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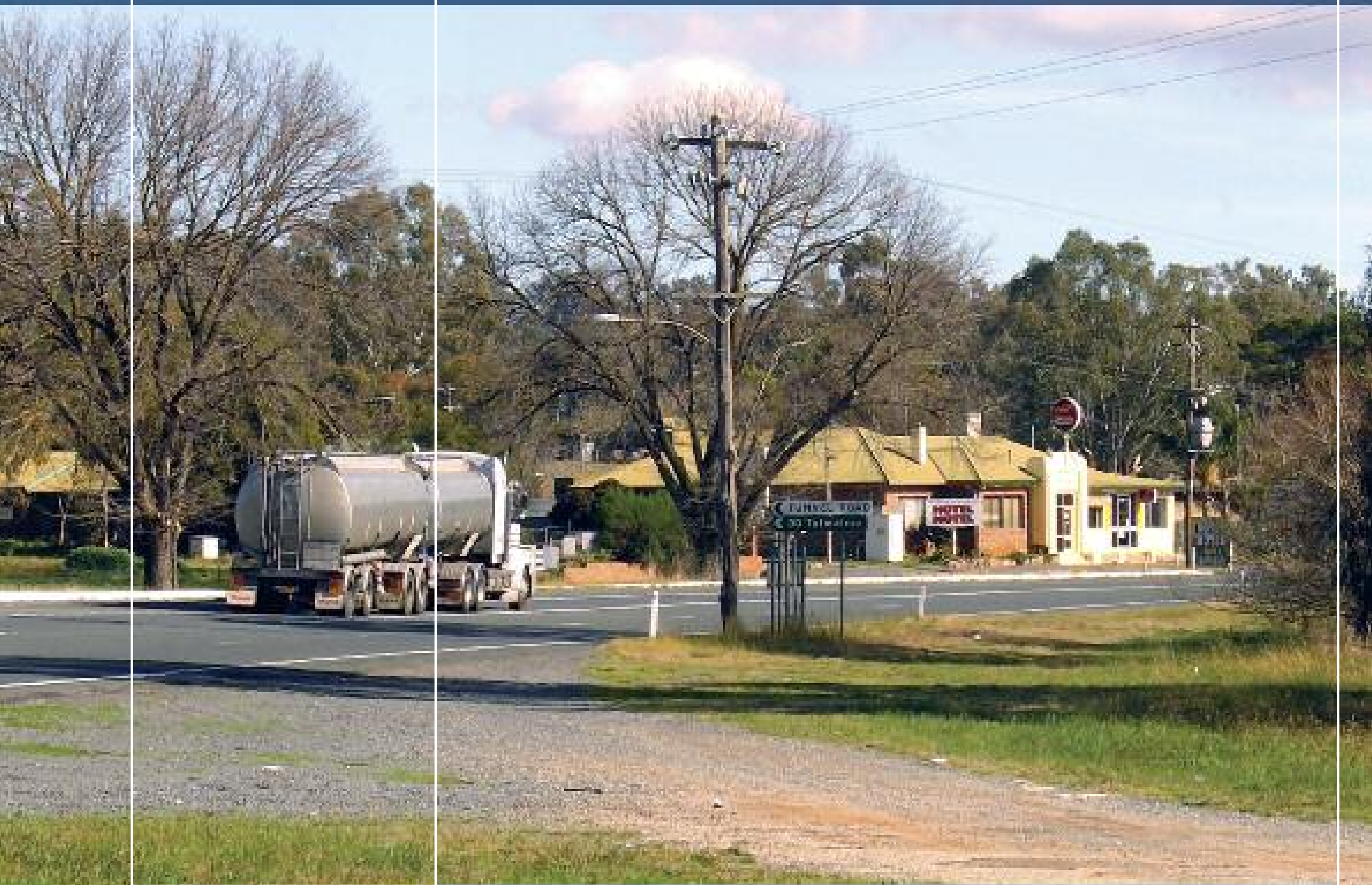

Hume Highway Upgrade

Woomargama bypass

Environmental Assessment
Technical Paper 4 – Groundwater

September 2009

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Hume Highway
Woomargama bypass

Groundwater Environmental Assessment

September, 2009

Roads and Traffic Authority

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Glossary

Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.
Confined aquifer	Where water-bearing rocks are overlain by a confining layer of low permeability strata.
Groundwater	The water contained in interconnected pores located below the watertable in an unconfined aquifer in a confined aquifer.
Groundwater flow	The movement of water through openings in sediment and rock; occurs in the zone of saturation.
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Infiltration	The flow of water downward from the land surface into and through the upper soil layers.
Permeability	The capacity of porous medium for transmitting water.
Recharge area	An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.
Unconfined aquifer	Where the groundwater surface (watertable) is at atmospheric pressure and the aquifer is recharged by direct rainfall infiltration from the ground surface.
Watertable	The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.

List of abbreviations

ADWG	Australian Drinking Water Guidelines
ANZECC	Australian and New Zealand Environment and Conservation Council
bgl	Below ground level
CoC	Chain of Custody
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DECC	Former Department of Environment and Climate Change (now DECCW)
DECCW	Department of Environment Climate Change and Water
DWE	Former Department of Water and Energy (now part of DECCW)
EC	Electrical conductivity
GDE	Groundwater dependant ecosystem
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
GIS	Geographical Information System
GPS	Global Positioning System
PB	Parsons Brinckerhoff Australia
TDS	Total dissolved solids
WA	Water Act
WMA	Water Management Act

List of units

g/L	gram per litre
L/s	litres per second
m AHD	metres Australian height datum
m bgl	metres below ground level
ML	Megalitres
µm	micrometre
mV	milli Volt
m/d	metres per day
mg/L	milligram per litre
mS/cm	milli Siemens per centimetre
µS/cm	micro Siemens per centimetre
ppm	parts per million

Executive summary

Woomargama is located within the NSW South-western Slopes Bioregion, which is characterised by foothills and ranges along the western fall of the Great Dividing Range (PB 2008). The exposed geology of the Woomargama area consists of fractured Ordovician metasediments, Silurian granites and unconsolidated alluvial sediments associated with Mountain Creek and its tributaries, and Sandy Creek. The alluvial deposits are underlain and surrounded by weathered Ordovician metasediments and Woomargama Granite. Outcrops of Woomargama Granite occur to the north and east of Woomargama and Black Rock Granite outcrops to the north of the Woomargama Granite. Ordovician sediments outcrop in and around Woomargama extending towards the south (Adamson and Loudon 1960).

There are two main groundwater flow systems in the Woomargama area — unconfined alluvium, and semi-confined fractured metasediments and fractured granite intrusions. Based on data from the field investigation, groundwater levels in the alluvium are generally shallow and were less than 3 metres below ground level (mbgl) for the Mountain Creek alluvium and slightly deeper for the Sandy Creek alluvium (12.35 mbgl). Water levels in the deeper fractured rock aquifers ranged between 15.9 and 22.4 mbgl, with shallower water levels in the weathered granite deposits (3.9–9.2mbgl). The overall groundwater flow direction in the alluvium is assumed to be towards the north in that alluvium associated with Sandy Creek and towards the north-west in that alluvium associated with Mountain Creek. It is assumed that groundwater in the deeper granite aquifer also flows north-west.

A hydrogeological investigation was conducted in the field at Woomargama over 2 days in May 2009 along the proposed route for the Hume Highway Woomargama Bypass (‘the project’ or ‘the proposed bypass’). The investigation aimed to provide insight into groundwater levels and groundwater quality in the vicinity of the proposed bypass. Water level measurements and groundwater samples were taken from boreholes identified in a preliminary groundwater investigation (PB 2008), Department of Water and Energy (DWE) bore searches and community consultation.

Groundwater salinity (electrical conductivity) in the Woomargama region is typically fresh to brackish, with the exception of bores W3 and GW064591, which exhibited saline conditions. pH conditions were near neutral and dissolved oxygen concentrations were outside Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) and Australian Drinking Water Guidelines (ADWG) guidelines for most bores. Groundwater in the measured Woomargama bores displayed variable ratios in major ions; however, water types were typically mixed cations (Na, Mg, Ca) with bicarbonate and chloride dominance. Bore GW06459 in the Ordovician metasediments, showed some sulphate dominance, while saline bore W3 had a Na-Mg-Cl water type. Dissolved iron and manganese concentrations were above the ADWG values in some bores.

There is limited availability for groundwater supply for road construction from the alluvial sediments associated with Mountain Creek. Small volumes would be available (such as less than 100 megalitres (ML) per year). The RTA has indicated it will need water for batch plants, site compounds and construction. Several DWE registered bores in the vicinity, and/or a newly installed bore in the alluvium would likely supply enough groundwater for the wet and dry batch plants.

The final detailed design of the proposed bypass needs to consider the groundwater system and its users. There is potential for some compaction of the alluvial aquifer as a result of the project. There is also potential for alteration of groundwater flows in the granite aquifers, which may affect springs adjacent to the proposed bypass. The issues of compaction and altered groundwater flow should be considered during the design stage to preventing or alleviate potential impacts to the groundwater system and its users that may arise from the proposed bypass construction.

1. Introduction

The NSW Roads and Traffic Authority (RTA) proposes to construct a highway bypass of the township of Woomargama located on the Hume Highway in south-west NSW (see Figure 1-1). The proposed Hume Highway Woomargama bypass ('the project' or 'the proposed bypass') would improve safety, amenity and convenience for local residents and travel efficiency for through and local traffic.

