The Northern Road Upgrade – Glenmore Parkway, Glenmore Park to Jamison Road, South Penrith

Roads and Maritime Services

Hydrology and flooding assessment

September 2016

The Northern Road Upgrade – Glenmore Parkway, Glenmore Park to Jamison Road, South Penrith

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01	21/04/2016	Draft – Hydrology and flooding working paper for issue to D&C Contractors	PD	SR	
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03	22/07/2016	Draft – Hydrology and flooding working paper based on a selected concept design including figures	PD		
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05	25/08/2016	Draft Hydrology and flooding working paper based on a preferred concept design	PD, BW	AH	TC
06	12/09/2016	Final Hydrology and flooding working paper based on a preferred concept design (after contractor review/inputs)	PD, BW *with input from Lendlease	AH	TC

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Appendix A. Model Results

Important note about this report

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

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

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

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs' Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

Roads and Maritime Services (Roads and Maritime) is proposing to upgrade The Northern Road between Glenmore Parkway, Glenmore Park and Jamison Road, South Penrith (referred to as 'the proposal' for the purposes of this report). The corridor is located about 47 kilometres west of the Sydney Central Business District (CBD). The proposal will upgrade The Northern Road to an eight-lane divided road, with three general traffic lanes and a kerbside bus lane in each direction, separated by a raised concrete median. The Northern Road will be continued as a six lane carriageway north of Jamison Road.

This section of The Northern Road is currently a four lane road, largely divided by a narrow median. Between 200 metres south of Smith Street and 200 metres north of Frogmore Road there is a 1.3 km section that is undivided.

Roads and Maritime is upgrading The Northern Road as part of the Australian and NSW governments' Western Sydney Infrastructure Plan, which will deliver $3.6 billion in road infrastructure improvements over the next 10 years. The proposal was announced in April 2014 by the (then) Prime Minister as part of the Western Sydney Infrastructure Plan's program of works to support the planned western Sydney airport at Badgerys Creek.

1.1 Purpose of this report

The potential hydrology and flooding impacts that may arise during the construction and operation of the project are presented, together with safeguards and management measures to mitigate any negative flood impacts. This includes outlining existing flood behaviour, identifying drainage upgrade options to provide the required flood immunity, summarising potential flood impacts of the road improvement and investigating possible mitigation options.

1.2 Methodology

The methodology for the assessment involved:

- Reviewing background information relevant to the proposal, including:
  - Previous flood studies including the Penrith Overland Flow Flood Overview Study (Cardno Lawson Treloar, 2006), South Creek Flood Study (Worley Parsons, 2015) and Penrith CBD Overland Flood Study (Cardno, 2015)
  - Survey data
  - GIS data
- Review of hydrological and hydraulic models of the concept design for the proposal
- Utilisation of the hydrological and hydraulic models of the concept design to assess the flood conditions along the site boundary for the 100 year average recurrence interval (ARI) and probable maximum flood (PMF) for existing, interim and operational conditions for the southern end of the project
- Utilisation of the hydrologic and hydraulic models of the concept design to determine peak 100y ARI flood levels for the section of the project from Glenmore Parkway to Jamison Road
- Identifying potential impacts on flood behaviour as a result of the proposal to determine compliance with the Scope of Works and Technical Criteria (SWTC) and considering government policies and guidelines including:
  - Floodplain Development Manual: the management of flood liable land (DIPNR, 2005)
  - Australia Rainfall and Runoff: A Guide to Flood Estimation (Engineers Australia, 1987)
  - Penrith Development Control Plan 2014 (Penrith City Council, 2014)
  - Austroads Guide to Road Design Part 5 (Austroads, 2013)
- Technical and reporting reviews by Jacobs, Roads and Maritime and the selected contractor.

The proposed upgrade of The Northern Road from Glenmore Parkway to Jamison Road is planned to be constructed before other planned upgrades of The Northern Road, directly south of the study area. The period between the completion of the proposal and the other planned upgrades of The Northern Road is referred to in this report as the 'interim condition'. The interim condition affects a short section of the study area south of Glenmore Parkway and is not expected to exist for more than two years following completion of this proposal.

2. Existing Environment

2.1 Study area description

The hydrology and flooding assessment relates to the study area for the proposal as illustrated in Figure 2.1. The study area is defined by the site boundary of the proposal which extends east and west of The Northern Road from about 180 metres south of Glenmore Parkway to approximately 100 metres north of Jamison Road. External catchments contribute to flows within the study area boundary and these have been considered as part of the hydrology and flooding assessment.

The study area lies within Surveyors Creek and Werrington Creek catchments as illustrated on Figure 2.1. South of Maxwell Street and Bringelly Road, the study area generally drains west and north-west, into Surveyors Creek. North of Maxwell Street and Bringelly Road, The Northern Road alignment generally follows a ridge defining the boundary of the Surveyors Creek and Werrington Creek catchments. Therefore, this section of the study area generally drains either west into Surveyors Creek, or north into Werrington Creek.

The land use for the study area and catchments draining to the study area is predominantly suburban and consists primarily of low density residential developments with some pockets of commercial developments and open spaces including parklands and a golf course.

There are a number of watercourses in the study area as shown in Figure 2.1. These watercourses form tributary branches of Surveyors Creek. The main tributary branch runs west of The Northern Road to the south of the study area and has dry weather flows. This watercourse passes under Glenmore Parkway and across Penrith Golf and Recreation Club and has its confluence with Surveyors Creek north of the M4 Western Motorway. This main tributary branch is joined by two smaller ephemeral tributaries which have their confluences upstream of Glenmore Parkway and within Penrith Golf and Recreation Club respectively. Directly north of the M4 Western Motorway, a tributary branch of Surveyors Creek drains catchments east and west of The Northern Road and is ephemeral in nature.

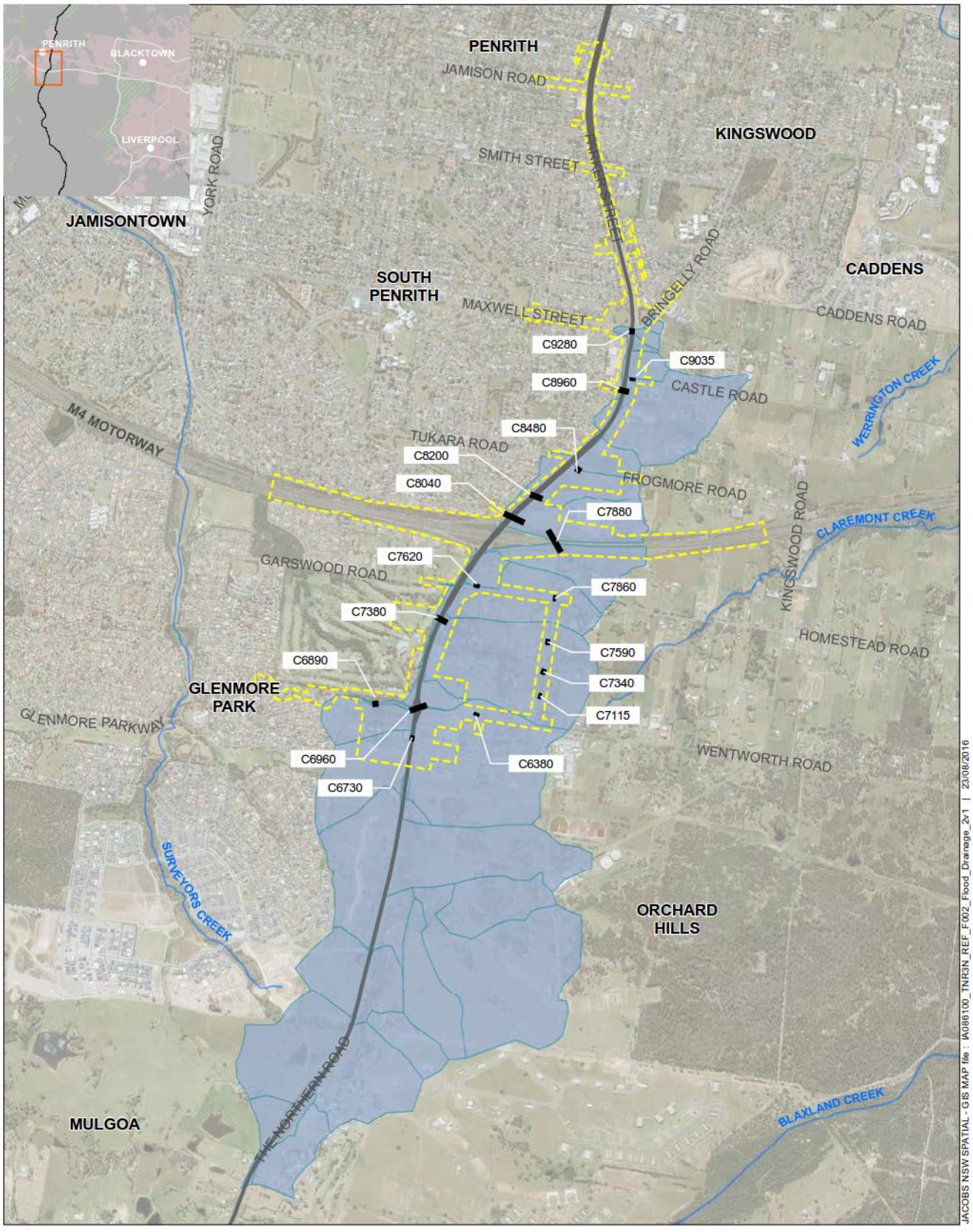
The road network is elevated above the natural ground level for a large portion of the study area. In order to convey water under the road network, there are 17 transverse drainage culverts within the study area. These culverts drain runoff from a combination of upstream catchment areas and in some locations, runoff from the road pavement. Details of the locations of these culverts and contributing upstream catchment areas are shown in Figure 2.2. Summary details of these transverse culverts are provided in Table 2.1.

The pavement drainage network discharges to a combination of Council's pit and pipe network, open swales and the transverse drainage culverts. Connections to Council's pit and pipe network are generally located in the north of the study area where the catchment is more urbanised. The pavement drainage network discharges into Council's drainage network into the following four locations: Hilliger Road, Oag Crescent, Smith Street and Jamison Road. The remaining pavement drainage outlets discharge either directly to the transverse drainage culverts or to swales and catch drains at the base of the road embankment, which in turn drain to transverse drainage culverts.

In addition to the transverse and road drainage, there are a number of other constructed drainage features within the study area which include:

- Property accesses over the watercourse to the west of The Northern Road south of Penrith Golf and Recreation Club
- A drainage easement approximately 6 metres wide, flowing east-west between neighbouring properties from the culvert beneath The Northern Road, approximately 180 metres south of Glenmore Parkway.

Figure 2-1 | The Northern Road Upgrade between Glenmore Parkway and Jamison Road



Legend

- The Northern Road (Existing)
- Transverse drainage culverts
- Study area
- Sub-catchments draining to transverse drainage

0 0.5 1 km

N

Figure 2-2 | Existing drainage features

Table 2.1 : Existing transverse drainage details

ID	Drainage feature	Location (refer to Figure 2.2)	Type	Size (mm)	No. of cells	Contributing catchment area (ha)
C6730	Transverse drainage culvert	The Northern Road 180 m south of Glenmore Parkway	RCP	1050	2	45.2
C6380	Transverse drainage culvert	Wentworth Road, 310 m east of The Northern Road	Reinforced Concrete Pipe (RCP)	675	1	1.5
C6890	Transverse drainage culvert	Glenmore Parkway 200 m west of The Northern Road	Reinforced Concrete Box Culvert (RCBC)	2400 x 1500	7	293.1
C6960	Transverse drainage culvert	Wentworth Road at intersection with The Northern Road	RCP	750	1	2.5
C7115	Transverse drainage culvert	Cross Road 150 m north of Wentworth Road	RCP	450	2	5.2
C7340	Transverse drainage culvert	Cross Road 275 m north of Wentworth Road	RCP	675	1	5.5
C7380	Transverse drainage culvert	The Northern Road 195 m south of Garswood Road	RCP	1050	3	58.5
C7590	Transverse drainage culvert	Cross Road 425 m north of Wentworth Road	RCP	450	1	1.9
C7620	Transverse drainage culvert	Homestead Road 75 m east of The Northern Road	RCP	525	2	2.2
C7860	Transverse drainage culvert	Cross Road at Homestead Road	RCP	450	3	3.8
C7880	Transverse drainage culvert	M4 Western Motorway 250 m east of The Northern Road (bridge)	RCP	1050	2	13.5
C8040	Transverse drainage culvert	The Northern Road, northern approach to M4 Bridge	RCP	1050	2	27.7
C8200	Transverse drainage culvert	The Northern Road, 200 m north of M4 interchange	RCP	1050	1	17.2
C8480	Transverse drainage culvert	Frogmore Road adjacent to The Northern Road	RCP	525	2	4.2
C8960	Transverse drainage culvert	The Northern Road, at Aspen Street	RCP	1200	3	25.7
C9035	Transverse drainage culvert	Castle Road adjacent to The Northern Road	RCP	450	1	25.7
C9280	Transverse drainage culvert	The Northern Road, near intersection of Maxwell Street/ Bringelly Road	RCP	525	1	1.66

2.2 Existing flood behaviour

Penrith Overland Flow Flood "Overview Study" (Cardno, 2006) was undertaken for Penrith City Council to generate sufficient information to define flood risk and prioritise flood risk management across the Penrith Local Government Area (LGA). Flood maps prepared as part of the overland flood study have been used to inform the regional flood behaviour within the catchments draining the study area for the 100 year ARI and PMF events. No flood maps are available for more frequent flood events. The flood maps provide a general overview of the flood risk and indicate that both the road network and some private properties are at risk of mainstream flooding from creeks, and of overland flooding resulting from local catchment runoff.

