and deck thickness.

The investigation found that the increased flow obstruction of the new bridge would cause a 0.12m and 0.03m increase in the flood level upstream of Windsor Bridge in the 5 year and 20 year ARI events respectively. These increases in flood levels were found to have a minor impact on areas of the floodplain used for grazing and turf production, and were found to affect a number of existing buildings.

The report recommended that detailed flood modelling be undertaken during detailed design of the bridge replacement to identify and confirm flooding impacts. It recommended that where impacts are identified, appropriate measures would be developed in consultation with landholders and implemented, as required, to minimize impacts on building structures, building accesses, and business opportunities.

Windsor Bridge Replacement Hydrology and Hydraulics Report, March 2013 prepared by SKM for Roads and Maritime

This report outlines the hydrology and hydraulic assessment undertaken for the detailed design of the proposed replacement at 20% design stage. The modelling approach was the same as outlined in this document.

The flood impact results indicated that that there is a slight reduction in flood levels during the 5 year ARI event as the obstruction to flow is reduced by the new bridge, while there is a slight increase in the 10 year ARI event due to an increase in obstruction from the larger profile bridge deck and barriers. There is no impact in the 20 year ARI event and larger events.

2.2 Topographic Data

2.2.1 Digital elevation models

Digital Elevation Models (DEMs) covering the majority of the study area were provided by Roads and Maritime under license from NSW Land and Property Information (LPI). The DEMs were generated from LiDAR collected in 2011 with a vertical accuracy of ±30cm and were obtained at grid sizes of 1m, 2m, 5m, and 10m.

In addition, 5m and 25m DEMs held by Jacobs with vertical accuracies of $\pm 2.5m$ and $\pm 12.5m$ respectively were obtained to provide terrain data where the 2011 LiDAR was not available. Further discussion of where the terrain data sources were used is provided in **Section 3.3.1**.

2.2.2 Bathymetric survey

Sydney Water provided bathymetric survey of the Hawkesbury River and South Creek for use in the study. The bathymetric survey was collected in 2011 and consisted of cross sections taken under the water surface level from bank to bank at regular spacing's of between 100 and 500 metres along the river.

Additional bathymetric surveys of the Hawkesbury River in the vicinity of Windsor Bridge were completed in 2016. The data extends upstream and downstream of the new bridge along the right bank of the channel. The data includes toe of bank details which were not captured during the 2011 survey.



2.2.3 Ground survey

Detailed ground survey required for the civil design of the bridge replacement was obtained from Roads and Maritime in November 2011 to develop the concept design phase. The survey was based on the MGA coordinate system using AHD.

Following review of the detailed survey, Jacobs obtained additional survey from Roads and Maritime in 2012 that included bathymetry survey and river scan sonar plans extending from 250m upstream to 750m downstream of the existing Windsor Bridge.

2.3 Design information

A civil design model of the proposed road works and scour protection and drawings of the proposed bridge replacement were obtained from the 100% detailed design documentation. The 100% detailed design bridgeworks drawings are provided in **Appendix A**.

The bridge replacement will be approximately 158m long, separated into five spans, and have design surface levels of about 12.0m AHD at the southern end and 10.0m AHD at the northern end. The bridge deck is 15.24m wide with a 1.5% cross fall and comprises 1850mm deep box girders with a 75mm thick asphalt layer. The bottom levels of the bridge soffit will be about 9.3m AHD at the southern end and 7.3m AHD at the northern end.

The bridge superstructure will be supported by four piers located in the river. The piers are oval in shape with a 1.85m width measured perpendicular to the flow direction. The piers will be connected to 2.4m wide pile caps near the upper tidal limit, which in turn will be connected to a single row of 4 x 1500mm diameter piles.

The proposed works also include a viewing platform on the southern foreshore which is based on retaining the end span of the existing bridge.

2.4 Aerial photography

Aerial imagery held by Jacobs (Ausimage, 2014) was obtained for the entire study area.

2.5 Spatial data

Various spatial data sets held by Jacobs were available for use in the study including main roads and local streets, towns, major drainage lines, land use categories, and cadastral boundaries.

2.6 Historic flood data

The following historic flood data was sourced for use in the study:

- Records of observed peak flood levels documented in the Warragamba Flood Mitigation Dam EIS Flood Study Report (WMA, 1994).
- WMAwater provided stage hydrographs records for selected historical flood events that were collected during the 1994 EIS Flood Study. The stage hydrographs were recorded at various water level gauges within the study area including gauges at Windsor and North Richmond.
- Jacobs obtained water level data at Windsor from Manly Hydraulics Lab (MHL) dated from 1987. The water level recorder is installed approximately 400m upstream of the existing Windsor Bridge. Review of the data showed there were a number of gaps in the data series during past flood events.

2.7 Hydrographs Provided by WMAwater

Hydrographs of inflow and tail water level boundary conditions for hydrodynamic flood modelling were provided by WMAwater on 21 January 2013. Hydrographs of the main upstream inflow and downstream tail water levels



were obtained from WMAwater's latest RUBICON hydraulic model. Inflow hydrographs for local creeks within the study area were obtained from WMAwater's calibrated RORB hydrologic model.