Parsons Brinckerhoff (PB) was commissioned by the RTA to undertake a desktop assessment of possible options for the bypass route. The study, completed in early 2008, identified a preferred route for the proposed bypass. Option B was selected for the Woomargama area. Most of the selected route is located over granite, crossing Mountain Creek to the west of Woomargama, before proceeding in a northerly direction past the western edge of Mount McKenzie and across Sandy Creek, then rejoining the current highway alignment. The route also crosses several natural drainage lines.

This report details a hydrogeological investigation to assess groundwater conditions at Woomargama and potential impacts of the proposed bypass on those conditions. The assessment has been prepared to meet the Director General's requirements for the Environmental Assessment of the project in relation to groundwater, which include but are not limited to:

- Site water demands and water supply.
- Existing and proposed water licencing requirements under the *Water Act 1912* (WA 1912) and *Water Management Act 2000* (WMA 2000).
- Impacts to groundwater dependent ecosystems.

The assessment aimed to provide insight into groundwater levels and quality to provide baseline measurements (pre-development conditions), against which future results can be compared. The assessment also sought to reaffirm the findings of the previous desktop study (PB 2008).

The report also addresses the likely impacts on groundwater quality and groundwater flow from construction and operation of the project, and proposes possible mitigation/management options for such impacts.

- DWE registered stock/domestic bore (not visited)
- DWE registered stock/domestic bore (visited)
- DWE registered irrigation bore (not visited)
- DWE registered town water supply bore (visited)
- Private unregistered bore (visited)
- Southern Alliance bore (decommissioned) (visited)
- Landcare bore (not visited)
- Preferred bypass route
- Creeks

Figure 1-1 Site & bore locations

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2. Legislation, water sharing plans and policy

2.1 Water legislation

Water in NSW is managed under two primary legal instruments – the *Water Act 1912* (WA 1912) and *Water Management Act 2000* (WMA 2000). The WMA 2000 is gradually being introduced in NSW and, as it becomes active for given areas, the old WA 1912 is repealed.

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 2000, any development taking or using water must:

- Include assessment of whether there is an adverse impact from the development to the river or aquifer and its dependent ecosystems.
- Protect basic landholder rights.

This assessment is achieved by the minimal harm provisions of sections 63 and 97 of the WMA 2000.

The WMA 2000 outlines water access licences; water supply works and requirements for water use approvals within the geographic area of a water sharing plan, and only applies to areas where a plan is in place. Once a water sharing plan has commenced, the WA 1912 is repealed for that water source and existing licences are automatically converted to new consents under the WMA 2000.

As there is no water sharing plan in place for surface water or groundwater in the Woomargama area, water access is governed under the WA 1912. It is anticipated that a generic macro water sharing plan for aquifers across NSW will be developed by the Department of Water and Energy (DWE) in the near future. Once this occurs, water will be controlled under the WMA 2000, but this not likely to commence within the next 12 months.

2.2 Groundwater sharing plans

As stated above, macro water sharing plans are currently being developed within NSW, which will provide a high level generic plan for water sources to transition into the WMA 2000. It is likely that Mountain Creek and Sandy Creek alluvium will be included in the macro water sharing plan currently being developed for inland alluvial systems. The fractured granites are likely to be included in a macro water sharing plan currently being developed for fractured rock systems in NSW.

2.3 Local and state government policies

Development of the proposed bypass will be governed by both local and state government policies. These include:

- Greater Hume Shire Local Environmental Plan (not yet available)

  Woomargama became part of the Greater Hume Shire in 2004; Council has commenced preparation of a new Local Environment Plan (LEP) to apply across the new shire, and to replace the existing planning instruments.

- *NSW Groundwater Policy Framework* (Department of Land and Water Conservation (DLWC) 1997)

  This comprises a set of three policy documents:

  - *NSW Groundwater Quality Protection Policy* (DLWC 1998)
  - *NSW Groundwater Quantity Management Policy* (*draft)* (DLWC n.d.)
  - *NSW Groundwater Dependent Ecosystem Policy* (DLWC 2002)

  The aims of the NSW Groundwater Policy are to slow, halt or reverse degradation in groundwater resources, ensure long-term sustainability of the biophysical characteristics of the groundwater system, maintain the full range of beneficial uses of these resources, and maximise the economic benefit to the region and state.

3. Assessment approach

3.1 Scope

The groundwater field investigation of land along the proposed bypass alignment comprised the following scope:

- Identification and recording (photograph and GPS location) of groundwater bores and springs.
- Gauging and sampling of groundwater bores that could be accessed.
- Laboratory analysis of water quality results, measurement of physical water parameters, and comparison with relevant guideline values.
- Overall assessment of pre-construction groundwater quality and levels.
- Characterisation of local and regional groundwater flow systems.
- Consideration of potential groundwater supply options.
- Consideration of the likely impacts on groundwater levels and quality during construction and ongoing operation.
- Proposal of management and mitigation solutions for potential groundwater impacts.

3.2 Field investigations

Previous work on the Hume Highway bypasses for Tarcutta, Holbrook and Woomargama (PB 2008) recommended that a detailed groundwater investigation be undertaken. The investigation was conducted in the field at Woomargama over 2 days during May 2009. Existing groundwater bores were identified in the preliminary investigation (PB 2008) from DWE bore searches and community consultation. These were used for the groundwater assessment.

To assess groundwater conditions the following activities were completed:

- Boreholes that could be accessed for water level measurements at Woomargama were gauged. Boreholes and springs were photographed.
- Boreholes that were able to be sampled were purged, where possible, and the following physical parameters were recorded: electrical conductivity (EC), temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS) and redox potential (redox Eh).
- Groundwater samples from selected bores were submitted to a National Association of Testing Authorities (NATA) accredited laboratory for detailed chemical analysis. Groundwater samples were analysed for major cations and anions, and dissolved metals (manganese and iron). Samples were flown to Sydney and then submitted to a NATA registered laboratory (ALS Environmental) under the appropriate chain-of-custody documentation and storage/transport protocols.

3.3 Data and study limitations

The following limitations apply to the fieldwork and subsequent data assessment for this report:

- The conclusions of this report are based on available data at the time of preparing the report and are indicative of the environmental conditions at that time.
- The Woomargama area is currently experiencing prolonged drought conditions and, therefore, the measured groundwater levels are likely to be influenced by the dry climatic conditions.
- There was a limited number of bores accessible for measurement of water levels and for water quality sampling.
- Bore head works occasionally prevented access to undertake water level measurements, and/or the bore had recently been pumped and, therefore, the water level was deemed to be unrepresentative of the local groundwater conditions.
- Water quality samples were taken as grab samples, and many bores were not able to be purged correctly prior to the taking of samples. In addition, some bores could not be accessed or pumps activated to enable the taking of water quality samples.

4. Climate, topography and geology

4.1 Climate

The climate of the Woomargama area is characterised by warm to hot summers and cool to cold winters. Seasonal rainfall variation is not great, but rainfall is winter dominant. Woomargama has an average rainfall of approximately 740 millimetres per year (mm/yr); this figure is based on records maintained by the Bureau of Meteorology for 115 years (Station No 072049, Bureau of Meteorology 2009).

Yearly rainfall for the last 30 years (1978–2008) was analysed and graphed using the cumulative deviation from the mean. Cumulative deviation from the mean rainfall represents discrete rainfall events as a continual trend over time; ultimately, periods of below and above average rainfall are highlighted. When below average rainfall is experienced, a downward trending slope is seen, while an upward trending slope represents above average rainfall.

The average rainfall for the period from 1978–1998 was 780 mm/yr. The rainfall data, when plotted as a cumulative deviation using the long-term average of 740 mm/yr, indicates above average rainfall (a rising trend) for this period (refer Figure 4-1). However, the rainfall record at this station is not complete after 1998. The next closest rainfall station is at Holbrook, approximately 14 kilometres (km) north of Woomargama (Station No 072022, Bureau of Meteorology 2009). The cumulative deviation plot for this station shows a similar rising trend until 2001 after which below average rainfall (a decreasing trend) is observed (refer Figure 4-2).

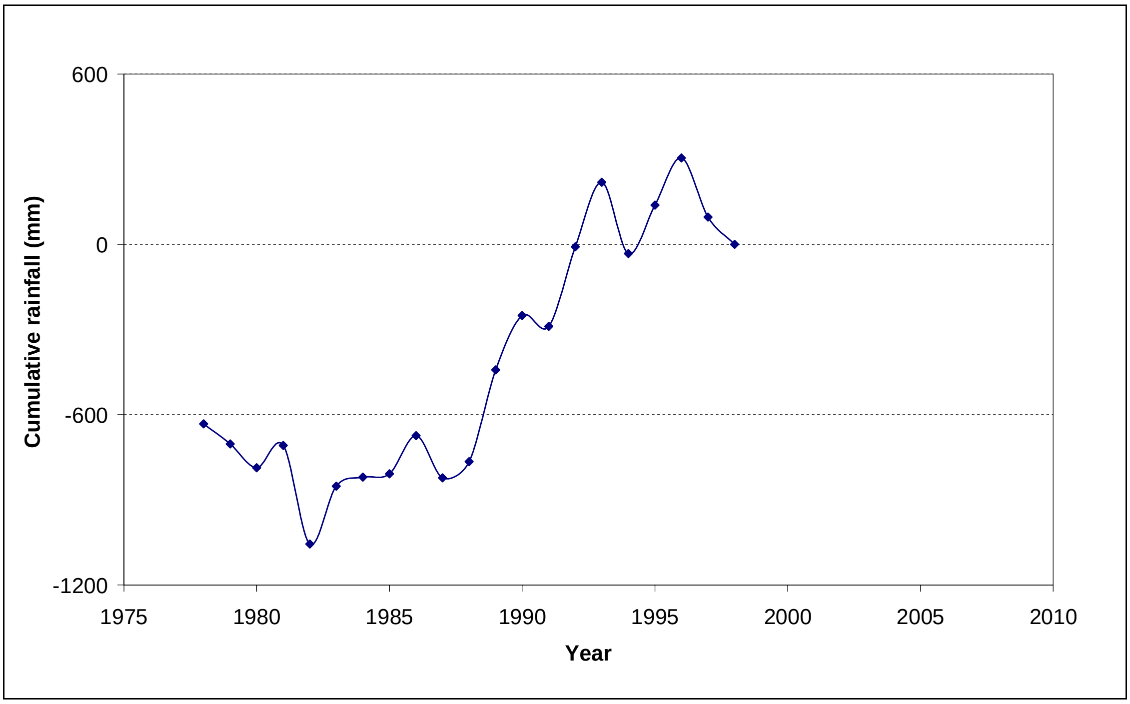


Figure 4-1 Cumulative deviation rainfall for 072049 (Woomargama)

