Windsor Bridge replacement project

HYDROLOGY WORKING PAPER – WORKING PAPER 8

NOVEMBER 2012

Roads and Maritime Services

Windsor Bridge Replacement

Hydrology working paper – working paper 8

November 2012 - Final

SINCLAIR KNIGHT MERZ

SKM

(blank page)

Contents

(blank page)

Glossary of terms and abbreviations

Abbreviations

Term	Meaning
ALS	Airborne Laser Survey
BoM	Bureau of Meteorology
Climate change	Changes to local and global weather patterns measured over long periods of time as a result of both natural processes and human activity.
DECC	Department for Environment and Climate Change (now OEH)
DECCW	Department for Environment and Climate Change and Water (now OEH)
DTM	Digital terrain model
EIS	Environmental Impact Statement
HCC	Hawkesbury City Council
HNFESP	Hawkesbury Nepean Flood Emergency Sub Plan
HNFMSC	Hawkesbury Nepean Floodplain Management Steering Committee
HNFMS	Hawkesbury Nepean Floodplain Management Strategy
LGA	Local Government Area
MHL	Manly Hydraulics Laboratory
NSW	New South Wales
OEH	Office of Environment and Heritage
RMS	Roads and Maritime Services NSW
SKM	Sinclair Knight Merz

Glossary

Term	Description
Annual Exceedance Probability (AEP)	Term used to describe the chance of a flood of a given or larger size occurring in any one year, expressed as a percentage. Eg. a 1% AEP flood means there is a 1% (ie. one-in-100) chance of a flood of that size or larger occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national plain of level corresponding approximately to mean sea level. All flood levels, floor levels and ground levels are normally provided in metres AHD (m AHD)
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. This is an average and does not imply any regularity in events – two 100-year ARI events may occur within a month and an area may go a thousand years without experiencing a 100-year ARI storm
catchment	A catchment is the area of land from which rainwater drains into a common point such as a reservoir, pond, lake, river or creek.
conveyance	A direct measure of the flow carrying capacity of a particular cross-section of a stream or stormwater channel. (For example, if the conveyance of a channel cross-section is reduced by half, then the flow carrying capacity of that channel cross-section will also be halved).

Term	Description
discharge	The rate of flow of water measured in terms of volume per unit time, eg. cubic metres per second (m3/s). Also known as flow. Discharge is different from the speed/velocity of flow which is a measure of how fast the water is moving.
extreme flood	An estimate of the probable maximum flood, which is the largest flood likely to ever occur.
flood	A relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage as defined by the FDM before entering a watercourse.
flood awareness	An appreciation of the likely effects of flooding and knowledge of the relevant flood warning and evacuation procedures.
flood hazard	The potential for damage to property or harm to persons during a flood or a situation with a potential to cause loss. In relation to this plan, the hazard is flooding which has the potential to cause harm or loss to the community. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.
flood level	The height of the flood described as either a depth of water above a particular location (eg. 1m above floor level) or as a depth of water related to a standard level such as Australian Height Datum (eg. flood level is 5m AHD).
flood liable/flood prone land	Land susceptible to flooding up to the PMF. The term flood liable or flood prone land covers the entire floodplain.
floodplain	The area of land that is subject to inundation by floods up to and including the PMF event.
Floodplain Development Manual (FDM)	Refers to the document dated April 2005, published by the New South Wales Government and entitled “Floodplain Development Manual: the management of flood liable land”.
Floodplain Risk Management Plan (FRMP)	A plan prepared for one or more floodplains in accordance with the requirements of the FDM or its predecessors.
Floodplain Risk Management Study (FRMS)	A study prepared for one or more floodplains in accordance with the requirements of the FDM or its predecessors.
flood risk	The chance of something happening that will have an impact. It is measured in terms of consequences and probability (likelihood). In the context of this plan, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
flood study	A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood events.
hydraulics	The study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrology	The study of rainfall and runoff process; in particular, the evaluation of peak discharges, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood).

Term	Description
Level 1	A Level 1 flood is defined as one in which the water level of the Hawkesbury-Nepean River is not expected to exceed 15.0 metres on the Windsor Bridge gauge. For such a flood the operation is within the scope of normal arrangements detailed in the respective SES Region and Local Flood Plans and the respective District and Local DISPLAN's.
Level 2	A Level 2 flood is defined as one in which the water level of the Hawkesbury-Nepean River is expected to exceed 15.0 metres on the Windsor Bridge gauge. In such a flood the operation will be beyond the scope of the respective SES Region and Local Flood Plans and the respective District and Local DISPLAN's. Additional planning in the form of State level arrangements is needed.
local drainage	Term given to small scale inundation in urban areas outside the definition of major drainage as defined in the FDM. Local drainage problem invariably involve shallow depths (less than 0.3m) with generally little danger to personal safety.
mainstream flooding	The inundation of normally dry land by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
peak discharge	The maximum discharge or flow during a flood measured in cubic metres per second (m3/s).
probable maximum flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation.
probable maximum precipitation (PMP)	The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.
probability	A statistical measure of the expected chance of flooding (see ARI).
risk	See flood risk.
runoff	The amount of rainfall that ends up as flow in a stream. Also known as rainfall excess.
velocity	The term used to describe the speed of floodwaters, usually in metres per second (m/s).
water level	See flood level.
water surface profile	A graph showing the height of the flood (ie. water level or flood level) at any given location along a watercourse at a particular time.

(blank page)

Executive Summary

The Roads and Maritime Services (RMS) is proposing to construct a new bridge across the Hawkesbury River at Windsor to replace the existing bridge that has reached the end of its economic life. To support the design and approval of the Windsor Bridge replacement, RMS is preparing an Environmental Impact Statement (EIS) under Part 5.1 of the *Environmental Planning and Assessment Act 1979*. The Windsor bridge replacement project ('the project') includes demolition and replacement of the current bridge and realignment of local roads on both banks of the Hawkesbury River.

The EIS is to address the Director General's Environmental Assessment Requirements (DGRs). Those related to flooding include:

- Justification for the proposed flood immunity and an assessment of the flooding impacts and characteristics to and from the project, including consideration of changes to rainfall frequency and/or intensity as a result of climate change;
- The potential impacts on flow velocities and directions, and impacts on bed and bank stability as a result of removal of the existing bridge and relocation of a new bridge downstream.

This hydrology assessment has been prepared as a specialist component of the EIS to address these requirements and to advise on possible mitigation actions to avoid or minimise impacts. Potential impacts and mitigation measures for sediment and erosion controls are addressed in the Soil, Water and Sediment Working Paper.

Windsor bridge is located over the Hawkesbury River and connects the town of Windsor with Freemans Reach and Wilberforce. Large floods along the Hawkesbury River inundate floodplain areas downstream of Penrith and to a greater extent downstream of Yarramundi, including floodplains that are north and south of the river near Windsor. Flooding near Windsor is amplified due to restricted discharge through gorges downstream of Wilberforce.

The bridge would connect Bridge Street in Windsor to Wilberforce Road and Freemans Reach Road. The project would have a minimum road level of RL 9.8 metres AHD (2.8 metres higher than the existing bridge). This would result in the new bridge being a similar height to the lowest level of Freemans Reach Road and higher than around 60 per cent of Wilberforce Road, from the bridge to Wilberforce. The increased height of the new bridge would result in a decrease in the frequency of the river crossing closures. Using historical flood level data from 1987 to 2011 the number and length of times water levels would be higher than the bridge for the existing bridge and new bridge was estimated. If the new bridge had been in place, the number of events would have been three instead of eight and the average duration of inundation would have decreased from 43 hours to 19.5 hours.

The frequency of overtopping would increase under climate change scenarios associated with an increase in rainfall intensities and runoff within the catchment. However as the replacement bridge would be designed to be overtopped, impacts from climate change are effectively mitigated.

Previous hydrological and hydraulic modelling was used to provide information on the existing environment. An appropriate level of additional modelling for assessing impacts for the EIS was then undertaken to identify the potential flooding impacts of the project at a regional and property level, for events up to and including the probable maximum flood. The project would result in an increased obstruction to flood flows in the Hawkesbury River at Windsor compared to the existing bridge. This obstruction has been assessed to adversely impact properties upstream of the bridge by increasing flood levels and to a lesser extent increasing the duration of inundation during floods. Consideration during detailed design is to be given to reducing the obstruction of the bridge within the waterway. In this way the impacts within the floodplain would be reduced.

Impacts would include an increase to water levels up to 0.12 metres in a 5 year ARI flood event at the bridge, up to 0.03 metres in a 20 year ARI event and up to 0.01 metres in a 100 year ARI event. In contrast, flood water levels downstream of the project and on the South Creek floodplain would decrease in the five year ARI event. These predictions indicate that the effect of the project on flood water levels would be greatest for the five year ARI event, minor for the 20 year and negligible for the 100 year ARI and PMF events. The potential impacts to land occupation and residential dwellings were assessed based on available data.

The floodplain north of the Hawkesbury River between Freemans Reach and Wilberforce is estimated to have around 1500 hectares of land inundated in a 5 year ARI event with the current bridge. Predominately this area is used for turf farming and grazing. The extent of inundation in this area is negligible due to the project. The existing average depth of inundation above ground level for this event is between 2 and 5 metres. The increase to depth of inundation is estimated to be greater than 0.05 metres for around 60 per cent of lots in this area. The increase in duration of inundation in a 5 year ARI is less than 10 per cent compared with the existing duration for water levels up to 10.5 metres AHD, however larger duration is estimated for water levels at 11 metres AHD (11 hours compared with 5 hours). It should be recognised that these are property lots and the vast majority are agricultural, horticultural or Crown land without any buildings or residential properties.

While the average flood impacts over the wider floodplain due to the project are minor, there are properties impacted by a higher level of flooding and thus increased flood damage costs and other impacts associated with flooding. Data from the recent Draft Hawkesbury Flood Risk Management Study (FRMS) was used to assess the magnitude of potential impacts from increased flooding due to the project. The data used to predict the increase in flood levels at residential buildings had limitations and uncertainties, however it provides an indication of likely impacts to residential properties.

Flood afflux (increase in water depths) at properties located upstream of Windsor Bridge and within floodplain areas upstream of the bridge has been assessed assuming building floor levels were at ground level (in accordance with assumptions from the draft FRMS). Buildings with an estimated afflux less than 0.01 metres are not included as this increase is considered negligible and beyond the accuracy of the modelling used to determine afflux. Properties subject to inundation greater than 1 metre for existing conditions were not included as the increase in flood depths is not significant compared with existing flood inundation. The largest impact on flooding levels from the project would occur during the lower ARI events such as the 5 year ARI and 20 year ARI events. Change in flood levels for various events included:

- In a 5 year ARI event one additional residential dwelling would experience over floor flooding (23 Wilberforce Road) and 25 buildings would experience afflux greater than 0.01 metres as a result of the project. Of these, three buildings have an existing depth of inundation greater than one metre. Average afflux for the 22 buildings would be 0.10 metres with the largest increase in water depths of 0.12 metres. Fifteen buildings would have a percentage increase in flooding greater than 25 percent, two of which are generally subject to low levels of flooding in the existing conditions (less than 0.1 metres). These two buildings would be at most risk of increased flood damage from increases in flood levels due to the project.

- In a 20 year ARI event there would be no additional buildings estimated to have over floor inundation. Thirty four (34) buildings would experience afflux greater than 0.01 metres, of these 31 properties have an existing depth of inundation greater than one metre. Average afflux for the three properties that would have increase greater than 0.01 metres and an existing depth less than one metre is 0.03 metres.
- In a 100 year ARI event there would be negligible changes to flood levels at buildings as a result of the project.

The following environmental management measures will be implemented to minimise impacts from flooding:

- During the detailed design of the new bridge, detailed flood modelling will be undertaken on the final design of the project to identify any additional impacts. This will include collecting survey data at potentially impacted properties with buildings upstream of the bridge. Where impacts are identified, appropriate measures will be developed in consultation with the landholders and implemented, as required, to minimise impacts on the building structures, building accesses and business opportunities.

The replacement bridge would be subject to high velocities in the Hawkesbury River that would potentially result in scour of bridge abutments and piers as well as the adjacent river bed and banks. Scour potential would be exacerbated near the bridge due to shading from the bridge deck which inhibits vegetation growth and due to the extended duration of inundation during floods. Unmitigated scour potentially would result in stability issues for the replacement bridge. Concept Design has included scour protection measures at the piers, river banks near abutments and for areas between the existing bridge and replacement bridge that are being filled and re-graded. Consideration has been given to the length of inundation experienced during floods, the rock level at the bridge and suitability of protection measures near the bridge (impacts due to shading). The project would include protection works near the existing retaining wall on the southern river bank.

As part of detailed design, scour potential would be assessed for a range of flows, using an approach that enables local velocities and distribution of flows between the existing bridge and replacement bridge to be represented and suitable mitigation measures adopted. A suitable modelling approach would be to develop a two-dimensional hydrodynamic model using bathymetry and would incorporate pier location, shape and orientation.

Construction

<u>Potential impacts of flooding on the project</u>

It is possible that a flood could occur during the construction or demolition period, which could have adverse effects on work activities and increase the risk of soil and sediment erosion. The impacts and associated environmental management measures for soil and sediment erosion are presented in Soil, sediment and water Working Paper. The occurrence of high river flows during construction or demolition could result in erosion of bed and bank material if the proposed scour protection measures have not yet been constructed.

Before the demolition of the existing bridge is completed, it could fail during a flood event causing damage to the new bridge. While the existing bridge is in poor condition, the new bridge would open by 2015 and the existing bridge is extremely unlikely to fail in the next three years.

The HNFESP uses the stream gauge located on Windsor Bridge (212903). This would need to be relocated due to the project.

Potential impacts of the project on flooding

The presence of construction infrastructure and equipment in the river (such as barges and temporary platforms) and the period when two bridges are present (whether partially constructed, demolished or complete) has the potential to increase flooding at properties upstream of the project. The increase in flood levels when both bridges are present (and complete) is estimated to be around 0.18 metres (that is 0.06 metres above the estimated increase with the replacement bridge alone) in a 5 year ARI event.

During the construction of the new bridge, increased flooding would be negligible until the launching of the new bridge commences. As the bridge is gradually launched across the river, the potential impact of flooding upstream would increase. It would take approximately 12 months to launch the bridge and complete finishing works before the opening of the new bridge.

Flood impacts would be greatest for properties that are near the bridge.

1 Introduction

1.1 Background

Roads and Maritime Services NSW (RMS) is proposing to construct a new bridge across the Hawkesbury River at Windsor to replace the existing bridge that has reached the end of its economic life. To support the design and approval of the Windsor bridge replacement project, RMS is preparing an Environmental Impact Statement (EIS) under Part 5.1 of the *Environmental Planning and Assessment Act 1979*. This hydrology working paper has been prepared as a specialist component of the EIS and presents:

- A description of existing climate and flood behaviour locally near Windsor Bridge and regionally along the Hawkesbury River. This provides a baseline for assessing potential changes as a result of the project.
- An assessment of flood related benefits and impacts of the project.
- Potential measures to avoid, manage or mitigate flood related impacts.

The Director General's Environmental Assessment Requirements (DGRs) related to flooding are provided in **Table 1-1** with reference to where these are addressed in this report. The second condition has been taken to focus on velocity and flows near the existing and replacement bridges.

Table 1-1 Relevant Director General Requirements for hydrology

Director General Requirement	Where addressed in report?
The EIS must address the following specific matters: **Soils, Sediments and Water -** including but not limited to:	
Justification for the proposed flood immunity and an assessment of the flooding impacts and characteristics to and from the project, including consideration of changes to rainfall frequency and/or intensity as a result of climate change;	Section 3.3
The potential impacts on flow velocities and directions, and impacts on bed and bank stability as a result of removal of the existing bridge and relocation of a new bridge downstream.	Section 3.3

1.2 Description of project

1.2.1 Overview

The project would comprise:

- Construction of a new bridge over the Hawkesbury River at Windsor, around 35 metres downstream of the existing Windsor bridge.
- Reconstruction and upgrading of existing intersections and bridge approach roads to accommodate the new bridge, including:
  - Removal of the existing roundabout and installation of traffic signals at the intersection of George and Bridge Streets.
  - Construction of a new dual lane roundabout at the intersection of Freemans Reach Road, Wilberforce Road, northern bridge approach road and the access road to Macquarie Park. All roads serviced by the new roundabout would require minor realignments.

    - Realignment of the southern and northern bridge approach roads. The new southern bridge approach road would generally follow the alignment of Old Bridge Street along the eastern side of Thompson Square. The northern bridge approach road would be a new road connecting the bridge to the new dual lane roundabout.
    - Construction of a shared pedestrian/cycle pathway for access to and across the new bridge.
    - Removal of the existing bridge approach roads and then backfilling, rehabilitating and landscaping these areas.
    - Demolition of the existing Windsor bridge including piers and abutments.
    - Landscaping works within Thompson Square parkland and adjacent to the northern intersection of Bridge Street, Wilberforce Road, Freemans Reach Road and the access road to Macquarie Park.
    - Redevelopment of part of The Terrace to provide continuous access along the southern bank of the river and under the replacement bridge to Windsor Wharf.
    - Construction of scour protection works on the southern and northern banks and around three bridge piers.
    - 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.
- Architectural treatments for noise mitigation, as required, where feasible and reasonable and in agreement with affected property owners.
- Flood mitigation works at individual properties, in agreement with affected property owners.
- Ancillary works including:
    - Adjustment, relocation and/or protection of utilities and services, as required.
    - Construction and operation of temporary construction, stockpiling and compound sites.

In **Figure 1-1** the main elements of the project are shown including the construction zone and project boundary.

In addition to the above-listed work elements, early works for further identification, salvage, recording and protection of Aboriginal and historic heritage, would be carried out as part of impact mitigation for the project. These early works would include:

- Salvage excavation at identified Aboriginal heritage sites on the southern bank of the river in accordance with the procedures identified in the Aboriginal heritage chapter of the Environmental Impact Statement for the project.
- Excavation, recording and protection of historic heritage in accordance with the procedures identified in the historic heritage chapter of the Environmental Impact Statement for the project.

1.2.2 The replacement bridge and intersections

The replacement bridge would be located around 35 metres downstream of the existing Windsor bridge. The southern bridge approach road would be via a new realigned section of Bridge Street, which would start at the existing intersection of George Street and Bridge Street and head generally north-west along the alignment of Old Bridge Street on the eastern side of the Thompson Square parkland. The existing roundabout at the George Street and Bridge Street intersection would be replaced by traffic signals. The replacement bridge would connect with the junction of Wilberforce Road, Freemans Reach Road and the Macquarie Park access road at a new dual lane roundabout intersection.

