3. Local catchment assessment

The local catchment assessment considers those drainage lines with small contributing catchments. The assessment is relevant because these local drainage lines potentially contribute to local water storages or become active drainage lines during large flood events. Understanding their relevance to the local area is therefore important to ensure the proposed bypass has minimal to no impact.

3.1 Assessment methods

The local catchment assessment was undertaken through a desktop study and supplemented by field investigation. The desktop study consisted of:

- Review of RTA (2008) *Hume Highway Upgrade Tarcutta Bypass: Preliminary Environmental Assessment* (prepared by PB for the RTA, November 2008)
- Review of aerial photographs and topographic data to identify creek crossings, floodways, irrigation channels and any other surface water flow paths that cross the proposed bypass.
- Identifying water storages, water quality and other infrastructure both upstream and downstream of a potential crossing.
- Considering the distribution and impact of low and high flows for each waterway, both during construction and operation.
- Evaluating surface water supply options for the construction of the proposed bypass in line with legislative and licensing arrangements.

The field investigation was undertaken from 27 – 30 October 2008. Each watercourse that was identified in the desktop study as potentially affected by the proposed bypass was assessed for:

- Quantity of water present.
- Evidence of erosion.
- Connection to existing infrastructure, such as local dams.
- Groundcover and surrounding land use type.

Water samples were taken for laboratory analyses where water was present in the waterways and in potentially affected farm dams in the vicinity of the proposed bypass to determine pre-construction water quality. More details regarding the water quality assessment are presented in Section 4.

3.2 Drainage lines and surface water bodies

Aside from Tarcutta Creek, the proposed upgrade crosses several local drainage lines. Several dams exist along some of the drainage lines. These drainage lines and dams are numbered for reference on Figure 3-1 and described below.

Drainage lines 1 through 4 are conveyed under the existing Hume Highway through culverts and converge to form a tributary of Tarcutta Creek west of the Hume Highway. They intersect the proposed bypass at the northern end. These drainage lines were noted as dry during the field investigation undertaken from 27 - 30 October 2008 and are classified as stream order 1 by the Strahler system. The drainage lines flow in a northerly direction into a large dam, D1, located west of the Hume Highway, between Tarcutta Creek and the existing Hume Highway. A small dam, D2, is located along drainage line 1 just downstream of the proposed bypass crossing. A dam, D3, is located along drainage line 2 and was noted to have some water present during the field investigation as shown in Photograph 3-1.

Photograph 3-1 Dam D3 located along drainage line 2

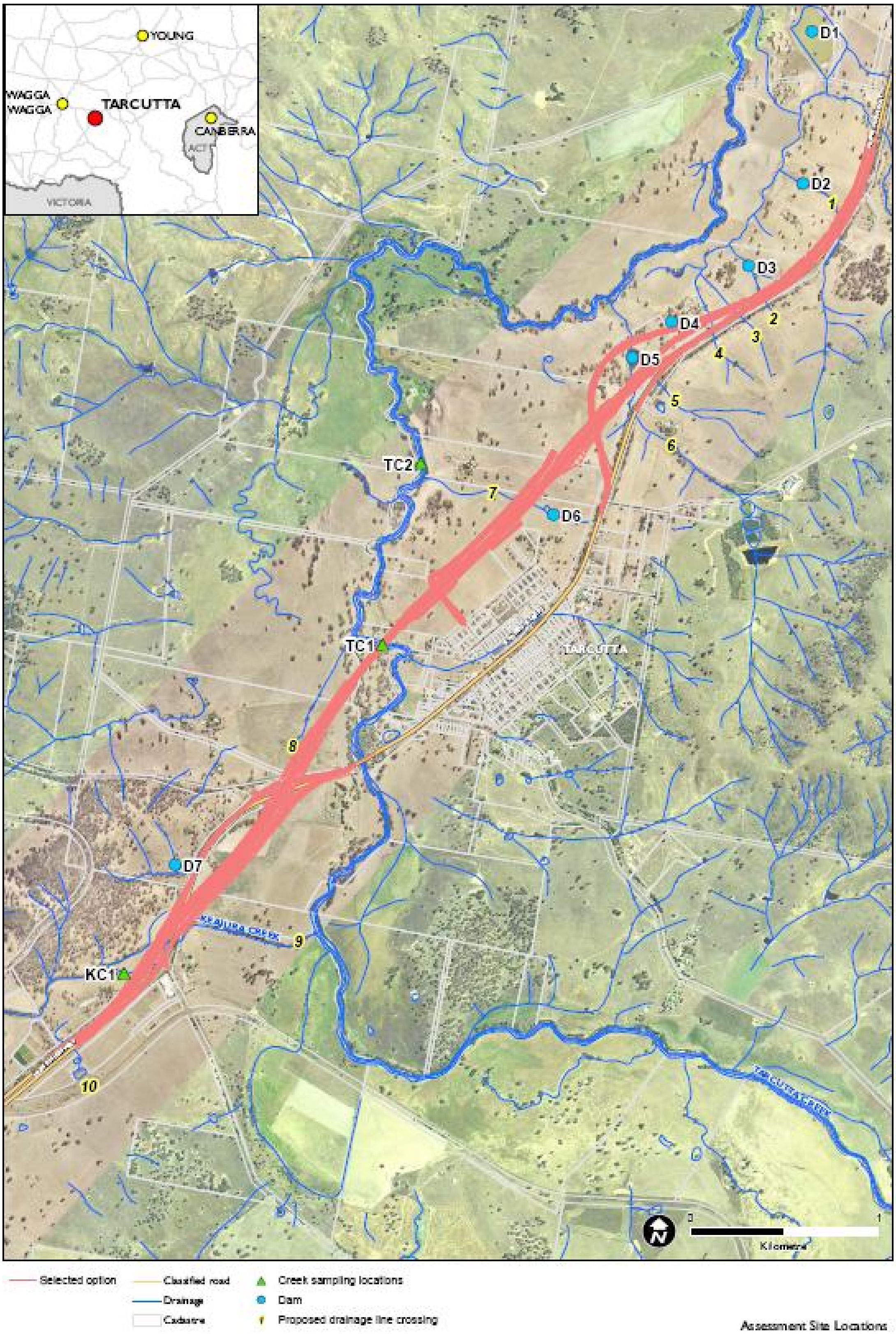

Figure 3-1 Local catchment assessment sites

A small dam, D4, exists between drainage lines 4 and 5, near the western edge of the proposed bypass. It was noted during the field investigation that some water was present within the dam, though it was not at full capacity, as shown in Photograph 3-2.

Photograph 3-2 Small dam, D4, located between drainage line 4 and 5

Drainage lines 5 and 6 are crossed in the vicinity of the proposed northern interchange between the proposed bypass and the existing Hume Highway and flow into a large dam, D5, located on the Toonga property. These drainage lines are classified as order 2 streams based on the Strahler system. It was noted during the field investigation that water was present within D5, as shown in Photograph 3-3, but the upstream and downstream drainage lines were dry.

Photograph 3-3 Toonga property dam, D5

Drainage line 7 is crossed south-west of Mates Road and is classified as an order 2 stream based on the Strahler system. Town Common dam, D6 (Photo 3-4), is located along drainage line 7, between the existing Hume Highway and the proposed bypass.

Photograph 3-4 Town Common dam, D6

Drainage line 8 is located in the vicinity of the proposed southern interchange between the proposed bypass and the existing Hume Highway and is classified as an order 2 stream based on the Strahler system. It appears that the drainage line would also intersect the proposed northbound off-ramp and would be crossed a second time just north of Keajura Creek. This drainage line is a remnant of the old Keajura Creek alignment and has been channelised in portions downstream of the existing highway before flowing into Tarcutta Creek.

Keajura Creek, drainage line 9, is located at the southern end of the proposed bypass. This drainage line represents a realignment of the natural channel. Keajura Creek is currently crossed by the existing highway, approximately 1km upstream from the junction of Keajura Creek and Tarcutta Creek. The upgrade would run almost parallel to the existing highway on the western (upstream) side as it crosses the creek. Keajura Creek is classified as an order 2 stream using the Strahler system. More details regarding the Keajura Creek crossing can be found in Section 2.

Drainage line 10 is a minor drainage line located at the southernmost end of the proposed bypass flowing into Keajura Creek just west of the existing highway and is classified as an order 1 stream using the Strahler system.

3.3 Impact assessment

3.3.1 Construction

Construction of the proposed bypass would involve site establishment and preparation works, earthworks, drainage works (culverts, bridges, water quality basins), pavement construction, and some ancillary works. As indicated in the previous sections, the proposed bypass would cross several local drainage lines. These drainage lines may be potentially blocked or diverted during the construction of the proposed bypass. Blockage of a drainage line has the potential to create areas of flooding or ponding on the upstream side of the proposed bypass and could prevent flows from reaching downstream in-line farm dams and receiving waters. Diversion of a drainage line also has the potential to prevent flows from reaching downstream in-line farm dams and receiving waters and may result in new areas experiencing flood inundation both upstream and downstream of the proposed bypass.

Management of runoff from the construction site has the potential to concentrate flows and erode the landscape. This has potential water quality impacts, which are detailed in Section 4. Additionally, interception of flows during construction may impact existing local and regional water users. Water supply is discussed in detail in Section 5.

3.3.2 Operation

As with the construction phase, the drainage lines that are crossed by the proposed bypass have the potential to be impacted by blockage or diversions during operation of the proposed bypass. Blockage or redirection of flows have the potential to cause localised flooding both upstream and downstream of the proposed bypass and impact water supply to downstream in-line dams and receiving waters as detailed in Table 3-1.

Table 3-1 Potential operational impacts

Location	Potential impacts
Drainage line 1	Upstream afflux, ponding, increased in-flows, scour
Drainage line 2	Upstream afflux, ponding, increased in-flows, scour
Drainage line 3	Upstream afflux, ponding, increased in-flows, scour
Drainage line 4	Upstream afflux, ponding, increased in-flows, scour
Drainage line 5	Upstream ponding or flooding, increased in-flows
Drainage line 6	Upstream ponding or flooding, increased in-flows
Drainage line 7	Upstream ponding or flooding, increased in-flows
Drainage line 8	Upstream ponding or flooding, increased in-flows
Drainage line 9	Upstream afflux, ponding, increased in-flows , scour
Drainage line 10	Upstream ponding or flooding, increased in-flows
D1	Blockage of receiving water from drainage lines 1 through 4, increased in-flows, water quality and supply
D2	Blockage receiving water from drainage line 1, increased in-flows, water quality and supply
D3	Blockage receiving water from drainage line 2, increased in-flows, water quality and supply
D4	Blockage receiving waters for sheet flow run-off, increased in-flows, water quality and supply, possible removal of dam
D5	Blockage receiving water from drainage lines 5 and 6, increased in-flows, water quality, possible removal of dam
D6	Water quality and supply
D7	No perceived impacts

During the site visit it was confirmed with land owners that the main use of the dams is for stock watering.

The bypass would create additional impervious areas that would generate additional runoff and potentially reduce groundwater recharge. Additionally, the runoff collected through the bypass longitudinal drainage system has the potential to concentrate and/or redirect flows. Runoff from the bypass also has the potential to impact water quality and water supply as detailed in Sections 4 and 5.

3.4 Management of impacts

3.4.1 Construction

It is recommended that the mitigation measures required for the operation of the proposed bypass, as detailed in Section 3.4.2, be implemented at the beginning of the construction phase to maintain the current flow paths of the drainage lines and minimise impacts resulting from construction. These measures are likely to include installation or modification of culvert crossings and associated scour protection works.

A soil and water management plan developed in accordance with *Soils and Construction: Managing Urban Stormwater* (Landcom, 2004) would be developed for the construction phase that would include Best Management Practice (BMP) measures, such as silt fencing, temporary diversions, berms, temporary sediment basins, etc., to minimise the disturbance to the drainage paths. Runoff from the construction site would be considered dirty water and treated before releasing into the downstream environment. Further details are provided in Section 4 regarding water quality impacts and mitigation measures.

3.4.2 Operation

Drainage Lines

Mitigation measures will be required to maintain flow paths, maintain inflow to some dams, and to prevent scour and sediment impacts. Proposed measures will include:

- Extension or replacement of the existing culverts to convey flow under the bypass and designed to prevent unacceptable increases in velocity or water levels.
- Installation of new culverts
- Appropriate scour protection measures implemented at the downstream end of proposed outlets.

Fish friendly crossings are required at Tarcutta Creek and Keajura Creeks only.

The longitudinal drainage system for the bypass should ensure that distribution of flow is maintained to match the existing flow distribution as closely as possible. Runoff from the bypass should be managed and treated before being discharged into sensitive environments (i.e. not all will be treated); flow should be discharged into the existing drainage lines where possible. Discharge points will be designed with appropriate scour protection where required. Further details are provided in Section 4 regarding water quality impacts and mitigations measures.

Concept alignment of the proposed bypass indicates that minor realignment works will be required for drainage line 8 near the southern end of the proposed bypass. These works will be designed to ensure the long term geomorphic stability of the watercourse.

Dams

All flow paths to existing dams will be maintained to the extent that is practical. Water quality measures will be implemented to prevent sediment inflow (see section 4 for further details).

There is potential for increased flow to some dams due to increased impervious surfaces from the road. Excess flows would be mitigated by:

- Increasing the capacity of the dam or
- Capturing flows in retention or detentions facilities.

Dams D4 and D5 are likely to be required to be moved, or decommissioned as the proposed bypass route passes over this dam. Further assessment of required changes to dams will be conducted during detailed design. Any proposed modifications will require a more detail assessment of the dam structure and possible approval from DWE to be granted.

4. Water quality

The assessment of water quality for the Tarcutta Creek catchment is relevant because the quality of water can potentially change the availability of water for both environmental and human uses. The assessment of water quality within the Tarcutta Creek catchment looks at potential impacts due to construction and operation of the proposed bypass on the existing environment within the catchment. The assessment was based on a review of water quality objectives, background information, a ‘snap shot’ sampling event within the catchment, and an assessment of the expected impacts that the proposed bypass may have. Mitigation measures aimed at protecting the existing water quality within the catchment are also identified.

4.1 Objectives and guidelines

4.1.1 RTA Water Policy

The RTA has developed a water policy that identifies a set of objectives for the management of water issues related to planning, design, construction, operation and maintenance of RTA roads. The policy summarises key design practices used to contain and treat road runoff and to minimise potential impacts to receiving aquatic and riparian environments. This is achieved through treatment of road runoff through ‘non-point’ source, or ‘dispersed’ techniques and maintaining existing stream/system hydrology.

4.1.2 ANZECC Guidelines

The Australian and New Zealand Environment and Conservation Council (ANZECC) published the revised *Australian and New Zealand guidelines for fresh and marine water quality* in 2000 (ANZECC, 2000). The guidelines form the central technical reference of the *National Water Quality Management Strategy*, which the Federal and all state and territory governments have adopted for managing water quality.