The flood maps indicate that the majority of the flood risk along the route of the proposal is south of the M4 Motorway where a number of properties and a section of The Northern Road are shown to be inundated for the 100 year ARI and PMF events. The maps indicate inundation of The Northern Road south of Glenmore Parkway and at the channel crossing into Penrith Golf and Recreation Club. North of the M4 Motorway, the maps indicate that The Northern Road is flood free for the 100 year ARI event, but with flooding of The Northern Road occurring at a number of the transverse culvert crossings for the PMF event. The maps also indicate that there are a number of properties at risk of flooding directly east and west of the study area boundary.

The flood models developed for the overland flood study were not considered suitable for the hydrology and flooding assessment for the proposal due to the coarse model resolution. Hydrologic and hydraulic models were therefore developed as part of the proposal to assess the flood behaviour within the study area. Details of the model development and model results are presented in Section 3 and 4. The model results have been used to provide a more accurate assessment of the flood levels and capacity of the drainage within the study area.

The model results indicate that the existing transverse culverts have a capacity less than 100 year ARI at a number of cross drainage locations. A summary of the flood mechanisms and flooding issues identified from the existing scenario models and anecdotal evidence is summarised below:

- Culvert C6730 (The Northern Road, 180 metres south of Glenmore Parkway) currently has a limited capacity. Flooding at this culvert is exacerbated by flows from the adjoining catchment south of the study area, which are diverted north along the base of The Northern Road embankment toward the inlet of culvert C6730
- Flows exceeding the capacity of culvert C6730 overtop The Northern Road at a low point 60 metres south of the culvert, and flow west over the floodplain before joining the creek west of the road
- Flow in the drainage easement downstream of culvert C6730 is limited by the capacity of the culvert
- Seven properties at the bifurcation of the two creeks south of Glenmore Parkway are likely to be flood affected in the 100 year ARI event. No ground level property survey information is available to determine if the flood affect would be above their floor level.
- At the intersection of The Northern Road and Jamison Road, the existing pavement drainage has limited capacity. As a result, surface water flows along the travel lanes of The Northern Road and ponds at a low point north of Jamison Road. This results in both a safety issue for vehicles using the road, and flooding of downstream properties. No property ground level survey information is available to determine if the flood affect would be above their floor level.
- Culvert C8960 (The Northern Road, near Aspen Street) currently has a surcharge pit at the outlet. This pit surcharges water into the adjacent vacant land with flows entering the rear of the adjacent private property.
- There is evidence of erosion at the inlet at Culvert C9035. This erosion has been gradually formed resulting in ponding of water north of Castle Road in The Northern Road reserve
- There are several private properties between Maxwell Street/Bringelly Road and Jamison Road which currently experience flooding impacts due to the road reserve terrain shedding flows away from the road and into private properties. Some properties immediately north of Rotary Park, experience more significant levels of inundation.

The Northern Road upgrade is at significant risk of flooding in a PMF event, particularly south of the M4 Motorway. The flood maps prepared as part of the Penrith Overland Flow Flood Study indicate that section of the route most at risk of flooding is between Culvert C6730 (about 180 metres south of Glenmore Parkway) and Culvert C7380 (about 195 metres south of Garswood Road). North of the M4 Motorway, the potential impact of flooding is reduced. The flood maps indicate pockets of inundation along The Northern Road at culvert C8960 (The Northern Road, at Aspen Street), Bringelly Road and Maxwell Street and at The Northern Road and Jamison Road.

3. Proposed Concept Design

3.1 Design Criteria

The drainage design criteria for the proposal was based on Roads and Maritime design and performance requirements as set out in the Scope of Works and Technical Criteria (SWTC), Austroads Guide to Road Design Part 5 and other relevant industry and government policies and guidelines. Key elements of the drainage design criteria relevant to flooding and hydrology is detailed in Table 3.1.

Table 3.1 : Drainage design criteria

Item	*Criteria*
Drainage General	The drainage design must include hydraulic modelling of watercourses that are crossed by the proposal to determine flooding and associated impacts, including assessment for 20 year, 50 year and 100 year average recurrence interval (ARI) events and probable maximum flood (PMF). The hydraulic modelling must include an assessment and identification of the impacts of the 100 year ARI event on properties and infrastructure at the site boundary.
Drainage General	The drainage system must separate cross drainage systems from pavement drainage systems.
Drainage General	The drainage design must result in minimal disruption to the existing natural surface and ground water hydrological regime and must not divert flow onto or into adjoining catchments.
Average Recurrence Intervals	Drainage infrastructure must be designed, as a minimum, for the ARI specified below: • Open drains (surface drains including channels, table drains, bench drains, catch drains, contour banks, drop downs, basin inflows and basin outflows.) – 5 years • Piped systems (including pits) – 10 years • Culverts– 100 years • Pavement drainage – 10 years
Pavement Drainage Flood Immunity	At least one traffic lane is trafficable in each direction on The Northern Road in the 100 year ARI storm event.
Transverse Drainage Blockage	Consider and address the impacts of blockages in transverse drainage and allow for a minimum of 50% blockage in cross drainage transverse pipes that are less than or equal to 600 mm diameter or box culverts that are less than or equal to 600 mm in height
Longitudinal Drainage Blockage	Pipes with a minimum 375 mm diameter must be used for longitudinal drainage pipes and a minimum 450 mm diameter for transverse drainage pipes. The design of the longitudinal pipe and pit drainage networks must incorporate a 20% blockage factor for drainage inlet pits on grade and 50% blockage factor for drainage inlet pits in sag. The drainage design must not increase the peak discharge into the existing drainage network by more than 3% at the site extents.
Temporary Drainage	All temporary drainage systems must satisfy the requirements of all relevant authorities.

Item	Criteria
Discharge into Council's Stormwater Drainage System	Any new or increased stormwater discharge into Penrith City Council's stormwater drainage system must be approved by Penrith City Council. Penrith City Council has confirmed that a 3% increase from existing flows will not require detention basins or tank since it is within the existing tolerances of hydraulic design. Any stormwater detention basins or tanks that are required to comply with the Council's requirements must be designed and analysed for 2, 10, 20 and 100 year ARI storm events.
Flooding	The drainage works must be designed to minimise changes to existing flooding characteristics for flood events up to and including the 100 year ARI, and must not increase upstream/downstream inundation levels at the site boundary. The Project Works and Temporary Works must be designed such that the potential for flooding of any other property is not increased by the presence of the Project Works or the Temporary Works at the site boundary. Transverse drainage must be designed to provide: (i) Minimum 100 year ARI flood immunity to The Northern Road; (ii) Maintain existing flood immunity to the local roads; (iii) Maintain existing flood immunity to surrounding property. The flood level increase upstream of the culvert at C6730 under the interim conditions is to be no greater than 240 mm and must not impact any existing dwellings. The flood immunity for The Northern Road in interim conditions must provide immunity against at least a 50 year ARI event.

3.2 Safety in Design

The safety in design process must satisfy company specific health and safety requirements, Work Health and Safety (WHS) Laws and Regulations and project specific requirements. More importantly it is required to maximise the safety of people during construction, operation and maintenance phases by developing all elements of the design with safety in mind. A summary of the key risks relevant to drainage design are provided in Table 3.2 and measures implemented in the design to reduce these risks.

Table 3.2: Key risk and measures to reduce risk relevant to drainage design

Risk	Measures to reduce risk
People falling into detention and water quality basins	Batter slopes of all open detention or water quality basins 1:4 to ensure people can climb out safely.
Slot drains present hazard to pedestrians and cyclists	Positioned away from cyclist and pedestrian traffic to prevent trips and falls.
Deep excavation required to replace culvert beneath M4 Motorway interchange	The existing culvert has been reused to avoid the need for deep (approximately 10m) excavation and confined space works that would be required to replace the culvert.
Deep manhole and risk of blockage on change in direction on culvert C8040	10 metre deep manhole on C8040 removed and replaced with pipe bend due to access risk down manhole. Sloped grating included at upstream headwall to minimise risk of blockage occurring.

3.3 Maintenance in Design

The concept design has considered maintenance requirements during the operation phase of the works. Key aspects of the design which have been significantly or entirely determined by maintenance requirements are:

- Vehicular access is provided to all drainage structures and water quality basins for routine maintenance (including routine operational water quality monitoring) and emergency response purposes
- Pavement drainage pipes have been designed with a minimum grade of 0.5% to allow for self-cleansing and to reduce maintenance requirements
- Where possible, above ground water quality and stormwater detention basins have been used to reduce maintenance of below-ground tanks and buried gross pollutant traps (GPTs).

The design for maintenance requirements is integral with the safety in design and due consideration will be given during detailed design.

3.4 Description of Concept Design

3.4.1 Construction Phase

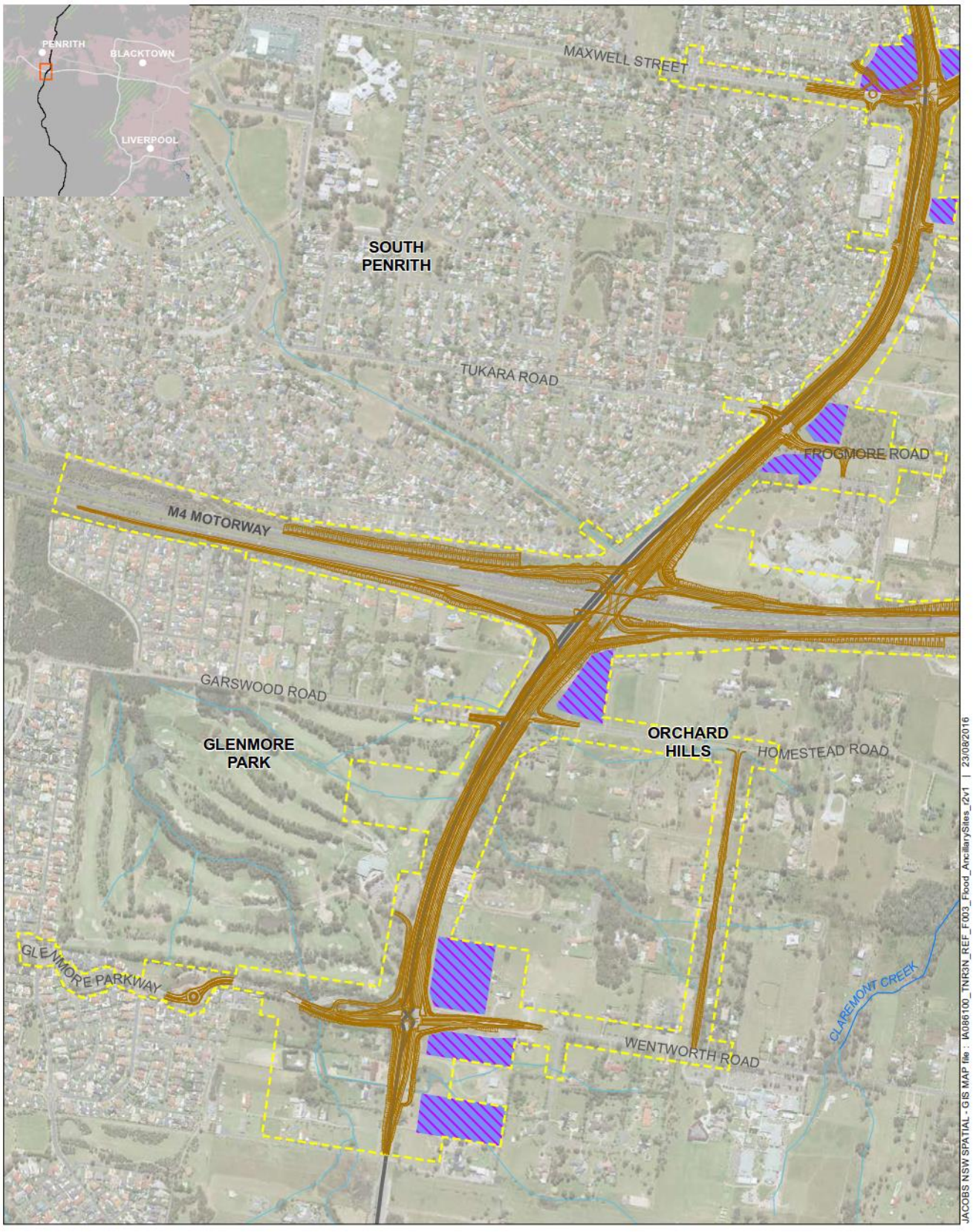
The construction phase would include development of compound sites for construction works and is likely to include stockpiles of construction material. Portable buildings and other items not fixed on the site compounds have the potential to float and be carried away if affected by deep floodwaters, and may then become lodged and cause blockage of bridges and culverts further downstream. This could cause flood level impacts for areas upstream of the blockage. In addition, stockpiles placed in inappropriate locations on the floodplain may obstruct flood flows and cause localised increases in flooding to nearby properties. The proposed construction phase compound sites are shown on Figure 3.1.

Compounds are generally located away from known overland flow paths to avoid flood impacts during construction. Temporary localised reshaping or bunding within proposed construction compound sites would be considered to avoid the potential impact of erosion and carriage of construction material. These measures would be outlined in the Construction Erosion and Sedimentation Control Plan.

Construction of the proposed upgrade would be staged to ensure drainage works provide earlier benefits to the catchments to avoid temporary impacts beyond those identified in this report.