The replacement bridge would be an incrementally launched bridge constructed of reinforced concrete and comprising five spans. The bridge deck would be about 15.5 metres wide and be supported on up to four piers in the river. It would have an overall length of about 160 metres, spanning both the river and The Terrace. This would enable The Terrace to be reconnected to provide vehicular, pedestrian and cyclist access to Windsor Wharf. The clearance under the bridge where it spans The Terrace would be about 3.6 metres, which would allow a range of service and emergency vehicles to pass under the bridge and access Windsor Wharf.

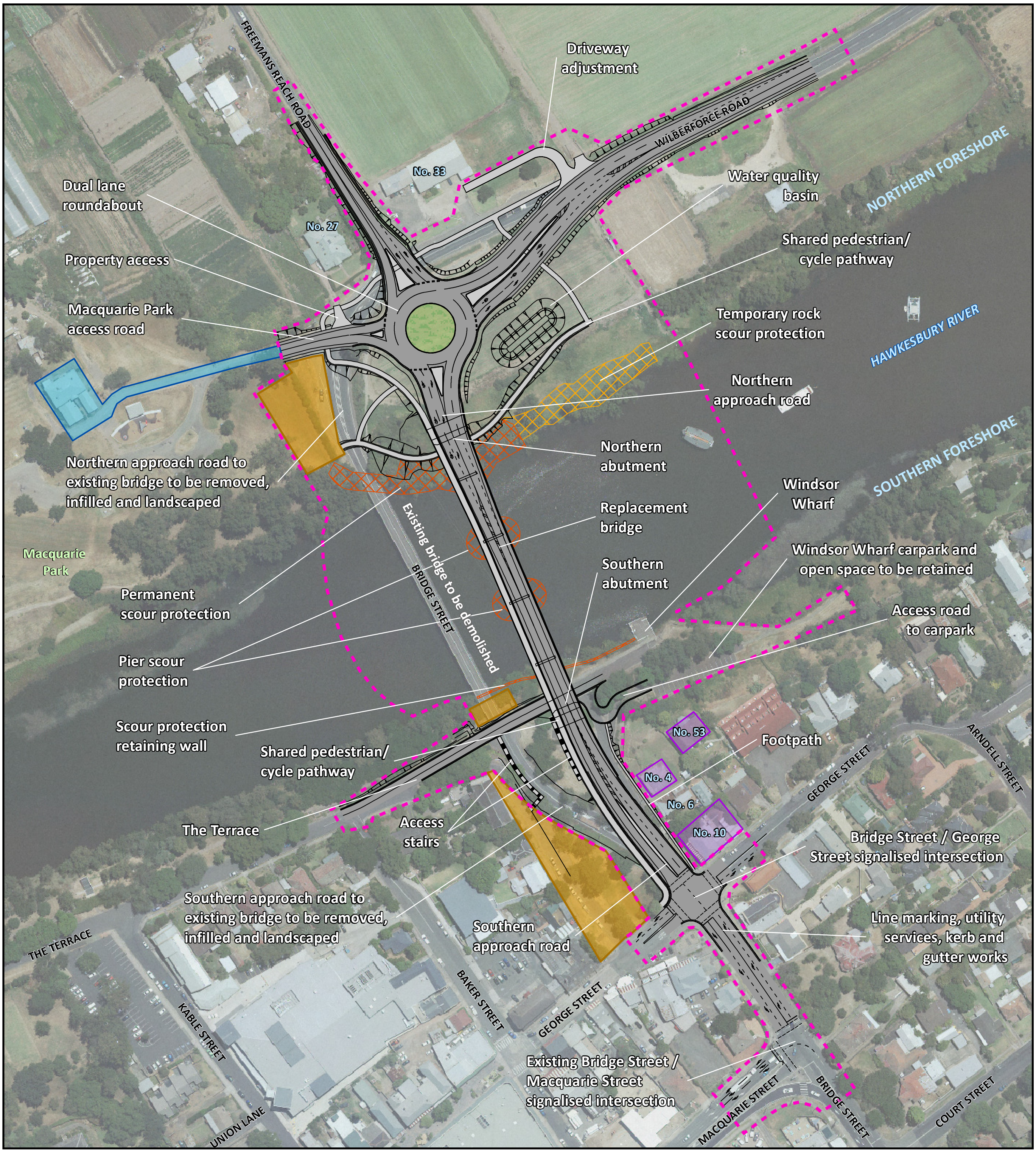
The replacement bridge would initially comprise two traffic lanes (one in each direction), each about 3.5 metres wide and with an adjacent two metre wide shoulder. There would also be a three metre wide shared pedestrian/cycle path on the western side of the bridge. The two metre wide road shoulders of the replacement bridge would allow the bridge to be re-configured to a three lane bridge in the future, when required. The introduction of the three lane configuration would occur when additional traffic capacity is required. The three traffic lanes would consist of two southbound lanes and one northbound lane.

The low point of the replacement bridge would be around 9.8 metres Australian Height Datum (AHD), making it around 2.8 metres higher than the lowest point of the existing bridge. The height of the replacement bridge may change slightly during the detailed design phase. This would give the replacement bridge a slightly higher level of flood immunity than the existing bridge. While the existing bridge is overtopped in a one in two year flood event, the replacement bridge is predicted to remain above water for the one in two year flood event but be overtopped in an event just smaller than the one in three year flood. This level of flood immunity is consistent with that of the northern approach roads (Wilberforce Road and Freemans Reach Road), which have a flood immunity that lies about midway between the one in two year and one in three year flood levels.

1.2.3 Demolition of the existing bridge

The existing Windsor bridge would be removed following commissioning of the replacement bridge and associated bridge approach roads. The existing bridge superstructure and substructure would be removed in sections, with temporary bracing installed, as required, to maintain the stability of remaining sections during the demolition process. Where possible the process of demolition would involve cutting or dismantling the superstructure and substructure into sections, with each section transported off-site for further demolition at an appropriately approved and licensed facility. Where possible the dismantled bridge elements would be reused or recycled, however some components of the bridge would require disposal at a landfill. Lead based paint has also been found on the bridge, so demolition activities would need to comply with relevant standards for managing lead based paint. Disruption of waterway traffic would be limited to the greatest extent practicable, with alternative navigation channels provided while the existing navigation span is closed for the demolition works.

Figure 1-1 | Key project elements



Indicative only – subject to detailed design

LEGEND

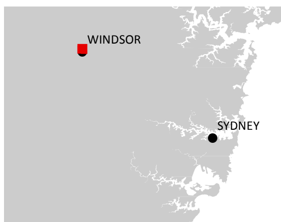
- Concept design
- Construction work zone
- Permanent rock scour protection (if required)
- Temporary rock scour protection (if required)
- Properties requiring flood mitigation works. Works subject to further consultation with and agreement from affected property owners.
- Properties requiring noise mitigation works. Works that are feasible and reasonable would be subject to further consultation with and agreement from affected property owners.
- Works subject to further council and stakeholder consultation

GDA 1994 | MGA Zone 56

A4 1:3,000

0 100

Metres



AUSIMAGE SKM

1.2.4 Pedestrian and cycling facilities

The project would incorporate facilities for pedestrians and cyclists and include a shared pedestrian/cycle pathway that would be constructed from Wilberforce Road and Macquarie Park, across the western side of the replacement bridge and southern approach road to the corner of George and Bridge Streets. Pedestrian and cyclist access along the southern bank of the river would also be improved with the connection and redevelopment of The Terrace. In addition, the following general works would be undertaken to improve pedestrian safety and access:

- Provision of a new 1.2 metre wide footpath adjacent to properties fronting Old Bridge Street.
- Provision of a new signalised pedestrian crossing on all four approaches to the intersection of Bridge Street and George Street.
- Provision of new pedestrian footpaths for safe access around and across the proposed dual lane roundabout at the junction of Freemans Reach Road, Wilberforce Road and the Macquarie Park access road including a path under the northern bridge abutment.

1.2.5 Water quality basin

The project would include 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. The water quality basin would be located on the eastern side of the proposed roundabout at the junction of Freemans Reach Road, Wilberforce Road and the Macquarie Park access road.

For the southern approach road a trash net to collect litter and a shut-off-valve to contain any spills in the stormwater system would be installed at the discharge point of the drainage system near Windsor Wharf.

1.2.6 Scour protection

Scour protection would be provided to protect the bridge abutments and piers from the erosive impacts of high river flows. On the southern bank, the scour protection would consist of a concrete panel retaining wall between Windsor Wharf and the existing bridge. Large diameter rocks (900 millimetres) and/or sandstone blocks would also be used to provide scour protection in some locations on the southern bank.

On the northern bank extensive rock and sandstone block scour protection would be required extending up the bank to about five metres above the usual water level. Other forms of scour protection such as a concrete grid planted with grass would be installed in areas above this where scour protection is required.

Scour protection using large rocks would be provided around three of the four bridge piers. Scour protection for each pier would cover an eight metre radius and would be to a depth of 4.5 metres. Dredging around the piers would be required to place the rocks below the river bed level. For the southernmost pier little or no scour protection would be required as bedrock is close to the surface in this location.

During the detailed design phase further work would be undertaken to minimise the visual impact of all visible scour protection and the extent and type of scour.

1.2.7 Public utility works

The existing bridge supports a number of public utilities which would be replicated on the replacement bridge including:

- A 450 millimetre water main (cement lined steel pipe).
- A 50 millimetre sewer rising main (galvanised iron pipe).
- A 100 millimetre electrical conduit.
- Telecommunications conduits (3 x 80 millimetre galvanised iron conduits).

Other public utilities that may need to be adjusted as part of the project include:

- High voltage overhead power lines from Macquarie Street to Wilberforce Road which cross the river on a similar alignment to the replacement bridge. These power lines would need to be relocated prior to bridge construction.
- Power lines near the corner of Wilberforce Road and Freemans Reach Road.
- Local stormwater drainage infrastructure.
- A rising main from Windsor Wharf to the local sewer system, which is used to pump out boat sewage holding tanks.
- A gravity sewer main, which runs beneath Old Bridge and Bridge Streets.
- A number of water mains on both the northern and southern river banks.
- Street lighting on both the northern and southern river banks.
- Telstra assets located on both sides of the river. In particular, Telstra assets located near the proposed southern bridge abutment would need to be relocated prior to construction of the bridge abutment.
- A new recycled water main for future use if required.
- Traffic signal cables along Bridge Street between George Street and Macquarie Street.

1.2.8 Urban and landscape concept design

The urban design and landscape concept design associated with the project was developed by applying project specific urban design principles and treatments. Works associated with the current concept design are described below.

Southern bank and Thompson Square area

At this stage of project development, the scope of works in Thompson Square parkland has yet to be fully defined and would be subject to further consultation with the community, government stakeholders and most importantly Hawkesbury City Council – who would be responsible for managing Thompson Square parkland in the longer term. For the purposes of assessment in the EIS, preliminary urban design and landscaping works for Thompson Square have been identified. These works have been developed with the objectives of providing pedestrian and cyclist access from the replacement bridge to various areas in Thompson Square and providing a base for additional urban design and landscaping works arising from the consultation process. The consultation process for the additional urban design and landscaping works for Thompson Square is ongoing and if possible the full scope of works would be presented and assessed in the Submissions Report. However, it is recognised that the full scope of works may not have been agreed before the completion of the Submissions Report and a post-approval Urban Design and Landscaping Plan for Thompson Square parkland maybe be required.

The scope of works assessed in the EIS include:

- Infilling the southern approach road to the existing bridge.
- Removal of some trees which are either in poor condition or would be impacted by the project.
- Minor earthworks in the Thompson Square lower parkland area to improve the connection of the parkland to the river.
- Construction of stairs from the bridge pedestrian/cyclist path to The Terrace and from Thompson Square road to The Terrace to provide pedestrian access.
- Reinstatement of the section of The Terrace and river bank currently bisected by the existing bridge and approach roads.
- Planting of trees and other vegetation in Thompson Square parkland.
- Landscaping in the road reserve between the three properties on Old Bridge Street and the southern approach road.

Bridge

The project specific urban design principles have been used to refine the visual appearance of the replacement bridge. This includes refinements to the pier shape, bridge superstructure and abutments to minimise its visual impact and provide context to the heritage values of Windsor.

Northern bank

- Infilling the northern approach road to the existing bridge.
- Minor earthworks to improve the visual appearance of the bank.
- Construction of pedestrian/cyclist paths to Wilberforce Road and Macquarie Park.
- Planting of trees and other vegetation.

1.2.9 Construction works

Temporary construction and compound sites

There would be two main construction and compound sites required for the duration of the project (about 18 months, excluding pre-construction and early works). One of these sites would be located within the turf farm between the Hawkesbury River and Wilberforce Road (Lot 2 DP 1096472 and Lot 2 DP65136); while the other would be sited on land between Old Bridge Street and Windsor Wharf (refer to Figure 1-1). The lower Thompson Square parkland would also be closed to public access and used to provide access for the construction of the southern abutment and approach road. The majority of the construction activity would be concentrated on the northern bank as this would be the location of casting yard for the incrementally launched bridge and would be the location where access to the river would predominately occur.

The construction compound on the southern bank would be located in the car parks and grassed areas and would support the construction of the southern approach road and other minor works.

Offices may be leased near Thompson Square for construction personnel.

Order of Construction Works

The order of construction works would be implemented to minimise environmental and traffic impacts as far as practical. The likely order of construction works would consist of the following:

- Pre-construction activities and early works – including construction compound and casting bed establishment, installation of environmental controls, public utility relocations or adjustments and additional investigations and heritage salvage.
- Construction of the bridge - including construction of the piers in the river, two bridge abutments and construction and launching of the bridge superstructure.
- Installation of scour protection on the banks and in the river.
- Construction of the northern roundabout and approach road and most of the southern approach road.
- Construction of temporary pavement both at Wilberforce Road and near the corner of George and Bridge Streets to provide additional road width to enable construction of the subsequent stages.
- Construction of the remainder of the southern approach road and the new sections of Freemans Reach Road, Wilberforce Road and Macquarie Park access road.
- Commissioning and opening of the replacement bridge to traffic.
- Demolition of the existing bridge and urban design works in Thompson Square, on the southern bank, northern bank and other adjacent areas.
- Removal of temporary structures and demobilisation of the construction facilities.

This proposed order of construction works is indicative and may change once detailed construction planning is completed. It is likely that some aspects of construction may overlap.

Construction period

It is anticipated that a construction period of around 18 months (excluding pre-construction and early works) would be required to complete the proposed works including demolition of the existing bridge.

Work hours

The majority of the construction works would be carried out during standard working hours, as detailed in **Table 1-2**. Some construction activities, in particular those requiring road closures, would need to be undertaken outside of standard working hours to prevent major disruptions to traffic and access. Other construction activities such as service relocations and cutovers may also need to be undertaken outside normal working hours. Low noise activities may also be undertaken outside of normal working hours to optimise construction efficiency.

Table 1-2 Standard working hours

Day	Start time	Finish time
Monday to Friday	7am	6pm
Saturday	8am	1pm
Sunday and public holidays	No work	

Construction equipment

The types of construction equipment likely to be used for the project would include (but would not necessarily be limited to) the following:

- Excavation plant, such as excavators, back hoes and front end loaders for pavement cutting, removal and general earthworks.
- Bobcats and sweepers.
- Compaction plant, including rollers, vibrating rollers, concrete vibrators and trench plate compactors.
- Pneumatic jack hammers.
- Profiling, milling and road paving plant.
- Jet-blasting and shot-blasting machines.
- Miscellaneous vehicles, including utilities, trucks, bogies and semi-trailers.
- Miscellaneous hand tools and equipment.
- Generators, lighting towers, signage and variable message boards.
- Various barges, workboats and pontoons.
- Piling rigs and various mobile and fixed cranes.
- Concrete and grouting pumps and transport vehicles.
- Support trusses, stress jacks and scaffold systems.

1.3 Project objectives

1.3.1 RMS Bridge Design Objectives

The bridge design objectives provided for the project include:

- Provide a crossing that has a higher level of flood immunity than the existing bridge.
- Provide a crossing with a flood immunity that is compatible with the surrounding approach roads.
- Major storm event check for no structural damage for a 2000 year Average Recurrence Interval (ARI) event.

The design and assessment would consider potential impacts:

- To upstream and downstream properties, and
- On regional flooding for events up to the Probable Maximum Flood (PMF).

1.4 Legislation and guidelines

Legislation and guidelines relating to works within flood liable land in New South Wales include:

- *Environmental Planning and Assessment Act 1979.*
- *Local Government Act 1993.*
- New South Wales *Floodplain Development Manual* (NSW Government, April 2005).
- *State Emergency Service Act 1989*.
- *State Emergency and Rescue Management Act 1989*.
- *Water Act 1912*.

- *Water Management Act 2000*.
- *Practical Consideration of Climate Change, Floodplain Risk Management Guideline* (DECCW, 2007)

1.5 Overview of Methodology

The results of previous hydrological and hydraulic modelling were used to provide information on the existing environment. An appropriate level of additional modelling for assessing impacts for the EIS was then undertaken to identify the potential flooding impacts of the project at a regional and property level, for events up to and including the probable maximum flood. The potential bed and bank scour effects of the project were also examined. Tasks undertaken are noted below.

- Collect and review data including:
  - Cadastre (from Land and Property Information).
  - A data set of land use classification prepared by the former Department of Environment and Climate Change (DECC). Land use was based on satellite imagery acquired between 1999 and 2007.
  - Two metre grid digital terrain model from Hawkesbury City Council derived from Airborne Laser Survey captured in 2007.
  - Water level data from 1987 to 2011 for gauge on the Hawkesbury River at Windsor from Manly Hydraulic Laboratory
  - Hawkesbury Nepean Flood Emergency Sub Plan (HNFESP) (SES, 2006)
  - Dataset of the location of residential structures and estimated ground levels at structures in the Hawkesbury Local Government Area used in the Hawkesbury Floodplain Risk Management Study (Draft 2012).
- Review of existing project related literature including:
  - Replacement of Windsor Bridge on MR182- Strategic Design Option1, RMS, drawing dated 19/8/2011.
  - Windsor Bridge over the Hawkesbury River – Hydraulic Analysis (WMAwater, August 2011).
  - Warragamba Flood Mitigation Dam Environmental Impact Statement, Flood Study (Warragamba Dam EIS Flood Study), Webb, McKeown and Associates, October 1994.
  - Proposed Warragamba Flood Mitigation Dam EIS (Volume 3), prepared for Sydney Water, ERM Mitchell McCotter, July 1995.
  - Achieving a Hawkesbury-Nepean Floodplain Management Strategy, Hawkesbury-Nepean Flood Management Advisory Committee (HNFMAC), Nov 1997.
  - Hawkesbury Floodplain Risk Management Study and Plan (Revised Draft for Public Exhibition), Bewsher Consulting, July 2012.
- Development of a hydraulic model to simulate hydraulic behaviour at the proposed bridge and when both bridges are present during the construction. HECRAS model software was adopted, which provides distribution of velocities at each structure and assessment of potential scour, such that an assessment of impacts to bed and bank stability was undertaken.
- Assessment of potential flood impacts during the operational phase (assuming the existing bridge is removed). Impacts assessed using the quasi-two dimensional hydraulic model (RUBICON) developed for the Warragamba Flood Mitigation Dam Environmental Impact Statement Flood Study and potential flood inundation of residential structures as provided in the draft Hawkesbury Floodplain Risk Management Study and Plan.