Inflow hydrographs were provided for ten locations within the study area, one main inflow for the river channel at Agnes Banks and nine local creek inflows. Hydrographs were obtained for 3 historical events and 7 design events ranging from the 5 year ARI to the PMF. The design event hydrographs relate to the 72 hour duration storm which was found to be critical in the EIS Flood Study (WMA, 1994). Peak flow rates and storm volumes from the 5, 20, 100 year ARI, and PMF hydrographs are shown in **Table 2-1**.

Inflow	Peak flow (m3/s)			Storm volume (ML)				
hydrograph	5 year	20 year	100 year	PMF	5 year	20 year	100 year	PMF
UPSTREAM	4,403	8,685	13,702	39,225	670,000	1,210,000	2,270,000	7,800,000
QREDBANK	108	154	238	222	7,900	9,800	16,100	31,800
QRICKABYS	184	264	403	371	12,400	15,900	24,600	50,800
QSOUTHUP	333	408	658	830	32,200	36,700	57,700	125,400
QSOUTHDN	164	201	324	408	15,600	17,400	27,900	61,500
QEASTERN	200	243	384	375	14,800	16,000	25,300	54,100
QWILBER	123	183	267	234	6,100	8,000	12,600	28,700
QCATTAI	314	411	592	546	22,500	25,900	37,700	77,000
QLITTLEC	185	263	380	332	12,500	15,900	23,100	45,500
QHOWES	446	671	979	840	24,200	32,200	49,900	104,800

Table 2-1 : Design storm peak flows and volumes from flow hydrographs provided by WMAwater

The peak flows and volumes of the upstream inflow are substantially higher than the local creek inflows. Local creek inflows are only a minor proportion of the upstream inflow. It is noted that the PMF peak flow of some local creek inflows is less than the 100 year ARI peak flow. This is believed to be a result of different temporal pattern adopted for the PMF compared to the other design events. Storm volumes of the PMF are all greater than the 100 year ARI.

Water level hydrographs at Sackville for the same historical and design events were also output from the RUBICON model and provided by WMAwater. The design event peak water levels at Sackville are shown in **Table 2-2**.

Table 2-2 : Design peak water levels at Sackville from hydrographs provided by WMAwater

Design Event	Peak water level (m AHD)
5 year	7.78
10 year	8.76
20 year	10.06
50 year	11.77
100 year	13.14
1000 year	17.50
PMF	22.39



3. Hydraulic Model Development

3.1 Modelling Approach

3.1.1 Methodology

To achieve the objectives of the study, Jacobs developed a new two dimensional hydrodynamic model of the river and floodplain within the study area, extending from Agnes Banks to Sackville. The hydrodynamic model was established using the digital terrain listed in **Section 2** and inputs from previous modelling, and was calibrated and validated against observed historical flood data. Existing and proposed conditions were modelled for a range of design flood events so that the change in existing flood behaviour could be quantified. The hydrodynamic model was initially developed in 2013 with the proposed scenario based on the 20% detailed design documentation and updated in 2016 to incorporate the 100% detailed design documentation.

Hydrologic and tail water level boundary conditions for the hydrodynamic model were obtained from WMAwater. Hydrographs of the main upstream inflow and downstream tail water levels were obtained from WMAwater's latest RUBICON hydraulic model. Inflow hydrographs for local creeks within the study area were obtained from WMAwater's calibrated RORB hydrologic model. The hydrographs were provided on 21 January 2013.

The new hydrodynamic model developed by Jacobs was calibrated and validated against observed peak flood levels and recorded stage hydrographs for three historical flood events. Parameter values in the hydrodynamic model were adjusted so that a satisfactory fit to the peak flood levels observed at Windsor was achieved.

The calibrated hydrodynamic model was used to simulate existing flood behaviour for a range of design flood events. Design peak flood levels and extents from the model were verified against those obtained from previous modelling and the design flood levels adopted by Hawkesbury City Council.

Appropriate adjustments were made to the existing case model in order to represent the new bridge replacement. The range of design flood events was run for the proposed case and water level, flow and velocity results obtained so the bridge replacement's impact on flood behaviour could be identified.

3.1.2 Model selection

A two-dimensional hydrodynamic model was developed for this study using TUFLOW version 2012-05-AD (BMT WBM). TUFLOW is an industry standard flood modelling platform widely used in Australia and the UK. The channel and floodplain topography in TUFLOW is defined as a uniform grid of cells with elevation and roughness values assigned to each cell, known as the 2D domain. The cell size adopted depends on the width of the river channel being modelled (preferably the channel should be defined using a minimum of 4 cells), as well as the modelling accuracy required and the length of computer run times. A grid size of 20m was adopted in this study for modelling all historical and design flood events, except for extreme events (the 2000 year ARI and the probable maximum flood (PMF)) where a grid size of 40m was adopted to achieve model stability.

3.2 Model Schematisation

A schematic of the TUFLOW model developed for the assessment is shown in **Figure 3-1**. The figure shows the extent of the models 2D domain, the location of model inflows, the downstream tail water boundary, and key existing hydraulic structures.

3.3 Model Configuration

3.3.1 Channel and floodplain geometry

The elevation of model grid points was defined using a variety of terrain data sources described in Section 2.2. The majority of floodplain and river bank levels were defined using the LiDAR 2m DEM. However detailed ground survey collected for the project was used where available, and a small portion of the model in the



storage area of Cattai Creek (approximately 10% of the model area) was defined using the 5m and 25m DEM. The terrain is relatively steep in the Cattai Creek catchment so the proportion of model volume in this area would be less than 10%. A figure showing the terrain data sources for the model is provided in **Figure 3-1**.