3.4.2 Interim and Operational Phase

Figure 3.2 provides a schematic of the drainage design for the interim and operational phase with further details provided in Table 3.3, Table 3.4 and Table 3.5.



Legend

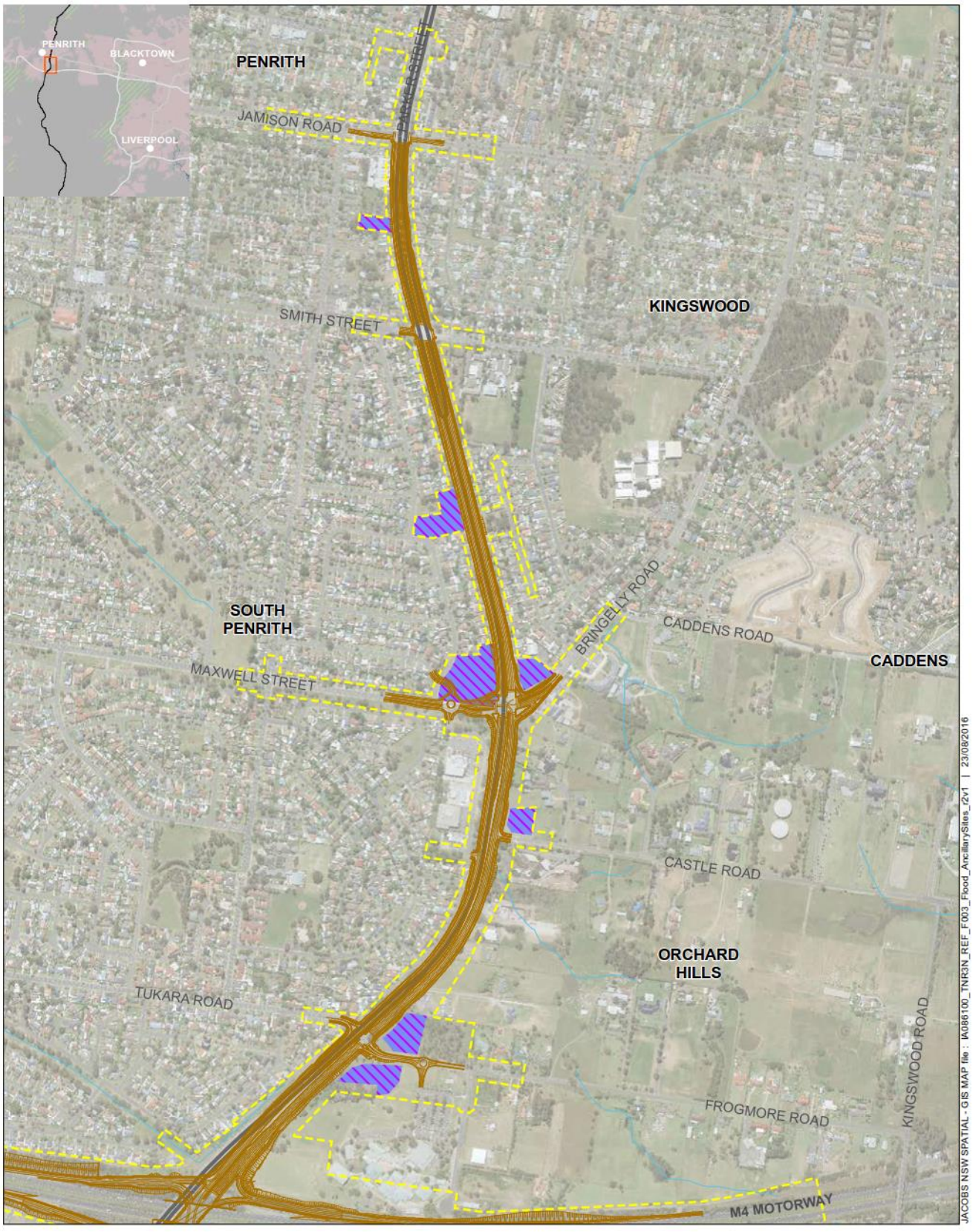
- The Northern Road Upgrade between Glenmore Parkway and Jamison Road
- The Northern Road (Existing)
- Proposal area
- Ancillary facilities - proposed locations

0 200 400 m

N

3-1b
3-1a

Figure 3-1a | Ancillary facilities - proposed locations



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3-1b

3-1a

Figure 3-1b | Ancillary facilities - proposed locations

Legend

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- The Northern Road (Existing)
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- Proposed pipe drainage
- Proposed tranverse drainage
- Flow direction
- Proposed slot drain
- Proposed drain pit
- Existing drainage to remain
- Proposed grass swale
- Proposed concrete line channel
- Proposed rock channel

0 100 200 m

N

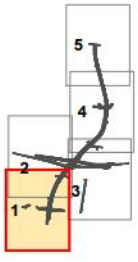
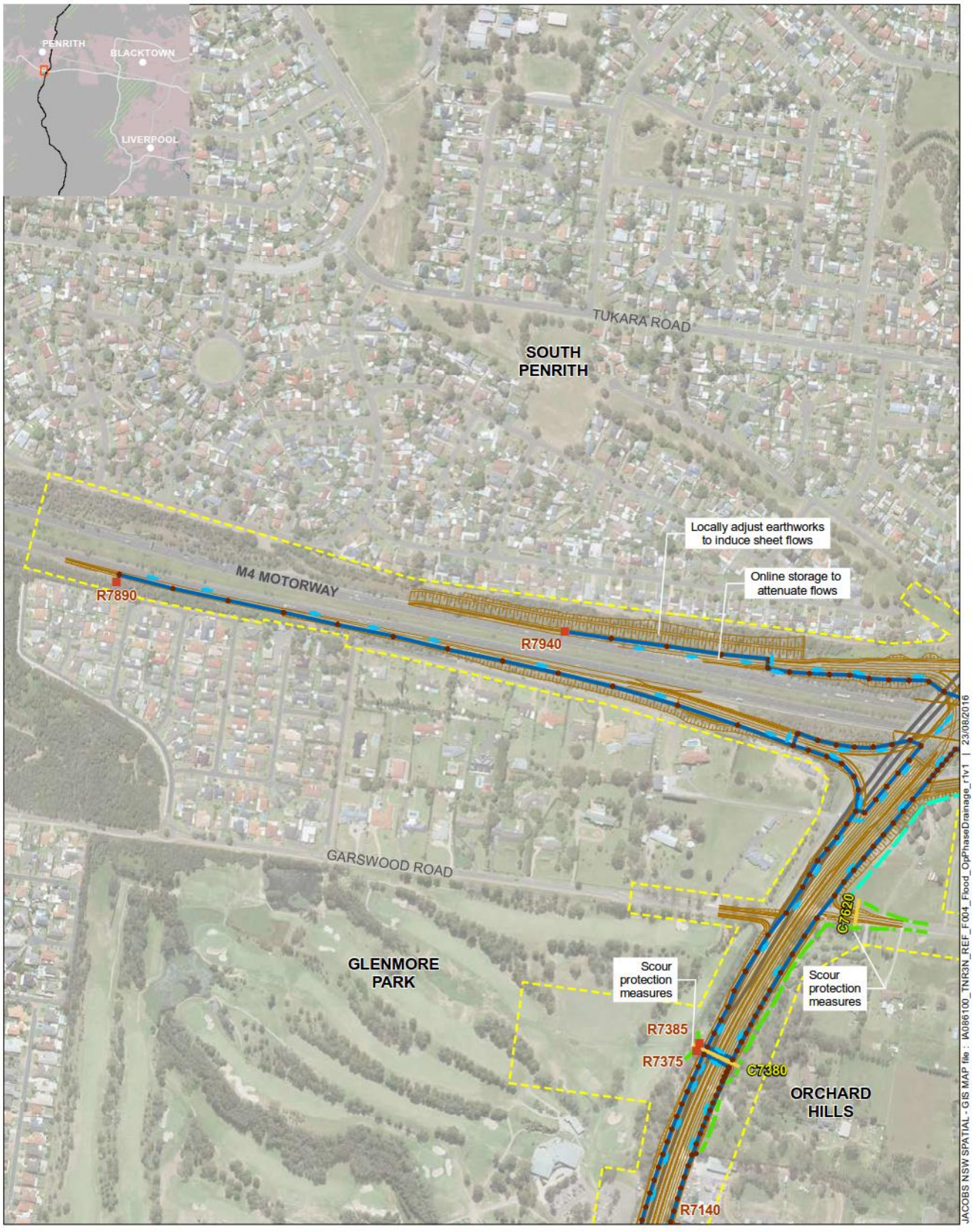


Figure 3-2 | Operational phase drainage features (Page 1 of 5)



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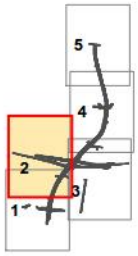
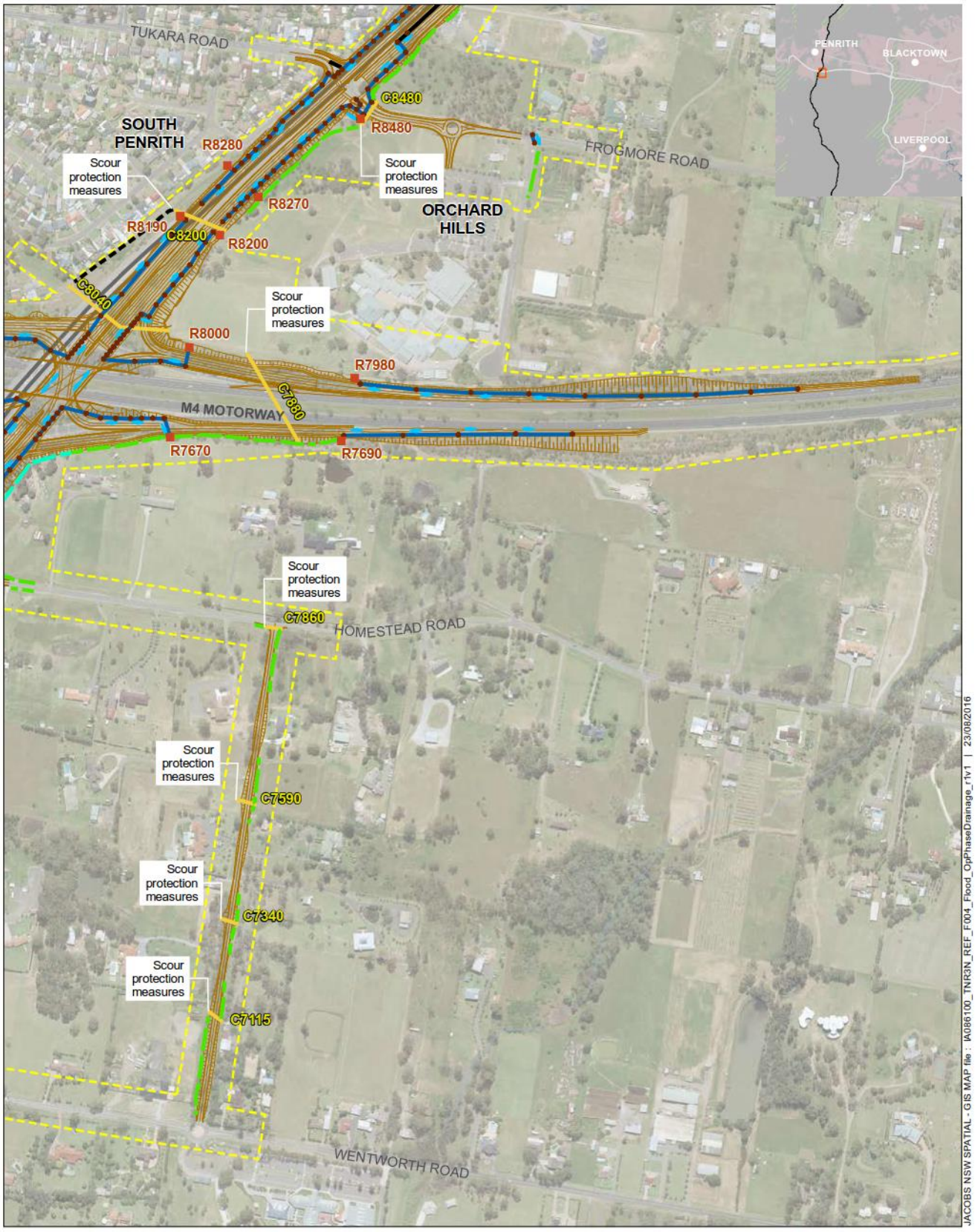


Figure 3-2 | Operational phase drainage features (Page 2 of 5)