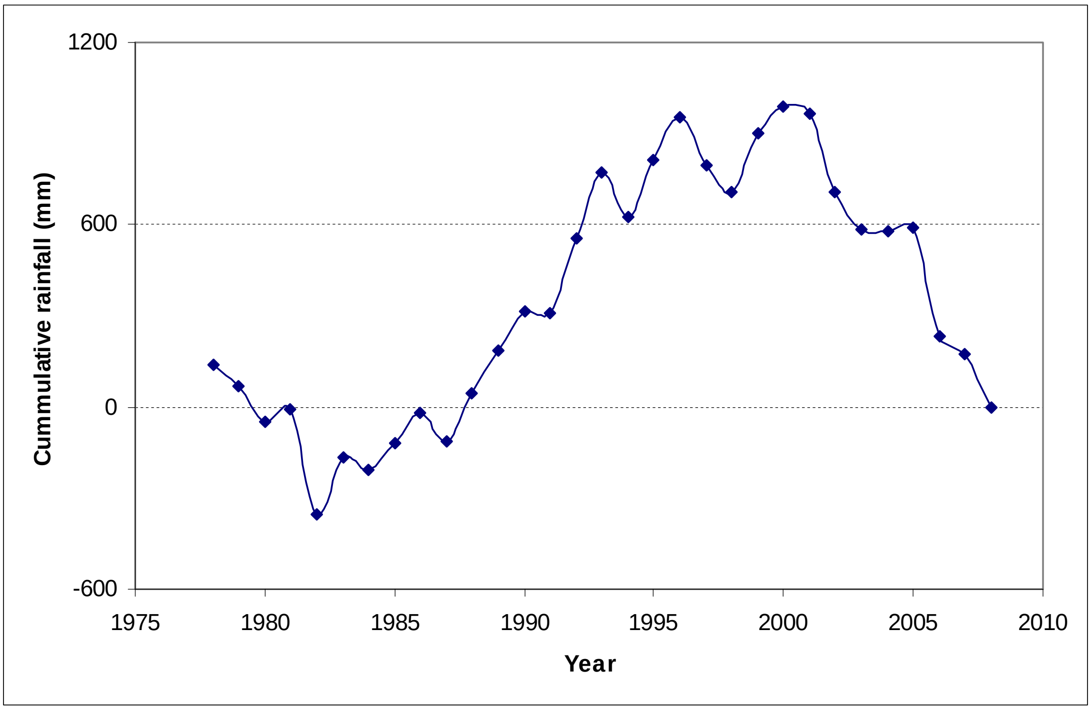


Figure 4-2 Cumulative deviation rainfall for 072022 (15 km north of Woomargama)

4.2 Topography

Woomargama is located within the NSW South-western Slopes Bioregion, which is characterised by foothills and ranges along the western fall of the Great Dividing Range. The town is situated on the alluvium floodplain of Mountain Creek, at an elevation of approximately 300–310 metres (m) above Australian height datum (mAHD). The nature of the topography in this area is distinguished by north–south trending valleys and ridges. Directly to the north of Woomargama, lies Mount McKenzie, a granitic intrusion which rises from the floodplain to approximately 500 mAHD (PB 2008).

4.3 Geology

The study area is located within the Wagga-Omeo Zone of the Lachlan Fold Belt, which is mapped on the *Wagga Wagga 1:250,000 Geology map, sheet no SI 5515* (Adamson and Loudon 1960). The Lachlan Fold Belt in the Woomargama area is characterised by Ordovician metasediments and Silurian granites, which make up the higher relief areas of the landscape.

Quaternary alluvium has accumulated in lower-lying, major drainage lines and forms flats and floodplains on the valley floors. The geology map (see Figure 4-3) does not show any major structural features or faults in the vicinity of the study area; however, the trend of lineaments is generally north-westerly, and this may reflect major joints, local faults, structural discontinuities or dykes.

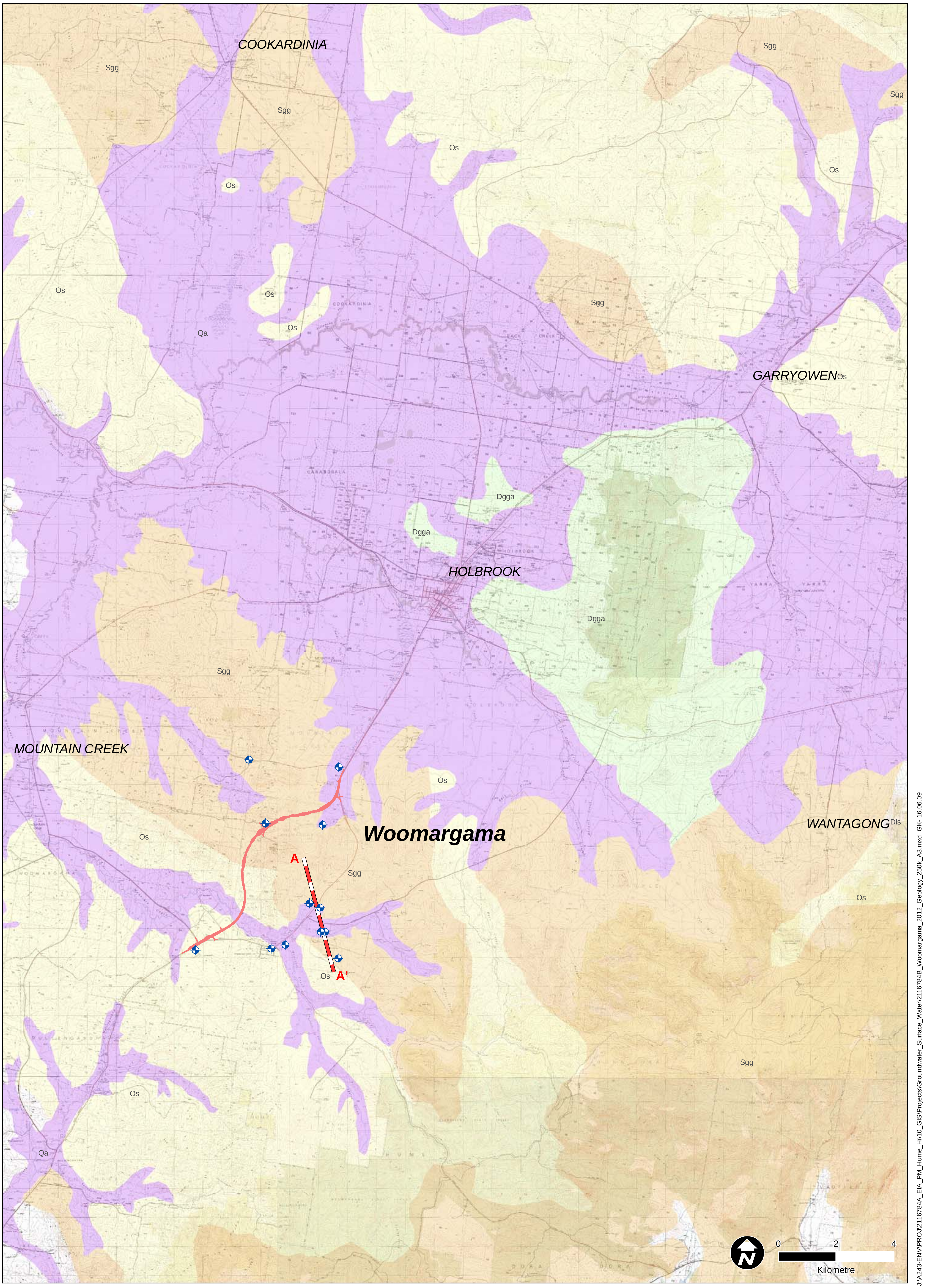
Alluvial deposits in the Woomargama area are mainly present in the creeks and drainage lines. The alluvial deposits comprise sand, silt, gravel and clay; the thickness of the alluvium is generally governed by bedrock topography. The thickness of alluvium generally ranges from 10 through to approximately 20 m for Mountain Creek, and this is likely to be similar for Sandy Creek. The alluvial deposits are underlain and surrounded by weathered Ordovician metasediments and Woomargama Granite.

Outcrops of Woomargama Granite occur to the north and east of Woomargama, and weathered granite underlies the alluvial deposits. Black Rock Granite outcrops to the north of the Woomargama Granite. Both granite deposits are Silurian in age and comprise a series of biotite granites, granodiorites, granites and gneiss granite, which have intruded into the surrounding Ordovician sediments. Ordovician sediments outcrop in and around Woomargama extending towards the south.