Most river bed levels were defined using a bathymetry DEM that Jacobs created from the bathymetry cross sections provided by Sydney Water. However within the project area where the detailed bathymetry collected by Roads and Maritime was available, this was used to define the river bed levels.

A comparison of the detailed bathymetric survey captured in 2012 with the recently obtained bathymetric data was undertaken to determine if there has been any significant changes in the river bed profiles which would affect the hydraulics at Windsor Bridge. The results of this comparison indicated negligible changes in the river bed profile and therefore, the model has not been updated to include the 2016 bathymetric survey data.

Buildings within the model extent were represented using increased Manning's 'n' roughness values.

3.3.2 Channel and floodplain roughness

Manning's 'n' roughness values applied to the 2D domain were defined for various land use types and vegetation covers based on aerial photography. The land use types and adopted Manning's 'n' roughness values are shown in **Table 3-1**. The values adopted for each land use and vegetation cover are based on previous modelling experience and are consistent with recommended values documented in Chow (1959). The river channel roughness value was adjusted for model calibration which is discussed in **Section 4.1**.

Floodplain use or type	Manning's 'n' value
River channel	0.025 – 0.03 *
Cleared floodplain and road corridors	0.03
Composite creek (bed and riparian vegetation)	0.05
Riparian and other vegetation	0.08
Rural residential	0.06
Urban	0.3
Individual buildings on the floodplain	1.0

Table 3-1 : TUFLOW model Manning's 'n' values

* Value adjusted between the ranges shown for model calibration

3.3.3 Hydraulic structures

The bridges over the Hawkesbury River at Windsor and North Richmond were represented in the TUFLOW model. Details of the existing bridge structures were obtained from works as executed and design drawings provided by Roads and Maritime, and photographs taken on site.

The bridges were modelled in TUFLOW as layered flow constrictions, which apply a blockage factor and loss coefficient to selected grid cells that varies with water depth. Loss coefficients for the existing Windsor Bridge were estimated based on the energy equation calculations documented in the HEC-RAS Hydraulic Reference Manual (USACE, 2010). The equivalent loss coefficient adopted in TUFLOW was back calculated from the bridge head loss calculations in HEC-RAS assuming a contraction and expansion loss coefficient of 0.3 and 0.5, which are recommended values for abrupt changes at bridges. A bridge loss coefficient was estimated for each flood event so that the effect of the bridge would be accurately represented at the peak of the flood being modelled. Traffic and pedestrian barriers on the bridges were assumed to be fully blocked with debris.



Legend

- 20m contour
- ---- Main roads
- Rivers
- ---- Upstream inflow boundary
- Downstream tailwater boundary
 Local creek inflows
 TUFLOW model extent





Data sources Jacobs 2015 Ausimage 2014 RMS 2015 LPI 2015



Legend





3Km

0

1 2

Data sources Jacobs 2015 Ausimage 2014 RMS 2015 LPI 2015

N



4. Model Calibration

4.1 Approach

The approach for calibrating the TUFLOW model was to input historical event inflow and tail water boundary conditions provided by WMAwater and adjust the Manning's roughness value of the river channel until an appropriate fit to observed peak flood levels at Windsor was achieved. Three historical flood events were used to calibrate the TUFLOW model.

The historical event hydrologic inputs provided by WMAwater underwent a separate calibration process that is documented in the Warragamba Flood Mitigation Dam EIS Flood Study (WMA, 1994). The RORB hydrologic model was calibrated to observed flow data recorded at various stream gauging stations, the majority of which were located upstream of Warragamba Dam.

4.2 Selection of Model Calibration Events

Historical events available for calibration were limited to those that were modelled by WMA in the Warragamba Flood Mitigation Dam EIS Flood Study (WMA, 1994). Ten historical events that occurred between 1961 and 1990 were available, the majority of which were significantly large floods. Peak levels at Windsor observed during these events ranged from about 5.4m to 14.95m AHD.

The historical events considered most suitable for model calibration in this study are those that reached a peak flood level within the elevation range of the bridge replacement's deck. This range is equivalent to minor flood events in the range from less than a 5 year to a 20 year ARI, and is where previous modelling has shown the greatest impact to existing flood behaviour will be. The bridge replacements impact on larger flood events has been shown to be negligible and so calibrating the TUFLOW model to larger events is not considered necessary for this study.

Historical events selected for calibration are shown in. The observed peak flood levels shown were recorded immediately upstream of the existing Windsor bridge. An approximate ARI of the events were determined based on the design flood level estimates adopted by Hawkesbury City Council (Bewsher, 2012).

Month and Year	Observed peak flood level at Windsor (m AHD)	Approximate ARI
August 1986	11.35	5 year
April 1988	12.80	10 year
April 1989	9.22	<5 year

Table 4-1 : Historical flood events selected for the TUFLOW model calibration

Figures of the historical event flow and stage hydrographs provided by WMAwater and input to TUFLOW for the model calibration are contained in **Figure 4-1**, **Figure 4-2** and **Figure 4-3**.