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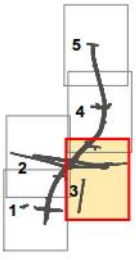
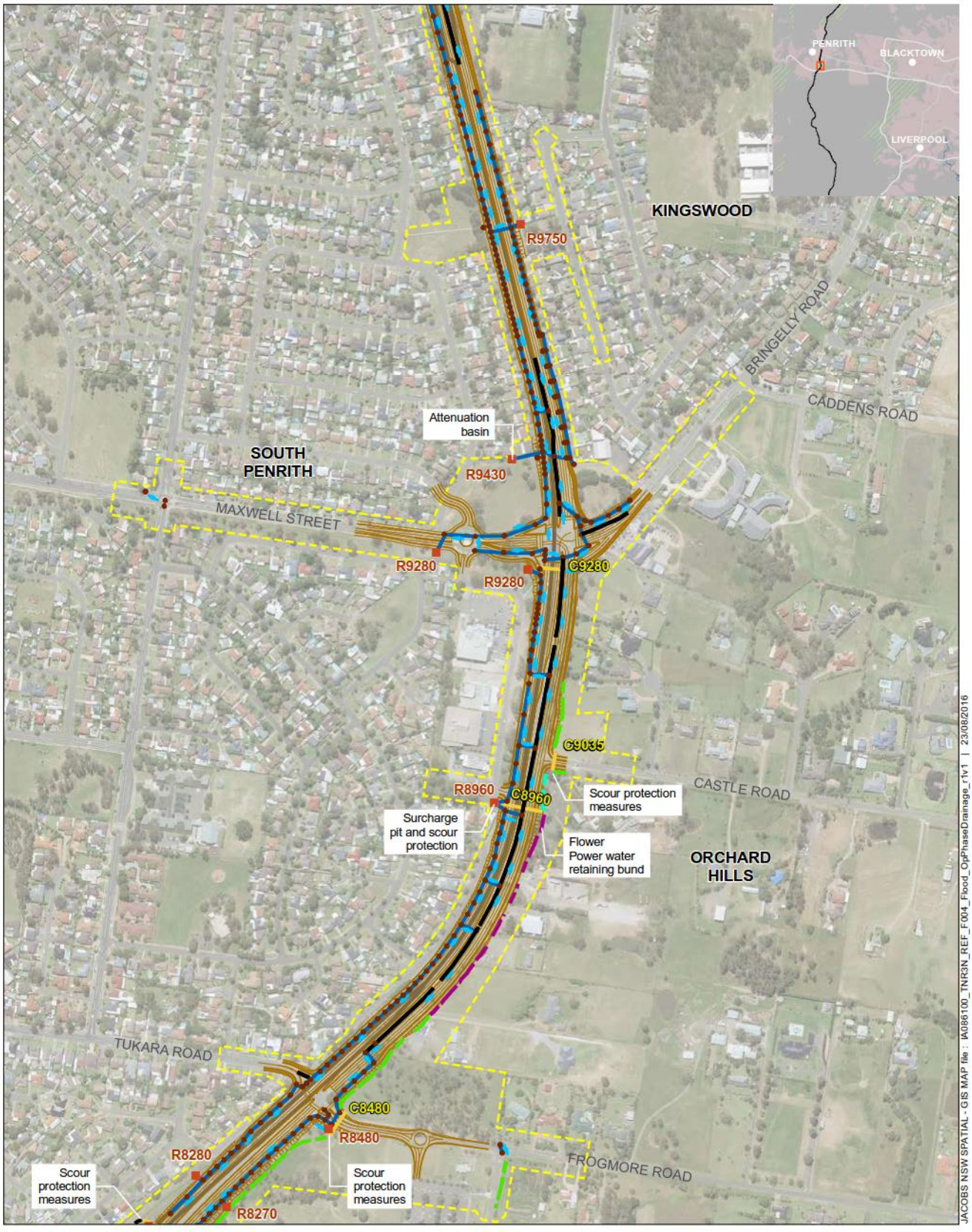


Figure 3-2 | Operational phase drainage features (Page 3 of 5)



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- The Northern Road Upgrade between Glenmore Parkway and Jamison Road
- The Northern Road (Existing)
- Study area
- Proposed pavement drainage outlets
- Proposed pipe drainage
- Proposed tranverse drainage
- Flow direction
- Proposed slot drain
- Proposed drain pit
- Existing drainage to remain
- Proposed grass swale
- Proposed concrete line channel
- Proposed rock channel

0 100 200 m

N

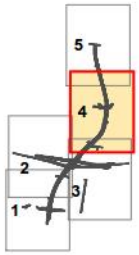


Figure 3-2 | Operational phase drainage features (Page 4 of 5)

Legend

- The Northern Road Upgrade between Glenmore Parkway and Jamison Road
- The Northern Road (Existing)
- Study area
- Proposed pavement drainage outlets
- Proposed pipe drainage
- Proposed tranverse drainage
- Flow direction
- Proposed slot drain
- Proposed drain pit
- Existing drainage to remain
- Proposed grass swale
- Proposed concrete line channel
- Proposed rock channel

0 100 200 m

N

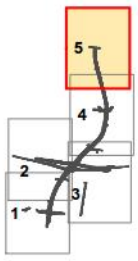


Figure 3-2 | Operational phase drainage features (Page 5 of 5)

Table 3.3 : Proposed transverse drainage strategy

ID	Location (refer to Figure 3.2)	Type	Size (mm)	No. of culverts	Invert level Inlet (m AHD)	Invert level Outlet (m AHD)	Critical level for overtopping road (m AHD)	Contributing catchment area (ha)	Comments
C6380	Wentworth Road, 310 m east of The Northern Road	RCP	675	1	48.09	47.74	49.95	1.5	Existing culvert to be retained.
C6730	The Northern Road 180 m south of Glenmore Parkway	RCBC	3000 x 1500	1	56.20	56.00	57.45	45.2	Culvert extended on upstream side to allow driveway acces road to properties Scour protection on the culvert outlet.
C6890	Glenmore Parkway 200 m west of The Northern Road	RCBC	2400W x 1500H	7	45.73	45.44	47.20	293.1	Existing culvert to be retained.
C6960	Wentworth Road at intersection with The Northern Road	RCP	750	1	50.92	50.00	51.42	2.5	Depressed inlet pit Scour protection on the culvert outlet.
C7115	Cross Road 150 m north of Wentworth Road	RCBC	1800 x 600	3	60.02	59.95	60.37	5.2	Scour protection on the culvert outlet.
C7340	Cross Road 275 m north of Wentworth Road	RCP	675	4	58.86	58.65	59.57	5.5	Scour protection on the culvert outlet.
C7380	The Northern Road 195 m south of Garswood Road	RCP	1200	4	46.66	46.37	48.88	58.5	Depressed inlet Scour protection on the culvert outlet.
C7590	Cross Road 425 m north of Wentworth Road	RCP	450	4	61.82	61.62	62.32	1.9	Scour protection on the culvert outlet.
C7620	Homestead Road 75 m east of The Northern Road	RCP	750	2	51.95	51.30	52.46	2.2	Depressed inlet Scour protection at the culvert outlet.
C7860	Cross Road at Homestead Road	RCBC	900 x 300	2	60.65	60.52	61.53	3.8	Scour protection at the culvert outlet.
C7880	M4 Western Motorway 250 m east of The Northern Road (bridge)	RCP	1050	2	57.46	54.59	58.28	13.5	Extend existing culverts to new inlet. Scour protection at the culvert outlet.
C8040	The Northern Road, northern approach to M4 Bridge	RCP	1050	2	52.28	50.83	55.26	27.7	Extend existing culverts to new inlet. Reuse existing culvert outlet. No scour protection required.
C8200	The Northern Road, 200 m north of M4 interchange	RCP	1050	1	55.30	54.74	57.12	17.2	Extend existing culverts to new inlet. Scour protection on the culvert outlet.
C8480	Frogmore Road adjacent to The Northern Road	RCP	675	4	59.20	58.70	59.72	4.2	Channelized outlet. Scour protection on the culvert outlet.
C8960A	The Northern Road, about 100 m south of Castle Road	RCP	1350	2	59.87	58.60	62.41	22.4	Headwall inlet, chamber pit outlet which connects to culverts C8960B and C9035B
C8960B	The Northern Road, at Aspen Street	RCP	1350	3	58.51	57.50	60.73	25.7	Chamber pit inlet. Piped connection to be provided for overflows from existing Flower Power pond outlet. Maintain existing overland flow route at culvert outlet. Localised reshaping and scour protection may be required a the culvert outlet.
C9035A	Castle Road adjacent to The Northern Road	RCP	675	2	61.38	61.08	62.22	2.5	Depressed inlet and pit outlet to culvert C9035B.
C9035B	The Northern Road south of Castle Road	RCP	1350	1	61.05	58.6	N/A	2.5	Pit inlet from C9035A and chamber pit outlet to culverts C8960A and C8960B
C9280	The Northern Road, near intersection of Maxwell Street/ Bringelly Road								This culvert will be decommissioned as part of the proposal

Table 3.4 : Proposed pavement drainage details

ID (refer to Figure 2.2)	Drainage feature	Comments
R6705	Pavement Drainage	Discharges to grass lined channel draining to culvert C6730
R6730	Pavement Drainage	Discharges to grass lined channel draining to culvert C6730
R6750	Pavement Drainage	Discharges to culvert C6730
R6850	Pavement Drainage	Discharges to grass lined channel draining to culvert C6730
R6890	Pavement Drainage	Discharges to bio retention containment basin
R6870	Pavement Drainage	Discharges to existing drainage basin
R6990	Pavement Drainage	Discharges to bio retention containment basin
R7140	Pavement Drainage	Catch drain to pavement drainage headwall
R7375	Pavement Drainage	Discharges to culvert C7380
R7385	Pavement Drainage	Discharges to culvert C7380
R7670	Pavement Drainage	Discharges to grass lined channel draining to culvert C7620
R7690	Pavement Drainage	Discharges to grass lined channel draining to culvert C7620
R7890	Pavement Drainage	Discharges to M4 drainage
R7940	Pavement Drainage	Discharges to M4 drainage
R7980	Pavement Drainage	Discharges to concrete lined channel draining to culvert C8040
R8000	Pavement Drainage	Discharges to concrete lined channel draining to culvert C8040
R8190	Pavement Drainage	Discharges culvert C8200
R8200	Pavement Drainage	Discharges culvert C8200
R8270	Pavement Drainage	Discharges to grass lined channel draining to culvert C8200
R8280	Pavement Drainage	Discharges to existing channel draining to culvert C8200
R8480	Pavement Drainage	Discharges to existing channel draining to culvert C8200
R8960	Pavement Drainage	Discharges to existing overland flow route at C8960 culvert outlet.
R9280	Pavement Drainage	Discharges to a Council's pit and pipe network
R9430	Pavement Drainage outlet	Discharges to a proposed detention basin
R9750	Pavement Drainage outlet	Discharges to Council's pit and pipe network.
R10170	Pavement Drainage outlet	Discharges to a proposed detention basin connected to Council's pit and pipe network
R10420	Pavement Drainage outlet	Discharges to Council's pit and pipe network.
R10620	Pavement Drainage outlet	Discharges to Council's pit and pipe network.

Table 3.5 : Proposed On-site detention basin details

ID (refer to Figure 2.2)	Drainage feature	Comments
R9430	Above ground detention basin	Pavement drainage from network R9430 drains to detention basin connected to Council's pit and pipe network on Smith Street
R10170	Below ground detention tank	Pavement drainage system R10170 drains into proposed below ground detention tank which discharges to Council's pit and pipe network on Hilliger Road
M4 East Bound Exit Ramp	Online storage	Below ground 1050 mm diameter pipe is connected to downstream 450 mm diameter pipe to provide storage and flow attenuation

The drainage design for the interim and operational phase of the proposal consists of the following aspects which are relevant to flooding:

- The road formation (including The Northern Road and its connections to local roads) would be widened to provide four lanes in each direction
- The road formation is proposed to be raised, where necessary, to provide flood immunity for the 100 year ARI event
- Upgrades to drainage infrastructure, including
  - Transverse drainage culverts and associated inlet and outlet earthworks and scour protection
  - Drainage easement channel modifications
  - Pavement drainage pit and pipe network
  - Open swales and catch drains
  - On-site Detention (OSD) basins/tank.

A series of open channels alongside the carriageway provide catch drains for the external catchment areas draining towards The Northern Road. Vegetated channels are provided in the southern section of the upgrade to preserve the area's rural aesthetic. Where space is constrained and there is a need for greater channel capacity, concrete or rock lined channels are provided. At the M4 Motorway interchange where culvert maintenance access is required, the channel provided between the outlet of culvert C7880 and inlet of Culvert C8200 is designed as a channel and permits vehicular crossing. Near Castle Road and Aspen Street where space is constrained by an existing irrigation pond, a chamber pit has been designed with connecting culverts to capture and convey flows within pipes. A maintenance entry lid would be installed within the proposed footway to allow inspections and periodic maintenance of the connecting culvert system.

The open channels proposed along The Northern Road in areas with driveways would be designed with culverts to allow vehicular crossing to maintain access to properties. The following pavement drainage outlets do not drain to transverse culvert locations instead they outlet directly to council's pit and pipe drainage network. These direct pipe connections would be designed to ensure flows do not increase beyond 3% into the pipe network for all design storm events:

- R9280 – The Northern Road, near intersection of Maxwell Street
- R9430 – 120 metres north of The Northern Road and Maxwell Street/ Bringelly Road intersection
- R9750 – The Northern Road opposite Mazepa Park
- R10170 – Smith Street near the intersection with The Northern Road
- R10420 – The Northern Road, 180 metres south of intersection with Jamison Road.
- R10620 – The Northern Road and Jamison Road intersection.