- Assessment of potential scour to the Hawkesbury River bed and banks as a result of the project.

1.6 Consultation informing this study

The hydrology and flooding assessment has been prepared drawing on information supplied by and consultation with the following organisations:

- Hawkesbury City Council
- Sydney Water
- Manly Hydraulics Laboratory.

(blank page)

2 Existing environment

2.1 Regional context

Windsor bridge is located over the Hawkesbury River and connects Bridge Street at Windsor with Wilberforce Road on the north bank of the River. Wilberforce Road provides access to Freemans Reach and Wilberforce. Windsor bridge is a significant river crossing as the nearest crossings are Richmond Bridge that is around 14 kilometres upstream, and Yarramundi bridge, around 18 kilometres upstream from Windsor bridge. Downstream the nearest bridge river crossing is the F3 freeway bridge at Mooney Mooney some 106 kilometres from Windsor bridge.

The Hawkesbury River drains the Nepean, Warragamba and Hawkesbury Rivers and their tributaries. The catchment extends from Goulburn in the south to the mouth of the Hawkesbury River at Broken Bay. The contributing catchment area is around 22,000 square kilometres and is referred to as the Hawkesbury-Nepean basin. The catchment includes natural bushland, areas developed for agriculture, commercial and industrial use and residential land use. The Hawkesbury-Nepean basin is the primary source for Sydney's water supply. There are five main storages including Warragamba Dam and four dams in the Upper Nepean catchment (Avon, Cataract, Cordeaux and Nepean dams).

The Nepean River extends to the Grose River junction, downstream the river becomes the Hawkesbury River. Large floods along the Hawkesbury River inundate floodplain areas downstream of Penrith and to a greater extent downstream of Yarramundi, including floodplains that are north and south of the river near Windsor. Flow in excess of the channel capacity inundates floodplains both to the north and south of the river between Yarramundi and Wilberforce. Flooding near Windsor is amplified due to restricted discharge through gorges downstream of Wilberforce. Much of the township of Windsor is built on a ridge above the river, the existing Windsor bridge and the floodplain north of the river is at a lower elevation and has been subject to more frequent and deeper inundation than properties in Windsor. Inundation of the existing bridge can last for several days as the floodwaters slowly recede.

2.2 Study area

Description of flooding and impact assessment considered in this working paper extends from Penrith Weir to Wilberforce. The detail of information along this reach varies considering the available datasets and methodology. Between Penrith Weir and Richmond flood levels are presented; between Richmond and Wilberforce the extent of inundation and water depths for individual lots in the floodplain are presented; and locally near the project surveyed floor levels of structures are available for assessment. An overview of the study area is shown on **Figure 2-2**.

2.3 Land use

From Richmond to Wilberforce there are large, low lying floodplain areas north and south of the Hawkesbury River. These areas have been extensively developed for agriculture and farming. There are some areas containing urban development, mainly around the townships of Freemans Reach, Wilberforce and Windsor. A dataset of land use classification, prepared by the former Department of Environment and Climate Change, were used to categorise activities undertaken within the study area. These land use classifications are more comprehensive than zoning land use maps. Within the study area there are various land use categories as presented in **Table 2-1** and shown in **Figure 2-2**.

For the purpose of this impact assessment categories have been combined into broader groups that are expected to experience similar flood impacts. These groups and associated categories are presented in **Table 2-1**.

Table 2-1 Land use classifications on the Hawkesbury River floodplain between Freemans Reach and Wilberforce

Broader land use groups	Various land use classifications
Pasture	Irrigated pastures
	Volunteer, naturalised, native or improved pastures
	Sown, improved perennial pastures
Horticulture	Cut flowers and herbs – irrigated
	Cropping - continuous or rotation - irrigated
	Orchard - tree fruits – irrigated
	Vegetables – irrigated
	Vineyard - grape and other vine fruits - irrigated
	Nursery
Horticulture - turf	Turf farming – irrigated
Intensive Animal Production	Intensive animal production – horse
	Horse stud and/or horse breeding facilities
	Intensive animal production – poultry
	Effluent ponds from intensive animal industries
Urban	Area recently under development for urban, commercial and/or industrial uses - infrastructure in place but no building activity
	Caravan park or mobile home village
	Industrial/commercial
	Residential
	Rural residential
	Sewage disposal ponds
	Tourist development
	Urban recreation
	Railway
	Road or road reserve
	Cemetery
Other	Special Category - Defence facility
	Quarry
	Water supply pressure reservoir including water filtration plant
	Government and private facilities - gaol, training centre, school, religious institutions & training centres, religious retreats
	National Park
	Private conservation agreement
	Land fenced for riparian management
	Riparian strip in urban and other developed areas but with minimal use
	Swamp
	Tree lot - exotic species
	Native forest
	Windbreak or tree corridor

Broader land use groups	Various land use classifications
	Lagoon or inland lake
	River, creek or other incised drainage feature; includes cowals in western NSW

2.4 Geomorphology

The Hawkesbury River is the largest river/estuary system in the Sydney region. It supports complex ecosystems that provide habitat for a multitude of native plant and animal species. An overview of the geomorphology near Windsor is taken from the Hawkesbury-Nepean River Management Forum (Warner, 2002). The Hawkesbury River is considered a tidal river and with an alluvial channel. The present channel is cut in silt-rich sands, which form fairly cohesive banks, with inset sandy deposits of post-settlement alluvium. The river channel between Freemans Reach and Wilberforce has large meanders with a floodplain up to six kilometres wide in places. Levees are sandy and between eight and 10 metres high.

2.5 Climate

Rainfall over the Hawkesbury River basin varies with higher rainfall in the south west reducing north towards the estuary. The Bureau of Meteorology (BoM) operates rainfall and evaporation gauges in the vicinity of the project. The closest weather station is at Richmond (station 067021 at UWS Hawkesbury). The historical rainfall and evaporation records for Richmond (BOM) show that it has a mean annual rainfall of around 800 millimetres and mean annual evaporation around 1410 millimetres. Monthly data for rainfall and evaporation at this gauge is shown on **Figure 2-1**.

Figure 2-1 Average Monthly Rainfall and Evaporation at Richmond (BoM, 2012)

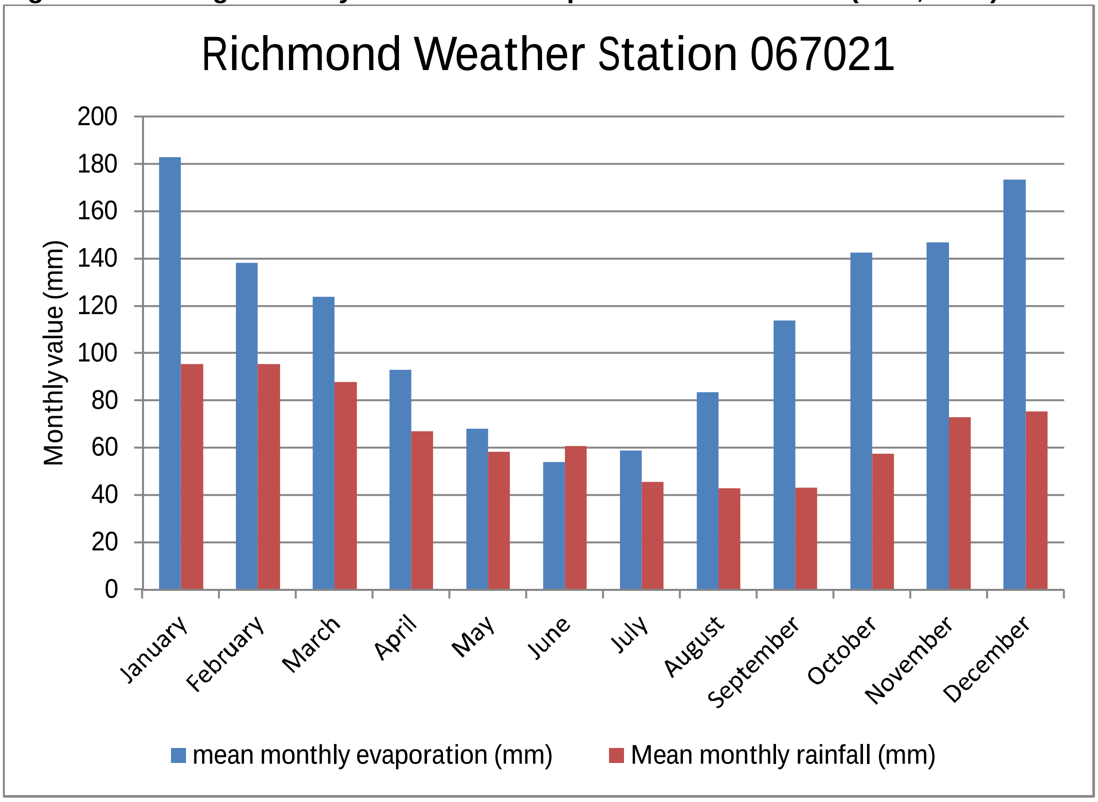
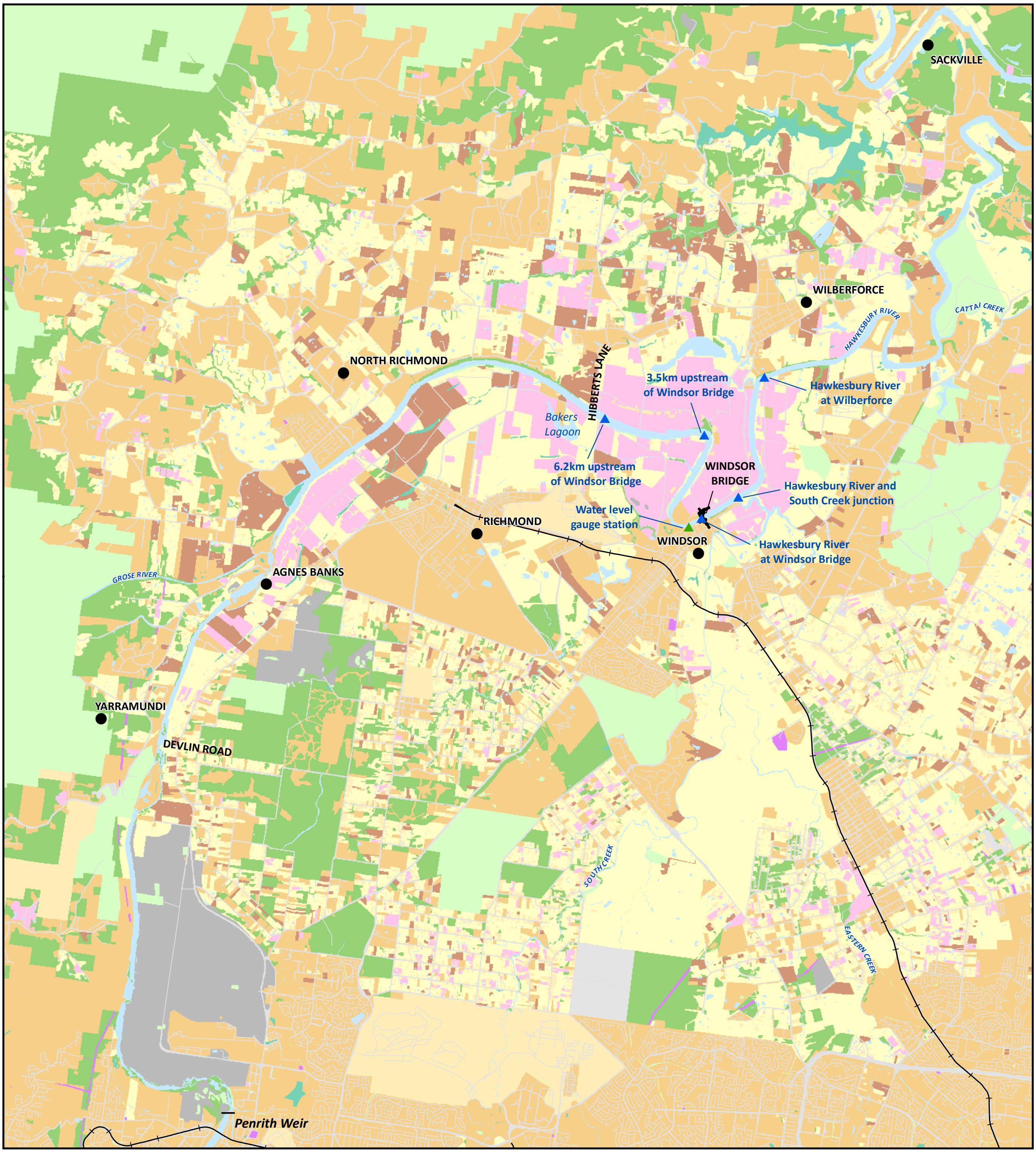


Figure 2-2 | Study area locality



Indicative only – subject to detailed design

LEGEND

- Water level gauge station
- Model location
- Road
- Railway

Land use

- Conservation Area
- Cropping
- Grazing
- Horticulture
- Intensive Animal Production
- Mining & Quarrying
- Power Generation
- River & Drainage System
- Special Category
- Transport & Other Corridors
- Tree & Shrub Cover
- Urban
- Wetland

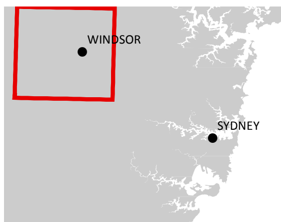
Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

GDA 1994 | MGA Zone 56

A4 1:150,000

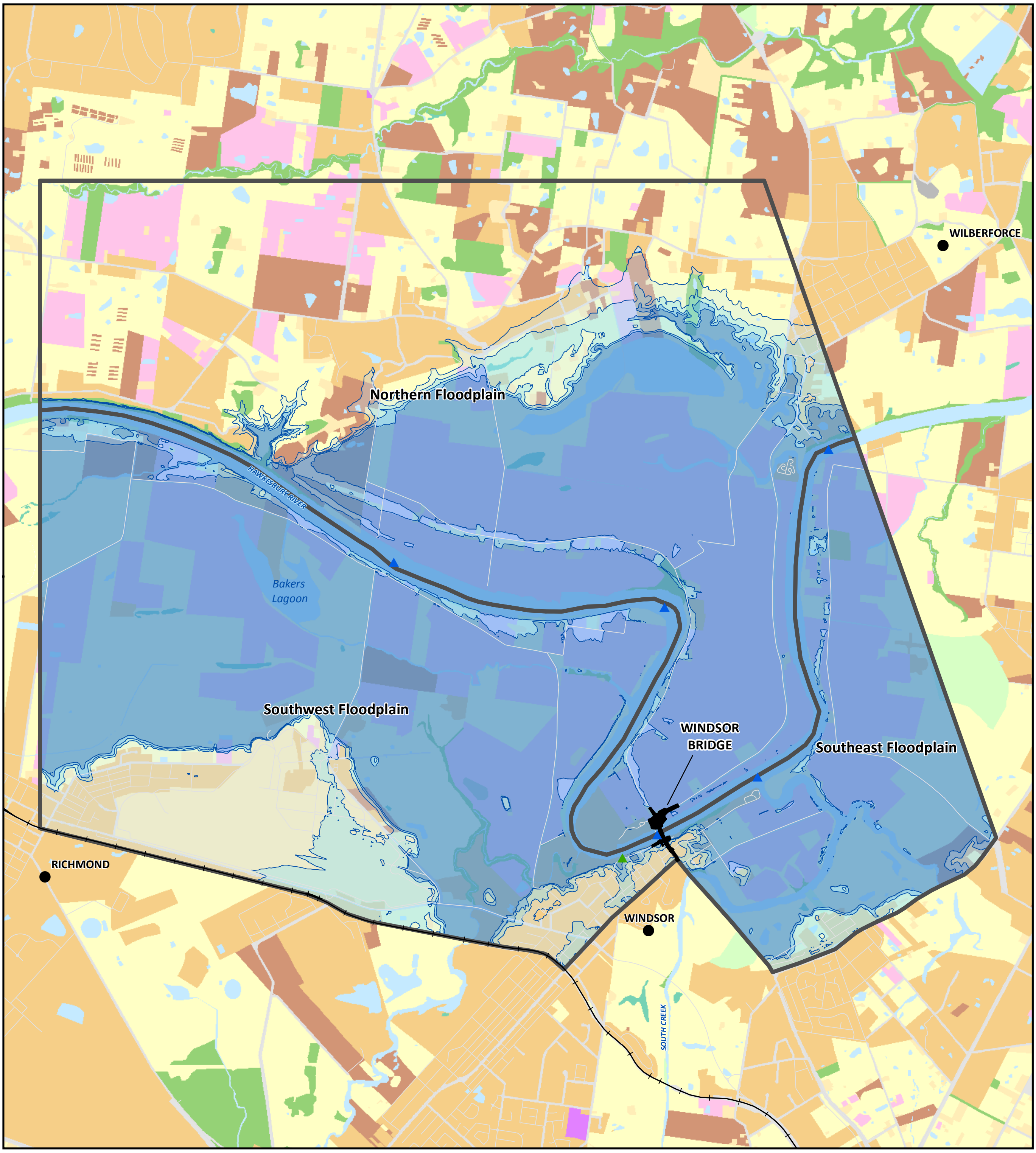
0 4

Kilometres



5/11/2012 | I:\NBIF\Projects\NB11459\Technical\GIS\GIS_Directory\ArcMap\Specialist_Reports\Hydrology\NB11459_002_Hy_StudyArea.mxd
Sydney Spatial Team - Prepared by : DD
Checked by : JC

Figure 2-3 | Land use and approximate extent of inundation



Indicative only – subject to detailed design

LEGEND

- 5 year ARI
- 20 year ARI
- 100 year ARI
- PMF
- Water level gauge station
- Model location
- Road
- Railway

Land use

- Conservation Area
- Cropping
- Grazing
- Horticulture
- Intensive Animal Production
- Mining & Quarrying
- Power Generation
- River & Drainage System
- Special Category
- Transport & Other Corridors
- Tree & Shrub Cover
- Urban
- Wetland

Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

GDA 1994 | MGA Zone 56

A4 1:55,000

0 2

Kilometres

Windsor Bridge replacement hydrological study

5/11/2012 | I:\NBIF\Projects\NB11459\Technical\GIS\GIS_Directory\ArcMap\Specialist_Reports\Hydrology\NB11459_004_Hy_Landuse.mxd
Sydney Spatial Team - Prepared by : DD
Checked by : JC

2.6 Flooding

Flooding in the vicinity of Windsor is influenced by a number of contributing factors including:

- Large flows from the Nepean River and spills from Warragamba Dam.
- Flow from tributary creeks along the Nepean and Hawkesbury Rivers downstream of Penrith which increase the flow in the Hawkesbury River.
- Extensive floodplain areas that become inundated when flow in the river exceeds the channel capacity. Floodplains act to temporarily store and attenuate flow.
- Constrained waterway capacity through the gorge area downstream of Wilberforce/Sackville, causing floodwaters to back up upstream of the gorge, particularly in large and extreme floods.
- Colo River inflows downstream of Sackville gorge that can impede flow passing through the gorge.