4.1.3 Department of Environment and Climate Change catchment objectives

For each catchment in NSW, the state government has endorsed the community's environmental values for water, known as 'Water Quality Objectives' (WQOs). These were adopted following extensive consultation with the community in 1998. Tarcutta Creek and its tributaries within the study area are classified within the Department of Environment and Climate Change (DECC) objectives as ’uncontrolled streams‘. Environmental values endorsed for these waters are listed in Table 4-1, along with key indicators used to assess water quality for each of these values.

Table 4-1 DECC Water quality objectives

Environmental value	Key indicators
Protection of water for aquatic ecosystems	Total phosphorous, total nitrogen, chlorophyll-a, turbidity, electrical conductivity, dissolved oxygen, pH and temperature
Protection of water for primary and secondary contact recreation	Turbidity, faecal coliforms, enterococci, pH and temperature
Protection of water for visual amenity	Clarity, surface films and litter, nuisance organisms
Protection of water for livestock, irrigation and homestead water supply	Electrical conductivity, faecal coliforms, pH, turbidity
Protection of water for consumption of aquatic foods (cooked)	Faecal coliforms, temperature

The DECC catchment objectives, along with ANZECC guidelines provide numerical water quality criteria for the protection of the above values. A summary of the numerical water quality criteria is provided in Appendix B. These have been adopted as the criteria for assessment of water quality for this project.

4.2 Existing conditions – water quality

4.2.1 Background information

There are no long-term detailed water quality records for the Tarcutta region. Electrical conductivity (EC)(mS/cm) is regularly recorded by DWE at the stream gauge in Tarcutta Creek at Old Borambola (410047), but there are no gauges that regularly monitor water quality in Keajura Creek or other tributaries of Tarcutta Creek. Since April 1999, the mean EC recorded in Tarcutta Creek at the Old Borambola Gauge was 0.26 mS/cm, with a maximum value of 1.04 mS/cm (DWE website, accessed 21 April 2009). While the higher levels recorded fall outside the ANZECC guidelines for a healthy, freshwater inland river, 80 per cent of the values recorded fall within guideline values.

A sediment slug has been noted within the Tarcutta Creek channel downstream of the confluence of Tarcutta Creek and Umbango Creek (the confluence being upstream of the study site) as reported in *The Ecological Health of Tarcutta Creek* (DLWC, 2001). This sediment slug is the result of an increased sediment supply to the creek resulting from historic soil erosion in the upper and mid Tarcutta Creek catchment due to clearing for agricultural development.

4.2.2 Surface water sampling

To provide further information regarding existing water quality within the waterways and water storages within the area of the proposed bypass, sampling was undertaken by PB during a site visit on 30th October 2008. This sampling was a one off event providing a 'snap shot' view of the water quality at this time. Samples were collected from Keajura Creek (KC1), two locations on Tarcutta Creek (TC1 and TC2) and from four small dams (D3, D5, D6, and D7) located in the vicinity of the proposed bypass (see Figure 3-1 for sampling locations). During the sampling event, Tarcutta Creek and Keajura Creek were noted to primarily consist of a series of pools with minimal surface flow. Based on the stream flow record at the DWE Old Borambola gauge (410047) the mean daily flow in Tarcutta Creek at the time of the sampling was 19.5 ML/d. This flow is equalled or exceeded 91.3 per cent of the time (refer to Section 1.2.3). A description of the field methodology adopted and detailed sampling results are provided in Appendix B.

The sampling results were compared to guideline values for the three key water uses in the area (aquatic ecosystems, irrigation and livestock water supply) provided in both the DECC catchment water quality objectives and the ANZECC guidelines. In summary, the results of the sampling indicated:

- Physical parameters:
  - Surface water was found to range in temperature from 19.44°C to 27.83°C.
  - Surface water ranged from slightly acidic to slightly alkaline (pH 6.59 to 8.29). Two of the small dams (D6 and D7) recorded levels above guidelines for protection of aquatic ecosystems, but within guidelines for irrigation and livestock water supply.
  - EC (a measure of salinity) was within guideline values except at one of the farm dams (D5) where levels just exceeded guidelines for protection of aquatic ecosystems and in Keajura Creek where a level of 1.85 mS/cm was recorded (guideline for protection of aquatic ecosystems 0.35 mS/cm).
  - All locations except Dam D7 had dissolved oxygen levels below the guideline values for protection of aquatic ecosystems. This has been attributed to surface water samples being collected from still water bodies (either in dams or from pools in non-flowing creeks).
  - Turbidity was within guideline values at half of the sampling locations. Dams D6 and D7 as well as Keajura Creek recorded levels above the guideline values for protection of aquatic ecosystems.
- Nutrients
  - Total nitrogen had a concentration range of 0.2 to 2.6 mg/L. All of the sites recorded total nitrogen concentrations above the guideline value for protection of aquatic ecosystems except for site TC1, but were all within guideline values for irrigation and livestock water supply.
  - Total phosphorus had a concentration range of <0.01 to 0.16 mg/L. All of the sites recorded total phosphorous concentrations above the guideline value for protection of aquatic ecosystems, except site TC1. Results at all locations, except TC1 and D7, also exceeded guideline values for irrigation water supply.

  Increased nutrient levels in the Tarcutta region could be attributed to the land use in the area. The surrounding area around the village of Tarcutta is used for grazing and cropping. Fertilisers are commonly used to improve pastures and increase the fertility of land for crops with runoff during higher rainfall into local dams and creeks contributing to the increased nutrient levels.
- Metals — cobalt, lead and zinc concentrations were analysed at each of the sampling locations. The results indicated that cobalt and lead levels were within guideline values. Zinc concentrations exceeded the guideline value for ecosystem protection, but were within guideline levels for irrigation and livestock water supply at all locations.
- Total petroleum hydrocarbons (TPH) were below the laboratory level of recording at all sampling locations except Dam 3 and Dam 7 where levels of 200 μg/L in the C15-C28 fraction were recorded.

- Concentrations of BTEX compounds (benzene, toluene, ethyl benzene, meta- and para-xylene and ortho-xylene) were below the laboratory level of recording at all sampling sites.
- Oil and grease concentrations at all sampling locations were less than the laboratory limit of reporting (5 mg/L).

No data was obtained to assess faecal coliform or enterococci levels to allow comparison of existing water quality to environmental values where these parameters are key indicators of the suitability of the water for human recreational activities and stock use (see

Table 4-1).

In summary, the results of this sampling event indicate that surface water within the Tarcutta Creek catchment has elevated nutrient levels and elevated zinc levels. Elevated nutrients are typical of catchments where grazing and cropping land uses are dominant as at Tarcutta. Elevated EC values were noted in Keajura Creek. This indicates a salinity issue in this area. Further discussion regarding salinity risk within the area is provided the Technical Paper 4 — Groundwater.

4.3 Impact assessment

The potential impacts on water quality relate to the construction of the proposed bypass and the management of stormwater for both the construction and operation of the proposed bypass. The water quality of the existing waterways could be affected by sediment, pollutants from roads (hydrocarbons and particles from vehicle wear and tear etc.) and additional nutrients following rehabilitation of exposed surfaces. Water quality can also be affected by the change in the hydrologic cycle resulting from the impervious surface of the road potentially altering groundwater recharge regimes.

Any impacts to water quality would affect aquatic ecosystems and water users within the catchment. It is noted that Tarcutta Creek forms part of the Aquatic Ecological Community in the Natural Drainage Systems of the Lower Murray River Catchment, which is listed as an endangered ecological community. Further assessment and discussion regarding impacts to this community is provided in Technical Paper 1 — Biodiversity.

4.3.1 Construction

Construction of the proposed bypass would involve site establishment and preparation works, earthworks, drainage works (culverts, bridges, water quality basins), pavement construction, and some ancillary works. These activities have the potential to generate pollutants that could affect surface water quality if appropriate controls are not in place.

The primary impact to water quality during construction would result from increased sediment loads as a result of land disturbance. Exposed soils would be readily transported with surface flows to nearby dams and waterways. It is noted that soils in the area are predominantly silts and clays. These finer particle type soils tend to remain in suspension for longer periods of time and hence there is a greater risk of sediment loads spreading further downstream from the construction area than if the sediments were larger. Increased sedimentation of waterways can smother benthic habitats and organisms, and can increase levels of nutrients, metals and other potential toxicants that attach to the sediment particles.

During the construction phase, there would be a need to undertake work within the main flow paths, such as during construction of the bridge across Tarcutta Creek. The impacts of increased turbidity and sediment loads in locations such as this are likely to be short-term but may have longer term ramifications depending on the flow behaviour within these waterways and the measures implemented during construction.

Salinity has been noted as a major issue within the Murrumbidgee River catchment and is understood to be attributed to land disturbance. The need to clear land for the proposed bypass and redistribution of surface water runoff may impact salinity levels in the local and regional catchment. Further discussion of salinity impacts is provided in the groundwater assessment for this project (Technical Paper 4 — Groundwater).

Other potential pollutants that could impact water quality during the construction period include:

- Hydrocarbons and chemicals as a result of spills and leaks from construction vehicles or fuel/chemical stores on construction sites.
- Oils and greases from construction equipment.
- Localised erosion of creek beds due to temporary works being placed within flow paths.
- Nutrients attached to sediment particles and from fertilisers used in landscaping works.
- Wastewater generation from construction sites.
- Gross pollutants/general litter from construction sites.

4.3.2 Operation

There is potential for pollutant export from the proposed bypass to adversely affect Tarcutta Creek, Keajura Creek, tributaries of these waterways and small storages within the catchment. Road runoff typically contains a range of pollutants including:

- Gross pollutants and litter.
- Sediment (pavement wear, vehicles, maintenance activities).
- Nutrients (roadside fertiliser application).
- Heavy metals (vehicle wear and tear).
- Petroleum hydrocarbons (vehicle spills and leaks).

Pollutants such as these would have greatest impact during small rainfall events following prolonged dry periods. Such situations allow pollutants to accumulate on the road surface during dry weather with the small rainfall event washing a concentrated 'first flush' of pollutants to receiving waters while stream flow is low. It is noted that typically flows in the Tarcutta Creek catchment are low (see section 1.2.3). This indicates a higher risk of pollutants generated from road runoff impacting on local waterways as small flows result in less dilution and assimilative capacity within the waterways.

Another key risk for water quality during operation of the proposed Tarcutta bypass is that of large spills from trucks/vehicles transporting a broad range of materials along the route. Depending on the nature of the spilt material such an occurrence could have catastrophic impacts on local waterways.

There is potential for sedimentation and/or scour impacts to occur during operation of the proposed bypass at bridges (across both Tarcutta Creek and Keajura Creek) and at culvert crossings. Piers on proposed bridges would provide localised sedimentation and scour locations. Similarly, the entrance and exit of culvert structures are key areas where sedimentation and scour are likely to occur. Soils in the area are predominantly silts and clays, which tend to remain in suspension for longer periods of time. The impacts of localised scour or sedimentation, therefore, have the potential to spread further downstream as sediments are transported with flow.

4.4 Mitigation measures

4.4.1 Construction

Mitigation measures would be required to prevent impacts that may result during construction of the proposed Tarcutta bypass. Measures required would include both management measures aimed at minimising the production of pollutants requiring treatment and physical measures aimed at settling sediment and preventing polluted water entering the local creeks. The measures would be documented within a soil and water management plan to be prepared as part of the construction environmental management plan in accordance with *Soils and Construction: Managing Urban Stormwater* (Landcom, 2004). The soil and water management plan would aim to achieve best practice soil and water management and would include measures such as:

- Implementing erosion and sediment controls, such as sediment basins, staked straw bales, silt traps, sediment fences, bunds and other containment devices.
- Diverting clean surface water run-off around construction works/disturbed areas to minimise the volume of water requiring treatment. These diversion works would be installed as soon as practical to ensure that drainage is in place during the early stages of construction.
- Planning construction activities to minimise the length of time that soils are exposed.
- Waterway structures and works:
  - Permanent drainage structures (e.g. culverts) should be installed as early as possible to ensure cross drainage is in place during early stages of construction.
  - Installing scour protection in creek bank areas where erosion risk is high.
  - Scheduling construction activities within waterways to coincide with dry periods or low flow periods, where possible (generally summer to autumn period).
- Restricting construction traffic to defined internal roads, and where required, operating wheel cleaning facilities at locations where vehicles leave the construction site.
- Ensuring that chemicals and fuels are appropriately stored and bunded.
- Revegetating and stabilising finished construction areas progressively.
- Regular maintenance and inspection of all erosion, sediment and pollution control devices to ensure efficient operation. This may also include regular water quality monitoring to ensure that the plan is effectively preventing impacts.
- Regular maintenance of construction vehicles and equipment to minimise risk of leaks and spills.
- Training of construction employees to implement spill response procedures and implement, maintain and be aware of sediment and erosion control measures and requirements.
- Training of construction employees on appropriate water management to minimise generation of gross pollutants.
- Regular water quality monitoring at key locations to ensure construction water quality management measures are effective.

Sediment basins would be a key pollution control measure and would be designed during the detailed design phase in accordance with the procedures set out in *Soils and Construction: Managing Urban Stormwater* (Landcom, 2004). The sediment basins would be designed to cater for the fine particle soils (silts and clays) that are present around Tarcutta. Monitoring during construction would also assess requirements for flocculating agents to be used to assist settling of sediment particles.

Site facilities would provide toilet and staff washing facilities, from which wastewater would be collected. This would ensure that no wastewater generated from site enters local waterways.

4.4.2 Operation

Pollutants generated with road runoff would require treatment prior to surface water entering local waterways. Treatment measures (such as basins, buffer zones and vegetated swales) would be designed to treat runoff occurring during small, frequent rainfall events. As discussed in Section 4.3.2, these are the events that have the most potential to impact water quality in local creeks and dams within the Tarcutta Creek catchment. During larger storm events, pollutants are likely to have been washed off the road surface relatively early in the storm event (and hence would receive some treatment by the various measures implemented), and during the peak of the event, local creeks and waterways would have much higher flows and hence a much higher dilution and assimilative capacity.

Sediment basins used during construction could be retained and provide an ongoing water quality improvement function during the operation of the proposed bypass at key sensitive area (i.e. Tarcutta Creek). The requirement for permanent water quality basins would be assessed during detailed design and would ensure that basins and any other treatment necessary would be installed at strategic locations to ensure that the impacts of pollutants on local environmentally sensitive waterways are minimised.

Scour protection works would be implemented at proposed bridge abutments and piers and waterway crossings. Requirements for scour protection would be assessed during detailed design of bridge and culvert structures. Such protection measures would be included in the design of these structures. These works would ensure that sedimentation resulting from scour within Tarcutta Creek, Keajura Creek and other local waterways is minimised.