3.4.3 Key design features

Key features of the design include:

- The longitudinal drainage design has predominantly been based on a pit and pipe network due to the tight corridor for the road alignment. In areas where the road alignment falls towards the central median, a slot drain has been specified to minimise flow widths. At 70 metre intervals the slot drain flows have been collected and piped across the carriageway.
- South of the M4, the drainage design is a network of pits and pipes with open channels beside the carriageway. These channels carry significant flows from external catchments and connect the network of culverts. Road drainage is not discharged into these channels to avoid mixing longitudinal and transverse flows. The longitudinal drainage network discharges into these channels at the transverse drainage locations following water quality treatment where required.
- South of the M4, grass channels are used wherever possible to preserve the rural aesthetic of the area.
- Where possible, above ground water quality and stormwater detention basins have been used to reduce maintenance of below-ground tanks. All detention basins and tanks include a GPT upstream to capture larger pollutants (5 mm and greater) and reduce debris settling within the tanks and basins.
- Vehicular access is provided to all drainage structures and water quality basins for routine maintenance (including routine operational water quality monitoring) and emergency response purposes;
- At Bringelly Road/Maxwell Street an above-ground 63 m^3 detention basin is used in preference to a buried detention tank for maintenance and cost benefits. A below ground GPT is to be installed upstream of the basin close to the road alignment to provide a hardstand area for maintenance vehicles.
- At Smith Street an underground 87 m^3 on-site detention tank is used due to narrow boundary constraints. The tank is located off the existing carriageway such that it can be built while the carriageway is still functional. A below ground GPT is to be installed upstream at the edge of the road alignment to allow easy access to maintenance vehicles.
- Boundary drainage treatment would be provided as part of property adjustments carried out between Maxwell Street and Jamison Road. The boundary drainage would address the existing overflow paths across the verge and footway and into private properties. Treatments would include footpath rotations towards The Northern Road and grated pavement drains to capture water prior to entry into private properties.
- Online storage has been utilised where the operational phase flow has increased marginally above 3% through increased pipe size selection rather than including additional OSD tanks and associated GPTs and a long term maintenance value engineering initiative.
- Runoff to the culverts from external catchments is unchanged as a result of the project works, therefore no increased flows through the culverts allow for the reuse of existing pipes in some locations.
- Pavement drainage pipes have been designed with a minimum grade of 0.5% to allow for self-cleansing and to reduce maintenance requirements.
- For small pit spacing near crests and sags the standard 1.25 metre lintel is replaced with large lintel SA pits (with a 3.25 metre lintel). This has reduced the number of pits required due to the increase in the pit spacing of up to 2 metres as a value engineering initiative.
- Glenmore Parkway culverts (7 of 2400 by 1500 mm) are to be retained as tie-in works from The Northern Road upgrade does not extend as far as the culvert. This subsequently reduces the impact on the local waterway by not requiring any works within the waterway.
- To reduce the impact to the pond at the Flower Power Garden Centre (south of Castle Road) culvert C9035 is joined with culvert C8960 via a large chamber with an overflow inlet from the Flower Power pond.
- All culverts have rip-rap scour protection (or similar) at their outlet headwalls to dissipate energy and prevent scour of the downstream landscape.

4. Flood Modelling

4.1 Introduction

Flood modelling was undertaken to assess the performance of the existing and proposed transverse and pavement drainage system. Hydrological modelling was carried out using the RAFTS hydrology model built-in within DRAINS for the surrounding rural catchments, and the ILSAX model for the road catchments.

The assessment has been based on hydrological and hydraulic models developed for the concept design. A review of these concept design models has been undertaken to ensure they are fit for purpose.

The assessment of existing and operational drainage requirements has been based on peak flow estimates for present day conditions. The analysis has been undertaken for the 100 year ARI event and PMF. As the proposal is located along an existing road alignment with minor changes to the existing drainage layout, it is expected that the proposal would also have minimal flood impacts for the more frequent ARI storm events and these more frequent events have therefore not been evaluated as part of this assessment.

The potential impact of land use changes on peak flows was not taken into consideration when sizing the transverse drainage. It has been assumed that self-regulating measures will be incorporated into future development which will control the rate of flow discharging to the road corridor to no larger than present day conditions.

4.2 Model review

A review of the concept design models has been undertaken to ensure fit for purpose. The models were schematised to assess the flood capacity of the current drainage network and for designing a drainage network for the proposal. The main limitations of the modelling approach are as follows:

- DRAINS provides outputs on the hydraulic grade lines in pipes and pits, however, its channel modelling capacity is limited. Details of the water levels at the headwall of the culvert inlets are available from the model; however peak water levels at the site boundary are not available.
- The DRAINS models were not schematised to model the PMF event. This is a significant flood event which will result in cross catchment flows between a number of culvert locations and across various catchment features, such as the M4 Motorway. This cross catchment flow has not been fully schematised in the model.
- HEC-RAS, a widely used one-dimensional (1D) model, has been used to model watercourses in the southern section of the proposal. The defining assumption for 1D modelling is that only the forces, velocities, and variations in the stream direction (upstream and downstream) are significant, and that those in the transverse or lateral direction are negligible. The flood mechanisms in this location are complex and a coupled 1D/2D hydraulic model would provide a better representation of the interaction of flows in this location.

It is recommended that coupled 1D/2D hydraulic modelling be undertaken for a more detailed representation of the interaction of flows between culverts and the entire route of the proposal at the detailed design stage. This will help refine the flows arriving at the culverts, conveyance through the culverts, and temporary ponding at culvert inlets plus provide a more accurate assessment of potential flood impacts.

4.3 Modelling software

Hydrological and hydraulic modelling software has been used to assess the hydrological and hydraulic conditions for the existing environment and to inform and assess the proposed design. Table 4-1 lists the software programs used for the analysis.

Table 4-1: Modelling software used for the hydrological and hydraulic analysis

Task	*Modelling software*
Pavement drainage – hydrology and hydraulics	DRAINS using RAFTS hydrology for rural catchments and ILSAX hydrology for roads and urban areas.
Transverse drainage – hydrology and hydraulics	HEC-RAS/DRAINS using RAFTS hydrology

DRAINS is a widely used piped drainage network design and analysis software package. It routes rainfall excess through a drainage network. Predominantly it t utilises ILSAX hydrology. It has add-on packages that enable it to generate hydrographs using RAFTS and WBNM hydrological routing models.

HEC-RAS is a widely used one-dimensional steady flow hydraulic model designed for channel flow analysis and floodplain determination. The models are typically arranged with branches or channels representing the flow paths and cross-sections and structures defining the conveyance characteristics of the branch.

4.4 Modelling approach

HEC-RAS has been used to determine behaviour of flooding in larger waterways located at the southern end of the study area. Constructed drainage features in this area include:

- Culvert C6730 (The Northern Road 180 metres south of Glenmore Parkway and Culvert C6890 - Glenmore Parkway 200 metres west of The Northern Road
- The drainage easement downstream of culvert C6730
- Property accesses constructed over the watercourse to the west of The Northern Road south of Penrith Golf and Recreation Club
- The size of these culverts, complexity of flooding, and the potential flood risk to surrounding properties has determined the modelling approach adopted for the above locations.
- The remaining culvert locations were modelled in DRAINS using RAFTS hydrology for modelling external catchment runoff and ILSAX hydrology model for pavement surface drainage.
- The pavement drainage system north of Maxwell Street discharges directly into Council drainage system. The pavement drainage system in this location has been modelled using Drains Software Package.

4.5 Data used in model development

4.5.1 Digital elevation models

Digital Elevation Models (DEMs) covering the entire study area were developed from LiDAR, Corridor survey data and Concept Design Stage Road model The DEM was used to delineate the catchment and sub-catchment boundaries and determine equal area slopes used in the hydrological model. The DEM Is also used to extract the waterways cross section area used to develop the hydraulic model geometry.

4.5.2 Aerial imagery

Aerial imagery was supplied for the entire study area. Aerial imagery has been used to inform the development of the hydrological and hydraulic models, including land uses and catchment imperviousness.

4.5.3 Structure surveys

Topographical surveys were undertaken of the various transverse culverts along the route to determine the culvert size, invert levels and dimensions (refer to Table 2.1).

4.5.4 Concept design data

Information on the operational drainage layout and road levels and alignment has been determined from the proposed concept design drawings.

4.5.5 Rainfall IFD Data

Rainfall intensity data required for the drainage design and analysis has been obtained from the Bureau of Meteorology (BOM) website.

4.6 Hydrological Analysis

4.6.1 Pavement Drainage hydrology

ILSAX model within DRAINS has been used to generate runoff hydrographs. The parameters in Table 4-2 have been used in DRAINS.

Table 4.2 : DRAINS model parameters

Description	*Value*
Runoff Method	ILSAX
Pervious area depression storage	5 mm
Impervious area depression storage	1 mm
Soil type	Type 3
Pipe Roughness Coefficient (Colebrook-White) Manning's n for Concrete Pipes	0.60 0.013
Minimum Pavement Drainage Time of Concentration	5 minute
Times of concentration calculated by:	Kinematic Wave equation
Pit Blockage Factors: Pits on grade Pits on sag	 20% 50%

Where the pavement drainage catchments drain to transverse locations, the flows from the pavement drainage have been lumped to the transverse drainage point. Further information on the various drainage design components and their connectivity is provided in Section 3.4.2.

4.6.2 Transverse Drainage hydrology

Hydrological modelling for transverse drainage was carried out using a RAFTS hydrology built-in within DRAINS. Transverse drainage hydrological model development involved determining catchment areas, catchment characteristics such as slopes, roughness, time of concentration, rainfall intensities, losses and then calculating peak flow rates from the drainage catchments that contribute flows to the transverse drainage. Catchments areas and characteristics were derived from topographical data (LiDAR data), aerial photos and concept design data. The initial and continuing losses were adopted from Walsh 1991, which are within those bounds recommended in Australian Rainfall and Runoff (AR&R) (Engineers Australia 1987). Details of the various RAFTS model parameters are provided in Table 4.3.

Table 4.3 : RAFTS model parameters

Description	*Adopted Value for 100 year ARI*	*Adopted Value for the PMF*
Impervious Areas Initial Loss	1 mm	0 mm
Impervious Areas Continuing Loss	0 mm/hr	0 mm/hr
Pervious Areas Initial Loss	10 mm	0 mm
Pervious Areas Continuing Loss	2.5 mm/hr	1.0 mm/hr
Bx (storage coefficient)	1.0	1.0

Hydrological models were developed for the following scenarios:

- Existing scenario. This scenario was based on the existing environment.
- Interim scenario. This scenario refers to the period of time between the completion of the proposal and the other planned upgrades of The Northern Road
- Operational phase. This scenario includes The Northern Road upgrade. In the southern portion of the study area, catchment flows are based on The Northern Road being fully upgraded. As discussed in Section 1.2, the proposed upgrade of The Northern Road from Glenmore Parkway to Jamison Road is planned to be constructed before other planned upgrades of The Northern Road, directly south of the study area. The assessment has therefore been undertaken based on the fully upgraded scenario to account for the increase in the imperviousness of the catchments contributing to the southern portion of the study area.

4.6.3 Rainfall IFD Data

Rainfall intensity frequency duration (IFD) data required for the drainage design and analysis for the project has been obtained from the Bureau of Meteorology (BOM) website. The 1987 IFD design rainfall data has been used for this analysis.

The intersections of The Northern Road and Jamison Road and The Northern Road and M4 were selected from the BOM data locations. It has been found that the rainfall intensity at The Northern Road and Jamison Road is the highest and the IFD data at this location has been selected as the location for BOM data for the hydrological analysis. The IFD values adopted for the project are detailed in Table 4.4

Table 4.4 : IFD data

Parameter	*2 year*	*50 year*
1 Hour Rainfall Intensity (mm/hr)	29.55	59.37
12 Hour Rainfall Intensity (mm/hr)	6.66	13.23
72 Hour rainfall Intensity (mm/hr)	1.92	4.51
Skewness G	0.03	
F2	4.30	
F50	15.79	

Estimates of the Probable Maximum Precipitation (PMP) for the study area up to 6 hours duration were prepared using the procedures given in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (BOM, 2003).

4.6.4 Temporal patterns

Temporal patterns for AR&R Zone 1 have been used for the hydrological analysis for the 100 year ARI event. The AR&R 1987 temporal pattern was used based on for consistency with the IFD data. The temporal pattern for the PMP event was sourced from BOM (2003).

4.6.5 Model simulations

The storms modelled include both the 100 year ARI and PMF. The modelled storm durations ranged from 5 minutes to 72 hours for the 100yr ARI storm event. 15, 30, 45, 60, 90, 180 and 360 minute durations storm were modelled for the PMF event. The critical storm duration for the cross-drainage catchments was less than two hours.

4.6.6 Model results

The peak discharges at the transverse drainage culverts and road drainage outlets are provided in Table A1 Appendix A for both the existing conditions and the operational phase. Details of flows at the outlets are provided in Table A2.

In locations where the increase in flows was greater than 3% for the 100 year ARI storm event, on-site detention was implemented to capture and control the release of flows. The model results in Table A.2 show that on-site detention reduces flows and there are no downstream locations where the increase in flow is greater than 3% or impacting private properties.

The increased road imperviousness and culvert upgrades indicate that there has not been a significant change in the upstream flows at the majority of locations. A significant reduction in flow was observed at culvert C6930 and culvert C7620.

There is a decrease in flows for the operational phase at culvert C6730 which is associated with a redistribution of flows in this area. This redistribution of flow results from culvert upgrade works planned as part of the full upgrade of The Northern Road. Schematic diagram showing flow distribution during the existing scenario and operational condition is shown in Figure 4.1 and figure 4.2.

