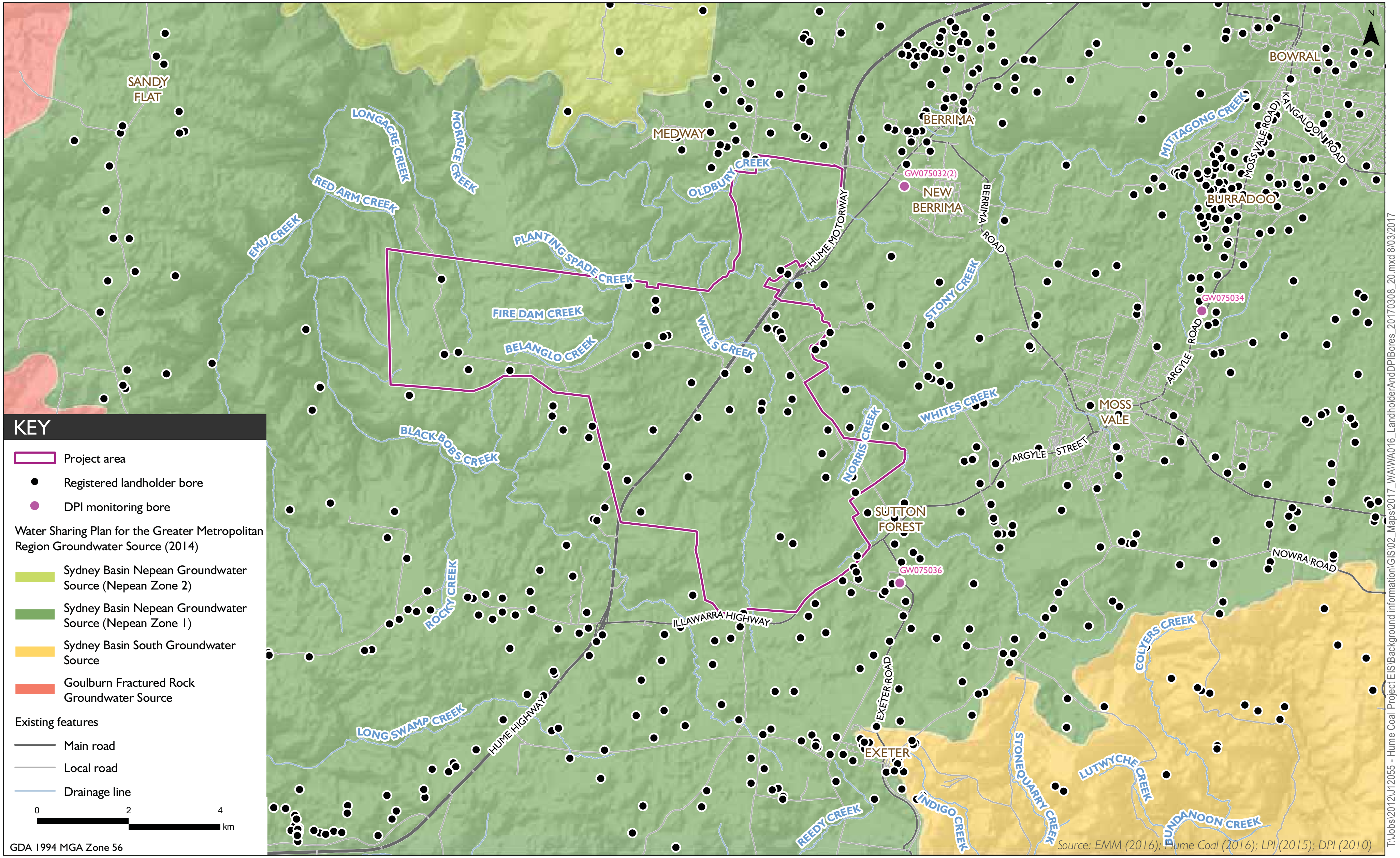


Landholder bores and DPI Water monitoring bores

Hume Coal Project
Water Assessment

Figure 6.17

EMM HUMECOAL

6.10.2 Ecosystems that rely or potentially rely on groundwater

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.

Ecosystems that could rely on either the surface or subsurface expression of groundwater within or surrounding the project area are those associated with:

- creeks where groundwater is interconnected and provides baseflow after runoff. This includes Medway Rivulet and some drainage channels in the northern and western areas of the project;
- shallow groundwater systems;
- springs associated with basalt hills south of the project area and springs at the shale/sandstone boundary near creeks;
- upland swamps in the wider locality, namely Stingray Swamp and Long Swamp; and
- terrestrial vegetation overlying shallow groundwater (within the vegetation's root zone).

These ecosystems have been classified into three categories according to their dependence on groundwater: non-dependent, facultative, and entirely/obligate (Figure 3.7).

Assessment of ecosystems reliant and potentially reliant on groundwater is described in the *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c). A summary is provided below.

Ecosystems that rely on groundwater are important environmental assets and typically occur where groundwater is at or near the land surface. NSW water sharing plans (WSPs) include schedules with lists of high priority groundwater dependent ecosystems (GDEs), which are required to be assessed using the minimal impact criteria outlined in the Aquifer Interference Policy.

There are no high priority GDEs identified within the project area in the Metropolitan Groundwater WSP. However, Paddys River Swamps (comprising Long, Hanging Rock, Mundego, and Stingray Swamps) and Wingecarribee Swamp (Figure 1.4) are listed in the WSP as high priority GDEs but are some distance from the project area. Paddys River Swamps are about 9 km to the south-west of the project area and the Wingecarribee Swamps are 13 km to the east (EMM 2017c). Peat swamps rely on both groundwater baseflow to the drainage channels in which these swamps occur and surface water runoff.

Long Swamp and Stingray Swamp have a facultative (proportional) dependence on groundwater as they would take a portion of their water requirements from the groundwater near ground surface and a portion from rainfall infiltration and stream surface flows.

Paddys River Swamps contain the Temperate Highland Peat Swamps on Sandstone listed in the NSW *Threatened Species Conservation Act 1995*. These swamps are also listed in the *Directory of Important Wetlands in Australia* (Environment Australia 2001).

One spring was recorded in cleared land on a basalt hill in the south of the project; however, given its location in a cleared area, there are no surrounding drainage lines that would rely on spring flow. Several springs were also recorded in cleared areas during surveys north and south of Oldbury Creek and Medway Rivulet. These springs would make a minor contribution to surface flows in the area to Oldbury Creek and Medway Rivulet, and therefore these systems are considered to be non-dependent.

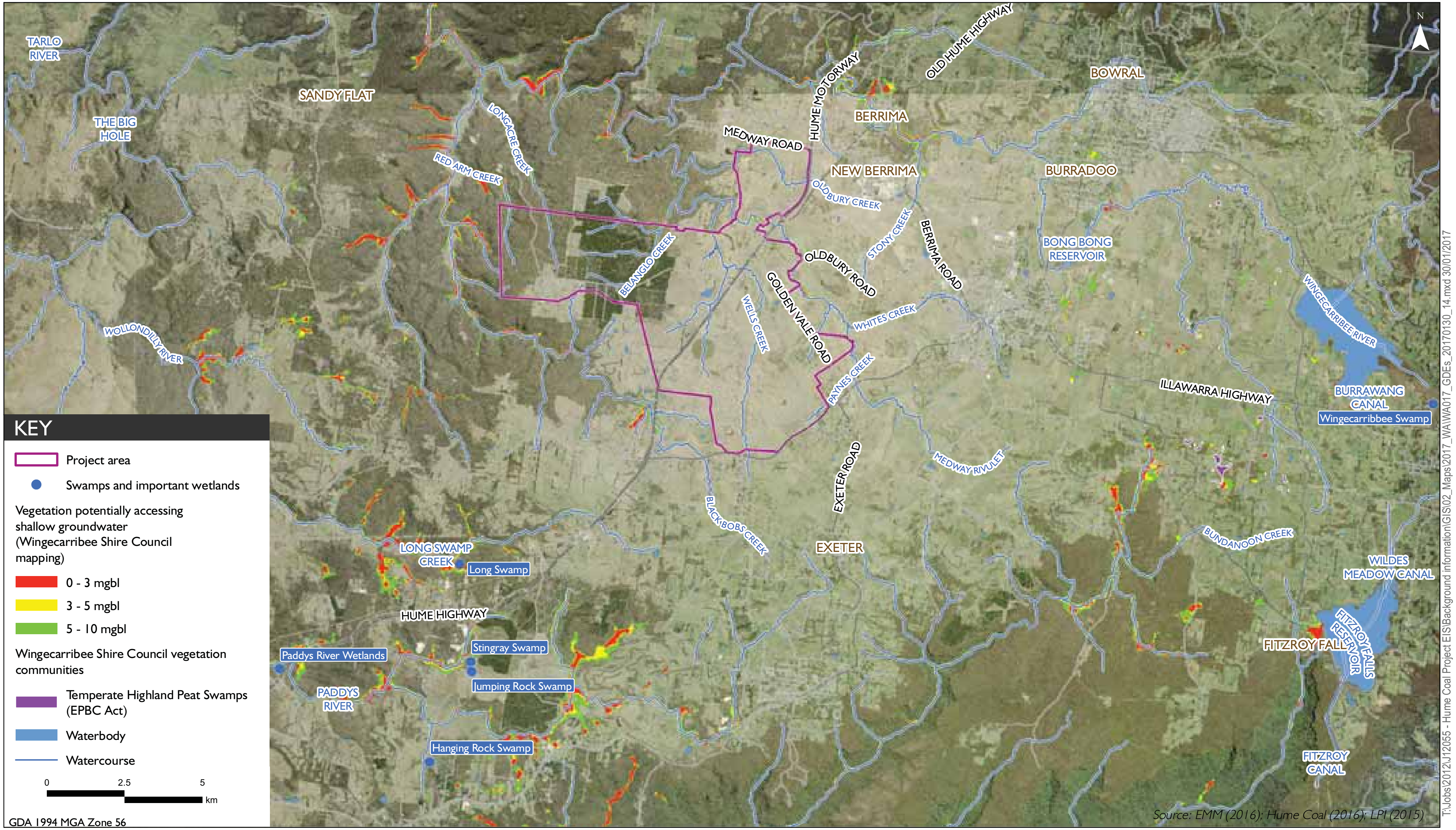
Terrestrial vegetation overlies shallow groundwater (0– 10 mbgl) in some places in and around the project area, mainly along rivers and creeks. These include Medway Rivulet, Wells Creek, Belanglo Creek, Longacre Creek and Red Arm Creek. Six of the native vegetation types in the *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c) study area occur where groundwater is less than 10 m deep and, therefore, have potential to access groundwater sporadically at these locations. One of these, namely Broad-leaved Peppermint Argyle Apple grassy woodland, contains the endangered Paddys River Box. Terrestrial vegetation also overlies shallow groundwater to the south of the project area, along Bundanoon Creek, and to the north along the Wingecarribee River (Figure 6.18).

None of these ecosystems described above have a facultative (highly dependent) dependence or are entirely dependent on groundwater.

An assessment of the aquatic fauna dependency on baseflow is provided in the *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c). Groundwater systems are also discussed in the Aquatic Ecology Assessment; stygofauna living in groundwater systems are entirely/obligate dependence on groundwater.

The groundwater within the project area may support stygofauna endemic to groundwater discharge or groundwater itself (EMM 2017c). Generally, stygofauna biodiversity is highest near the water table and declines with depth from the ground surface, and is also highest in recharge areas (EMM 2017c).

Stygofauna studies undertaken for the project in 2013 and 2014 collected a total of one specimen of aquatic fauna (a crustacean) and three of terrestrial (commonly, an ant, a springtail, and a water strider) from 19 groundwater bores (8 within the project area and 11 outside of the project area) (EMM 2017c). The crustacean was collected from a shallow groundwater monitoring bore (5 mbgl), while the remainder were from three deeper bores (between 78 and 87 mbgl); all four bores intersect the Hawkesbury Sandstone. No stygofauna was found in any of the seven sampled bores that intersect the Illawarra Coal Measures in the project area. No rare or significant stygofauna was identified.



Ecosystems that potentially rely on groundwater

Hume Coal Project
Water Assessment

Figure 6.18

EMM HUMECOAL

7 Site conceptual model

This chapter discusses the conceptual surface water and groundwater model for the project area. The conceptual model brings together the monitoring results and background information to develop an understanding of how the water systems interact with each other and the project.

7.1 Introduction

The hydrological conceptual model provides a schematic illustration of the various interacting components of the hydrological cycle. It includes the groundwater systems, surface water systems, flow paths, recharge and discharge mechanisms, and the interaction between these various hydrological components and geological units. It forms the basis for developing the numerical groundwater flow model.

The conceptual model is based on the information presented in Chapters 5 and 6 and is shown in Figure 7.1.

