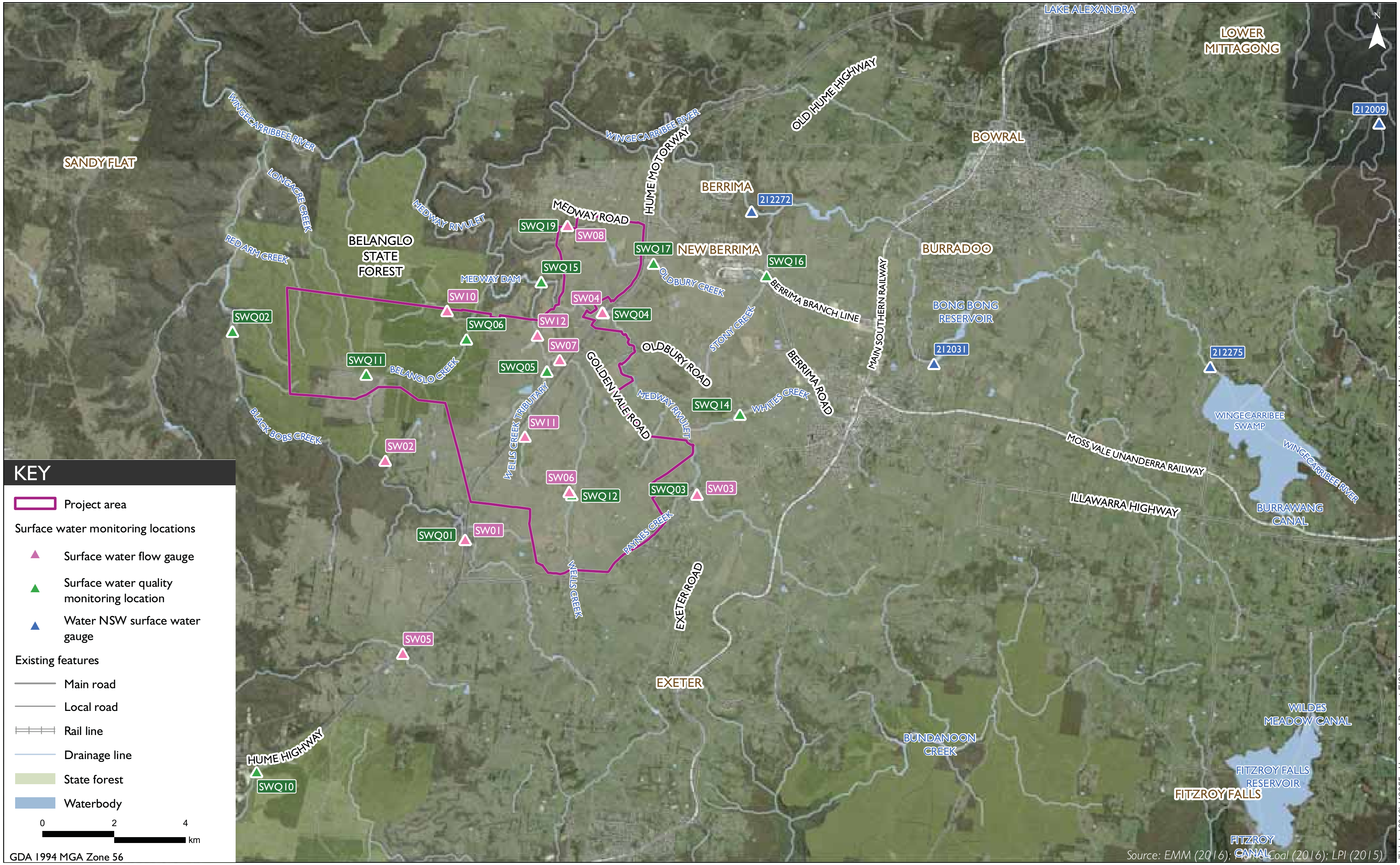


KEY

- Project area
- Surface water monitoring locations
  - Surface water flow gauge
  - Surface water quality monitoring location
  - Water NSW surface water gauge
- Existing features
  - Main road
  - Local road
  - Rail line
  - Drainage line
  - State forest
  - Waterbody

0 2 4 km

GDA 1994 MGA Zone 56

EMM HUMECOAL

Surface water monitoring locations

Hume Coal Project
Water Assessment

Figure 4.1

4.1.2 Surface water level monitoring

Surface water level monitoring began in January 2012 at three project-specific stream flow gauges and later expanded to 11 level monitoring locations. An overview of the project's surface water flow monitoring data range is provided in Figure 4.2. Gaps in the monitoring occurred when equipment malfunctioned.

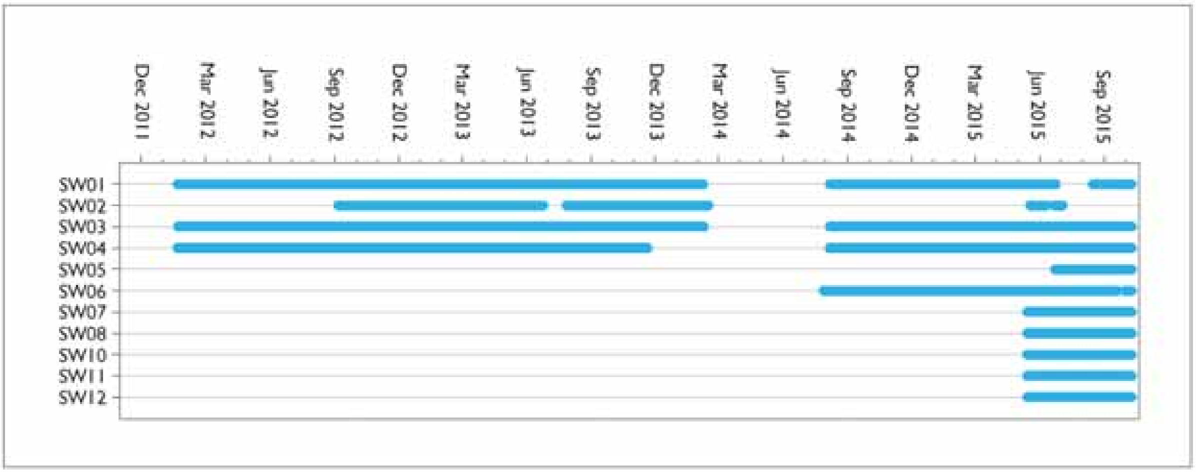


Figure 4.2 Surface water level monitoring overview

Bubbler system and pressure transducer installations at each surface water level monitoring site record water level data. Data collected included flow rates and flow volumes, commonly referred to as stage-discharge rating curves. WSP PB (2016c) reduced and refined uncertainty in the rating curves, as a result of complex topography, by including additional water level, transect, and flow velocity measurements for each monitored section of the watercourses.

Three Sydney Catchment Authority (SCA) flow gauging stations in the project area (Figure 4.2) provided additional flow data:

- Wingecarribee River at Bong Bong Weir 212031;
- Wingecarribee River at Berrima 212272; and
- Wingecarribee River at Greenstead 212009.

4.1.3 Surface water quality monitoring

Australian Laboratory Services (ALS) has completed monthly baseline surface water quality monitoring since April 2012. Monitoring has included samples for laboratory analysis and field physicochemical parameters (WSP PB 2016e). These results have contributed to the understanding of potential groundwater and surface water connectivity in the project area. The surface water quality monitoring timeline is shown in Figure 4.3. Several surface water quality monitoring sites are no longer included in the monitoring network as they are outside the amended project area boundary and considered unlikely to be affected by the project as they were regularly dry sites (SWQ07, SWQ08, and SWQ13) or they became too difficult to access (SW02).

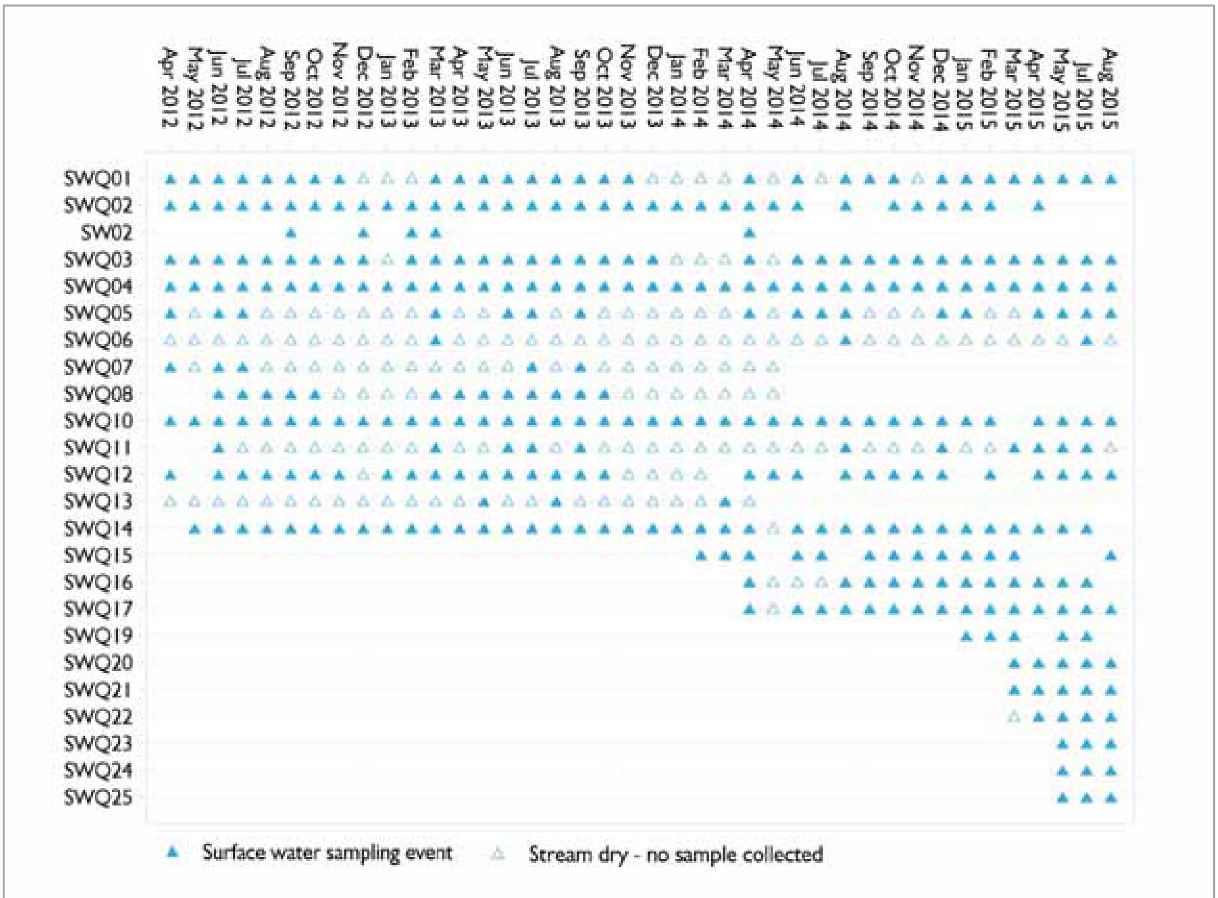


Figure 4.3 Surface water quality monitoring overview

The field physicochemical parameters monitored included: pH, electrical conductivity (EC), oxidation reduction potential (redox), temperature and dissolved oxygen. The laboratory analytes included: physical parameters, major cations and anions, alkalinity, dissolved metals, nutrients, oil and grease, aromatic hydrocarbons (benzene, toluene, ethyl-benzene, xylene and naphthalene (BTEXN)), and total recoverable and petroleum hydrocarbons. Isotopes (radiocarbon, oxygen-18, and tritium) were also analysed in 2013 to provide additional understanding of groundwater and surface water connectivity at three locations (one at Medway Rivulet and two at Wells Creek) (WSP PB 2016b).

Result accuracy, reliability, and precision were established by implementing field and laboratory quality assurance and quality control (QA/QC) procedures. These QA/QC procedures included: analysis of unstable parameters in the field, calibration of equipment, delivery of samples to the laboratory within holding times, collection of blind duplicate samples, maintenance of samples at a cool temperature, collection of blind duplicate samples, analysis of spiked and control samples, and use of gloves during sampling (WSP PB 2016b).

i Surface water assessment criteria

WSP PB (2016b) used the ANZECC and ARMCANZ water quality guidelines (2000) as assessment criteria for baseline surface water quality. Application of these guidelines considers the environment type (in this case: freshwater aquatic ecosystems), environmental values and existing condition, as well as the level of acceptable change. The toxicant trigger values for the protection of 95% of species have been used, as the project area's existing environment condition is classified as slightly to moderately disturbed. Default trigger values for the physicochemical constituents (ie EC and ammonia) for upland rivers in south-east Australia were adopted, with trigger values also derived from ecosystem data for unmodified or slightly disturbed ecosystems.

The trigger values in the drinking water guidelines (NHMRC 2016) were also considered (WSP PB 2016b). This is a requirement as the Wingecarribee River catchment is a southern (upstream) sub-catchment of the larger Hawkesbury-Nepean River catchment, which is within the Warragamba Drinking Water Catchment, where reference to the water quality objectives in the State Environmental Planning Policy (SEPP) (Sydney Drinking Water Catchment 2011) and NSW Healthy Rivers Commission of Inquiry into the Hawkesbury-Nepean River catchment (HRC 1998) is required.

4.1.4 Geomorphology assessment

Field geomorphology surveys were conducted between May 2012 and October 2015 (WSP PB 2016c). These surveys verified desktop assessments of river styles and geomorphic features within the project area.

The assessment collected geomorphological observation data, including bed and bank composition (where accessible), extent of riparian vegetation, geomorphological units and flow characteristics at the catchment and reach scale. The geomorphic assessment was completed using principles and terminology of the River Styles Framework (WSP PB 2016c).

The study area for the geomorphology assessment included streams in the surface infrastructure areas and above the proposed underground mining area, as well as pertinent streams surrounding the project area and streams potentially influenced by the project. The streams selected for the geomorphology assessment provided a catchment-based perspective for assessment. Site selection was based on the following criteria:

- headwaters originating within the project area;
- areas with key underlying geology and groundwater;
- representative reaches based on desktop assessment (aerial photography);
- areas with key surrounding land use characteristics;
- range of stream order; and

- the location of the existing surface water quality monitoring sites.

4.2 Groundwater monitoring

4.2.1 Groundwater monitoring network

Parsons Brinckerhoff designed and implemented a dedicated project groundwater monitoring network to investigate hydrogeological conditions in the project area (WSP PB 2016e). Up to four years of baseline hydrogeological data has been collected. The network was developed in consultation with DPI Water (then NOW) directly and via the GMMP (EMM 2017b).

The groundwater monitoring network includes groundwater monitoring bores, vibrating wire piezometers (VWPs), and landholder bores located within and around the project area. Project monitoring bores and VWPs are positioned to provide spatial coverage, investigate the major hydrogeological environments, and monitor potentially sensitive features. Specifically, the groundwater network was designed to:

- identify and characterise water bearing units and aquitards in the project area, with particular focus on characterising groundwater flow and quality within the main groundwater bearing unit, Hawkesbury Sandstone, and the mining target, Illawarra Coal Measures;
- provide spatial representation and flux of pressure heads across the project area to investigate potential vertical hydraulic gradients and connectivity between water bearing units and the underlying target coal seam;
- investigate the potential for surface water–groundwater interaction; and
- monitor potential sensitive features, including Medway Dam, Long Swamp, landholder bores and potential groundwater dependent ecosystems.

The Hawkesbury Sandstone, which directly overlies the Wongawilli Coal Seam (mining target), is the main water bearing zone monitored due to its dominance in the geological setting and use by landholders.

4.2.2 Monitoring bores

AR 47: Bore construction information is to be supplied to DPI Water by submitting a "Form A" template. DPI Water will supply "GW" registration numbers (and licence/approval numbers if required) which must be used as consistent and unique bore identifiers for all future reporting.

i Installation

Highland Drilling Pty Ltd (drilling contractor), under the supervision of Parsons Brinckerhoff hydrogeologists, completed all of the project groundwater monitoring bore drilling and installation, and where applicable decommissioning, in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC 2012). Drilling mostly used open hole rotary drilling techniques, with clean water for the drilling fluid. However, deeper boreholes, ie those intersecting the Illawarra Coal Measures, and boreholes for VWP were fully or partially diamond cored with drilling muds and additives.

The groundwater monitoring bores were installed to intersect the most productive water bearing zones and were effectively sealed from overlying formations.

During drilling, the supervising hydrogeologist completed:

- geological assessment at 1 m intervals, based on visual inspection of drill cuttings or drill core, and production of bore log;
- recording of water interceptions and airlift yields at each water bearing zone intersected;
- measurement of water quality for all major water bearing zones intersected. This typically involved measurement of field physio-chemical parameters and selected samples undergoing more detailed laboratory analysis; and
- specific design of the monitoring installation.

Monitoring bore licences were obtained from DPI Water before drilling works began. Form A: Particulars of Completed Works forms (drilling completion forms) were submitted to DPI Water after the monitoring bores and vibrating wire piezometers were complete.

Water used and produced during drilling was managed in accordance with the Hume Exploration Project Review of Environmental Factors (REF) (Hume Coal 2011, 2012, and 2014). Water for drilling was sourced from licensed supply or farm dams. There were no instances of uncontrolled release of water; water was discharged only when it met the water quality limits specified in the REF. All drilling scraps, drilling fluids and water that did not comply with REF limits was contained in above-ground tanks and disposed of at a licensed waste facility.

ii Geophysical logging

Geophysical data is useful to identify fine details within the geological units (notably the precise location of coal), and inferred hydrogeology via changes in conductivity.

Downhole geophysical logging took place at 20 of the deep project bore holes at nested locations (WSP PB 2016e). The bore holes are identified in Table 4.1. The geophysical tools used included calliper, gamma, resistivity and neutron. The gamma logs are included in the summary bore logs (Appendix L). Gamma radiation emitted from coal and shale is greater than from other sedimentary rocks; coal and shale units can be identified in a gamma log by an elevated gamma signal.

iii Monitoring bore details

> *AR 34: Details on all bores and excavations for the purpose of investigation, extraction, dewatering, testing and monitoring.*

The groundwater monitoring network installation occurred between September 2011 and October 2014 (WSP PB 2016e). The network consists of:

- 54 groundwater monitoring bores at 22 locations. Often multiple monitoring bores are installed next to one another at the same location; this is called a nested location. Each bore at a nested location is installed to a different depth, monitoring a different zone within the groundwater systems. Nested sites provide information on the vertical hydraulic gradients and inferred vertical connectivity at that location.

- 11 vibrating wire piezometer (VWP) sensors within three bores. The sensors collect information on pore pressure within a geological formation that can infer groundwater pressure. Similar to nested bores, positioning the sensors at different depths provides an understanding of vertical hydraulic gradients.

- Three landholder bores, two within the project area and one to the north. All monitor the Hawkesbury Sandstone.

Table 4.1 and Figure 4.4 show details and locations of the groundwater monitoring bores. Summary bore logs are included in Appendix L.

Table 4.1 Groundwater monitoring bores overview

Bore ID	Ground level (mAHD)	Total depth (mgbl)	Screen interval (mbgl)	Monitored formation	Lithology	Licence number
Project monitoring bores						
HU0018PZA[2]	691.7	108	96–99	Illawarra CM	Wongawilli coal seam	10BL604639
HU0018PZB	692.0	90	76–88	Hawkesbury SST	Sandstone	
HU0019PZA[2]	720.7	108	100.5–103.5	Illawarra CM	Wongawilli coal seam	10BL604640
HU0019PZB	720.5	84	70–82	Hawkesbury SST	Sandstone	
HU0020PZA	703.3	79.5	71.5–77.5	Hawkesbury SST	Sandstone	10BL604639
HU0020PZB[2]	703.7	88	80–86	Illawarra CM	Wongawilli coal seam	
HU0023PZA[1,2]	680.5	139.5	136.5–138.7	Illawarra CM	Wongawilli coal seam	10BL604919
HU0023PZB[1]	680.6	130	118–130	Hawkesbury SST	Sandstone	
HU0023PZC[1]	680.8	97.6	85–97	Hawkesbury SST	Sandstone	
HU0032LDA[2]	646.6	121	108–114	Illawarra CM	Wongawilli coal seam	10BL605105
HU0032LDB	646.6	89	58–88	Hawkesbury SST	Sandstone	
HU0035PZA[2]	681.4	152	54–78	Hawkesbury SST	Sandstone	10BL605140
HU0035PZB	680.8	35	16–34	Ashfield Shale	Siltstone	
HU0037PZA	703.8	111	102–105	Illawarra CM	Siltstone	10BL605073
HU0037PZB	703.8	90	72–87	Hawkesbury SST	Sandstone	
HU0038PZA[2]	658.5	116.9	104.9–107.9	Illawarra CM	Wongawilli coal seam	10BL605142
HU0038PZB	658.4	78	74–77	Hawkesbury SST	Sandstone	
HU0038PZC	658.3	63	56– 62	Hawkesbury SST	Sandstone	
HU0042PZA[2]	702.5	162	156–159	Illawarra CM	Wongawilli coal seam	10BL605170
HU0042PZB[1]	702.7	141	134–140	Hawkesbury SST	Sandstone	
HU0042PZC	702.0	150	143–149	Hawkesbury SST	Sandstone	
HU0043XPZA[2]	692.0	111	95–101	Illawarra CM	Wongawilli coal seam	10BL605222
HU0043XPZB	691.8	87	77–86	Hawkesbury SST	Sandstone	
HU0044XPZA	641.9	12	8–11	Illawarra CM	Wongawilli coal seam	10BL605223
HU0044XPZB	647.0	5	4–4.5	Hawkesbury SST	Sandstone	
HU0056XPZA[1,2]	735.4	150	143.5–144	Illawarra CM	Wongawilli coal seam	10BL605256
HU0056XPZB	735.5	140	133–139	Hawkesbury SST	Sandstone	
HU0056XPZC	735.5	26	19–25	Robertson Basalt	Basalt	