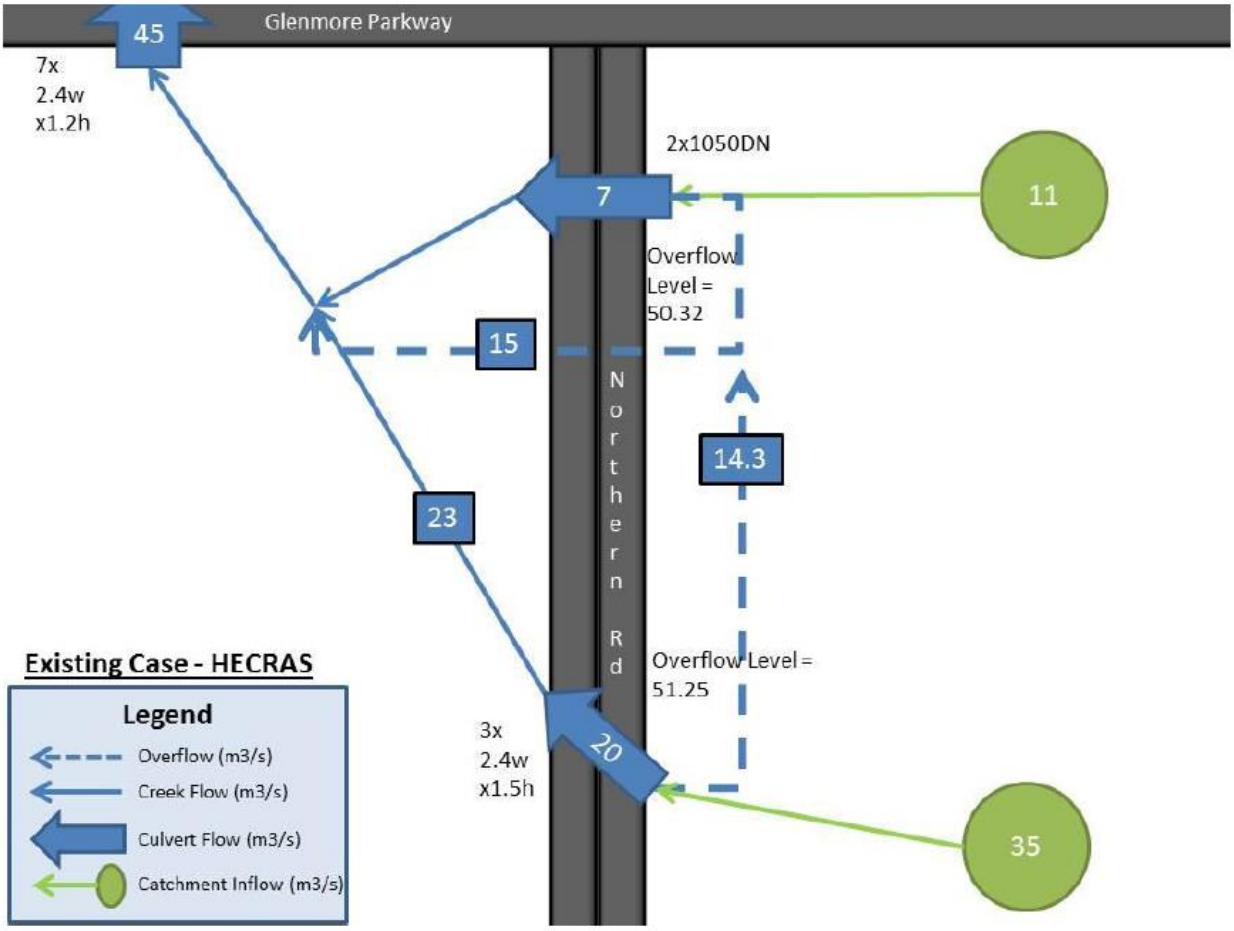


Figure 4.1 Existing100yr ARI flow distribution between Road Chainage 6200 and 7000

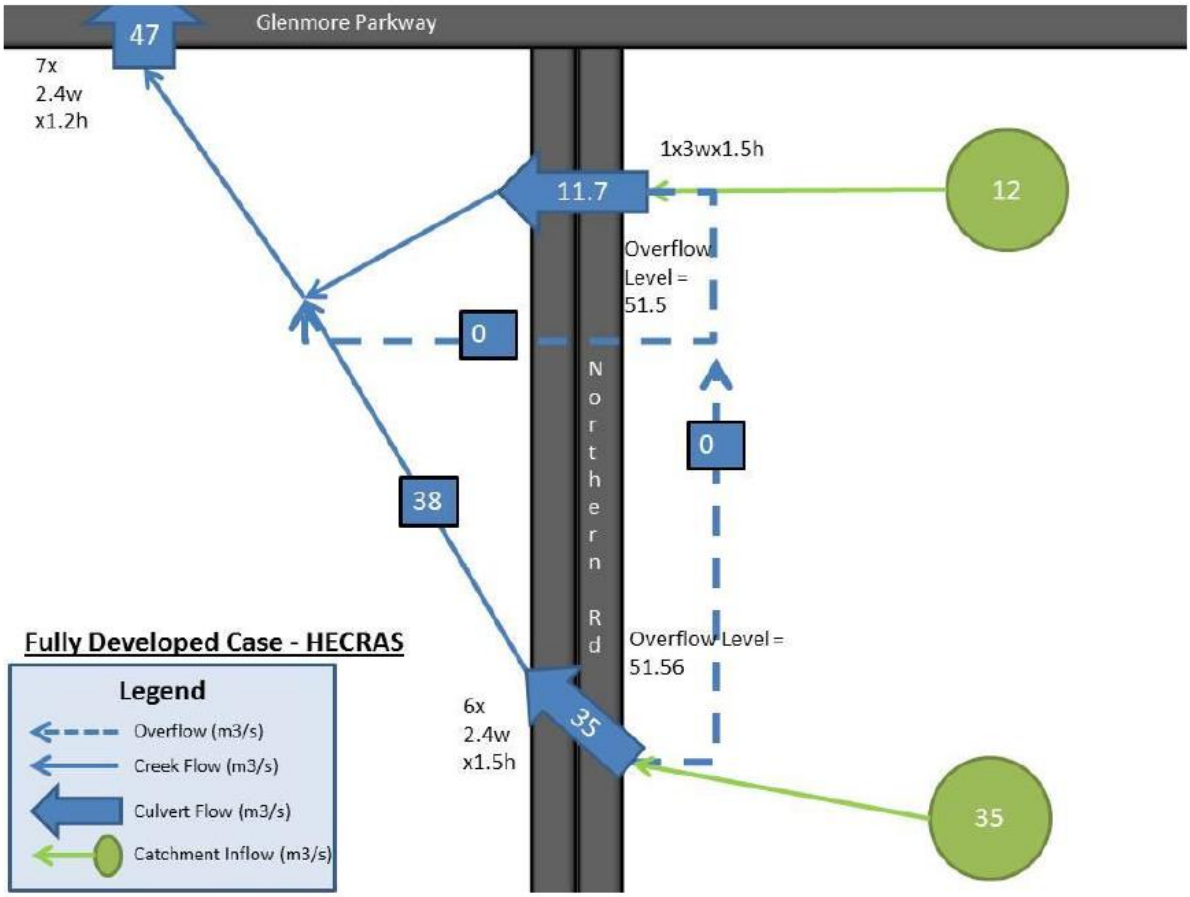


Figure 4.2 Fully developed 100yr ARI flow distribution between Chainage 6200 and 7000

In the interim scenario, the proposed upgrade of The Northern Road from Glenmore Parkway to Jamison Road would be built with all the drainage upgrades necessary to facilitate the construction of the other planned upgrades of The Northern Road. In the southern section of the study area, culvert C6730 will be upgraded to cater for the 100 year ARI flows based on The Northern Road being fully upgraded. The flows for culvert C6730 and C6890 for existing and interim conditions are listed in Table 4.5 and show the altered flow distribution in the vicinity of culverts C6280 and C6730 during the interim stage.

Table 4.5 : Interim culvert flow impacts

ID	100 year ARI flow (m^3/s)		Comment
	Existing	Interim	
C6730	6.96	14.97	Significant increase due to culvert upgrade
C6890	45.2	44.73	Minor reduction

4.6.7 Model verification

In the absence of any stream flow gauge data or historic flood level data to calibrate the DRAINS and RAFTS models, the model results were validated against peak flow calculated using the Probabilistic Rational Method (PRM) for representative catchments. The assessment was undertaken for the 100 year ARI event based on the proposed scenario model The results of this model verification are presented in Table A.2 and have been found to be of the same order of magnitude as those obtained from the RAFTS model.

4.7 Hydraulic Modelling for Transverse Drainage

4.7.1 Model development

A HEC RAS model was developed for the watercourses and constructed drainage features in the south of the study area. Three model scenarios were generated as follows:

- Existing scenario. This scenario was based on the existing environment.
- Interim scenario. This scenario was used to to assess hydraulic performance for the 'interim condition' as described in Section 1.2.
- Operational phase. This scenario included the proposed Northern Road upgrade.

DRAINS has been used to model the remaining transverse drainage locations.

4.7.2 Model schematisation

The channel and floodplain geometry for the HEC RAS model has been defined using cross sections derived from the LiDAR DEM, field survey data and the design data. Cross sections were schematised upstream and downstream of the culverts to define the expansion and contraction zones and along the modelled channels to adequately define changes in geometry and channel bed slope.

Details of the culvert type, material, dimensions and invert levels for each crossing have been based on survey data and the concept design data as detailed in Table 2.1 and Table 3.3 respectively. Culvert entry and exit losses have been informed by aerial imagery, structure photographs and the concept design data. The HEC RAS and DRAINS manuals have been used to estimate appropriate losses for the various culvert types.

Aerial imagery and culvert data has been used to define appropriate culvert, channel and floodplain Manning's n values within the HEC RAS mode and are based on typical values from AR&R. Table 4.6 sets out the values adopted in the HEC RAS model.

Table 4.6 : Adopted Manning's n values for the HEC RAS model

Manning's n value	*Model Feature*	*Description*
0.1	Channel and floodplain	Densely vegetated areas
0.05	Channel and floodplain	Scattered brush, heavy weeds
0.012	Channel and culverts	Concrete lined channels and concrete culverts

4.7.3 Boundary conditions

The HEC RAS model was run in steady-state mode with inflow boundary conditions based on the DRAINS and RAFTS hydrological model data. The peak flows used in the model for the existing scenario and operational phase are presented I Table A1. The interim condition runs were based on the interim scenario flows presented in Table 4.5.

A normal depth boundary was used to define the downstream boundary condition and was based on the channel slope over the modelled reach length.

As discussed in Section 4.3, DRAINS and RAFTS hydrology are integrated and separate boundary conditions are not required.

4.7.4 Model simulations

For culvert C6730 (180 metres south of Glenmore Parkway) and the Glenmore Parkway culverts, the DRAINS and HEC-RAS models have been run for the 100 year ARI and PMF design flood events for the critical storm duration. For the 100y ARI event the 2 hour rainfall event produces the largest flow arriving at culvert C6730. The peak flows from the DRAINS model were then entered into the HEC-RAS model for simulation.

For all other transverse drainage culverts from Glenmore Parkway to Jamison Road the concept design DRAINS model only included the 100y ARI storm events. The 2hr rainfall event was predominantly the critical duration for many of the culvert catchments.

Where detention basins were downstream of a culvert, the detention basin outlets were checked for performance with the 10y and 100y ARI peak flows to manage nuisance flooding and peak flood impacts.

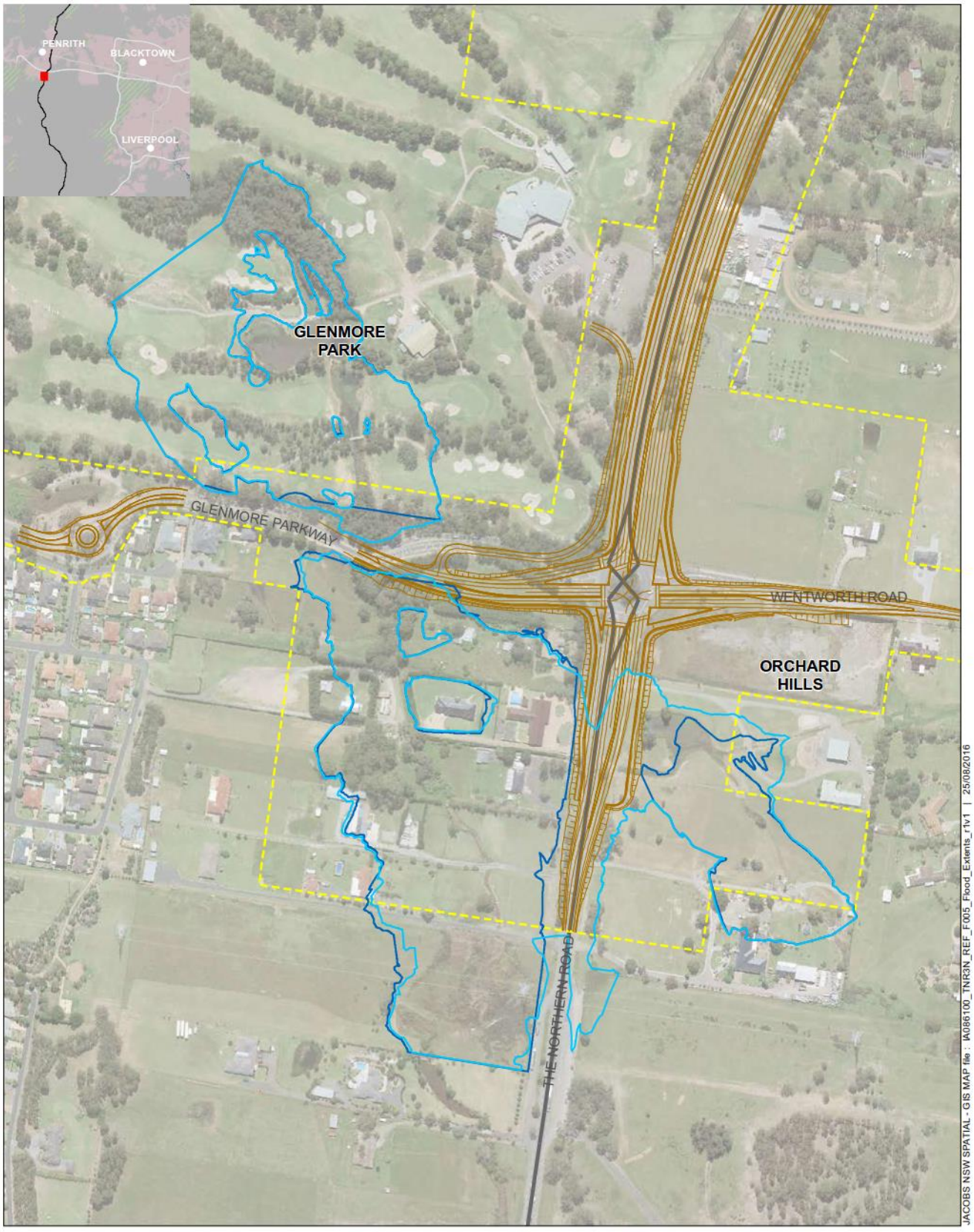
4.7.5 Model Results

The flood model results for the 100 year ARI are presented in Table A4. The table provides information on modelled flood levels and a comparison to the design road levels to demonstrate the flood immunity of The Northern Road for the existing and interim scenarios and the operational phase.