4.4 Groundwater dependent ecosystems

Groundwater dependent ecosystems (GDEs) are communities of plants animals and other organisms that depend on groundwater for survival (Department of Land and Water Conservation 2002). A GDE may either be entirely dependent on groundwater for survival, or it may use groundwater opportunistically or for a supplementary source of water (Hatton and Evans 1998). GDEs are most likely to occur in areas with shallow groundwater levels close to the surface.

The alluvial groundwater systems within the study area have shallow water levels and comprise the unconsolidated alluvial sediments associated with Mountain Creek and, possibly, Wilson Creek, Sandy Creek and Native Dog Creek. Riparian vegetation associated with these creeks may depend on groundwater to some degree, and this is discussed further in the ecology assessment (PB 2009). Local shallow flow systems also exist within the granite; these are displayed as springs, seeps or spring fed dams on the granite hill slopes.



Woomargama preferred bypass route
Cross-section
Bore

Geology
Quaternary Alluvium (Qa)
Holbrook Granite (Dgga)
Silurian Granite (Sgg)
Ordovician Metasediments (Os)

Figure 4-3 Geology

5. Methodology

5.1 Field investigations

The groundwater field investigation was undertaken at Woomargama over a 2 day period on 26 and 27 May 2009. Landholders identified as directly affected by the proposed bypass were contacted, and arrangements were made to visit each property and to inspect bores and springs if present. One affected property could not be inspected due to site access restrictions.

Not all bores on the DWE database that were identified in the previous report (PB 2008) were accessed during the field trip. Those not accessed either:

- Were not on a property directly affected by the proposed bypass and, therefore, there was no agreement with the relevant landholder for an on-site inspection.
- Could not be located using the coordinates provided in the DWE database.
- Were old and have since been decommissioned.

During the field inspection, the majority of bores sampled and gauged were registered with the DWE.

Bores were inspected and standing water levels were measured using a water level meter where access could be obtained. The bore depths were also measured using the water level meter when possible. The nature of the bore head works and pumping equipment within the bore sometimes prevented the taking of a water level. Some bores had pumps that were active at the time of inspection. In these cases, water levels were not measured due to the risk associated with damaging equipment or the pump. In addition, the water level from an actively pumping bore would not be representative of local groundwater conditions. Where bores could not be measured, an estimate of the total bore depth and an estimated water level was provided by the landholders, if possible.

Bores sampled for groundwater chemistry were selected based on access and the feasibility of taking water samples. Preference was given to active bores equipped with pumps, as these bores were deemed to have groundwater representative of the aquifer (due to recent pumping/purging of the water in the bore column). Bores located along the entire length of the proposed bypass route were sampled, which included bores in the different aquifer systems. Table 5-1 lists bores inspected during the field investigations. It also indicates bores that were gauged and sampled for water quality field parameters and/or for laboratory analysis.

One bore was wrongfully identified in the field as DWE registered bore GW064587. For the laboratory analysis this bore name is used, but for future reference in this report, this bore is labelled ‘W1’ bore.

The sample for well GW057333 was taken from the tap of a feeding trough, which was supplied with water from the well through a pipeline.

The depth of well GW024660 was significantly shallower in the field measurement (13.07 metres below ground level (mbgl)) than indicated by the DWE database (30.2 mbgl). The well was installed in May 1966, so it is possible that significant silting up has occurred.

The total depth of bore GW025660 was significantly shallower in the field measurement (10.2 mbgl) than in the DWE database (30.5 mbgl).

The town water supply consists of three spear points and a bore. A sample was taken from a tap at the operation shed.

Table 5-1 Gauged and sampled bores

Site name	Groundwater level measurement	Field parameters measured	Sample taken for laboratory analysis
GW064591 (MC65491)	x	x	x
Town Water Supply	x	x	x
W1		x	x
W2	x	x	x
W3 (TMC 24)	x	x	x
GW027869	x	x	x
W4		x	x
GW024660	x		
GW057333	x	x	x
GW057375 (MC57375)	x	x	x
GW025660	x	x	x
GW503248	x	x	x

Many of the private bores visited had pumps installed and samples were collected from well heads, taps or available pipe outlets. At locations where bores were not used regularly, pumps were turned on and water was allowed to flow prior to sampling. Where bores were not equipped with pumps, or where the pump could not be activated, grab samples were collected using a 45 millimetre (mm) disposable bailer.

Groundwater bores were sampled for water quality field parameters to establish baseline values of water quality in the Woomargama region. Field parameters — which included temperature (^{o}C), electrical conductivity (milli Siemens per centimetre (mS/cm)), pH (pH units), dissolved oxygen (milligrams per litre (mg/L)) and percent saturation), total dissolved solids (mg/L) and redox potential (milli Volt (mV)) — were measured using a Quanta Hydrolab water quality meter. Electrodes were calibrated daily according to the manufacturer's specifications.

Land along the proposed bypass route was inspected to identify the presence of springs and salt scalds. The locations of sites visited were recorded using a GPS and the sites were also marked on large scale aerial photo map. Figure 1-1 shows the registered DWE bores, indicating their use: stock/domestic, irrigation or town water supply. Private bores and two decommissioned Southern Alliance bores that were identified in the field were also mapped. Four Landcare bores were identified in the previous desktop study (PB 2008). Photographs of bores GW064591, GW027869, W2 and well GW024660 are shown in Photos 1–4.

5.2 Analytical assessment and criteria

Selected samples were submitted for analytical laboratory analysis of major dissolved cations and anions, and dissolved iron and manganese, in sample bottles as specified by the laboratory and listed in Table 5-2.

Table 5-2 Sample bottles and preservation types

Parameter	Preservation
Major cations and anions – Ca, K, Na, Mg, Cl, HCO_3, SO_4	1 x 250 mL plastic, unpreserved
Dissolved metals – iron and manganese	1 x 60 mL plastic, preserved with HNO_3 (field filtered)

Samples for dissolved metals were filtered in the field using 0.45 micrometre (μm) cellulose acetate membrane filters and preserved in the field by acidification using concentrated analytical grade nitric acid (HNO_3) to pH<2. All samples were stored 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. Chain of Custody (CoC) procedures were followed and copies of the CoC documents and analysis results are provided in Appendix A.

Assessment criteria from the Australian Drinking Water Guidelines (ADWG) (National Health and Medical Research Council (NHMRC) (2004) and the Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) were used to assess groundwater quality against the guideline values for the identified beneficial uses. Groundwater from sampled bores is mainly used for stock and domestic water supply and some minor recreational supply (watering of sportsgrounds). Groundwater may also provide base flow discharge to local streams.

Table 5-3 shows the guideline values for the water quality parameters.

Table 5-3 Assessment criteria

Parameter	ADWG		ANZECC Guidelines
	Health (mg/L)	Aesthetic (mg/L)	Trigger values (mg/L)
Temperature (^oC)	c	N/A	
EC (μS/cm)			125-2200[b]
pH	d	6.5-8.5	6.5-8.0[b]
TDS (mg/L)	d	500	
DO (% saturation)	c	>85	85-110[b]
Redox potential (mV)			
Sulphate as SO_4	500	250	
Chloride	c	250	
Calcium			
Magnesium			
Sodium	c	180	
Potassium			
Manganese (dissolved)	0.5	0.1	1.9[a]
Iron (dissolved)	d	0.3	ID

Notes:

a- ANZECC (2000) - 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems
b- ANZECC (2000) – trigger values for lowland rivers in south-east Australia
c- ADWG (2004) - No Health based guideline value is considered necessary
d- ADWG (2004) - insufficient data to set guideline value based upon health considerations
ID- ANZECC (2000) - insufficient data to derive a reliable trigger level

6. Groundwater flow systems

6.1 Background

6.1.1 Aquifer characteristics

There are two main aquifer systems present in the Woomargama area:

- Unconsolidated and unconfined alluvial aquifers.
- Semi-confined fractured rock aquifers.

The previous desktop study (PB 2008) suggested that the alluvial aquifer is the major aquifer accessed for groundwater resources in the area, and that groundwater levels in the alluvium were likely to be relatively shallow (less than 10 m). The groundwater levels in the fractured metasediments are likely to be deeper, with lower bore yields and higher groundwater salinity than the alluvium.

The watertable in the Woomargama area is generally a muted reflection of the land topography of both the alluvial and the fractured rock aquifers, and there is hydraulic connectivity between the two aquifer systems. Under the influence of gravity, groundwater flows from recharge areas located higher up in the landscape, toward discharge areas in lower-lying areas of the landscape. Groundwater discharge can occur in the form of springs/seeps, or directly to surface water bodies. Springs occur where there is a pathway for the water to escape and where the watertable (or groundwater pressure) is above ground level (Photo 5). Seeps can occur were there is very shallow groundwater in the weathered granite sediments (Photo 6) and where fractures in the deeper granite extend to the surface, thus creating a pathway for groundwater.

Groundwater movement in the alluvium is via intergranular flow, where sand lenses or bands are interconnected and provide preferential pathways of higher permeability (fractures and fissures). Groundwater flow in the fractured rock aquifer is predominantly via secondary porosity. Groundwater movement within the two flow systems is from the south-east to the north-west, which is consistent with the local topography.

Unconsolidated alluvial aquifers

The majority of boreholes in the Woomargama area are shallow and obtain their supply from groundwater within the alluvial systems. The alluvium generally has a higher permeability than the surrounding fractured rock aquifers. Yields from bores constructed within the alluvial aquifer at Woomargama range from 0.01 to 6.25 litres per second (L/s).

From the data contained in the DWE database, the bore depths in the alluvium range from 3 to 30.5 m below ground level (mbgl) (see Table 6-1).