The ten highest recorded flood levels at Windsor since 1857 are shown in **Table 2-2**. The height of the existing bridge is about seven metres AHD.

Table 2-2 Flood levels of the 10 highest recorded flood events in Windsor (since 1857)

Year	Month	Flood level at Windsor (metres AHD)
1867	June	19.7
1864	June	15.1
1961	November	15.0
1964	June	14.8
1900	July	14.5
1978	March	14.5
1870	April	14.1
1956	February	13.8
1879	September	13.6
1990	August	13.5

2.6.1 Windsor bridge flood Immunity

Access to Windsor from areas north of Hawkesbury River (such as Wilberforce and Freemans Reach townships) during floods is limited by the level of the existing Windsor Bridge and low lying sections of Freemans Reach Road and Wilberforce Road. Levels along Freemans Reach Road vary between 9.6 and 12.8 metres AHD with the low point at the intersection with Wilberforce Road and a second low point at 10 metres AHD around 2 kilometres from Wilberforce Road. Levels along Wilberforce Road vary between 8.4 to 10.8 metres AHD between Windsor Bridge and where the road crosses Buttsworth Creek. Levels are based on Airborne Laser Survey data. Additionally Wilberforce Road is potentially inundated due to local catchment runoff surcharging culverts at Buttsworth Creek. The existing bridge is around 1.4 metres lower than the low point on Wilberforce Road and 2.6 metres lower than Freemans Reach Road.

Water level records for the river gauge at Windsor between 1987 and 2011 show there have been eight events for which water levels were higher than the level of the existing bridge (7 metres AHD). The average duration of these events was 43 hours.

2.6.2 Hydraulic modelling

Hydrologic and hydraulic modelling for the Hawkesbury-Nepean River was done as part of the Warragamba Dam EIS Flood Study (Webb, McKeown and Associates, October 1994). The hydraulic model used RUBICON software, which is a one-dimensional hydraulic model. The model was established to represent flow along the river, in tributary waterways and flowpaths across the floodplains. It does not allow for two-dimensional flow behaviour such as flow around river bends or flow variation within a floodplain. The cross section layout used in the model was coarse with distances between cross sections of two to three kilometres. The model was calibrated against major flood events. The most frequent occurring event assessed was a 5 year ARI event. Modelling considered the flood operations of the increased spillway at Warragamba Dam.

Hawkesbury City Council recently released the Hawkesbury Floodplain Risk Management Study and Plan as a Draft for Public Exhibition (dated July 2012). This study included flood maps for the 5 year, 20 year, 50 year, 100 year, 200 year, 500 year and 1000 year ARI floods and the probable maximum flood (PMF). Flow and water levels used to prepare maps was based on the RUBICON model originally developed for the Warragamba Dam EIS Flood Study. Hawkesbury City Council provided flood inundation maps as digital image files, which are presented in **Appendix A**.

2.6.3 Flow distribution

Peak flows at Windsor and flow at Sackville are presented in Table 2-3. Flows at Windsor are from the RUBICON model output for existing conditions, reporting locations are shown on **Figure 2-2**. Flow at Sackville provides an indication of combined flow within the river and floodplains at Windsor as there is limited floodplain at Sackville. Results provide an indication of the distribution of flow between the main river channel and flow onto the floodplain at Windsor. As floods increase in size a larger proportion of flow is conveyed or stored within the floodplains and doesn't pass Windsor bridge.

Table 2-3 Peak design flows near Windsor Bridge

Location	Peak Flow (m^3/s)			
	5 year ARI	20 year ARI	100 year ARI	PMF
Hawkesbury River 6.2km upstream of Windsor bridge	3,790	7,140	8,310	8,420
Hawkesbury River 3.5km upstream of Windsor bridge	3,750	6,610	7,660	7,800
Hawkesbury River at Windsor bridge	3,650	5,440	6,240	6,690
Hawkesbury River at Sackville#	**3,680**	**6,260**	**10,800**	**32,000**

Taken from *Warragamba Dam EIS Flood Study (1994), Table D15 (Page D62).*

2.6.4 Flood levels and velocities

Peak water levels at Windsor are 11.1 metres AHD and 17.2 metres AHD for the 5 and 100 year ARI events respectively (reference Warragamba Dam EIS Flood Study, 1994). The current height of Windsor bridge is seven metres AHD. The existing bridge is overtopped by around 4.1 metres and 10.2 metres of water for the 5 and 100 year ARI events, respectively.

Peak flood levels near Windsor bridge are presented in **Table 2-4**.

Flood profiles along the river are relatively flat in a 5 year ARI event and decreases in more infrequent events.

Flow for a 100 year ARI event in the Hawkesbury River channel is at depths of up to 20 metres with an average channel velocity up to 3.5m/s. The depth of water and the velocity within the floodplain varies over the duration of a flood and for various sizes of floods. For a 5 year ARI event and larger (less frequent), velocities are largest when the river level is rising. Velocities are lower when the peak water level occurs, due to slow moving water over the floodplain.

The preliminary flood mapping, refer to **Section 2.6**, provided a spatial variation of water depths between Richmond and Wilberforce. Depths vary over the floodplains in a 5 year ARI from less than one metre to over 5 metres. In a 100 year ARI event depths are up to 16.8 metres with the average depth around 5 metres. An overview of average depths within each land use zone over the floodplain is provided in **Section 2.6.5**.

Table 2-4 Peak water levels near Windsor Bridge

Location	Peak Water Level (metres AHD)			
	5 year ARI	20 year ARI	100 year ARI	PMF
Hawkesbury River 6.2km upstream of Windsor Bridge	11.56	13.71	17.31	25.55
Hawkesbury River 3.5km upstream of Windsor Bridge	11.42	13.66	17.30	25.54
Hawkesbury River at Windsor Bridge	11.04	13.61	17.29	25.54

2.6.5 Flood affected properties

General

Flood extent maps (**Appendix A**) indicate large areas are inundated between Richmond and Wilberforce in a 5 year ARI event. The FRMS reported, within the Hawkesbury Local Government Area (LGA), 40 residential and 14 commercial/industrial buildings[1] would experience inundation above floor levels in a 5 year ARI event. The number of buildings increases considerably for larger events with 466 residential and 86 commercial/industrial for a 20 year ARI, and 3387 residential and 609 commercial/industrial for a 100 year ARI event. The annual average cost of flood damages within the LGA was estimated to be about $18 million. The FRMS considered potential damage to residential dwellings alone. Buildings identified as commercial/industrial were considered in terms of potential damages associated with residential dwellings on these properties. No estimate of potential flood damages to agriculture, commercial or industrial activities was done.

Inundation of Lots

An inundation assessment was done for this EIS to identify flooding of the various land use categories within the floodplain. Preliminary flood maps were produced using results from the RUBICON model that were projected over the digital terrain model (developed from Airborne Laser Survey data that was provided by Hawkesbury City Council). Visually the extents of inundation north of the Hawkesbury River between Richmond and Wilberforce correspond with the extents provided by Hawkesbury City Council; thus preliminary flood maps are considered suitable to use for the assessment of flood impacts.

Figure 2-3 shows the land use variation within the estimated 5, 20 and 100 year ARI events and the PMF extents within three broad zones. The number of lots, area within each land

1 Hawkesbury Floodplain Risk Management Study (Bewsher Consulting, Draft July 2012)

use and the estimated average depth of inundation for existing conditions within each zone is presented in **Table 2-5**. Zones represent:

- Northern floodplain between Freemans Reach and Wilberforce.
- South west floodplain between Richmond and Windsor bounded to the south by the railway.
- South east floodplain Windsor to Wilberforce, includes lower reaches of South Creek bounded by roads.

Estimated Inundation of Residential Buildings

Hawkesbury City Council provided access to the dataset of residential structures used in the Floodplain Risk Management Study (Draft 2012)[2]. Limitations of this data include:

- The location of buildings was based on cadastre with reference to the garbage collection dataset for land occupancy, rather than survey of individual properties.
- The ground level data has been obtained from Airbourne Laser Survey (ALS) and ground levels between measured points are interpolated – which may not be an accurate reflection of actual ground level between two points.
- The ALS ground level data for each lot that contains a building may not accurately reflect the actual ground floor level of the building. This is because the ALS ground level data for each lot may not be taken where the building is located on a lot. For example on a lot that has a slope, the ground level data may be from the lowest point of the lot, rather than the highest point where buildings are often located.
- The data may not accurately reflect the floor level of a building as a building may be raised or located on an earth mound, a feature common of many of the buildings in the floodplain. An example of the difference between the ALS data and actual floor level (from a conventional survey) is 27 Wilberforce Road, at the corner of Wilberforce Road and Freemans Reach Road. The ALS data for this property is 10.23 metres AHD, where the survey data is 12.99 metres AHD.
- The data was prepared to assess damages to residential dwellings, which may be located on either a residential lot or associated with a commercial land use. Thus buildings that are large sheds and associated offices used for agricultural activities such as turf farming and horticulture are not explicitly captured in the data. Land use for each identified building was based on Council's zoning and broad assumptions were applied for assessment of potential damages, for example where a property is located in an agricultural zone the land use was classified as residential to reflect that dwellings are often associated with this land use. Commercial zones that are also used for residential dwellings were classified as commercial and therefore potential residential impacts may be understated.

[2] The dataset of residential structures within the floodplain was made available for reference in the project by Hawkesbury City Council's consultant Bewsher Consulting. The data is subject to the limitations reported in the Floodplain Risk Management Study. The dataset is draft and should not be relied upon without independent checking; the property details are approximate and are not based on floor level survey.

Table 2-5 Estimated number of lots inundated

Land use groupings	5 year ARI event			20 year ARI event			100 year ARI event			PMF event		
Northern Floodplain	number of lots	area inundated (ha)	average depth (m)	number of lots	area inundated (ha)	average depth (m)	number of lots	area inundated (ha)	average depth (m)	number of lots	area inundated (ha)	average depth (m)
Grazing	52	330	2.9	53	330	4.5	63	350	6.1	71	380	12.4
Horticulture	39	260	2.1	39	260	4.4	39	260	8.0	39	260	16.3
Horticulture - turf	73	630	3.1	73	630	5.4	73	630	9.0	75	640	16.8
Intensive Animal Production	7	90	1.8	8	90	2.9	10	110	4.9	11	110	10.5
Other	43	100	4.5	43	100	6.1	43	100	8.5	44	110	14.3
Urban	43	60	3.8	59	60	4.0	135	80	3.4	188	130	8.5
Total	*257*	*1470*		*275*	*1470*		*363*	*1530*		*428*	*1630*	
South East Floodplain												
Grazing	50	270	3.6	51	270	5.9	51	270	9.3	51	270	17.5
Horticulture	5	30	4.5	5	30	7.3	5	30	11.0	5	30	19.2
Horticulture - turf	55	310	3.6	55	310	6.2	55	310	9.9	55	310	18.2
Intensive Animal Production	5	20	3.3	5	20	4.9	5	20	7.7	5	20	16.0
Other	4	0	4.5	4	0	6.3	4	0	9.6	4	0	17.9
Urban	43	20	1.6	69	20	2.1	213	40	2.1	227	40	9.9
total	*162*	*650*		*189*	*650*		*333*	*670*		*347*	*670*	
South West Floodplain												
Grazing	50	700	3.8	51	700	5.6	54	700	8.0	54	700	15.5
Horticulture	16	140	2.0	16	140	4.1	17	150	7.3	18	150	14.8
Horticulture - turf	32	570	3.7	32	570	5.8	32	570	9.2	32	570	17.4
Intensive Animal Production	3	50	3.2	3	50	4.9	3	50	8.2	3	50	16.4
Other	7	10	6.2	7	10	8.3	7	10	11.8	7	10	20.0
Special Category	1	200	3.9	1	200	5.4	1	200	1.7	5	280	6.2
Urban	43	90	2.0	99	90	1.9	310	130	2.0	1101	210	5.4
total	*152*	*1760*		*209*	*1760*		*424*	*1810*		*1220*	*1970*	

In addition to buildings from the data provided through Hawkesbury City Council, RMS surveyed floor levels[3] for properties near the bridge and within the upstream floodplain that are potentially impacted by the project. The location, floor level and estimated depth of existing flooding at these buildings are provided in **Table 2-6**. In the existing conditions, of the buildings which RMS have a detailed survey of the floor levels:

- Twenty four buildings on twelve properties are estimated to experience above floor inundation in a 5 year ARI event.
- Thirty-four buildings on sixteen properties are estimated to experience above floor inundation in a 20 year ARI event.
- Thirty-five buildings on sixteen properties are estimated to experience above floor inundation in a 100 year ARI event.

Estimated existing inundation of other residential properties identified in the Hawkesbury City Council database (ie. where there is no detailed survey of floor levels) for existing conditions include:

- Three buildings experience above floor inundation in a 5 year ARI event.
- 130 buildings experience above floor inundation in a 20 year ARI event.
- 699 buildings experience above floor inundation in a 100 year ARI event.

It is noted these are a subset of potentially inundated properties considered in the Floodplain Risk Management Study which accounted for properties in the whole Hawkesbury LGA.

2.6.6 Emergency management

Floods in the Hawkesbury-Nepean River are classified in the Hawkesbury Nepean Flood Emergency Sub Plan (HNFESP) as either Level 1 (when water level at Windsor is less than 15 metres AHD) or Level 2 (for floods greater than 15 metres). State Emergency Services (SES) manages evacuation during a Level 2 flood in accordance with measures provided in the HNFESP. The plan covers the area between Wallacia to downstream of Spencer. The purpose of the HNFESP covers responsibilities for emergency management, preparedness, evacuation and recovery measures. Flood evacuation routes are for areas on the south side of Hawkesbury River. Windsor's evacuation routes include recently constructed Windsor flood evacuation bridge (centreline height 17.8 metres AHD) and Windsor Road (closed at 13.5 metres AHD). Emergency access in the HNFESP does not include evacuation from the northern floodplain to Windsor via the existing bridge.

The HNFESP notes that the stream gauge at Windsor (reference 212426) is used for emergency planning. This gauge is located around 50m upstream of the existing bridge.

Emergency management for Level 1 floods is addressed in the Hawkesbury City Local Flood Plan (a sub-plan of the Hawkesbury City Local Disaster Plan). The Plan notes that the council closes and re-opens its own roads as does RMS (Subsections 3.13.2 and 3.13.3). This plan does include a flood traffic management plan for Wilberforce Road and Freemans Reach Road.

[3] Survey provided in February and October 2012

Table 2-6 Estimated depth of overfloor inundation for existing conditions

Property Address	Surveyed Floor Level (mAHD)	Estimated Existing Flood Depth above surveyed floor level (m)			
		5 year ARI	20 year ARI	100 year ARI	PMF
1 Thompson Square	14.03	-	-	3.26	11.51
5 Freemans Reach Road	13.12	-	0.49	4.16	12.41
5 Freemans Reach Road	13.47	-	0.14	3.81	12.06
5 Freemans Reach Road	11.52	-	2.09	5.76	14.01
27 Wilberforce Road	12.99	-	0.62	4.29	12.54
27 Wilberforce Road	11.17	-	2.44	6.11	14.36
33 Wilberforce Road	10.34	0.69	3.27	6.94	15.19
33 Wilberforce Road	10.97	0.06	2.64	6.31	14.56
33 Wilberforce Road	11.67	-	1.94	5.61	13.86
1A Wilberforce Road	10.88	0.18	2.74	6.41	14.66
1A Wilberforce Road	10.86	0.20	2.76	6.43	14.68
1A Wilberforce Road	10.88	0.18	2.74	6.41	14.66
1A Wilberforce Road	10.86	0.20	2.76	6.43	14.68
23 Wilberforce Road	11.11	-	2.51	6.18	14.43
23 Wilberforce Road	10.93	0.13	2.69	6.36	14.61
98 Cordners Lane	11.69	-	1.96	5.61	13.85
124 Cornwallis Road	10.51	0.74	3.15	6.79	15.03
124 Cornwallis Road	9.42	1.83	4.24	7.88	16.12
295 Freemans Reach Road	11.22	0.05	2.44	6.08	14.32
295 Freemans Reach Road	11.09	0.18	2.57	6.21	14.45
295 Freemans Reach Road	10.92	0.35	2.74	6.38	14.62
295 Freemans Reach Road	11.01	0.26	2.65	6.29	14.53
1 Gow Lane	9.23	2.09	4.44	8.07	16.31
1 Gow Lane	9.36	1.96	4.31	7.94	16.18
332 Cornwallis Road	11.42	0.07	2.27	5.89	14.13
332 Cornwallis Road	11.17	0.33	2.53	6.14	14.38
362 Cornwallis Road	11.63	-	2.07	5.68	13.92
156 Freemans Reach Road	10.81	0.35	2.83	6.49	14.73
238 Freemans Reach Road	10.69	0.43	2.94	6.60	14.84
238 Freemans Reach Road	11.53	-	2.10	5.76	14.00
238 Freemans Reach Road	10.19	0.93	3.44	7.10	15.34
238 Freemans Reach Road	10.21	0.91	3.42	7.08	15.32
490 Freemans Reach Road	11.19	0.33	2.51	6.12	14.36
521 Freemans Reach Road	11.16	0.39	2.54	6.15	14.39
521 Freemans Reach Road	10.88	0.67	2.82	6.43	14.67

3 Impact assessment

3.1 Concept design for the replacement bridge

The replacement bridge would be about 160 metres long (between abutments), with a deck width of around 15.5 metres that has a cross grade of around 1.5%. The bridge deck thickness is about 2.2 metres with 1.3 metres high concrete barriers either side of the travel lanes and a collapsible pedestrian balustrade. The bridge would be supported by 4 piers about 2.2 metres wide. The bridge and approach roads would fall from south to north from a level of around 12.1 metres AHD at the southern abutment to around 9.8 metres AHD at the northern abutment.

The replacement bridge presents a larger obstruction to flood waters within the Hawkesbury River channel than the existing bridge, as the bridge deck is deeper, barriers are higher and the piers are wider, although there are less of them.

3.2 Operation

3.2.1 Flood immunity

An objective of the project is to improve the level of flood immunity. The bridge connects Bridge Street in Windsor to Wilberforce Road and Freemans Reach Road. The project has adopted a minimum road level of RL 9.8 metres AHD (2.8m higher than the existing bridge), which is around the same level as the minimum level of Freemans Reach Road and is higher than approximately 60% of the length of Wilberforce Road from the bridge to Wilberforce.