7.2 Conceptual model components

- Rainfall evaporation and evapotranspiration:
  - high average annual rainfall (approximately 960 mm/yr);
  - evaporation exceeds rainfall, on average, from September to March (pan evaporation 1,264 mm/yr); and
  - evapotranspiration from vegetation.
- Drainage lines:
  - most drainage lines in the project area are confined valley settings with occasional floodplains; and
  - upper reaches have low flow energy.
- Surface water use:
  - town water supply via storages (including Medway Reservoir, although not being used);
  - landholder diversion pumps and storages for licensed water supply, mostly for irrigation;
  - basic landholder rights (harvestable rights dams/riparian access for stock and domestic supply); and
  - harvestable rights dams for irrigation.

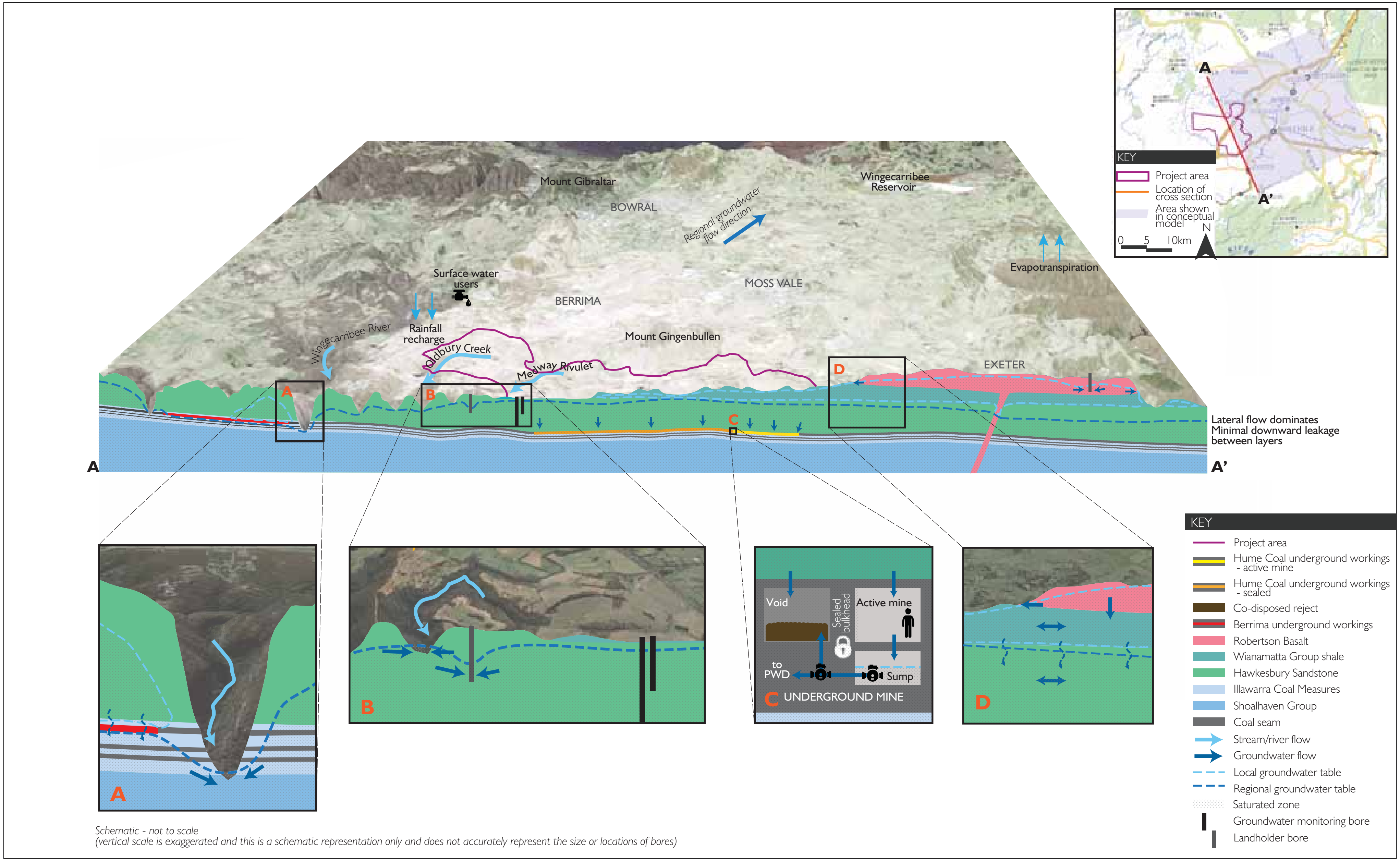
- Geological setting:
  - negligible alluvium in the project area, minor alluvium present along the upstream Wingecarribee River;
  - surface geology is dominated by Triassic sedimentary units: Hawkesbury Sandstone (west) and Wianamatta Group (Ashfield Shale) (east);
  - Hawkesbury Sandstone is a regionally continuous, porous and fractured flat-lying sandstone between 50–120 m thick in the project area;
  - the older Triassic Narrabeen Group disconformably underlies the Hawkesbury Sandstone and was eroded over the project area, but is present to the north of the project area;
  - Permian Illawarra Coal Measures (ICM) contains the mining target, Wongawilli Coal Seam;
  - outcrop of ICM occurs where watercourses have incised through the Hawkesbury Sandstone in the west;
  - the older Permian Shoalhaven Group is about 100 m thick and overlies Palaeozoic basement;
  - stratigraphy regionally dips to the east and has few structural features;
  - faults that have been inferred have small displacement (5–10m), with the exception of the Cement Works Fault north of the project area;
  - there are numerous igneous intrusions, including dykes and diatremes, assumed to be Jurassic; and
  - Tertiary Robertson Basalt overlies the Wianamatta Group (Ashfield Shale) in the south.
- Groundwater systems
  - localised, low permeability, unconfined groundwater systems are present in Robertson Basalt and Wianamatta Group (Ashfield Shale) (insert D in Figure 7.1);
  - the Wianamatta Group (Ashfield Shale) acts as a regional aquitard (retarding downward flow into the Hawkesbury Sandstone);
  - groundwater in the basalt is typically low yielding (unless localised fractures are intercepted), and quality is fresh;
  - groundwater in the shale is typically poor quality and low yielding;
  - the Hawkesbury Sandstone contains the major groundwater system in the region; groundwater is typically fresh and bore yields range from low to high; and
  - low permeability water bearing zones in the ICM and Shoalhaven Group generally restrict groundwater flow.

- Recharge:
  - average rainfall recharge is modelled as about 2% of annual rainfall;
  - rainfall recharge occurs mostly where Hawkesbury Sandstone and Robertson Basalt are exposed at the ground surface;
  - minor recharge occurs where Ashfield Shale outcrops; minor recharge to Ashfield Shale also occurs from overlying basalt, where present; and
  - recharge to Hawkesbury Sandstone is mostly from direct rainfall on outcrop and only very minor volumes are from overlying shale, where present.
- Groundwater discharge:
  - drainage to surface water (baseflow) – the largest discharge component;
  - extraction from landholder bores (insert B in Figure 7.1);
  - evaporation from water table, where shallow, and from surface water features;
  - evapotranspiration;
  - seepage/springs and evaporation along escarpments (insert A in Figure 7.1). Spring discharge between basalt and underlying Wianamatta Group (Ashfield Shale) (insert D in Figure 7.1);
  - deep drainage into old Berrima Colliery, and subsequently into Wingecarribee River (insert A in Figure 7.1); and
  - regional groundwater through flow in the Hawkesbury Sandstone and ICM is to the south-east.
- Groundwater flow:
  - lateral flow dominates, with minimal downward flow between layers (insert D in Figure 7.1);
  - groundwater flow in Hawkesbury Sandstone is via dual porosity: pores and minor structural features (fractures, joints, bedding planes);
  - regional flow influenced by stratigraphic dip and topography, generally towards the east;
  - minor localised flow to the north and west associated with local topographic gradients; and
  - faults typically do not appear to influence groundwater flow on a regional scale within the project area as demonstrated by long-term pumping tests.

- Groundwater levels:
  - stable hydraulic head regionally;
  - variable influence close to pumping landholder bores; and
  - around Berrima Colliery, significant depressurisation and desaturation as a result of full extraction mining, and continual discharge to the Wingecarribee River.
- Vertical gradients and connectivity:
  - downward trending gradients in the north-western part of project area;
  - steep vertical gradients along escarpments and seepage faces, where discharge occurs;
  - the top of the Hawkesbury Sandstone is often unsaturated, both where exposed and where it underlies the Wianamatta Group (Ashfield Shale) (insert D in Figure 7.1);
  - downward vertical gradients between the Wianamatta Group (Ashfield Shale) and the underlying Hawkesbury Sandstone– results in a low consistent groundwater flow from the shale to the sandstone (limited by the low hydraulic conductivity of the shale); and
  - hydraulic connection between Hawkesbury Sandstone and ICM occurs where there is minimal interburden between these units (ie in the west).
- Groundwater use:
  - numerous landholder bores associated with farmland, extract groundwater from the Hawkesbury Sandstone and a smaller number source groundwater from the Robertson Basalt to the south. Most of the bores yields are for stock and domestic use.
- Surface water/groundwater interaction:
  - most streams in the project area are classified as gaining streams with groundwater providing baseflow to streams; and
  - limited leakage from surface water into groundwater – limited to the area immediately upstream of Medway Dam structure (ie artificially raised stream height).
- Ecosystems that potentially rely on surface and/or groundwater:
  - there are no high priority GDEs identified within the project area, the closest one is Long Swamp, a temperate highland peat swamp, 7 km to the south;
  - minimal habitat for dense native fauna;
  - drainage lines and creeks may provide surface water for in-stream ecosystems during times of flow;
  - ecosystems may rely on surface expressions of groundwater at: creeks, where baseflow contribution is significant; springs, along the basalt hills in the south; upland swamps, in the south;

- vegetation root zones may rely on shallow groundwater (<10 mbgl) near some creeks; and
- stygofauna is unlikely to be significant in the area.

* Hume Coal mine / water interaction:
  - groundwater inflows to the sump during active mining will be removed to allow mining to continue, and then recycled and reused for mining operations (inflow into sump) (insert C in Figure 7.1);
  - groundwater inflow into void areas (inflow into void) (insert C in Figure 7.1). This water is part of the recovery process and remains part of the groundwater source;
  - rainfall onto the infrastructure area (disturbed area) is harvested and stored in a series of mine water dams and stormwater basins for use in mining operations; and
  - water excess to mining operations is pumped from the primary water dam (PWD) into the void underground (this mitigates depressurisation and drawdown and allows faster recovery of the groundwater system).



Conceptual hydrological model

Hume Coal Project

Water Assessment

Figure 7.1

7.3 Surface and groundwater connectivity

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

7.3.1 Existing situation

The water assessment for both groundwater and surface water has specifically considered and focused on understanding groundwater and surface water interconnectivity, and changes to this relationship as a result of the project.

The streams in the area are mostly (in time and location) gaining systems. That is, the water table is at a higher elevation than the stream stage, and therefore groundwater supplies baseflow to streams. In the western part of the project area, this relationship can be observed at the ground surface where spring flows from the banks of the escarpments to the nearby surface water creeks.

However, upstream of the Medway Dam structure the dam wall artificially elevates the stream stage above the surrounding groundwater levels causing some of the surface water runoff to recharge the groundwater system.

7.3.2 Situation during mining

During the project's operation, the streams would remain as gaining streams, although with slightly decreased levels of baseflow compared to the pre-mining conditions. It has been predicted groundwater baseflow will still be provided to streams, even at the maximum water table drawdown due to mining in year 17. Under mining conditions streams continue to gain baseflow from the groundwater system.

In the area upstream of the Medway Dam structure (ie the localised area where the dam/stream is losing some flow), it has been predicted that water table drawdown would also result in some induced flow from the overlying surface water system. This loss has been accounted for in the licence requirements outlined in Section Chapter 12 as required by the AIP.

8 Assessment methods

This chapter summarises the numerical modelling and other methods used in the water assessment.

AR 15: Full technical details and data of all surface and groundwater modelling, and an independent peer review of the groundwater model.

AR 58: The results of any models or predictive tools used.

Numerical modelling and analytical techniques were used for this water assessment to develop the site water balance, investigate potential changes in flood extent, and predict water quantity and quality changes to surface water and groundwater resources. Full technical reports detailing methods are included for each assessment in Appendices D, E, F, G, I, and K.

8.1 Surface water runoff

The four sediment basins (SBs), four mine water dams (MWDs), and the primary water dam (PWD) manage rainfall-runoff from catchments affected by the project. The locations of the basins and dams were chosen to minimise interception of runoff from the broader catchment areas not affected by mining, material handling, or processing operations. A rainfall-runoff model was used to simulate expected runoff using historical rainfall data from 1889 to 2015 from the SILO Data Drill dataset (DSITIA 2015). The volume of surface water runoff from SB, MWD and PWD catchments was estimated using the Australian Water Balance Model (AWBM) rainfall-runoff model (Boughton 1993).

Full details of the AWMB rainfall-runoff model, including calibration and results, are discussed in Appendix D (WSP PB 2016a).