Table 4.1 Groundwater monitoring bores overview

Bore ID	Ground level (mAHD)	Total depth (mgbl)	Screen interval (mbgl)	Monitored formation	Lithology	Licence number
HU0072PZA	640.1	129	124–127	Illawarra CM	Wongawilli coal seam	
HU0072PZB	640.5	99	92–98	Hawkesbury SST	Sandstone	10BL605181
HU0072PZC	640.9	46	39–45	Hawkesbury SST	Sandstone	
HU0073PZA[2]	655.8	172	151–169	Illawarra CM	Sandstone	
HU0073PZB	655.1	124	119–122	Illawarra CM	Wongawilli coal seam	10BL605329
HU0073PZC	654.9	86	79–85	Hawkesbury SST	Sandstone	
HU0088PZA[2]	655.4	148	143–146	Illawarra CM	Wongawilli coal seam	10BL605235
HU0088PZB	655.3	128	121–127	Hawkesbury SST	Sandstone	
HU0096PZA[2]	699.2	121	111–120	Illawarra CM	Tongarra coal seam	
HU0096PZB	699.1	101.3	92.3–98.3	Illawarra CM	Wongawilli coal seam	10BL605407
HU0096PZC	699.04	89	6–87	Hawkesbury SST	Sandstone	
HU0098PZ[1.3]	699.06	108	69–87	Hawkesbury SST	Sandstone	10BL605407
HU0118PZA[2]	612.5	15.3	7.3–13.3	Hawkesbury SST	Sandstone	10BL605497
HU0129PZA[2]	679.1	171	167–170	Illawarra CM	Wongawilli coal seam	10BL605509
HU0129PZB	679.2	153	146.5–152.5	Hawkesbury SST	Sandstone	
HU0133PZA[1, 2]	648.2	127	120–126	Illawarra CM	Tongarra coal seam	
HU0133PZB[1]	648.2	112.5	108.5–111.5	Illawarra CM	Wongawilli coal seam	10BL605568
HU0133PZC[1]	648.0	83.8	79.8–82.8	Hawkesbury SST	Sandstone	
HU0136PZA	718.5	204	200–203	Illawarra CM	Wongawilli coal seam	
HU0136PZB[1]	718.5	167.8	157.8–166.8	Hawkesbury SST	Sandstone	10BL605498
HU0136PZC	718.5	59.6	52.6–58.6	Roberson Basalt	Basalt	
HU0142PZA	672.4	130.7	127–129	Illawarra CM	Wongawilli coal seam	
HU0142PZB	672.3	119	112–118	Hawkesbury SST	Sandstone	10BL605572
HU0142PZC	672.2	85	81–84	Hawkesbury SST	Sandstone	
HU0143PZA	649.6	125.8	118.8–124.8	Illawarra CM	Siltstone	
HU0143PZB	649.6	113	109–112	Illawarra CM	Wongawilli coal seam	10BL605606
HU0143PZC	649.4	95.9	91.9– 94.9	Hawkesbury SST	Sandstone	
Vibrating wire piezometers						
HU0040CH[2]	656.5	98	V1–120.1	Wongawilli seam	Coal	
			V2–106.9	Hawkesbury SST	Sandstone	10BL605428
			V3–81	Hawkesbury SST	Sandstone	
			V4–40	Hawkesbury SST	Sandstone	
HU0077CH[2]	689.7	128	V1–87	Wongawilli seam	Coal	
			V2–72	Hawkesbury SST	Sandstone	10BL605427
			V3–58	Hawkesbury SST	Sandstone	
HU0122CH[2]	634.5	120	V1–112.2	Wongawilli seam	Coal	
			V2–86	Hawkesbury SST	Sandstone	10BL605569
			V3–45	Hawkesbury SST	Sandstone	
			V4–15	Hawkesbury SST	Sandstone	

Table 4.1 Groundwater monitoring bores overview

Bore ID	Ground level (mAHD)	Total depth (mgbl)	Screen interval (mbgl)	Monitored formation	Lithology	Licence number
Landholder bores						
GW106652	652.3	120	25–120	Hawkesbury SST	Sandstone	10BL162638
GW108194	-	121.5	42–121.5	Hawkesbury SST & Wongawilli seam	Sandstone & Coal	10BL164544
GW106710	672.4	115	64–108	Hawkesbury SST	Sandstone	10BL106710
DPI Water monitoring bores						
GW075032	679.2	91	24–29	Hawkesbury SST	Sandstone	-
			73–88	Illawarra CM	Shale	
GW075034	665	101	90–100	Hawkesbury SST	Sandstone	-
GW075036	670.4	100	73–84	Hawkesbury SST	Sandstone	-
GW072401	-	32	-	Hawkesbury SST	Sandstone	10BL156071

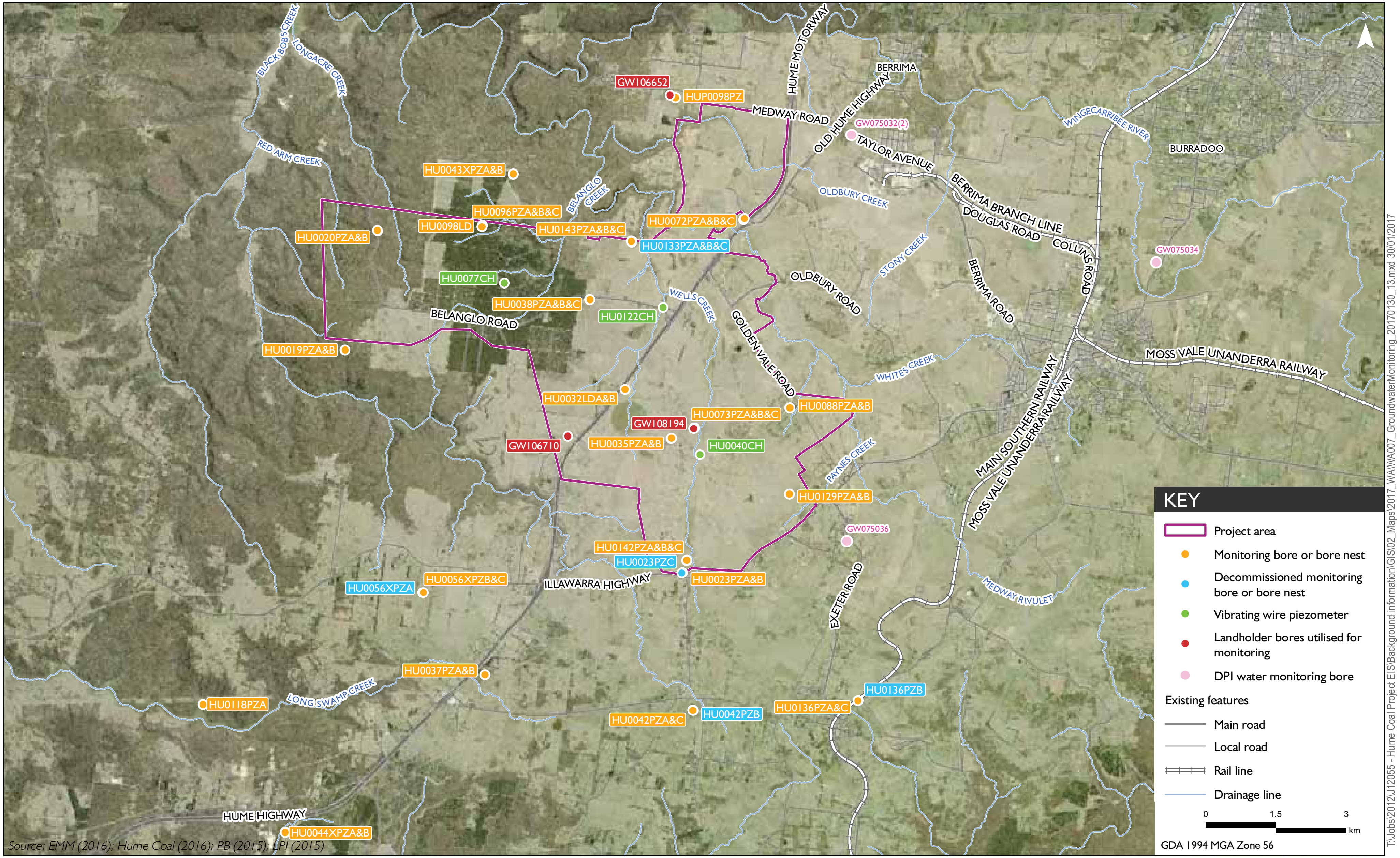
Notes: Source: WSP PB 2016e, DPI Water Groundwater monitoring network database (DPI Water 2016b).
SST = Sandstone, CM =Coal Measures, VWP = vibrating wire piezometer
mAHD = metres Australia Height Datum, mbgl = metres below ground level.
1 = decommissioned bore.
2 = geophysical log completed.
3 = bore installed for pump testing only and was decommissioned– bore was not part of the ongoing monitoring network.
- = unknown.

4.2.3 Hydraulic testing

A diverse range of hydraulic tests was conducted to provide site-specific information on the hydraulic properties of the groundwater systems. The tests completed include rising and falling head tests (slug tests), packer tests, laboratory core permeability tests and constant rate pumping tests (WSP PB 2016e). The locations of the various tests are shown in Figure 4.5.

i Slug testing

Slug tests provided an indication of the hydraulic parameters of the formation in the immediate vicinity of the screened interval of a monitoring bore. Slug tests were carried out at 42 project groundwater monitoring bores (Figure 4.5). This involved installing an electronic water level logger in the bore, displacing water in the bore using a slug (comprising a solid bailer), and recording the water level change over time. The results provide an indication of the rock's bulk hydraulic conductivity, or rate of groundwater flow, in the immediate vicinity of the screened interval.



Groundwater monitoring locations
Hume Coal Project
Water Assessment
Figure 4.4

ii Packer testing

Packer testing provided information on the hydraulic properties of the rock mass at specific depth intervals (generally at thicknesses of between 6.5 and 8.5 m). The results are indicative of the primary permeability of the rock mass as well as secondary permeability that may be associated with joints and fractures. Packer testing was conducted on open boreholes by Strata Control Technology in September 2013, and March and April 2015.

Within three key open boreholes, 28 depth intervals were tested, representing a range of geological conditions (Figure 4.5). Packer testing used double packers and injected water into a sealed test interval and measured the rate of water flow (or pressure build up and decay) over a period of time.

iii Laboratory core permeability

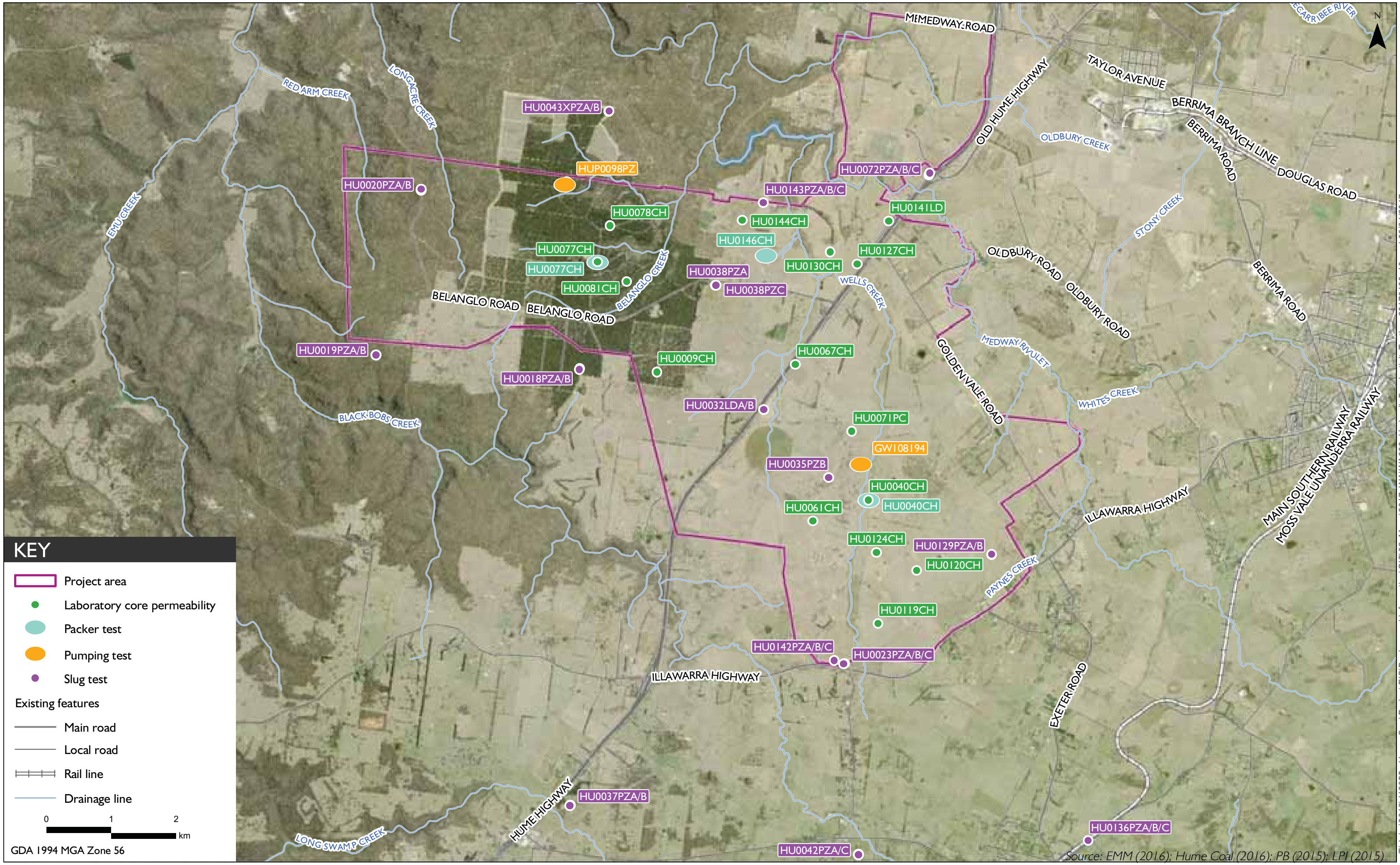
Laboratory core permeability testing provided information on the hydraulic properties of the rock mass at specific depth intervals (about 0.1 m intervals). The results are indicative of the primary permeability of the rock mass and do not account for the effects of secondary permeability that may be associated with joints and fractures.

Core Laboratories Australia tested a total of 39 samples from 16 core hole locations (Figure 4.5) (WSP PB 2016e). Between one and ten core samples were selected from each borehole and were tested for vertical and horizontal permeability. The core samples were representative of the range of lithologies and permeabilities throughout the stratigraphic profile across the project.

iv Pumping tests

Pumping tests pumped water from a test bore at a suitable constant rate and for enough time for a significant drawdown response in nearby monitoring bores. Pumping tests were a direct and reliable method to obtain estimates of groundwater system hydraulic properties, including storativity, transmissivity and horizontal hydraulic conductivity. Pumping tests also provided information on the extent and sustainability of the aquifer and the degree of connection with nearby surface water sources if they were present.

Two constant rate pumping tests were conducted in the project area: a 24-hour test at HU0098PZ and a 7-day test at GW108194. Coffey (2016a) assessed the groundwater level observations from the test and monitoring bores using the computer-based 'WTAQ' algorithm for confined/unconfined groundwater systems.



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Groundwater hydraulic conductivity testing

Hume Coal Project
Water Assessment

Figure 4.5

4.2.4 Groundwater level monitoring

Groundwater level monitoring began in November 2011 at six project monitoring bores and later at other monitoring locations following installation (WSP PB 2016e). The duration of the groundwater level monitoring period at each project monitoring bore, VWP, and landholder bore is shown in Figure 4.6. For a majority of locations there is over two years of groundwater level monitoring data. Groundwater level data has also been obtained from six DPI Water monitoring bores at four locations near the project area.

Solinst pressure transducers and data loggers are installed in all the project groundwater monitoring bores and monitor groundwater levels every six hours. When the loggers were downloaded, manual groundwater level measurements were also recorded to calibrate the logger data. A barometric data logger installed above the water table at HU0018PZA records changes in atmospheric pressure. Data from this logger is used to correct for the effects of changing barometric pressure and barometric efficiency on groundwater levels.

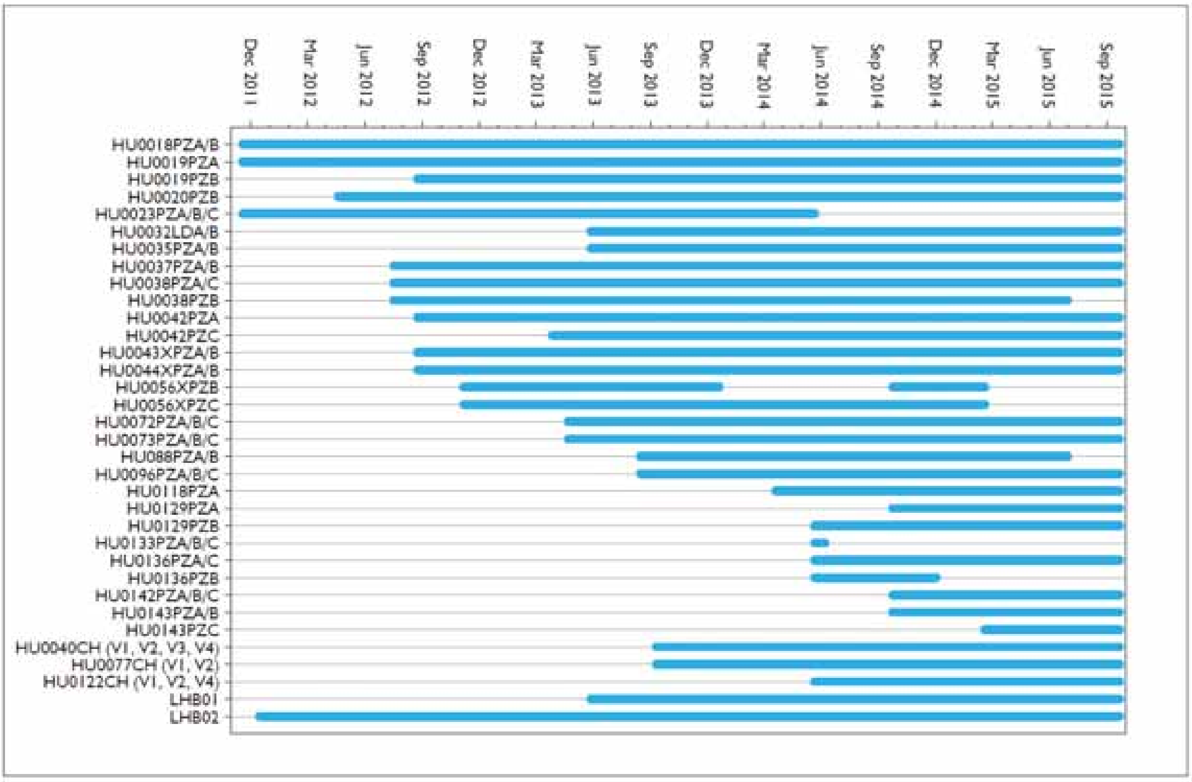


Figure 4.6 Groundwater level monitoring overview

4.2.5 Groundwater quality monitoring

An initial round of groundwater quality monitoring was completed following each monitoring bore installation. Groundwater quality monitoring has continued at either a quarterly (ie every three months) or annually (WSP PB 2016e). The schedule of groundwater quality monitoring is shown in Figure 4.7.

The groundwater sampling method used at each bore was determined based on the depth of the bore, the depth to groundwater, and the hydraulic conductivity of the screened formation. The sampling techniques and criteria for selection are shown in Table 4.2.

Table 4.2 Sampling techniques and criteria for selection

Criteria for sampling technique	Sampling techniques	Description
Higher yielding, shallower monitoring bores	Submersible pump	Typically, three well volumes are purged before sampling to allow a representative groundwater sample to be collected. If purged until dry, the bore is allowed to recharge and the recharge water is sampled. Water quality parameters (including pH, temperature and electrical conductivity (EC)) are measured during purging and pumping to monitor water quality changes, and to indicate representative groundwater suitable for sampling and analysis.
Low yielding bores, or deeper bores with high purge volumes	Micro-purge™ system	The micro-purge™ system allows groundwater to be drawn into the pump intake directly from the screened portion of the groundwater system, eliminating the need to purge relatively large volumes of groundwater from these bores. Water quality parameters (including pH, temperature and electrical conductivity (EC)) are measured during purging and pumping to monitor water quality changes, and to indicate representative groundwater suitable for sampling and analysis.
Shallow bores	Disposable bailer	Bailers are used to purge three well volumes before sampling to allow a representative groundwater sample to be collected. If purged until dry, the bore is allowed to recharge and the recharge water is sampled. Water quality parameters (including pH, temperature and electrical conductivity (EC)) are measured during purging to monitor water quality changes, and to indicate representative groundwater suitable for sampling and analysis.
Bores with deep groundwater levels	Snap sampler	A snap sampler is a dedicated in-well sampling device that provides a representative groundwater sample by passively sampling groundwater that flows through the screened section of the well where it is positioned. The device is removed from the well to collect the groundwater samples, and is then replaced in the well to allow for sample collection during the next sampling round.
When pumps malfunction	HydraSleeves™ or double check bailer	Used to collect groundwater samples from within the screened interval of wells when pumps malfunctioned. The sleeve or bailer is lowered into the well, and following equilibration of the well the sample is collected. HydraSleeves™ have a one-way reed valve that collapses when the sleeve is full, preventing groundwater from the upper sections of the bore mixing with the sample in the sleeve during retrieval.

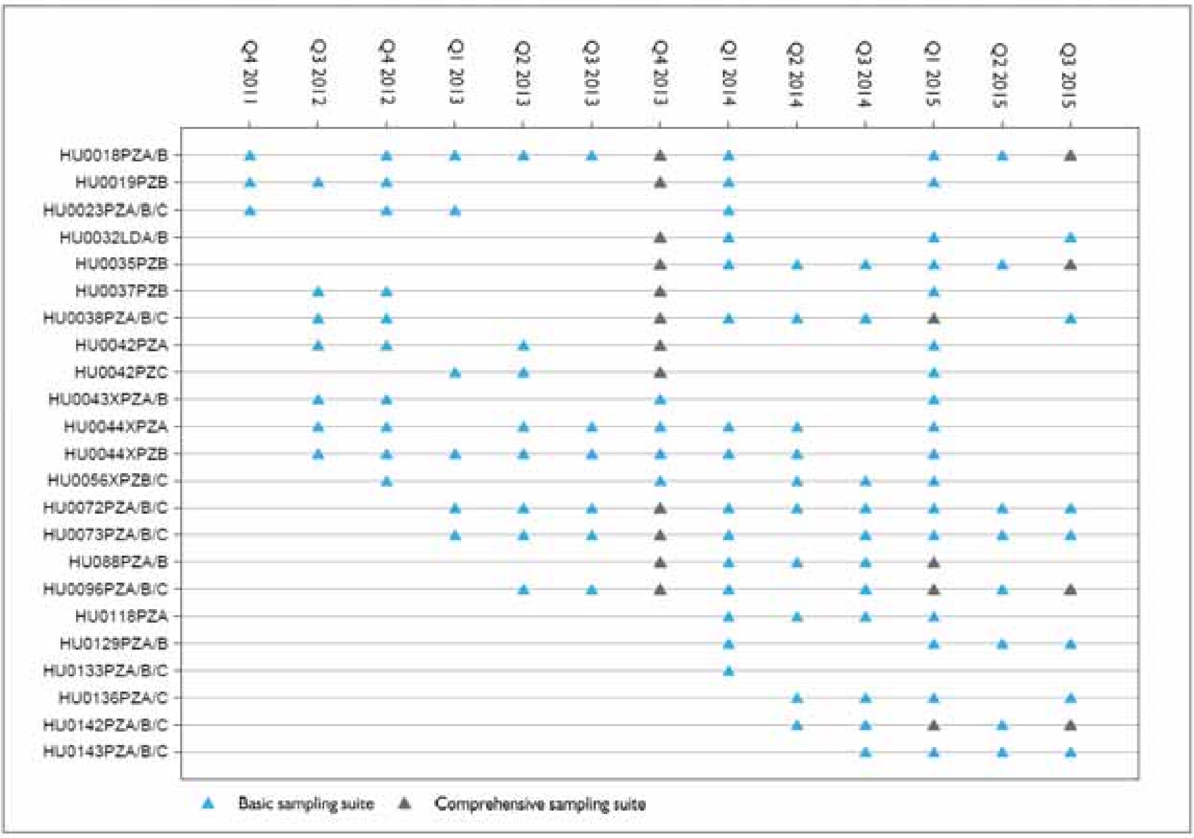


Figure 4.7 Groundwater quality sampling overview

Water quality samples were collected in laboratory provided sample bottles, with appropriate preservation. Samples undergoing dissolved metal analysis were filtered through a 0.45 µm filter in the field before collection in nitric acid preserved plastic sample bottles. Samples were stored on ice and sent to the laboratory under appropriate chain-of-custody protocols.