The level of the replacement bridge is optimum as it provides connection to the existing roads while improving the flood immunity for the crossing. A higher level would not improve access across the river in floods as the northern roads would be inundated and it would require extensive road works on the northern bank to transition to the existing road profiles. Placing the bridge at a lower level would limit access across the river, as currently occurs.

The replacement bridge results in a decrease in the probability of the river crossing being closed. Based on historic flood events between 1987 to 2011[4], the decrease in the number of events that the river water level is above the existing and proposed deck levels is from eight events to three events, within the 24 years of record. The average duration of these events decreases from 43 hours to 19.5 hours per event.

3.2.2 Flood impacts

The project has the potential to exacerbate flooding to adjacent properties and to the wider floodplain due to the bridge superstructure and approach roads obstructing the waterway area to a greater extent than the existing bridge. The impact to flow behaviour was assessed using hydraulic modelling as described in **Appendix B**. Presentation of impacts to flood behaviour is provided below.

[4] recorded water levels at Windsor gauge (MHL stream gauge 212426)

Flow Distribution

The predicted peak flows and change in flow are presented in **Table 3-1** at selected locations near Windsor. The tabulated values are representative of flow within the main river channel. For the project the change in flow is minor with a small reduction in the peak flow in the river (less than one per cent) in a 100 year ARI event. Peak flows reduce due to attenuation of floods when water levels increase and due to some redistribution of water onto the floodplains.

Table 3-1 Peak design flows near Windsor Bridge

Location on Hawkesbury River	Existing Bridge (m^3/s)				Change due to project * (m^3/s)			
	5 year ARI	20 year ARI	100 year ARI	PMF	5 year ARI	20 year ARI	100 year ARI	PMF
6.2km upstream of Windsor Bridge	3,790	7,140	8,310	8,420	-10	-20	-	-120
3.5km upstream of Windsor Bridge	3,750	6,610	7,660	7,800	-10	-60	-50	-90
Windsor Bridge	3,650	5,440	6,240	6,690	-10	-140	-60	-20

* *Negative values refer to decrease in flow*

Flood Levels

The existing peak water levels and the change in peak flood levels for the 5, 20, 100 year ARI event and PMF due to the project are provided in **Table 3-2** near the bridge and **Table 3-3** for the reach between Penrith and Sackville. Locations referenced are shown on **Figure 2.2**. Differences in model results less than 0.01 metres are considered to be within the accuracy of modelling and are thus considered negligible for the purpose of identifying potential impacts.

Results presented indicate that the project would have a varying impact on flood events for different recurrence intervals. Of the events modelled, the largest impact would occur for a 5 year ARI event. The flood level would increase by 0.12 metres just upstream of the replacement bridge and would propagate further upstream causing flood level increases of 0.06 metres at North Richmond and 0.03 metres at Devlins Road. The upstream impact would dissipate just downstream of Penrith Weir. In contrast to upstream flood levels, downstream flood levels at Wilberforce and Sackville in the 5 year ARI event would decrease by 0.02 metres.

For the 20 year ARI event, the project would result in a flood level increase of 0.03 metres just upstream of the bridge, which would propagate further upstream to be a 0.02 metres increase at Hibberts Lane and 0.01 metres increase at Devlins Road. As for the 5 year ARI event, downstream flood levels at Wilberforce and Sackville in the 20 year ARI event would decrease by 0.01 metres.

The results of the 100 year ARI and PMF peak water levels suggest that the impact of the project on major and extreme flood behaviour would be negligible with an increase of 0.01 metres in the 100 year ARI event immediately upstream of the replacement bridge.

Table 3-2 Peak Flood Levels near Windsor Bridge

Location on Hawkesbury River	Existing Bridge (m AHD)				Change due to project (m)			
	5 year ARI	20 year ARI	100 year ARI	PMF	5 year ARI	20 year ARI	100 year ARI	PMF
6.2km upstream of Windsor bridge	11.56	13.71	17.31	25.55	0.10	0.02	-	-
3.5km upstream of Windsor bridge	11.42	13.66	17.30	25.54	0.10	0.02	-	-
Windsor bridge	11.04	13.61	17.29	25.54	0.12	0.03	0.01	-

Table 3-3 Peak Flood Levels along Hawkesbury River *

River Locations	Existing flood levels (m AHD)				Change in flood level (m)			
	5 year ARI	20 year ARI	100 year ARI	PMF	5 year ARI	20 year ARI	100 year ARI	PMF
Downstream of Penrith Weir	19.24	22.07	25.26	30.97	-	-	-	-
Devlins Road	13.77	17.34	20.1	28.92	0.03	0.01	-	-
Yarramundi	13.04	16.12	18.22	25.98	0.04	0.01	-	-
North Richmond	12.43	15.11	17.52	25.64	0.06	0.01	-	-
Hibberts Lane	11.63	13.74	17.31	25.53	0.09	0.02	-	-
Windsor Bridge	11.04	13.61	17.29	25.54	0.12	0.03	0.01	-
South Creek Junction	10.99	13.6	17.28	25.53	-0.02	0.01	-	-
Wilberforce	10.75	13.53	17.23	25.51	-0.02	0.01	-	-
Sackville	7.78	10.06	13.14	22.39	-0.02	0.01	-	-
Floodplain Locations								
Agnes Banks	13.01	14.53	18.18	25.96	0.04	-	-	-
Richmond	16.09	16.19	17.31	25.56	-	-	-	-
Bakers Lagoon	11.24	13.68	17.35	25.57	0.11	0.02	-	-

*Results from RUBICON hydraulic model (WMAwater, 2012)

Flood Duration

Results from hydraulic modelling indicate that the project results in an increase in the duration of inundation due to more temporary storage engaged when water levels increase. Of the events modelled this increase is largest for the 5 year ARI event. The change in time that the predicted water levels are above various levels is provided in **Table 3-4**. These increases would be less than 10% of the existing duration up to 10.5 metres AHD. As water levels rise and fall there would be between five to ten percent increase in duration. The largest difference is estimated when the peak water level occurs and is associated with increased temporary storage.

For larger, less frequent, events the difference is less as the project has less flood impact during these events.

Table 3-4 Change in flood duration – 5 year ARI event

Water Level (m AHD)	Duration above water level with existing bridge (hours)	Increase duration due to project (hours)
9.8	34	1.5
10	31	1.5
10.5	21	2
11	5	5.7

Property impacts

Potential flood impacts to properties would include increased number of inundated properties, increase in depth of flooding, duration of inundation and velocities at properties. These impacts can increase risk to people who live or work at the properties and increase to potential flood damages associated with the residential or commercial activities undertaken within properties. Changes to flood behaviour at properties can include impact to property accesses. Properties most vulnerable to impacts would be those located where the estimated increase in flood levels is greatest (upstream of the bridge).

Existing flood risk to residential dwellings in the Hawkesbury LGA is addressed in the Draft Floodplain Risk Management Study and Plan (Bewsher, July 2012). Property data used in this study was provided through Hawkesbury City Council for use in this EIS to estimate impacts from the project. This is supplemented for properties close to the project for which floor levels were surveyed. Additionally a wider assessment has been done to consider potential impacts to land use other than residential dwellings.

Potential impacts to properties between Richmond and Wilberforce

An assessment of the potential flood impacts to properties upstream of the project has been undertaken using the model results presented in **Table 3-2** and **Table 3-3**, ALS data over the floodplain and cadastre. Assessment is for the northern floodplain and the southwest zone as shown on Figure 2-2. Flood levels downstream of the project (in the southeast zone) are not considered as flood levels slightly reduce due to the project in the 5 year ARI event and have only a minor increase in a 20 year ARI event (up to 0.01m which is considered within the range of model accuracy) and no change in a 100 year ARI event.

The assessment indicates that one additional lot would experience flooding in a 5 year ARI in the southwest zone due to the project and up to 359 lots (in the northern and southwest zones) are expected to experience an increase in a 5 year ARI flood depth due to the project. The percentage increase of flood depths of five percent (for example 0.05 metre increase in depth above an existing flood depth of one metre) is estimated for 200 of the lots, an additional 103 lots are estimated to have an increase of up to ten percent and an additional 51 lots an estimated increase up to 15 percent. The distribution of increases to depths for various land use are presented in **Table 3-5**.

The assessment indicates that one additional lot would experience flooding in a 20 year ARI in the southwest zone due to the project and up to 581 lots (in the northern and southwest zones) are estimated to experience an increase in a 20 year ARI flood depth due to the project. For all lots potentially subject to an increase in inundation depth, the percent increase of flood depths above the existing flood depths is less than 5%.

The majority of the area subject to inundation is for agricultural purposes, refer to **Table 3-5**. Agricultural damage is usually quantified by considering both the depth of inundation and time of inundation, and the following are suggested criteria for damage (Read Sturgess & Associates, 2000):

- Grain and vegetable crops are expected to be lost when the flood depth is between 0 and 0.15 m, no matter how long the land is flooded for;
- Pasture, vines and orchards are damaged when the inundation time is greater than 7 days and/or the depth of flooding is greater than 0.15 m.
- Significant livestock losses occur when the depth of flooding is greater than 0.15 m and/or the inundation time is greater than 7 days.

Table 3-5 Potential impacts to flood depths on properties between Richmond and Wilberforce – 5 year ARI event

Land use groupings	Existing Conditions		Replacement Bridge	
	Estimated area inundated (ha)	Average depth of inundation (metres)	Average depth of inundation (metres)	Increase in average depth (metres)
Northern Floodplain				
Grazing	330	2.95	2.99	0.04
Horticulture	260	2.15	2.21	0.06
Horticulture – turf	630	3.06	3.11	0.05
Intensive Animal Production	90	1.83	1.88	0.05
Other	100	4.48	4.53	0.05
Urban	60	3.81	3.85	0.03
South West Floodplain				
Grazing	700	3.79	3.86	0.07
Horticulture	140	2.03	2.09	0.07
Horticulture - turf	570	3.75	3.82	0.08
Intensive Animal Production	50	3.22	3.29	0.06
Other	10	6.19	6.28	0.09
Special Category	200	3.88	3.94	0.06
Urban	90	2.03	2.06	0.03

Potential impacts to residential buildings between Richmond and Wilberforce

Flood afflux (increase in water depths) of buildings located upstream of Windsor bridge, and on the northern floodplain, was assessed from the preliminary mapping prepared for this EIS, surveyed floor levels undertaken by RMS and buildings identified from the HCC dataset used in the FRMS. Identification of existing flood impacted properties does not represent a replication of flood assessment undertaken for the FRMS, nor does it accurately identify overfloor inundation for properties other than surveyed by RMS, as survey of floor levels was not undertaken when developing this dataset for the FRMS. It provides an indication of likely impacts to residential properties. Impacts to properties may include increased flood damages, impacts on the safety of residents and impacts to property access.

Buildings with an estimated increase in flooding of less than 0.01 metre due to the project are not included in this assessment as this increase is considered negligible and beyond the accuracy of the modelling used to determine afflux. Properties subject to flooding greater than one metre for existing conditions are not included in this assessment as the increase in flood depths is minor compared with existing flood inundation.

Table 3-6 shows the existing flood depths and estimated increase in flood levels for buildings with surveyed floor levels. The increase to flood depths is shown for the five, 20 and 100 year ARI events. Results for the PMF are not provided as there is negligible increase in flood levels for this event. These results indicate that:

- In a five year ARI event one additional residential dwellings would be experience over floor flooding (23 Wilberforce Road) due to the project and 25 buildings would experience increased flooding levels greater than 0.01 metre. Of these 25 buildings, three buildings have an existing over floor flooding of greater than one metre. Average increase in flood levels due to the project for the other 22 buildings would be 0.10 metre, with the largest increase in water depth of 0.12 metre. There would be 15 buildings with an increase in flood levels due to the project of greater than 25 percent, two of which are generally subject to low levels of flooding in the existing conditions (less than 0.1 metre). These two buildings would be at most risk of increased flood damage from increases in flood levels due to the project.
- In a 20 year ARI event there would be no additional buildings experiencing over floor flooding due to the project. Thirty four (34) buildings would experience increases in flood levels due to the project of greater than 0.01 metre however, 31 properties have an existing depth of inundation greater than one metre. The average increase in flood levels for the three properties that have increase greater than 0.01 metre and an existing depth less than one metre is 0.03 metre.
- In a 100 year ARI event there are negligible changes to flood levels at buildings due to the project.

Estimated afflux for buildings other than those surveyed, was assessed using the HCC dataset. As noted previously this data assumes residential buildings have floor levels at the ground levels of the properties. The predicted impacts for the different flood events include:

- In a five year ARI event there would be no additional residential dwellings would be experience over floor flooding due to the project. Three residential dwellings would experience increases in flood levels of greater than 0.01 metre due to the project and of these, one dwelling has an existing depth of inundation greater than 1 metre. The increase in flood levels at these buildings due to the project would be 0.11 metre.
- In a 20 year ARI event there would be four additional residential dwellings that would experience over floor flooding due to the project. One hundred and thirty (134) residential dwellings would experience increases in flood levels greater than 0.01 metre due to the project, however 45 properties have an existing depth of flooding greater than one metre. Average increase in flood levels due to the project for the other 89 properties would be 0.02 metre with the highest experiencing an increase of 0.03 metre.
- In a 100 year ARI event there would be negligible changes to flood levels at properties due to the project.

Table 3-6 Increase to over floor inundation for buildings near Windsor Bridge

Property Address	Surveyed Floor Level (metres AHD)	Estimated Flood Depth above surveyed floor level (metres)			Estimated Increase in Flood Depths (metres)		
		5 year ARI	20 year ARI	100 year ARI	5 year ARI	20 year ARI	100 year ARI
1 Thompson Square	14.03	-	-	3.26	-	-	0.01
5 Freemans Reach Road	13.12	-	0.49	4.16	-	0.03	0.01
5 Freemans Reach Road	13.47	-	0.14	3.81	-	0.03	0.01
5 Freemans Reach Road	11.52	-	2.09	5.76	-	0.03	0.01
27 Wilberforce Road	12.99	-	0.62	4.29	-	0.03	0.01
27 Wilberforce Road	11.17	-	2.44	6.11	-	0.03	0.01
33 Wilberforce Road	10.34	0.69	3.27	6.94	0.11	0.03	0.01
33 Wilberforce Road	10.97	0.06	2.64	6.31	0.11	0.03	0.01
33 Wilberforce Road	11.67	-	1.94	5.61	-	0.03	0.01
1A Wilberforce Road	10.88	0.18	2.74	6.41	0.12	0.03	0.01
1A Wilberforce Road	10.86	0.20	2.76	6.43	0.12	0.03	0.01
1A Wilberforce Road	10.88	0.18	2.74	6.41	0.12	0.03	0.01
1A Wilberforce Road	10.86	0.20	2.76	6.43	0.12	0.03	0.01
23 Wilberforce Road	11.11	-	2.51	6.18	0.12	0.03	0.01
23 Wilberforce Road	10.93	0.13	2.69	6.36	0.12	0.03	0.01
98 Cordners Lane	11.69	-	1.96	5.61	-	0.02	<0.01
124 Cornwallis Road	10.51	0.74	3.15	6.79	0.11	0.02	<0.01
124 Cornwallis Road	9.42	1.83	4.24	7.88	0.11	0.02	<0.01
295 Freemans Reach Road	11.22	0.05	2.44	6.08	0.11	0.02	<0.01
295 Freemans Reach Road	11.09	0.18	2.57	6.21	0.11	0.02	<0.01
295 Freemans Reach Road	10.92	0.35	2.74	6.38	0.11	0.02	<0.01
295 Freemans Reach Road	11.01	0.26	2.65	6.29	0.11	0.02	<0.01
1 Gow Lane	9.23	2.09	4.44	8.07	0.11	0.02	<0.01
1 Gow Lane	9.36	1.96	4.31	7.94	0.11	0.02	<0.01
332 Cornwallis Road	11.42	0.07	2.27	5.89	0.10	0.02	<0.01
332 Cornwallis Road	11.17	0.33	2.53	6.14	0.10	0.02	<0.01
362 Cornwallis Road	11.63	-	2.07	5.68	-	0.02	<0.01
156 Freemans Reach Road	10.81	0.35	2.83	6.49	0.08	0.02	<0.01
238 Freemans Reach Road	10.69	0.43	2.94	6.60	0.07	0.02	<0.01
238 Freemans Reach Road	11.53	-	2.10	5.76	-	0.02	<0.01
238 Freemans Reach Road	10.19	0.93	3.44	7.10	0.07	0.02	<0.01
238 Freemans Reach Road	10.21	0.91	3.42	7.08	0.07	0.02	<0.01
490 Freemans Reach Road	11.19	0.33	2.51	6.12	0.10	0.02	<0.01
521 Freemans Reach Road	11.16	0.39	2.54	6.15	0.10	0.02	<0.01
521 Freemans Reach Road	10.88	0.67	2.82	6.43	0.10	0.02	<0.01

Emergency Management

The project would not be expected to impact on Level 2 floods as defined in the Hawkesbury Nepean Flood Emergency Sub Plan. A level 2 flood is between a 20 and 100 year ARI event and as noted in **Table 3-2** and **Table 3-3**, the estimated impacts in these events would be negligible and thus associated impacts to emergency management for a Level 2 flood would not be significant.

The HNFESP uses the stream gauge located on Windsor Bridge (212903). This would need to be relocated due to the project.

The increase in bridge level for the project would present improved access during floods from the northern floodplain for Level 1 events. Improvements can be considered as part of future traffic management plans developed as part of Hawkesbury local emergency management planning.

3.2.3 Climate Change

The 'Practical Consideration of Climate Change, Floodplain Risk Management Guideline' (DECCW, 2007) provides a range of predicted climate change impacts for various regions. Within the Sydney Metropolitan region the likely change in extreme rainfall is estimated to be between -3 and +12 per cent up to 2030 and -7 and +10 per cent up to 2070. These changes are applied to all frequency events and various duration events (greater than one day). The Floodplain Risk Management Study reported that peak flood levels are highly sensitive to increases in rainfall. A ten percent increase in rainfall results in an increase of 0.9m in peak flood level in a 100 year ARI at Windsor. Alternatively the current 100 year ARI flood would occur more frequently and would become around a 60 to 70 year ARI event with a 10% increase in rainfall. [5]

Consideration of climate change for the project would be associated with the bridge being overtopped in more frequent events. The replacement bridge has been designed to be overtopped during floods, therefore mitigation measures for climate change are not likely to be significant.

Changes in rainfall intensity could potentially result in flows during floods occurring quicker resulting in increased channel velocities. Potential increases can be associated with greater depths of scour. A conservative approach for estimation of scour and subsequent inputs to the structural design of the bridge has been undertaken for concept design. Similarly consideration for climate change is to be maintained for detailed design.