5. Water supply

The assessment of potential changes to water supply as a result of the proposed bypass is relevant because of the need to identify water supplies for the project without impacting the local and regional environment and users. The construction of the proposed bypass would require the use of water and may impact existing local and regional water users. The specifics of the impact(s) on existing water users would be examined once the construction phase has been planned for and water requirements have been determined.

5.1 Existing conditions – water supply

5.1.1 Legislation

The access, taking and use of water is managed under two primary legal instruments in NSW – the WA and WMA. Both Acts may apply to the proposed bypass. Relevant issues administered under these Acts include:

- Taking water from a river, dam or aquifer for road construction and dust suppression.
- Changing the course of a river.
- Constructing works on a designated floodplain.
- Protecting aquatic environments and domestic and stock water users including managing small farm dams.

In relation to water licensing and approvals, the WMA only applies where a water sharing plan has commenced — in this case the *Water Sharing Plan for the Tarcutta Creek Water Source* (DNR 2004).

The WMA outlines water access licence, water supply works and water use approvals requirements within the geographic area of a plan; once a water sharing plan has commenced, the WA is repealed for that water source and existing licences are automatically converted to new consents under the WMA.

Water sharing plans specify the rules for accessing water, including water trading and may also specify whether new licences may be granted. Plans also include mandatory consent conditions for new water supply works approvals. Water sharing plan flow access rules are established to protect the water for the environment during critical low flow periods, protect medium flows and ensure that high flows are not mined. The aim of these rules is to attempt to share the water between competing, consumptive water users. Some of the plans have a mechanism to vary the low-flow access rules during the term of the Plan to increase the level of environmental protection.

In all other areas of NSW, the WA continues to be the main water licensing legislation. There is an embargo in place on the granting of new licences for commercial purposes within the Murray-Darling Basin.

Basic landholder rights cover the taking of water for domestic and stock usage, constructing small farm dams (harvestable rights) and native title rights to water. Under the WMA any development taking or using water must assess whether there is an adverse impact from the development to the river or aquifer and its dependent ecosystems, and must protect basic landholder rights. This assessment is achieved by the minimal harm provisions of sections 63 and 97 of the WMA.

Any structure constructed on a designated floodplain that potentially alters the passage of floodwater may need to be assessed in accordance with the WA regulations and may require a floodplain work approval.

Under Part 8 of the WA Tarcutta Creek is not a designated floodplain. A Part 8 floodplain approval is not required for construction and earth works on the floodplain (note – this may not exclude separate approvals for development on the floodplain under the *Environmental Planning and Assessment Act 1979*).

Any activity or earth works (e.g. embankments, road culverts, causeways, concrete footings for buildings) on waterfront land may now require a controlled activity approval under section 91 (2) of the WMA. Clause 39A of the *Water Management (General) Regulation 2004* outlines exemptions for a controlled activity approval. The RTA, as a public authority is exempt from requiring a controlled activity approval. In addition sections 18(1)a and 38(1)(b) state that a roads authority is exempt from obtaining an access licence for road construction/maintenance. It should be noted that no such exemptions exist under the WA for road construction purposes; however, since construction would take place within the bounds of the Tarcutta Creek Water Source, the WMA overrides the WA. If water for construction is chosen to be sourced outside of the Tarcutta Creek Water Source area, this water may need to be obtained through the water trading market to overcome the embargo currently in place on the granting of new licences for all surface water within the Murray-Darling Basin.

5.1.2 Water access

The *Water Sharing Plan for Tarcutta Creek Water Source 2003* was developed by DWE under the WMA to establish rules for sharing water between the environmental needs of the river and water users, and also between different types of water users. The plan describes three separate management zones for the Tarcutta Creek catchment, with the proposed bypass being located in the Borambola Management Zone. Each management zone is subject to specific flow access conditions that seek to protect water for the environment, basic landholder rights and licensed water users.

The Tarcutta Creek catchment has a large number of active water users, with more than 100 WMA water access licences granted within the catchment. Total share component (annual entitlement) for these licences is regulated through the *Water Sharing Plan for Tarcutta Creek Water Source 2003* and is currently 5,549 ML[1].

The major water uses include irrigation of lucerne and improved pasture to support the dairy industry and for cattle grazing, summer and winter cereal crops, apple, stone fruit and blueberry orchards, small areas of viticulture and water supply for domestic and stock purposes. There is a small local water utility licence for the village of Humula (located in the upper part of the catchment to the south of Tarcutta).

[1] Source: Department of Water & Energy website. Accessed 6 December 2007. Subject to change resulting from water trading or granting of new licences.

Current land use in the area proposed under the bypass is predominantly grazing land, improved pasture and lucerne. There was no clear evidence of irrigation infrastructure (including irrigation channels) during a field inspection in October 2008 nor from air photo analysis. Further downstream from the proposed bypass there are several active water users including a fully established dairy that accesses Tarcutta Creek for water supply. Additionally, most riparian landholdings access Tarcutta Creek for domestic use (mostly non-potable) and stock watering under a basic landholder right (without requiring a water licence). Advice from DWE is that no formal records are maintained for WMA section 52 domestic and stock water users, but that anecdotal evidence suggests water is extracted from Tarcutta Creek for domestic and stock use within or adjacent to the area proposed for the bypass.

5.2 Impact assessment

5.2.1 Construction impacts

Estimated water requirements

Indicative quantities of water required during construction are outlined in Table 5-1.

Table 5-1: Estimated volumes of water for construction

Water type	Activities	Quantities (approximate)[1,2]
Potable or reclaimed water	Earthworks construction (compaction and pavement stabilisation of soft soils, if encountered).	80 ML over the 2-year construction period (based on 6 per cent moisture content)
Potable or reclaimed water	Dust suppression.	50 ML (100,000 L/day over the 2-year construction period)
Potable or reclaimed water	Vegetation watering (from vehicle only).	50 ML (estimated 20,000 plants, each receiving 20 litres of water per week for one year)
Potable water only	Concrete and asphalt batching.	11 ML (comprising 7.5 ML of concrete and 3.5 ML of lean mix) over the 2-year construction period

Notes: 1. ML = megalitres; L/day = litres per day

2. These quantities would be subject to refinement during detailed design.

Water sources

Groundwater

RTA (2007) estimated that the construction water requirements for the Sturt Highway to Tarcutta upgrade could be met by extracting local groundwater, as surface water volumes were likely to be limited due to drought conditions. This is likely to be the case for the proposed Tarcutta bypass. Groundwater may be sourced through the Riverina Water County Council. Several privately operated bores exist along the length of the proposed bypass. Agreements may be made with local landholders to source water from one or more of these bores, in association with the DWE. More information on using groundwater sources for construction supply can be found in PB (2009). More information regarding groundwater water sources is presented in Technical Paper 4 — Groundwater.

Surface water

Another potential source of water may be from local dams. As described in Section 3, five dams exist along the length of the proposed construction site. One of these dams is a Town Common dam. Arrangements with local landholders may be investigated once an approximate water volume is known.

Another option is to construct new dams to collect run-off for use during construction, some of which may be used for temporary sedimentation water quality basins. Proposed new dams have the potential to impact the existing flow distribution of the local catchment and reduce flows to the downstream environment or receiving waters. This could also reduce the amount of water available to local landholders during construction phase of the project.

Off-site

Alternatively, it may be necessary to transport water from an off-site source. The current embargo on the granting of new water licences would require obtaining water through the Murray-Darling Basin water trading market. This may be in the form of either a permanent or temporary water licence. General or high security water licences may be purchased. This process would include:

- Identifying water licence holders with the required water entitlements who are willing to trade their allocation. This may be done independently or through a broker.
- Completing appropriate DWE application forms and submitting the appropriate fee (~$250 for permanent licence transfer/ ~ $25 + $1/ML for temporary licence transfer).
- Time for DWE to process licence transfer (estimated at six weeks).
- Considering water is only required for temporary construction works, temporary water purchases may be more suitable than permanent arrangements, if the water market is entered into.

Water access

Once a water source for construction is confirmed, the method of conveyance and storage can be determined. If water is to be sourced from existing, local dams, further storage is unlikely to be necessary and tanker trucks may only be required for transport to the work site. If water is to be sourced from local groundwater bores, water may be pumped and transported as needed. If water is to be sourced from a more distant location, storage tanks or reservoirs may be necessary to store water closer to the work site.

5.2.2 Operation

The potential operational impact to water supply due to the proposed bypass depends on the water source. As for the construction phase, new dams have the potential to impact the existing flow distribution of the local catchment and reduce flows to the downstream environment or receiving waters. This could also reduce the amount of water available for local landholders.

5.3 Mitigation measures

5.3.1 Construction

Sourcing water from local dams would require arrangements with local landholders for access and agreement on the amount of water to be extracted. Additionally, arrangements could be investigated to construct new dams that could be mutually beneficial to the local landholders for use during and after construction of the proposed bypass. New dams should be designed so as not to prevent environmental or operational flows from reaching the downstream environment or receiving waters.

If water is to be sourced from a more distant location, storage tanks or reservoirs may be necessary to store water closer to the work site.

During the next phase of the proposed bypass design, the Tarcutta Hume Alliance will conduct more detailed analysis of anticipated water requirements during construction. Understanding water requirements will enable a more informed decision as to the most appropriate source of water.

5.3.2 Operation

Again, arrangements could be investigated to construct new dams that could be mutually beneficial to the local landholders for use during and after construction of the proposed bypass. New dams should be designed so as not to prevent environmental or operational flows from reaching the downstream environment or receiving waters.

6. Conclusions

This report has identified and addressed the surface water impacts associated with construction and operation of the proposed bypass. The assessment has looked at impacts to flooding, local catchments, water quality and water supply and concludes the following:

6.1 Flooding

Potential flooding impacts identified during construction can be mitigated through adequate construction planning and implementation of mitigation measures identified in Section 2.5.1. Based on the modelled proposed bypass alignment design option, this assessment has identified a reduction in flood storage area and an increase in flood levels generally between the proposed alignment and the existing highway. Changes to flood velocities were found not to be significant, however, this would require further assessment during detailed design. Measures to mitigate these impacts would be incorporated into the proposed bypass design. Possible mitigation measures (such as optimising the width of the proposed floodplain waterway area, floodway diversion channels and flood proofing of properties) have been identified in Section 2.5.2.

Incorporation of identified measures during both construction and operation of the project would ensure flood impacts are managed appropriately.

6.2 Local catchments

Potential impacts to local watercourses during construction that have been identified during construction can be mitigated through measures outlined in Section 3.4.1. These measures focus on ensuring that current flow paths are maintained and best management practices are implemented to protect the watercourses.

Measures to protect local watercourses during operation of the proposed bypass would be incorporated into the bypass design. The longitudinal drainage system would be designed to ensure that distribution of flow is maintained to match the existing flow distribution as closely as possible. Existing culverts would be extended or replaced and new culverts installed, where required, to maintain flow paths. Scour protection measures would be incorporated to each of these crossings as required. Runoff from the bypass would be managed and treated before being discharged into the existing drainage lines where possible. Fish friendly crossings would be required at Tarcutta and Keajura creeks.

6.3 Water quality

Mitigation measures would be required to prevent water quality impacts during construction of the proposed Tarcutta bypass. Measures required would include both management measures aimed at minimising the production of pollutants requiring treatment and physical measures aimed at settling sediment and preventing polluted water from entering the local creeks. Measures would be documented in a soil and water management plan to be prepared as part of the construction environmental management plan in accordance with *Soils and Construction: Managing Urban Stormwater* (Landcom, 2004).

There is also potential for impact to water quality during operation of the proposed bypass. Treatment measures (such as basins, buffer zones and vegetative swales) would be designed to treat runoff from small, frequent events and would be designed to capture the ‘first flush’ of pollutants at sensitive areas. Design of water quality basins would occur during detailed design and would ensure that basins and any other treatment necessary would be installed at strategic locations to ensure that impacts of pollutants on local environmentally sensitive waterways are minimised.

Scour protection works would be implemented at proposed bridge abutments and piers and waterway crossings as required. These works would ensure that sedimentation resulting from scour within Tarcutta Creek, Keajura Creek and other local waterways is minimised.

6.4 Water supply

The availability of surface water sources to supply water for the proposed bypass is discussed in Section 5. During the next phase of the proposed bypass design, the Tarcutta Hume Alliance will conduct more detailed analysis of anticipated water requirements during construction. Understanding water requirements would enable a more informed decision as to the most appropriate source of water.

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Appendix A

Tarcutta Creek flood study

Contents

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1. Introduction

A flood assessment of Tarcutta Creek was undertaken to evaluate the impacts of the proposed highway works on the existing flow regime and on the properties in the vicinity of the township of Tarcutta. The assessment consisted of a review of available information and data; and hydrologic and hydraulic modelling of Tarcutta Creek.

1.1 Catchment overview

The Tarcutta Creek catchment is located in the Murrumbidgee area of New South Wales, with flows discharging into the Murrumbidgee River near Oura, North-West of Tarcutta. The catchment study area is approximately 1660 km^2 and extends from Courabyra and Carabost in the South, through Tarcutta in the North to the Old Borambola streamflow gauge, North-West of Tarcutta. The catchment is comprised mostly of pastoral farming land, although contains a number forested areas (including Murraguldrie, Carabost and Bago State Forests).

Tarcutta Creek has two main tributaries; Keajura Creek and Umbango Creek. Carabost and Murraguldrie Creeks form tributaries of Umbango Creek and there are a number of smaller tributaries of Tarcutta Creek.

1.2 Available data

- Topographic survey used for the existing RTA investigation.
- Preliminary Flood Investigation Report No. 2008.2 (RTA, 2008).
- Orthophotography, Aerial Laser Survey (ALS) data, and Railway Survey (AAMHATCH, 01/2009).
- Work As Executed (WAE) plans for existing Hume Highway Tarcutta Creek Bridge and floodway bridge (RTA, 1969).
- WAE plans for existing Hume Highway Keajura Creek Bridge (RTA, 1961).
- Tarcutta Flood Study, Hume Highway Tarcutta - Floor Level Survey (RTA, 11/2006).
- Historic rainfall data – 6 minute Pluviograph rainfall intensity data obtained from Bureau of Meteorology for the following stations: Hume Reservoir (72023), Wagga Wagga Amo (72150), Adelong (Etham Park) (72159) and Tooma (Eudlo) (72163).
- Historic streamflow data – Tarcutta Creek at Old Borambola (station number 410047) obtained from PINNEENA DVD.
- Raw streamflow data – Tarcutta Creek at Old Borambola (station number 410047) obtained from NSW Department of Water and Energy.

1.3 Previous studies

The RTA carried out a preliminary flood investigation of Tarcutta Creek in July 2008 to approximate existing flood conditions and to estimate a bridge opening size over Tarcutta Creek for the proposed bypass. The investigation consisted of a HEC-RAS hydraulic model to estimate the flood extents using flows derived from a Watershed Bounded Network Model (WBNM) hydrologic model developed by Webb, McKeown and Associates (WMA). The investigation report with results from the modelling, hydrographs for the Tarcutta Creek Catchment, and surveyed cross-section data was available to PB for review, but not the HEC-RAS or WBNM models.