Flood levels at the site boundary are provided in the southern section of the study area where HEC RAS model results are available. DRAINS provides outputs on the hydraulic grade lines in pipes and pits. The DRAINS model results have been used to determine the peak head water levels upstream of the culvert inlets in areas not modelled by the HEC RAS model. Potential flood level impacts at the study area boundary have been inferred from afflux values at the upstream culvert inlets and changes to the downstream flows values discussed in Section 4.6.6.

Flood mapping has been prepared for the 100 year ARI event for the existing scenario and operational phase as shown in Figure 4.1. The flood mapping has been prepared for the southern portion of the proposal within the domain of the HEC-RAS model. The complexity of flooding, and the potential flood risk to surrounding properties has necessitated the preparation of flood maps for this area.

The flood maps indicate that there are some differences in extents between the existing scenario and operation phase, particularly upstream of The Northern Road. This is consistent with the afflux changes reported in Table A4, which show a 0.73 metre reduction in flood levels upstream of Culvert C6730 for the 100 year ARI event.



Legend

- The Northern Road Upgrade between Glenmore Parkway and Jamison Road
- The Northern Road (Existing)
- Study area
- Existing 100y flood extent
- Proposed 100y flood extent

0 100 200 m

N

Note:
Flood extents are approximate only and areas located outside the flood extents may be subject to flooding. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

Figure 4-1 | Existing and proposed 100 year flood extents

The flood map indicates that are a number of properties at risk of flooding within or adjacent to the study area boundary east and west of The Northern Road. The maps indicate that these properties are at risk of flooding for both the existing scenario and operational phase. However, in the absence of floor level information it is not knows whether the dwellings would be subject to inundation. For the operational phase, the model results indicate a reduction in flood levels upstream of culvert C6730 with a marginal increase in flood levels downstream of culvert C6730. For the interim scenario, the model results indicate a maximum afflux increase of 250 mm upstream of culvert C6730 with a marginal increase in flood levels downstream of this culvert. The model results show that drainage and catchments covering the northern portion of the proposal are not prone to flooding and the risk of flooding in these areas is expected to be low.

Results for the PMF event have been provided for the southern portion of the proposal within the domain of the HEC-RAS model as shown in Table 4.7. Due to the extreme nature of the PMF event, a number of overland flow paths are activated which are not represented in the DRAINS model. Flood level values extracted from the DRAINS model for the PMF event are therefore likely to be unreliable and are not presented in this report. As discussed in Section 4.2, it is recommended that coupled 1D/2D hydraulic modelling be undertaken for a detailed representation of the interaction of flows between culverts and the entire route of the proposal at the detailed design stage.

Table 4.7 : PMF levels for the southern portion of the proposal

Culvert ID	*Road crossing*	*Operational Road level (m AHD)*	*Water level at project boundary*		
			Existing (m AHD)	*operational (m AHD)*	*Afflux – change (m)*
C6730	The Northern Road 180 m south of Glenmore Parkway	51	54.77	54.77	0
C6890	Glenmore Parkway 200 m west of The Northern Road	48.16	49.88	49.95	+0.07

The model results indicate that The Northern Road and Glenmore Parkway would be inundated at the culvert crossings in this storm event.

5. Potential Flood Impacts

5.1 Construction Phase

A number of construction activities have the potential to impact flooding. The inclusion of any temporary fill within the floodplain (e.g. stockpiles) would reduce floodplain storage, which can result in increased flood elevations. Temporary crossings of the watercourses may also be required during the construction and have the potential to impact on flooding. Temporary compound sites would be required to enable the construction of the project and would include stockpiling of material and assets required to complete the construction. Construction phase impacts to flooding have not been modelled as part of the concept design assessment.

If stockpiles are to be located within the floodplain, the obstruction of flow paths and loss of floodplain storage has the potential to cause flooding impacts. Loose material stored within the floodplain has the potential to be mobilised during a flood, which can become a hazard during a flood, and may also contribute to blockage of hydraulic structures.

Temporary watercourse crossings may be required for some of the watercourses traversed by the project to facilitate construction activities. Temporary watercourse crossings may result in the following potential impacts:

- Disturbance of the watercourse bed and banks, resulting in erosion and sedimentation
- Partial obstruction of low flows, resulting in minor modification of downstream flow
- Scour of the bed near the culvert inlets and outlets.

The proposed compound sites (refer to Section 3.4.1 for further information) are shown on Figure 3.1. The compound site boundaries have been compared to modelling results discussed in Section 4 and flood maps prepared as part of the Penrith Overland Flow Flood "Overview Study" (Cardno, 2006). The model results and flood maps indicate that the majority of the compounds sites are not at risk of flooding for the 100 year ARI event. There is a risk of flooding affecting two compound sites:

- The southeast corner of the compound site at the intersection of The Northern Road and Wentworth Road.
- A drainage line runs through the proposed compound adjacent to culvert C6730 which poses a flood risk. Ponding of flood water upstream of culvert C6730 also results in flooding at the site.

To ensure the benefits of the flood mitigation measures included in the design are realised early in the development of the proposal, it is recommended that these measures are implemented during early stages of the construction phase.

5.2 Interim and operational phase

During the interim period and the proposal's operational phase there is potential for impacts on existing flood behaviour, primarily due to:

- Increased impervious areas causing an increase in surface runoff volumes and peak flows
- Drainage and culvert upgrades altering existing flow distributions
- The widened road embankment encroaching into the floodplain causing a reduction in channel conveyance and floodplain storage.

Afflux at an upstream location and difference in peak discharge at downstream project boundary are shown in Tables 5.1 and Table 5.2 respectively. Discussion on the impacts is provided in the comments column of the Tables. .

Table 5. 1: Modelled transverse drainage afflux for the 100 year ARI event

Culvert ID	Road crossing	Operational Road level (m AHD)	Water level at culvert inlet			Comments
			Existing (m AHD)	Operational (m AHD)	Afflux – change (m)	
C6380	Wentworth Road, 310 m east of The Northern Road	57.85	57.45	57.45	0.00	No additional flood impacts. Culvert upgrades are not proposed for this location. Road has flood immunity for 100 year ARI storm event. The upstream build-up of storm water is contained with the road reserve
C6730	The Northern Road 180 m south of Glenmore Parkway	51	50.56	49.83	-0.73	As shown in Figure 4.1 and Figure 4.2, upgrading Culvert C6280 has resulted in a significant quantity of flow being redirected away from culvert C6730. The discharge through this culvert has reduced by above 50%. This has resulted in decrease of an afflux by 0.73 m upstream of the culvert and hence site upstream boundary. As shown in Table 5.1 peak flow at site downstream boundary has reduced by over 50% as well. This will result in reduced afflux at the downstream boundary. The Northern Road has flood immunity for a 100 year ARI storm event. Improved conveyance downstream reduces peak flood levels along the drainage easement and limits the increase in afflux at the culvert to less than 240 mm in the interim condition. The road is not overtopped in the smaller events for the interim case and has 50 year flood immunity which is an improvement over the existing scenario which sees The Northern Road overtop in a 10 year ARI storm event.

Culvert ID	Road crossing	Operational Road level (m AHD)	Water level at culvert inlet			Comments
			Existing (m AHD)	Operational (m AHD)	Afflux – change (m)	
C6890	Glenmore Parkway 200 m west of The Northern Road	48.16	46.94	46.96	+0.02	Modelling has indicated that there would be minor afflux impact upstream of this culvert. This is attributed to reduced flood flow path as all the flows are diverted through the upgraded culvert C6280. Afflux has increased by +0.02 m at the road reserve boundary. Potential flood impacts on properties located upstream of this culvert may be expected however further assessment with potential upgrade of the upstream channel and cleaning of the existing culvert silt during detailed design to avoid any afflux impacts. These potential measures should be investigated during detailed design to ensure no afflux impacts are introduced to surrounding properties.
C6960	Wentworth Road at intersection with The Northern Road	53.9	N/A	51.42	N/A	No culvert crossing in the existing scenario at this location. A depressed inlet is provided at this location. The flood level in the proposed scenario is 2.5 m below proposed road level. The road has flood immunity for 100 year ARI.
C7115	Cross Road 150 m north of Wentworth Road	61.08	60.38	60.37	-0.01	Minor reduction in flood impacts between existing scenario and the operational phase The road has flood immunity for 100 year ARI.
C7340	Cross Road 275 m north of Wentworth Road	60.22	59.38	59.57	0.19	The increase in afflux upstream of C7340 is due to the raised road embankment. The increases are expected to be contained within the existing road reserve. The existing scenario water level is lower as the existing road level is lower and is frequently inundated.

Culvert ID	Road crossing	Operational Road level (m AHD)	Water level at culvert inlet			Comments
			Existing (m AHD)	Operational (m AHD)	Afflux – change (m)	
						The road has flood immunity for 100 year ARI.
C7380	The Northern Road 195 m south of Garswood Road	49.23	49.41	48.88	-0.52	There will be a reduction in upstream afflux, due to an increase in culvert size. The existing road level was low. Modelling indicates that it is overtopped during frequent storm events. There is no change in peak flow during the operational phase and hence no increase in afflux at downstream boundary. The road has flood immunity for 100 year ARI. Peak flow at the downstream boundary has reduced by 1%
C7590	Cross Road 425 m north of Wentworth Road	63.19	62.39	62.32	-0.07	There will be a reduction in upstream afflux, due to an increase in culvert size. This would result in an increase in downstream afflux which would be contained within the road reserve. The road has flood immunity for 100 year ARI.
C7620	Homestead Road 75 m east of The Northern Road	53.7	52.59	52.46	-0.13	There will be a reduction in upstream afflux, due to an increase in culvert size. This would result in an increase in downstream afflux which would be contained within the road reserve. The road has flood immunity for 100 year ARI.
C7860	Cross Road at Homestead Road	61.4	61.39	61.53	0.14	The increase in afflux upstream of C7860 is due to the raised road embankment. The increases are expected to be contained within the road reserve, with minimal increase in upstream flood extent. The local road is overtopped for 100 year ARI. As shown in Table 5.2 Culvert C7860 has downstream peak flow reduced by 5. This will result in reduced afflux downstream.

Culvert ID	Road crossing	Operational Road level (m AHD)	Water level at culvert inlet			Comments
			Existing (m AHD)	Operational (m AHD)	Afflux – change (m)	
C7880	M4 Western Motorway 250 m east of The Northern Road (bridge)	60.16	57.98	58.28	0.29	The increase in afflux at the culvert inlet reflects the upstream extension to the existing culvert. The increase will be accommodated within the inlet works and M4 road reserve boundary. The M4 has flood immunity for 100 year ARI.
C8040	The Northern Road, northern approach to M4 Bridge	63.57	55.25	55.26	0.01	Negligible afflux impacts between existing scenario and the operational phase. The inlet works would be shaped to avoid any afflux impacts upstream of the inlet. As shown in Table 5.2 there is no increase in peak flow at the downstream boundary and hence no increase in downstream afflux. The road has flood immunity for 100 year ARI.
C8200	The Northern Road, 200 m north of M4 interchange	58.19	57.11	57.12	0.01	Negligible afflux impacts between existing scenario and the operational phase. As indicated in Table 5.2 the peak flow at the downstream boundary of C8200 has not changed and hence no increase in afflux downstream. The road has flood immunity for 100 year ARI.
C8480	Frogmore Road adjacent to The Northern Road	60.92	60.23	59.72	-0.51	There will be a reduction in upstream afflux, due to an increase in culvert size. However, as the road level was lower in the existing scenario runoff overtopped the road and joined flow downstream of this culvert. Modelling has indicated that peak flow has reduced by 4% at downstream boundary and hence reduced afflux. The road has flood immunity for 100 year ARI.

Culvert ID	Road crossing	Operational Road level (m AHD)	Water level at culvert inlet			Comments
			Existing (m AHD)	Operational (m AHD)	Afflux – change (m)	
C8960	The Northern Road, at Aspen Street	62.29	61.60	60.73	-0.87	There will be a reduction in upstream afflux, due to an increase in culvert size. The existing road level is low and runoff overtopped during frequent events. There was less storage upstream in the existing case. Peak flow has reduced by 5% during the operational phase. Downstream afflux will reduced due to reduced peak flow. The road has flood immunity for 100 year ARI.
C9035	Castle Road adjacent to The Northern Road	63.38	62.57	62.22	-0.35	There will be a reduction in upstream afflux, due to an increase in culvert size. Discharge at the downstream site boundary has increased by 1.5% which is less than 3% peak discharge increase by Penrith City Council. Downstream reshaping of the outlet near Aspen Street would be undertaken to contain any surcharge flows from the culvert. This would improve the existing scenario where flows currently impact surrounding properties. The road has flood immunity for 100 year ARI.