Table 6-1 Available groundwater data from the DWE database (April 2009, within 4km^2 of Woomargama)

Bore No	Completed	Purpose	Depth* (mbgl)	Property	SWL* (mbgl)	Yield* (L/s)	Aquifer	Salinity
GW007544	1/08/1947	Stock	41.5		26.2	0.16	Silurian granite	Fresh
GW020572	1/08/1963	Town water supply	3	Woomargama spearpoints			Quaternary alluvium	
GW024660	1/05/1966	Domestic/stock	30.2	Culbara	1.8	1.52	Granite	
GW025660	1/05/1965	Stock	30.5	Culbara	0	0.01	Quaternary alluvium	
GW025878	1/01/1966	Irrigation	25.9	Woomargama station			Silurian granite	
GW025881	1/01/1966	Irrigation	35.1	Woomargama station			Silurian granite	
GW027869	1/02/1968	Domestic/stock	61	Mount Raven	15.2	1.9	Silurian granite	Good
GW027952	1/06/1967	Domestic/stock	13.7	Culbara	1.5	1.26	Quaternary alluvium	
GW027961	1/02/1968	Domestic/stock	76.2	Spring Valley	6.11 (dec 92)		Silurian granite	Brackish
GW028496	1/02/1968	Stock	61	Spring Valley	15.2	0.44	Silurian granite	Fair
GW033234	1/02/1968	Stock	76.2	Spring Valley			Silurian granite	
GW034623	1/08/1971	Domestic/stock	5.5	Spring Valley	0	1.52	Quaternary alluvium	Fresh
GW039361	1/03/1985	Town water supply	7.3	Woomargama bore	2	6.25	Quaternary alluvium	
GW044633	1/06/1976	Domestic/stock	9.9	Elan Valley			Quaternary alluvium	
GW050178	1/01/1975	Domestic/stock	8.5	Dunraven			Quaternary alluvium	
GW057333	1/01/1973	Domestic/stock	14	Culbara			Quaternary alluvium	
GW057375	1/10/1982	Domestic/stock	26	Culbara	3.31(Oct 2006)	1.13	Quaternary alluvium	0-500ppm^
GW058440	1/10/1983	Domestic/stock	43.9	Shenandoah	10.6	1.01	Ordovician metasediments	Good
GW064126	1/04/1987	Domestic/stock	100.1	Shanahan	45.5	0.23	Ordovician metasediments	Good
GW064587	1/01/1988	Domestic	27.4	Pinere PTY Ltd	5.4	2.4	Ordovician metasediments	0-500ppm
GW064591	1/01/1988	Domestic/stock	54.9		17.88 (dec 95) 21.33 (jul 02)	1	Ordovician metasediments	0-500ppm
GW065737	14/11/1988	Domestic/stock	39.9		6.1	0.7	Ordovician metasediments	Good
GW501584	18/07/2004	Town water supply	12	Woomargama TWS	1.67	3.4	Quaternary alluvium	
GW503248	10/12/2001	Domestic/stock	36	Elan Valley	10.8	0.3	Silurian granite	

Notes:

* Standing Water Level (SWL) , measured at the completion of drilling, unless specified otherwise
^ ppm = parts per million

Fractured rock aquifers

The fractured rock aquifers generally produce low and unpredictable groundwater yields, with groundwater quality that is often variable and may be brackish or saline. Yields from bores constructed in the fractured rock range from 1–2 L/s where dense jointing occurs (Baker et al 2001) and are, therefore, typically connected with flow via secondary porosity.

Data contained in the DWE database indicates that bores constructed in the fractured rock aquifers in the area have yields ranging from 0.16 to 2.4 L/s, with good groundwater quality. Bore depths extend to between 25.9 and 100.1 mbgl (see Table 6-1).

6.2 Groundwater levels

Limited information on groundwater levels was available from the DWE groundwater bore database. Table 6-1 shows all DWE registered groundwater bores, which were installed between 1947 and 2004, within 4km of the proposed bypass route (see Figure 1-1).

Standing water level data is available for most bores. Two bores have been installed since 2000 and all other bores were installed before 1990. Table 6-1 shows that standing water levels for the Quaternary alluvium ranged between 0 and 3.31 mbgl. For the Silurian granites, the standing water levels ranged between 6.11 and 26.02 mbgl. The standing water levels for the Ordovician metasediments ranged between 5.4 and 45.5 mbgl.

Only a limited number of bores could be sampled in the field due to land access restrictions. Many bores/wells that were visited were not directly affected by the proposed bypass. These bores were included to determine the overall groundwater conditions of the different aquifers. Bore depths and water level measurements collected at the visited sites in Woomargama are shown in Table 6-2. Bore depths measured during the field investigation did not always match the DWE database values. This could be due to silting up of wells and bores or the partial collapse of bores over time. The bore depth for W2 was established from bore details made available by the owner of the bore.

Table 6-2 Bore depths and water level measurements

Site name	Date measured	Bore depth (mBGL)	Water level (mBGL)	Water level (mAHD)	Aquifer
GW064591	26/05/2009	N/A	21.86	295.53	Ordovician metasediments
TWS	26/05/2009	N/A	2.86	307.14	Alluvium (MC)
W2	26/05/2009	102	22.35	336.93	Granite
W3	26/05/2009	14.34	12.35	295.24	Alluvium (SC)
GW027869	26/05/2009	NA	15.91	333.38	Granite
GW024660	27/05/2009	13.08	3.93	328.76	(Weathered) granite
GW057333	27/05/2009	14	2.9	310.97	Alluvium (MC)
GW057375	27/05/2009	11.71	3	308.28	Alluvium (MC)
GW025660	27/05/2009	10.2	-0.37	330.37	Alluvium (MC)
GW503248	27/05/2009	27.63	9.18	320.82	(Weathered) granite

N/A – Not Available

Most bores access the alluvium associated with Mountain Creek at Woomargama township, with only one bore identified in the Sandy Creek alluvium.

Groundwater levels of bores in the Mountain Creek alluvium were less than 3 mbgl. Bore GW025660 is artesian with a standing water level of 37 centimetres (cm) above ground level. This bore was 10.2 m deep at the time of the field investigation.

Figure 6-1 shows a conceptual north–south cross-section and illustrates indicative groundwater levels in intersecting bores and flow systems for the two main aquifers.

The groundwater level from the bore in the Sandy Creek alluvium was 12.35 mbgl at bore W3. This bore was used by CSIRO (2004) for monitoring purposes (as TMC 24) from November 2002 to April 2004. Groundwater levels during that period ranged between 11.9 and 12.2 mbgl. The bore is screened from 12.25 to 14.45 mbgl.

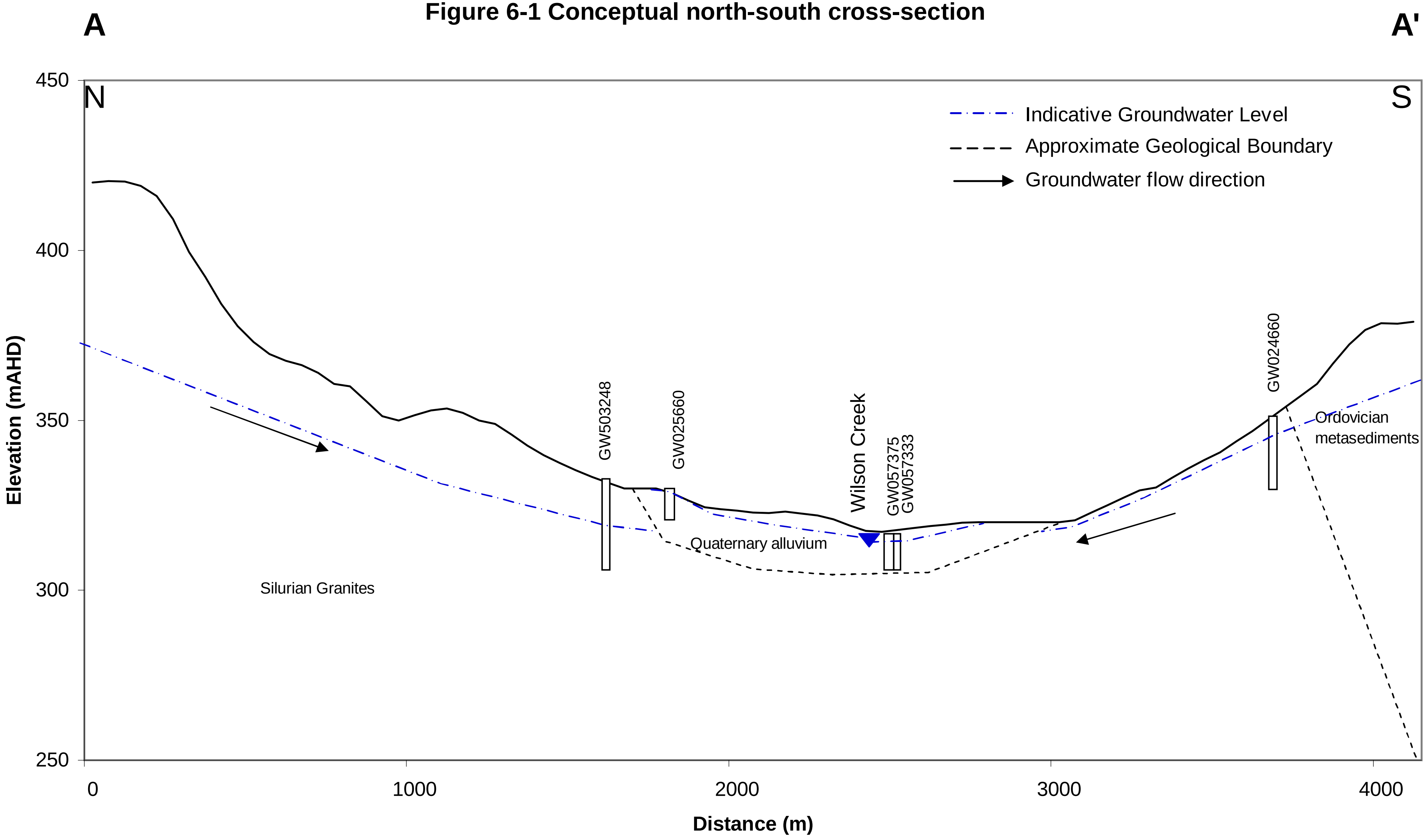
The groundwater levels within the granite ranged between 3.93 and 22.35 mbgl. Water levels were generally shallower in bores installed in weathered granite sediments at lower elevations and deeper in bores located at higher elevations in the deeper fractured rock.