Groundwater samples are analysed by ALS for either the standard or comprehensive suite of analytes shown in Table 4.3. Standard quarterly samples were collected from a representative 23 monitoring bores. The comprehensive analytical suite is collected annually operational monitoring bores, or when additional water quality data is required.

Table 4.3 Standard and comprehensive analytical suites

Suite	Analytes
Standard	Field parameters (pH, EC, redox potential, DO, temperature)
	EC, TDS, TSS
	Major ions (calcium, magnesium, sodium, potassium, sulphate, chloride, alkalinity, acidity) and silica
	Dissolved metals (aluminium, antimony, arsenic, barium, boron, cadmium, chromium, cobalt, copper, fluoride, iron, ferrous iron, lead, magnesium, manganese, molybdenum, nickel, selenium, strontium, zinc)[1]
	Total metals (iron, manganese)[2]
Comprehensive	Standard suite
	Turbidity, BOD
	Nutrients (ammonia as N, nitrite as N, nitrate as N, reactive phosphorous, phosphorous, total phosphorus)
	TRH/BTEX
	PAHs, phenols
	Pesticides (OCPs, OPPs)
	Total coliforms, faecal coliforms and *E. Coli*

Notes: 1 = Before December 2013 only iron and manganese were analysed and ferrous iron has been included since June 2015.

2 = Not analysed prior to 2015.

TDS – total dissolved solids, TSS – total suspended solids, BOD – biochemical oxygen demand, TRH – total recoverable hydrocarbons, BTEX – benzene, toluene, ethylbenzene, xylene, PAH – polycyclic aromatic hydrocarbons, OCPs – organochlorine pesticides, OPPs – organophosphorous pesticides.

Field and laboratory QA/QC procedures are used to establish accurate, reliable and precise results. Some QA/QC procedures included: analysis of unstable parameters in the field, calibration of equipment, submitting laboratory samples within holding times, collection of blind duplicate samples, keeping samples chilled and wearing gloves during sampling (WSP PB 2016e).

Groundwater was also sampled for isotopes (radiocarbon, oxygen-18, and tritium) to determine groundwater system dynamics, recharge/discharge processes, groundwater system connectivity, groundwater–surface water linkages and potential ecosystem dependence on groundwater. Isotopes were analysed in samples from 15 groundwater monitoring locations in 2011 and 2013 (Parsons Brinkerhoff 2016e).

i Groundwater assessment criteria

a. Ecological water quality criteria

The methodology and criteria for ecological water quality assessment in Australia are presented in the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000).

The guidelines present assessment criteria (referred to as 'trigger values') for a range of organic and inorganic chemicals, which are applicable to both protection of aquatic ecology, and suitability for primary industries. While the guidelines are not specifically 'groundwater criteria', they apply at the point of use or exposure and are therefore relevant where an aquatic ecosystem is partially or wholly dependent on groundwater, or where groundwater supply supports primary industry.

b. Health-based water quality criteria

The methodology and criteria for health-based assessment of drinking water quality in Australia are presented in the National Health and Medical Research Council (NHMRC) and Natural Resource Management Ministerial Council (NRMMC)'s Australian Drinking Water Guidelines (NHMRC 2016). The ADWG lists health-based and aesthetic criteria for various organic and inorganic chemicals. Because groundwater systems within the study area are accessed for potable water supply, both the health-based and aesthetic criteria have been considered in this assessment.

4.2.6 Ecology surveys

Extensive ecology surveys and assessments have been completed for the project; the details and results of the field surveys are in the *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c). The ecology survey considered threatened species as well as mapping the baseline ecology across the greater project area.

Paddys River Swamps (comprising Long, Hanging Rock, Mundego, and Stingray Swamps) and Wingecarribee Swamps are identified as high priority GDEs in the Metropolitan Groundwater WSP. These GDEs are, however, some kilometres from the mine area, being 9 km to the south-west and 17 km to the east, respectively (Figure 1.4). The National Atlas of Groundwater Dependent Ecosystems (BoM 2012) was also considered.

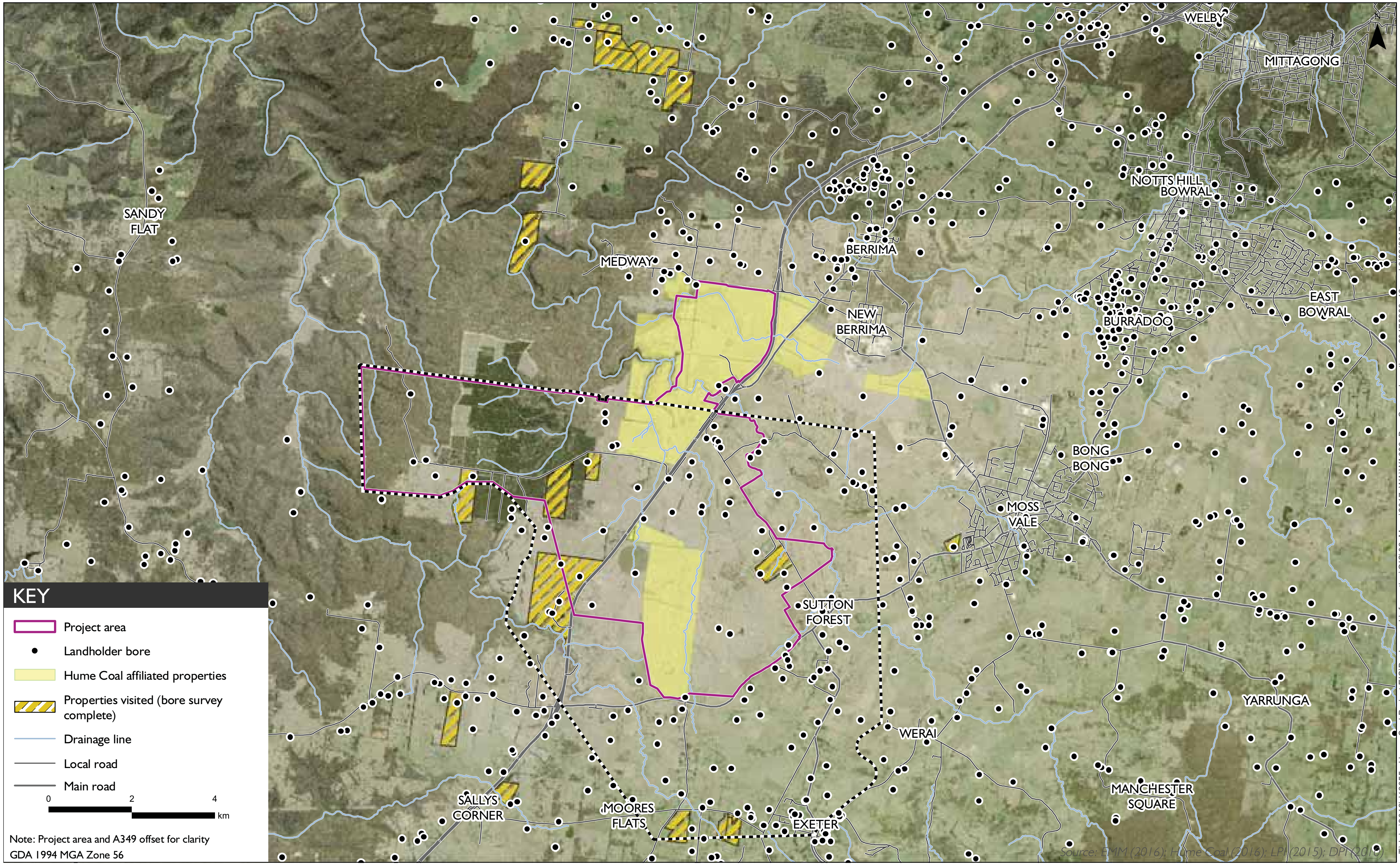
Although the GDEs are at a distance from the mine, the design of the surface water and groundwater monitoring network has considered these GDEs, with shallow monitoring and water quality sampling from the nearest swamp area.

Stygofauna sampling assessed 19 groundwater monitoring bores (8 within the project area and 11 outside it) in 2013 and 2014 (EMM 2017c). The bores sampled ranged in depth from 5 to 172 metres below ground level (mbgl), allowing for spatial characterisation of the potential for stygofauna in the Robertson Basalt, Wianamatta Group, Hawkesbury Sandstone, and Illawarra Coal Measures.

4.2.7 Bore census

Bore surveys were completed in March and April 2014 at properties in the project area and in May and June 2015 at properties near the former Berrima Colliery (WSP PB 2016e). The locations of the properties are shown in Figure 4.8.

Bore surveys involved visiting the homes of landholders within about 2 km of the proposed mine to question them about the bores on their property, their groundwater use, and possible effects from mining on groundwater levels at bores near Berrima Colliery. Where possible, baseline groundwater level and quality information was also collected.



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Bore survey locations

Hume Coal Project

Water Assessment

Figure 4.8

5 Surface water

This chapter describes the surface water features, geomorphology, and surface water use within the project area.

AR 60: Scaled plans showing the location of:
- wetlands/swamps, watercourses and top of bank
- riparian corridor widths to be established along the creeks
- existing riparian vegetation surrounding the watercourses (identify any areas to be protected and any riparian vegetation proposed to be removed)
- the site boundary, the footprint of the proposal in relation to the watercourses and riparian areas
- proposed location of any asset protection zones

AR 61: Photographs of the watercourses/wetlands and a map showing the point from which the photos were taken.

AR 68: The EIS must describe background conditions for any water resource likely to be affected by the development, including:
a. Existing surface and groundwater.
b. Hydrology, including volume, frequency and quality of discharges at proposed intake and discharge locations.
c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters.
d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.

AR 71: The EIS must map the following features relevant to water and soils including:
a. Acid sulfate soils (Class 1, 2, 3 or 4 on the Acid Sulfate Soil Planning Map).
b. Rivers, streams, wetlands, estuaries (as described in Appendix 2 of the Framework for Biodiversity Assessment).
c. Groundwater.
d. Groundwater dependent ecosystems.
e. Proposed intake and discharge locations.

AR 72: Identify relevant water quality objectives for surface and groundwater, including indicators and associated trigger values or criteria, in accordance with National Water Quality Management Strategy Guidelines. Reference the water quality objectives for the Wingecarribee River catchment in the "NSW Healthy Rivers Commission of Inquiry into the Hawkesbury Nepean Catchment". Identify any downstream users and uses of the discharged water classified in accordance with relevant ANZECC 2000.

AR 79: A full description of the development including those aspects which have the potential to impact on the quality and quantity of surface and groundwaters at and adjacent to the site, including:
- the mining proposal and mine layout
- the location, mapping and geomorphology of all creeks and water resources overlying and adjacent to the proposed mining area
- the hydrogeological fluxes between surface and groundwaters, including the filling of pine feather voids
- the location, management and storage of all hazardous materials- the disposal of wastes from the treatment of mine waters in the mine water treatment plant
- the management of dirty water from the washing and preparation of coal for transport
- the location, sizing and description of all water quality management measures
- the location and description of all water monitoring points (surface and ground waters)
- on-site domestic (sewage) wastewater management

AR 80: A detailed assessment of the development on water resources which considers the design, construction, operational and decommissioning phases and have regard for operation during periods of wet weather and include:
-details of measured and predicted coal mine, preparation area and stockpile area performance with respect to water quality management
-details of measures proposed to be adopted to offset impacts associated with construction activities eg earthworks, vegetation clearing and track construction
-impacts on overlying and adjacent creeks and water resources within risk management zone associated with subsidence
-impact of the proposed on-site domestic (sewage) wastewater management and associated effluent disposal area
-pre-development and post development run off volumes and pollutant loads from the site
-details of the measures to manage site water associated with processing coal and coal reject, general stormwater runoff and any human activities likely to affect water quality at the site, and how neutral or beneficial effect on water quality (NorBE) principles will be assessed and applied
-assessment of the impacts of the development on receiving water quality and volume, both surface and groundwater including from the filling of pine feather voids and associated impact on interaction and baseflows of surface waters
-details of the structural stability, integrity, ongoing maintenance and monitoring of all site water management measures including dams over the life of the project
-details of proposed monitoring of groundwater levels, surface water flows, groundwater and surface water quality, along with information as to how the proposed monitoring will be used to monitor, and, if necessary, mitigate impacts on surface water and groundwater resources
-the principles outlined in the 'Managing Urban Stormwater - Soils and Construction - Mines and Quarries' Manual prepared by the Department of Environment and Climate Change (2008)

AR 84: The EIS should provide a description of the location, extent and ecological characteristics and values of the identified water resources potentially affected by the project.

5.1 Overview of surface water features

AR 39: Identification of all surface water features including watercourses, wetlands and floodplains transected by or adjacent to the proposed project.

AR 40: Identification of all surface water sources as described by the relevant water sharing plan.

The project area is mostly located within the Wingecarribee River catchment of the Upper Nepean and Upstream Warragamba Water Source. The Wingecarribee River catchment is a southern (upstream) sub-catchment of the larger Hawkesbury-Nepean River catchment and part of the Warragamba Drinking Water Catchment. The Hawkesbury-Nepean River catchment has an approximate area of 21,400 km^2. Outside of the project area, a small portion of the south-eastern corner of A349 lies within the Bundanoon Creek catchment, a sub-catchment of the Shoalhaven River catchment (of the Shoalhaven River Water Source)(Figure 3.1).

Local sub-catchments of the Wingecarribee River catchment within the project area ultimately discharge into the Wingecarribee River, at least 5 km downstream from the project area. These include:

- Medway Rivulet catchment, incorporating the Oldbury Creek sub-catchment, where most of the project area and the surface infrastructure are located; and
- Black Bobs Creek catchment, incorporating Red Arm Creek and Longacre Creek sub-catchments.

The drainage lines (including creeks) within the project area (shown in Figure 1.4) generally drain in a north to north-westerly direction and flow into the Wingecarribee River. The Wingecarribee River flows east to west, north of the project area. The median flow in the Wingecarribee River (about 30 ML/day) is higher than the median flow in both Medway Rivulet (about 5 ML/day) and Oldbury Creek (about 2.5 ML/day) (WSP PB 2016c).

Medway Rivulet is the main creek in the project area. Its major tributaries include Oldbury Creek, Paynes Creek, Wells Creek, Wells Creek tributary and Whites Creek (Figure 1.4). The headwaters of Medway Rivulet begin near Moss Vale. Surface water flow is influenced by several in-stream storages, or ponded sequences, that impede continuous flow within the upper catchment. Near the project surface infrastructure area, Medway Rivulet is confined by steep gullies (WSP PB 2016c). Downstream of the project area, Medway Rivulet has been dammed to create a 1,350 ML reservoir, Medway Dam. The reservoir is part of the Wingecarribee Shire Council's water supply system. The Wingecarribee Shire Council holds a 900 ML WAL to take water from Medway Dam for town water supply; however, the Medway Water Treatment Plant has not been operational since 2013 (WSP PB 2016c).

The dam and water treatment plant is a third tier source of supply within the partially interconnected water supply system of the Wingecarribee Shire. The dam receives direct point source discharge from Moss Vale Sewage Treatment Plant, as well as agricultural runoff which has resulted in prolonged periods of toxic cyanobacteria blooms within the reservoir (Beca, 2010). A report commissioned by Wingecarribee Shire Council in 2010 found that "the risk of waterborne disease causing organisms in the treated water from the Medway water treatment plant is between 100 and 1,000 times greater than is considered acceptable where indirect potable reuse [of sewage discharge] is planned" (Beca, 2010). Based on information obtained from the Wingecarribee Shire Council in 2016 through the *Government Information (Public Access) Act 2009,* the water treatment plant was shut down on 12 June 2013, with a plant upgrade included in the Wingecarribee Shire Council's draft budget in coming years.

Oldbury Creek begins near New Berrima and joins Medway Rivulet 1.5 km downstream from the reservoir. Similarly to Medway Rivulet, the creek is characterised by several in-stream storages that impede continuous flow within the upper catchment. A large agricultural in-stream storage dam is next to the proposed CPP area.

There are no known wetlands or swamps within the project area. As noted previously, there are several temperate highland peat swamps about 9 km south-east and 17 km east of the project area. These features are discussed in Section 6.10.1.

Photographs and a map showing the point from which photos of the watercourses and drainage lines were taken within and around the project area are included in Appendix F (WSP PB 2016c).

5.2 Flow and geomorphology

AR 65: Geomorphic and hydrological assessment of water courses including details of stream order (Strahler System), river style and energy regimes both in channel and on adjacent floodplains.

Drainage line geomorphology is shown in Figure 5.2. Drainage line behaviour varies markedly at differing flow stages. Low flow, bankfull, and overbank stages were used to define the different behaviour of the local drainage lines. The variety of valley settings, bed/bank composition, and vegetation characteristics result in changes to drainage line behaviour. Most of the local drainage lines are classified as 'confined valley setting with occasional floodplain'. 'Confined valley' settings dominate where the mine surface infrastructure is proposed (WSP PB 2016c).

The upper reaches of the drainage lines have low elevation gradients, resulting in low flow energy. The low flow energy restricts channel geometry changes and erosion ability. As watercourses transition to partly-confined valley settings, erosion and geometry change is localised and limited to reaches with increased flow energy. Channels with non-cohesive bed and bank materials are more sensitive to changes in geometry and erosion (WSP PB 2016c).

Streamflow data from WaterNSW and Hume Coal gauges were analysed for flow duration curves and volumetric runoff coefficients (ie the percentage of rainfall that becomes stormwater runoff from a particular surface) (WSP PB 2016a). Depending on the ground cover, ground slope, and rainfall intensity, the run-off coefficient could be negligible (eg low rainfall intensity on flat, sandy soil) or higher than 80% (eg high rainfall on sloping, clay soil) (WSP PB 2016c). Of the flow data analysed, runoff coefficients varied greatly between gauge locations and over time. The lowest runoff coefficient was 18% for the long-term average at a WaterNSW gauge on the Wingecarribee River (212009). The highest runoff coefficient was 88% for a 5 month period in 2015 at a Hume Coal gauge located on Medway Rivulet (SW04).

A flow duration curve represents how often any given flow discharge is likely to be equalled or exceeded. The x-axis corresponds to probabilities of exceedance, while the y-axis corresponds to streamflow discharges. Daily flow duration curves for the WaterNSW gauging stations in the Wingecarribee River are shown in Figure 5.1 (WSP PB 2016a). The x-axis represents the likelihood of exceedance, and the y-axis represents stream flow discharges as runoff depths. Only 1% of the daily runoff depths are greater than 7 mm/day at all gauging sites. Flow occurs in the river (ie non-zero flow) for about 90% of the time at each gauge.