Table 5.2 : Modelled downstream flows for existing and operational scenarios

ID (refer to Figure 3.2)	Drainage feature	Location	Existing scenario		Operational scenario		Percentage difference	
			100 year ARI	PMF	100 year ARI	PMF	100 year ARI	PMF
C6730	Transverse drainage culvert	The Northern Road 180 m south of Glenmore Parkway	21.8	194	11.7	165	-54	-15
C6380	Transverse drainage culvert	Wentworth Road, 310 m east of The Northern Road	0.41	2.23	0.41	2.23	0	0
C6890	Transverse drainage culvert	Glenmore Parkway 200 m west of The Northern Road	45.2	318	46.3	326	2	3
C6960	Transverse drainage culvert	Wentworth Road at intersection with The Northern Road	0.91	5	0.91	5	0	0
C7115	Transverse drainage culvert	Cross Road 150 m north of Wentworth Road	1.72	11.7	1.88	11.7	2	0
C7340	Transverse drainage culvert	Cross Road 275 m north of Wentworth Road	1.88	12.1	1.88	12.1	0	0
C7380	Transverse drainage culvert	The Northern Road 195 m south of Garswood Road	16.3	97.7	16.2	99.6	-1	2
C7590	Transverse drainage culvert	Cross Road 425 m north of Wentworth Road	0.745	4.43	0.768	4.43	3	0
C7620	Transverse drainage culvert	Homestead Road 75 m east of The Northern Road	0.868	5.46	0.616	3.9	-29	-29
C7860	Transverse drainage culvert	Cross Road at Homestead Road	1.77	9.33	1.69	9.33	-5	0
C7880	Transverse drainage culvert	M4 Western Motorway 250 m east of The Northern Road (bridge)	1.99	16.8	1.99	18.9	0	13
C8040	Transverse	The Northern Road, northern approach to M4	11.1	28.3	11.1	28.3	0	0

ID (refer to Figure 3.2)	Drainage feature	Location	Existing scenario		Operational scenario		Percentage difference	
			100 year ARI	PMF	100 year ARI	PMF	100 year ARI	PMF
	drainage culvert	Bridge						
C8200	Transverse drainage culvert	The Northern Road, 200 m north of M4 interchange	4.27	10.9	4.27	13.5	0	24
C8480	Transverse drainage culvert	Frogmore Road adjacent to The Northern Road	1.78	11.1	1.7	10.1	-4	-9
C8960	Transverse drainage culvert	The Northern Road, at Aspen Street	14.5	54.4	14.7	54.4	1.5	0
C9035	Transverse drainage culvert	Castle Road adjacent to The Northern Road	1.62	7.91	1.54	7.91	-5	0
C9280*	Transverse drainage culvert	The Northern Road, near intersection of Maxwell Street/ Bringelly Road	0.91	5	0.91	5	2	3

*Culvert C9280 will be decommissioned as part of the proposal.

Hydrologic and hydraulic models were developed to determine discharge and flood levels during the existing scenario and the interim & operational phase scenarios. Difference in discharge and/or flood level at point of interest was determined to assess the potential impact of the proposal.

The impact assessment has been undertaken for the interim and fully operational conditions.

The modelling results also show that minor increases in flows for the 100 year ARI as a result of the proposal are likely at some locations. These increases in flows are deemed to be minor and acceptable and contained with the proposed road reserve.

The modelled afflux on the upstream inlet of each cross-drainage culvert for the 100 year ARI event is detailed in Table A.4. Information is also provided on the change in flood levels at the site boundary within the domain of the HEC RAS model.

The results indicate the locations where there would be increased afflux greater than ±0.01 metres. Impacts in the range of ±0.01 metres are considered within the model tolerance. The following locations have adverse flood impacts as a result of the proposal:

- There would be a 240 mm increase in flood levels upstream of culvert C6730 (south of Glenmore Parkway) for the 100 year ARI event for the duration of the interim scenario. This increased flood level would not impact any dwellings and would only be temporary (during interim period) until the adjoining planned upgrades of The Northern Road to the south are built.
- There would be a 0.02 metre increase in flood levels upstream of culvert C6890 (Glenmore Parkway 200 metres west of The Northern Road) for the 100 year ARI event in the interim scenario and operational phase. There is a potential impact to properties which will need to be evaluated further during detailed design.
- The proposed upgrade of Cross Road will result in raised road levels. This will reduce frequency of the road flooding, but will result in water ponding at the upstream side of the road. The modelling indicates that the afflux upstream of culverts C7340 and C7860 on Cross Road will increase. The effect of these increases would be contained within the site boundary and not affect private property.
- There would be a 0.29m increase in flood levels upstream of culvert C7880 (M4 Western Motorway 250 metres east of The Northern Road) for the 100 year ARI event. The increase in afflux at the culvert inlet reflects the upstream extension to the existing culvert. The increase is at grade, and will be accommodated within the inlet works and proposed road reserve of the M4 Motorway.

The model results also indicate that there is a flood risk to The Northern Road at Culvert C7860 (Cross Road at Homestead Road) for the 100 year ARI event. Cross Road is overtopped with flood depth of 0.13m. Cross Road is not considered an arterial road, this overtopping is considered reasonable given the minor significance of the road corridor.

6. Safeguards and Management Measures

6.1 Construction phase

Based on the flood maps prepared as part of the Penrith Overland Flow Flood "Overview Study" and the model results from this study, there is a risk of flooding affecting two of the proposed compound sites. Appropriate mitigation measures against construction phase flood impacts include locating stockpiles and other site material in areas away from flood flow paths, and preferably where peak flood depths and velocities are likely to be low.

6.2 Interim phase

Culvert C6730 on The Northern Road, south of Glenmore Parkway, is predicted to cause an increase in flood levels upstream of the road during the 100 year ARI event, during the interim phase. This increased flood level would not impact any property and would only be temporary, until the adjoining planned upgrades of The Northern Road to the south are built. This phase is to be communicated to affected property owners.

6.3 Operational phase

The existing flow regimes have been retained as far as practicable. Some localised increases in velocity are predicted to occur downstream of some culverts. Such increases would be managed through scour protection measures at the culvert outlets. Minor increases in flow are likely to occur at some locations. However, these are deemed to be minor and within an acceptable range of less than 3% increase in downstream flows. In the instances of flow increases, outlet treatment measures would be introduced to control the extent of flows and avoid private property impacts.

The proposed culverts have been assessed for afflux. The majority would comply with Roads and Maritime environmental requirements. There are a number of locations where increases in afflux have been identified for the operational phase:

- Upstream of culvert C6890 (Glenmore Parkway 200 metres west of The Northern Road) there would be a 0.02 metre increase in flood levels. A dwelling floor level survey should be undertaken to determine the potential impact on dwellings resulting from any increase in flood levels in this area.
- The modelling indicates that the afflux upstream of culverts C7340 and C7860 on Cross Road will increase. The effect of these increases is likely to be contained close to the road reserve boundary and not affect property. Design of the culverts C7340 and C7860 should be optimised during detailed design to reduce the flood impacts.

7. Recommendations

In additional to the safeguards and management measures discussed in Section 6, the following measures are also recommended for detailed design stage:

- Coupled 1D/2D hydraulic modelling should be undertaken to provide a detailed representation of the interaction of flows between culverts and the development proposal at the detailed design stage. This will help refine the flows arriving at the culverts, conveyance through the culverts, and temporary ponding at culvert inlets plus provide a more accurate assessment of potential flood impacts.
- Further assessment of the OSD is required as insufficient information on Council's stormwater network has been made available to accurately assess this flood mitigation measure and comply with Roads and Maritime's environmental requirements.

8. References

Austroads, 2013, *Austroads Guide to Road Design Part 5*

Bureau of Meteorology, 2003, *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method*

Cardno Lawson Treloar, 2006, *Penrith Overland Flow Flood Overview Study*

Cardno, 2015, *Penrith CBD Overland Flood Study*

DIPNR, 2005, *Floodplain Development Manual: the management of flood liable land*

Engineers Australia 1987, *Australian Rainfall and Runoff – A guide to flood estimation*, Reprinted in 2001, ACT, Australia.

Engineers Australia 2013, *Australian Rainfall and Runoff Revision Project 2: Spatial Patterns of Design Rainfall, Final Report*, ACT, Australia

Engineers Australia, 1987, *Australia Rainfall and Runoff: A Guide to Flood Estimation*

Penrith City Council, 2014, *Penrith Development Control Plan 2014*

US Army Corps of Engineers 2010, *HEC-RAS River Analysis System Hydraulic Reference Manual Version 4.1*

Walsh, MA, Pilgrim, DH & Cordery, I 1991, 'Initial Losses for Design Flood Estimation in New South Wales', International Hydrology & Water Resources Symposium, Perth, Australia.Worley Parsons, 2015, *South Creek Flood Study*

Appendix A. Model Results

Table A.1 : Modelled downstream flows for existing and operational scenarios

ID (refer to Figure 3.2)	Drainage feature	Location	Existing scenario		Operational scenario		Percentage difference	
			100 year ARI (m3/s)	PMF (m3/s)	100 year ARI (m3/s)	PMF (m3/s)	100 year ARI	PMF
C6730	Transverse drainage culvert	The Northern Road 180 m south of Glenmore Parkway	21.6	194	11.7	165	-54	-15
C6380	Transverse drainage culvert	Wentworth Road, 310 m east of The Northern Road	0.41	2.23	0.41	2.23	0	0
C6890	Transverse drainage culvert	Glenmore Parkway 200 m west of The Northern Road	45.2	318	46.3	326	2	3
C6960	Transverse drainage culvert	Wentworth Road at intersection with The Northern Road	0.91	5	0.91	5	0	0
C7115	Transverse drainage culvert	Cross Road 150 m north of Wentworth Road	1.72	10.6	1.88	11.5	9	8
C7340	Transverse drainage culvert	Cross Road 275 m north of Wentworth Road	1.88	11.7	1.96	12.1	4	3
C7380	Transverse drainage culvert	The Northern Road 195 m south of Garswood Road	15.4	93.9	15.2	90.3	-1	-4
C7590	Transverse drainage culvert	Cross Road 425 m north of Wentworth Road	0.75	4.32	0.77	4.35	3	1
C7620	Transverse drainage culvert	Homestead Road 75 m east of The Northern Road	0.87	5.15	0.62	3.69	-29	-28
C7860	Transverse drainage culvert	Cross Road at Homestead Road	1.77	9.04	1.69	9.13	-5	1
C7880	Transverse drainage culvert	M4 Western Motorway 250 m east of The Northern Road (bridge)	1.83	16.5	1.83	16.5	0	0
C8040	Transverse drainage culvert	The Northern Road, northern approach to M4 Bridge	6.7	48.9	6.6	48.8	-1	0

ID (refer to Figure 3.2)	Drainage feature	Location	Existing scenario		Operational scenario		Percentage difference	
			100 year ARI (m3/s)	PMF (m3/s)	100 year ARI (m3/s)	PMF (m3/s)	100 year ARI	PMF
C8200	Transverse drainage culvert	The Northern Road, 200 m north of M4 interchange	3.57	21.44	3.3	19.62	-8	-8
C8480	Transverse drainage culvert	Frogmore Road adjacent to The Northern Road	1.78	11.1	1.7	10.1	4%	9%
C8960	Transverse drainage culvert	The Northern Road, at Aspen Street	13.4	50.6	13.4	50.6	0	0
C9035	Transverse drainage culvert	Castle Road adjacent to The Northern Road	1.62	7.9	1.62	7.9	0	0
C9280*	Transverse drainage culvert	The Northern Road, near intersection of Maxwell Street/ Bringelly Road	1.38	5	-	-	-	-
R9280	Road drainage outlet	The Northern Road, near intersection of Maxwell Street	-	-	0.259	5.09	-	-
R9430	Road drainage outlet	120 m north of The Northern Road and Maxwell Street/ Bringelly Road intersection	1.84	8.9	1.84	9.64	0	8
R9750	Road drainage outlet	The Northern Road opposite Mazepa Park	1.57	8.61	1.61	8.63	3	0
R10170	Road drainage outlet	Smith Street near the intersection with The Northern Road	1.05	4.48	1.08	6.026	3	35
R10420	Road drainage outlet	The Northern Road, 180 m south of intersection with Jamison Road.	0.56	2.76	0.57	3.417	3	24
R10620	Road drainage outlet	The Northern Road and Jamison Road intersection.	1.92	8.45	1.99	8.6	3	1.8

*Culvert C9280 will be decommissioned as part of the proposal.

Table A.2 :Hydrological model verification

ID (refer to Figure 3.2)	Drainage feature	Location	RAFTS	PRM	Percentage Difference
C6730	Transverse drainage culvert	The Northern Road 180 m south of Glenmore Parkway	11.7	10.85	7
C6890	Transverse drainage culvert	Glenmore Parkway 200 m west of The Northern Road	46.3	46.56	-1
C7380	Transverse drainage culvert	The Northern Road 195 m south of Garswood Road	16.2	13.59	11

Table A.3 :Culvert C6730 Peak flood levels (m AHD) – Full upgrade conditions

ARI event	Q Total	Water Surface Elevation
100yr	11.7	11.7
50yr	9.61	9.61
20yr	8.11	8.11
10yr	6.52	6.52
5yr	5.3	5.3
2yr	3.37	3.37
1yr	2.29	2.29