Bore GW064591, located in the Ordovician metasediments, recorded a water level of 21.86 mbgl. Two Southern Alliance bores, located close to GW064591 (see Figure 1-1), were installed in Ordovician metasediments in December 2007 and have since been decommissioned. One bore was installed to a depth of 58 mbgl and had a standing water level of 6.5 mbgl at the completion of drilling. The second bore was drilled to a depth of 52 mbgl with a standing water level of 20 mbgl at the completion of drilling.

Groundwater level information was collated for the two separate flow systems — fractured rock and alluvial aquifers. The levels were then converted into mAHD so that the groundwater flow direction could be determined.

The overall groundwater flow direction in the alluvium is towards the west for Mountain Creek and the north for Sandy Creek (see Figure 6-2). It is assumed that groundwater in the fractured rock aquifer follows the surface and general catchment topography and, therefore, flows are also likely to be generally towards the north/north-west.

Figure 6-1 Conceptual north-south cross-section



Preferred bypass route
Rivers
10m elevation contours
Bore - Alluvium
Bore - Granite (point measurement)
Bore - Ordovician metasediments (point measurement)
Groundwater flow direction in alluvium
Indicative groundwater flow direction in the fractured rock
Cross-section

Figure 6-2 Groundwater flow directions (May 2009)

6.3 Current groundwater use

As listed on the DWE groundwater database, the majority of bores in the Woomargama area are licensed to supply domestic and stock requirements. Three boreholes are registered and licensed for town water supply for Woomargama and two boreholes are licensed for irrigation purposes (DWE 2009). The town water supply extraction for the water year 2007–2008 was 13 megalitres (ML) (Riverina Water City Council 2008).

The town water supply bores are located next to the current Hume Highway in Woomargama township, on the up gradient side of the proposed bypass.

Four additional unregistered private bores were identified during the field investigation. 'W2' and 'W4' were used for stock and domestic purposes. Bore 'W3' was used as a CSIRO monitoring bore until April 2004. The W1 bore standpipe is no longer used.

DWE bore GW027961 is located just to the west of the proposed bypass corridor, but during fieldwork it was identified that this bore had been decommissioned. DWE bore GW064591 is located in the direct vicinity of the current Hume Highway and the proposed bypass would not affect this bore anymore than at present. One unregistered private bore (W4) is located close to the proposed bypass and might be affected during construction and/or operation.

All current renewable ('high yield') bore licences are located within the fractured rocks of the Lachlan Fault Belt Groundwater Management Area 811 (GWMA 811). All alluvial bores are also licensed as part of GWMA 811, since no separate GWMA exists for the alluvium in Woomargama.

6.4 Potential for groundwater supplies

Groundwater supply from the granite aquifer is generally low and is not, therefore, recommended as a viable water source for the project (pers. comm. DWE 2009). The Ordovician metasediments are a slightly higher yielding water supply, but may have water quality issues.

The alluvium is the best available water supply source in the direct vicinity of the proposed bypass. However, there is limited availability for a groundwater supply for road construction from the alluvial sediments associated with Mountain Creek. The availability of water from the alluvial aquifer is largely dependent on the volume requirements. Small volumes might be available. However, larger volumes of groundwater for continuous supply are unlikely to be available from within the alluvium. All groundwater extraction bores would require a licence under the *Water Act 1912*.

The RTA has indicated water will be required for batch plants, site compounds and construction. The batch plant water would need to be a reliable supply, of good quality. The volume of groundwater needed is likely to be 5 ML for the entire project.

13 ML/year is currently extracted for Woomargama's town water supply, but as much as 100 ML/year may be available. The Alliance has indicated that there is agreement from Riverina Water, which controls Woomargama's water supply, for the project to access water from the town water supply for concrete production. As part of any agreement to supply water, the bore infrastructure may be upgraded and left as a positive legacy to the township when construction is completed. Pipelines would be placed on the ground surface in the road reserve of the existing highway both north and south to allow the transfer of water from the bore to the batch plants. The town water supply has good water quality.

A possible alternative water supply option that requires further consideration is the Hume Weir.

The extraction of groundwater may have a small localised impact on groundwater levels and new bores should, therefore, be located at a maximum distance from existing groundwater bores. Licence conditions from DWE would state a minimum distance condition from neighbouring bores. Impacts to existing bores would have been considered by DWE upon granting of the licence.

7. Groundwater quality

7.1 Background

The two main aquifer systems present in the Woomargama area are slightly different in terms of groundwater chemistry. The alluvial aquifers are typically lower in salinity, while the fractured rock is generally characterised by higher levels of salinity. However, salinity levels can be quite variable within each aquifer. The salinity level of sampled groundwater is dependent on the surrounding geology, the flow paths and residence times (the time water has been in the aquifer).

Dryland salinity is a minor issue in the Woomargama area (PB 2008). The areas affected have either high groundwater or a localised perched watertable, with the potential to become saline over time. They are generally isolated areas. Breaks of slope salinity, which can occur in areas where the ground slope begins to flatten out, may potentially be more common as ground surface slopes in the Woomargama area range from relatively flat to greater than 20 degrees.

Historical water quality data (summer of 1992–1993) indicates that most bores have fresh water quality and only one bore in the DWE database has brackish water quality (see Table 6-1). The Landcare bore TMS.V.1 (see Figure 1-1) also exhibited brackish water quality at this time.

Previous research (PB 2008) identified groundwater springs at two sites in the vicinity of Woomargama. One site was located on the Willis property. It is likely that the springs are permanent water bodies, which have increased flows during wetter periods and continue to flow along the drainage line to Mountain Creek. The electrical conductivity of the water sampled was low; therefore, salinity is not likely to be an issue in this area of the floodplain. The other site was located at the Williams' property. The groundwater springs are likely to be permanent water bodies due to the dam structures in place (PB 2008).

Salt scalds were not identified during the field investigation. Springs were identified in the Spring Valley area.

7.2 Results

7.2.1 Field parameters

Groundwater samples for analysis of field parameters (water temperature (^{o}C), EC (mS/cm), pH (pH units), DO (mg/L and per cent saturation), TDS (gram per litre (g/L)) and redox (mV) were collected from 14 bores during the 2 day groundwater field investigation at Woomargama. The field parameters measured are summarised in Table 7-1.

Table 7-1 Field parameters

Site No	Aquifer type	Temperature (^{o}C)	EC (mS/cm)	DO (mg/L)	pH (pH units)	TDS (mg/L)	DO (% saturation)	Redox potential (mV)
GW064591	Ordovician metasediments	16.26	2.68	2.12	6.62	1.7	21.4	25
TWS	Alluvium (MC)	15.19	0.517	11.96	7.23	0.3	109.6	14
W2	Granite	17.45	1.82	10.74	6.91	1.2	101	119
W3	Alluvium (SC)	17.34	7.14	11.93	6.72	4.6	117.4	N/A
GW027869	Silurian granite	17.25	0.838	7.45	7.61	0.5	70.9	109
W4	Silurian granite	17.48	0.599	15.83	7.67	0.4	106	-11
GW057375	Quaternary alluvium	16.27	0.326	9.93	7.08	0.2	74.2	227
GW057333	Quaternary alluvium	13.63	0.299	6.95	7.16	0.2	66	197
GW025660	Quaternary alluvium	16.07	0.755	9.34	6.74	0.5	66.5	220
GW503248	Silurian granite (weathered)	16.07	0.600	3.95	6.7	0.4	39.6	263
W1	Quaternary alluvium	15.29	0.515	14.61	7.33	0.3	141.1	113

N/A – Not Available

Groundwater temperatures ranged from 15.19 ºC to 17.48 ºC in the sampled bores.

EC ranged from 0.6 to 7.14 mS/cm. The highest salinities were measured in bores W3 (7.14 mS/cm) within the Sandy Creek Alluvium and GW064591 (2.68 mS/cm) in the Ordovician metasediments. Bore W3 was used for salinity monitoring purposes by CSIRO (2004) and a salinity of 7 mS/cm was measured in December 2002. The high salinity is due to parna-rich alluvium and local waterlogged conditions, which connect groundwater to salt stores in the soil (CSIRO 2004). The EC values at these locations were greater than the ANZECC (2000) assessment criteria and are considered high. Waters of this elevated salinity are generally not suitable for human consumption or for use as irrigation for certain crops. Results showed that the alluvial aquifer is generally fresher than the granite aquifer.

Slightly elevated salinity was also observed at W2 (1.82 mS/cm) within the granite aquifer system. EC values at all other locations were less than 1 mS/cm, indicating that the groundwater in these locations ranges from fresh to slightly brackish.