Figure 4-2 : April 1988 inflow hydrographs





Figure 4-3 : April 1989 inflow hydrographs

4.3 Calibration Results

A river channel Manning's 'n' roughness value of 0.027 and the other values shown in **Table 3-1** were adopted in the TUFLOW model for all calibration events. The modelled peak flood levels at Windsor and North Richmond compared to the observed levels are shown in **Table 4-2** and **Table 4-3**.

Historical Event	Observe (m AHD)	TUFLOW		WMA, 1994	
		Modelled (m AHD)	Difference (m)	Modelled (m AHD)	Difference (m)
August 1986	11.35	11.40	+0.05	11.32	-0.03
April 1988	12.80	12.86	+0.06	12.79	-0.01
April 1989	9.22	8.85	-0.37	8.57	-0.65

Table 4-2 : Observed and modelled peak water levels at Windsor

The TUFLOW model provided a good fit to observed peak levels at Windsor for the August 1986 and April 1988 events, producing modelled levels 0.05m and 0.06m higher than those observed. A poorer fit was achieved for the April 1989 event with a modelled level 0.37m lower than that observed. The poorer fit is consistent with the RUBICON model calibration where the modelled level was 0.65m below the observed (WMA, 1994). The TUFLOW model calibration is slightly improved for the April 1989 flood event compared to the previous RUBICON model calibration. The poorer fit of both models could be the result of the RORB hydrologic model underestimating the peak flow for this event.



Historical Event	Observe (m AHD)	TUFLOW		WMA, 1994	
		Modelled (m AHD)	Difference (m)	Modelled (m AHD)	Difference (m)
August 1986	13.02	13.25	+0.23	N/A	N/A
April 1988	14.68	14.64	-0.04	N/A	N/A
April 1989	10.14	10.44	+0.3	N/A	N/A

Table 4-3 : Observed and modelled peak water levels at North Richmond

Flood levels predicted by the TUFLOW model at North Richmond were generally higher than those observed, however a very good fit was achieved for the April 1988 event. RUBICON model calibration results at North Richmond were not documented or discussed in the EIS Flood Study Report (WMA, 1994).

Water level hydrographs from the TUFLOW model were also compared against recorded stage hydrographs available at Windsor, North Richmond and Richmond. **Figure 4-4**, **Figure 4-5**, and **Figure 4-6** show the TUFLOW model hydrographs compared with the available recorded hydrographs for the August 1986, April 1988, and April 1989 events respectively.

The modelled hydrographs all show a reasonable fit to the recorded data. Model hydrographs for the August 1986 event show a good fit to the rising limb, peak and receding limb at both North Richmond and Windsor. The April 1988 model hydrographs show a poor fit on the rising limb but an improved fit at the peak and receding limb at North Richmond and Windsor. While the April 1989 model hydrograph at Richmond also show a good fit to the peak and receding limb of the storm.



Figure 4-4 : August 1986 observed and modelled stage hydrographs





Figure 4-5 : April 1988 observed and modelled stage hydrographs



Figure 4-6 : April 1989 observed and modelled stage hydrographs



4.4 Conclusions on Model Calibration

The TUFLOW model was calibrated to three minor flood events that occurred in August 1986, April 1988, and April 1989. The approximate ARI's of these events ranged from less than a 5 year to a 10 year ARI.

Peak water levels and stage hydrographs from the TUFLOW model were compared with recorded data available. The model produced a good fit to peak levels at Windsor for the August 1986 and April 1988 events but a poorer fit to the smaller April 1989 event peak level. The fit to the April 1989 event was slightly improved when compared to the previous RUBICON modelling (WMA, 1994). The poorer fit of both models could be the result of the RORB hydrologic model underestimating the peak flow for this event.

Stage hydrographs from the model also provided a good fit to the recorded data, particularly for the August 1986 event where the rising limb, peak and receding limb all fit well to the recorded data at North Richmond and Windsor.

The TUFLOW model is considered satisfactorily calibrated for the flood magnitudes of concern and is therefore considered suitable for the assessment of flood behaviour and flood impacts as a result of the bridge replacement.



5. Existing Flood Behaviour

5.1 Selection of Design Events

The selected design events for this study include the 5, 10, 20, 50, 100 and 2000 year ARI events and PMF event. These events have been selected to serve the flood impact assessment and floodplain risk management aspects of the study and for input into bridge design and scour assessments.

5.2 Input data

5.2.1 Inflows

Inflow hydrographs into the TUFLOW model for the design events have been obtained from WMAwater at a number of inflow points on the Hawkesbury River, South Creek, Cattai Creek and Little Cattai Creek. Refer to **Figure 3-1** for the model inflow locations. The inflow hydrographs are shown in **Appendix C**.

Inflow hydrographs for the 2000 year ARI were estimated by scaling up the 1000 year ARI hydrographs by an appropriate factor. An estimate of the 2000 year ARI upstream peak flow was interpolated between the 1000 year ARI and PMF peak flows at a log normal scale. The 1000 year ARI hydrograph was then factored up to achieve the 2000 year ARI peak flow estimate. The same factor was also applied to the local inflow hydrographs.

5.2.2 Tail water boundary

Water level hydrographs at Sackville have been obtained from the RUBICON model for the design events. These have been adopted as the TUFLOW model downstream boundary conditions. Refer to **Figure 3-1** for the tail water boundary location. The tail water level hydrographs are shown in **Appendix C**. A 2000 year ARI water level hydrograph was estimated using the same procedure used to determine the 2000 year ARI inflow hydrographs.