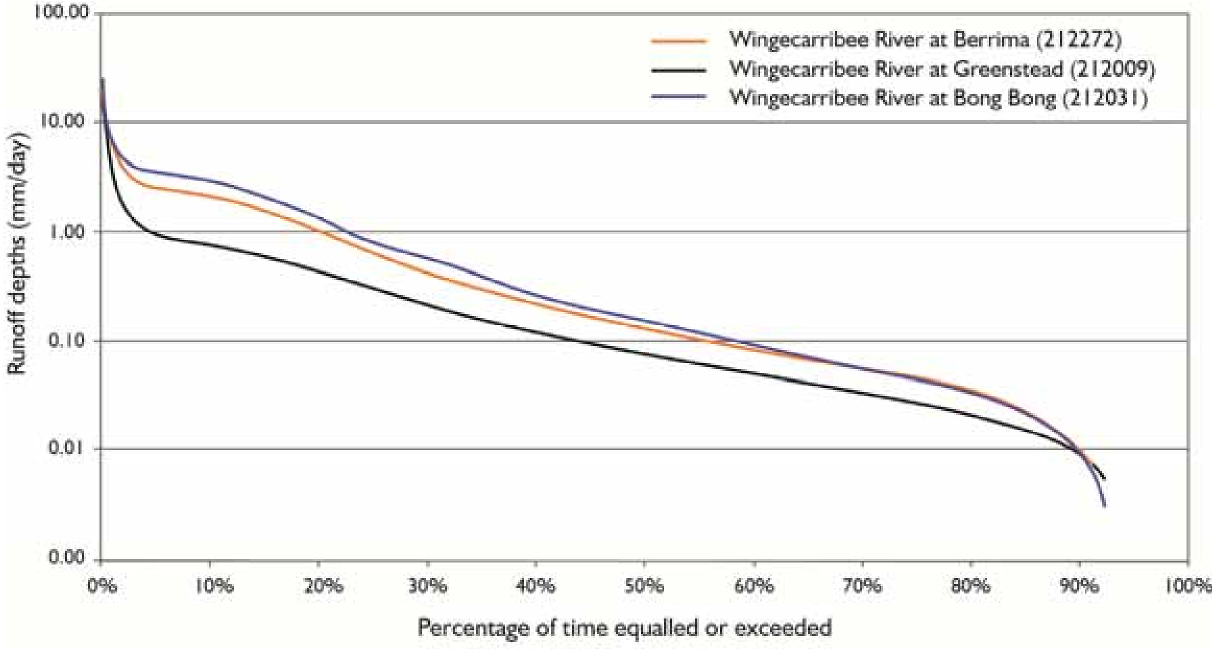
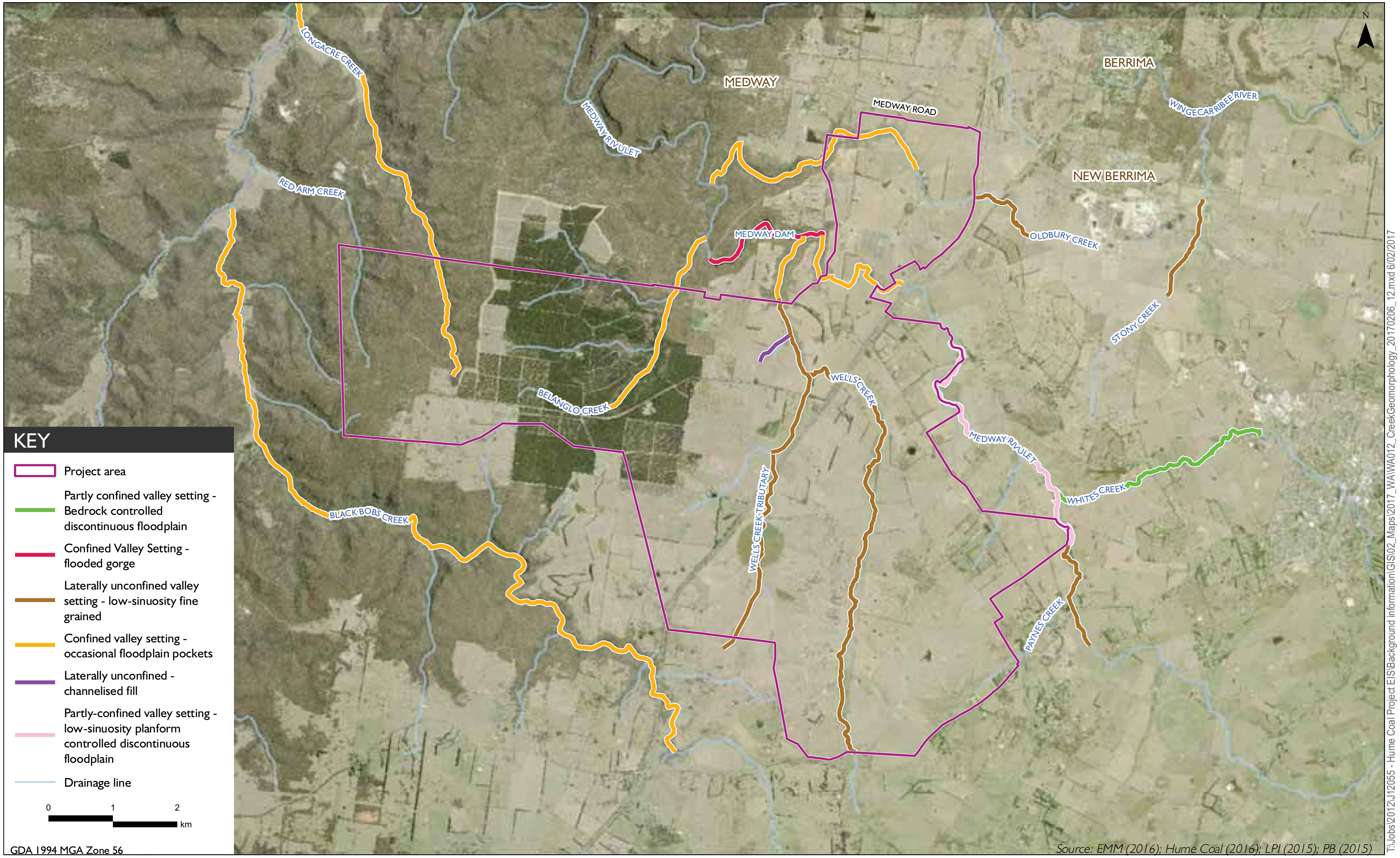


Figure 5.1 Flow duration curves for Wingecarribee River (WaterNSW gauges)

The Strahler stream classification system was applied to a subset of the Land and Property Information *Topographic dataset – Hydroline feature class* (LPI 2014) spatial dataset (WSP PB 2016c). This is a method of classifying waterways according to the number of tributaries associated with each. Numbering begins at the top of a catchment where the headwaters of the system start. As the stream order increases the contributing catchment area and channel size also increase. The lower downstream limit for flow assessment was determined to be the area where the Wingecarribee River joins the Wollondilly River.

When two 1st order streams join, the watercourse downstream is classified as a 2nd order stream, and so on. At its confluence with Medway Rivulet, downstream of the project area, Oldbury Creek is a 4th order stream under the Strahler stream classification. At its confluence with the Wingecarribee River, Medway Rivulet is a 5th order stream. Stream order classification is shown in Figure 5.3.



Drainage line geomorphology
Hume Coal Project
Water Assessment
Figure 5.2

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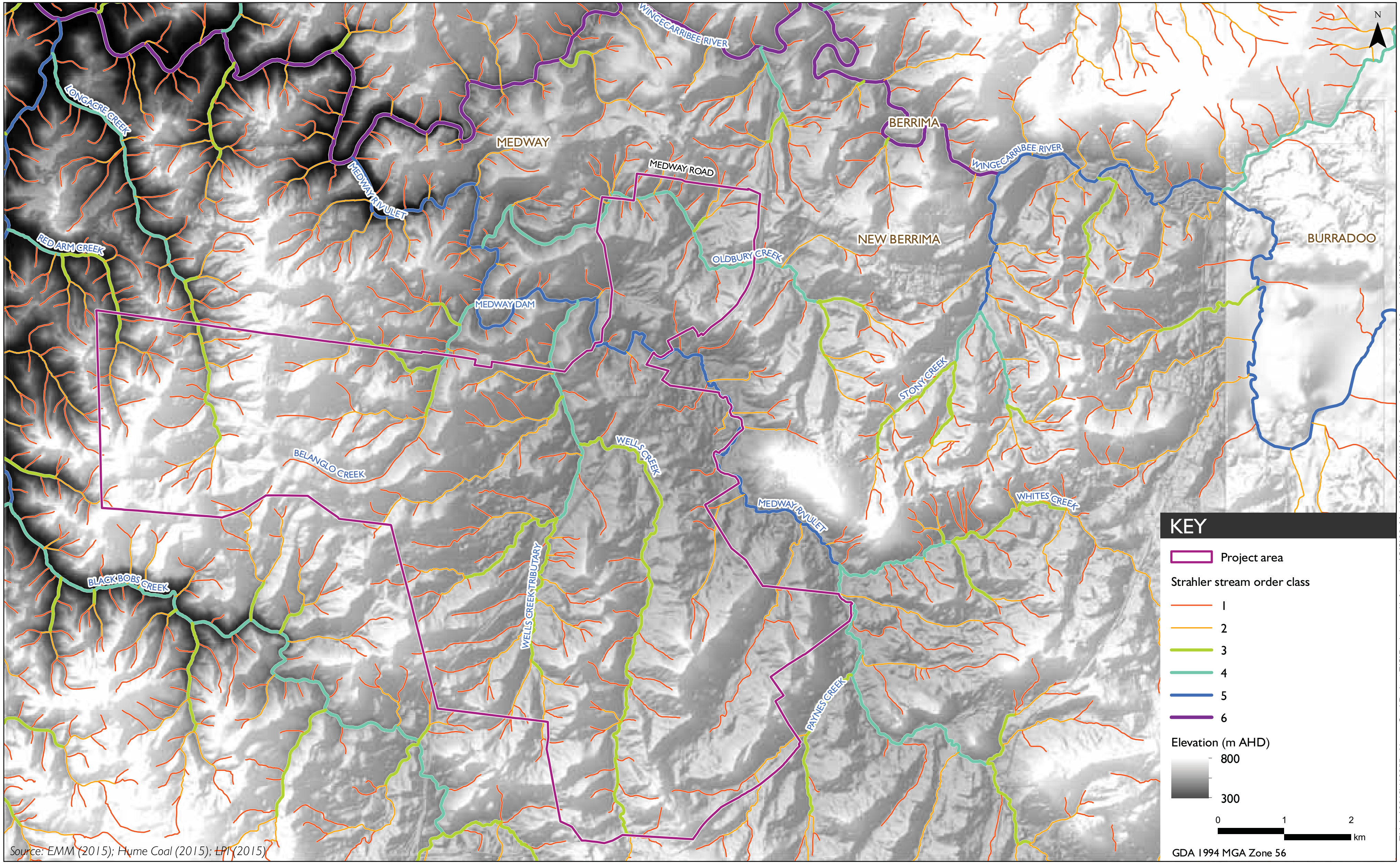

Stream order

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Water Assessment

Figure 5.3

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5.3 Surface water quality

Baseline water quality data collected between April 2012 and September 2015 from the Hume Coal surface water monitoring program are included and comprehensively analysed in Appendix E (WSP PB 2016b). The results from baseline monitoring will continue to be collected up to the start of project construction for future analysis. Data collection will continue during the project's construction and operation. Section 4.1.3 details the surface water quality monitoring program. Table 5.1 summarises the baseline water quality data for each surface water system on which this assessment has been based. The sections below summarise the surface water quality data.

Table 5.1 Summary of baseline surface water quality data per system

Management zone	Drainage line	Number of water quality monitoring locations	Total number of water quality samples collected[3]	Data range
Medway Rivulet	Medway Rivulet	4	90	Feb 2012–Sep 2015
	Oldbury Creek	5[1]	45	Apr 2012–Sep 2015
	Wells Creek and Wells Creek tributary	4	55	Apr 2012–Sep 2015
	Whites Creek	1	38	May 2012–Sep 2015
	Belanglo Creek and Planting Spade Creek	2	8	Mar 2013–Sep 2015
Lower Wingecarribee River	Wingecarribee River	1[2]	na	na
	Black Bobs Creek	4	72	Apr 2012–Aug 2015
	Longacre Creek	1	12	Jun 2012–Sep 2015
	Stony Creek	1	13	Apr 2014–Sep 2015
Lower Wollondilly river	Wollondilly River	1[2]	na	na
	Long Swamp Creek and Hanging Rock Swamp Creek	2	51	May 2012–Sep 2015
Bundanoon Creek	Indigo Creek	1	3	Jun 2013–Apr 2014

Notes: 1.Includes three farm dam monitoring locations.

2. WaterNSW monitoring location – samples not collected as part of the project.

3. Represents the maximum number of samples collected; however, not all parameters were necessarily used for analysis.

5.3.1 Summary of surface water quality

Baseline data has been compared against the Australian Drinking Water Guidelines (ADWG) (NHMRC 2016) and the ANZECC and ARMCANZ (2000) guidelines for irrigation, livestock drinking, aquatic ecosystems, and recreation; nutrients were compared against the recommended water quality objectives in HRC (1998). Within Medway Rivulet and Oldbury Creek in the project area, surface water typically complies with the most conservative guideline values, with the exception of the following:

- Salinity – although water is typically fresh, electrical conductivity (EC), a measure of salinity, typically exceeds the ANZECC and ARMCANZ (2000) guideline for aquatic ecosystems. The shale geology, underlying much of the project area, is a likely contributor to the salinity levels in surface water systems.

- Nutrients – most nitrogen and phosphorus samples exceed the WQOs recommended in HRC (1998). Agricultural practices and town effluent discharges into local streams are likely contributors to elevated nutrient levels.

- Metals – elevated levels of iron are typically observed compared to the ANZECC and ARMCANZ (2000) guideline for irrigation. Silver is typically elevated in Oldbury Creek compared with the ANZECC (2000) guideline for aquatic ecosystems. Some elevated levels of copper have been observed in Medway Rivulet and some elevated levels of aluminium in both Medway Rivulet and Oldbury Creek compared with the ANZECC and ARMCANZ (2000) guideline for aquatic ecosystems. Some elevated levels of manganese have been observed in both Medway Rivulet and Oldbury Creek compared with the ANZECC and ARMCANZ (2000) guideline for recreation. The Triassic rocks (shale and sandstone) underlying much of the project area are typically high in iron and manganese and are a likely contributor to elevated metals.

No BTEX chemicals (benzene, toluene, ethylbenzene, and xylene) were detected in baseline samples in either Medway Rivulet or Oldbury Creek.

A useful way of representing water quality data distribution is by box and whisker plots for key parameters. The box (the rectangle) represents the data range for the middle 50% of values (the data between the first and third quartiles). The horizontal line in the middle of the box represents the median value. The whiskers (the vertical lines extending up and down from the box) represent the data range for the 25% highest and lowest values, respectively (ie the data above and below the third and first quartiles). The bold numbers shown in the centre of the box represents the number of data points used.

Box and whisker plots of TDS concentrations sampled from drainage lines in the project area are presented in Figure 5.4. The results show that all streams in the project area are fresh, with TDS less than 500 mg/L. Belanglo Creek, Planting Spade Creek, Longacre Creek, Long Swamp Creek and Hanging Rock Swamp Creek are typically fresher than other streams in the project area with TDS generally less than 100 mg/L.

Box and whisker plots of pH sampled from drainage lines in the project area are presented in Figure 5.5. pH is generally between 5.5 and 8.0. pH is typically higher in drainage lines within agricultural land (eg Medway Rivulet, Oldbury Creek and Stony Creek) and lower in streams within natural or forested catchments (eg Belanglo Creek, Planting Spade Creek, Longacre Creek, Long Swamp Creek and Hanging Rock Swamp Creek). pH can be below the lower guideline value of 6.5 in some of the drainage lines with natural or forested catchments.

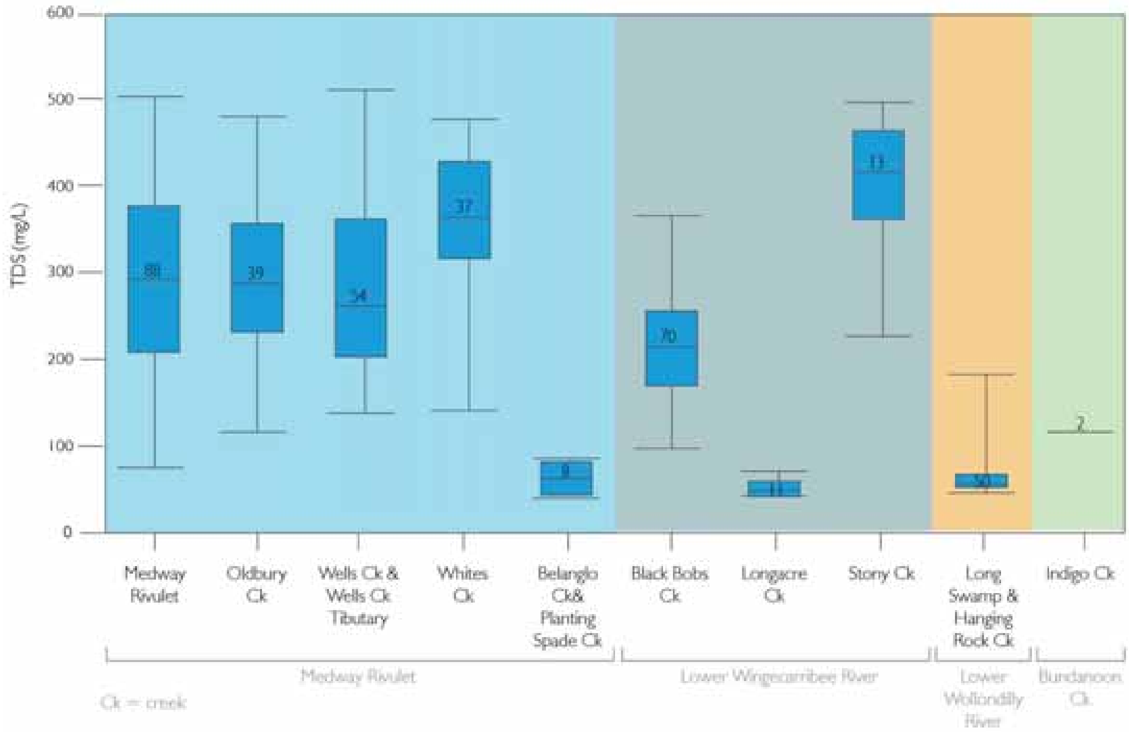


Figure 5.4 Baseline TDS

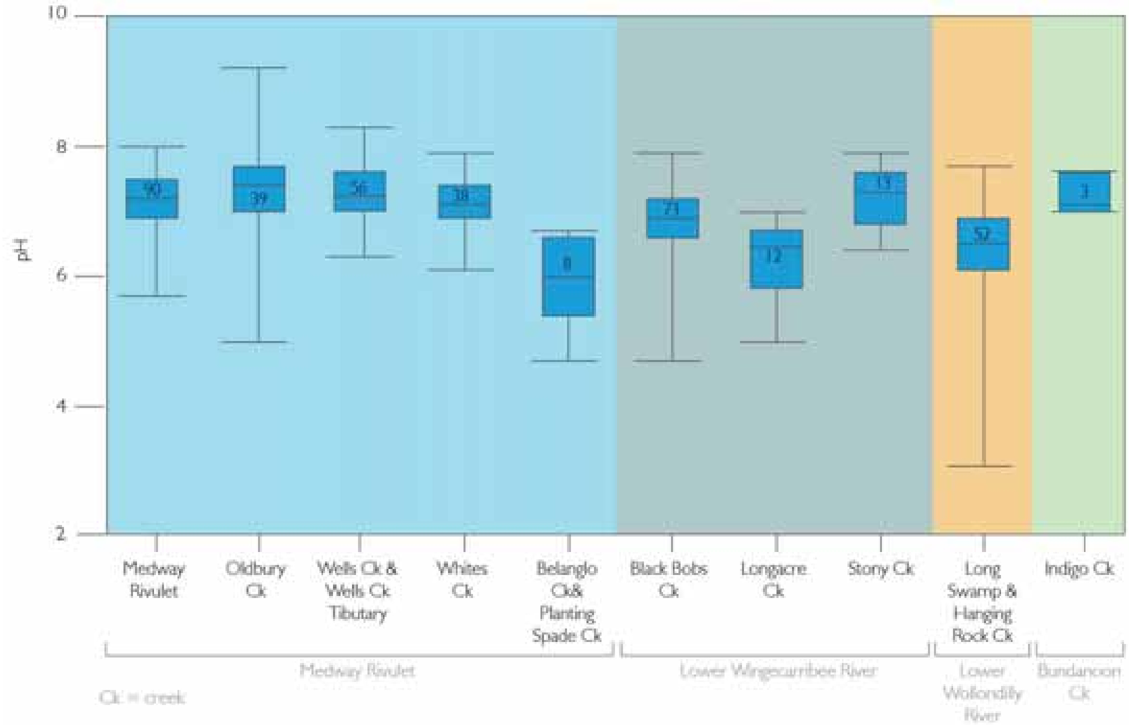


Figure 5.5 Baseline pH

5.4 Environmental values

Environmental values (EVs) are established by the community for what is considered important for water use (HRC 1998). EVs for the Hawkesbury River Catchment are set out in the Healthy Rivers Commission Independent Inquiry into the Hawkesbury Nepean River System (HRC 1998).

Regional EVs are assigned based on land use regions within the Hawkesbury-Nepean River catchment. Table 5.2 shows the land use regions within the project area and applicable EVs (WSP PB 2016c).

Site specific preliminary water quality objectives for Medway Rivulet and Oldbury have been developed from baseline surface water quality monitoring to reflect the existing environmental values. Details of these objectives are included in Appendix E.

Table 5.2 Environmental values and uses for surface water in and downstream of the project area

Land use regions	Regional environmental values
Predominately forested	Aquatic ecosystems Primary contact recreation Secondary contact recreation Visual amenity Homestead water supply Livestock water supply
Mixed-use rural and drinking water with clarification and disinfection	Aquatic ecosystems Primary contact recreation Secondary contact recreation Visual amenity Drinking water – clarification and disinfection Irrigation water supply Aquatic foods (cooked)

Source: HRC 1998.

5.5 Surface water use

AR 35: Details on existing dams/storages (including the date of construction, location, purpose, size and capacity) and any proposal to change the purpose of existing dams/storages.

AR 41: Detailed description of dependent ecosystems and existing surface water users within the area, including basic landholder rights to water and adjacent/downstream licensed water users.

5.5.1 Human water use and water-related assets

Within and down gradient of the project area, surface water is used by landholders, council and ecosystems. Surface water diversion works (pumps) and storages are used to extract and store surface water for water supply. There are 188 WALs within the six surface water management zones applicable to the project area. The average share component for stock and domestic, and unregulated use is 44 units (WSP PB 2016c).

The surface water-related assets in the region are:

- storages used for town water supply, including: Medway Reservoir (Medway Dam) (1,350 ML) and Lake Burragorang (Warragamba Dam) (more than 2,000,000 ML) downstream of the project area; and Wingecarribee Reservoir (24,130 ML), Bundanoon Creek Dam (2,000 ML), and Fitzroy Reservoir (9,950 ML) upstream of the project area;
- Shoalhaven transfer scheme, a dual-purpose water supply and hydro-electric power generation scheme that allows water collected in the Fitzroy and Wingecarribee Reservoirs and the Tallowa Reservoir (on the Shoalhaven River) to be transferred to Sydney water supply;
- Highlands Source Pipeline, an 80 km pipeline linking Wingecarribee Reservoir to Goulburn;
- town sewage treatment plants, including Boral, Robertson, Berrima and Moss Vale;
- various weirs on Wingecarribee River;
- diversion works (pumps) and storages used by local water users to extract surface water for water supply;
- landholders with basic water rights; and
- ecosystems with potential to be impacted by changes in surface water quality including:
  - instream ecosystems; and
  - riparian ecosystems exposed to overbank flows and flooding.

Sewage treatment plants within the Wingecarribee Local Government Area that discharge into local creeks are summarised in Table 5.3.

Table 5.3 Sewage treatment discharges within Wingecarribee Shire

Treatment plant	Capacity (as per EPL)	Discharge location
Berrima	100–219 ML	Oldbury Creek
Bowral	1,000–5,000 ML	Wingecarribee River (with wet weather overflows into Mittagong Creek)
Bundanoon	219–1,000 ML	Reedy Creek (which drains into Paddys River, which drains into Wollondilly River)
Mittagong	1,000–5,000 ML	Sheepwash Creek and Iron Mines Creek (which drain into Nattai River)
Moss Vale	219–1,000 ML	Whites Creek (which drains into Medway Rivulet upstream of Medway Dam)
Robertson	15–150 ML	Wingecarribee River

Notes: Sourced from treatment plants' Environment Protection Licences.

Most of the diversion works and dams are used for irrigation (WSP PB 2016c). The second most common use for dam water is to conserve water. The second most common uses for pumps are for town water supply and industrial use.

There are 11 pumps and 6 dams associated with WALs within the Medway Rivulet Management Zone. Figure 5.6 shows the location of diversion works and storages with associated WALs in the Medway Rivulet, Lower Wingecarribee River, Lower Wollondilly, and Bundanoon Creek management zones. Table 5.4 lists the diversion works and storages in each management zone (WSP PB 2016c).