The flood frequency curve for the Tarcutta Creek at Old Borambola (station number 410047) is shown in Figure 1. Based on analysis of the flood frequency analysis, WMA recommended to the RTA that the flood frequency curve is accurate up to approximately the 5 year ARI event. This is based on the number of gaugings and fit of the flood frequency curve up to this AEP. Beyond this level, only one gauging exists and the flood frequency curve exhibits extremely high negative skew. A full review of the relative accuracies of the flood frequency analysis and the WBNM model developed by WMA are discussed in Section 3.1.3.

Based on advice from WMA, the RTA adopted a 100 year ARI peak design flow equal to 750 m^3/s using a weighted average between the flood frequency analysis and the WBNM model,. The 20 year ARI peak design flow adopted was obtained using interpolation between the 5 year and 100 year ARI peak design flows.

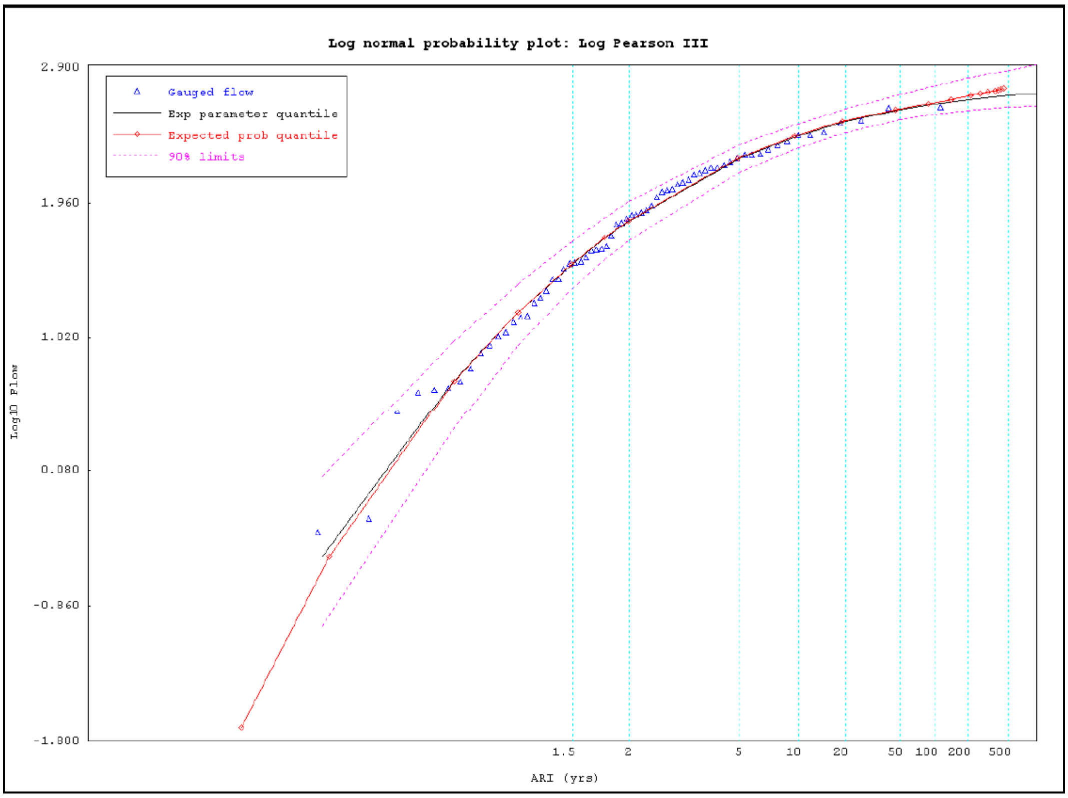

Figure 1 Flood Frequency Curve - Tarcutta Creek at Old Borambola. Station Number 410047 (RTA, 2008)

Table 1 Summary of flows used in RTA preliminary flood investigation (RTA, 2008)

ARI	WBNM model (m^3/s)	Flood Frequency Curve (m^3/s)	Design Floods at Tarcutta (adopted for preliminary flood investigation) (m^3/s)
5	N/A	182	182
20	599	328	554
100	1097	444	750
PMF	5498	N/A	5498

The investigation resulted in the recommendation of a 200m bridge opening for the selected bypass option.

2. Methodology

2.1 Hydrologic Modelling

2.1.1 Model overview

A hydrologic model of the Tarcutta Creek catchment was developed using the Watershed Bounded Network Model (WBNM) software program. WBNM has been used extensively across Sydney and NSW for both urban and rural flood investigations and was also used for the preliminary hydrologic investigation by WMA.

WBNM is an event based hydrologic model that calculates flood hydrographs from either recorded storm rainfall hyetographs or design storm rainfall parameters. The catchment is represented in the model as a series of sub-catchments for which factors affecting runoff such as land use (proportion of pervious versus impervious land surfaces), rainfall losses, and routing of runoff both through the catchment and through channels are defined. Details of how WBNM was used to represent the Tarcutta Creek catchment are provided below.

The model of the Tarcutta Creek catchment developed for this study was used to estimate flow generated from the catchment during the 20 year, 100 year and 2000 year Average Recurrence Interval (ARI) design storm events and the Probable Maximum Precipitation (PMP) design event.

2.1.2 Hydrologic model setup

The Tarcutta Creek catchment has a total area of 1660 km^2 upstream of the Old Borambola gauge (Station number 410047). The catchment was divided into 20 sub-catchments to enable greater definition of catchment parameters within the WBNM model. The breakdown, location and area of each sub-catchment are illustrated in Figure 9.

Catchment parameters such as sub-catchment areas, land use, percentage imperviousness, sub-catchment links and channel definition within the catchment were defined based on contour maps, aerial photography, and knowledge of the catchment.

The adopted percentage impervious value of 5 percent was determined based on aerial and ground photography and knowledge of the catchment.

2.1.3 Model parameters

Values adopted to represent initial and continuing losses were based on model calibration (detailed in Section 2.1.8) and recommendations within Australian Rainfall and Runoff (2001). Adopted loss values are detailed in Table 2.

Table 2 Adopted loss values

Event	Pervious areas		Impervious areas	
	Initial Loss (mm)	**Continuing Loss (mm/hr)**	**Initial Loss (mm)**	**Continuing Loss (mm/hr)**
20 year ARI	23	2.5	1	0
100 year ARI	23	2.5	1	0
2000 year ARI	10	2.5	1	0
PMP	10	2.5	1	0

Catchment lag parameters and stream lag factors were adopted based on model calibration. The lag parameter for all sub-catchments was adopted as 1.6 and the impervious lag factor was adopted as 0.1. A stream lag factor of 1 was adopted for the natural channels in the catchment. The adopted factors are within the ranges recommended in *WBNM Theory* (Boyd et al, 2007).

2.1.4 Rainfall intensity duration parameters

Rainfall Intensity Frequency Duration (IFD) parameters were obtained for a central location within the catchment from Australian Rainfall and Runoff, Volume 2 (Engineers Australia 1987, 2001). The IFD parameters adopted for this study and input into the WBNM model developed for the Tarcutta Creek catchment are shown in Table 3.

Table 3 Tarcutta Creek catchment IFD parameters

Variable	Symbol	Value
Rainfall intensity (mm/hr) (2 year ARI; 1 hour storm duration)	${}^{2}I_{1}$	21.9
Rainfall intensity (mm/hr) (2 year ARI; 12 hour storm duration)	${}^{2}I_{12}$	4.30
Rainfall intensity (mm/hr) (2 year ARI; 72 hour storm duration)	${}^{2}I_{72}$	1.15
Rainfall intensity (mm/hr) (50 year ARI; 1 hour storm duration)	${}^{50}I_{1}$	44.00
Rainfall intensity (mm/hr) (50 year ARI; 12 hour storm duration)	${}^{50}I_{12}$	7.50
Rainfall intensity (mm/hr) (50 year ARI; 72 hour storm duration)	${}^{50}I_{72}$	1.85
Average coefficient of skewness	G	0.22
Geographical factor (2 year ARI)	F2	4.305
Geographical factor (50 year ARI)	F50	15.35

2.1.5 PMP calculations

PMP storms were calculated based on procedures outlined in the *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method* (Bureau of Meteorology, 2006) and *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method* (Bureau of Meteorology, 2003).

As outlined in the guidebooks, the Generalised Short-duration Method (GSDM) was used for the 3 and 4.5 hour duration events, while the Generalised Southeast Australia Method (GSAM) was used for the 24 hour and above durations. An envelope curve (Figure 2) was fitted to the GSDM and GSAM preliminary rainfall depth estimates to determine the rainfall depths of the intermediate durations.

The GSAM method requires input of three spatially varying factors. It was found that the Topographic Adjustment Factor (TAF) varied significantly over the catchment. Therefore, the catchment was sub-divided into three sections in order to properly estimate the preliminary GSAM PMP depths. Parameters used for the GSDM and GSAM methods are shown in Table 4 and Table 5.

Table 4 GSDM PMP parameters

Parameter	Value
Moisture adjustment factor	0.75
Elevation adjustment factor	2
Percentage defined as ‘rough’	25

Table 5 GSAM PMP parameters

Parameter	Catchment section		
	1	2	3
Centroid of sub-division (Easting)	563173.99	565839.41	586526.6
Centroid of sub-division (Northing)	6094362.04	6074260.00	6061531.07
Extreme precipitable water (annual)	66.28	66.28	66.28
Extreme precipitable water (autumn)	53.59	53.59	53.59
Topographic adjustment factor	1.05	1.08	1.22

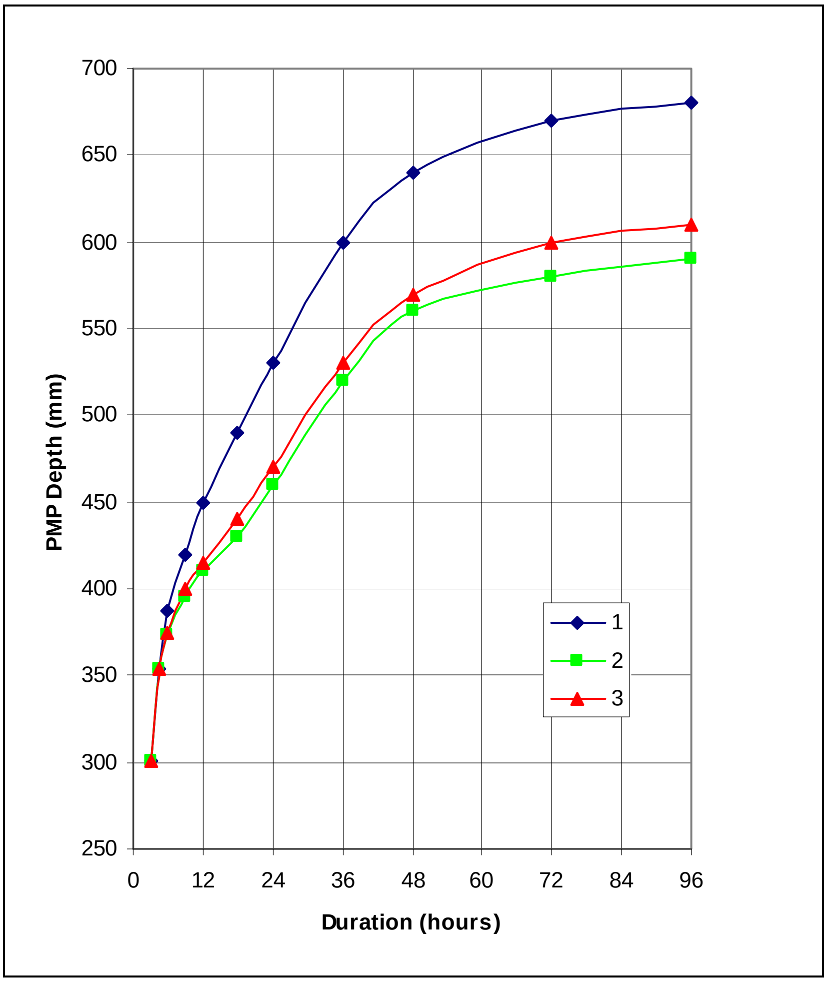

Figure 2 Tarcutta Catchment – PMP enveloping curve

2.1.6 2000 year ARI calculations

The 2000 year ARI rainfall depths were calculated based on recommendations within Australian Rainfall and Runoff (2001). As per the PMP calculations, the catchment was split into three sections, due to the calculation method using interpolation between the 50 and 100 year ARI and PMP events.

2.1.7 Climate change

'Climate change' refers to future changes in climate that are driven by an increase in heat from the sun, retained in the Earth's atmosphere. There is presently a general consensus amongst climate experts that climate change is occurring and that most of the warming observed over the last 50 years is attributable to human activities that have increased atmospheric concentrations of greenhouse gases (IPCC 2007).

Evidence of climate change has been identified by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2006) to include increased average temperatures, changes in annual rainfall and increased climate extremes (more intense droughts and extreme rainfall events).

In the Murrumbidgee catchment (within which this project is located), the future climate is likely to experience increased extreme rainfall events. The CSIRO predicts a five per cent increase in extreme rainfall (1 in 40 year ARI 1 day rainfall event) in 2070 (CSIRO 2007). Given the uncertainties in hydrologic estimates including the estimation of the design rainfalls, design temporal patterns, loss rates and areal reduction factors, a change in rainfall of 5% for a large catchment such as Tarcutta Creek would be considered to be within the order of accuracy of model estimates. Therefore, a 5% increase in rainfall intensities scenario was not assessed.

Additionally, current advice on how to incorporate potential impacts of climate change into the flood study process is provided in *Floodplain Risk Management Guideline: Practical Consideration of Climate Change (DECC, 2007).* This guideline recommends sensitivity analyses looking at low, mid and high sea level rises (0.18, 0.55 and 0.91m), in combination with low, mid and high level rainfall intensity increases to assess changes in flood behaviour.

In line with the DECC guideline, rainfall intensities for the 100 year ARI event within the WBNM model were increased by 10%, 20% and 30% in a series of model runs to assess a range of potential climate change scenarios. Peak flows estimated for each of these three scenarios are listed in Table 6. As expected increases in rainfall intensity may result in increased flows that would potentially lead to increased water levels, changes time to peak, and increased velocities.

Table 6 Tarcutta Creek climate change results – 100 year ARI (m^3/s)

Location	10% increase in rainfall intensity	20% increase in rainfall intensity)	30% increase in rainfall intensity
Tarcutta Creek – upper catchment (T5 outflow)	419	495	577
Umbango Creek – discharge to Tarcutta Creek (U3 outflow)	551	652	757
Keajura Creek – discharge to Tarcutta Creek (K3 outflow)	201	237	274
Tarcutta Creek – upstream of Tarcutta township (T6 outflow)	952	1,131	1,317
Tarcutta Creek – downstream of Tarcutta township (T7 outflow)	1,118	1,325	1,540
Tarcutta Creek – at Old Borambola gauge (T11 outflow)	1,115	1,330	1,555

To accommodate the predicted impact of climate change, further flood modelling assessment of potential climate change impacts would be undertaken, as necessary, during the detailed design and would be in consultation with DECC.