The model was compared against flow duration curves developed from the flow gauge record at SW08, on Oldbury Creek, and nearby WaterNSW gauges. The model compares very well for high flows. Low flow situations become less comparable, when the contribution from baseflow and Berrima sewage treatment plant discharge becomes significant. The calibration result indicates the model is conservative with respect to low flows as it predicts lower harvestable volumes available from site runoff for reuse in mining operations during dry periods. Good calibration to high flows means the model is capable of reliable predictions of potential uncontrolled spill risk from storages during wet periods.

Average long-term runoff coefficients from the AWBM model for both wet and dry climate examples were simulated for the various landform types present within the surface infrastructure area catchment (Table 8.1). The model output was incorporated into the project's water balance model to directly simulate daily reservoir water balances for each SB, MWD and the PWD (Section 8.2).

Table 8.1 Simulated average long-term (1889 to 2015) runoff coefficients from AWBM model for various landform types within surface infrastructure area catchment

Climate	Impervious	Undisturbed	Active spoil	Hardstand
Wet (1949 – 1967)	79%	47%	54%	59%
Dry (1991 – 2009)	74%	35%	46%	49%

8.2 Water balance

AR 12: A detailed and consolidated site water balance.

AR 26: Provide a description of any site water use (amount of water to be taken from each water source) and management including all sediment dams, clear water diversion structures with detail on the location, design specifications and storage capacities for all the existing and proposed water management structures.

AR 28: Provide a detailed and consolidated site water balance.

AR 30: Identification of water requirements for the life of the project in terms of both volume and timing (including predictions of potential ongoing groundwater take following the cessation of operations at the site – such as evaporative loss from open voids or inflows).

AR 42: Description of all works and surface infrastructure that will intercept, store, convey, or otherwise interact with surface water resources.

AR 57: Proposed methods of the disposal of waste water and approval from the relevant authority.

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

8.2.1 Overview

A water balance model of the project's water management system was developed using GoldSim software to assess the dynamics of the mine water balance under varying climatic conditions throughout the project's operation. The model was configured to simulate the daily operations of all major components of the water management system.

The GoldSim model was simulated with a daily time step for a 19-year duration. The model was run (simulated) 107 times. Each individual model simulation is called a 'realisation'. Each of the 107 realisations used a different 19-year sequence of historical rainfall and evaporation data (or climate sequences), developed by 'stepping through' the SILO Data Drill sourced historical climate data from 1 January 1889 to 1 January 2015 (DSITI 2015). The first realisation started on 1 January 1889, the second realisation started a year later on 1 January 1890 and so on. The model inputs (demands and groundwater inflows) were varied in the model over the 19-year simulation period. Probability distributions were then developed using the daily and annual results from all of the 107 realisations.

The simulated inflows and outflows included in the model are shown in Table 8.2. Refer to Section 2.3 for discussion on the water management system components and operating philosophy. The model assumptions, input/output estimates, and results are summarised in the following sections; full details are included in Appendix D (WSP PB 2016a).

The water balance model (WSP PB 2016a) has been conservatively designed and demonstrates that water surpluses and deficits can be managed successfully for all climate sequences. The operational water balance model will be optimised during detailed design, mainly fine tuning the stored water levels within the PWD to optimise water efficiency and pumping volumes. This will be included in the Water Management Plan, and is discussed Chapter 13.

Table 8.2 Modelled inflows and outflows of the water management system

Inflows	Outflows
Direct rainfall on water surface or storages	Evaporation from water surface or storages
Surface water runoff captured within each basin or dam	SB03 and SB04 release to Oldbury Creek (post first flush)
Groundwater inflow to mine sump	
Groundwater inflow to void	Underground mine operations water supply
	Product coal handling water supply
	CPP process water supply
	ROM stockpile water supply
	Co-disposed make-up water supply
	Administration and workshop area fire water supply

Notes: 1.The following are not included in the model: potable water supply, supply from licensed bores and MWD08.

8.2.2 Model assumptions

The following assumptions were made in the water balance analysis for the adopted water management strategy:

- Water that cannot be stored within the PWD or the void spaces will be treated and discharged to Oldbury Creek (this is a provisional assumption that by modelling has demonstrated is not required).
  - Most of the groundwater collected in the sump will be used in meeting the project water demand. The sump will collect return water from the underground mining equipment, decant from co-disposed reject and runoff from MWD07. The mixed water from these sources will be pumped to the PWD for reuse.

- The sump will aim to pump out all water to the PWD for project use. When the PWD is at the maximum level set for operations of 124 ML, the water in the sump will be injected into the void space behind the bulkheads. If the void space is full and cannot take the excess water then the sump will continue pumping to the PWD.

- Similarly, if the water volume in the PWD is very low and unable to meet water demands then additional water will be sourced from the pumped and natural groundwater that will be stored in the void spaces. This is analogous to extracting water from a licensed groundwater bore.

- A pumping strategy has been included in the water balance model.

- It is assumed the 'sediment zone' of SBs and MWDs is 50% full of sediment throughout the simulation. It is assumed SBs and MWDs cannot be pumped out below the 'sediment zone' and that the only outflows from the remaining 'sediment zone' is evaporation.

- The initial volume at the start of the 19-year period simulation was assumed to be 100 ML for the PWD and 6 ML for the underground sump so that mining operation could be supplied with water until rainfall-runoff or groundwater could be harvested. Other basins and dams were assumed empty at the start of the simulations.

- No allowance has been made for seepage from water storages, which would be minor.

- Annual void space behind the bulkheads was estimated from the ROM production schedule and provided by Hume Coal.

- Annual groundwater inflows to the sump and the void spaces were assessed by the groundwater model. The co-disposed reject volumes and annual groundwater inflows to the void spaces were subtracted from the total void space volume created annually due to mining to obtain net void space available for injection. This input data was provided by Hume Coal.

- Annual groundwater inflow to the sump was distributed uniformly to obtain average daily inflow rates.

- Annual demand estimates have been distributed uniformly to obtain average daily demands.

- Water is pumped from the void to the PWD at a rate that is adequate to meet peak daily demands when required.

- Inflows to MWD08 are not considered in the water balance as the dam is part of the provisional WTP and independent of the mine water balance which covers water transfers between the SBs, other MWDs, the underground mine and the PWD, if required.

- The water balance modelling is focussed on the operational phase and does not consider sediment dams that will be required at the construction phase.

- While the model assesses the performance of the system under historical extremes that may reasonably be expected to reoccur in the future, it does not quantify the potential impact of future climate change on the site water balance.

8.2.3 Site water balance

Figure 8.1 shows the concept that was input into GoldSim for the site water balance.

i Inflow estimates

Surface water runoff from mine site catchments was calculated using the AWBM rainfall-runoff model using the SILO Data Drill daily rainfall and evapotranspiration data (DSITIA 2015). The AWBM rainfall-runoff model is described in Section 8.1.

Direct rainfall onto water storages (dams and stormwater basins) was determined based on assumed dam stage-storage-area relationships (refer to Section 2.3.2 for dam capacities and Appendix D (WSP PB 2016a) for stage-storage relationships).

Modelled groundwater inflow estimates for inflow into the mine sump and void were provided from the numerical groundwater model (Sections 8.6 and 11.1.1). Annual groundwater inflow for the mine operation period is shown in Figure 12.1.

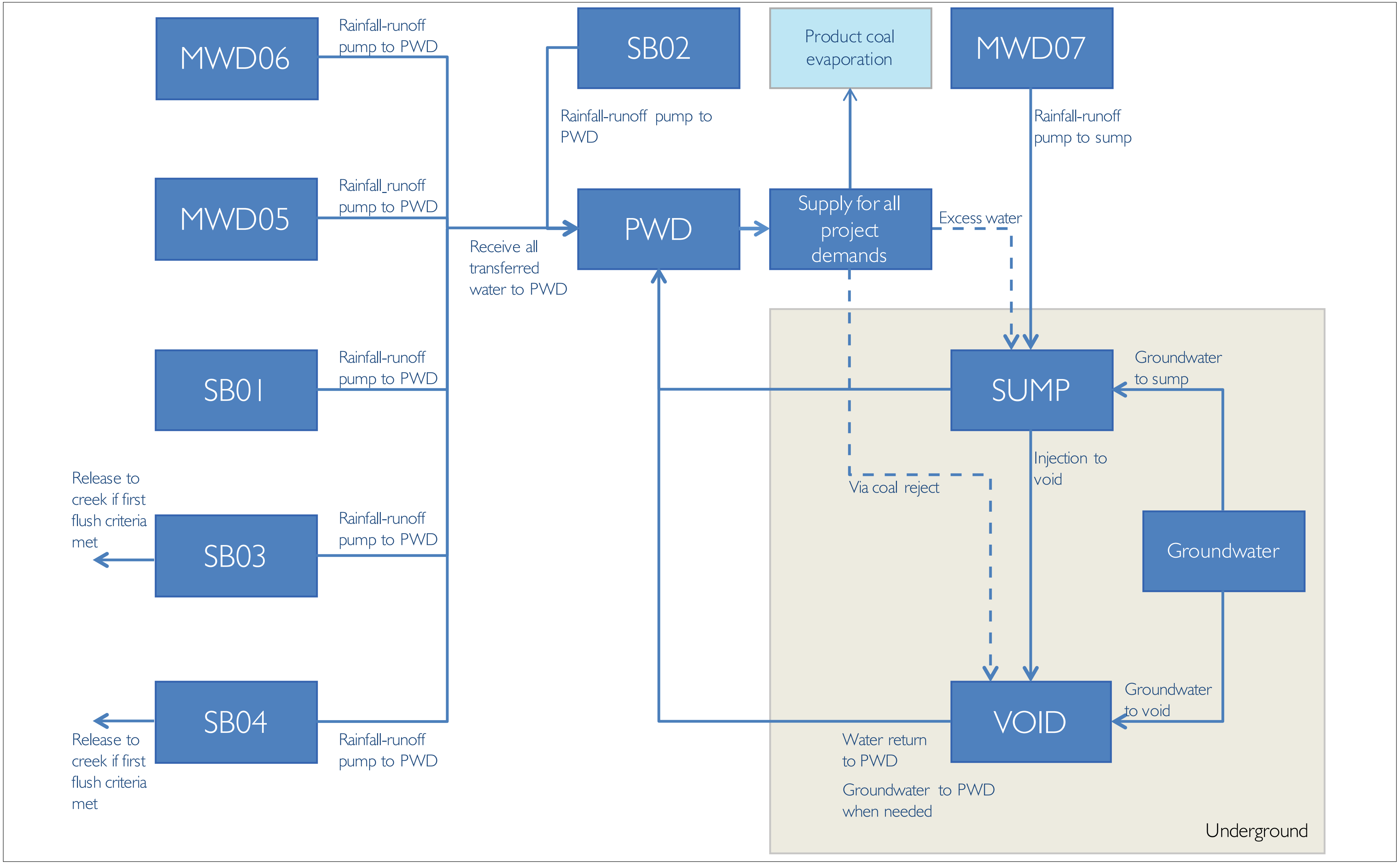
Water imported from licensed groundwater bores is available if additional water is required during the project (eg prior to water in the sealed void becomes available).

ii Outflow estimates

Individual water demands for the project are calculated or estimated for the life of the mine. Demand components are shown in Figure 2.6 and discussed in Section 2.3.1. The total annual net demand (water supplied minus water returned) is estimated to peak in Year 15 at 886 ML. Refer to Appendix D (WSP PB 2016a) for details on how these demands were derived.

Evaporation estimates for open water storages were based on SILO Data Drill sourced daily Morton's Lake evaporation data (Morton 1983; DSITIA 2015). Evaporative surface area for dams and stormwater basins were determined based on assumed dam stage-storage-area relationships (refer to Section 2.3.2 for dam capacities and Appendix D (WSP PB 2016a) for stage-storage relationships).

For assessment of the injection volumes of surplus water to the mine void, the void space availability was calculated by assessing total void space available after co-disposed reject volumes emplacement per year. Injection to and pumping from the void space behind the bulkheads is assumed to occur in accordance with rules governing the PWD level and the net site water demands.