Coastal sea level rise produced by DECCW (as part of the 'NSW Sea Level Rise Policy Statement' (DECCW 2009)) has been assumed to be applicable to the township of Windsor. These projections are sea level rise of 40cm by 2050 and sea level rise of 90cm by 2100. The Floodplain Risk Management Study reported that sea level rises produce no significant increases in peak flood levels for the majority of the floodplain.

Consideration of property mitigation measures is to consider impacts due to climate change where appropriate. Other potential risks due to climate change are identified and addressed in the Climate change chapter of the EIS.

[5] Hawkesbury Floodplain Risk Management Study and Plan, Draft July 2012, Bewsher Consulting, pages 17 and 18

3.2.4 Bed and Bank Scour

Flow direction

The project includes a bank slope transition from Macquarie Park property to the replacement bridge on the northern bank. Earthworks in this area potentially increase scour of bank material by removal of existing vegetation, earthworks, location of proposed footway and the bridge abutment. Concept design includes a bank grade that is consistent with the river bank slopes immediately downstream (east) of the project. This would reduce the opportunity of general scour along the river banks by providing consistent direction of flow within the river channel and limiting local areas where eddies can establish during floods.

As the replacement bridge grades from south to north and is higher than the existing bridge, turbulence may occur for flows less than those that substantially overtop the road, such as 1 or 2 year ARI event. Potentially this may result in increased scour of the river bed and banks near the abutments.

Flow Velocity

Average channel velocities are estimated to be up to 3.5m/s for a 100 year ARI event. Velocities are estimated to be higher in the centre of the channel. These velocities potentially cause scour of the river bed material which is exacerbated due to local turbulence at the piers. Scour potentially occurs on river banks where floodplains are constrained through bridge structures.

On the southern bank there is an existing retaining wall, gabions and vegetated fill where the former wharf was located. This area would be potentially impacted due to local turbulence due to high velocities near the proposed location of Pier 1 and the existing retaining wall.

Scour of material from the river bed and banks would potentially result in stability issues for the replacement bridge. Concept Design for the replacement bridge has considered potential scour and includes protection measures along the river banks. Consideration has been given to the length of inundation experienced during floods, the rock level at the bridge and suitability of protection measures under bridges (impacts due to shading).

Removal of material from the river bed and banks may result in water quality issues. This is addressed in the Soil, sediments and water working paper.

3.3 Construction

3.3.1 Potential impacts of flooding on the project

It is possible that a flood could occur during the construction or demolition period, which could have adverse effects on work activities and increase the risk of soil and sediment erosion. The impacts and associated environmental management measures for soil and sediment erosion are presented in Section 7.6. The occurrence of high river flows during construction or demolition could result in erosion of bed and bank material if the proposed scour protection measures have not yet been constructed.

Before the demolition of the existing bridge is completed, it could fail during a flood event causing damage to the new bridge.

3.3.2 Potential impacts of the project on flooding

The presence of construction infrastructure and equipment in the river (such as barges and temporary platforms) and the period when two bridges are present (whether partially constructed, demolished or complete) has the potential to increase flooding at properties upstream of the project. The increase in flood levels when both bridges are present (and complete) is estimated to be around 0.18 metres (that is 0.06 metres above the estimated increase with the bridge alone) in a 5 year ARI event. The period between opening the new bridge and completing the demolition of the existing bridge would be about four months

During the construction of the new bridge, increased flooding would be negligible until the launching of the new bridge commences. As the bridge is gradually launched across the river, the potential impact of flooding upstream would increase. It would take approximately 12 months to launch the bridge and complete finishing works before the opening of the new bridge.

Flood impacts would be greatest for properties that are near the bridge (refer to **Section 3.2.2**).

3.3.3 Potential Impacts – scour

The piers for the existing and replacement bridges are not aligned in the direction of flow, which presents a risk of turbulence, redistribution of flow and increase of potential scour during the construction period. The proposed earthworks on the river banks for temporary works presents a risk of scour of the river bank where vegetation is removed and suitable protection not provided.

If high river flows occur during construction there is potential for erosion of bank material where designed scour protection measures have not been constructed. This may result in undermining the bridge superstructure.

During construction there would be exposed soils and uncovered stockpiles that potentially could cause erosion or mobilise fine sediments, which may in turn impact on water quality in the river. Impacts and mitigation measures associated with this type of erosion are addressed in the Soil, Water and Sediment working paper.

4 Environmental management measures

4.1 Operation

4.1.1 Flood mitigation measures

Further options to minimise the depth of the bridge's superstructure and its overall obstruction of the waterway will be considered during detailed design.

The stream gauge located on Windsor Bridge (212903) may need to be relocated due to the project.

4.1.2 Flood affected properties

There would be impacts to property and buildings between Richmond and Windsor due to the project. Potential environmental management measures will be discussed with and agreed to with the owners to offset flood inundation impacts. Consideration will be given to the current land use and heritage values, changes to property access for a range of flood events, protection measures such as sealing doors and windows and developing and reviewing and revising a flood emergency plan. Mitigation of impacts will be subject to the flood risk and potential flood damages for a range of flood events and will be undertaken drawing on investigations that include:

- Additional Survey of building floor levels, access roads and supplementary buildings.
- Development of a suitable two-dimensional hydraulic model to provide velocities and water depths at properties. The extent of the model will cover impacted properties and will represent floodplain hydraulics.
- Assessment of potential flood damages.

Environmental management measures will be developed in accordance with floodplain management principles outlined in the *Floodplain Development Manual* (2005) and may include improvement to property access, house raising, building protection measures such as sealing doors and windows, protection levees and flood emergency plans.

The following environmental management measures will be implemented to minimise impacts from flooding:

- Flood impact mitigation requirements and options for affected buildings will be investigated during detailed design. Appropriate measures will be identified, developed and implemented, as required and in consultation with the landholders, to minimise impacts on the building structure, building access and business opportunities.
- During the detailed design of the new bridge, detailed flood modelling will be undertaken on the final design of the project to identify any additional impacts. This may require additional survey at potentially impacted properties where significant impacts are identified. Appropriate measures will be identified, developed and implemented, as required, to minimise impacts on the building structures, building accesses and business opportunities.

- Suitable scour protection would be provided to protect the bridge abutments, piers and banks during operation.

4.1.3 Scour mitigation measures

Scour of bed and bank material is expected as a result of the project due to high velocities in the river channel which is exacerbated at the piers where turbulence occurs. Permanent mitigation measures for pier scour is not recommended in design manuals, rather the structural design of the bridge is to consider the potential scour in events up to the 2000 year ARI. This method has been adopted in the concept design by considering scour potential for the maximum velocity during for floods up to the 2000 year ARI. This approach is to be maintained for the completion of the design.

Concept design of measures to mitigate scour along the banks of the river and near abutments has been provided for the project as presented on drawings in **Appendix B**. Measures include:

- Rock rip rap protection around the replacement bridge piers to maintain river bed levels following minor floods events.
- Rock rip rap protection along the northern bank into the river bed and around the adjacent pier (4).
- Maintain consistent river bank slope between the existing bridge approach through to limit of works downstream of the replacement bridge. Earthworks to ensure flow is not impeded or potentially result in local turbulence that would instigate scour of bank material. Surface treatments would be suitable to withstand flood velocities.
- Non-vegetated bank protection under the northern abutment of the replacement bridge to mitigate potential impacts due to shading under the bridge.
- A new retaining wall on the southern abutment.

Scour protection measures are to consider local changes in velocities and directions of flow for a range of events in accordance with requirements of the DGRs. Change in velocities and directions of flow will be assessed using a two-dimensional hydraulic model using ground level survey within the channel and on the banks of the river. The requirements for scour protection may change substantially from described above as this is a worst case assessment for scour protection.

4.2 Construction

4.2.1 Flood mitigation measures

The Construction Environment Management Plan will contain measures to minimise impacts of flooding. The risk of flooding during construction cannot be avoided, however measures to limit the impact of flooding include:

- The extent of obstructions within the river will be minimised as far as practicable at all times during construction and demolition.
- The time between completion of construction of the replacement bridge and demolition of the existing bridge will be minimised as far as practicable.
- Construction infrastructure and equipment will be removed from the river channel and floodplain in the event of a forecast flood to minimise both the risk of damage to infrastructure/equipment and the risk of flood impacts on properties.
- Appropriate procedures to manage the effects of flooding during construction, and minimise any associated adverse environmental impacts to the greatest extent practicable, will be incorporated into a construction environmental management plan and emergency response plan (to be prepared and approved before the start of construction). The emergency response plan would include procedures to ensure adequate warning of floods is obtained and that appropriate emergency response procedures are implemented in a timely manner
- Suitable scour protection would be provided to protect the bridge abutments, piers and banks during construction.

Access to the river would be required for the construction of the project. This access would likely be through the turf farm temporary construction site located on the north eastern side of the existing bridge. Stabilisation of the bank in this area would be required and may include temporary rock rip rap into the channel and surface treatment that minimises removal of soil. Details of sediment and erosion controls for construction are addressed in the Soil, sediments, water and waste working paper.

(blank page)

5 Conclusion

5.1 Operational

The replacement bridge and road alignment provides a benefit with respect to flood immunity for the Hawkesbury River crossing as the replacement bridge is around 2.8m higher than the existing bridge. The estimated frequency of overtopping between the existing bridge and the replacement bridge, based on recorded water levels at Windsor gauge from 1987 to 2011, reduces from 8 to 3 events over the 24 year period. The average duration of inundation decreases from 43 hours to 19.5 hours per flood event. The proposed level of the replacement bridge provides a greater level of flood immunity than Wilberforce Road and a flood immunity similar to that along Freemans Reach Road

The frequency of overtopping would increase under climate change scenarios associated with an increase in rainfall intensities and runoff within the catchment. However as the replacement bridge would be designed to be overtopped, impacts from climate change are effectively mitigated.

The project would result in an increased obstruction to flood flows in the Hawkesbury River at Windsor compared to the existing bridge. This obstruction would adversely impact properties upstream of the bridge by increasing flood levels and to a lesser extent increasing the duration of inundation during floods. Impacts would include a 0.12 metre increase in the 5 year ARI flood level at the bridge, 0.03 metre in a 20 year ARI and 0.01 metre in a 100 year ARI. Consideration during detailed design would be given to reducing the obstruction of the bridge within the waterway. In this way the impacts within the floodplain would be reduced.

The floodplain north of the Hawkesbury River between Freemans Reach and Wilberforce is estimated to have around 1500ha of land inundated in a 5 year ARI event. Predominately this area is used for turf farming and grazing. The average depth of inundation in this event is between 2 and 5 metres. The project results in increase in depths of up to 0.12 metres. Approximately 60% of lots in this area are estimated to experience increases in inundation depth greater than 0.05 metres. The increase in duration of inundation in a 5 year ARI is less than 10 percent compared with the existing duration up to a water level of 10.5 metres AHD, with greatest impact when water levels are up to 11 metres AHD which occur for 11 hours compared with 5 hours. Further investigations are required to assess potential flood damages in these areas and the significance of changes due to the project.

Flood afflux (increase in water depths) at properties located upstream of Windsor Bridge and within floodplain areas upstream of the bridge has been assessed assuming building floor levels were at ground level (in accordance with assumptions from the draft FRMS). Buildings with an estimated afflux less than 0.01 metres are not included as this increase is considered negligible and beyond the accuracy of the modelling used to determine afflux. Properties subject to inundation greater than 1m for existing conditions were not included as the increase in flood depths is not significant compared with existing flood inundation. The largest impact on flooding levels from the project would occur during the lower ARI events such as the 5 year ARI and 20 year ARI events. Potential flooding impacts for different events include:

- In a 5 year ARI event one additional residential dwellings would experience over floor flooding (23 Wilberforce Road) and 25 buildings would experience afflux greater than 0.01 metre. Of these, three buildings have an existing depth of inundation greater than one metre. Average afflux for the 22 buildings would be 0.10 metre with the largest increase in water depths of 0.12 metre. There are 15 buildings with a percentage increase in flooding greater than 25 percent, two of which are generally subject to low levels of flooding in the existing conditions (less than 0.1 metre). These two buildings are at most risk of increased flood damage from increases in flood levels due to the project.
- In a 20 year ARI event there are no additional buildings would experience over floor flooding. Thirty four (34) buildings would experience afflux greater than 0.01 metre, of these 31 properties have an existing depth of inundation greater than one metre. Average afflux for the three properties that have increase greater than 0.01 metre and an existing depth less than one metre is 0.03 metre.
- In a 100 year ARI event there are negligible changes to flood levels at buildings.

Macquarie Park House is subject to the largest increase in above floor inundation from those for which surveyed floor levels were available. The building, Macquarie Park House is heritage listed and is owned by Hawkesbury City Council and currently used as a commercial café and restaurant. The estimated flood level for a 5 year ARI event is predicted to increase from 0.19 metres to 0.31 metres (0.12 metres increase). Apart from increasing water levels in the main building, access to the property would be potentially impacted and inundation of other buildings on the property may occur. Additional survey of the property would be carried out as part of detailed design to determine appropriate environmental management measures.

The following environmental management measures will be implemented to minimise impacts from flooding:

- During the detailed design of the new bridge, detailed flood modelling will be undertaken on the final design of the project to identify any additional impacts. This will include collecting survey data at potentially impacted properties with buildings upstream of the bridge. Where impacts are identified, appropriate measures will be identified, developed and implemented, as required, to minimise impacts on the building structures, building accesses and business opportunities.

The replacement bridge would be subject to high water velocities that would potentially result in scour of bridge abutments and piers as well as the adjacent river bed and banks. Scour would be exacerbated at bridges due to shading under the bridge deck that limits vegetation establishment and due to the extended duration of inundation during floods. Unmitigated scour potentially would result in stability issues for the replacement bridge. The replacement bridge is to include scour protection measures at the piers, river banks near abutments, in areas of filling between the existing bridge and replacement bridge and near the existing retaining wall on the southern river bank.

5.2 Construction

It is possible that a flood could occur during the construction or demolition period, which could have adverse effects on work activities and increase the risk of soil and sediment erosion, or increase flooding to upstream properties. The occurrence of high river flows during construction or demolition could result in erosion of bed and bank material if the proposed scour protection measures have not yet been constructed. Before the demolition of the existing bridge is completed, it could fail during a flood event causing damage to the new bridge. While the existing bridge is in poor condition, the new bridge would open by 2015 and the existing bridge is extremely unlikely to fail in the next three years.

During the construction of the new bridge, increased flooding would be negligible until the launching of the new bridge commences. As the bridge is gradually launched across the river, the potential impact of flooding upstream would increase. It would take approximately 12 months to launch the bridge and complete finishing works before the opening of the new bridge. An estimate of the potential increase flooding at properties upstream of the project when both bridges are present/constructed shows a potential increase in flood levels to be around 0.18 metres (that is 0.06 metres above the estimated increase with the replacement bridge alone) in a 5 year ARI event. Flood impacts would be greatest for properties that are near the bridge.

The HNFESP uses the stream gauge located on Windsor Bridge (212903). This would need to be relocated due to the project.

(blank page)

6 References

- Replacement of Windsor Bridge on MR182- Strategic Design Option1 (drawing), 19/8/2011. Roads and Traffic Authority (RTA) of NSW: Sydney.
- Windsor Bridge over the Hawkesbury River – Hydraulic Analysis, August 2011. WMAwater
- Warragamba Flood Mitigation Dam Environmental Impact Statement - Flood Study, October 1994. Webb, McKeown and Associates
- Director General's Environmental Assessment Requirements, 24 November 2011.
- Practical Consideration of Climate Change, Floodplain Risk Management Guideline, 2007. DECCW
- http://www.bom.gov.au/climate/data/index.shtml?map_type=cdio&code=1
- Hawkesbury-Nepean River Reaches Geomorphology and Human Impacts, Dr Robin Warner, prepared for Hawkesbury-Nepean River Management Forum, June 2002
- Hawkesbury Nepean Flood Emergency Sub Plan (HNFESP), SES, 2006
- Waterway Design : a guide to the hydraulic design of bridges, culverts and floodways, Austroads, 1994

(blank page)

Appendix A Flood Inundation Plans

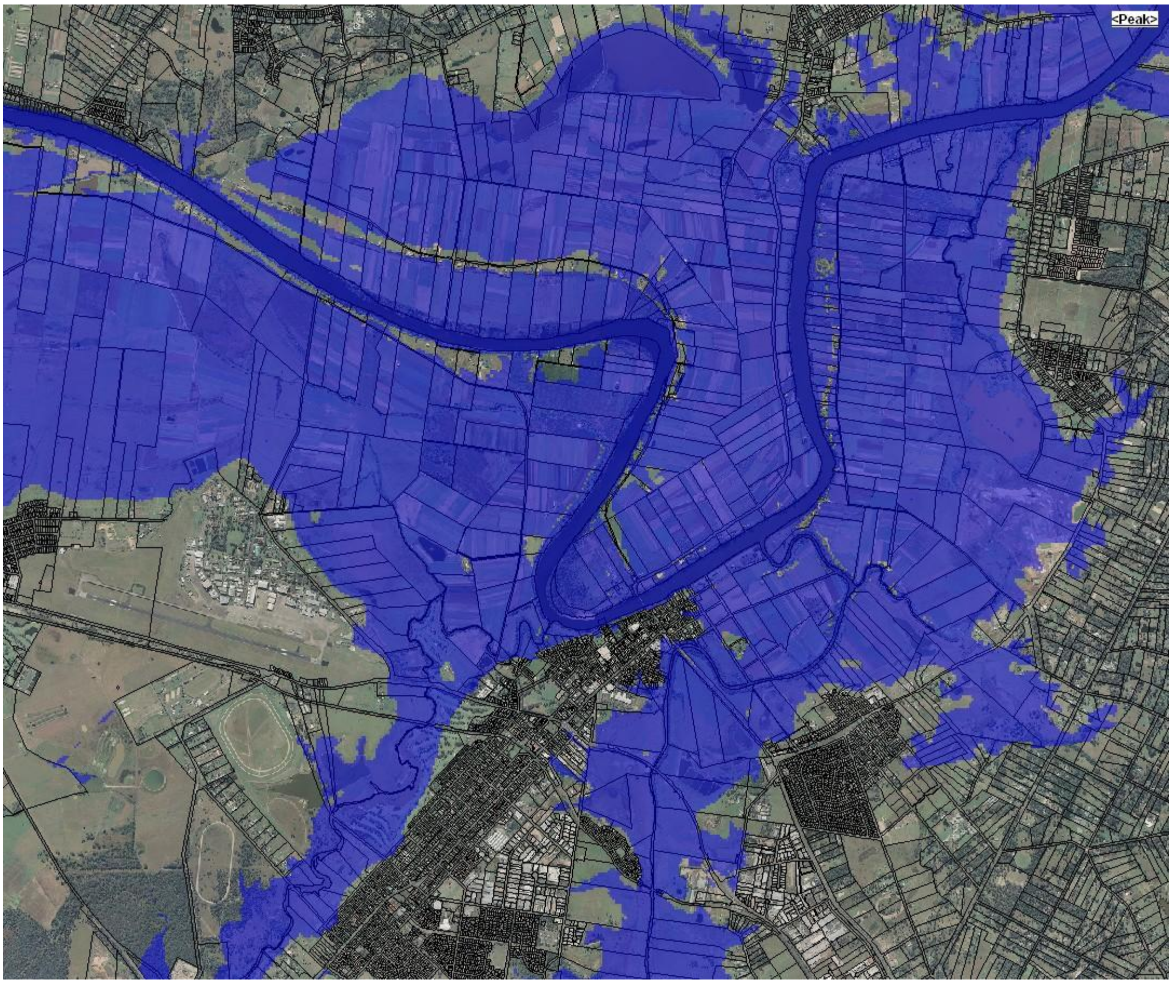


Figure A-6-1 Flood Extent 5 year ARI (provided by Hawkesbury City Council)