2.1.8 Model calibration

Model calibration involves adjusting one or more of the model parameters in order to match observed or measured data. Streamflow data was available from the Tarcutta Creek at the Old Borambola gauge (Station number 410047). Six minute Pluviograph rainfall intensity data was available from four rainfall gauges close to the catchment; Hume Reservoir (72023), Wagga Wagga Amo (72150), Adelong (Etham Park) (72159) and Tooma (Eudlo) (72163).

The two events (October 1992, October 1993) that were used for calibration for the preliminary flood investigation were selected. In addition to these events, the September 2000 and September 2005 events were also selected for calibration purposes. Limited recorded peak water levels were available for the September 2005 event.

Calibration involved the following procedure:

- Baseflow was subtracted from the recorded hydrographs.
- The Initial Loss was adjusted so that the modelled volume matched the recorded volume.
- The lag parameter C was adjusted to match peak discharge values.

Data Quality

The quality of the rainfall and streamflow data varied for each calibration event. An analysis of the quality of rainfall data and streamflow data are shown in Table 7 and Table 8.

Table 7 Rainfall data quality

Rain Gauge	October 1992	October 1993	September 2000	September 2005
72023	Full record	Full record	Full record	Full record
72150	Mostly complete, with 24h period with interpolated data	Mostly complete, with 24hr period with interpolated data	No data available	Full record
72159	No data available	Full record	Full record	Significant amount of interpolated data
72163	No data available	No data available	Full record	Full record

Table 8 Tarcutta Creek at the Old Borambola gauge (410047) data quality

Calibration event	PINNEENA quality code (at event peak)	Hydrographer's comments
October 1992	130 – not quality coded	No comment available
October 1993	130 – not quality coded	No staff gauge, orifice post knocked over at 45 degrees, orifice loose in holder.
September 2000	91 – Theoretical segment of curve that has been derived by two theoretical means (which agree within 20%) and has not been substantiated by discharge observations	Orifice washed out during this event. Trace was badly affected by orifice instability during this period. Records heavily edited during this event to remove spikes and hunting plus large rises in trace. Also edited to height at commencement of flood and back to gauge height observed on the 11th. Actual peak height of event has been estimated using profile, confirmed by survey to within +/- 0.100m from a very faint silt mark in the grass and commencement/end heights.
September 2005	91 – Theoretical segment of curve that has been derived by two theoretical means (which agree within 20%) and has not been substantiated by discharge observations	No comment available

Calibration Results

The calibration parameters for each calibration event are plotted in Figure 3. Total event discharge volumes are shown in Table 9. The resulting hydrographs are shown in Figure 4 to Figure 7.

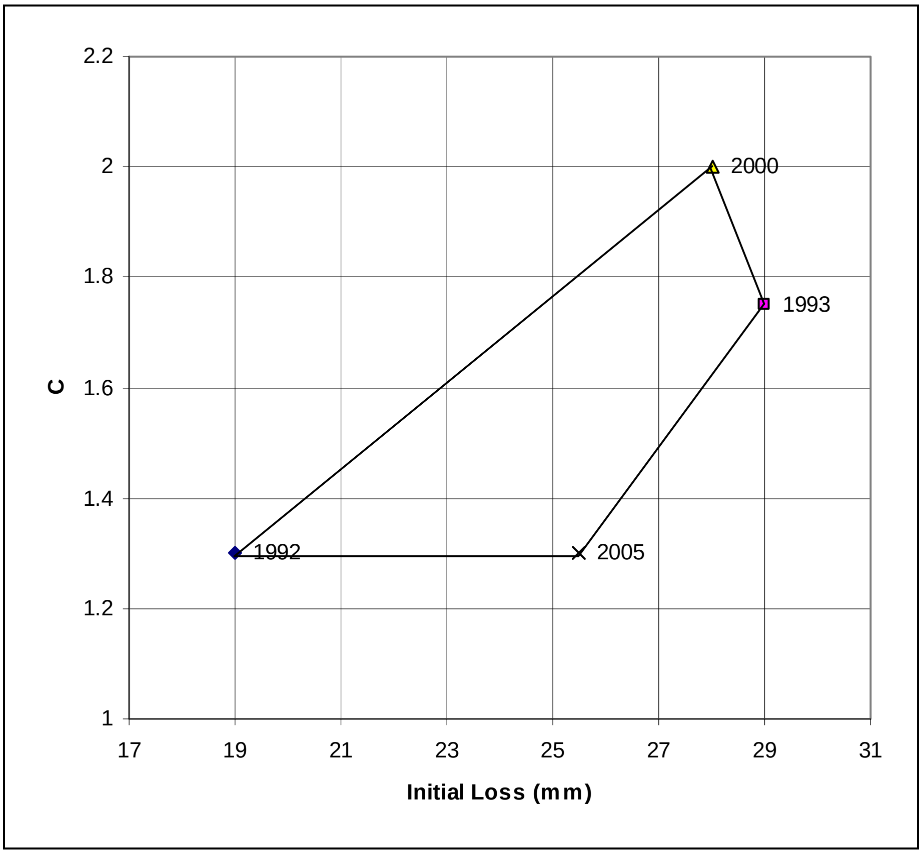

Figure 3 **Calibration parameters for calibration events**

Table 9 **Total discharge volumes**

Event	Recorded (ML)	WBNM model (ML)	Difference (ML)	Difference (%)
October 1992	32984	34892	1908	5.8
October 1993	38525	36414	2111	5.5
September 2000	20208	24053	3845	19.0
September 2005	21834	21755	79	0.4

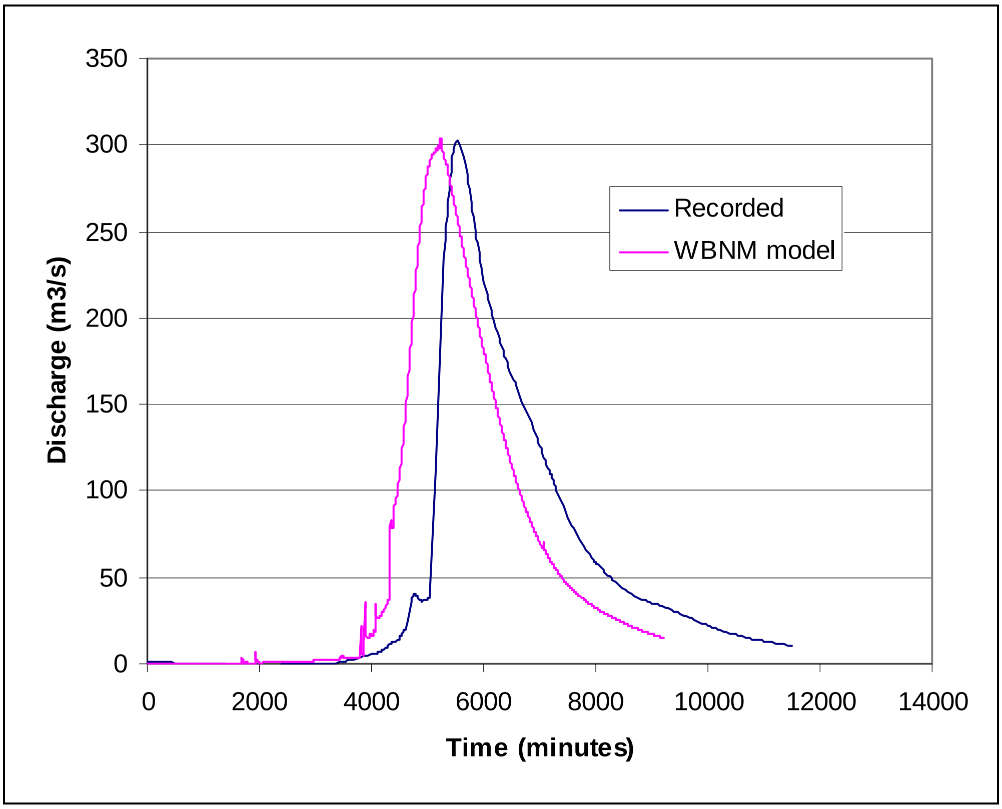

Figure 4 **October 1992 event hydrograph comparison**

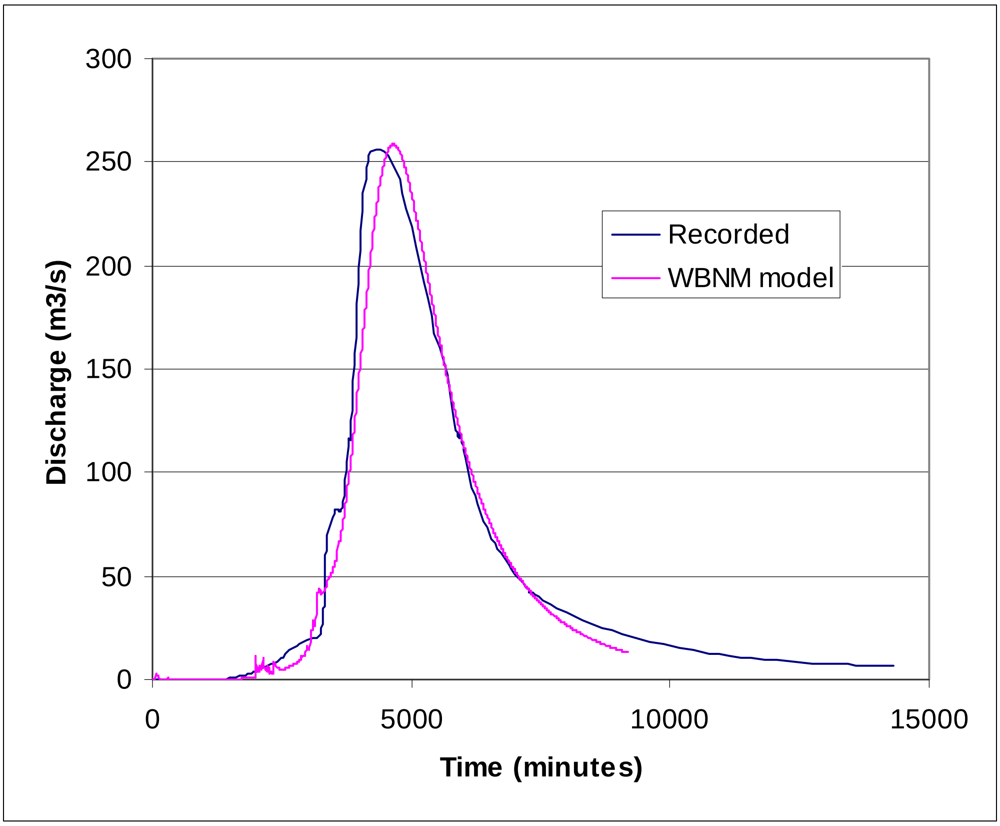

Figure 5 **October 1993 event hydrograph comparison**

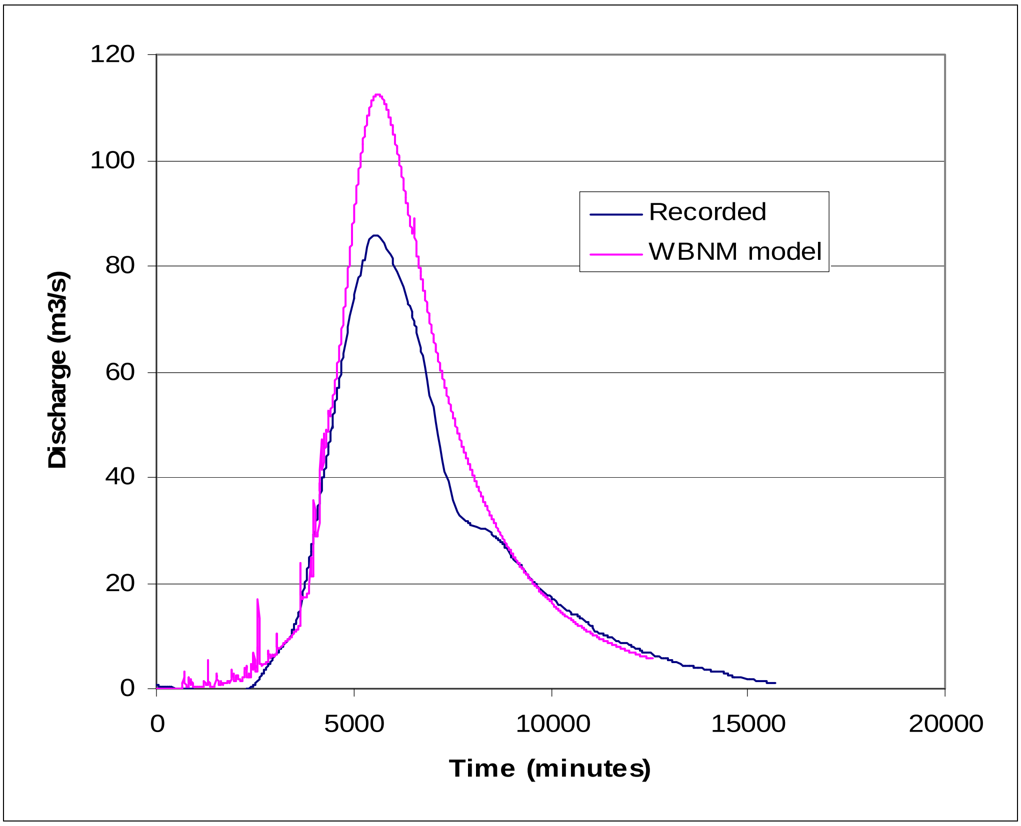

Figure 6 September 2000 event hydrograph comparison

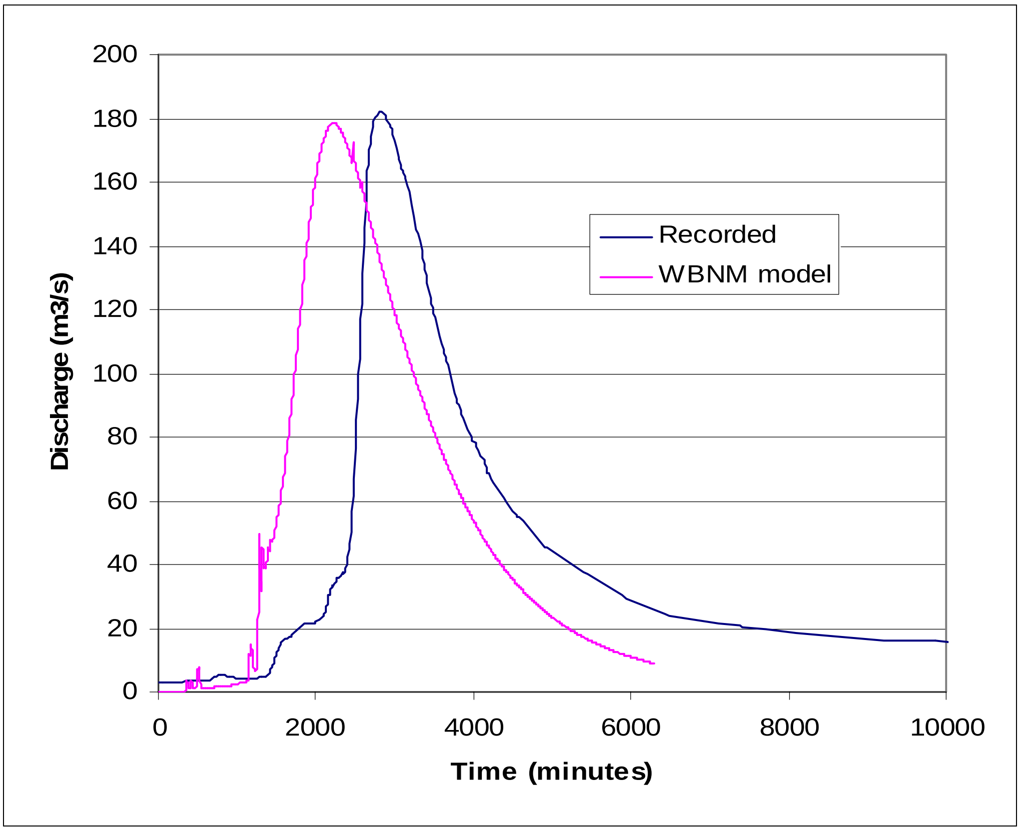

Figure 7 September 2005 event hydrograph comparison

The hydrographs obtained from the calibrated WBNM model were used as input into the TUFLOW model developed for this study to enable calibration against the recorded peak water levels for the September 2005 event. The results are shown in Table 10.