Water balance model flow schematic
Hume Coal Project
Water Assessment
Figure 8.1

iii Operating rules

The following operating rules have been assumed for the water balance assessment:

- MWDs and SBs:
  - All SBs and MWDs except MWD07 and MWD08 pump directly to the PWD at defined peak daily pumping rates.
  - All SBs and MWDs can only pump water to the PWD when the sediment store is fully saturated and water is above the sediment store volume. The sediment store is assumed to contain water volume equal to half the volume of the sediment store.
  - Water transfer from SB01 to the PWD and from SB02 to the PWD is not restricted by any volumetric constraint in the PWD.
  - No overflows from SB01 and SB02 are allowed to occur in the model; however, spillways have been provided to direct overflows from these dams to nearby watercourses (overflows may occur under very high rainfall conditions, such as those that significantly exceed the 500 year ARI event).
  - Water transfer from other SBs and MWDs into the PWD is stopped when the PWD water volume is greater than 730 ML.
  - Releases to Oldbury Creek from SB03 and SB04 are assumed to occur when the first flush criteria are satisfied. If first flush criteria are not met, the water will be pumped to the PWD.
- PWD:
  - The PWD is the main dam that will supply water to meet all demands except the potable water requirement, which will be sourced from registered bores.
  - The PWD operating levels are between 83 and 124 ML. The PWD is designed, however, to store all water on site and has a storage limit of 730 ML.
  - The water balance has been optimised to avoid overflows from the PWD. If there is a risk of overflow from the PWD, water will be treated in the WTP and then released to Oldbury Creek.
- Sump:
  - The underground sump is the ultimate point of water collection from all underground water sources and includes transfer from MWD07, groundwater, decant from the co-disposed reject emplacement and unused water from the underground mining operation.
  - When the PWD level is less than 124 ML, water accumulated daily at the sump is pumped to the PWD.
  - When the PWD level is more than 124 ML, the water accumulated at the sump is injected into the void space behind the bulk heads. If there is no void space available, then the water accumulated at the sump will continue to be pumped to the PWD.

- The underground mine sump is assumed to be 6 ML and will maintain this volume in the sump most of the time unless water deficit occurs.

- Void:

  - Water transfer from the void spaces behind the bulkheads to the PWD occurs when the PWD level is less than 83 ML and occurs at a daily rate that ensures the level of the PWD remains at 83 ML at the end of each daily time step.

8.2.4 Water balance model results

Full details of the water balance results are contained in Appendix D (WSP PB 2016a).

The average annual project water balance summary from 107 climate sequences is shown in Figure 8.2. The total inflows and outflows for the surfaces storages (not including MWD07 inputs) over the life of the mine are modelled to be 26,949 ML and 26,922 ML respectively, with an initial volume of 100 ML in storage and a final volume of 108 ML. For the underground mine (including MWD07 inputs) over the life of the mine the total inflows and outflows are modelled to be equal at 16,646 ML for each. The total inflows and outflows for the void over the life of the mine are modelled to be 23,586 ML and 3,410 ML respectively. The relatively higher inflows than outflows modelled for the void is due to groundwater inflow filling the void. MWD08 is excluded from the water balance as it is a small storage associated with the provisional water treatment plan.

As discussed in Section 2.3.1 and shown in Figure 2.7, the project water demand will be fully met by using:

- harvestable rainfall-runoff from the mine water dams;
- groundwater collected in the underground mine sump; and
- groundwater harvested from the void, when required in times of deficit.

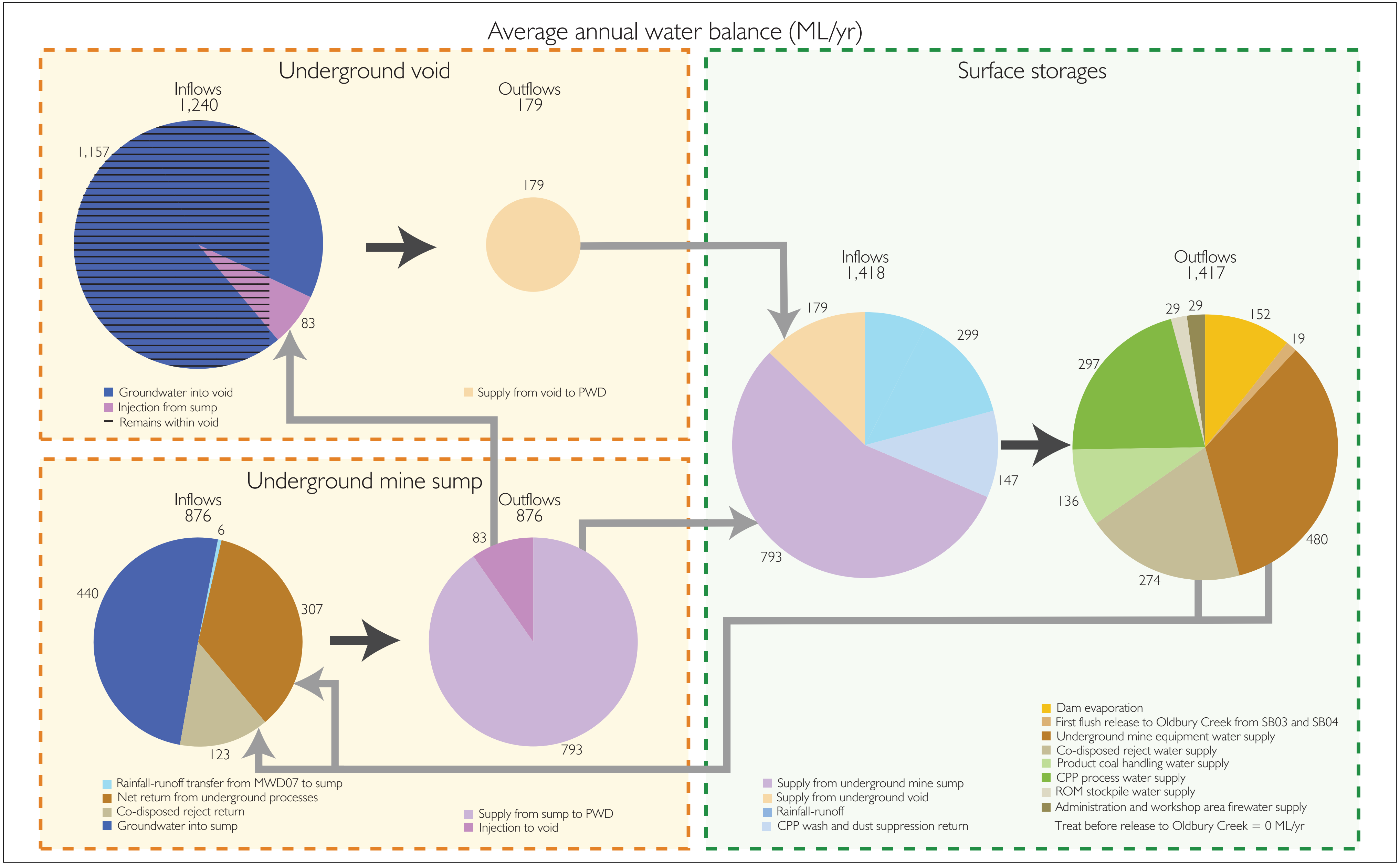
The water balance model was used to check if uncontrolled overflows would occur from any of the storages under the assumed AWBM estimated rainfall-runoff volumes. The model has predicted that none of the basins or dams will overflow under all 107 climate realisations.

The volumes of groundwater injected into the underground void over time were investigated in the water balance model. The investigation included assessment of available void space over time and project water demands. Based on the 107 climate sequences, it is most likely (75% chance) that at least 2,000 ML of water would be injected into the void throughout the 19-year mining period. The injection rate would not be constant and would depend on available void space and the amount of excess water.

Excess water is likely to be generated when the void space becomes full towards the last 4 years of the proposed 19-year operational mining period. Under this circumstance the groundwater that would be collected in the sump and from other sources cannot be reinjected and will require pumping straight into the PWD provided the dam volume is not greater than 730 ML.

Simulations undertaken for 107 climate sequences showed that the excess water can be managed by either reinjection or by pumping into the PWD, and there is no requirement for disposing of excess water by treatment and release to Oldbury Creek.

The water balance modelling indicates that the groundwater from the underground mine will be enough to meet demand and additional water from licensed bores will not be required during operation, other than for potable water supply.



Based on mean annual climate sequence from 107 climate sequences

EMM HUMECOAL PROJECT

Average annual water balance summary

Hume Coal Project
Water Assessment

Figure 8.2

8.3 Flow impact assessment methods

Flow effects have been assessed for:

- Medway Rivulet sub-catchment (not including Oldbury Creek) and Oldbury Creek sub-catchment where the project is located; and
- Lower Wingecarribee River, Lower Wollondilly River, and Bundanoon Creek management zones. Although, these catchments are located outside of the project area, baseflow interception is predicted to occur as a result of depressurisation associated with the underground mining.

For the flow impact assessment, the Medway Rivulet sub-catchment is defined as the blue areas in Figure 2.4 and the Oldbury Creek sub-catchment is defined as the purple area in Figure 2.4.

Existing (pre-mining) flow conditions for Medway Rivulet and Oldbury Creek were established using the AWBM rainfall-runoff model (refer to Section 8.1 and Appendix D (WSP PB 2016a)). The following flow conditions were assessed during the mine's operation:

- reduction in catchment area associated with project storages;
- discharge of water, following containment of first flush, from SB03 and SB04 to Oldbury Creek, estimated for dry and wet years using the GoldSim water balance model developed for the Water Balance Assessment (Section 8.2 and Appendix D (WSP PB 2016a)); and
- interception of natural baseflow to streams associated with depressurising groundwater systems during underground mining was estimated using the numerical groundwater flow model (Section 8.6 and Appendix I (Coffey 2016b)).

The resulting changes in flow were analysed by comparison to the relevant flow duration curve for Medway Rivulet and Oldbury Creek. A flow impact assessment for Medway Rivulet was made including and also excluding discharge from the Moss Vale sewage treatment plant. Changes in yield were estimated for both wet and dry climate sequences for the Medway Dam catchment, Medway Rivulet catchment (excluding Oldbury Creek sub-catchment), Oldbury Creek sub-catchment, and the Medway Rivulet Management Zone. The results are shown in Section 10.1.3 and 10.1.3.

Existing (pre-mining) flow conditions for the Lower Wingecarribee River, Lower Wollondilly River, and Bundanoon Creek Management Zones were approximated using the AWBM results modelled for the Medway Rivulet Management Zone and scaled appropriately for each catchment area. This was considered a reasonable approach given that the AWBM model was calibrated to observed flows at gauge 212009 on the Wingecarribee River (Figure 4.1), which receives runoff from a total catchment area of 58,700 ha and so represents regional scale flows (refer to Appendix F for further details). These pre-mining flows were then compared against the intercepted baseflow volumes estimated by the groundwater model (Section 8.6, Section 11.1.3, and Appendix I (Coffey 2016b)) to assess the potential change in yield for these catchments. The results are shown in 10.1.3.

8.4 Surface water quality

The following project activities have been assessed for potential surface water quality changes:

- discharge from SB03 and SB04 (when first flush and water quality criteria are met) to Oldbury Creek;
- runoff from access roads outside of the mine water management system; and
- depressurisation of deeper groundwater from underground mining.

As the water balance model (refer to Section 8.2) demonstrates that the PWD has adequate capacity to contain all surplus water and treatment and release of water from the PWD is not required for all climate sequences, the scenario of treating and releasing water from the PWD is, therefore, not assessed.

Refer to Section 10.2 for further details.

The methods used for assessment are summarised below and described in detail in Appendix E (WSP PB 2016b).

8.4.1 Discharge from stormwater basins to Oldbury Creek

Model for Urban Stormwater Improvement Conceptualisation (MUSIC) modelling was used to assess the potential total suspended solids (TSS) and nutrient (total phosphorus (TP) and total nitrogen (TN)) loads and concentrations in Oldbury Creek in accordance with NorBE (neutral or beneficial effect) criteria, and to calculate the maximum concentrations of other constituents to achieve NorBE criteria for mean annual pollutant loads as a result of discharge from SB03 and SB04. The MUSIC modelling was in accordance with the WaterNSW standards (SCA 2012, SCA 2015, and WaterNSW 2015).

i TSS and nutrients

MUSIC model nodes were set for SB03 and SB04, which will discharge to Oldbury Creek, and for SB01, SB02, PWD and MWD08, which are sub-catchments of Oldbury Creek that will be removed from the catchment during the project's operation. Each node was set to represent the existing conditions of the catchment (assumed to be fully pervious and agricultural land use) and conditions during mine operation (a mix of pervious and impervious areas, with sizes based on the surface infrastructure design, and industrial land use). For the operational phase, the sub-catchments of SB01, SB02, PWD, and MWD08 are not included as they will not contribute runoff to Oldbury Creek (but will report to the mine water management system).

Climate data input was obtained from WaterNSW, as per the WaterNSW standard (2012) template, and included a range of wet and dry periods between 1997 and 2001 at 6-minute time intervals. This data was converted to daily data for the GoldSim water balance model (Section 8.2) to generate outflow time series for the SB01, SB02, PWD, and MWD08 catchments in their existing conditions, and for SB03 and SB04 in their operational conditions (note: the areas that will become SB03 and SB04 sub-catchments in the operational phase drain to Medway Rivulet in the existing case). For the operational phase, the discharge volumes from SB03 and SB04 took into account the first flush pumping to PWD. The stormwater pollutant parameters used for industrial land were in accordance with the WaterNSW standard (2012). Results are discussed in Section 10.1.2ii.

ii Other constituents

Runoff from the catchments of SB03 and SB04 has a low risk of contact with small amounts of coal that may be brought into the catchments via mine vehicle traffic. Capturing the first flush and pumping to PWD for storage and reuse should account for this low risk of coal contact, and the remaining volume of water discharged into Oldbury Creek would be clean. Nevertheless, an assessment has considered potential coal-derived constituents (in addition to TSS and nutrients) in case the first flush does not remove all constituents.