5.3 Results for existing conditions

The TUFLOW model has been run for the design events for the entire duration of each event in the model domain. Peak levels immediately upstream of the existing Windsor Bridge and peak flow velocities in the channel centre at the bridge are summarised in **Table 5-1**. Note that due to the flood behaviour in the Hawkesbury-Nepean River Valley, the peak velocity occurs on the rising limb of the flood, approximately 30 hours before the peak flood level. This is due to the topography of the river valley between Sackville and Wisemans Ferry creating a flow "choke" which causes floodwaters to back up upstream of the choke resulting in a reduction of flow velocities.

Design event	Peak level upstream of Bridge (m AHD)	Peak Flow Velocity at Channel Centre at Bridge (m/s)
5 year	11.00	2.7
10 year	12.25	3.0
20 year	13.80	3.2
50 year	15.97	3.3
100 year	17.77	3.4
2000 year	23.19	2.9
PMF	26.76	3.1

Table 5-1 : Peak flood levels and flow velocities upstream of the existing bridge

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The TUFLOW model confirms that the existing bridge would be submerged in the 5 year ARI flood, with the peak flood level of 11m AHD exceeding the bridge deck level of 7.15m AHD.

Flood depth mapping for the study area for the design events is presented in Appendix D.

The point at which floodwaters break out on to the adjacent floodplain at Freemans Reach affects the behaviour of flooding at Windsor Bridge as flow that breaks out on to this floodplain will bypass the river and bridge. Flow hydrographs in the river and floodplain at Windsor were output from the TUFLOW to gain an appreciation of this behaviour. The flow and stage hydrographs output from the model for the 5, 20, and 100 year ARI events are shown in **Figure 5-1**, **Figure 5-2** and **Figure 5-3**.

The figures show that peak flow in the river remains within a relatively small range regardless of the size of event, ranging from around 3,500m³/s in the 5 year to just over 5,000m³/s in the 100 year ARI event. In contrast, the peak flow over the floodplain increases significantly with larger events, from around 250m³/s in the 5 year to over 10,000m³/s in the 100 year event. The floodplain is engaged when flow in the river is between 3,500 and 4,000m³/s, which is equivalent to a flood level at Windsor of between 10m and 11m AHD.



Figure 5-1 : 5 year ARI flow and water level hydrographs at Windsor









Figure 5-3 : 100 year ARI flow and water level hydrographs at Windsor



5.4 Model verification

5.4.1 Comparison of flood levels

The TUFLOW model results have been verified against the previous RUBICON modelling and the Hawkesbury City Council Floodplain Risk Management Study and Plan (Bewsher, 2012). The flood levels are compared for Windsor in **Table 5-2** and for North Richmond in **Table 5-3**.

Design event			
	TUFLOW	RUBICON	Hawkesbury FRMS&P
5 year	11.00	11.04	11.1
10 year	12.25	12.18	12.3
20 year	13.80	13.61	13.7
50 year	15.97	15.65	15.7
100 year	17.77	17.29	17.3
PMF	26.76	25.54	26.4

Table 5-2 : Verification of peak flood levels at Windsor

Table 5-3 : Verification of peak flood levels at North Richmond

Design event	Peak level at North Richmond (m AHD)				
	TUFLOW	RUBICON*	Hawkesbury FRMS&P		
5 year	13.00	12.5	12.5		
10 year	14.15	14.0	14.0		
20 year	14.97	15.1	15.3		
50 year	16.17	16.3	16.4		
100 year	17.84	17.4	17.5		
PMF	26.8	25.6	26.5		

*Source: Post-Dam scenario, Table D16, WMA (1994)

The TUFLOW results at Windsor are similar to the RUBICON and the FRMS&P flood levels at Windsor Bridge for the 5 and 10 year ARI events, within +/- 0.1m of the other peak flood levels. The difference between the flood level estimates increases with increasing flood magnitude, with the TUFLOW results up to 0.5m higher than the RUBICON and the FRMS&P flood levels in the 100 year ARI event and up to 1.2m in the PMF. The TUFLOW results at North Richmond are 0.5m higher than RUBICON in the 5 year ARI event, similar for the 10 to 50 year ARI event and higher for the 100 year ARI and PMF events. Less focus was placed on the model calibration at North Richmond as the greatest flood impacts were expected to be in the vicinity of Windsor.

The higher flood levels in the TUFLOW model for larger floods are mainly attributed to the different study objectives and calibration processes selected for the models. The TUFLOW model was developed to focus on flood impacts in minor floods and was calibrated to three minor historical events, though it is noted that the TUFLOW model was not well calibrated to the smallest event (< 5 year ARI). Whereas the RUBICON model was developed focusing on larger floods and calibrated and validated against ten historical events. As the focus of this study is on assessing the impacts of the bridge replacement, and not on establishing design flood levels for flood planning purposes, the discrepancy in flood level estimates for larger events was considered acceptable.



The difference in flood levels is also attributed to the more detailed definition of the river channel and floodplain achieved with the recent bathymetric survey and LiDAR survey, and the 2D model resolution of 20m (40m for the 2000 year ARI and PMF runs). This is particularly significant downstream of Wilberforce where the river enters gorge country and exhibits numerous sharp bends.