Table 10 Comparison of peak water levels for September 2005 event

Location	Recorded (mAHD)	Modelled (mAHD)	Difference (m)
Upstream Farm Bridge	231.69	231.4	-0.29
Tarcutta Hotel	227.35	226.9	-0.45

Discussion

The modelled total discharge volume and peak discharge show reasonable agreement with recorded values. The hydrograph peak for the September 2000 event was purposely not matched due to the recorded hydrograph being "heavily edited" (NSW Department of Water and Energy (2009). However, the modelled rising and falling limb of the hydrograph compared well with the recorded hydrograph. It is also noted that the modelled October 1992 and September 2005 events produce reasonable results with a shift in timing compared to the recorded hydrographs. However, the response time of the rising limb of the hydrograph is comparable in both cases, which may suggest spatial differences in rainfall patterns between the recorded rainfall and the rainfall actually received by the catchment.

As shown in Table 10, modelled peak water levels for the September 2005 event were in the order of 0.3m to 0.5m below the recorded levels. Further investigation has revealed that the 20 year ARI event (approximately 345 m^3/s or 180% higher than the September 2005 event) results in water levels closer to, but still lower than the recorded September 2005 event. Considering details of the recorded levels are unavailable (including accuracy, nature and location of water levels marks and survey accuracy), it is difficult to confirm the validity and usability of the recorded levels for model calibration purposes.

Calibration resulted in large deviations in model parameters for each calibration event, as shown in Figure 3. For the purposes of design flood events it is necessary to adopt one set of model parameters. A lag parameter of 1.6 was adopted, based on this value being recommended in *WBNM Theory* (Boyd et al, 2007) for ungauged or un-calibrated catchments. This value also equals the mean lag parameter value for the calibration events. An Initial Loss of 23 millimetres was adopted for the 20 year and 100 year ARI events. This value represents the conservative low bound solution when adopting a lag parameter of 1.6. Given the calibration events each represent comparatively low flow events, applying the calibrated model parameters to large to extreme events, when wet antecedent conditions are likely to occur, must be approached with caution. Therefore, an Initial Loss value equal to 10 millimetres was adopted for the 2000 year ARI and PMP events.

2.2 Hydraulic Modelling

2.2.1 Model overview

A hydraulic model of the Tarcutta Creek floodplain was developed using the two dimensional hydraulic modelling software, TUFLOW. TUFLOW is an implicit finite difference model which is specifically orientated towards establishing flow patterns in coastal waters, estuaries, rivers, floodplains and urban areas. The software has the ability to dynamically link to the one dimensional (1D) network hydrodynamic program ESTRY, meaning that both the two dimensional (2D) and one dimensional (1D) domains are combined to form one model. This has the advantage of increased resolution and accuracy for in-channel flows, which are essentially 1D in nature, while still accurately modelling the complex floodplain flows and their interaction with channel flows.

2.2.2 Model development

Model extent

The Tarcutta Creel TUFLOW model was developed to represent the Tarcutta Creek, Keajura Creek, and their respective floodplains in the vicinity of Tarcutta. The extent of the Tarcutta Creek TUFLOW model is illustrated in Figure 10.

The TUFLOW model is based on a one-dimensional component representing the main flow paths of Tarcutta Creek and Keajura Creek cut through the two-dimensional domain, representing the overbank floodplain areas. This enables a larger cell size to be used, resulting in faster simulation times, without compromising the resolution of the main channels.

Two-dimensional (2-D) domain

Grid definition

The 2D domain within a TUFLOW model is defined based on a network of square cells, known as a grid. The resolution of the grid (cell size), is adopted based on the modelling objectives and required definition within the floodplain. For the Tarcutta Creek model, a 10 metre grid size was adopted.

Each grid cell was assigned an elevation based on a Digital Elevation Model (DEM) developed from the Airborne Laser Scanning (ALS) data and railway survey provided by AAMHATCH.

Hydraulic floodplain structures

Significant hydraulic structures were manually input into the TUFLOW model. This included z-lines to correctly represent the flood levees, railway embankment, existing Hume Highway embankment and proposed Hume Highway embankments. Bridges were generally modelled within the 1-D domain. The existing Hume Highway Bridge over the Tarcutta Creek Floodway, the Proposed Hume Highway Bridge over Tarcutta Creek and the Proposed Hume Highway Bridge over Tarcutta Creek Floodway were modelled in the 2-D domain using flow constrictions. The locations of hydraulic structures included in the model are shown in Figure 10.

One-dimensional (1-D) domain

Channel definition

The 1D domain within TUFLOW represents watercourses through a network of channels (representing the conveyance of flows) and nodes (representing the storage of inundated areas). For the Tarcutta Creek model, the main channel was defined along the centrelines of the Tarcutta Creek and Keajura Creek and the storage at nodes was defined based on channel cross sections. The TUFLOW model assumes no moveable channel bed.

The channel cross-section data were extracted from the DEM and checked against RTA surveyed cross-sections along Tarcutta Creek. The cross-sections are spaced at 50m to 100m intervals. Cross-sections were trimmed to the main channel or extended as needed to adequately define the 1D network for the purposes of the TUFLOW modelling.

Hydraulic structures

As stated above, bridges were generally modelled within the 1-D network, where bridge loss tables were developed in accordance with AustRoads Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways (1994). Bridges modelled included:

- Existing Hume Highway Bridge over Tarcutta Creek
- Existing Hume Highway Bridge over Keajura Creek
- Three smaller existing farm bridges
- Proposed Hume Highway Bridge over Keajura Creek

The existing bridge over Keajura Creek will remain and be utilised for the bypass on-ramp. The locations of hydraulic structures included in the model are shown in Figure 10.

Manning's Roughness

The Manning's roughness factors for the channel and floodplain were selected based on the orthophotography, land use and field photos of Tarcutta Creek. Tarcutta and Keajura Creek channels are characterised by the presence of aquatic vegetation and debris along the channel banks. The floodplain areas are mostly agricultural pasture land. Manning's n-values were input into the TUFLOW materials database as listed in Table 11.

Table 11 Manning's values used in TUFLOW model

Model location	Description	Manning's n
In channel (1-D) areas	Aquatic vegetation and snags/debris present in channel	0.04
	Aquatic vegetation and snags/debris present in channel with spare bush on channel banks	0.045
Overbank floodplain (2-D) areas	Agricultural pasture land	0.035
	Agricultural crop land	0.04
	Sparse bush land	0.05
	Urban areas	0.10*
	Roads	0.015

* *The manning's roughness value for urban land use is set much higher than the actual manning's roughness of the surfaces present in these areas. This is a hydraulic modelling approach used to represent the buildings in these areas that have been filtered out of the DEM. By applying this approach, flow through residential areas is severely restricted as it would be if the buildings were present in the model, however floodplain storage volume (including that which occurs within buildings) is still accounted for. This approach has been adopted together with 'blocking out' significant buildings within the floodplain.*

Boundary Conditions

Flow inputs

Flow hydrographs extracted from the WBNM hydrologic model were input to the TUFLOW model. Hydrographs were applied at the upstream boundaries of Tarcutta and Keajura Creeks, and an area flow hydrograph applied directly onto the 2-D domain over the model to represent the local catchment flows.

Inflow hydrographs applied to the model were the design 20 year, 100 year and 2000 year ARI and PMF design events. The September 2005 historical event was also applied to the model for calibration purposes.

Downstream Boundary Conditions

As only a portion of Tarcutta Creek was modelled in this study, the flood levels at the downstream model boundary were defined through a stage-flow relationship curve. The downstream cross-section information was input into a HEC-RAS model and multiple profiles for various flows were run to develop the stage-flow table utilised by TUFLOW (an HQ type boundary) for the boundary conditions.

2.2.3 Model Calibration and Verification

Observed High Water Marks

As detailed in Section 2.1.8, the observed high water marks at two locations for the historical September 2005 flood event were used for calibration purposes. There is some doubt over the validity or applicability of these observed high water marks. Therefore, sensitivity analysis on the TUFLOW model parameters will be undertaken for the final design.

3. Assessment Findings and Results

3.1 Hydrologic model results

3.1.1 Critical durations

The Tarcutta Creek WBNM model was run for a range of standard durations for the design 20, 100 and 2000 year ARI and PMP events. The duration resulting in the maximum peak discharge for each event was adopted as the critical duration for that event. These critical durations are shown in Table 12.

Table 12 Critical durations

Event	Critical duration (hours)
20 year ARI	30
100 year ARI	18
2000 year ARI	6
PMP	6

3.1.2 Peak flows

Peak flows estimated by the WBNM model of the Tarcutta Creek catchment at key locations within the catchment are listed in Table 13. The locations represent the major tributaries within the catchment, and key inflow locations for the hydraulic model (TUFLOW) developed for Tarcutta Creek.

Table 13 Tarcutta Creek peak flows, (m^3/s)

Location	20 year ARI	100 year ARI	2000 year ARI	PMP
Tarcutta Creek – upper catchment (T5 outflow)	198	343	866	3,335
Umbango Creek – discharge to Tarcutta Creek (U3 outflow)	254	451	1,160	4,348
Keajura Creek – discharge to Tarcutta Creek (K3 outflow)	91	166	446	1,697
Tarcutta Creek – upstream of Tarcutta township (T6 outflow)	449	779	1,956	7,471
Tarcutta Creek – downstream of Tarcutta township (T7 outflow)	525	914	2,267	8,586
Tarcutta Creek – at Old Borambola gauge (T11 outflow)	524	905	2,203	8,055

3.1.3 Choice of flood estimation method

Australian Rainfall and Runoff (AR&R) (2001) provides guidance on the appropriate choice of flood estimation method. For this study, two methods of flood estimation were undertaken; a flood frequency analyses (adopted from the previous study RTA 2008)) and the PB design rainfall event model (WBNM).The design peak flows were adopted by:

- defining the Annual Exceedance Probability (AEP*) at which one method of flood estimation is considered to become more accurate than another, i.e. the AEP where the WBNM model becomes more accurate than flood frequency analysis. This AEP is defined where the accuracies of the two methods are equal and termed the AEP of indifference.
- selection of design peak flows based on one of two approaches:
  - adopt the flood frequency values for events up to the AEP of indifference, and adopted the rainfall based method values for events above the AEP of indifference;
  - adopt the flood frequency values for events up to the AEP of indifference, and adopt a weighted average between the two methods based on their relative accuracies for events above the AEP of indifference..

As discussed in Section 1.3 above, WMA performed a flood frequency analysis and analysis of gauging, rating tables and cross section information and recommended that the 20% AEP (approximately 5 year ARI) event be adopted as the AEP of indifference for the previous study. This was based on the number of gaugings and fit of the flood frequency curve up to this AEP. Only one gauging exists above this AEP and the flood frequency curve exhibits extremely high negative skew. WMA recommend that the second approach from above be selected to estimate the design flows for the previous study, where values above the AEP of indifference were adopted based on weighted averages between the previous WBNM model and the flood frequency analysis. WMA recommend that a value of approximately 750 m^3/s was suitable for the 1% AEP event for the Preliminary Flood Investigation (RTA 2008). Full details of the analyses were not available for this study.

As such, it was not possible to carry out this type of Bayesian analysis in the current study, as some variables obtained from the flood frequency analysis process were not available for review. However, the AEP of indifference recommend from the previous study was adopted for the current study, and the first approach from above was selected to estimate the design flows; the 5 year ARI peak value was adopted as the mean between the flood frequency analysis and the PB WBNM model, and the 20 year, 100 year, 2000 year and PMP peak values are adopted from the PB WBNM model as listed in Table 13. Flood frequency curves for the different methods are shown in Figure 8.

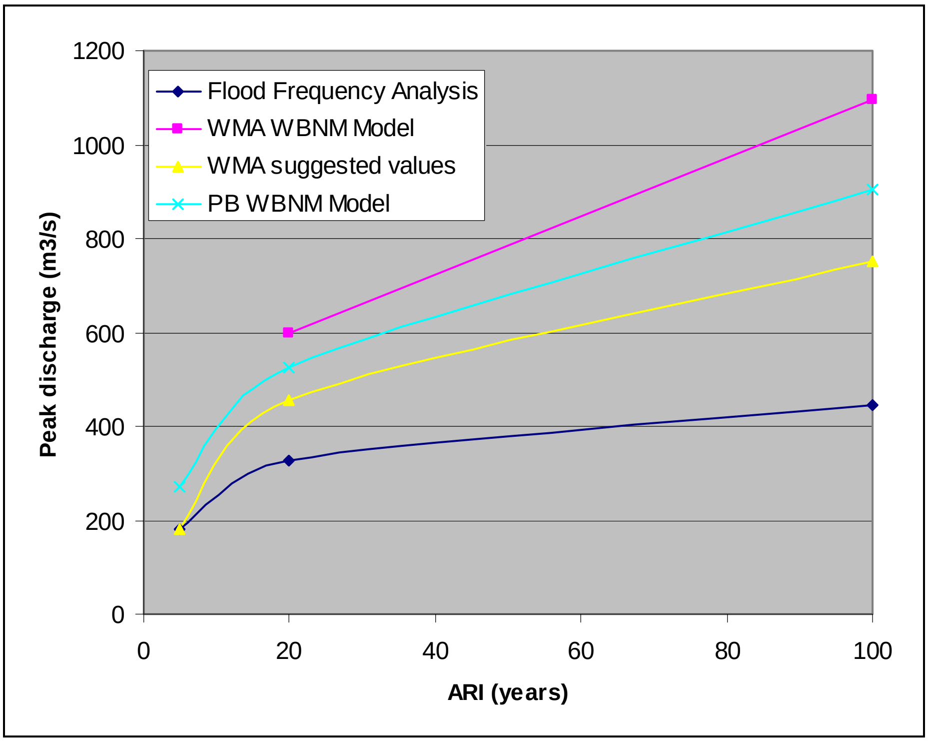

Figure 8 Frequency curves for different methods

*Note that the AEP is the probability of a particular rainfall amount for a specified duration being equalled or exceeded in any 1 year period or as "on the average once in every x years" (an average recurrence interval, or ARI, of x years). As such, the 20 year, 100 year and 2000 year ARIs can be expressed as 5%, 1% and 0.05% AEPs, respectively.