A leachate test was performed by RGS (2016) on coal and coal reject materials to assess the potential mobilisation of contaminants in runoff. Comparison of average leachate concentrations with average baseline concentration in Oldbury Creek (at SW08 (Figure 4.1)) shows that some dissolved species are higher in the coal leachate than in the receiving environment (Table 8.3). These constituents have been selected for further assessment.

Table 8.3 Comparison of baseline surface water and leachate concentrations

Constituents	Units	Mean baseline concentration (Oldbury Creek)	Mean leachate concentration
Major ions			
Calcium	**mg/L**	**27**	**31**
Chloride	mg/L	56	43
Magnesium	mg/L	**10**	**11**
Sodium	mg/L	38	3.7
Sulfate as SO4	mg/L	**45**	**126**
Dissolved metals			
Aluminium	**mg/L**	**0.08**	**0.99**
Antimony	mg/L	<0.001	no value reported
Arsenic	mg/L	**<0.001**	**0.006**
Barium	mg/L	0.04	no value reported
Beryllium	mg/L	<0.001	no value reported
Boron	mg/L	<0.05	<0.05
Cadmium	mg/L	**<0.0001**	**0.005**
Chromium	**mg/L**	**<0.001**	**0.001**
Cobalt	mg/L	**<0.001**	**0.55**
Copper	mg/L	**0.001**	**0.26**
Iron	mg/L	**0.25**	**5.9**
Lead	mg/L	**<0.001**	**0.11**
Manganese	mg/L	**0.17**	**2.2**
Mercury	mg/L	<0.0001	no value reported
Molybdenum	**mg/L**	**<0.001**	**0.002**
Nickel	mg/L	**<0.001**	**1.2**
Selenium	mg/L	**<0.01**	**0.04**
Silver	mg/L	0.01	no value reported
Zinc	mg/L	**0.01**	**2.8**

Table 8.3 Comparison of baseline surface water and leachate concentrations

Constituents	Units	Mean baseline concentration (Oldbury Creek)	Mean leachate concentration
Major ions			
Physicochemical			
Electrical Conductivity	µS/cm	476	402
pH	pH units	**7.4**	**3.7**
Total Dissolved Solids	mg/L	291	241

Notes: 1.Bold text indicates where results in leachate were higher than baseline conditions; these constituents were selected for further assessment.

MUSIC modelling was used to assess the mean annual pollutant loads for the 17 constituents highlighted in bold in Table 8.3 from the SB03 and SB04 catchments under existing conditions. The loads were calculated using the MUSIC model described in Section 8.4.1i as a mass balance model, with the mean concentration for each constituent specified as the mean baseline concentration measured at SW08.

The MUSIC model was then used to identify the mean concentration of each constituent that would need to be achieved in the releases under the operational scenario to meet the NorBE criterion of a 10% reduction in the mean annual pollutant load.

The results are provided in Table 8.4, which identifies the preferred levels of mean concentration in the releases from SB03 and SB04 for each of the 17 water quality constituents. Concentrations of these that were below the laboratory limit of detection during the baseline monitoring would also need to remain at or below the laboratory limit of detection in the releases from SB03 and SB04. Comparison of these levels with samples collected from SB03 and SB04 as part of the routine monitoring program will establish discharge of an appropriate water quality.

Table 8.4 Preferred levels of mean concentrations for constituents in releases from SB03 and SB04

Dissolved species	Oldbury Creek baseline mean concentration (mg/L)	Preferred levels of mean concentration in combined SB03 and SB04 releases (mg/L)	% load reduction from existing to operation
Calcium	27	175	-11%
Magnesium	10	65	-11%
Sulfate as SO_4	45	290	-11%
Aluminium	0.08	0.48	-10%
Arsenic	<0.001	0.001	*N/A*
Cadmium	<0.0001	0.0001	*N/A*
Cobalt	<0.001	0.001	*N/A*
Copper	0.001	0.0065	-11%
Iron	0.25	1.6	-13%
Lead	<0.001	0.001	*N/A*
Manganese	0.17	1.1	-11%
Molybdenum	<0.001	0.001	*N/A*
Nickel	<0.001	0.001	*N/A*
Selenium	<0.01	0.01	*N/A*
Zinc	0.01	0.065	-11%

8.4.2 Mine access roads

There are two mine access roads located outside the water management system (see Figure 1.6):

- the main mine access road from Mereworth Road to the administration and workshop area; and
- the access road between the ventilation shaft and the man and materials portal.

Vehicles using the roads will not be transporting coal and vehicles leaving the site via the main mine access road will use the drive-through wheel wash at the administration and workshop area to prevent coal dust from contaminating surfaces outside the water management system.

MUSIC modelling has been used to assess the potential water quality effects of the runoff from these roads on surface water quality in the receiving environment and assess compliance with the NorBE criteria.

Existing and operational scenarios were modelled using MUSIC by representing the sub-catchments of the road corridors in their existing conditions, as a mix of existing sealed and unsealed roads and agricultural land, and proposed conditions, as sealed/unsealed roads. The operational phase scenarios included simulation of stormwater quality treatment measures to achieve the NorBE criteria. Modelling was in accordance with the WaterNSW standards (2012).

Model nodes were established for the two access roads. The main mine access road follows the ridge line and drains to Medway Rivulet, and is a sealed road, with a total road corridor area (including embankments) of 5.02 ha. The other access road also drains to Medway Rivulet and is an unsealed road with a total (not including embankments) area of 1.32 ha. The assessment of the sealed road included the road embankments as it warranted a more detailed assessment and sub-catchment breakdown due to the relatively higher impact of a sealed road on the local catchments. The unsealed road was assessed more simplistically by modelling the impact of the area of the trafficked surface only.

Each model node was designed to represent the part of the catchment taken up by the proposed road corridors under existing and also operational conditions. Input climate data was the meteorological template obtained from WaterNSW, as described in Section 8.4.1.

The existing conditions scenario was set up for each of the sub-catchments using a combination of the ‘agricultural’ and existing ‘sealed road’ MUSIC source nodes. The operational scenario was set up for each of the sub-catchments using the ‘sealed/unsealed roads’ and ‘revegetated land’ MUSIC source nodes and assumed to be 100% impervious for sealed roads, and 50% pervious and 50% impervious for unsealed roads. The stormwater parameters are shown in Table 8.5 and are in accordance with the WaterNSW standards (2012).

Table 8.5 Source node parameter inputs for mine access road MUSIC model (log mg/L)

Land use	TSS		TP		TN	
	Mean	SD	Mean	SD	Mean	SD
Baseflow						
Agricultural	1.3	0.13	-1.05	0.13	0.04	0.13
Unsealed roads	1.2	0.17	-0.85	0.19	0.11	0.12
Sealed roads	1.2	0.17	-0.85	0.19	0.11	0.12
Revegetated land	1.15	0.17	-1.22	0.19	-0.05	0.12
Stormflow						
Agricultural	2.15	0.31	-0.22	0.3	0.48	0.26
Unsealed roads	3	0.32	-0.3	0.25	0.34	0.19
Sealed roads	2.43	0.32	-0.3	0.25	0.34	0.19
Revegetated land	1.95	0.32	-0.66	0.25	0.3	0.19

Notes: 1. SD – standard deviation.

For the operational scenario, vegetated swales were included in the MUSIC model to treat the runoff from the sealed and unsealed roads. Vegetated swales are typically broad, shallow channels that convey and filter stormwater runoff using vegetation to remove coarse sediment (ie reduce TSS). The performance of swales largely depends on the vegetation height, and the gradient and length of the swale. MUSIC has default parameters for vegetated swales; however, the following parameters were adjusted from the default settings:

- The exfiltration rate was changed from 0 mm/hr to 2 mm/hr, which is the mid-range value for 'medium clay' recommended by MUSIC. This is a conservatively low value as the soils in the area have sandy clay characteristics that would justify a higher exfiltration rate.
- The background concentration for a swale is defaulted to be relatively high. These values were adjusted in accordance with the approach detailed in Fletcher et al. (2004) so that a more realistic reduction of pollutant load would be determined.

The adopted parameters for the swales are given shown in Table 8.6.

Table 8.6 Swale parameters used in MUSIC model for mine access road assessment

Swale parameter	Adopted values
Length (m)	Varied to meet NorBE criteria
Bed slope (%)	3
Base width (m)	1
Top width (m)	5
Depth (m)	0.6
Vegetation height (m)	0.3
Exfiltration rate (mm/hr)	2
Background concentration TN (mg/L)	0.89
Background concentration TP (mg/L)	0.096

8.4.3 Depressurisation of groundwater systems from underground mining

Numerical groundwater modelling predicts that baseflow in surface water systems will be decreased as a result of depressurisation of groundwater systems from the underground mining activities. This is discussed in detail in Section 11.1.3 and Appendix I (Coffey 2016b). A reduction in baseflow will result in reduced loadings of all water quality constituents. However, some constituent concentrations may increase as a result of decreased baseflow. This would occur where concentrations in groundwater are lower than surface water (ie reduction in baseflow results in less dilution of surface water concentrations). On the other hand, some constituent concentrations may decrease as a result of reduced baseflow where concentrations in groundwater are higher than surface water (ie reduction in baseflow results in less total constituent mass present in streamflow). In this latter case, surface water quality would be improved with a reduction in baseflow.

To assess the influence of decreased baseflow on surface water quality, 80th percentile baseline water quality data were compared to 80th percentile baseline groundwater quality data. The comparison is shown in Appendix E (WSP PB 2016b) and the results are discussed in Section 10.2.2iii.

8.5 Flood modelling

SEAR 3: An assessment of the potential flooding impacts of the development.

The study area for the numerical flooding assessment included the areas where surface infrastructure is proposed. The surface infrastructure area includes the administration and workshop area, the CPP area and supporting infrastructure (ie access roads, bridges, conveyors). The administration and workshop area is in the Medway Rivulet sub-catchment and the CPP area is in the Oldbury Creek sub-catchment. The administration and workshop and CPP areas have the potential to modify flooding in local catchments and be subject to flooding.

For the purpose of the flooding assessment, the Medway Rivulet sub-catchment is defined as the blue areas in Figure 2.4 and the Oldbury Creek sub-catchment is defined as the purple area in Figure 2.4.

The area above the proposed underground mining area is not part of the study area for the flooding assessment. The underground mine workings will result in negligible impacts on flooding in overlying catchments. Worst case estimates of subsidence associated with the proposed first workings mining method predict 'imperceptible' surface disturbance due to mining, with predicted settlement of less than 20 mm (EMM 2017e; Mine Advice 2016). Such disturbances are low enough in magnitude as to not affect flooding regimes.

The flooding assessment considered potential flooding associated with surface infrastructure during operation and the final landform at completion of rehabilitation. The surface infrastructure will generally remain unchanged throughout mine operation.

Flood modelling was not used for the construction phase as the layout of temporary construction facilities will generally match the surface infrastructure layout used during operations. A layout with the maximum footprint and elevation was considered so as to assess potential flooding events. In relation to construction, the proposed surface infrastructure is all located outside of the 1 in 100 year floodplain with the exception of the access road crossings and the conveyor crossing. Management of construction of these two pieces of infrastructure with respect to flooding will be determined during detailed design when the construction method and staging is known and the outcomes and management measures, if required, will be documented in the Construction Environmental Management Plan (CEMP).

The flooding assessment is summarised in the following sections and discussed in detail in Appendix G (WSP PB 2016d).

8.5.1 Hydrologic analysis

Hydrologic modelling determines runoff generated from rainfall on a catchment. The runoff estimates are then used by the hydraulic analysis (Section 8.5.2). Hydrologic models of the Medway Rivulet and Oldbury Creek sub-catchments were developed using the XP-RAFTS software program. Both sub-catchments were further divided into smaller sub-catchments, each with individual input parameters for the model.

The models of the Medway Rivulet and Oldbury Creek sub-catchments developed for this study were used to estimate flow generated from the catchment for the 5 year ARI, 20 year ARI, 100 year ARI and the probable maximum flood (PMF) design storm events to represent a reasonable range of extreme event flood conditions. The models estimated flow for the following scenarios:

- existing scenario – which represents the current state of the Medway Rivulet and Oldbury Creek sub-catchments based on LiDAR data collected on 25 October 2013;
- operational scenario – which incorporates the proposed surface infrastructure for the mine and associated mitigation measures; and
- rehabilitation scenario – which is the final landform at completion of the project.

Model input parameters and calibration are outlined in detail in Appendix G (WSP PB 2016d).

Design rainfall hyetographs for storm events up to the 100 year ARI were generated, and probable maximum precipitation (PMP) was calculated.