In comparison, the resolution of the RUBICON is relatively coarse downstream of Cattai, with reach intervals of 3 - 10km and the highly irregular channel geometry is simplified into three reaches between Cattai and Sackville. The dynamic flow conditions in this section of the River, particularly at the bends, are not replicated at this resolution.

Figure 5-4 shows the channel centreline flood surface profiles from the TUFLOW and RUBICON models for the 100 year ARI event. As a 2D model, TUFLOW is able to represent the highly dynamic flow conditions in the river as demonstrated by the irregular flood profile, where sudden drops in the flood profile correspond with sharp bends in the river and the resulting high hydraulic energy losses. The largest drops exceed 0.5m.

The TUFLOW model also represents the super-elevation in flood surface profile across the channel (not shown on the plot), where the flood level may be up to 0.3m higher on the outside of the bend than the inside of the bend. The complexity of these flow conditions are lost in the RUBICON model, where the section between Sackville and Cattai Creek is simplified to three reaches with a linear water surface profile between nodes.

This modelled flood behaviour also explains why the difference between the TUFLOW and RUBICON flood levels at Windsor increase with event magnitude. As flows and flow velocities increase, so do the head losses at the channel bends and hence greater incremental difference in flood level with distance upstream from Sackville.



Figure 5-4 : Comparison of TUFLOW flood surface profiles and available RUBICON results for the 100 year ARI event



In summary, although the TUFLOW model produces a higher peak flood level at Windsor when compared to the previous RUBICON modelling, the TUFLOW model is considerably more detailed in definition of the Hawkesbury River channel geometry and complex flow patterns, and hence these higher flood level estimates are considered valid. Further, it is noted that the TUFLOW model is calibrated to smaller magnitude events from less than a 5 year up to a 10 year ARI magnitude, given that the greatest flood impact from the new bridge will be at these smaller events during which the bridge just becomes overtopped. The model is therefore deemed to be fit for the purposes of this flood impact assessment.

5.4.2 Bridge hydraulics

The representation of the hydraulics at the existing and new bridges was validated against HEC-RAS models developed during the concept design. The hydraulic head loss across the bridges in the TUFLOW model was observed to be similar to the head loss in the HEC-RAS model. The head losses at the flood peak from the TUFLOW and HEC-RAS models are compared in Table 5 4 for the 5, 10 and 20 year ARI events. The head losses for larger events are not compared since the head loss across the bridge at the flood peak in these events is negligible.

Design event	TUFLOW	HEC-RAS
5 year	0.06	0.04
10 year	0.01	0.02
20 year	0.01	0.00

Table 5-4 : Comparison of TUFLOW and HEC-RAS hydraulic losses (m AHD) at the existing Windsor Bridge

5.4.3 Flood extents

The flood extents derived from the TUFLOW model were compared to the flood mapping in the Hawkesbury Floodplain Risk Management Plan (Bewsher, 2012) and were found to be consistent with the mapping in the FRMS.



6. Flood Impact Assessment

6.1 Updates to the hydraulic model

The calibrated TUFLOW model was modified by removing the existing bridge and adding the new bridge, viewing platform, scour protection and road embankments into the model as 2D structures. Hydraulic losses for the new bridge and viewing platform were estimated using the same procedure as the existing bridge and applied in the TUFLOW model.

The model for the proposed condition was run for the selected design flood events adopting the same inflow and downstream boundary conditions as the existing case model.

Results of the proposed conditions have been compared with existing scenario results to identify the change in flood behaviour as a result of the bridge replacement and associated works. Supplementary information on the proposed case flood results for input into the bridge design is provided in **Appendix E**.

The following conditions were not modelled as part of the flood impact assessment:

- Launching stages of the bridge during construction.
- Geometry of embankments and road works during construction activities.
- External changes to the catchment conditions and hydrology, including climate change.

6.2 Flood impacts

6.2.1 Overview of impacts

The new bridge and associated works causes changes to flood behaviour. The new bridge has different number and location of piers, increased height of the deck plus increased thickness of the bridge superstructure including barriers. The new bridge will allow greater conveyance of smaller events, i.e. less than the 2 year ARI event while there will be additional obstruction to flows for events just impeded by the new bridge, i.e. for the 2 year ARI event and events greater than the 2 year ARI. As the new bridge becomes more deeply submerged with larger events, the impact on flooding decreases to a nil impact.

The change in available waterway area within the channel between the existing Windsor Bridge and the new bridge is shown in **Figure 6-1**. As can be seen, the existing and replacement bridges provide similar waterway areas up to the underside of the existing bridge deck (6.1m AHD). Between the levels of 6.1m and 10.0m AHD, the replacement bridge provides a greater waterway area. Above the level of 10.0m AHD, the bridge replacement will provide less waterway area.





Figure 6-1 : Flow area v height relationship within the channel for the existing bridge and proposed replacement bridge

6.2.2 Flood levels

Peak flood levels in the existing and proposed case upstream of the existing Windsor Bridge are summarised in **Table 6-1**. The results indicate that the new bridge has a nil or minor impact on peak flood levels, particularly in the larger magnitude events when the new bridge is fully submerged.