Table 5.4 Water management zones and users

Water Source	Management zone	Number of diversion works (pumps)	Number of storages (dams)	Total annual volume (ML)
Shoalhaven	Bundanoon Creek	5	4	1,007
Upper Nepean and Warragamba	Lower Wingecarribee River	29	12	1,072
	Lower Wollondilly River	86	32	4,138
	Medway Rivulet	13	7	1,027

Within the Upstream Warragamba and Upper Nepean, and the Shoalhaven Unregulated River Water Sources basic water rights includes:

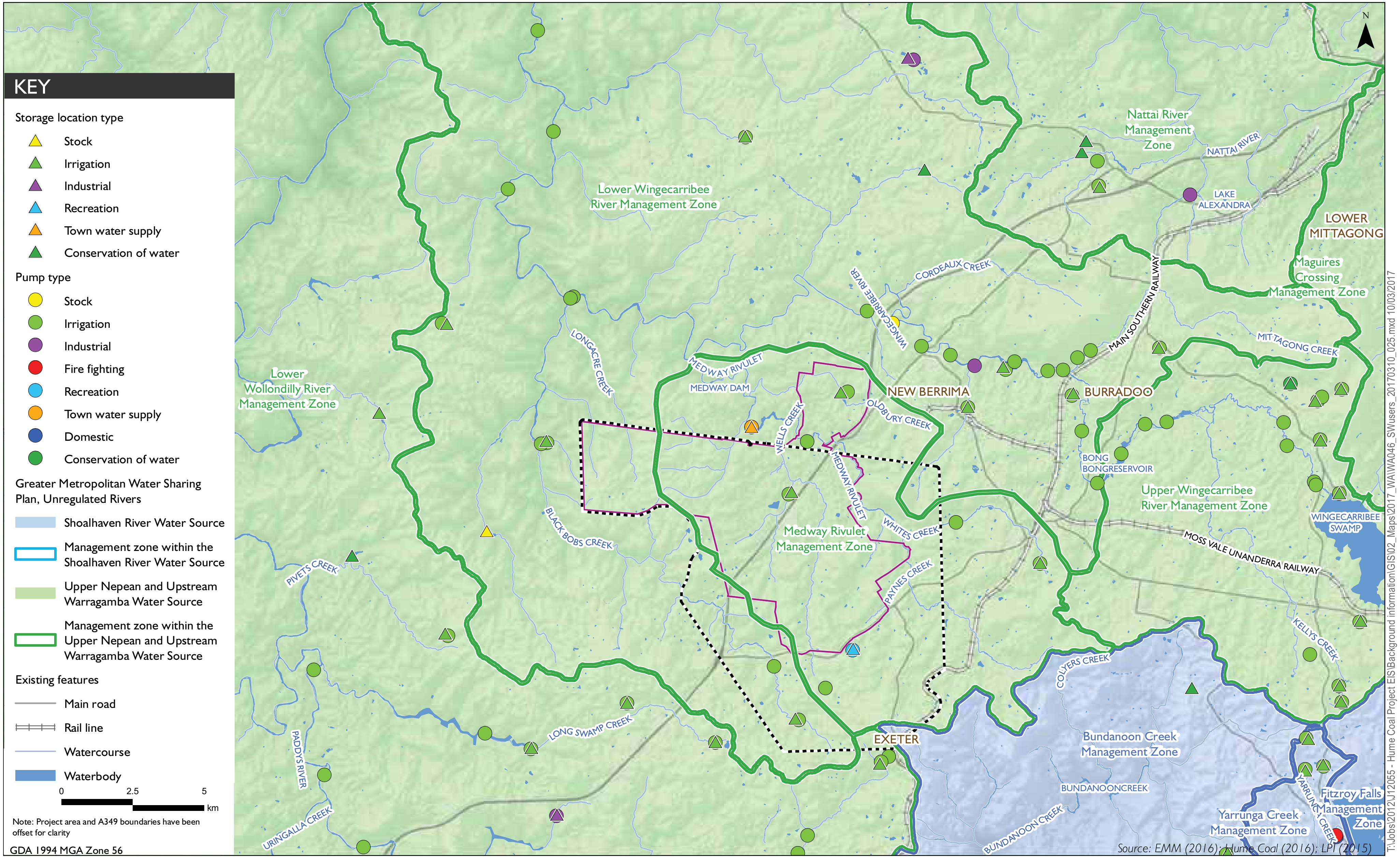
- Domestic and stock rights– landholders with stream frontage can take water without a licence for use in households, gardens and/or stock drinking water. The Greater Metropolitan Region Unregulated Water Sources Water Sharing Plan 2011 estimates water requirements for domestic and stock rights to be:
  - 13.6 ML/day in the Shoalhaven Unregulated River Water Source; and
  - 21 ML/day in the Upstream Warragamba and Upper Nepean and Water Source.
- Harvestable rights – landholders are allowed to build dams on minor streams that capture 10% of the average regional rainfall-runoff on their property.
- Native title water rights – there are no native title water rights licences within the region.

5.5.2 Ecosystems that potentially rely on surface water

The ecosystems that are potentially reliant on surface water include: instream ecosystems that depend on streamflow (including in-stream ecosystems reliant on groundwater baseflow), and riparian ecosystems that depend on surface water and overbank flows.

The *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c) describes in detail ecosystems that potentially rely on surface water, including details on wetlands, proposed locations of asset protection zones, riparian corridor widths, native vegetation extent, and aquatic ecology.

The surface water ecological sensitive features in the region include temperate highland peat swamps and pine plantations surrounding Stingray and Hanging Rock Swamps (Figure 1.4). Temperate highland peat swamps listed as endangered ecological communities under the EPBC Act, include: Paddys River Swamps (comprising Long, Mundego, Stingray and Hanging Rock Swamp) and Wingecarribee Swamp (Figure 1.4). Paddys River Wetlands and the Wingecarribee Swamp are listed in the *Directory of Important Wetlands in Australia* (Environment Australia 2001). Temperate highland peat swamps on sandstone, are high priority groundwater dependent ecosystems listed in the Metropolitan Groundwater WSP.



EMM HUMECOAL

Surface water users

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Water Assessment

Figure 5.6

6 Groundwater

This chapter describes the geological and hydrogeological setting, including groundwater recharge, flow, and use.

AR 48: A description of the watertable and groundwater pressure configuration, flow directions and rates and physical and chemical characteristics of the groundwater source (including connectivity with other groundwater and surface water sources).

AR 68: The EIS must describe background conditions for any water resource likely to be affected by the development, including:
a. Existing surface and groundwater.
b. Hydrology, including volume, frequency and quality of discharges at proposed intake and discharge locations.
c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters.
d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.

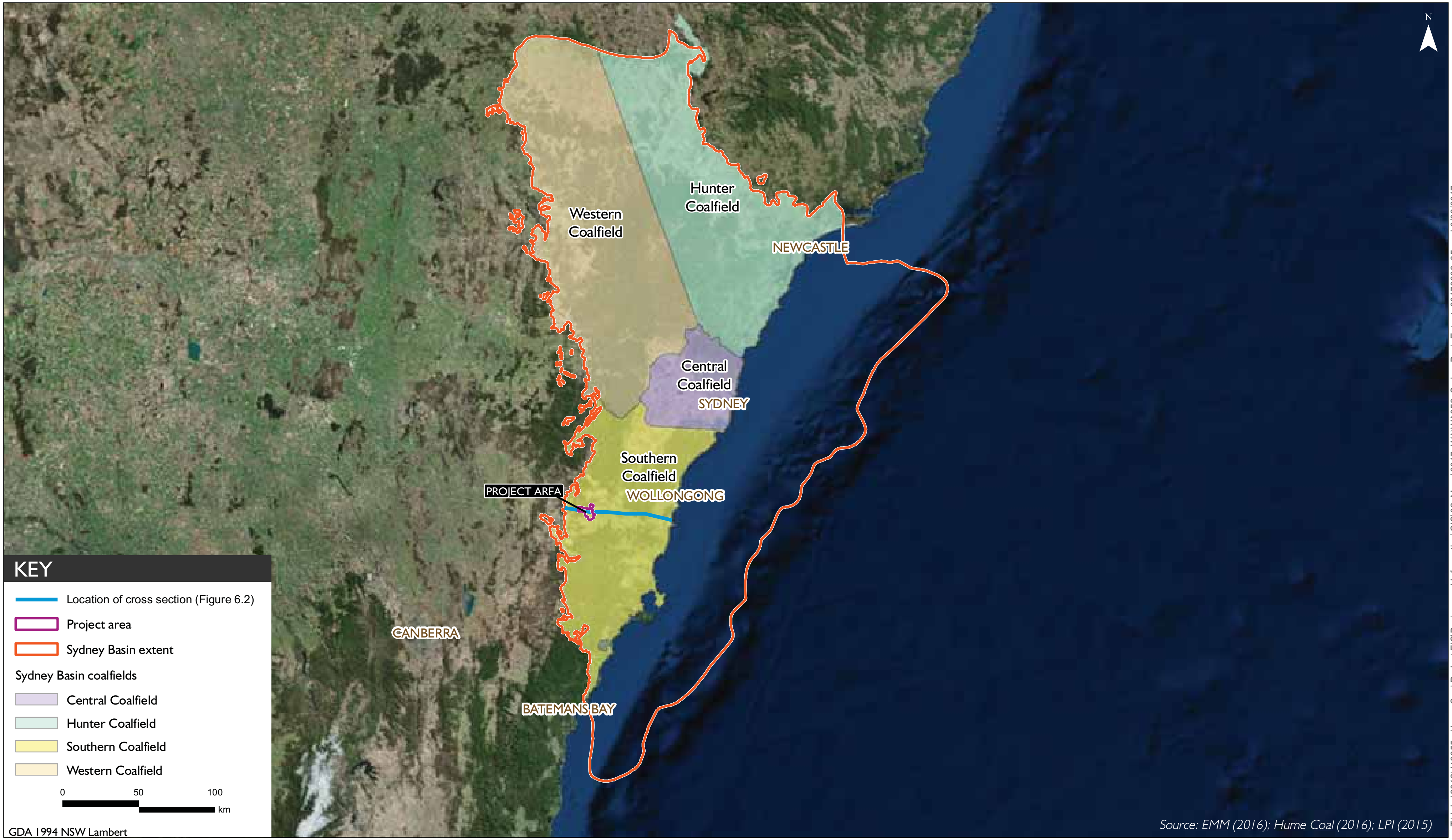
AR 71: The EIS must map the following features relevant to water and soils including:
a. Acid sulfate soils (Class 1, 2, 3 or 4 on the Acid Sulfate Soil Planning Map).
b. Rivers, streams, wetlands, estuaries (as described in Appendix 2 of the Framework for Biodiversity Assessment).
c. Groundwater.
d. Groundwater dependent ecosystems.
e. Proposed intake and discharge locations.

AR 72: Identify relevant water quality objectives for surface and groundwater, including indicators and associated trigger values or criteria, in accordance with National Water Quality Management Strategy Guidelines. Reference the water quality objectives for the Wingecarribee River catchment in the "NSW Healthy Rivers Commission of Inquiry into the Hawkesbury Nepean Catchment". Identify any downstream users and uses of the discharged water classified in accordance with relevant ANZECC 2000.

AR 84: The EIS should provide a description of the location, extent and ecological characteristics and values of the identified water resources potentially affected by the project.

6.1 Regional geological setting

The sedimentary, Permo-Triassic Sydney Basin extends north south along some 350 km of central NSW coastline (from Newcastle to just north of Batemans Bay), and extends to the Great Dividing Range in the west. About one quarter of the basin is offshore to the east of the shoreline (Brunker & Rose 1967). The onshore sedimentary units are thickest (up to 4.5 km) in the northern part of the basin (Geoscience Australia 2016).



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Sydney Basin extent

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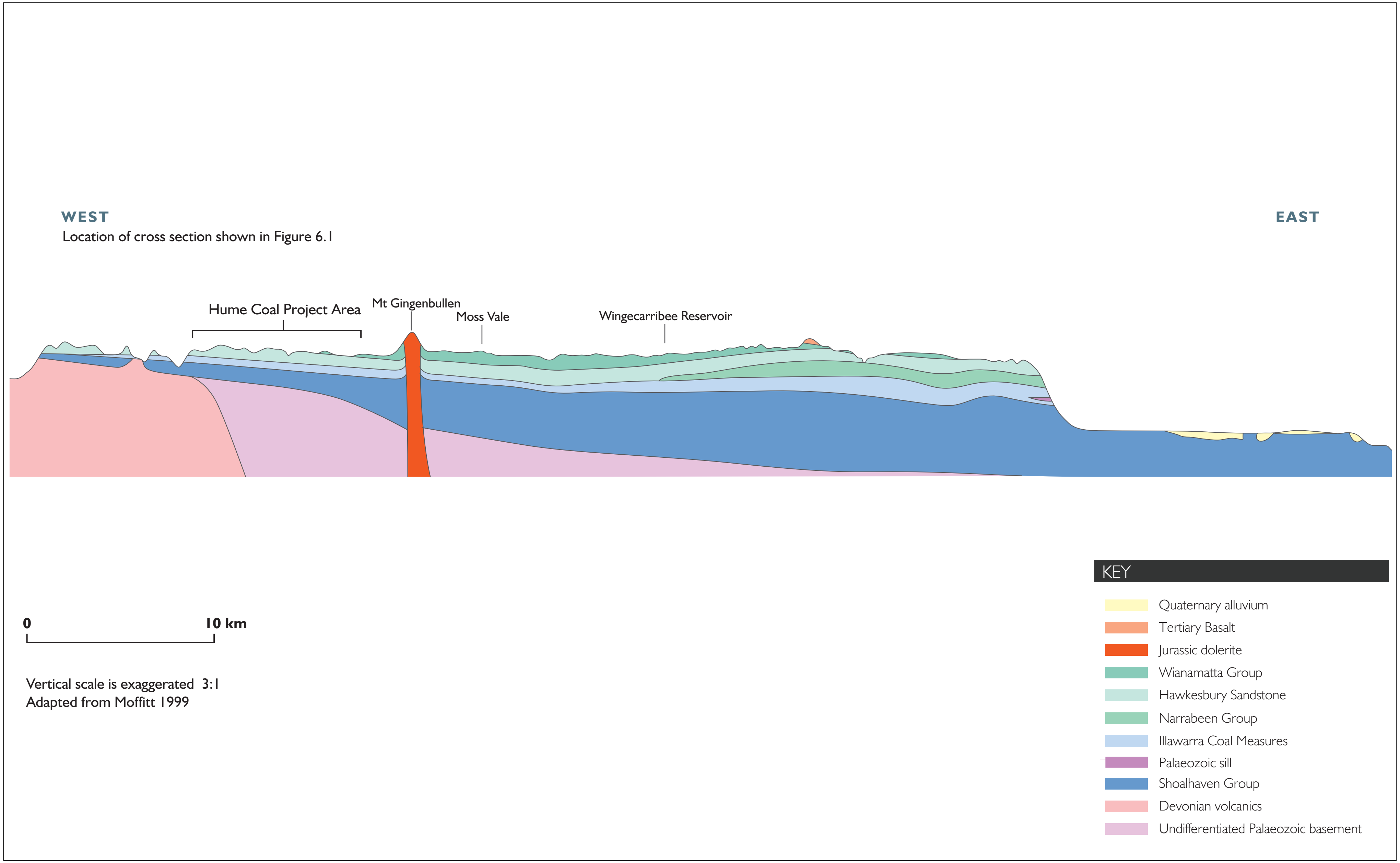
Figure 6.1



Regional geological cross section

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Figure 6.2

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During the early stages of basin development, marine volcanic sediments and the Permian Shoalhaven group were deposited (Blevin et al. 2007). Swamp environments during a colder climate in the late Permian allowed for deposition of the Illawarra Coal Measures (ICM), which contain the coal seam proposed to be mined – the Wongawilli seam. Subsequently, very large rivers deposited the Triassic Hawkesbury Sandstone (Moffit 1999; Rust & Jones 1987). Shallow marine sediments, and later more river sediments, continued to accumulate in the basin during the Jurassic, although most majority of these younger rocks have since been eroded (Blevin et al. 2007). Although significantly eroded in places, the Wianamatta Group is present in the east of the project area. Post-Triassic volcanism emplaced Jurassic intrusions and Tertiary basalts (McLean & David 2006).

6.2 Local geological setting

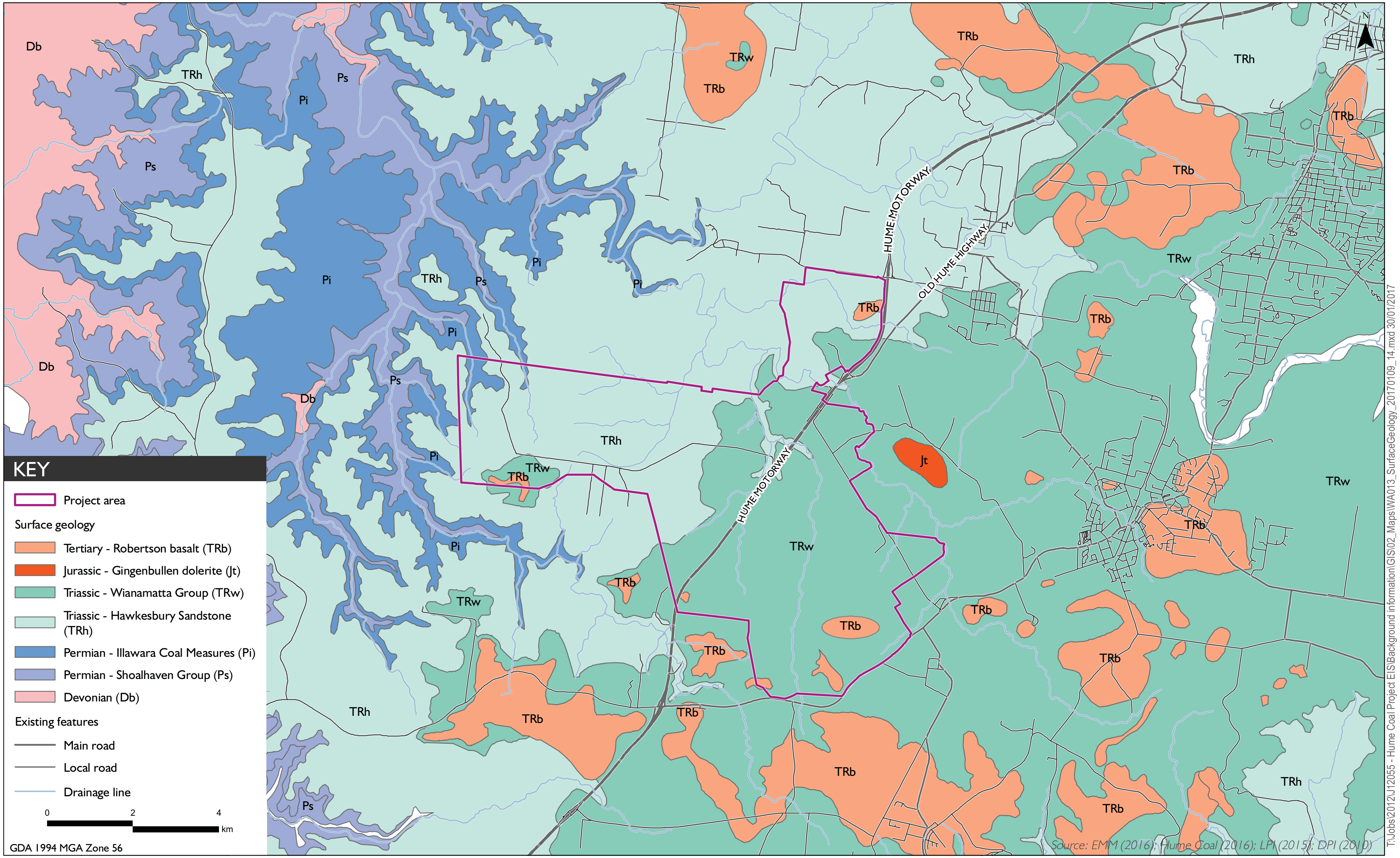
The project area is located in the Sydney Basin's Southern Coalfield underlain by the Triassic sedimentary Hawkesbury Sandstone and the Wianamatta Group's Ashfield Shale (Moffit 1999).

The Ashfield Shale outcrops over much of the eastern part of project area while the Hawkesbury Sandstone is exposed over much of the western part (Moffit 1999). The Hawkesbury Sandstone has been incised by creek channels and, as a result, Permian coal outcrops next to drainage lines in the west. The hills to the immediate south of the project area comprise remnants of thick Tertiary Robertson Basalt flows that overly the Ashfield Shale (Moffit 1999). Surface geology, or outcrop, is shown in Figure 6.3.

Erosion during the mid-Triassic removed the latest Permian and early Triassic interburden in the south-western half of the project area, resulting in the Hawkesbury Sandstone directly overlying the Wongawilli Coal Seam. The interburden increases in thickness to the north-east and is comprised mainly of fine grained sediments, including the uppermost carbonaceous Wongawilli Coal Seam ply (WR ply) and a volcanic tuff, the Farmborough Claystone Member of the Permian Illawarra Coal Measures. In some historical geological assessments, the upper Permian interburden above the Wongawilli seam has been referred to as the basal Triassic Narrabeen Group (sandstone, siltstone, conglomerate and shale); however, it is not mapped to be present within the project area and so is not referenced further in this assessment.

Late Jurassic igneous intrusive activity and Tertiary igneous extrusive activity was significant in the region and resulted in numerous volcanic breccia necks and sills, basalt flows and dykes (McLean & David 2006).

Minor Quaternary alluvium is present the upstream reaches of the Wingecarribee River, north-east of the project area (Moffit 1999).



Surface geology

Hume Coal Project

Water Assessment

Figure 6.3

6.2.1 Stratigraphy

The stratigraphy of the project area is provided in Figure 6.4.

Age	Group	Formation	Symbol	Rock type
Tertiary	Robertson Basalt		TRb	Basalt and volcanic breccia
Jurassic		Gingenbullen dolerite	Jt	Dolerite (microsyenite) intrusion
Triassic	Wianamatta Group	Ashfield Shale	TRw	Shale
		Mittagong Formation	TRm	Shale, laminate and sandstone
		Hawkesbury Sandstone	TRh	Quartz sandstone
Permian	Illawarra Coal Measures	Illawarra Coal Measures undifferentiated (where present)	Pi	Shale, sandstone, siltstone and claystone, including WR ply and Farmsborough Member
		Wongawilli Coal Seam	Pi	Coal
		Illawarra Coal Measures undifferentiated	Pi	Shale, sandstone, siltstone and coal
	Shoalhaven Group	Shoalhaven Group undifferentiated	Ps	Sandstone, shale, siltstone
Devonian		Undifferentiated volcanics	Đb	Sediments and volcanics
Ordovician		Undifferentiated volcanics	O	Slate, metamorphic rocks

Figure 6.4 Project area stratigraphy

6.2.2 Geological units

The geological units relevant to the project area are summarised in this section. Only minor alluvium associated with the upstream Wingecarribee River occurs outside the project area, and is not relevant to the project and has not been considered further.

i Tertiary and Jurassic

The hills in the southern part of the project area and immediately outside are capped with remnant, isolated Tertiary Robertson Basalt flows (Moffit 1999). Some 15% of the project area has outcropping basalt (Coffey 2016a). There is also a notable igneous Jurassic intrusion, the Mount Gingenbullen dolerite sill, that has formed a steep hill immediately east of the project area (Thomas, Biggin & Schmidt 2000). Smaller igneous intrusions have been observed during drilling programs and as lineaments in aerial photography (R Doyle 2015, pers comm, September). The Tertiary basalt outcrops are unrelated to the Mount Gingenbullen intrusion.

ii Triassic

a. Wianamatta Group

Of the Wianamatta Shale Group, the Ashfield Shale dominates within the project area (WSP PB 2016e). This unit comprises dark grey to black shale and siltstone interbedded with lithic sandstones and siltstone, and very minor coal bands. Reference to the borehole logs indicates that the Ashfield Shale can be up to 50 m in thick in the east of the project area; however it tapers towards the centre of the project area and is absent in the west (Appendix L).

b. Mittagong Formation

The Mittagong Formation is a transitional unit of about 6–15 m in thickness (Herbert & Helby 1980) between the Ashfield Shale and the Hawkesbury Sandstone. The unit is floodplain sediments deposited at the end of the Hawkesbury Depositional Episode.