Calibration used rainfall data from nearby weather stations and streamflow data from baseline surface water level gauges. Initial and continuing rainfall losses and B factor were adjusted within reasonable ranges until the model was calibrated.

The hydrologic model was checked by comparing the model flow estimates against probabilistic rational method (PRM) calculations for the 5 year, 20 year and 100 year ARI events for Medway Rivulet.

The Medway Rivulet and Oldbury Creek hydrologic models were run for the 5 year, 20 year and 100 year ARIs and the PMP rainfall events for the existing, operation and rehabilitation scenarios. The 5 year, 20 year and 100 year events were run for durations of 15 minutes to 48 hours, and the PMF event was run for durations up to 96 hours, to determine the critical duration for each event. Peak flows generated within the Medway Rivulet and Oldbury Creek sub-catchments that are input to the hydraulic model and the critical duration identified for each return period are included in Appendix G (WSP PB 2016d). Results indicate the PMP critical duration for the Medway Rivulet catchment was the 4 hour event, and for Oldbury Creek it was the 2.5 hour event.

8.5.2 Hydraulic assessment

HEC-RAS hydraulic models were developed for Medway Rivulet, Oldbury Creek, and their tributaries to assess extreme flood levels in the project area. HEC-RAS is a one-dimensional hydraulic model that can simulate steady or unsteady flow in rivers and open channels. The river channel and floodplain is represented in HEC-RAS as a series of topographic cross-sections. The model can assess the effects of obstructions, such as bridges, culverts, weirs, and structures in the channel and floodplain.

Cross sections of the river channel and flood plain were extracted from a digital terrain model derived from LiDAR data collected in late 2013. Cross sections were extracted about every 100 m along the length of Medway Rivulet and Oldbury Creek and tributaries. Additional cross sections were extracted at locations where there is hydraulic constraint, eg road crossings, to provide additional level of detail in the model. Cross sections varied in length from about 300 m to 1,500 m depending on the depth and size of channel and width of floodplain. Junctions were modelled where tributaries join main channels; equal water levels were assumed across the junctions. Locations are shown in Figure 8.3.

Cross section surveys conducted at SW04 (in 2013 and 2015) and SW08 (in only) were included in the model to aid development of rating curves and to provide calibration.

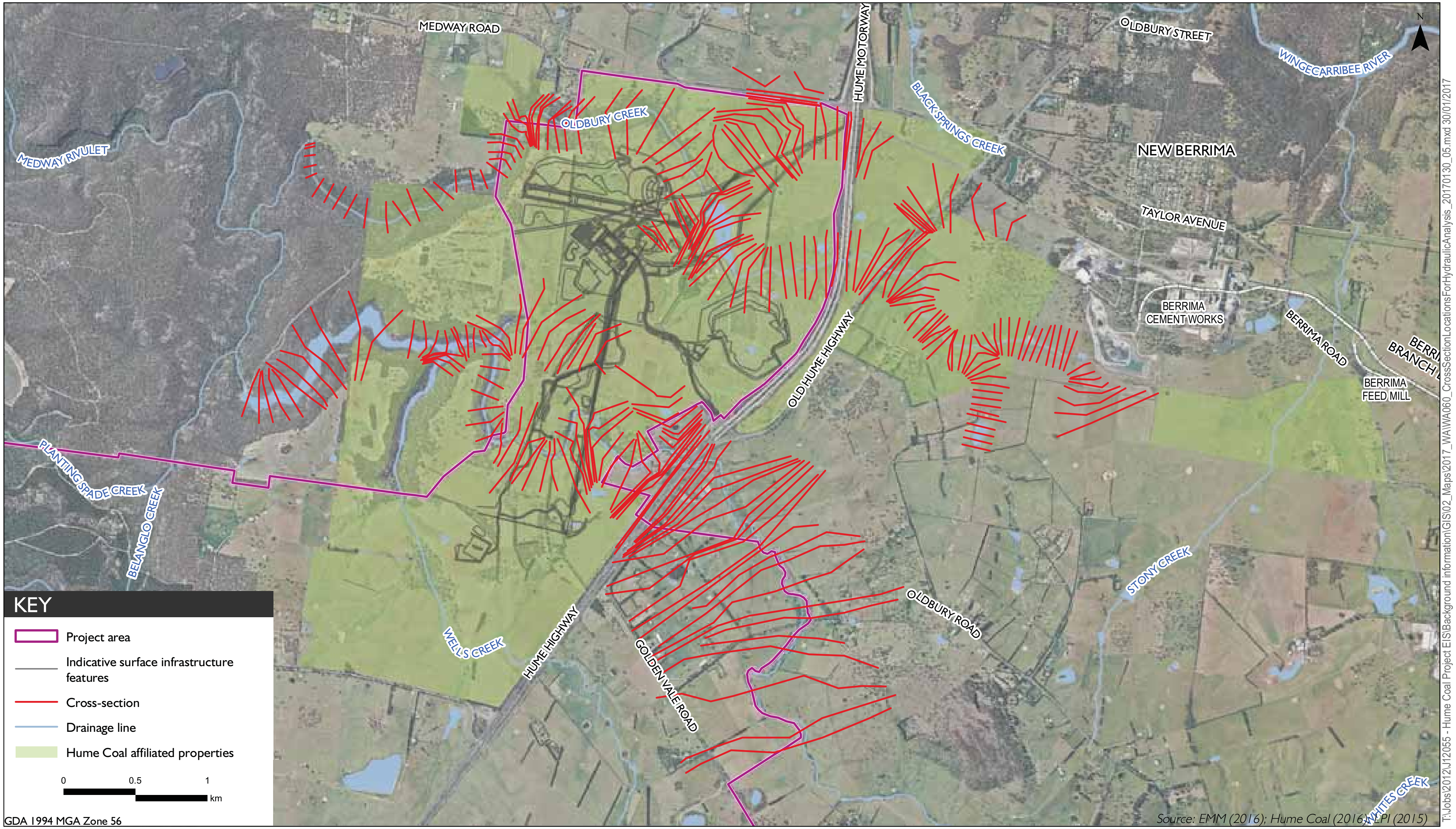
Inflows were assigned to reaches of the hydraulic model for each stream/tributary, based on the flow outputs of the hydrologic model. Boundary conditions and hydraulic roughness parameters implemented in the model are discussed in Appendix G (WSP PB 2016d).

The Medway Rivulet and Oldbury Creek models were run for the 2 year, 5 year, 100 year ARI and PMF events for the existing, operation and rehabilitation scenarios detailed in Section 8.5.1. The surface infrastructure is assumed to generally remain the same throughout mine operation; a maximum footprint and elevation layout and has been considered so as to assess potential worst case flooding.

Flood modelling was not used for the construction phase as the layout of temporary construction facilities will generally match the surface infrastructure layout used during operations. The temporary accommodation village is proposed only during the project’s construction phase and will not be used during the operation phase. The temporary village has not been assessed as it will be on a ridge and will not influence flooding regimes in Medway Rivulet.

Existing structures (including Medway Dam, bridges, instream storages, and culverts) along Medway Rivulet and/or Oldbury Creek and a proposed culvert along Medway Rivulet were included in the HEC-RAS models.

The model results are discussed in Section 10.3 and Appendix G (WSP PB 2016d).



Cross section locations for hydraulic analysis

Hume Coal Project
Water Assessment

Figure 8.3

8.6 Groundwater numerical flow model

AR 2: A groundwater assessment to determine the likelihood and associated impacts of groundwater accumulating and subsequently discharging from the workings post cessation of mining, including consideration of the likely controls require to prevent or mitigate against these risks as part of the closure plan for the site.

AR 66: Detailed modelling of potential groundwater volume, flow and quality impacts of the presence of an inundated final void (where relevant) on identified receptors specifically considering those environmental systems that are likely to be groundwater dependent.

A regional numerical groundwater flow model was developed for the project to determine the effects of mining on the groundwater and surface water systems in the region and whether these effects complied with the Aquifer Interference Policy (AIP); in particular, to determine mine inflows and water table drawdown and deeper depressurisation due to sub-surface mining. It was used to determine landholder bore drawdown interference and influence on other environmental users during mining and the post-mine recovery period. A substantial database of Hume Coal data and data from published sources was used as a basis to develop and calibrate the numerical groundwater model.

The model was in accordance with the *Australian Groundwater Modelling Guidelines (AGMG)* (Barnett et al. 2012) was used to develop the model. The current model according to AGMG conforms to most criteria for Class 3 model classification, with the remaining criteria conforming to Class 2.

The model design, calibration, and uncertainty are summarised in the following sections; full details are included in Appendix I (Coffey 2016b). The results of the model are discussed in Chapter 11.

The model has been independently peer reviewed by two experienced groundwater modellers. The peer reviewers agree that the model objectives have been satisfied, the model calibration is satisfactory, the model predictions conform to best practice, and the model is fit for purpose. The peer review reports are included in Appendix J.

8.6.1 Model objectives

The numerical groundwater flow model's objectives are to quantify potential mining impacts to groundwater and surface water, and compare the impacts with the AIP requirements. These were considered in the model's design, construction, and calibration.

8.6.2 Model development

i Extent and boundary conditions

The regional groundwater flow model was developed using MODFLOW-SURFACT Version 3 (Hydrogeologic) in early 2015, and has since undergone multiple refinements (Coffey 2016b). The model extent (752 km^2) (Figure 8.4) was selected to represent a significant area around the project area to determine in detail and model potential impacts from the project.

The model domain extends across two groundwater sources: Sydney Basin Nepean Groundwater Source, and the Sydney Basin South Groundwater Source. Within the Sydney Basin Nepean Groundwater Source there are two management zones: the Nepean Management Zone; and, Nepean Management Zone 2 (Figure 8.5). The model domain extends across several surface water sources: Upper Wingecarribee River, Lower Wingecarribee River, Medway Rivulet, Lower Wollondilly River, Nattai River, and Bundanoon Creek (Figure 8.5). For this assessment, the Lower Wingecarribee River and Medway Rivulet water sources have been further divided into sub-catchments. Model boundaries were set far enough away from the mining region to not interfere with drawdown/depressurisation created by mining.

ii Layers

Thirteen active model layers have been used to represent the differences between hydrostratigraphic units to maintain adequate layer depth resolution, and so changes arising from mine extraction can be modelled. These layers and properties are shown in Table 8.7.

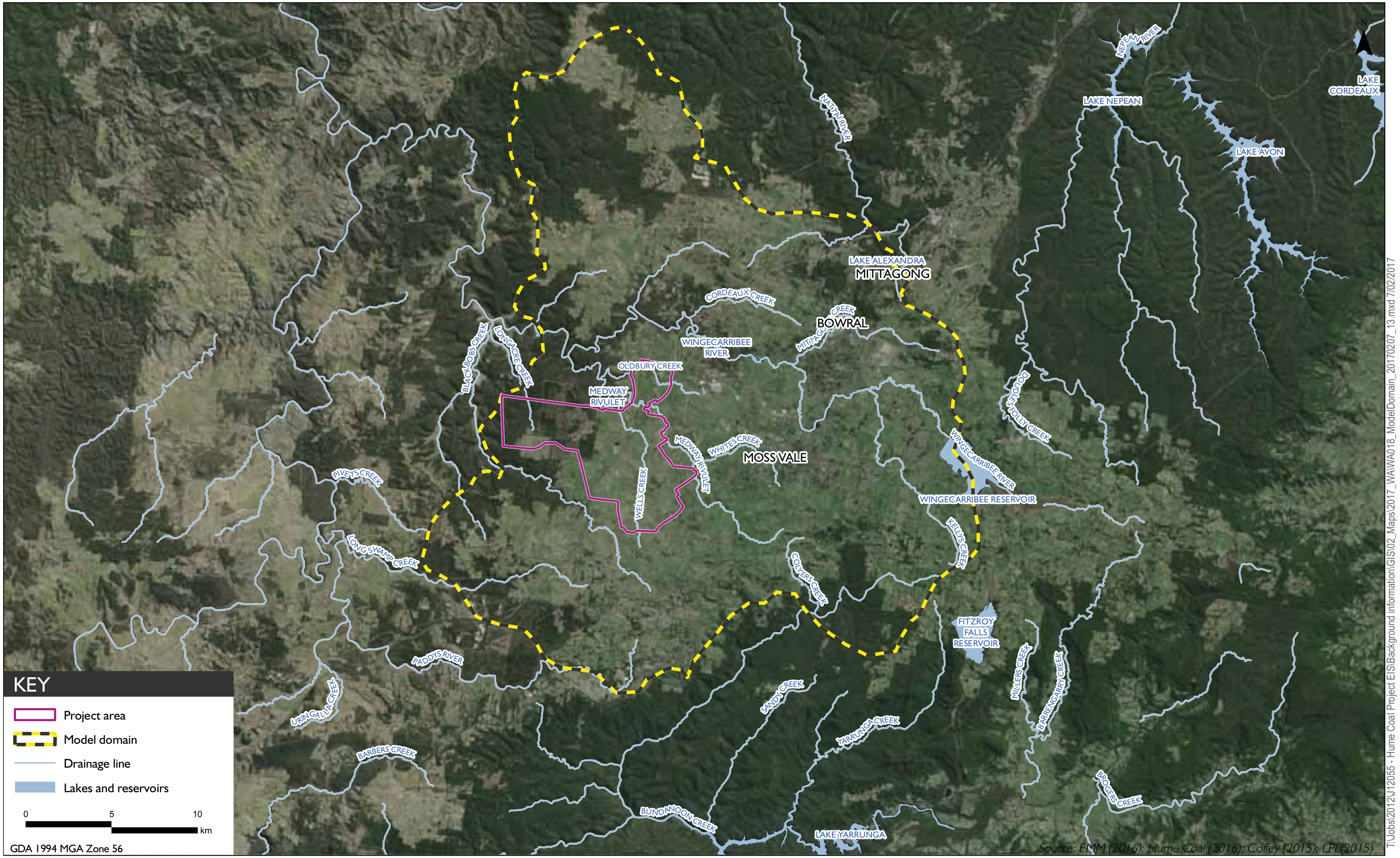
The grid cell dimensions used were 50 x 50 m over the project area, 50 x 100 m over the Berrima Colliery lease, and 200 x 200 m over the rest of the model domain. The cell spacings were reduced for greater detail in the mining zone.