Design event	Flood Level (m AHD)		Difference (m)
	Existing	Proposed	
PMF	26.76	26.76	0.00
2000 year	23.19	23.19	0.00
100 year	17.77	17.77	0.00
50 year	15.97	15.97	0.00
20 year	13.80	13.80	0.00
10 year	12.25	12.28	+0.03
5 year	11.00	11.04	+0.04

Table 6-1 : Comparison of existing and proposed case flood levels upstream of the existing bridge

The model results confirm that there are no flood level impacts for the majority of the design flood events with minor increases in flood levels for both the 5 year and 10 year ARI events due to an increase in obstruction from the larger profile of the new bridge and associated works.



The flood level for the 2 year ARI event at the existing bridge has been estimated from the Flood Frequency Analysis (FFA) undertaken for the Windsor gauge (WMAwater, 1994). The FFA indicates a 2 year ARI flood level of 8.7m AHD at the Windsor Gauge. **Figure 6-1** demonstrates that the flow area within the channel at the new bridge structure is greater than the existing bridge structure at the 2 year ARI flood level and that flood impacts for the 2 year ARI are therefore unlikely.

The changes in peak flood levels for the 5 year and 10 year ARI events have been mapped and are presented in **Appendix F**. These flood level impact maps show the extent of changes in flood levels as a result of the new bridge and associated works. The maps indicate that the flood level impacts for the 5 year and 10 year ARI events extend to a large area upstream and downstream of the new bridge. For the 5 year ARI event, the majority of the flood level increases are 0.02m and extend upstream of the replacement bridge to near Inalls Lane, Richmond, on the Hawkesbury River and Carrington Road, Londonderry on Rickabys Creek. There are also localised areas of flood level increases in the range of 0.03m to 0.05m directly upstream of the replacement bridge. The maps indicate a decrease in flood levels downstream of the new bridge in the range of 0.01m to 0.02m extending from Windsor to Cattai. For the 10 year ARI event, flood level increases are generally in the range of 0.01m to 0.02m and extend upstream to Inalls Lane, Richmond, on the Hawkesbury River and Cattai. For the 10 year ARI event, flood level increases are generally in the range of 0.01m to 0.02m and extend upstream to Inalls Lane, Richmond, on the Hawkesbury River and Carrington Road, Londonderry on Rickabys Creek. Localised impacts up to 0.1m occur directly upstream of the new bridge. There are localised increases in levels up to 0.025m along Freemans Reach Road and occur where there is a large change in ground elevations (approximately 5m difference) between Freemans Reach Road and the adjoining farm land to the south of the road.

6.2.3 Flow velocities

In the proposed case, peak flow velocities in the channel centre downstream of the new bridge generally do not change significantly as detailed in **Table 6-2**. Flow velocities increase at this location due to the changed bridge configuration, including the increased waterway opening and the pier configuration. The flow velocities shown in **Table 6-1** are averaged across the model grid cell and through the depth of flow. Localised flow velocities, for example at bridge piers, are likely to be greater.

Design event	Peak flow velocity (m/s)				
	Existing	Proposed	Change		
PMF	2.47	2.9	0.3		
2000 year	2.5	2.7	0.2		
100 year	2.64	2.6	-0.04		
50 year	2.56	2.53	-0.03		
20 year	2.39	2.4	+0.01		
10 year	2.08	2.27	+0.19		
5 year	1.82	1.95	+0.13		

Table 6-2 : Change in peak flow velocity in the centre of the channel in the vicinity for the new bridge

* The peak flow velocities and impacts shown above are for a location just downstream of the new bridge and 20m out from the southern (Windsor-side) river bank. Flow velocities typically exhibit the greatest increase in the proposed case in this location.

Flow velocities along the southern side of the river are observed to increase by the greatest amount in the proposed case. Of particular concern is the potential impact of increased velocities on the gabion scour retaining wall located on the southern foreshore. Modelled peak flow velocities at various points along the southern foreshore were therefore examined for existing and proposed conditions and a summary of the impacts is provided in **Table 6-3**. Figures of peak flow velocities at the TUFLOW model cell points for existing and proposed conditions are also provided in **Appendix G**.



Location along southern foreshore	5 year ARI		10 year ARI		20 year ARI		100 year ARI	
	Existing velocity (m/s)	Proposed scenario velocity (m/s)	Existing velocity (m/s)	Proposed scenario velocity (m/s)	Existing velocity (m/s)	Proposed scenario velocity (m/s)	Existing velocity (m/s)	Proposed scenario velocity (m/s)
Upstream of the existing bridge	1.4 - 1.7	1.4 - 1.8	1.5 - 1.9	Nil change	1.6 - 2.0	Nil change	1.7 - 2.1	1.6 - 2
At the existing bridge	1.8	1.1	2.0	1.2	2.3	1.4	2.5	1.5
At the new bridge	1.6	1.8	1.9	2.3	2.1	2.6	2.3	2.9
Downstream of the new bridge	1.6 - 1.7	1.7 - 1.8	1.8 - 2.0	2 - 2.1	2.1 - 2.3	2.2	2.3 - 2.6	2.3 - 2.4

Table 6-3 : Flow velocities (m/s) at the southern foreshore

Table 6-1 shows that the greatest increase in peak velocities along the southern bank occurs at the location of the new bridge with up to 26% increases in velocities in the 100 year ARI event. Upstream of the existing bridge, velocities would only increase for minor floods. There would be a reduction in velocity at the location of the existing bridge for all events. Downstream of the new bridge there would generally be small changes in the velocities between the existing and proposed scenarios.