The Mittagong Formation is difficult to identify in borehole logs due to its similarity in appearance to both the Hawkesbury Sandstone and Ashfield Shale. It is generally not mapped as surface outcrop, likely due to the difficult identification in situ.

c. Hawkesbury Sandstone

The Hawkesbury Sandstone is a flat-lying, sheet sandstone between 50 and 120 m thick within the project area (Coffey 2016a; Rust & Jones 1987; Appendix L). The Hawkesbury Sandstone forms the major landform influence in the region and is the main cliff-forming sequence. This unit was deposited in an active fluvial system and, in some locations, deposition has eroded the entire Narrabeen sequence and portions of the underlying Illawarra Coal Measures (O'Neill & Danis 2013).

The Hawkesbury Sandstone is a medium to coarse grained quartz arenite (sedimentary rock with more than 90 % detrital quartz) with minor siltstone, shale, mudstone and laminate lenses (McLean & David 2006; Scheibner & Basden 1998). Layering and cross-bedding is also present.

d. Illawarra Coal Measures

The Illawarra Coal Measures comprise interbedded siltstone, claystone, conglomerate, quartz-lithic sandstone, shales and coal seams (McLean & David 2006). The unit is about 50 m thick in the project area. Within the project area the mining target Wongawilli Seam is the uppermost unit of the Illawarra Coal Measures and is up to 8 m thick. The top of the Wongawilli Seam is about 70–180 mbgl.

Stratigraphy between the Wongawilli Seam and the Hawkesbury Sandstone is largely absent over the south-western half of the project area, but thickens to the north and east. Where present, interburden is comprised of fine grained sediments including the volcanic tuff known as the Farmborough Claystone Member, the carbonaceous Wongawilli Coal Seam ply (WR ply) and the informal Unnamed Member No 3 of the Eckersley Formation.

e. Shoalhaven Group

The Shoalhaven Group's Berry Siltstone comprises sandy grey mudstone, claystone, siltstone and sandstones deposited under shallow marine conditions (McLean & David 2006). This unit is more than 100 m thick and unconformably overlies the strongly folded Palaeozoic basement (Moffit 1999).

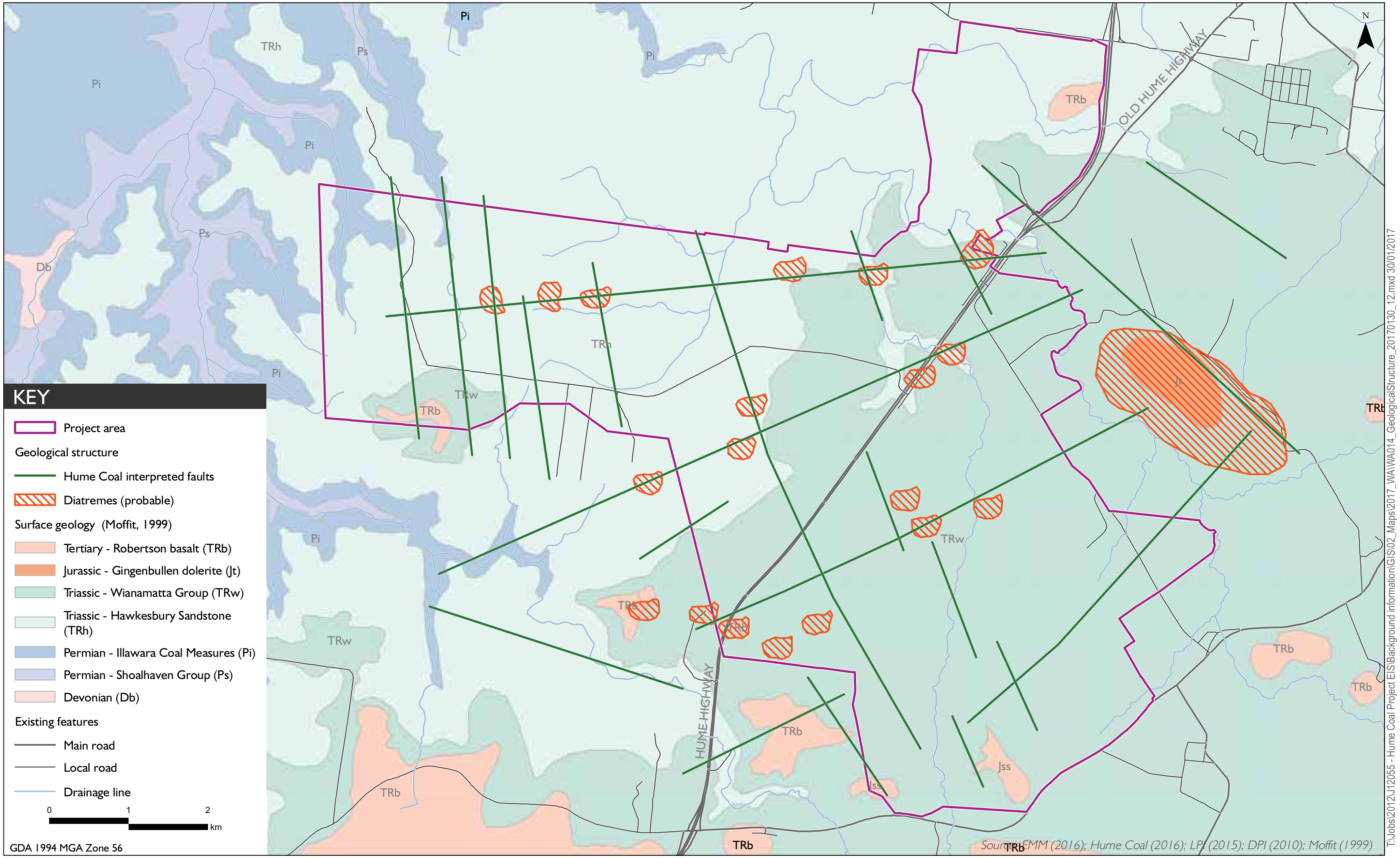
6.2.3 Geological structure

Stratigraphy across the project area is regionally continuous and gently dipping to the east. Moffit (1999) has mapped few structural features within the project area; however, immediately north, a northwest-southeast structure 8 km long is identified as the Cement Works Fault. Hume Coal interprets this as a major fault extending to basement, with a maximum displacement of between 50 m and 65 m (R Doyle 2016, pers comm, 27 July; Coffey 2016a). The Sydney Basin is unconformably bound by the Devonian Lachlan Fold Belt, which outcrops some 5 km to the west of the project area (Figure 6.3).

On a local scale, Hume Coal has interpreted probable minor faults and structural features that intersect the coal seam within the project area based on results from exploration drilling programs, geophysics, and previous work in the area (Figure 6.5). The dominant alignment is north-north-west to south-south-east, while a secondary faulting direction is shown as east-south-east to west-north-west (R Doyle 2015, pers comm, September). Most of these probable features are likely to have small offsets and are unlikely to extend to the basement or higher up into the overlying stratigraphy (R Doyle 2016, pers comm, 12 September).

The Southern Highlands region has a higher density of igneous intrusions than elsewhere in the Sydney Basin (Coffey 2016a). Several igneous intrusions (dykes) are interpreted to radiate to the west and south-west from Mount Gingenbullen, a large Jurassic dolerite sill (R Doyle 2015, pers comm, September). These dykes are typically spatially associated with minor faulting, although the age of intrusions is unknown. There are numerous diatremes spatially associated with the faults within the project area; Hume Coal interprets the diatremes to have intruded into the existing structures rather than to be synchronous (R Doyle 2016, pers comm, 27 July).

A Tertiary major sub-vertical structural feature underlying the main Robertson Basalt outcrop around Exeter is interpreted from hydraulic head data, regional lineaments and structural contour surfaces (Coffey 2016a). This feature runs about east-north-east to west-south-west, below the basalt body and was likely a pathway for the basalt extrusion. Weathering and hydraulic conductivity are assumed to be enhanced along its plane (Coffey 2016a).



Geological structure

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Figure 6.5

6.3 Hydrogeological units

AR 44: The known or predicted highest groundwater table at the site.

The groundwater units within the project area are defined as:

- localised low permeability groundwater systems associated with the Robertson Basalt and Wianamatta Group shales;
- regional porous fractured rock groundwater system in the Hawkesbury Sandstone; and
- localised water bearing zones associated with the Illawarra Coal Measures and the Shoalhaven Group.

Localised groundwater systems can be associated with unconsolidated Quaternary alluvium in major streams and river valleys within the region (ie upper reaches of the Wingecarribee River), although not within the project area.

6.3.1 Localised low permeability systems

Both the Robertson Basalt and the Wianamatta Shale are isolated low permeability geological units. Within the project area, the Robertson Basalt overlies the Wianamatta Shale, where present. Spring discharge is observed at the contact between the basalt and underlying Wianamatta Group Shale (McLean & David 2006). The basalt is likely to be a stable, low volume source of recharge to the shale (Coffey 2016b).

The Wianamatta Group shale has low permeability and acts as a regional aquitard, impeding groundwater recharge and restricting downward vertical flow. Fracturing within the shale can allow minor hydraulic connection with the underlying Hawkesbury Sandstone and minor supplies of poor quality water (Ross 2014). Groundwater within the shale is generally brackish to saline and bores within the shale are generally very low yielding (DNR 2006).

The hydraulic connectivity between the overlying basalt and shale and the Hawkesbury Sandstone is conceptualised as only allowing a consistent low rate of leakage from the lower permeable shale and basalt into the higher permeable regional sandstone.

The water level in the regional (underlying) Hawkesbury Sandstone varies across the project area. For most of the area where shale is present, the water levels in bores are at elevations within the overlying shale; however, in some bores intersecting the sandstone, the water levels are below the shale, and there are unsaturated conditions in the sandstone above those levels. This is apparent in the area to the south of the project area where there is a sub-vertical structural feature underlying the main area of Robertson Basalt. The major sub-vertical structural feature associated with the Robertson Basalt is assumed to be a flow barrier based on hydraulic head behaviour around the feature (Coffey 2016a).

South of the structural feature there is no connectivity between the basalt and Hawkesbury Sandstone, while north of the feature there is some degree of connectivity (Coffey 2016a).

Regardless of whether or not the localised low permeability geological units are in direct connection with the underlying sandstone, leakage from the upper units to the lower regional sandstone would be limited.

6.3.2 Regional groundwater system

The Hawkesbury Sandstone forms a major unconfined to semi-confined porous rock groundwater system and constitutes most of the groundwater storage volume in the Southern Coalfield (McLean & David, 2006; Ross 2014). Confined conditions are greatest where the overlying Wianamatta Group shales and Tertiary Basalt are present and relatively thicker (McLean & David 2006). Unsaturated conditions in the uppermost Hawkesbury Sandstone are widespread where the Wianamatta Group is present (Coffey 2016a). The unsaturated zone is thickest (about 60 m) to the east of Mount Gingenbullen (Appendix L; Coffey 2016a), highlighting that transfer from the Wianamatta Group to the Hawkesbury Sandstone does not transfer easily into the Hawkesbury Sandstone.

Groundwater monitoring bore drilled through the Hawkesbury Sandstone typically intersected multiple water bearing zones associated with bedding plane joints, sub-vertical joints and faults, and to a lesser extent coarse cross-beds (Appendix L). Local zones of perched groundwater can exist associated with bedding planes and shale or siltstone lenses (Coffey 2016a; DNR 2006).

Groundwater within the Hawkesbury Sandstone in the project area is generally fresh (150 – 1000 mg/L) and bores range in yield from low to high (Ross 2014). The median bore yield for bores within a 9 km radius of the centre of the project area are 2 L/sec (DPI Water 2015). As the groundwater within the Wianamatta Group is of poorer quality, it further verifies that most of the groundwater within the Hawkesbury Sandstone is recharged directly at outcrops with limited leakage from the shale.

6.3.3 Localised water bearing zones Illawarra Coal Measures and Shoalhaven Group

The low permeability and porosity of the Permian Illawarra Coal Measures and Shoalhaven Group have generally low hydraulic conductivity, although there are some zones of somewhat higher hydraulic conductivity in the Illawarra Coal Measures. Hydraulic connection between the Wongawilli Coal Seam and the Hawkesbury Sandstone potentially occurs where there is no interburden between the two units (ie in the southern part of the project area).

6.4 Hydraulic conductivity

Hydraulic testing (including: in situ pumping and packer tests at bores within and nearby the project area, data from core laboratory tests, and specific capacity data from government records) has allowed a comprehensive assessment to be made of hydraulic conductivity (K) for the different hydrogeological units in the project area (Coffey 2016a).

Within the project area, tectonic disturbance and igneous activity has resulted in overall relatively higher K compared to elsewhere in the Southern Coalfield and also the Western Coalfield (Coffey 2016a). There is an exponential decrease in K and decrease in storativity with depth due to increasing overburden pressure, except where deformation and intrusions are present (Coffey 2016a).

A summary of the K values for each hydrogeological unit is shown in Table 6.1 (Coffey 2016a). The heterogeneous nature of the Hawkesbury Sandstone is reflected by a wide range of measured K values (0.001 – 10 m/day). The ratio between vertical K and horizontal K (Kv/Kh) is about 0.01 (Coffey 2016a).

Table 6.1 Hydraulic conductivity for hydrogeological units in the project area

Hydrogeological unit	Hydraulic conductivity K (m/day)	Source
Basalt	6	derived from government records and reports
Wianamatta Group	0.9	derived from government records and reports
Hawkesbury Sandstone	0.001–10	measured values from within and nearby the project area
Illawarra Coal Measures	0.01–0.9	measured values from within and nearby the project area

6.5 Groundwater recharge and discharge

Direct rainfall infiltration is the primary source of recharge to the groundwater system (Coffey 2016a). Rainfall recharge is greater in un-forested areas and where the Hawkesbury Sandstone is exposed at the ground surface.

Coffey (2016a) analysed the magnitude of rainfall recharge by assessing water table rise following rainfall in shallow monitoring bores. Lower rainfall recharge was indicated for the Wianamatta Group as compared to the Hawkesbury Sandstone and the basalt. For the numerical groundwater model (Section 8.6, Coffey 2016b), average annual recharge to the water table across the project area was estimated to be 2% of the annual rainfall. The Metropolitan surface water WSP references slightly higher average recharge, at 6% of annual rainfall, but the value of 6% was determined for a much larger area that also included alluvium and broader areas of outcropping Hawkesbury Sandstone. Both regional and local scale model outcomes are typically not overly sensitive to variations in rainfall recharge values below 10% (EMM 2015a); therefore the difference between the rainfall recharge value applied in this assessment and that of the WSP is considered insignificant.

Direct rainfall recharge is most likely to occur where the Hawkesbury Sandstone is exposed in the western part of the project area, rather than where the lower permeability Wianamatta Group shales outcrop (in the eastern part of the project area). Most of the drainage lines in the project area are considered to be gaining streams (Coffey 2016a), and therefore direct recharge from streams is likely to be very minor. Localised rainfall recharge is also likely to occur in the basalt geological layer.

Groundwater discharges via several mechanisms in the region. The discharge mechanisms include:

- drainage to surface water (baseflow): the largest component of discharge of about 1.5% of annual rainfall (Coffey 2016a). Surface water flow has been recorded in the lower reaches of Black Bobs Creek and Medway Rivulet and Wingecarribee River during dry periods, indicating groundwater discharges into these surface water drainage channels (Coffey 2016a);
- extraction of groundwater from existing landholder bores;
- evapotranspiration from the water table, depending on land use and depth to groundwater;
- seepage/springs and increased evaporation along the escarpments, particularly along geological layer boundaries with contrasting vertical hydraulic conductivity (ie the interface between the Hawkesbury Sandstone and Illawarra Coal Measures, and the Ashfield Shale and Hawkesbury Sandstone), particularly along the cliff escarpments in the downstream reaches of Black Bobs Creek and Medway Rivulet;
- groundwater drainage into the existing underground workings of the decommissioned Berrima Colliery to the north; and

- regional groundwater throughflow, to the south-east.

Discharge from the localised low permeability Robertson Basalt occurs at seeps/springs at lithological contact points with the underlying shale or along fractured zones. Seasonal springs are unlikely to be connected to the regional system and do not appear to sustain permanent flows to the upper reaches of nearby creeks. The large differences in groundwater head and quality between the basalt and shale, and deeper Hawkesbury Sandstone indicates that leakage from perched systems into the Hawkesbury Sandstone groundwater is minor (Coffey 2016a).

6.5.1 Baseflow

Baseflow is the component of streamflow that is sourced from groundwater and is released from groundwater system storage during low streamflow conditions. Baseflow steadily decreases following surface runoff. This decrease with time is often termed the groundwater recession (Domenico & Schwartz 1990). As shown in Figure 6.6A, where the base of a stream is lower in elevation than the surrounding water table, the stream can gain water from groundwater inflow (ie baseflow); this condition is referred to as a 'gaining' stream. Conversely, as shown in Figure 6.6B, where the water table is lower in elevation than the base of a stream, the stream can lose water to the underlying water table; this condition is referred to as a 'losing' stream. The relationship between surface water and groundwater can change along the course of a stream channel, and can also change over time. Surface water and groundwater connectivity depends on hydraulic gradients (the slope of the water table), stream bed and aquifer hydraulic conductivity.

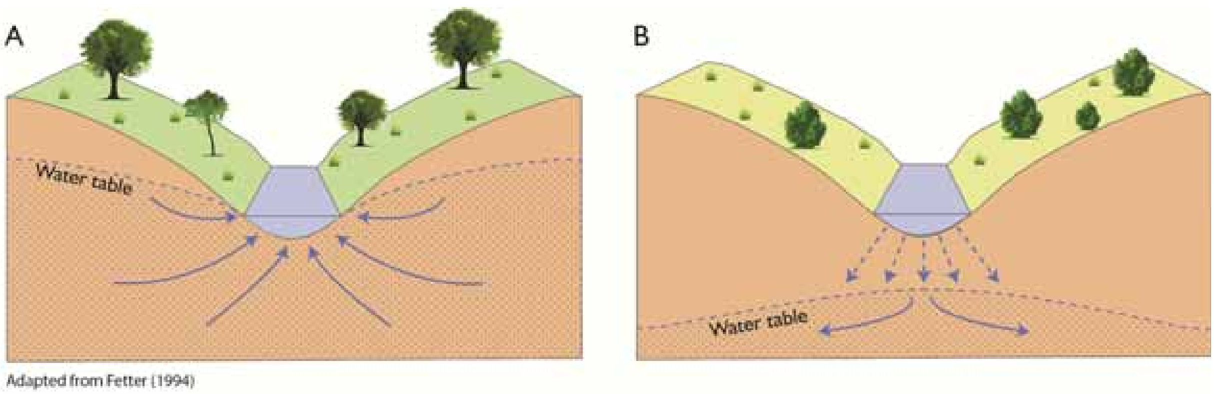


Figure 6.6 Gaining and losing streams

If groundwater is extracted from a groundwater system that is connected to the water table (unconfined or semi-confined), the water table will be lowered. If this extraction occurs in an area where there are gaining streams it is likely the amount of baseflow will decrease over time depending on the rate of extraction (ie intercepted proportion of baseflow would be captured). The degree of influence on the water table and intercepted baseflow therefore depends on the properties of the groundwater system, connectivity between the groundwater and stream, and the rate and amount of extraction.

The groundwater level in the project area is typically higher than the stream beds; hence, the streams in the area are generally classified as gaining streams (WSP PB 2016c).

Groundwater baseflow was analysed undertaken by Coffey (2016a) by separating baseflow from total stream flow using the local-minimum method (Wahl & Wahl 1995). The baseflow results are area-averages for an entire catchment. The baseflow analysis indicates that annual baseflow to drainage channels is estimated to be 1.5–2% of annual rainfall for the project area. However, the local geology surrounding the stream bed influences baseflow contributions. Baseflow from the Hawkesbury Sandstone was calculated to be around 3% of annual rainfall. Baseflow from the Wianamatta Group is lower and was calculated to be 1–1.5% of annual rainfall. Basalt has significantly enhanced baseflow capacity compared to the sedimentary rocks and was calculated to be up to 30% of annual rainfall (Coffey 2016a).

6.5.2 Deep discharge

Groundwater inflow to Berrima Colliery, north of the project area (Figure 1.4), is in this study as considered deep discharge. Coffey (2016a) reports that of the groundwater inflow that occurs within the Berrima Colliery workings, the majority drains to the Wingecarribee River with minor volumes extracted and used for non-potable uses. Since mining ceased in 2013, measured discharge from the mine workings has been in the range 1.5–3.2 ML/day.

6.6 Groundwater levels and flow

Groundwater flow in the Hawkesbury Sandstone and the underlying Wongawilli Seam occurs as a dual porosity system comprising connected intergranular pore spaces and structural features including fractures, bedding planes and joints (Ross 2014).