3.2 Hydraulics

3.2.1 Model scenarios

The TUFLOW model was run for the 20, 100 and 2000 year ARI and the PMF design events to assess the impact of the proposed highway bypass. Two hydraulic scenarios have been modelled using the TUFLOW model; the existing and the proposed scenario.

3.2.2 Model results

Tables 14 through 17 list detailed results for each of the modelled design events for the existing and proposed conditions at key locations within the study area.

Table 14 Peak water level results (mAHD)

Location	Event	Existing (mAHD)	Proposed (mAHD)	Impact (Afflux*) (m)
Property				
Residential Property 1	20 year ARI	227.69	227.70	0.01
	100 year ARI	228.02	228.06	0.04
	2000 year ARI	228.81	229.06	0.26
	PMF			
Residential Property 2	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	229.61	229.62	0.01
	2000 year ARI	230.61	230.69	0.08
	PMF			

Water treatment plant	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	227.72	227.75	0.03
	2000 year ARI	229.02	229.16	0.15
	PMF			
Tarcutta Hotel	20 year ARI	227.33	227.34	0.01
	100 year ARI	227.61	227.71	0.10
	2000 year ARI	228.73	228.94	0.21
	PMF			
No 6 - Building 1	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	227.71	227.75	0.03
	2000 year ARI	229.07	229.22	0.15
	PMF			
No. 8 - Building 2	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	227.72	227.75	0.03
	2000 year ARI	229.11	229.25	0.14
	PMF			
No. 10 - Building 3	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	227.87	227.87	0.00
	2000 year ARI	229.16	229.29	0.14
	PMF			
No. 12 - Building 6	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2000 year ARI	229.26	229.39	0.13
	PMF			
Police House (Building 4)	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2000 year ARI	229.09	229.24	0.14
	PMF			
Police station (Building 5)	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2000 year ARI	229.13	229.27	0.15
	PMF			
Service Station	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2000 year ARI	228.29	228.65	0.37
	PMF			
Shop	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2000 year ARI	229.00	229.13	0.13
	PMF			
Bridges				
Existing Hume Highway bridge over Tarcutta Creek	20 year ARI	228.61	228.62	0.01
	100 year ARI	229.38	229.40	0.02
	2000 year ARI	230.32	230.43	0.11
	PMF			
Existing Hume Highway bridge over Tarcutta Creek floodway	20 year ARI	228.54	228.55	0.01
	100 year ARI	229.20	229.21	0.01
	2000 year ARI	229.97	230.06	0.09
	PMF			
Existing Hume Highway bridge over Keajura Creek	20 year ARI	230.53	230.53	0.00
	100 year ARI	231.44	231.42	-0.03
	2000 year ARI	232.49	232.57	0.09
	PMF			
Proposed Hume Highway bridge over Tarcutta Creek	20 year ARI	226.75	226.88	0.12
	100 year ARI	226.99	227.16	0.18
	2000 year ARI	227.63	228.00	0.36
	PMF			
Proposed Hume Highway bridge over	20 year ARI	227.45	227.49	0.04
	100 year ARI	227.71	227.77	0.06

	2000 year ARI	228.14	228.28	0.14
	PMF			
Proposed Hume Highway bridge over Keajura Creek	20 year ARI	230.66	230.63	-0.03
	100 year ARI	231.54	231.51	-0.02
	2000 year ARI	232.64	232.73	0.09
	PMF			

*Note that while values are listed to the nearest 0.01m for the purpose of this assessment, the accuracy of model is within the order of (+/- 0.1m)

Table 15 Approximate duration of inundation (hours)

Location	Event	Existing	Proposed	Impact
Residential Property 1	100 year ARI	15	15	0
Residential Property 2	100 year ARI	8.5	8.5	0
Water treatment plant	100 year ARI	9.5	11	1.5
Tarcutta Hotel	100 year ARI	11.5	13	1.5
No 6 - Building 1	100 year ARI	Floor level not inundated	Floor level not inundated	-
No. 8 - Building 2	100 year ARI	Floor level not inundated	Floor level not inundated	-
No. 10 - Building 3	100 year ARI	Floor level not inundated	Floor level not inundated	-
No. 12 - Building 6	100 year ARI	Property not flood affected	Property not flood affected	-
Police House (Building 4)	100 year ARI	Property not flood affected	Property not flood affected	-
Police station (Building 5)	100 year ARI	Property not flood affected	Property not flood affected	-
Service Station	100 year ARI	Property not flood affected	Property not flood affected	-
Shop	100 year ARI	Property not flood affected	Property not flood affected	-

Table 16 Peak discharge (m^3/s)

Location	Event	Existing	Proposed	Impact
Existing Hume Highway Bridge over Tarcutta Creek	20 year ARI	361.31	361.42	0.11
	100 year ARI	617.04	615.75	-1.29
	2000 year ARI	782.06	758.11	-23.95
	PMF	1282.3		
Existing Hume Highway Bridge over Tarcutta Creek Floodway	20 year ARI	162.69	162.43	-0.26
	100 year ARI	260.55	259.78	-0.77
	2000 year ARI	334.82	334.96	0.14
	PMF	605.39		
Existing Hume Highway Bridge over Keajura Creek	20 year ARI	90.65	90.66	0.01
	100 year ARI	182.66	167.47	-15.19
	2000 year ARI	440.45	452.14	11.69
	PMF	1371.1		
Proposed Hume Highway Bridge over Tarcutta Creek	20 year ARI	NA	234.48	NA
	100 year ARI	NA	393.75	NA
	2000 year ARI	NA	1129.36	NA
	PMF	NA		NA

Location	Event	Existing	Proposed	Impact
Proposed Hume Highway Bridge over Tarcutta Creek Floodway	20 year ARI	NA	253.82	NA
	100 year ARI	NA	461.47	NA
	2000 year ARI	NA	969.11	NA
	PMF	NA		NA
Proposed Hume Highway Bridge over Keajura Creek	20 year ARI	NA	90.71	NA
	100 year ARI	NA	194.23	NA
	2000 year ARI	NA	489.81	NA
	PMF	NA	N/A	NA

Table 17 Peak velocities at bridges (m/s*)

Location	Event	Existing	Proposed	Impact
Existing Hume Highway Bridge over Tarcutta Creek	20 year ARI	3.73	3.69	-0.04
	100 year ARI	4.85	4.78	-0.07
	2000 year ARI	4.65	4.31	-0.34
	PMF	7.12		
Existing Hume Highway Bridge over Tarcutta Creek Floodway	20 year ARI	1.71	1.70	-0.01
	100 year ARI	2.40	2.39	-0.01
	2000 year ARI	2.80	2.74	-0.06
	PMF	3.61		
Existing Hume Highway Bridge over Keajura Creek	20 year ARI	1.20	1.16	-0.05
	100 year ARI	1.92	1.69	-0.24
	2000 year ARI	3.75	3.58	-0.18
	PMF	5.20		
Proposed Hume Highway Bridge over Tarcutta Creek	20 year ARI	0.81	0.97	0.17
	100 year ARI	0.92	1.26	0.35
	2000 year ARI	1.47	2.27	0.80
	PMF	2.81		
Proposed Hume Highway Bridge over Tarcutta Creek Floodway	20 year ARI	1.63	1.77	0.14
	100 year ARI	2.19	2.47	0.29
	2000 year ARI	2.85	3.48	0.63
	PMF	3.07		
Proposed Hume Highway Bridge over Keajura Creek	20 year ARI	0.98	1.52	0.54
	100 year ARI	1.41	2.23	0.82
	2000 year ARI	1.82	3.59	1.77
	PMF	2.67		

* Note that while values are listed to the nearest 0.01m/s for the purpose of this assessment, the accuracy of model is within the order of (+/- 0.1m/s)

Table 18 Peak velocities at properties (m/s*)

Location	Event	Existing	Proposed	Impact
Residential Property 1	20 year ARI	0.14	0.19	0.05
	100 year ARI	0.65	0.79	0.14
	2,000 year ARI	0.48	0.36	-0.12
	PMF			
Residential Property 2	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	0.04	0.03	-0.01
	2,000 year ARI	0.56	0.61	0.06
	PMF			
Water treatment plant	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	0.02	0.03	0.01
	2,000 year ARI	0.96	1.01	0.04
	PMF			
Tarcutta Hotel	20 year ARI	0.09	0.08	-0.01
	100 year ARI	0.44	0.35	-0.10
	2,000 year ARI	2.38	2.14	-0.24
	PMF			
No 6 - Building 1	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	0.02	0.02	0.01
	2,000 year ARI	0.70	0.72	0.02
	PMF			
No. 8 - Building 2	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	0.03	0.05	0.02
	2,000 year ARI	0.75	0.77	0.01
	PMF			
No. 10 - Building 3	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	0.00	0.01	0.01
	2,000 year ARI	0.91	0.94	0.03
	PMF			
No. 12 - Building 6	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2,000 year ARI	1.18	1.23	0.05
	PMF			
Police House (Building 4)	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2,000 year ARI	0.58	0.64	0.07
	PMF			
Police station (Building 5)	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2,000 year ARI	0.56	0.63	0.07
	PMF			
Service Station	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2,000 year ARI	0.03	0.08	0.05
	PMF			
Shop	20 year ARI	Protected by levee	Protected by levee	-
	100 year ARI	Not flood affected	Not flood affected	-
	2,000 year ARI	0.31	0.39	0.08
	PMF			

* Note that while values are listed to the nearest 0.01m/s for the purpose of this assessment, the accuracy of model is within the order of (+/- 0.1m/s)