The Hawkesbury Sandstone was represented by six layers to allow the suitable development of hydraulic head profiles and allow the depressurisation effects of mining to be incorporated.

Based on hydraulic head observations, the Robertson Basalt was not explicitly simulated in the regional model; however, its presence has been incorporated in the recharge rate for the Wianamatta Group, where it underlies the basalt. The Mount Gingenbullen intrusion was also not explicitly modelled based on the observed extents of drawdown created from the Berrima Colliery and coal mines from other regions.

An additional, smaller numerical basalt model was developed to calculate depressurisation in the basalt associated with the Hume Coal mine. The model was developed with MODFLOW-SURFACT Version 3, with a model domain area of 15 km^2 and a boundary that followed the south-eastern basalt geological unit. The model grid comprised two layers (Robertson Basalt and notional underlying layer) with cell dimensions of 100 x 100 m (Coffey 2016b).

Hydraulic parameters were assigned to each layer based on lithology and depth below ground surface. Both horizontal and vertical hydraulic conductivity were included.

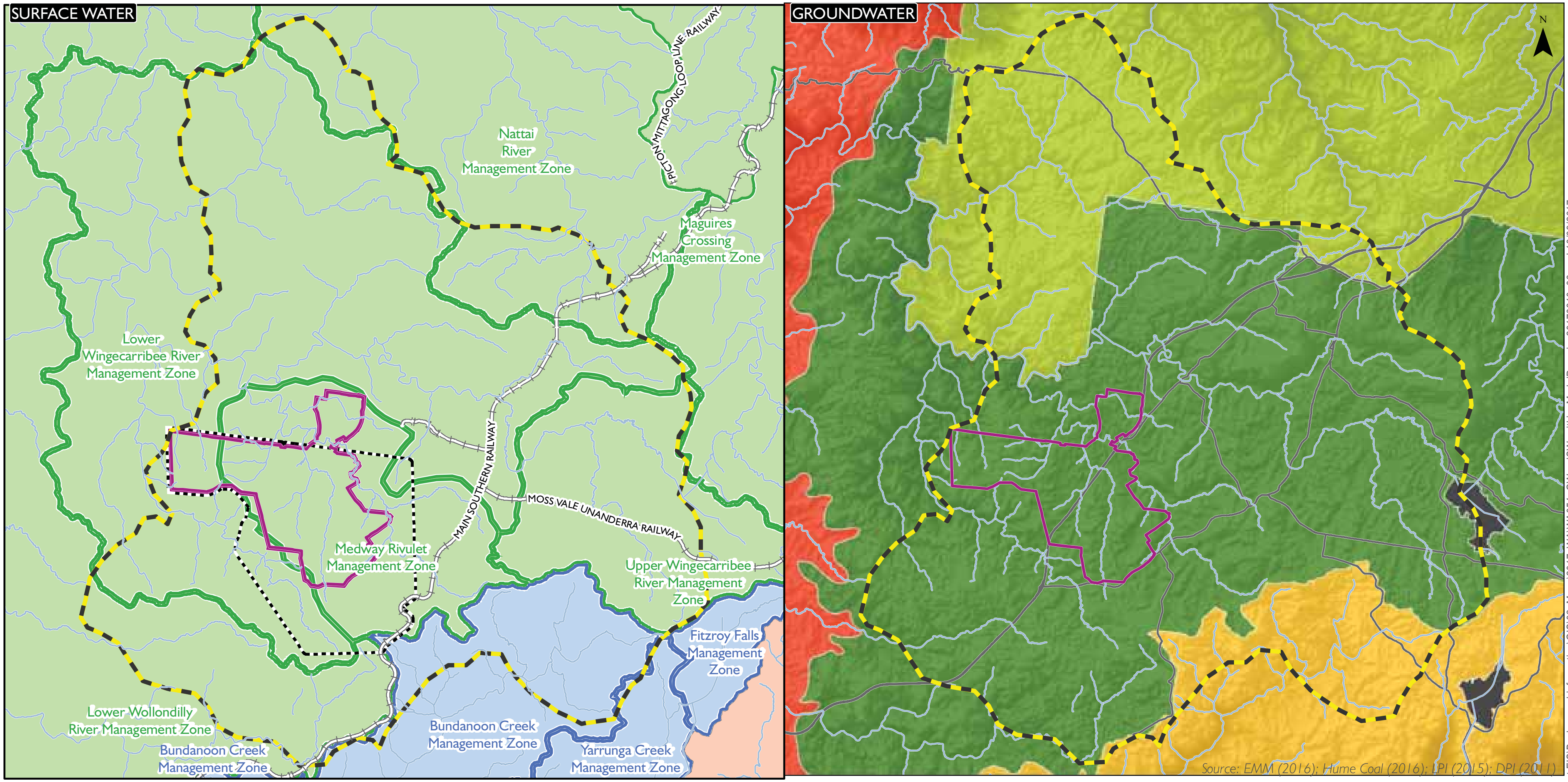


Numerical groundwater model domain

Hume Coal Project
Water Assessment

Figure 8.4

EMM HUMECOAL



KEY

Greater Metropolitan Water Sharing Plan, Unregulated Rivers

- Shoalhaven River Water Source
- Management zone within the Shoalhaven River Water Source
- Upper Nepean and Upstream Warragamba Water Source
- Management zone within the Upper Nepean and Upstream Warragamba Water Source

Water Sharing Plan for the Greater Metropolitan Region Groundwater Source (2014)

- Sydney Basin - Nepean Sandstone Zone 2
- Sydney Basin - Nepean Sandstone Zone 1
- Sydney Basin South Groundwater Source
- Goulburn Fractured Rock Groundwater Source

- Project area
- Model domain
- Waterbody
- Drainage line

Note: Project area and A349 boundaries have been offset for clarity

0 2 4 km

GDA 1994 MGA Zone 56

T:\Jobs\2012\J12055 - Hume Coal Project EIS\Background information\GIS\02_Maps\2017_WAIWA054_GWandSW_withingModelDomain_20170310_08.mxd 10/03/2017

Groundwater and surface water sources within model domain

Hume Coal Project
Water Assessment

Figure 8.5

Table 8.7 Active model layers and parameters

Model layer	Geology	Average depth to base^ (mbgl)	Average thickness (m)	Horizontal K# (m/day)	Vertical K# (m/day)
1	Wianamatta Group	30	55 (where present)	1	0.01
2	Hawkesbury Sandstone	56	53 where overlain by Wianamatta Group Shale. Decreases to nil from edge of Wianamatta Group to limit of sandstone	0.6	0.001
3		86	30	0.05	0.003
4		120	34	0.03	0.0005
5		127	7	0.01	0.0005
6		129	2	0.005	0.001
7		131	2	0.005	0.001
8	Interburden (Unnamed Member 3, WWR Ply & Farmborough Claystone)	133	4*	0.005	0.001
9	Wongawilli Seam above mined section	135	2*	0.005	0.001
10		137	2*	0.005	0.001
11	Wongawilli Seam mined section	140	3.5	0.005	0.001
12	Illawarra Coal Measures	160	19	0.0001	0.0001
13	Shoalhaven Group	250	120	0.0001	0.0001

Notes: ** = applied only within project area, not present everywhere so a minimum model thickness of 0.1 m is applied.*

 # = modelled parameters.

^ = average depth to base in project area.

mbgl = metres below ground level.

K = hydraulic conductivity.

iii Recharge, discharge, and flow

a. Rainfall and evapotranspiration

Rainfall recharge to the model domain was applied as a constant percentage of rainfall estimated for the project area based on BoM rainfall data (2% of 957 mm/yr). Evapotranspiration was applied across the model domain at a maximum rate of 3 mm/day (1095 mm/year), to 1.5 m deep, based on land surface types and proportions.

b. Rivers, drainage lines, reservoirs

The Wingecarribee River and the Medway Dam were simulated using the MODFLOW River package, which allowed two-way transfer of water between the creeks and groundwater. The applied vertical hydraulic conductivities (Kv) of the stream beds were set at a high value to allow free interaction between the surface and groundwater. The remaining drainage lines were simulated using the MODFLOW Drain package due to their ephemeral nature.

Wingecarribee Reservoir was simulated with a constant head condition in the top model layer. This assignment was based on water level data that indicate a relatively constant level for the past several years. Water was allowed to exchange with the subsurface in either direction depending on groundwater levels.

c. Alluvium

Alluvium is confined to the upper reaches of the Wingecarribee River and represents a small proportion of the total recharge area. It is assumed that recharge to the alluvium would discharge mainly to the river rather than to underlying clay dominant Wianamatta Group. Based on the alluvium's limited extent, recharge to underlying rock is considered a negligible component of the total recharge to the Wianamatta Group. The alluvium is not considered a separate groundwater source in the WSP. Hence, the alluvium has not been considered a separate unit from the Wianamatta Group in the model.

d. Groundwater bores

The model simulates pumping from 83 high extraction irrigation or industrial use bores associated with water access licences (WALs) of 5,300 ML/yr, and 299 stock and domestic bores. As there is no measured usage for the stock and domestic bores, they were assigned a constant pumping rate of 3 ML/yr each. Following calibration, the rate of extraction for the high extraction bores was varied to an optimal rate of 5,147 ML/yr, which likely accounts for over-pumping and pumping from unlicensed bores. For bores that extract groundwater from more than one model layer, the pumping rate was split proportionally based on the transmissivity of each layer.

iv Mine workings

Relaxation effects in the rock immediately above the mine were set to nominally 2 m. This is also the adopted height of groundwater drainage (desaturation). This approximate height of deformation has been described as typical for other first workings mines around the world and depends on road width, horizontal stress, roof rock strength, and rock bolting (Coffey 2016b). It is significantly less than the deformation zone for full extraction mining. In the model, there is assumed to be negligible change in hydraulic conductivity above the deformation zone within the project area. This is not the case for full extraction mines at Berrima Colliery and Loch Catherine to the north of the project. The parts of the Berrima and Loch Catherine mines that underwent full extraction mining, and subsequent caving, have been modelled with an average height of desaturation of 53 m above the roof.

v Structure

The net influence of fractures and faults in the area was considered during developing and running the groundwater model. Hydraulic conductivity estimates from the long-term pumping tests (of which there were eight) largely incorporate the influence of nearby faults and fractures in their results. In addition, the Berrima mine inflow data, which has been used as an input to the numerical groundwater model (Coffey 2016b), inherently includes consideration of the influence of faults and fractures on groundwater flow.

vi Hydraulic connection

The model was also used to quantify the simulated flow of groundwater between the low permeability Wianamatta Group shale and the upper Hawkesbury Sandstone. Within the numerical groundwater model area (Figure 8.4), baseline movement of groundwater from the Wianamatta Group shales to the upper Hawkesbury Sandstone was modelled to be consistently around 11.1 ML/day using the numerical groundwater model (discussed in Section 8.6 and 11.2.1). As a comparison to provide perspective, across the area where the Wianamatta Group is conceptualised to be hydraulically connected to the Hawkesbury Sandstone (28,118 ha), the amount of water movement of 11.1 ML/day from the shale to the underlying sandstone is equivalent to a very small rainfall event of 0.04 mm.

8.6.3 Calibration

The model was calibrated in two stages: transient simulation over a notional period of 32 years (approximating the effects of mining between 1926 and 2011, when the Berrima Colliery mine was active) to obtain a starting head distribution, and transient calibration over the main calibration period (between 2011 and 2014, the last stages of Berrima Colliery). The measured discharge from the Berrima Colliery void also provided an additional calibration aid for the model (Coffey 2016b). Verification was between the period 1 January 2015 to 27 August 2015.