TDS values ranged from 0.2 mg/L to 4.6 mg/L. As expected, TDS results correlated with EC results, with the highest TDSs observed at W3 (4.6 mg/L), GW064591 (1.7 mg/L) and W2 (1.2 mg/L). Concentrations of TDS at these bores also exceeded the ADWG (NHMRC 2004). TDSs at all other bores were less than the ADWG (2004) concentration and at or below 0.5 mg/L.

The pH levels ranged from 6.62 (GW064591) to 7.67 (W4) and indicated near neutral groundwater conditions. pH was within ANZECC (2000) and ADWG (2004) guideline values.

DO (percent saturation) concentrations in the groundwater were between 21.4 % (GW064591) and 141.1 % (GW064587). DO values above 100 % suggest oxygen saturation conditions have been reached and are indicative of temperature differences between calibration solutions and the groundwater measured. Oxygen saturation levels were outside the ANZECC (2000) guideline range (85–110 % saturation) at the majority of bores, with 6 of the 11 bores showing concentrations less than the lower ANZECC (2000) guideline value and ADWG guideline concentration (85 % saturation). Concentrations lower than 85 % were observed at GW064591, GW027869, GW057333, GW057375, GW025660 and GW503248, and concentrations higher than 110 % were observed at GW064587 and W3.

Redox conditions at most bores were oxidising, with the exception of slightly reducing conditions observed at W4. The redox potential ranged from -11 mV at W4 to 263 mV at GW503248.

7.2.2 Major ions and water type

Groundwater samples from selected bores were submitted to the laboratory for analysis of major dissolved cations (calcium, magnesium, sodium and potassium), anions (chloride and sulphate) and alkalinity (bicarbonate alkalinity as $CaCO_3$). Results are summarised in Table B-1 in Appendix B.

Change in water type highlights a change in the relative proportion of major ions due to water–rock interaction and hydrogeochemical reactions in an aquifer. Water type was calculated from the cation and anion concentrations in the groundwater using Aquachem version 5.1, using a classification scheme based on the occurrence of major species that comprise more than 20 % of total cations and anions, calculated in milli equivalents per litre (meq/L).

Cation concentrations ranged from 12 mg/L to 181 mg/L for calcium, 9 mg/L to 225 mg/L for magnesium, and 1 mg/L to 9 mg/L for potassium. Sodium concentrations typically ranged from 22 mg/L to 184 mg/L, with the exception of W3 which showed elevated sodium concentrations of 1,070 mg/L, which is not unexpected for salinized alluvial aquifers. Sodium concentrations exceeded the ADWG (2004) concentrations (180 mg/L) at GW064591 (184 mg/L) and W3 (1,070 mg/L).

Anion concentrations ranged from 1 mg/L to 377 mg/L for sulphate and 21 mg/L to 2,190 mg/L for chloride. ADWG (aesthetic) concentrations were exceeded at GW064591 for sulphate and chloride and at W2 and W3 for chloride.

Bicarbonate alkalinity (as $CaCO_3$) ranged from 36 mg/L to 364 mg/L.

The water type calculated for the Woomargama region is shown in Table 7-2.

Table 7-2 Groundwater type

Site	Water type	Geology
GW064591	$Mg\text{-}Na\text{-}Ca\text{-}Cl\text{-}SO_4$	Ordovician metasediments
TWS	$Na\text{-}Mg\text{-}Cl\text{-}HCO_3$	Alluvium (MC)
W2	Ca-Mg-Na-Cl	Granite
W3	Na-Mg-Cl	Alluvium (SC)
GW027869	$Ca\text{-}Na\text{-}Mg\text{-}Cl\text{-}HCO_3$	Silurian granite
W4	$Na\text{-}Mg\text{-}Ca\text{-}HCO_3\text{-}Cl$	Silurian granite
GW057375	$Ca\text{-}Na\text{-}Mg\text{-}HCO_3\text{-}Cl$	Quaternary alluvium/granite
GW057333	$Ca\text{-}Na\text{-}Mg\text{-}HCO_3\text{-}Cl$	Quaternary alluvium
GW025660	$Mg\text{-}Na\text{-}Ca\text{-}Cl\text{-}HCO_3$	Quaternary alluvium
GW503248	$Mg\text{-}Na\text{-}Ca\text{-}HCO_3\text{-}Cl$	Silurian granite
W1	$Na\text{-}Mg\text{-}Cl\text{-}HCO_3$	Quaternary Alluvium

Most bores show mixed cation water types, with a dominance of chloride and bicarbonate. The exceptions are W3, which shows a sodium–magnesium–chloride water type and is a shallow bore present in the Sandy Creek alluvium, and GW064591, which had a mixed cation and chloride water type with an elevated proportion of sulphate consistent with its location within the Ordovician metasediments.

A dominance of chloride in the chemical composition indicates that there is possible recharge from freshwater sources, including rainfall recharge and possibly surface water. Chloride dominant water types are also associated with high salinity groundwater. The bicarbonate component of the water type indicates that the chemistry of the water is being affected by the surrounding geology.

The cation/anion contribution to the water type is also shown in the Piper plot in Figure 7-1.

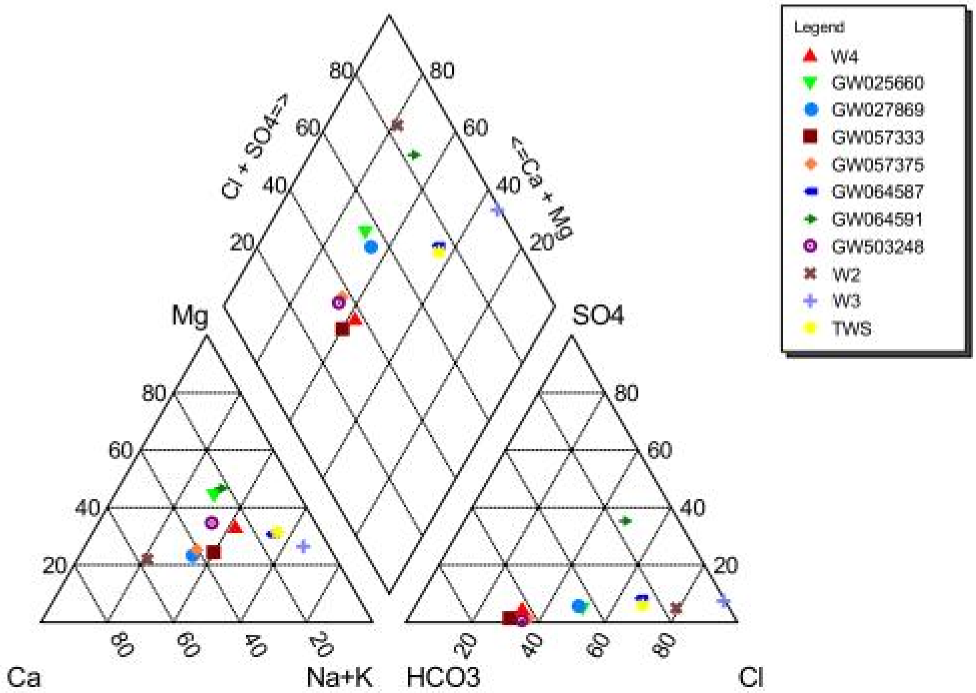


Figure 7-1 Piper plot of groundwater in the area

7.2.3 Metals

Groundwater samples were collected for analysis of dissolved metals (manganese and iron). A summary of the dissolved metal results is provided in Table B-1 in Appendix B.

Dissolved manganese concentrations ranged from 0.012 mg/L to 1.32 mg/L. The ADWG (2004) aesthetic guideline (0.1 mg/L) was exceeded at GW064591, TWS, W4 and GW025660. The ADWG (2004) health guideline (0.5 mg/L) was exceeded at W2.

Dissolved iron concentrations ranged from below detection (0.05 mg/L) to 22.6 mg/L. Concentrations were above the ADWG (2004) aesthetic guideline value (0.3 mg/L) at GW064591, TWS, W4, GW024660, GW057333, GW057375 and GW025660.

8. Potential groundwater impacts

Aquifers beneath the proposed bypass corridor could be affected acutely by the bypass construction and in the longer term. Whilst some of the following construction and operational impacts seem the same, it is important to acknowledge that construction impacts would become apparent as construction commences, while operational impacts would remain for the long term.

8.1 Construction impacts

Construction of the proposed bypass would have short-term impacts on ground conditions and, therefore, potentially groundwater flows. Considering the results and findings of the groundwater assessment, potential impacts during construction may include:

- Potential impacts on unconfined alluvial aquifers as a result of aquifer compaction caused by construction of controlled fills, structures and other compaction activities: The effects of ground compaction include aquifer compaction, which may result in impediment or prevention of the natural groundwater flow to the north-west. This may cause waterlogging and ponding to the immediate south-east of the construction site, and would also result in the lowering of the watertable to the west and north-west. Compaction is considered a minor issue for the locality, as it would only occur in alluvial areas.

- Potential impacts on known existing extraction bores: Bore W4 is located within close proximity to the proposed bypass, and depending on the final corridor location the bore may be destroyed or impacted during the construction process. Depending on the final corridor location, some of these bores may be destroyed or impacted during the construction process and would need to be replaced at a distance from the proposed bypass. The new location would need to be assessed as suitable for the relevant landholder, who may have infrastructure associated with the bore in its present location, including power, pipes and tanks.

- Potential impacts on groundwater dependent ecosystems: Springs and seeps are likely to be present adjacent to the proposed bypass. Changes in groundwater levels due to construction could occur. GDE's are discussed in more detail the ecology assessment (PB 2009).