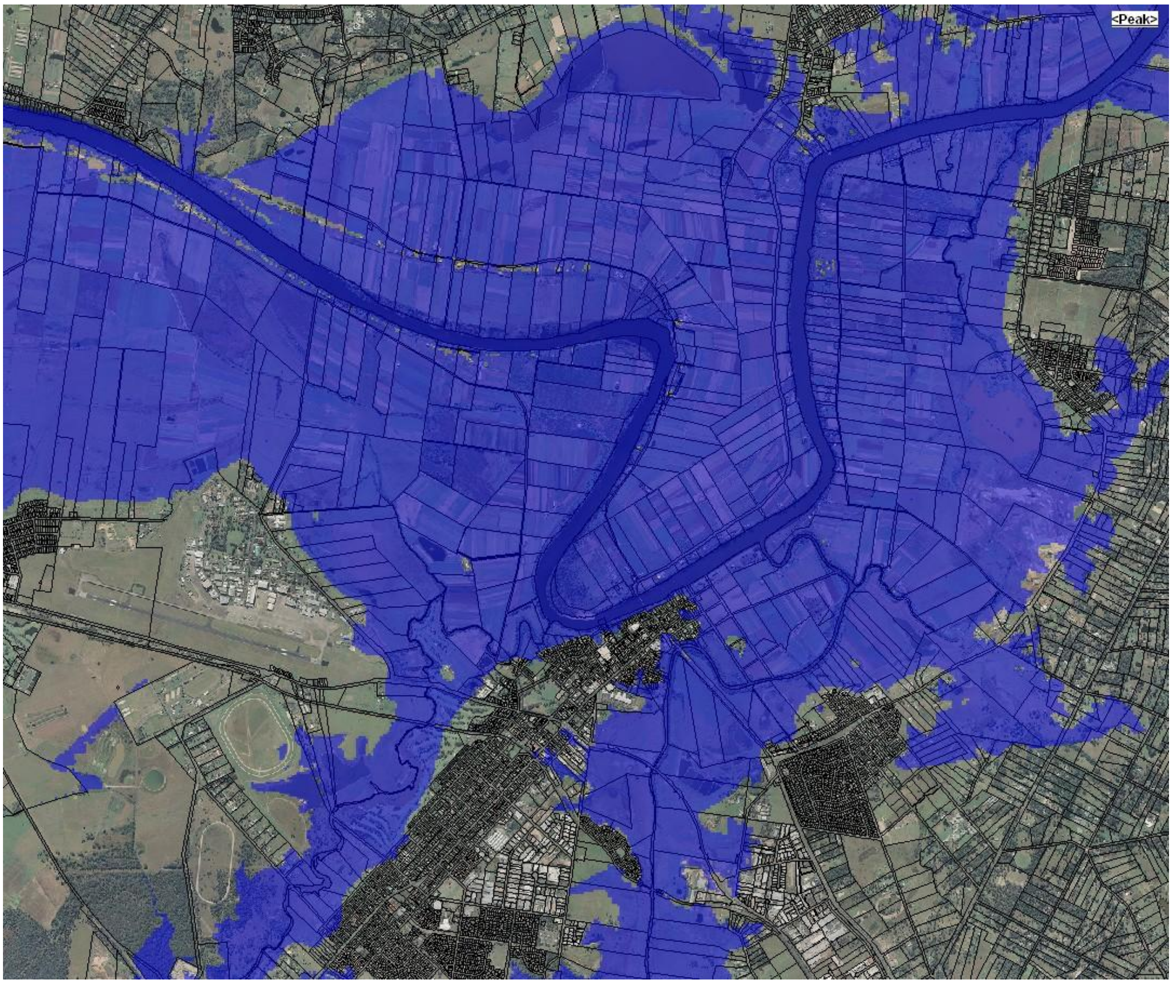


Figure A-6-2 Flood Extent 10 year ARI (provided by Hawkesbury City Council)

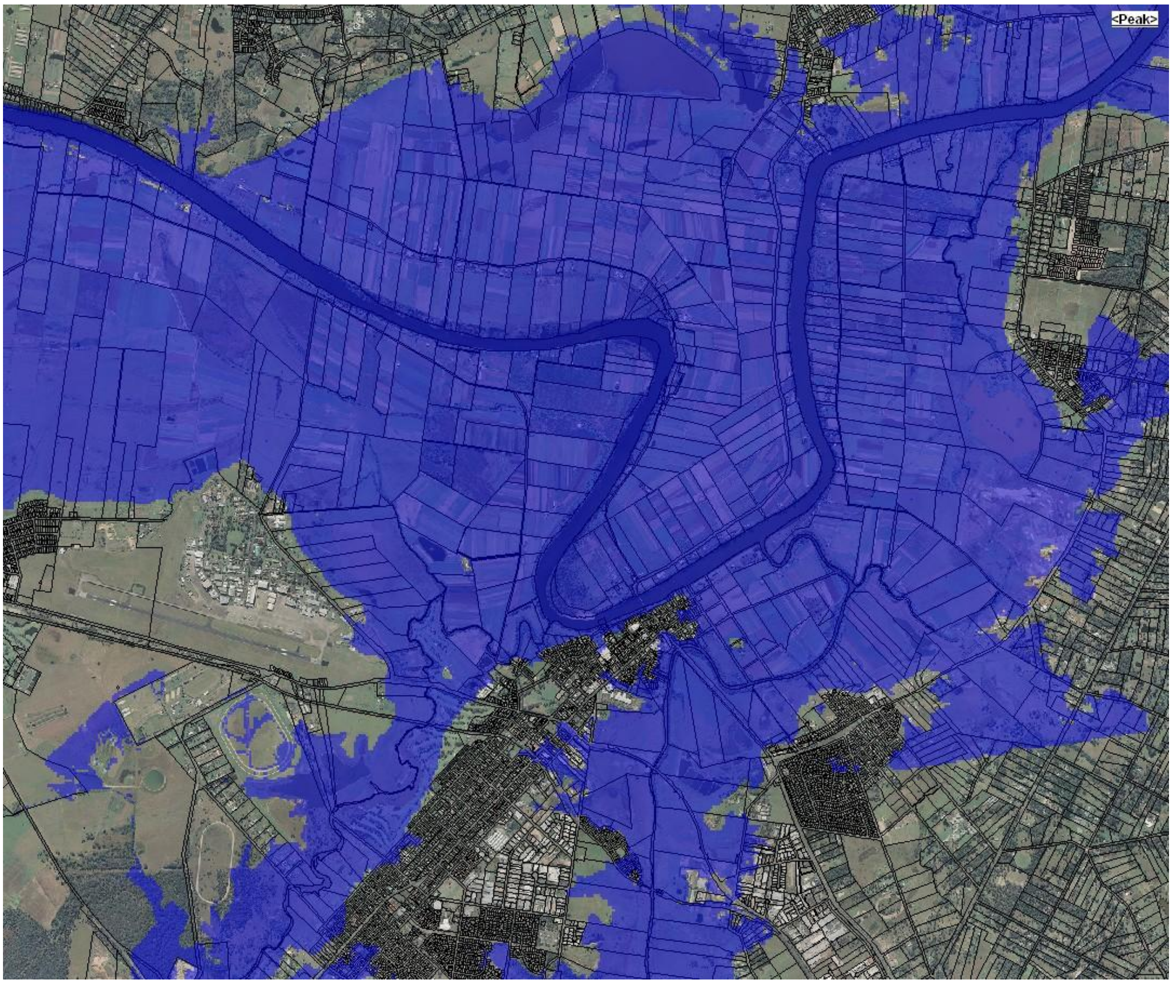


Figure A-6-3 Flood Extent 20 year ARI (provided by Hawkesbury City Council)

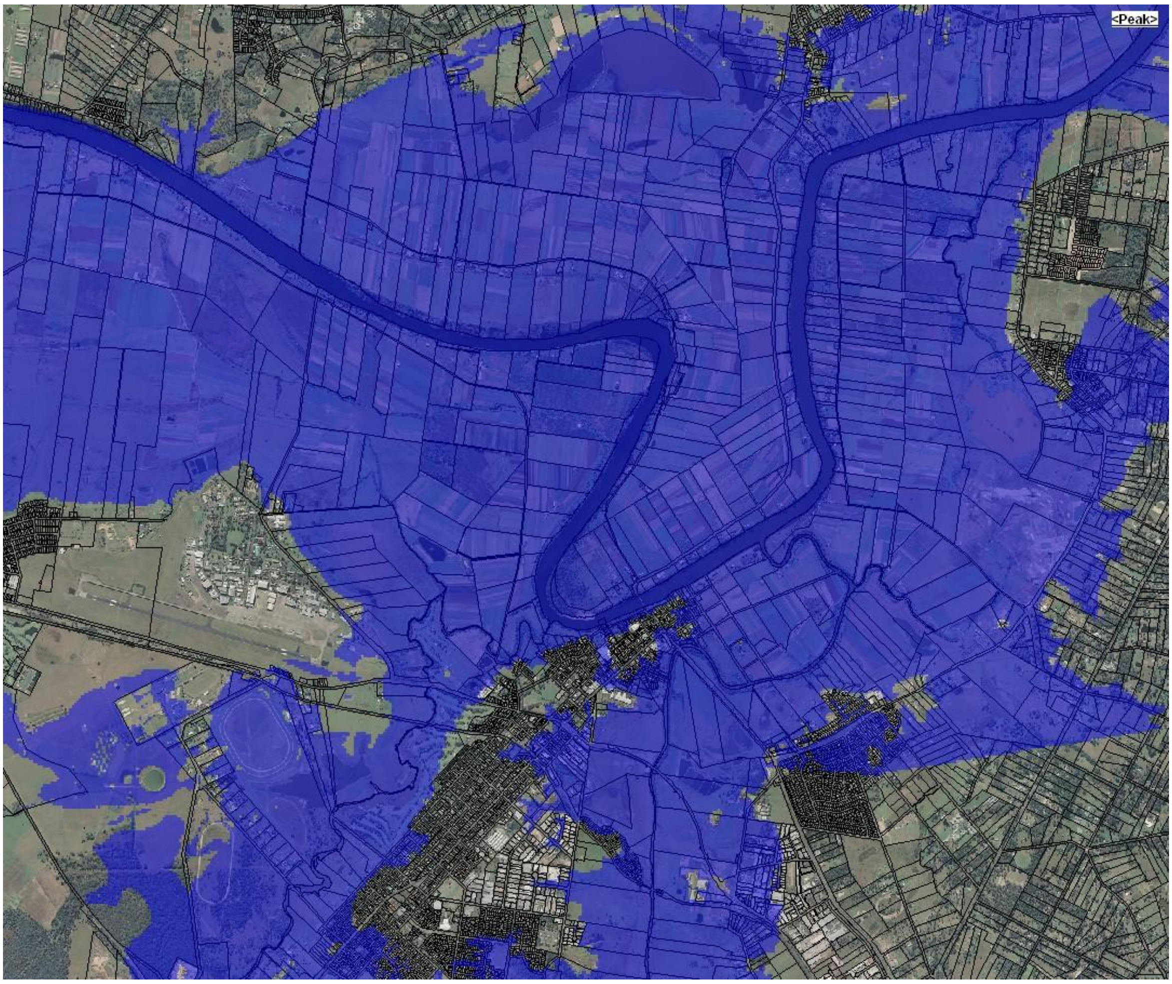


Figure A-6-4 Flood Extent 50 year ARI (provided by Hawkesbury City Council)

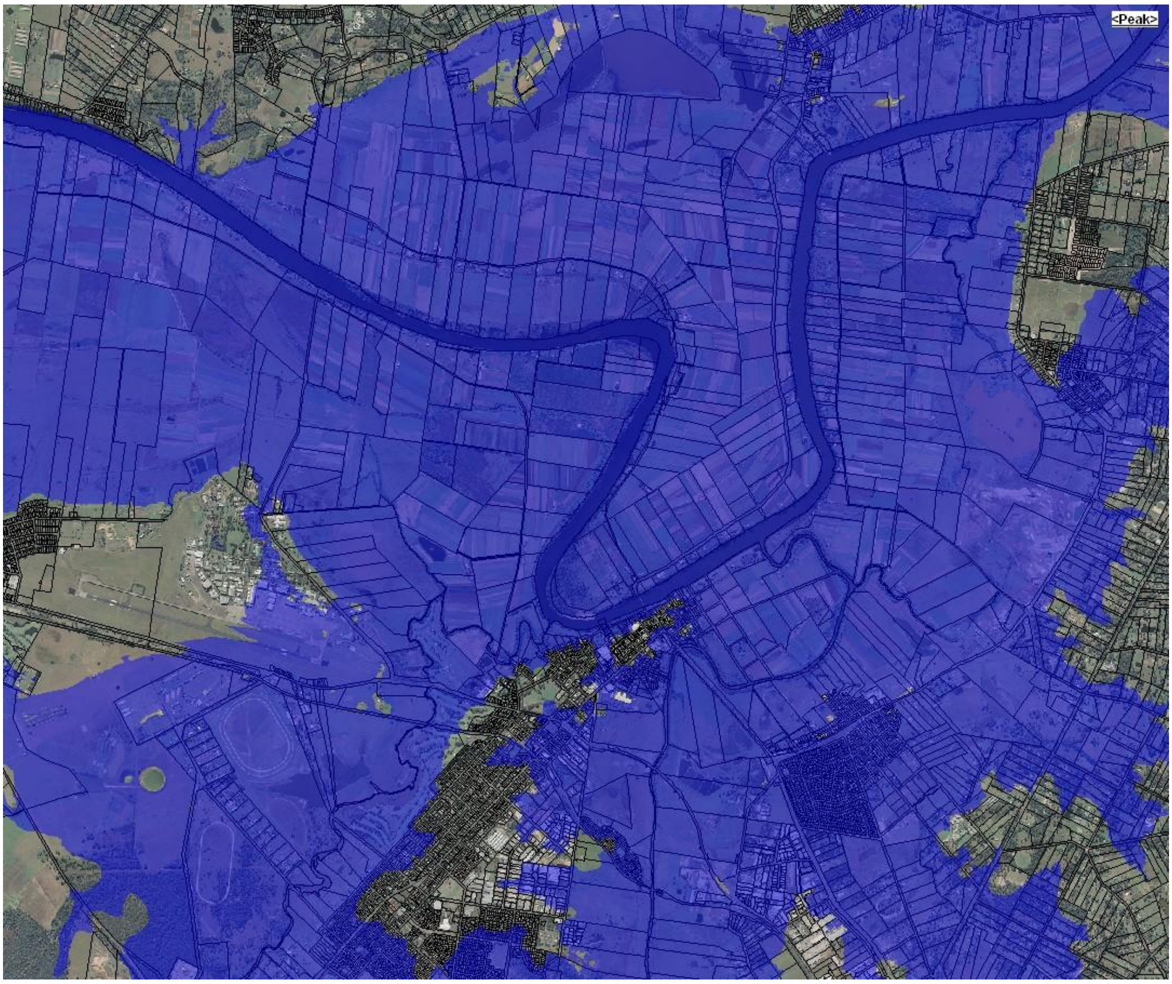


Figure A-6-5 Flood Extent 100 year ARI (provided by Hawkesbury City Council)

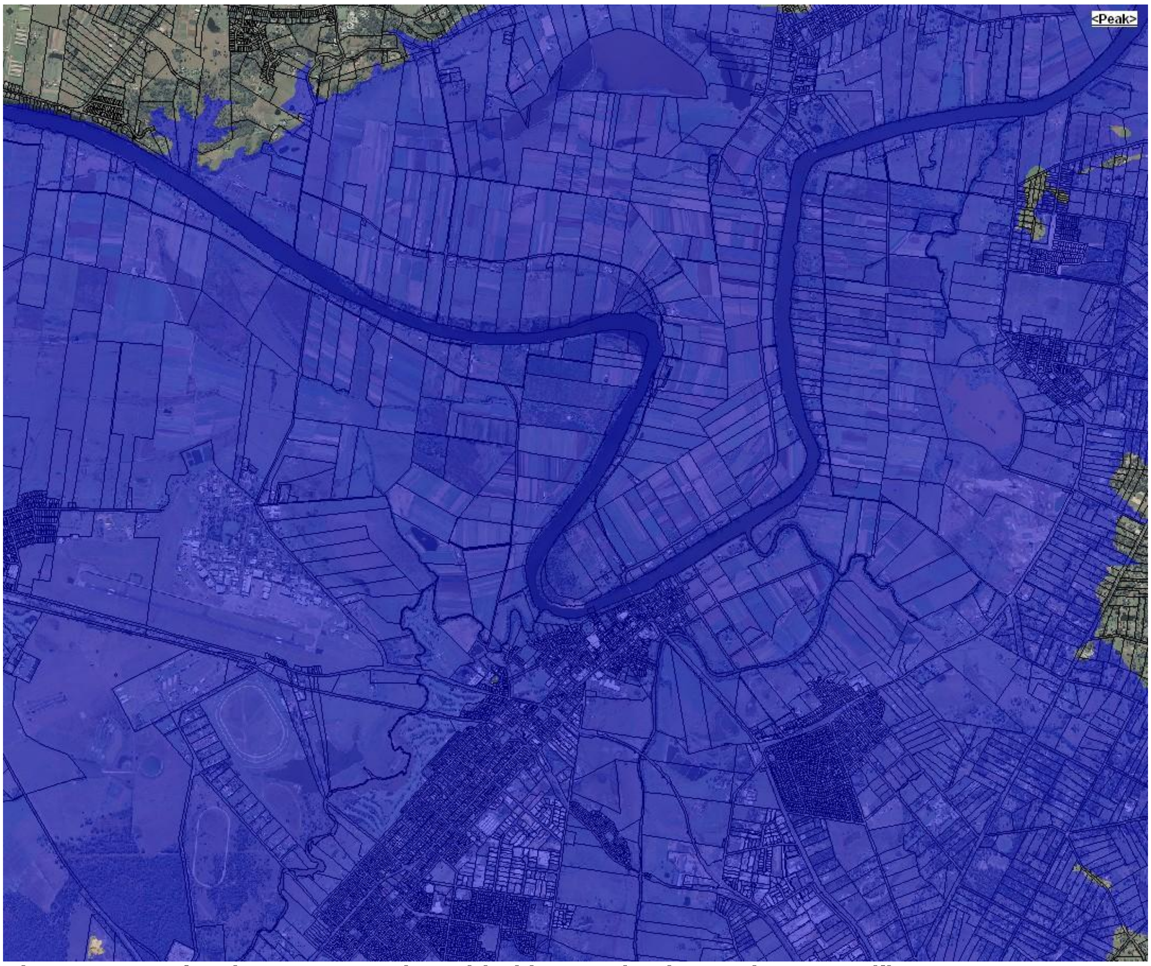


Figure A-6-6 Flood Extent PMF (provided by Hawkesbury City Council)

Appendix B Overview of HECRAS modelling

Introduction

Hydraulic investigations were undertaken to assess flood impacts due to the project and enable scour potential to be estimated. Flood events considered were 5, 20, 100 and 2000 year ARI and the PMF.