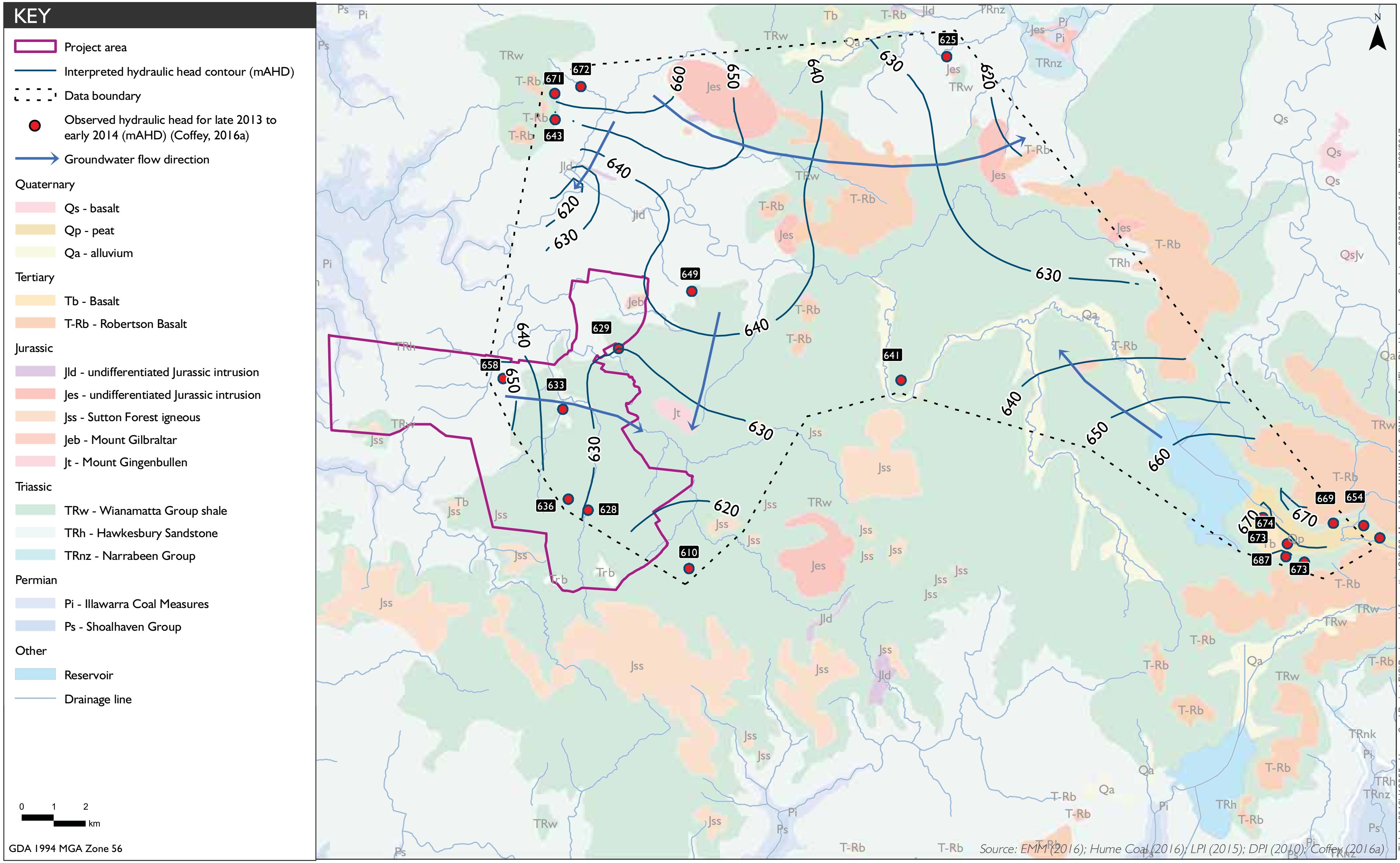
The regional groundwater flow direction in the Hawkesbury Sandstone and Wongawilli Coal Seam is influenced by the location of major hydraulic boundaries in the landscape, including:

- topography;
- recharge areas, particularly along the western project area boundary at elevated areas where the Hawkesbury Sandstone outcrops;
- discharge areas – typically associated with lower or steep topographic gradients, such as cliff escarpments; and
- stratigraphic dip of the geological units.

The main groundwater flow direction in the Hawkesbury Sandstone is regionally from areas of higher elevation in the west towards the east; this is consistent with the regional topography and stratigraphic dip (Coffey 2016a). However, there is some localised groundwater flow to the north towards Medway Dam, to the west from the Wingecarribee Reservoir, and to the west towards the deeply incised gullies of Black Bobs Creek consistent with local topographic decreasing elevations. Regional groundwater levels and flow directions in the upper Hawkesbury Sandstone are shown in Figure 6.7. The data in Figure 6.7 is from late 2013 to early 2014, which was the period of monitoring data with the greatest spatial coverage.

The groundwater flow directions in the overlying low permeability shale and basalt groundwater systems are influenced by local topography and transmissivity, and consequent groundwater gradients. Groundwater flow in the basalt is thought to radiate outward from the centre of the basalt outcrop, with most flow within fractures and joint networks and negligible flow through the pore spaces (Coffey 2016a). The groundwater levels and flow direction in the Wianamatta Group is shown in Figure 6.7. The data in Figure 6.7 is from late 2013 to early 2014, which was the period of monitoring data with the greatest spatial coverage.

Groundwater levels (hydraulic head) from the Hume Coal groundwater monitoring network show very little change over time, except for periodic drawdown as a result of pumping from private landholder bores (Coffey 2016a). In some locations, small long-term decreases in hydraulic head are observed due to long-term pumping from landholder bores and/or drainage into historic mine voids (Coffey 2016a). North of the project area, in the Berrima Colliery area, drawdown and significant vertical hydraulic head gradients are evident at monitoring bores and private landholder bores as a result of the last phases of the full extraction mining at Berrima Colliery (up to 2013) (Coffey 2016a). The hydraulic head data from bores in the Berrima mine area provide valuable insight on the groundwater systems and their response to dewatering during mining activities. The secondary extraction mining method employed at Berrima mine had significantly more drawdown influence on the overlying groundwater systems than the first workings method proposed for the project due to the different mining procedure and consequent limited vertical extent of caved goaves.



Groundwater levels & flow direction in Upper Hawkesbury Sandstone

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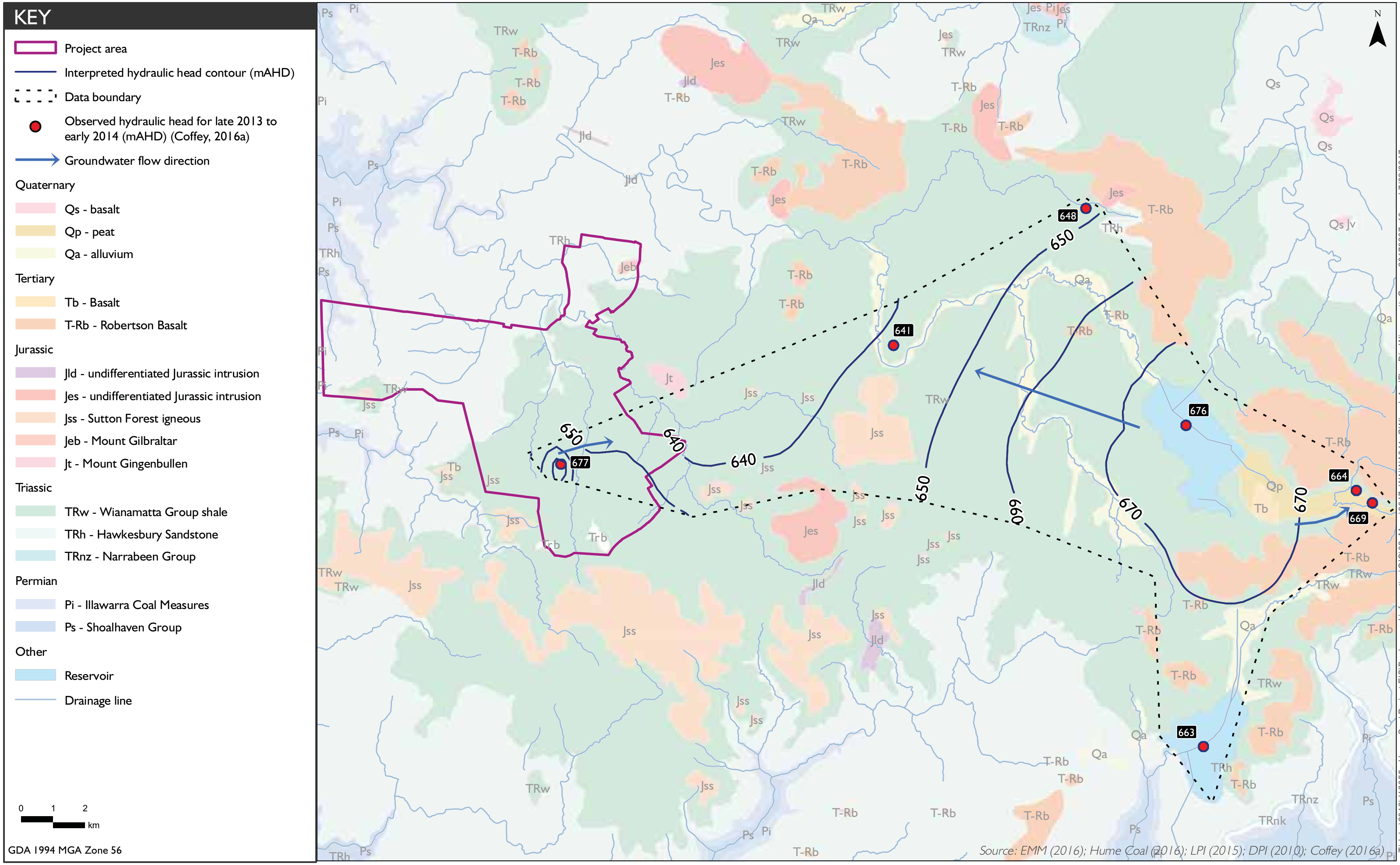
Figure 6.7



Groundwater levels & flow direction in Wianamatta Group

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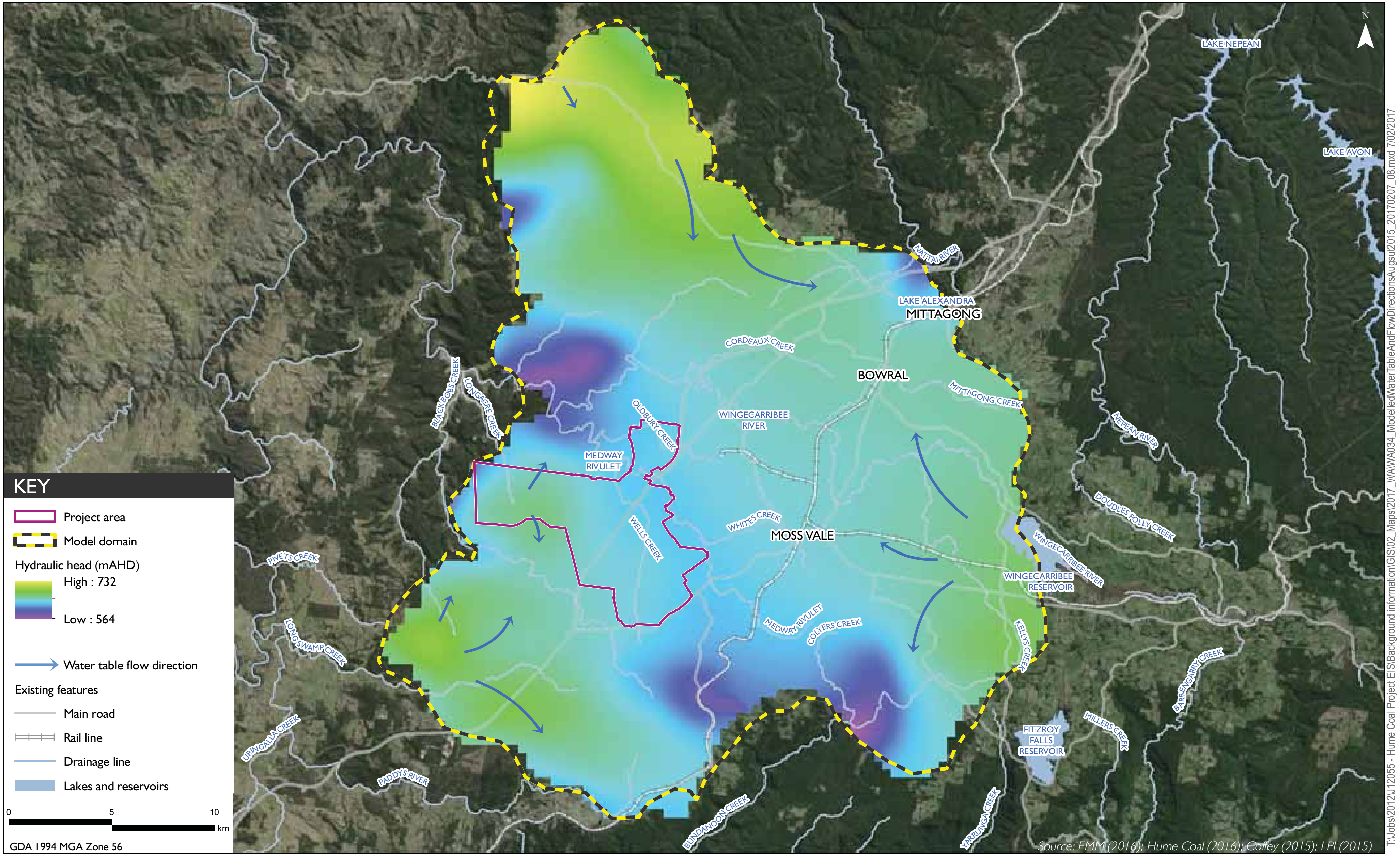
Figure 6.8



Modelled water table and flow directions as at August 2015

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Figure 6.9

6.7 Vertical head gradients

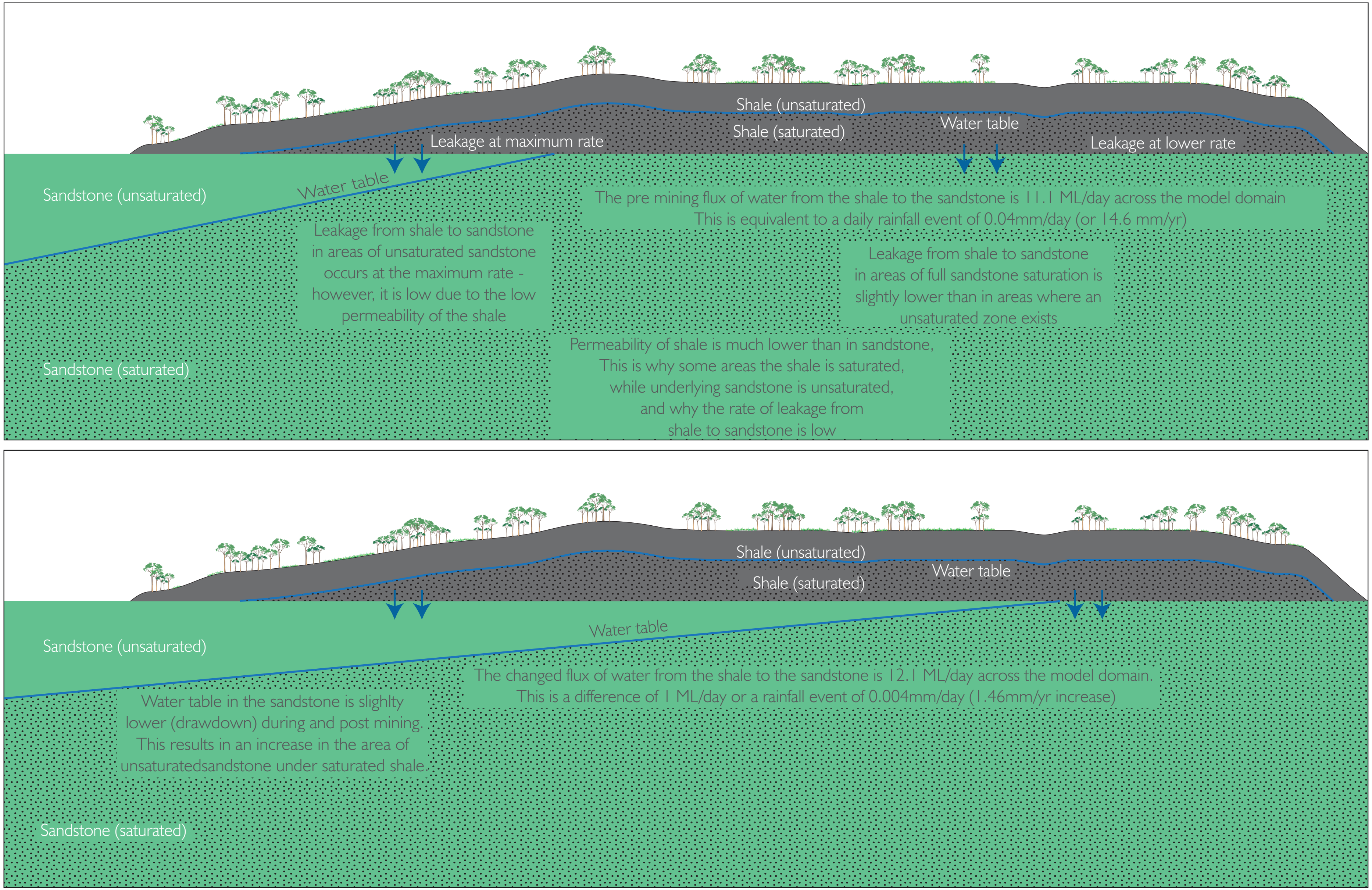
The vertical hydraulic head differences between different groundwater units are variable, reflecting recharge areas, cliff escarpment discharge, and local groundwater systems within the Hawkesbury Sandstone. Groundwater level monitoring data indicates (Coffey 2016a):

- downward trending vertical gradients are present in the north-western part of the project area, consistent with areas of recharge;
- significant vertical hydraulic head gradients exist north of the project area, and desaturation associated with the full extraction mining and related deformation in the overlying units at the Berrima Colliery. This effect has not migrated south into the northern end of the project area due to incised watercourses that act as groundwater flow barriers;
- steep vertical hydraulic gradients generated by discharge at seepage faces are present next to escarpments;
- significant, downward vertical hydraulic gradients are present in the Wianamatta Group where overlain with Robertson Basalt;
- small vertical hydraulic head gradients exist in the central part of the project area, due to distance from mining and escarpments and minimal recharge at this location; and
- negligible vertical hydraulic head gradients exist within the Robertson Basalt. However, there is a large vertical hydraulic head gradient between the basalt and the underlying sedimentary units (note this large vertical head does not translate to large flow due to the very low hydraulic conductivity of the Wianamatta shales).

Some of the data presented in the numerical model report (Appendices H and I) suggests there is a zone of saturation above the Berrima Colliery. The extent and location of this saturated zone is unknown. For a conservative approach, in this water assessment the Hawkesbury Sandstone is interpreted as being desaturated above the full extraction workings in the northern part of Berrima Colliery and as having a local zone of saturation above the first workings in the southern part of the mine. It is likely this local saturated zone is somewhat disconnected from the regional groundwater system, although some leakage from the local system to the regional system is likely to occur. Over time, this saturated zone is expected to increase in size and eventually reconnect with the regional groundwater system as the groundwater above the Berrima Colliery recovers.

The connectivity between the overlying Wianamatta Group shale and the Hawkesbury Sandstone is conceptualised as a stable low rate of leakage from the above low permeability system into the below high permeability regional sandstone system. This assessment conservatively assumes there is a direct hydraulic connection between the base of the Wianamatta Group shale, and the underlying upper Hawkesbury Sandstone. Although, it has also been interpreted from vertical head distributions that a desaturated zone in some areas could separate the two formations – in which case leakage from the shale into the underlying sandstone would be expected to already be occurring at a maximum flux rate. Figure 6.10 shows a schematic representation of the relationship between the local groundwater system in the Wianamatta Group and the regional groundwater system in the Hawkesbury Sandstone during pre-mining (A) and during mining (B) conditions.

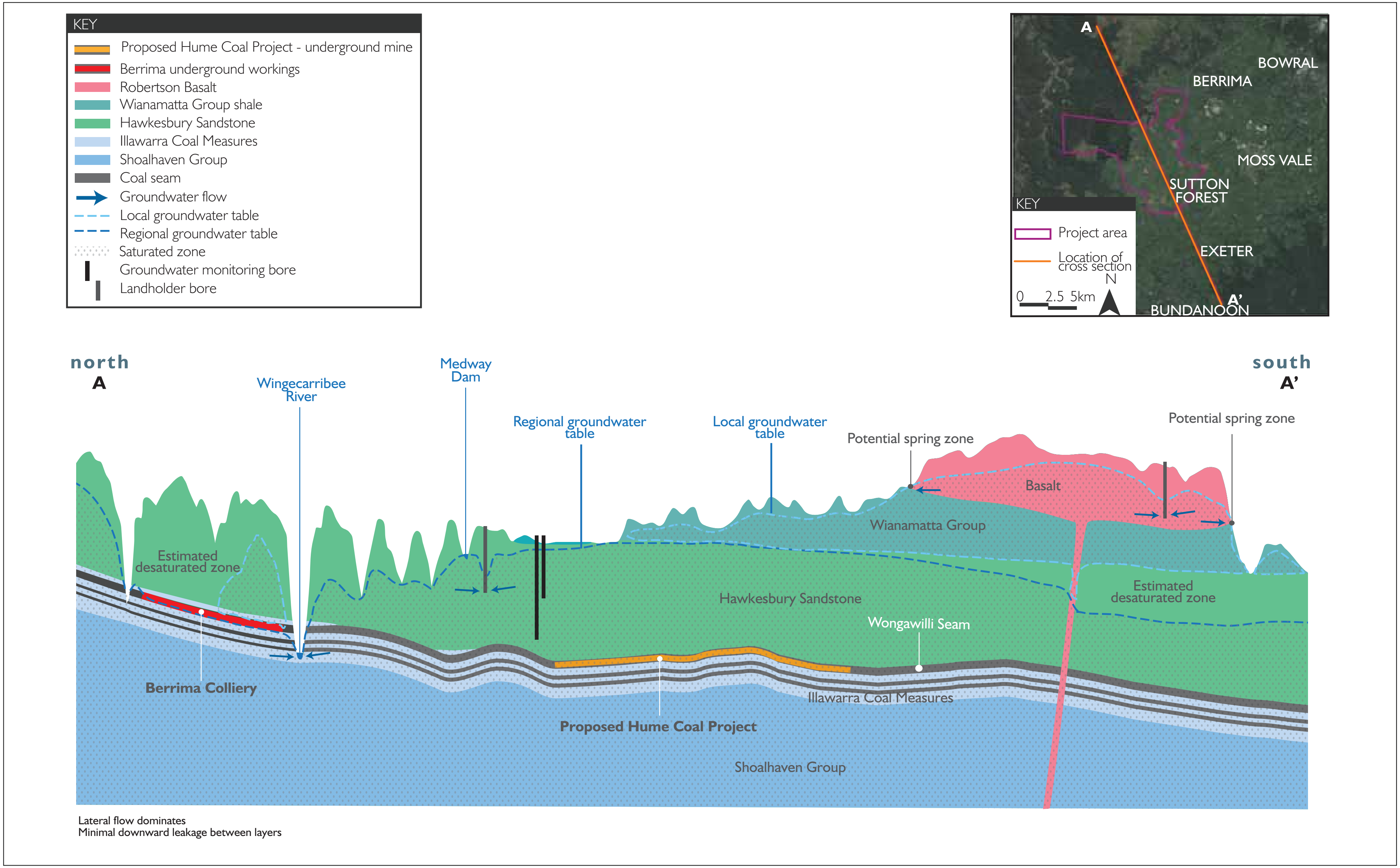
An interpreted hydrogeological cross-section for the existing (pre-mining) situation, including the Berrima Colliery, is shown in Figure 6.11. This cross section is schematic and has an exaggerated vertical scale.



Schematic representation of Wianamatta Group - Hawkesbury Sandstone Relatonship

Hume Coal Project
Water Assessment
Figure 6.10

EMM HUMECOAL PROJECT



Schematic - not to scale
(vertical scale is exaggerated and this is a schematic representation only and does not accurately represent the size or locations of bores)

Interpreted hydrogeological cross-section - existing situation

Hume Coal Project
Water Assessment

Figure 6.11

6.8 Groundwater quality

AR 52: An assessment of groundwater quality, its beneficial use classification and prediction of any impacts on groundwater quality.