- Potential short-term impacts from cuttings: Cuttings in the fractured rock are likely to intersect fractures/springs, which are likely to seep.

- Potential impacts associated with accidental spills or leakage from construction equipment: Unless this is managed carefully, it has the potential to contaminate groundwater aquifers. The alluvial aquifer is likely to be more vulnerable to groundwater contamination than the fractured granite. Groundwater could potentially become contaminated with sediment and/or road construction materials, such as fuels, lubricants and hydraulic oils. A decrease in water quality or the contamination of groundwater could be problematic for groundwater users and the environment.

- Groundwater extraction for construction will result in some local groundwater level drawdown from the aquifer. The impacts are likely to be localised due to the small volumes being extracted. It is likely that only those users within very close proximity would be affected and it is unlikely that either the aquifer integrity or water quality would be affected from groundwater extraction due to the low extraction volumes.

The impacts of construction on springs and seeps and on aquifer compaction can be mitigated by the final road design. Impacted existing boreholes can be relocated, and accidental spills can be managed using best practices.

8.2 Operational impacts

Following construction of the proposed bypass, ground conditions in the vicinity could potentially change permanently. These long-term impacts could include:

- Potential long-term impacts on unconfined alluvial aquifers as a result of aquifer compaction under the proposed bypass: This compaction was also identified as an impact from the construction phase. The construction of the proposed bypass has the potential to change ground conditions permanently. The amount of alluvium in the area is minor (both laterally and vertically in extent), and compaction is considered a minor issue for the Woomargama area. However the potential consequences of aquifer compaction include:
  - Impediment to or prevention of the natural groundwater flow to the north-west: This may cause small localised waterlogging and ponding to the immediate east of the proposed bypass, and could result in minor lowering of the watertable to the north-west.
  - Potential impacts to groundwater dependent ecosystems: Springs and seeps are likely to be present adjacent to the proposed bypass. Changes in groundwater flows due to changes in the aquifer induced by the presence of the proposed bypass could affect the usability of this natural water resource.
- Contamination of groundwater by surface runoff and/or accidental spills or leakage of hazardous materials: The unconfined alluvial aquifer and shallow local groundwater systems in the granite are vulnerable to groundwater contamination. Without careful management, groundwater could potentially become contaminated with heavy metals and organics (such as hydrocarbons) arising from vehicle use and the associated tyre wear and emissions.

The impacts of operation on springs and seeps and on aquifer compaction can be mitigated by the final road design. Accidental spills can be managed using best practices.

9. Management and mitigation of impacts

Final design of the proposed bypass is a key issue for the management and mitigation of the groundwater system. Considering ground conditions and groundwater flow during the design stage will assist in preventing or alleviating potential impacts that may arise from the project construction and operation. Potential impacts and mitigation/management strategies are discussed below and have been summarised in Table 9-1:

- The proposed bypass design should consider impacts on the alluvial aquifer from ground compaction. Road construction has the potential to cause compaction of the alluvial sediments and this in turn could induce changes to groundwater flows. The degree of compaction will be further assessed in the geotechnical investigations. The groundwater impacts (if substantial) may be able to be managed or prevented by the following measures:
  - Construction of a bridge road for that part of the highway that crosses the small alluvial areas associated with Mountain Creek.
  - Inclusion of adequate drainage in the road design if/where the alignment is constructed as a fill platform. This would include culverts and diversion drains.
- Appropriate drainage infrastructure should be developed and implemented to minimise and manage possible groundwater seepage/springs in areas of cut into the fractured granite rock. Drainage of the road/construction area to allow these seeps to flow freely is important for construction and ongoing management
- It may be necessary to decommission and relocate certain boreholes where the proposed bypass corridor overlies or is within very close proximity to an existing borehole. The new borehole location would need to consider existing infrastructure associated with the bore (such as tanks, pipes and power supplies) and also the hydrogeology of the landholder’s property for the location of a new bore to maintain security and quality of supply.
- A hazardous materials plan (and spill emergency procedure) should be implemented as part of the construction environmental management plan (CEMP). Fuels or hazardous materials should be stored in accordance with relevant standards and legislation depending on the volumes and nature of the materials. Procedures for refuelling and maintenance of plant and vehicles that minimise the risk of spills and associated impacts on the alluvial groundwater should also be developed and adhered to. Spill kits should be kept with plant or vehicles to clean up any accidental spills which may occur during construction.
- The location of additional extraction bores should consider the proximity to existing groundwater users. The new bore should ideally be placed at the maximum distance away from any neighbouring bores.

Table 9-1 Potential groundwater impacts and mitigation measures

Potential impact	Timeline	Mitigation/management measure
Ground compaction inducing changes to shallow aquifer conditions	Construction and operation	Road design should consider the impacts of ground compaction on the aquifer conditions. Incorporating bridges, culverts, diversion drains and pondages into final road design in areas over alluvium may alleviate or prevent impacts to shallow aquifer conditions. Ongoing groundwater level and water chemistry monitoring should be undertaken during construction and operation.
Water extraction boreholes may be near proposed road alignment	Construction and operation	Boreholes may need to be decommissioned and relocated to maintain a reliable water supply for land owners.
Impact to springs/seeps in fractured rock areas	Construction and operation	Road design in areas with known springs/seeps should consider under road drainage to prevent impeding the flow of existing springs/seeps
Short-term impacts from cuttings	Construction	Drainage of the road/construction area to allow these seeps to flow and ongoing management
Releases of hazardous materials (fuels, chemicals etc) to groundwater	Construction	Implement a hazardous materials plan and spill management procedure during construction. Use spill kits and bounded areas for refuelling and maintenance.
Groundwater extraction for construction will result in some local groundwater level drawdown from the aquifer	Construction	Location of potential new extraction bores should be at the maximum distance away from existing groundwater users to minimize potential impacts.

10. Groundwater management plan

A groundwater management plan may be required for the construction of the proposed bypass. The plan would need to be developed in accordance with the relevant government legislation and policies. Suggested content for the plan includes but is not limited to:

- Department of Environment Climate Change and Water (DECCW) specific requirements, including procedures to ensure that construction works are undertaken in accordance with relevant legislation and government policy.
- Consideration of the potential for groundwater to supply the water requirements of the proposed bypass construction. Negotiation with DECCW and Riverina Water on issues such as obtaining a licence to drill water supply bores and options for temporary trading of groundwater allocation for use in an existing bore (such as a town water supply or irrigation bore) should be considered and incorporated into the groundwater management plan.
- Specific mitigation measures to prevent identified potential impacts to the aquifer.
- Establishment of a groundwater monitoring network, including a combination of drilling monitoring boreholes and or monitoring existing stock bores. Monitoring bores should be located both east and west of the proposed bypass. The number and location of bores is not critical, but should consider both groundwater systems (alluvial and fractured rock) and up-gradient and down-gradient locations. Provision for changes to the monitoring network and program may be required if changes to groundwater conditions are observed during construction.
- Monitoring of the groundwater network for water levels and chemistry. The plan should determine the frequency of monitoring and the parameters to be monitored (at a minimum quarterly monitoring or dataloggers should be installed, and field parameters and major ions should be monitored).
- Emergency response procedures for any critical incident that could potentially affect the aquifer system (such as spills overlying the aquifer).
- Communication procedures for educating the project team on groundwater issues.

11. Conclusions

Based on the findings of the groundwater investigation the following conclusions can be made:

- There are two main aquifer systems present in the Woomargama area — unconsolidated alluvium and fractured rock aquifers.
- The main water supply aquifer for groundwater resources in Woomargama is the alluvial aquifer.
- Groundwater levels in the alluvium are shallow (less than 3 mbgl) for the Mountain Creek alluvium and slightly deeper for the Sandy Creek alluvium (12.35 mbgl). Water levels in the deeper fractured rock aquifers ranged between 15.9 and 22.4 mbgl, with shallower water levels in the weathered granite deposits (3.9–9.2 mbgl).
- The overall groundwater flow direction in the alluvium associated with Mountain Creek is towards the west-north-west. In the alluvium associated with Sandy Creek it is towards the north. It is assumed that groundwater in the deeper aquifer also flows north-west.
- Groundwater usage is largely for stock and domestic purposes. However, there are also three town water supply bores.
- There is some potential for a groundwater supply to be obtained for use in batch plants from the alluvial sediments associated with Mountain Creek downstream (to the west) of Woomargama. Larger volumes for continuous supply are unlikely to be available from within the alluvium.
- During highway construction and operation, the potential impacts to groundwater include:
  - Compaction of alluvium during highway construction could affect groundwater flow.
  - The up-gradient (south-eastern) side of the proposed bypass could experience raised groundwater levels, waterlogging and/or dryland salinity.
  - The down-gradient (western) side of the proposed bypass could experience lowered groundwater levels.
  - Impacts to springs could occur due to cut/fill in granite along the proposed bypass alignment.
  - Some boreholes located within the alignment may require relocation.
  - Releases of hazardous materials during construction have the potential to affect groundwater quality. Contaminated runoff from the proposed bypass whilst the highway is operational could also potentially affect the aquifer.
- Potential mitigation measures include:
  - Considering the impacts of aquifer compaction during the design of the proposed bypass and incorporating bridges, culverts and drainage infrastructure into the road design to prevent or alleviate potential waterlogging impacts or impacts to groundwater levels.
  - Considering existing springs up-gradient of the proposed bypass alignment, incorporating culverts and drainage to allow springs to flow freely.
  - Incorporating a hazardous materials management plan and spill management procedures into the CEMP.

- Relocating boreholes that are affected by the road construction to maintain water supply to land owners.

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