Figures

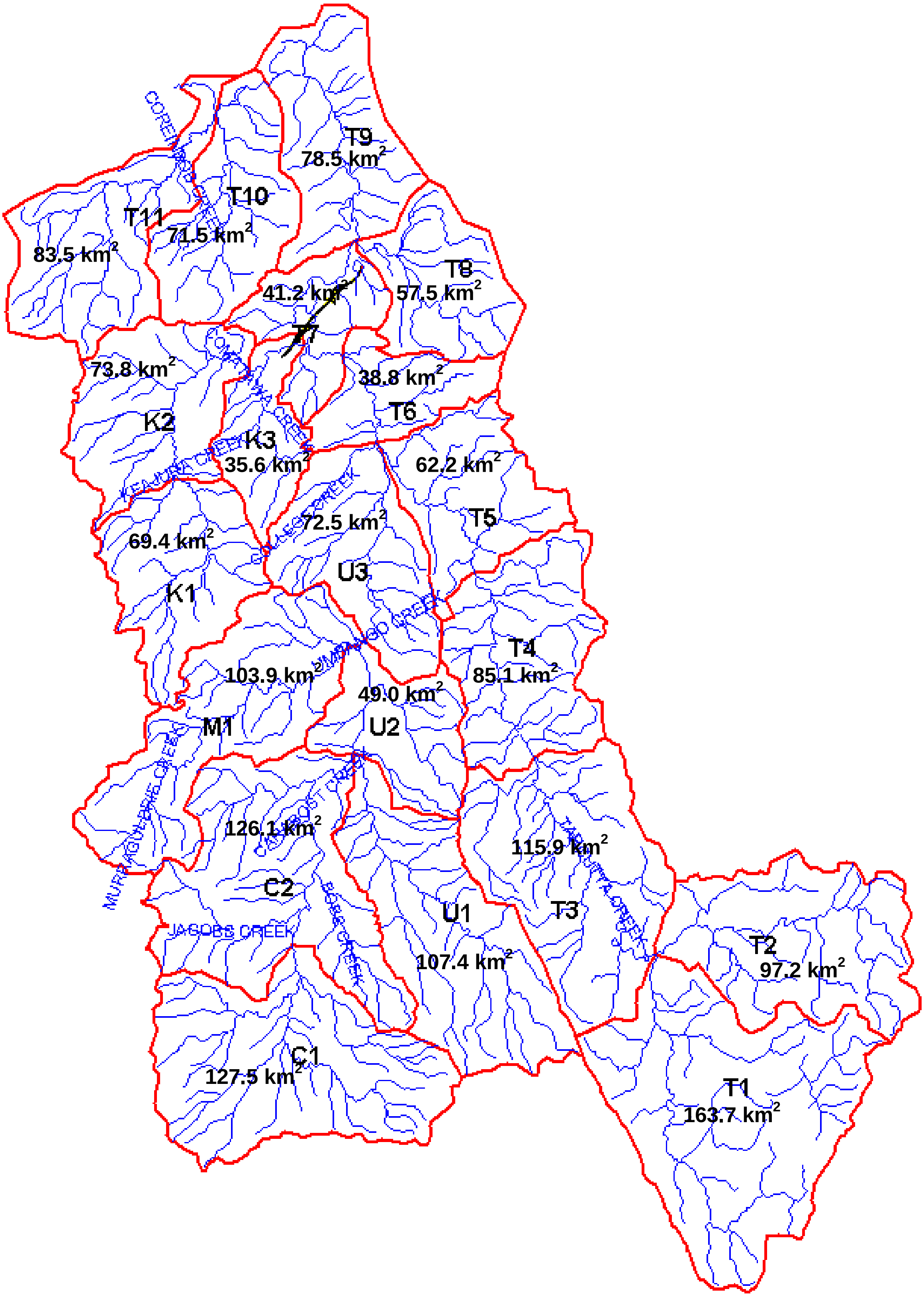

Figure 9 Hydrologic model layout

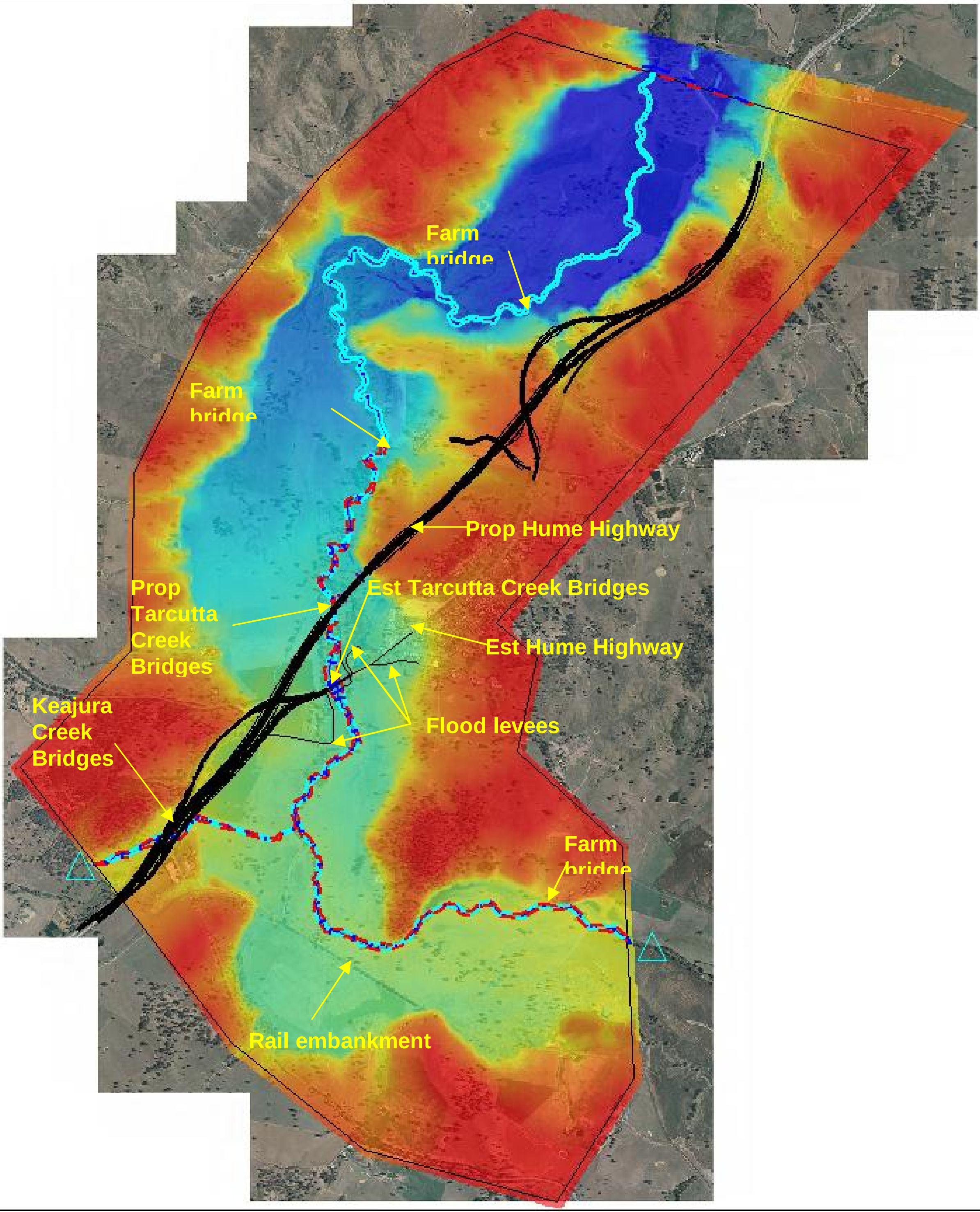

Figure 10 **Hydraulic model layout**

Appendix B

Water quality

Water Qualtiy Guidelines

Parameter	ANZECC Guidelines			DECC Water Quality Objectives for Murrumbidgee River Catchment								
	Ecosystem Protection	**Irrigation Water Supply**	**Stock Water Supply**	**Aquatic Ecosystem Protection**	**Visual Amenity**	**Primary Contact Recreation**	**Secondary Contact Recreation**	**Livestock water supply**	**Irrigation Water Supply**	**Homestead Water Supply**	**Drinking Water**	**Aquatic Foods (cooked)**
pH	6.5 – 7.5	6.0 - 9.0	6.0 - 9.0	6.5 – 8.0	-	5.0 – 9.0	-	-	4.5 - 9.0	6.5 - 8.5	6.8 - 8.5	-
Temperature (^{o} C)	-	-	-	refer to ANZECC Guidelines	-	15-35°C for prolonged exposure	-	-	-	-	-	less than 2°C change over 1 hour
Turbidity	2-25 NTU	-	-	2-25 NTU	-	6 NTU	-	-	-	5 NTU	site specific determinant	-
Suspended Solids	-	-	-	-	-	-	-	-	-	-	-	40 µg/L
Dissolved Oxygen	90 – 110 % saturation	-	-	90-100% stauration	-	-	-	-	-	-	80% saturation	-
Salinity EC (µS/cm) Total Dissolved Solids (mg/L)	30 - 350 µS/cm	crop dependant refer to Table 4.2.5 ANZECC Guidelines	livestock dependant, refer Table 4.3.1 ANZECC Guidelines	30 - 350 µS/cm	-	-	-	refer to ANZECC Guidelines	Crop dependant: refer to ANZECC Guidelines	500 - 100 mg/L	1500 µS/cm	-
Total phosphorus	0.05 mg/L	0.05mg/L	-	0.02 mg/L	-	-	-	-	-	-	-	-
Total nitrogen	0.25 mg/L	5 mg/L	-	0.25 mg/L	-	-	-	-	-	-	-	-
Clarity	-	-	-		< 20% change	< 20% change	< 20% change	-	-	-	-	-
Surface films and litter	-	-	-	-	none visible	none visible	none visible	-	-	-	-	-
Nuisance organisms	-	-	-	-	not in unsightly amounts	not in unsightly amounts	not in unsightly amounts	-	-	-	-	-
Algae	-	-	-	-	-	< 15 000 cells/mL	< 15 000 cells/mL	11 500 cells/mL	none visible	2000 algal cells/ mL	2000 algal cells/ mL	-
Faecal coliforms	-	crop dependant	medain <100/ 100mL	-	-	median < 150 / 100 mL	median < 1000 / 100 mL	geometric mean <100 / 100mL	refer to ANZECC Guidelines	0 per 100mL	0 per 100 mL	<14 mpn /100ml
Enterococci	-	-	-	-	-	median < 35 / 100 mL	median < 230 / 100 mL	-	-	-	-	-
Chemical contaminants	non-toxic levels	-	-	refer to ANZECC Guidelines	-	refer to ANZECC Guidelines	refer to ANZECC Guidelines	refer to ANZECC Guidelines	refer to ANZECC Guidelines	refer to ANZECC Guidelines	refer to ANZECC Guidelines	non-toxic levels

Notes:
- indicates no guideline value available

Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000)

NSW Water Quality Objectives: Murrumbidgee River and Lake George catchment NSW DECC (1998)

Surface water sampling methodology

Surface water samples were collected from dams and creeks by taking a grab sample with a bucket. Field parameters were measured using a Hydrolab water quality meter for water temperature (oC), electrical conductivity (mS/cm), pH, dissolved oxygen (mg/L and % saturation), total dissolved solids (g/L) and redox (mV). Electrodes were calibrated daily according to the manufacturer's specifications.

Samples were collected for analytical laboratory analysis for turbidity, suspended solids, major dissolved cations and anions, dissolved and total metals, nutrients, BTEX, and total petroleum hydrocarbons (TPH). Surface water samples were collected in sample bottles as specified by the laboratory as listed in the table below, with appropriate container preservation where required. Any samples which were highly turbid were analysed for total metals with all other samples being filtered for dissolved metals. Samples for metals were filtered in the field using 0.45□m cellulose acetate membrane filters and preserved in the field by acidification using concentrated analytical grade (HNO3) to pH<2. All samples were kept on ice and couriered to the laboratory within the laboratory holding periods. Analysis of the samples was performed by ALS Laboratory Group (a NATA registered Laboratory) in Smithfield. Standard Chain of Custody (COC) procedures were followed.

Sample bottles and preservation types

Parameter	Preservation
Physical properties – turbidity and suspended solids	1 x 1L plastic, unpreserved
Major cations and anions – Ca, K, Na, Mg, Cl, HCO3, SO4	1 x 250 mL plastic, unpreserved
Total metals	1 x 125 mL plastic, preserved with HNO3 (unfiltered)
Dissolved metals	1 x 125 mL plastic, preserved with HNO3 (field filtered)
Nutrients – NO3-N, NO2-N	1 x 250 mL plastic, unpreserved
Nutrients – Total P, NH3-N	1 x 250 mL plastic, preserved with sulphuric acid to pH<2
BTEX/TPH (C6-C9)	2 x 40 ml amber vials (sodium bisulphate)
TPH (C10-C36)	1 x 1 L amber glass (unpreserved)

Tarcutta
October 2008 Sampling
Surface Water Analytical Results

	Units	LOR	Guideline Values[1] Aquatic Ecosystems	Irrigation Water Supply	Livestock Water Supply	Sampling Results D3	D5	D7	TC1	D6	KC	TC2
Date Sampled						29/10/2008	29/10/2008	29/10/2008	29/10/2008	29/10/2008	30/10/2008	30/10/2008
Easting						E147 45 11.4	E147 44 47.8	E147 43 11.1	E147 43 50.8	E147 44 27.7	E147 43 03.4	
Northing						S38 15 26.9	S38 15 41.4	S35 17 10.5	S35 16 30.7	S35 16 09.5	S35 17 25.8	
Water source type						Dam	Dam	Dam	Creek	Dam	Creek	**DRY**
Water Type						Na-K-Mg-HCO3-Cl	Na-Mg-K-HCO3-Cl	K-Mg-HCO3	Na-Mg-Ca-HCO3-Cl	K-Na-Mg-HCO3-Cl	Na-Mg-Cl-HCO3	
Field Parameters												
Temperature	°C	0.1	---	---	---	25.64	23.62	27.83	23.8	26.59	19.44	---
Electrical Conductivity	mS/cm	1	0.03-0.35	1-8[a]	0-7.5[b]	0.243	0.374	0.118	0.174	0.132	1.85	---
pH		0.01	6.5-8.0	4.5-9.0	6.0-9.0	6.92	8	8.17	7.99	8.29	6.57	---
Total Dissolved Solids	g/L	0.1	---	---	0-5[b]	0.2	0.2	0.1	0.1	0.1	1.2	---
Dissolved Oxygen	% saturation		90-110	---	---	84.8	80.4	97.7	88.2	80	57.7	---
Redox Potential	mV	1	---	---	---	85	75	79	103	80	205	---
Physical Parameters												
Suspended Solids	mg/L	1	---	---	---	17	10	30	10	23	73	---
Turbidity	NTU	0.1	2-25	---	---	18.3	9.8	44.1	10.1	26.2	41.2	---
Alkalinity												
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	---	---	---	<1	<1	<1	<1	<1	<1	---
Carbonate Alkalinity as $CaCO_3$	mg/L	1	---	---	---	<1	<1	<1	<1	<1	<1	---
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	---	---	---	70	95	35	50	50	340	---
Total Alkalinity as $CaCO_3$	mg/L	1	---	---	---	70	95	35	50	50	340	---
Dissolved Major Anions												
Sulfate as SO_4	mg/L	1	---	---	<1000	8	10	2	6	6	115	---
Chloride	mg/L	1	---	<175, >700[c]	---	22	46	6	17	9	321	---
Dissolved Major Cations												
Calcium	mg/L	1	---	---	1000	5	10	2	6	4	69	---
Magnesium	mg/L	1	---	---	---	5	12	4	6	3	77	---
Sodium	mg/L	1	---	<115, >460[c]	---	22	28	4	14	7	196	---
Potassium	mg/L	1	---	---	---	20	27	14	3	14	6	---
Dissolved Metals												
Cobalt	mg/L	0.001	---	0.05[e]	1	<0.001	<0.001	0.002	<0.001	---	<0.001	---
Lead	mg/L	0.001	0.0034	2[e]	0.1	0.001	0.001	0.001	<0.001	---	<0.001	---
Zinc	mg/L	0.005	0.008	2[e]	20	0.034	0.044	0.041	0.068	---	0.053	---
Total Metals												
Cobalt	mg/L	0.001	---	---	---	---	---	---	---	0.002	---	---
Lead	mg/L	0.001	---	---	---	---	---	---	---	0.004	---	---
Zinc	mg/L	0.005	---	---	---	---	---	---	---	0.054	---	---
Nutrients												
Nitrite + Nitrate as N	mg/L	0.01	7[d] (Nitrate)	---	<400 Nitrate, <30 Nitrite	0.29	0.34	0.03	<0.01	0.03	<0.01	---
Total Kjeldahl Nitrogen as N	mg/L	0.1	---	---	---	2.3	2.2	2.5	0.2	2.4	0.7	---
Total Nitrogen as N	mg/L	0.1	0.25	5	---	2.6	2.5	2.5	0.2	2.4	0.7	---
Total Phosphorus as P	mg/L	0.01	0.02	0.05	---	0.1	0.09	0.03	<0.01	0.16	0.07	---
Oil & Grease	mg/L	5	---	---	---	<5	<5	<5	<5	<5	---	---
Monocyclic Aromatic Hydrocarbons												
Benzene	µg/L	1	600[d]	---	---	<1	<1	<1	<1	<1	<1	---
Toluene	µg/L	2	---	---	---	<5	<5	<5	<5	<5	<5	---
Ethylbenzene	µg/L	2	---	---	---	<2	<2	<2	<2	<2	<2	---
meta- & para-Xylene	µg/L	2	---	---	---	<2	<2	<2	<2	<2	<2	---
ortho-Xylene	µg/L	2	200	---	---	<2	<2	<2	<2	<2	<2	---
Total Petroleum Hydrocarbons												
C6 - C9 Fraction	µg/L	20	---	---	---	<20	<20	<20	<20	<20	<20	---
C10 - C14 Fraction	µg/L	50	---	---	---	<50	<50	<50	<50	<50	<50	---
C15 - C28 Fraction	µg/L	100	---	---	---	200	<100	200	<100	<100	<100	---
C29 - C36 Fraction	µg/L	50	---	---	---	<50	<50	<50	<50	<50	<50	---

Values non-compliant with Aquatic Ecosystem guidelines
Values non-compliant with Irrigation Water Supply guidelines
Values non-compliant with Livestock Water Supply guidelines

LOR = Laboratory level of reporting

1 Guideline values adopted based on both ANZECC 2000 and DECC WQO (1998)
Values based on Tarcutta area being an upland river area (altitude > 150m)

a Crop dependent. Based on combination of Field Crops and Pastures, the predominant enterprises in the Tarcutta area

b Livestock dependent. Based on the combination of all livestock types with no adverse effects expected

c Crop dependent.

d Level for 95% protection of species in freshwater

e Long term trigger value