Survey

Survey available near the existing and proposed bridge was used to establish a HECRAS hydraulic model. Survey included:

- detailed ground survey (including a transect along the river bed at the existing bridge) was provided by RMS
- A two metre grid digital terrain model that was derived from Airbourne Laser Survey captured in 2007, provided by Hawkesbury City Council. The extent covers Hibbert’s Lane at Freeman’s Reach to the Hawkesbury River at Wilberforce. The DTM does not include surface levels below the water line.

Geotechnical Data

SKM undertook geotechnical investigation for the project to characterise the subsurface conditions. Findings are reported in NB11459 - ESGN-RP-0126- Geotechnical Interpretive Report (Draft July 2012). Geotechnical units were established from the available background geotechnical information and the results of the test pit excavations, boreholes, CPTu, and laboratory testing. Table B.1 outlines the geotechnical units developed for the project, this is reproduced from the Geotechnical report.

Table B.1 – Summary of geotechnical units

Topography	-4.0 to 14.0 m AHD		
Soils	Northern abutment and river section: (Fr) Southern abutment: (Bp)		
Geology	Northern abutment and river section: (Qpl) and (Rwa) Southern abutment: (Tl) and (Rwa)		
Unit symbol	**Subsurface unit**	**Relevant locations**	**Material description**
1	Fill	SA-BH01, SA-BH03, TP04, TP05, TP06	Limited fill was encountered in the boreholes. Some fill was encountered on the southern abutment area and northern approach, associated with previous road and or wharf platforms constructed and any river bank restoration/reclamation.
Tertiary Deposits			
2	Cemented sands and Clays	SA-BH01 to SA-BH03	Cemented gravelly sands and very stiff clay materials to depths of at least 2 to 3 metres. These materials are understood to generally have a consistency of stiff to hard. Materials are known to have moderate to high erosion potential, fluvial origin.
Alluvial Deposits			
3A	Silty clay	NA-BH01, NA-BH02, TP01 to TP06, OW-BH01 to OW-BH04	Silty clay, typically low to medium plasticity, trace of fine gravels, firm to stiff consistency, and trace of organics, alluvial.
3B	Clayey/silty sand		Clayey/silty sand with trace of gravel. Typically fine to medium grained, trace fine to medium gravels, angular to sub-angular, very loose to loose, alluvial.
3C	Sand		Sand with trace silt/clay/gravel. Typically fine to coarse grained, loose to medium dense, alluvial.
3D	Gravels/ cobbles		Sandy gravel with some cobbles. Typically fine to coarse grained, sub-angular to rounded, dense to compact with SPT refusal, some igneous origin gravels/cobbles, alluvial.
Bedrock			
4A	Sandstone/ Siltstone	NA-BH01, NA-BH02, OW-BH01 to OW-BH04, SA-BH01	**(Class V)** Siltstone and fine grained sandstone laminite. Typically extremely low strength, extremely to highly weathered, fractured.
4B	Sandstone/ Siltstone		**(Class IV)** Siltstone and fine grained sandstone laminite. Typically very low to low strength, highly weathered, fractured
4B	Sandstone/ Siltstone		**(Class II)** Siltstone and fine grained sandstone laminite. Typically medium to high strength, slightly weathered, slightly fractured.

Note: (1) m AHD = Metres Australian Height Datum

(2) A classification of the rock-mass has also been provided which has generally been undertaken in accordance with the guidelines presented in for foundations on sandstone and shales in the Sydney Basin (Pells et al, 1998).

Geotechnical Rock Units – Bridge Abutment and Piers

Borehole drilling was undertaken at each of the two abutment and four pier locations for the bridge replacement. The inferred levels and rock units for each abutment and pier location are presented in Table C.2 below.

Table B.2 – Description of foundation rock units

Geotechnical Unit	Chainage (m)	Geotechnical Unit Details			Borehole ID
		Top Depth RL m AHD	Bottom Depth RL m AHD	Summary Description	
Abutment A – Southern Abutment					
Unit 4A	213.5	4.8	3.7	Class V Sandstone	SA-BH01
Unit 4B		3.7	0.1	Class IV Shale	
Unit 4C		0.1	> -4.2	Class II Shale	
Pier 1					
Unit 4C	241.5	-4.4	> -12.4	Class II Shale	OW-BH01
Pier 2					
Unit 4B	276.5	-11.0	-11.6	Class IV Shale	OW-BH02
Unit 4C		-11.6	> -19.0	Class II Shale	
Pier 3					
Unit 4B	311.5	-11.7	-12.2	Class IV Shale	OW-BH03
Unit 4C		-12.2	> -19.8	Class II Shale	
Pier 4					
Unit 4C	346.5	-11.4	> -18.8	Class II Shale	OW-BH04
Abutment B – Northern Abutment					
Unit 4C	370	-11.9	> -17.6	Class II Shale	NA-BH02

Hydraulic Modelling Methodology

Hydrologic and hydraulic modelling for the Hawkesbury-Nepean River was done as part of the Warragamba Dam EIS Flood Study. The hydraulic model used RUBICON software, which is a quasi two-dimensional model. The cross section layout used in the model was coarse with distances between cross sections of two to three kilometres. The model was calibrated against major flood events and there are concerns on the ability of the model to reproduce the recession limb of the hydrographs for flood events smaller than a 5 year ARI event. The most frequent occurring event assessed was a 5 year ARI event. Modelling considered the flood operations of the increased spillway at Warragamba Dam. Results from this model have been used for flood planning by Hawkesbury City Council and thus are adopted in this project.

The RUBICON model was used to assess flood impacts for the replacement bridge. A water level verses discharge relationship for the replacement bridge was derived using a HECRAS model established locally near the bridge. This relationship was used in the RUBICON model to assess impacts along the Hawkesbury River and its floodplain.

Hydrology for the 2000 year ARI event and events more frequent than a 5 year ARI is not available from the modelling done for the Warragamba Dam EIS Flood Study. The 2000 year ARI is required for assessment of ultimate limit design of the bridge in terms of scour potential. For the Concept Design an estimate of the 2000 year ARI event was undertaken by SKM adopting procedures in ARR (2001) using the 100 year ARI, 1000 year ARI and the PMF events. The rising limb of the hydrographs for the 100 year ARI and the PMF did not vary significantly at Windsor Bridge. The flow and water level hydrographs for the 2000 year ARI event were estimated by interpolating between these events. The peak 2000 year ARI flow was estimated to be 6300 m^3/s. This estimate has not been derived using a hydrologic model, however it is considered a suitable estimate for Concept Design considering the nature of flooding near Windsor in extreme events. Detailed Design is to verify this estimate using hydrologic modelling.

Scour

Standard bridge design approach is to design scour protection works for a 100 year ARI event and ensure the bridge stands in a 2000 year ARI event. For a 2000 year ARI event the potential scour at abutments and piers is provided to the bridge designers to ensure bridge structural integrity.

Scour assessment has conservatively assumed that all material subject to scour is non-cohesive. This is reasonable as the material on the river banks is generally alluvium material. The exception is on the southern bank where there is some sandy clay.

Scour potential was estimated using routines in HECRAS and guidelines in Waterway Design (Austroads, 1994).

The bridge formation results in a minimum reduction in waterway width as abutments are set back into the river banks. The regional topography is such that extensive floodplains to the north of the bridge convey flow in excess of the channel capacity or due to elevated tailwater from the restriction through the Sackville gorge. Therefore constriction of flow through the bridge is not significant.

The potential risks to the bridge due to scour are from the removal of river bed material at the piers (local scour) and along the river banks that may potentially impact the stability of the abutments.

HECRAS Model

The HEC-RAS model extends 800m upstream and 1000m downstream of the existing bridge, and covers a cross section width of approximately 500m, which includes the main river channel, the southern bank at Windsor, and a portion of the northern bank. Figure C1 shows the location of cross sections in the model. Cross sections were defined using digital terrain model provided by Hawkesbury City Council and detailed survey provided by RMS. A Manning's 'n' roughness value of 0.034 was adopted as used in the quasi two-dimensional model. The width of the cross sections was comparable to that used in the RUBICON model at a similar location. Dimensions of the existing bridge structure were taken from field survey and design drawings supplied by RMS.

Representation of the existing and proposed bridge decks for all scenarios assessed, assumed that traffic barriers and pedestrian handrails would be an obstruction to flow due to the high likelihood of floating debris causing complete blockage of these structures during a flood event.

A range of discharges and tailwater levels were assessed in the model to develop water level verses discharge relationship.

Flow and water level hydrographs were provided from the quasi two-dimensional RUBICON model (WMAwater, 2012) at a number of model nodes between Richmond and Wilberforce. Results were for existing conditions and with the replacement bridge for the 5 year, 20 year, 100 year ARI events and the Probable Maximum Flood (PMF).

Subsequently the HECRAS was run as an unsteady model (version 4.1.0) using inflow hydrograph upstream of the bridge and tailwater levels at the junction of South Creek. Results were interrogated to find the maximum velocity, which was used to assess scour potential at the piers and abutments. Events assessed were the 5 year, 20 year, 100 year and 2000 year ARI events.

The model was setup for existing conditions and for the replacement bridge with the existing bridge removed.

Results

Water levels and average channel velocities from the HECRAS model were verified against results from RUBICON. Estimated velocities and potential scour from HECRAS are presented in Table C1.

Table B 1 Estimated velocities for replacement bridge scenario

Design Event	Average channel velocity at replacement bridge (m/s)		Potential Scour Depths (m)		
	Maximum (flow when velocity occurs, m3/s)	At Peak Flood Level	At Piers	North Abutment	South Abutment
5 year ARI	2 (3350)	1.7	5	6.6	2.7
20 year ARI	2.8 (4920)	0.7	5.8	8.7	3.6
100 year ARI	3.1 (5500)	0.5	6.1	9.4	3.9
2000 year ARI	3.2 (5880)	0.4	6.1	25	2.1

Results in the tables indicate minor differences in average channel velocities reported in *Windsor Bridge over the Hawkesbury River – Hydraulic Analysis, WMAwater, August 2011*. Previously the maximum velocity for a 5 year ARI was reported as 2.3m/s and 3.5m/s for the 100 year ARI, compared with 2 m/s and 3.1 m/s for the corresponding events. This could be due to the location of the reporting, as velocities from HECRAS 500 metres upstream of Windsor Bridge are higher than those at the replacement bridge. The values presented in Table C1 refer to average cross sectional velocities at the replacement bridge. Higher velocities occur in the middle of the channel, near piers 2 and 3, than adjacent to the banks. This variation of velocities has been considered when assessing scour potential.

Predicted scour depths at the piers for the 100year ARI event is 6.1m which results in scour to -9.4m AHD (assuming river bed level around -3.3m AHD). Scour is limited to the level of rock at Pier 1 (-4.4m AHD). Predicted scour depths at the north abutment is around 9.5 metres in a 100 year ARI event and up to 4 metres on the southern abutment. Results for scour potential for the 2000 year ARI event on the north abutment is not considered reasonable. However on this bank scour protection works are to be provided thus mitigating scour.

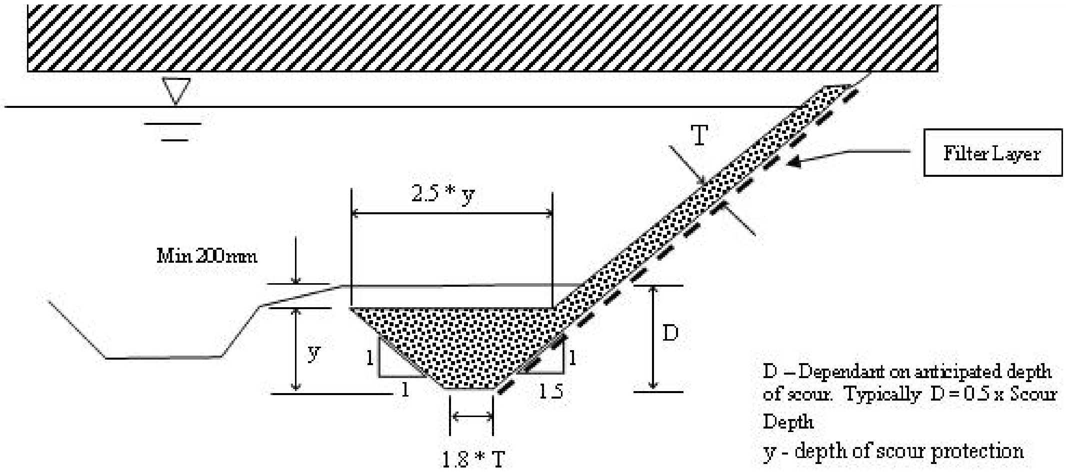
Scour Countermeasures

Scour protection is recommended along the river banks near the bridge to prevent movement of material that potentially impacts on the bank material near the abutment. Proposed protection is rock rip rap sized using guidelines in Waterway Design (Austroads, 1994).

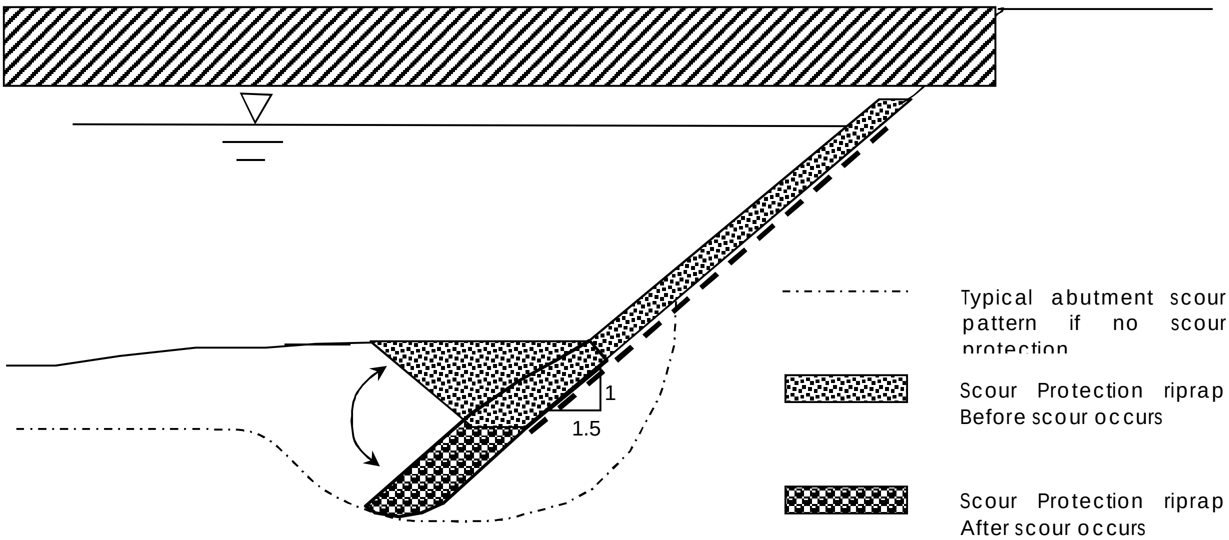
The US Federal Highways Administration publication Countermeasures for Hydraulic Problems at Bridge Sites has highlighted one of the principal causes of failure of abutment protection is due to undermining of the toe of the protection by scour through the bridge.

The recommended counter measure is to provide rip rap material at the toe of the abutment to ensure the abutment protection cannot be undermined. The abutment scour toe treatment beneath the bridge is provided in the manner shown in Figure B2.

- **Figure B2 - Typical Scour Protection Treatment**



This allows for the toe of the abutment to fall into the scour hole created, protecting the abutment from being undermined by further scour as demonstrated in Figure B3. There must be sufficient material at the base of the abutment to line any scour hole that threatens to undermine the abutment.



- **Figure B3 - Scour Protection After Maximum Potential Scour Has Been Realised**

Figure C1 | HEC-RAS hydraulic model layout

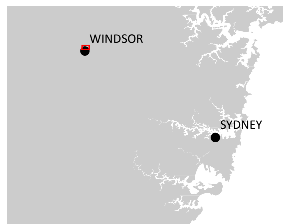
LEGEND

- HEC-RAS model cross-section
- HEC-RAS model reach
- Concept design
- Cadastre

Indicative only – subject to detailed design

DATA SOURCES
Imagery: AUSIMAGE 2011
Cadastre: LPI

0 200
Metres



Windsor Bridge replacement hydrological study

26/10/2012 | I:\NBIF\Projects\NB11459\Technical\GIS\GIS_Directory\ArcMap\Specialist_Reports\Hydrology\NB11459_001_Hy_HEC-RAS_Landscape.mxd
Sydney Spatial Team - Prepared by : DD
Checked by : JC

Northern bank/abutment

Fill and regrading of the northern river bank is included as part of the project. Scour protection measures are proposed along the bank up to the bridge abutment. Rock rip rap is shown to be continued through bridge as the existing ground and vegetation cover is to be altered to accommodate the footpath and that it is unlikely for vegetation to be established under the bridge.

All rock riprap would be underlain with a layer of geotextile fabric to prevent material from being washed out through the voids. The geotextile is to be in accordance with RMS specification DCM R63 and the manufacturer's specification.

Southern bank/abutment

The existing bridge abutment supports part of the wharf access road and thus is to be retained. There are gabion walls on either side of the existing bridge into the river. These gabions are not currently surveyed and the condition to achieve the design life of the wharf access road. Subject to structural analysis scour protection measures may be required at the existing pier.

The southern abutment is located some 20m south (back from) the river bank. Between the abutment and the river there is an existing access road to the wharf and a retaining wall along the river bank (top of wall approximately 3.5m AHD and bottom at 0.7m AHD). This access road is to be retained at the current vertical and horizontal alignment. To protect the road and bank from scour, measures are required.