Baseline water quality data collected between October 2011 and September 2015 from the Hume Coal groundwater monitoring program are included and details are presented in Appendix K. The results from baseline monitoring will continue to be collected up to the start of project construction and will be available for future analysis. Section 4.2.5 outlines the groundwater quality monitoring program. Table 6.2 summarises the baseline water quality data for each groundwater system used in this assessment. The sections below summarise the groundwater quality data.

Table 6.2 Summary of baseline water quality data per groundwater system

Groundwater system	Number of water quality monitoring bores	Total number of water quality samples collected	Data range
Robertson Basalt	2	9	December 2012–September 2015
Wianamatta Group	1	7	December 2013–September 2015
Hawkesbury Sandstone	23	131	October 2011–September 2015
Wongawilli Seam	15	93	October 2011–September 2015
Illawarra Coal Measures	3	14	March 2013–September 2015

6.8.1 Summary of groundwater quality

Figure 6.12 shows a histogram of pH for baseline samples collected from the groundwater monitoring bores in the Wianamatta Group, Hawkesbury Sandstone, and the Wongawilli Seam. pH conditions straddle neutral values for the Robertson Basalt and Wianamatta Group, while pH conditions are slightly more acidic in the Hawkesbury Sandstone and Wongawilli Seam.

Figure 6.13 shows a histogram of total dissolved solids (TDS), a measure of salinity, for baseline samples collected from the groundwater monitoring bores in the Wianamatta Group, Hawkesbury Sandstone, and the Wongawilli Seam. Groundwater is generally fresh in the Hawkesbury Sandstone and Illawarra Coal Measures and comparable to surface water (Section 5.3), indicating proximity to recharge areas. Groundwater quality is also fresh in the Robertson Basalt although the mean TDS is slightly higher compared to the sandstone and coal. The Wianamatta Group hosts brackish groundwater remnant from the marine depositional setting, long residence times, and coastal rainfall influence. The similarity of TDS measurements between the Illawarra Coal Measures and Hawkesbury Sandstone indicates they are hydraulically connected between the units. Local elevations in the Hawkesbury Sandstone TDS measurements are attributed to higher salinity groundwater leaking from the overlying Wianamatta Group, where present. Figure 6.14 shows spatial variability of the average TDS for monitoring bores in each monitored zone. The lower salinity groundwater observed in the Hawkesbury Sandstone in the west and north-west is indicative of flushed recharge areas and absence of overlying shale. Two monitoring bores (HU0142PZB and HU0142PZC) showed anomalous TDS results after the bores were installed (up to 3,172 mg/L); these results have been interpreted as an influence of the bore installation and are not representative of natural groundwater.

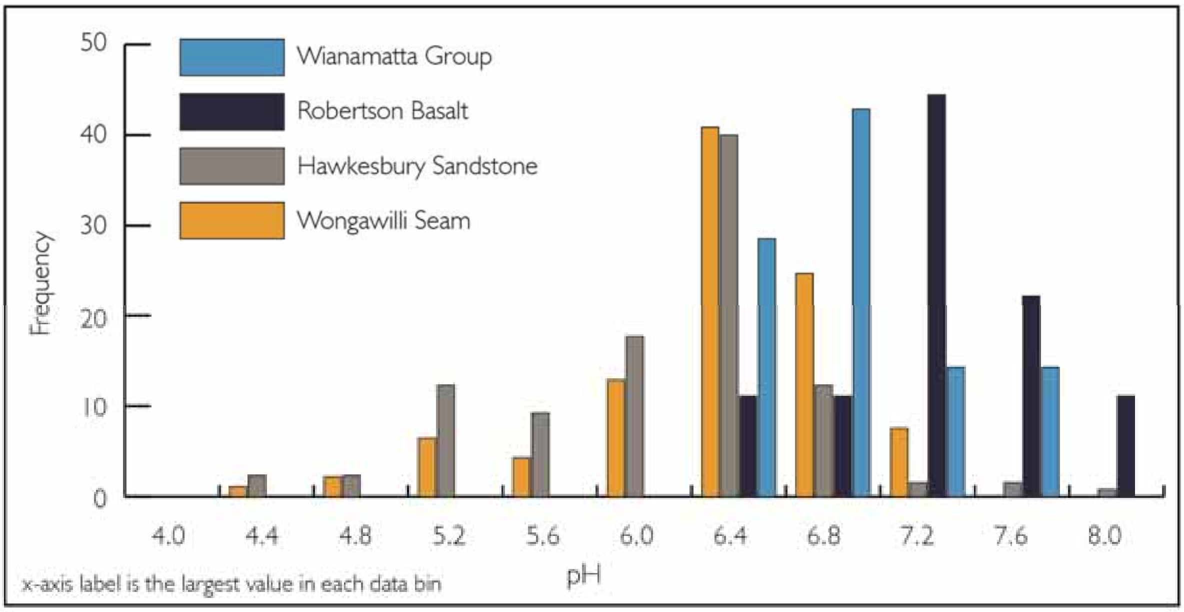


Figure 6.12 Histogram of groundwater pH

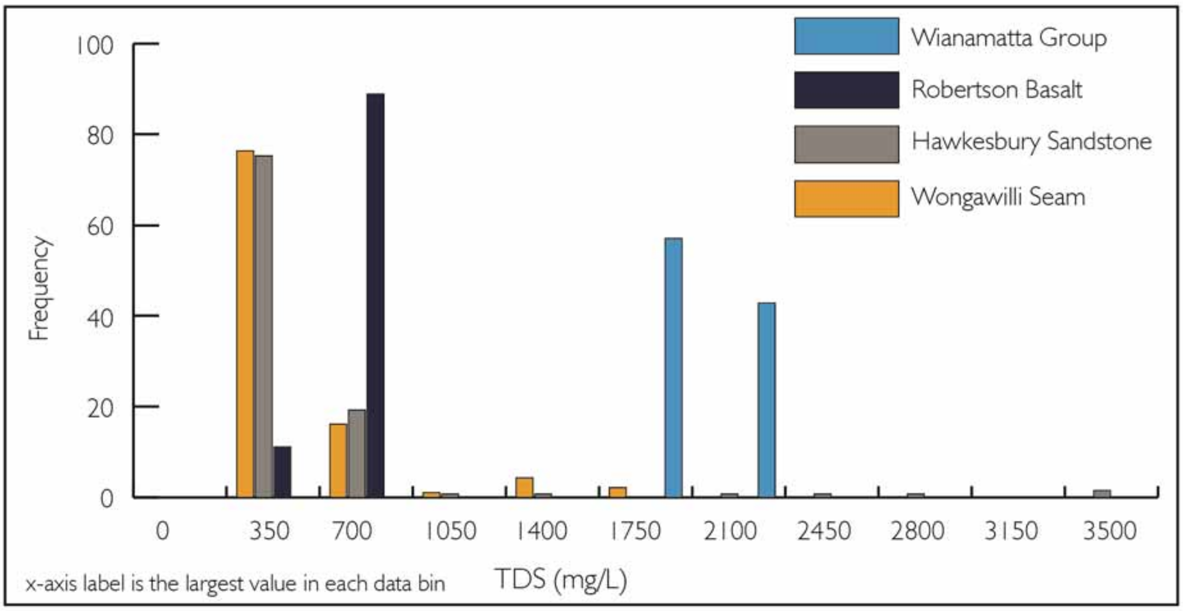
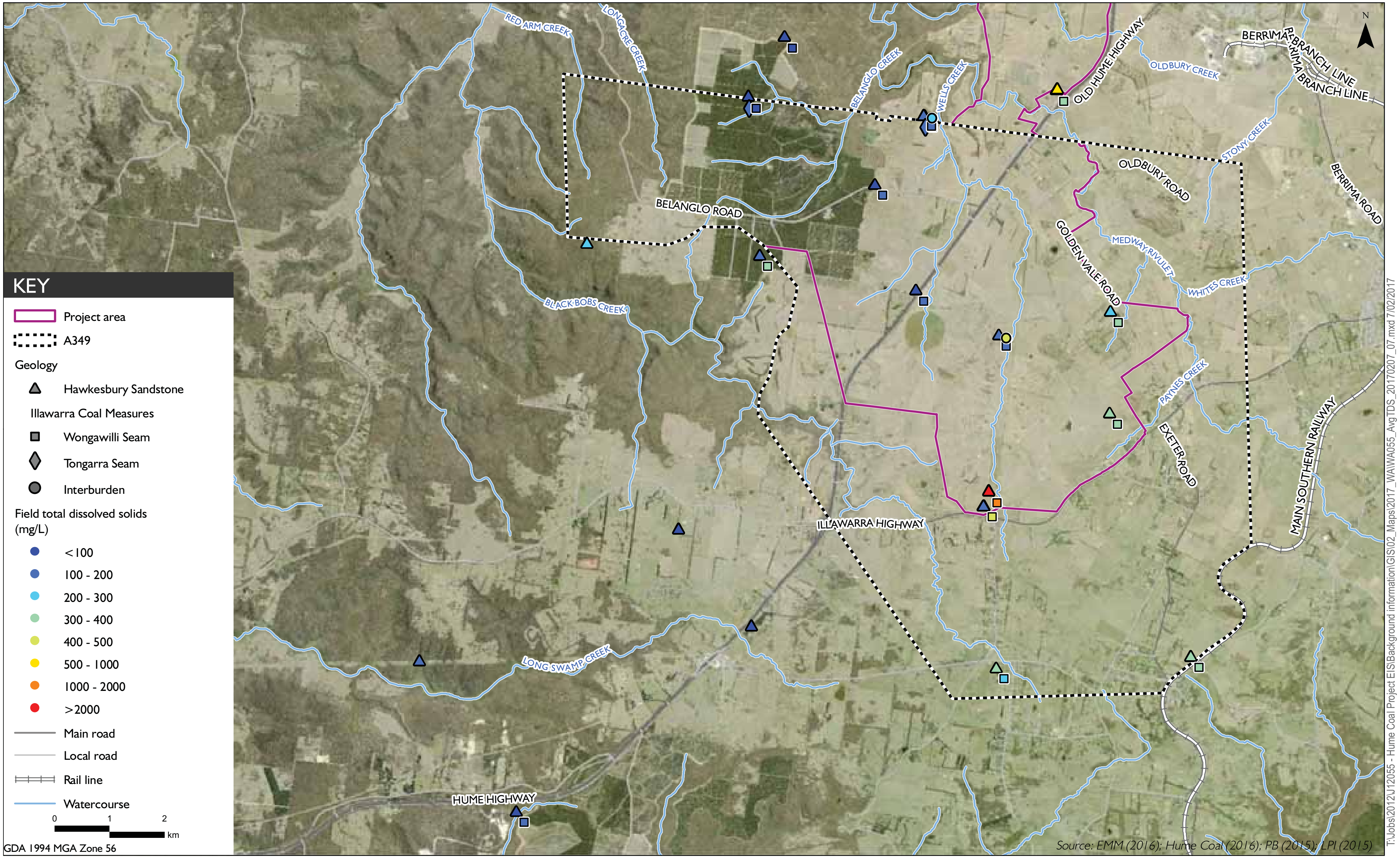


Figure 6.13 Histogram of groundwater TDS



Distribution of average TDS for monitoring bores within Hawkesbury Sandstone and Illawarra Coal Measures

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Water Assessment
Figure 6.14

Dominant water type for each monitored formation is shown in Table 6.3. The dominant hydrochemical water type in the basalt was Mg-Ca-HCO3-Cl, indicating the groundwater represents a mixture of rainfall recharge that has been influenced by mineral dissolution within the basalt rock.

The predominant hydrochemical water type in the WG shale formation is Mg-Ca-Na-Cl-HCO_3. The strong chloride component in the shale is likely to be associated with connate salts from its original marine deposition, and also longer residence time and coastal rainfall with weakly dissolved salts subject to evapotranspiration over time.

The Hawkesbury Sandstone varies in water type. There is a continuous range in cations from magnesium-rich to sodium-rich groundwater, but none that are rich in calcium. There are two distinct distributions of groundwater types for anions; one type consists of bicarbonate and chloride with very low sulphate and the other consists of sulphate and bicarbonate without chloride.

Table 6.3 Dominant major ion chemistry for each groundwater system

Groundwater system	Water type
Robertson Basalt	Mg-Ca-HCO_3-Cl
Wianamatta Group	Mg-Ca-Na-Cl-HCO_3
Hawkesbury Sandstone	Na-Cl, Na-Mg-Cl-HCO_3, Mg-Na-SO_4-HCO_3
Wongawilli Seam	Na-Cl
Illawarra Coal Measures	Ca-Na-HCO_3

Concentrations of most dissolved metals are typically low for most samples collected from each groundwater system, with many measurements below detection limits. This is typical of groundwater with reasonably neutral pH.

No organic compounds were detected above the limit of detection in either the Wianamatta Group or the Illawarra Coal Measures groundwater. Minor detections of naturally occurring toluene and petroleum hydrocarbons were observed in the Hawkesbury Sandstone and Wongawilli Seam groundwater.

6.8.2 Spatial and temporal variability in baseline monitoring data

Hawkesbury Sandstone groundwater sampled from the western part of the project area, where the sandstone outcrops, has a dominant Na-Cl signature, which is typical of rainfall recharge close to the coast. While, Hawkesbury Sandstone groundwater sampled from areas overlain by Wianamatta Group shale has a dominant Mg-CO_3 signature, which is characteristic of older groundwater that reflects a greater degree of water-rock interaction in the groundwater system (Appendix K).

Groundwater in the shale has a higher solute load than groundwater in the other formations, which is typical of the Wianamatta Group shales in the Sydney basin. However, the salinity of the groundwater in the one monitoring bore that intersects the shale is only moderately higher than groundwater sampled from other formations. It would not be unusual for groundwater in thicker occurrences of the Wianamatta Group shales to have salinity values (EC and TDS) an order of magnitude higher than that observed in the study area (Ross 2014).

Groundwater quality in the Hawkesbury Sandstone and the Wongawilli Seam are similar. Although it is common for groundwater in the Hawkesbury Sandstone to have a low solute load, coal seam groundwater would typically be expected to have greater salinity and greater variability in the geochemical signature. There was no significant distinction observed between groundwater in the Hawkesbury Sandstone, the Wongawilli Coal Seam, the ICM, and the basalt. This similarity in geochemical signature suggests a limited degree of soluble mineral phases in each of these formations.

The groundwater quality appears to have remained relatively unchanged across the monitoring period, showing very little seasonal variation or long-term trends. For example, Figure 6.15 and Figure 6.16 show major ion chemistry changes over time for two Hawkesbury Sandstone monitoring bores: HU0142PZB, in the south-eastern part of the project area, and HU0096PZC, in the north-western part of the project area. At each bore, the individual parameters maintain relatively consistent concentrations across the monitoring period.

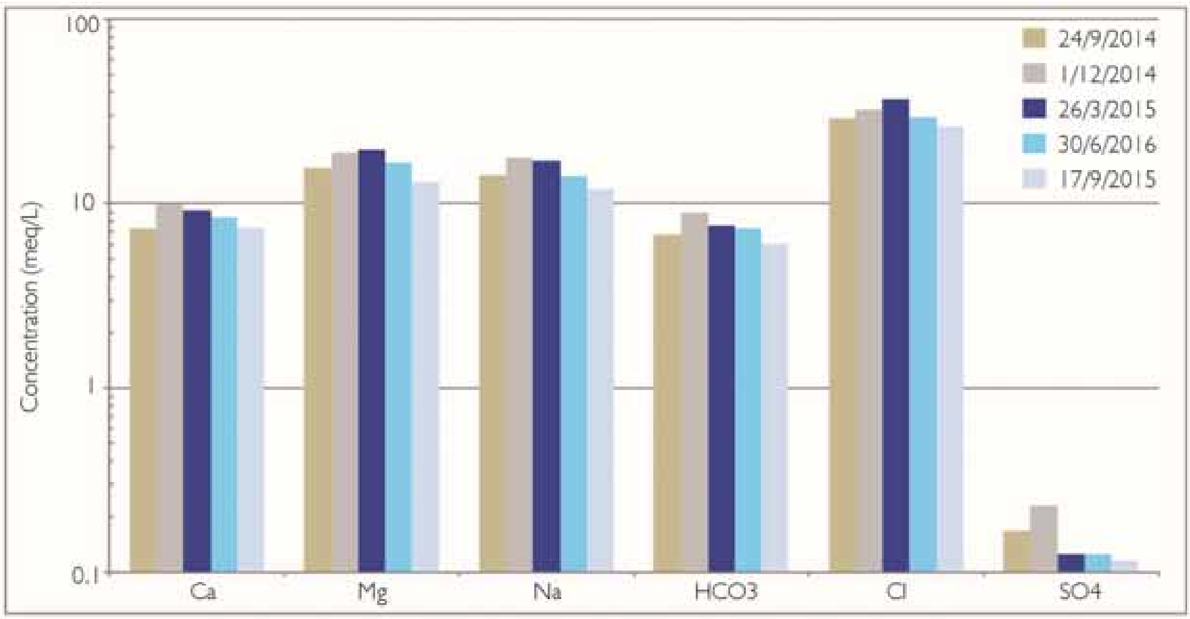

Figure 6.15 Major ion chemistry changes over time at Hawkesbury Sandstone bore HU0142PZB

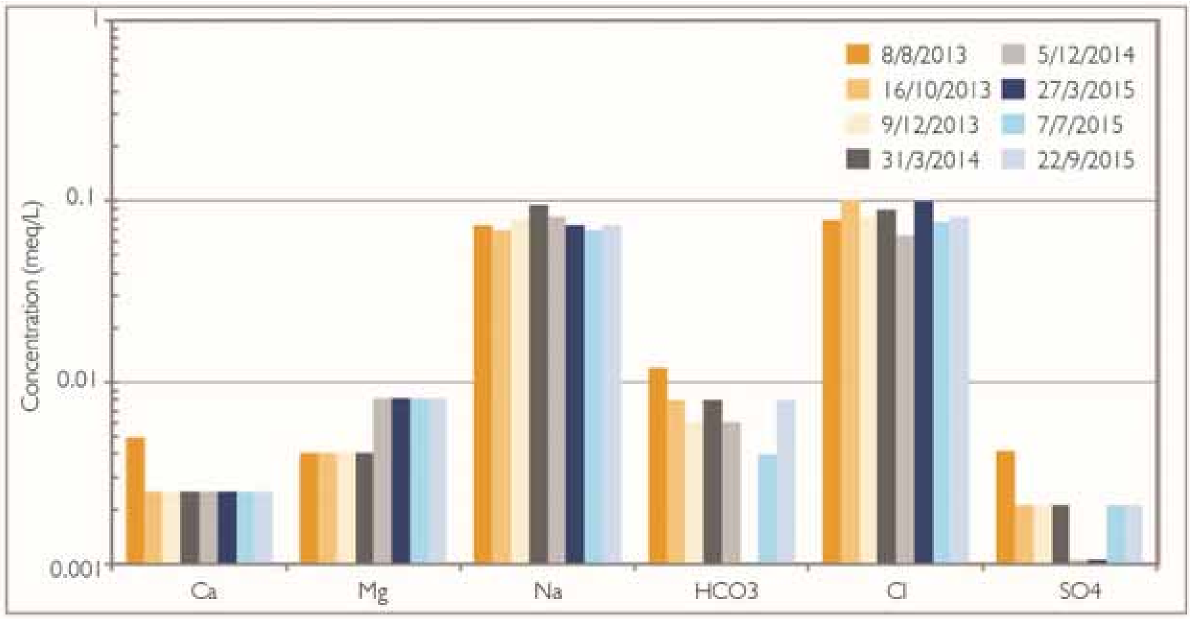

Figure 6.16 Major ion chemistry changes over time at Hawkesbury Sandstone bore HU0096PZC

6.9 Beneficial uses

AR 68 (part): The EIS must describe background conditions for any water resource likely to be affected by the development, including:
c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters.
d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.

The groundwater quality of the basalt is characterised by relatively low TDS and around neutral pH, with very few exceedances of the water quality assessment criteria. Where exceedances occurred, they are generally associated with metals concentrations that are marginally above the ANZECC and ARMCANZ (2000) ecological criteria. Accordingly, groundwater associated with the basalt intrusions in the study area is likely to be suitable for a broad range of beneficial uses, from a water quality perspective.

Groundwater associated with the Wianamatta Group shales is typically too saline, and the yield is too low, to support a broad range of beneficial uses. Although the TDS is relatively moderate with respect to shale groundwater in other parts of the Sydney Basin, it is still above the aesthetic guideline value for drinking water (NHMRC 2016), and is generally considered to have limited potential as a groundwater resource.

Groundwater in the Hawkesbury Sandstone is an important local water supply resource, and is developed to support domestic and stock supply, and irrigation. It is characterised by a low salinity and, in combination with good bore yields, makes it suitable to support most beneficial uses. Environmental values associated with the Hawkesbury Sandstone are likely to include: primary industries (irrigation and general water uses, stock drinking water, aquaculture and human consumption of aquatic foods), drinking water, and, in places of discharge to streams, aquatic ecosystems.

6.10 Groundwater use

AR 51: The existing groundwater users within the area (including the environment), any potential impacts on these users and safeguard measures to mitigate impacts.

6.10.1 Landholder and DPI Water monitoring bores

According to DPI Water's groundwater bore database (DPI Water 2015b), there are less than 400 registered landholder bores and three DPI Water monitoring sites within a 9km radius from the middle of the project area. There are 43 landholder bores within the project area (excluding bores on Hume Coal property). These bores are shown in Figure 6.17.

DPI Water monitoring bores are used to monitor groundwater levels and water quality at locations across the state. Often the monitoring bores are constructed as 'nested sites' with multiple bores screening different formations. One of the three DPI Water monitoring sites is a nested site with two bores installed to different depths (GW075032), the remaining monitoring sites are single bore sites (GW075034 and GW075036) (Figure 6.17).

The median bore depth of the private landholder bores is about 85 m, with most bores extracting groundwater from the Hawkesbury Sandstone. Landholder groundwater pumping from the basalt is concentrated around Exeter, south of the major sub-vertical feature. Landholder bores are mainly associated with the farmed areas, with very few bores observed in the Belanglo State Forest. Landholder licensed bores are mainly for domestic and stock use.

Coffey (2016a) identified 83 private water bore access licences within the 9 km radius of the project area with a combined level of entitlement of 5,300 ML/year. It is possible a number of unregistered bores also exist, but these are likely to be stock and domestic bores, and unlikely to be used for irrigation. As regulatory agencies for the area do not meter usage, the actual usage from registered bores is unknown.

A number of basic rights bores (registered for stock and domestic use) also exist; there is no volumetric entitlement associated with these bores. The total usage of basic rights bores within 9 km from the middle of the project area is estimated to be 950 ML/year.