The changes in velocity occur as a result of:

- Relocating the bridge constriction and the concentration of flow from the existing bridge to the new bridge. This causes velocities at the existing bridge to reduce and velocities at the new bridge to increase.
- 2) The increased waterway area provided by the new bridge compared to the existing bridge (as shown in Figure 6-1) allows more flow through the bridge opening when flood levels are below 10.5m AHD. This causes a general increase in flow velocity through the bridge opening.
- 3) The sloping deck configuration of the new bridge forms a preferential flow path along the southern side of the river since the bridge deck is higher on this side. This generally causes velocities on the southern side to increase and velocities on the northern side to decrease.

6.3 Discussion on flood impacts

6.3.1 Differences in estimated flood level impact at concept design

The flood impact resulting from the new bridge was estimated at the concept design stage to be 0.01m in the 100 year ARI event and 0.12m in the 5 year ARI event. The flood impact was estimated using the previous HEC-RAS model and RUBICON model.

At detailed design, the flood impacts for the larger events including the 20 year ARI are negligible and for the 5 and 10 year ARI events impacts have been reduced. This is due to bridge design being updated in the detailed design stage and conservative assumptions made with respect to the number of bridge piers and deck thickness during the hydraulic modelling for the concept design.



7. Conclusions

This hydrology and hydraulic assessment was prepared with the objectives of assessing the Windsor Bridge replacement's impact on existing flood behaviour and providing design flood details for the detailed design of the bridge structure and scour protection. A new hydrodynamic flood model using TUFLOW was developed by Jacobs and used for the assessment.

The TUFLOW model of existing conditions was run for a range of design flood events. The TUFLOW model was then updated to represent the new bridge and associated works. The proposed case model was run for the full range of design flood events and the peak water level and flow velocity results compared with existing condition results.

The model results indicate that there are no flood level impacts for the majority of the design flood events with minor increases in flood levels for both the 5 year and 10 year ARI events. In general increases in flood levels are 0.02m for the 5 year ARI event and in the range of 0.01m to 0.02m for the 10 year ARI event. Peak flood level increases of up to 0.1m are localised to upstream of the new bridge.

The replacement bridge would alter peak flow velocities in the river channel and the adjacent river banks due to the change in waterway area and the bridge configuration. The largest increase in the peak flow velocity will occur along the southern bank at the location of the new bridge with up to 26% increases in velocities in the 100 year ARI event. The increase in flow velocities may increase the risk of scour and erosion occurring at the base of the existing retaining wall on the southern bank during a flood event. Further investigation on the condition of the existing retaining wall at the southern foreshore has been undertaken as part of this project to determine the scour protection measures required.



8. References

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The sole purpose of this report and the associated services performed by Jacobs is to undertake a hydrology and flooding assessment in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was agreed to with the Client.

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Appendix A. 100% Detailed Design Bridge Drawings



Cad File: C:\users\jganz\appdata\local\projectwise\rms_projects\dms00616\NB98005-ECP-DG

Jul 2016, - 07:13:01 Cad File: C:\users\jganz



Appendix B. Calibration Event Flood Maps



Legend





Data sources

Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure B-1 | August 1986 event modelled flood depths and levels.







2km N @ A4 Data sources

Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure B-2 | August 1988 event modelled flood depths and levels.







Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure B-3 | August 1989 event modelled flood depths and levels.



Appendix C. TUFLOW Model Boundary Condition Hydrographs





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Appendix D. Existing Flood Depth and Level Maps







Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-1 | Existing 5 year ARI flood depths and levels







Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-2 | Existing 10 year ARI flood depths and levels







Data sources

Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-3 | Existing 20 year ARI flood depths and levels







Data sources

Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-4 | Existing 50 year ARI flood depths and levels







Data sources

Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-5 | Existing 100 year ARI flood depths and levels







Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-6 | Existing 2000 year ARI flood depths and levels



Legend





Data sources

Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure D-7 | Existing PMF ARI flood depths and levels



Appendix E. TUFLOW Results at Windsor Bridge Replacement

Flood level and flow velocity hydrographs are shown in this appendix for the proposed case. Flood levels are shown upstream of the new bridge, and flow velocities are shown for the river channel centre approaching the new bridge.

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Appendix F. Flood Level Impact Maps



Legend



Figure F-2 | Windsor Bridge Replacement 10 year ARI flood impact



Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015



Legend

 Locality 	Change in flood level	10 to 10
─ + Rail	(mm)	📃 10 to 20
Main roads	-50 to -20	📒 20 to 50
LGA boundary	20 to -10	50 to 100

N 0 1 2km 1:90,000 @ A4

Data sources Jacobs 2015, Ausimage 2014, RMS 2015, LPI 2015

Figure F-1 | Windsor Bridge Replacement 5 year ARI flood impact



Appendix G. Flood Velocity Impact Maps





Figure H-8-1 : 100 year ARI peak flow velocities (blue is existing, red is proposed)





Figure H-8-2 : 20 year ARI peak flow velocities (blue is existing, red is proposed)





Figure H-8-3 : 10 year ARI peak flow velocities (blue is existing, red is proposed)





Figure H-8-4 : 5 year ARI peak flow velocities (blue is existing, red is proposed)