Calibration targets included:

- hydraulic head data (49 points at 23 locations, including the Berrima Colliery, with monitoring intervals between 1 and 3 years) showing both seasonal changes and mine-induced drawdown;
- shallow groundwater discharge or baseflow to drainage channels and creeks;
- deep groundwater discharge (discharge to the Berrima Colliery void); and
- the measured hydraulic conductivity values across the region.

Inclusion of sub-vertical groundwater flow barriers associated with, but not penetrating, the Robertson Basalt (inferred from airborne geophysics and hydraulic head observations) helped to successfully calibrate the measured hydraulic head values from piezometers in the southern portion of the model domain.

Modelled results compare reasonably well with observed hydraulic heads. Further details about the calibration and verification results are included in Appendix I (Coffey 2016b).

8.6.4 Uncertainty and sensitivity analysis

Sensitivity analysis was conducted on a number of parameters, including the relaxation height, Kv, and mine drain conductance. The sensitivity analysis indicated the Kv distribution was the most sensitive parameters in the simulations. The final calibrated Kv distribution has was also aided by a combination of observations from pumping tests, stream baseflow, and Berrima Colliery inflow discharge observations. The calibrated Kv distribution is therefore considered to have a high level of reliability. Coffey (2016b) has concluded this reduced uncertainty in the model’s outputs.

The four main contributors for uncertainty at a local scale between observed and modelled hydraulic heads include:

- the accuracy of the vibrating wire piezometer data, which is considered to be within ± 10 meters;
- layer thickness in the model and the vertical position of piezometer screen intervals;
- the variable size of piezometer screen intervals leading to variations in pressure head readings; and
- the uncertain Berrima Colliery mining schedule and extraction that stopped in 2013.

8.6.5 Scenario modelling

Predictive model simulations were run for a 100 year period for the most probable future scenario and included the first workings mine layout, average rainfall, bulkhead injection, and co-disposal reject filling.

Changes to groundwater hydraulic head simulated by the numerical model were calculated as:

- the drawdown as a result of the project only; and
- total drawdown as a result of existing stresses (ie drainage to the Berrima Colliery mine void, and landholder bore pumping), and the project.

The model results and predicted groundwater impacts are discussed in Chapter 11.

8.7 Groundwater quality

The groundwater model simulations and review of the project activities and design indicate the potential for groundwater quality changes as a result of:

- induced transfer of water between groundwater systems;
- co-disposed reject emplacement in sealed mined voids; and
- seepage from stockpiles to the shallow water table.

The methods used to assess these changes for each of the above potential sources and processes are summarised in the following sections and discussed in detail in Appendix K.

8.7.1 Water quality change from induced transfer between groundwater systems

Underground mining will result in temporary depressurisation of the overlying groundwater system. This is predicted to temporarily increase the vertical (downward) hydraulic gradients in the water bearing formations immediately above the mine footprint. The depressurisation effects in the shallow Hawkesbury Sandstone will result in a temporary increase in the vertical gradient between the Wianamatta Group shale and the Hawkesbury Sandstone, with a resultant increase in the flow of more saline groundwater from the shale, downward, into the upper Hawkesbury Sandstone. This effect is expected to be most pronounced during the peak mining years, and will decrease as mined panels are sealed (ie dewatering is no longer necessary) and the panels are allowed to hydraulically re-equilibrate to background conditions.

To assess the magnitude of transfer of higher salinity water from the Wianamatta Group shale into the upper Hawkesbury Sandstone and the change in salt balance, time-series flow data were obtained from the numerical groundwater model (Section 8.6). Two scenarios were investigated: the existing case (ie no project influence), and the case with project influence. This allows for assessment of the incremental increase in transfer as a result of mining activities.

A mixing model was used to assess the resultant groundwater quality from mixing different proportions of groundwater from the Wianamatta Group shale and the Hawkesbury Sandstone.

The connectivity between the overlying shale and the Hawkesbury Sandstone is conceptualised as a consistent low volume of leakage from the above low permeability system into the below high permeability regional sandstone system. This assessment conservatively assumes 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 flow rate.

The results are summarised in Section 11.2.1.

8.7.2 Water quality effects of co-disposed reject

Once the void is sealed and re-saturated with natural groundwater, it is expected the groundwater will chemically interact with the emplaced reject material. Any dissolved species leached from the reject material will be transported with the natural flow of groundwater in the direction of the prevailing hydraulic gradient in the coal seam. Accordingly, the anticipated change to groundwater quality arising from this process has been assessed through consideration of the geochemical testing results (specifically, kinetic leach column (KLC) testing) using representative samples of reject material and groundwater for leaching (RGS 2016).

The results of KLC testing were used as a conservative indication of the resultant groundwater quality following interaction with the reject material emplaced in the void. Data were selected from the leach columns that were considered to provide the closest representation to the expected conditions in the subsurface. Namely, columns were selected that used fine reject material (for conservatism), leached with groundwater obtained from the Wongawilli seam, in fully saturated columns (ie as opposed to intermittently wet and dry columns). Data from two columns with these specifications were assessed: one column that was amended with limestone (KLC 24; as proposed for the reject material before emplacement), and one column without limestone amendment (KLC 22). The use of limestone is intended to increase the acid buffering capacity of the reject material. This will aim to retain a near-neutral pH and reduce mobilisation of metals in groundwater if sulphide minerals in the rejects are subject to oxidation.

A detailed methodology for the KLC tests is provided in RGS (2016). The columns were prepared with representative samples of reject material generated from drill core recovered from the Wongawilli Seam within and around the project area. The columns were then continuously saturated with groundwater sampled from the coal seam. Leachate samples were collected at the start of the test and then monthly for six months. Samples were submitted to ALS Environmental, a NATA-accredited analytical laboratory, to analyse pH, EC, major ions, speciated alkalinity, acidity, and metals.

The results of the KLC tests were compared to groundwater quality in the Wianamatta Group shale and the Hawkesbury Sandstone from the baseline monitoring program. This allowed for assessment of whether the leachate from the KLC tests had the potential to degrade the natural groundwater quality and, thus, potentially reduce its beneficial uses. An important assumption is that under post-mining conditions, once hydraulic pressures are re-established, the groundwater that comes in contact with the co-disposed reject in the void is likely to be groundwater flowing laterally through the coal seam, and will continue to flow laterally through the coal seam following contact with the reject materials. Hence, the receiving environment is considered to be the groundwater resources within the Wongawilli coal seam, down hydraulic gradient from the co-disposed reject materials. However, for conservatism, the KLC results were also compared to baseline Hawkesbury Sandstone water quality as this is the primary groundwater resource accessed in the project area and surrounds.

The assessment indicated that limestone amendment of the reject material prior to emplacement in the mine void is likely to produce leachate that is indistinguishable from natural groundwater quality. The results are discussed further in Section 11.2.2.

8.7.3 Seepage from stockpile runoff

During the initial 12–18 months as the project is developed, the coal reject will be stored temporarily in a coal reject stockpile, next to the CPP, until enough void space is available underground and underground emplacement can begin. The stockpile will consist of combined filtered fines and coarse reject. The stockpile will be progressively constructed, contoured and, when full, top-dressed and re-vegetated. An additional temporary reject stockpile may also be required at times when the underground reject emplacement operations are interrupted due, for example, to maintenance.

Stormwater controls will be implemented for the surface operations of the mine, including the coal reject stockpile location, to prevent the stockpile management area from receiving stormwater runoff from the surrounding areas. However the stockpile(s) will still be exposed to rainfall, a portion of which could infiltrate the stockpile, contribute to the oxidation of sulphide minerals present in the reject, and potentially mobilise acid and solutes generated from the water-reject interaction.

As with the assessment of underground emplacement of coal reject material discussed in Section 8.7.2, the results of KLC testing were used as a conservative indication of the water quality that would result from the interaction of rainfall with the stockpiled reject material. Data were selected from the leach columns that were considered to provide the closest representation of intermittent rainfall on a reject stockpile. Namely, columns were selected that used fine reject material (for conservatism), leached with deionised water as a proxy for rain water, in intermittently wet and dry columns that approximate the conditions of periodic rainfall on the reject stockpile with drying cycles between storms. Data from three columns with these specifications were assessed:

- one column containing only the composite reject material (KLC 10);
- one column that was amended with 1% limestone (KLC 16); and
- one column that was amended with 2% limestone (KLC 18).

Limestone increases the acid buffering capacity of the reject material, to prevent excessive generation of acidity and mobilisation of metals in infiltrating rain water if sulphide minerals in the reject are subject to oxidation.

The methods used to conduct the KLC tests are summarised in Section 8.7.2.

The results of the KLC tests were assessed relative to the appropriate water quality criteria for drinking water, primary industries and aquatic ecosystems. The results were also compared to groundwater quality in the Hawkesbury Sandstone from the baseline monitoring program (refer to Section 4.2), to assess whether the leachate from the KLC tests had the potential to degrade the natural groundwater quality and potentially reduce its beneficial uses if water from the reject stockpile drained into the underlying formation.

It is important to note that the assumption of monthly rainfall infiltration into the reject stockpile, particularly once it is top dressed and revegetated, is inherently conservative for the following reasons:

- Review of average rainfall and evaporation patterns in the study area presented in Coffey (2016a) indicated that a soil moisture deficit is likely to occur for eight months of an average year (from September to April), when pan evaporation exceeds the average monthly rainfall.

- The re-vegetation of the stockpile will also introduce transpiration as an added impediment to deep drainage of rainfall into the reject stockpile.

- The stockpile will be contoured to promote efficient surface runoff of rainfall falling on the stockpile, further reducing the potential for rainfall to infiltrate the reject stockpile.

The results are summarised in Section 11.2.3.

9 Assessment criteria

This chapter outlines the adopted assessment approach for project related impacts to water resources and water users. Potential impacts and assessment criteria are discussed.

The assessment of project-related impacts to water resources and water users considers the requirements of the *WMA 2000*, the relevant water sharing plans, the NSW Aquifer Interference Policy 2012 (the AIP), the Commonwealth Department of Environment *Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources* (DoE 2013) and the *Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals* (IESC 2015).

9.1 Compliance with water licensing requirements

This project has been assessed against the licensing requirements of the WMA 2000, and of the relevant water sharing plans.

9.2 Potential impacts and water users

Potential impacts to water resources and water users due to the project are as follows:

- the construction and use of site infrastructure;
- interception of groundwater;
- injection of water behind the bulkheads; and
- on-site water storage.

Changes to the baseline conditions caused by these activities are termed 'direct impacts'. Direct impacts in relation to groundwater and surface water could be changes:

- in surface water quantity, including changes to surface water flow and levels, and water availability;
- to surface water quality, including changes in salinity and salt balance, and concentrations of other important water quality parameters (such as pH, major cations and anions and dissolved metals);
- to flooding regime;
- in groundwater quantity, including changes to groundwater levels/pressures and flow; and
- in groundwater quality, including changes in salinity and salt balance, and concentrations of other important water quality parameters (such as pH, major cations and anions and dissolved metals).

According to the *Significant impact guidelines* (DoE 2013), the direct impacts listed above would be classified as significant if they "are of sufficient scale or intensity as to significantly reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring" (p16).

Users identified that would be potentially affected by mining water impacts in the region include:

- high priority ecosystems that rely on groundwater (GDEs as listed in a water sharing plan);
- ecosystems that potentially rely on groundwater;
- watercourses, drainage lines, creeks and swamps that receive baseflow;
- groundwater users (private landholder bores and associated infrastructure);
- surface water users; and
- stream environments.

9.3 Adopted criteria

Based on the discussion in Chapter 3 about assessment requirements outlined in the relevant policies and guidelines, site appropriate assessment criteria have been developed for both surface water and groundwater-related impacts. These are presented in the following sections.

In addition, reference to the *Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals, including completion of the information requirements checklist* has also been considered in this assessment. The completed checklist is included in Appendix B.

9.3.1 Surface water

i Water quantity, including flow, levels and availability

Potential impacts associated with the change in flow regime as a result of the project could include:

- erosion of stream banks from increases in stream energy as a result of sporadic water releases from the operations;
- decreased access for water users as a result of decreased streamflow due to reduced catchment areas and intercepted baseflow; and
- decreased availability of water for instream and riparian ecosystems as a result of decreased streamflow due to reduced catchment area and intercepted baseflow.

Criteria for assessing impacts to water quantity are:

- percentage reduction in yield in surface water quantity; and
- increase in number of no-flow days.

ii Water quality

To assess whether the project and associated treatment measures will have a NorBE on surface water quality, pollutant loads (for both the existing conditions (pre-development) and operational phase (post-development) and concentrations the MUSIC model predicted have been assessed against the following criteria outlined in the WaterNSW standards (SCA 2012):

- The mean annual pollutant loads for the post-development case (including mitigation measures) must be 10% less than the pre-development case for TSS, TP and TN.

- Pollutant concentrations for TP and TN for the post-development case (including mitigation measures) must be equal to or better compared to the pre-development case for between the 50th and 98th percentiles over the five-year modelling period when runoff occurs. Periods of zero flow are not accounted for in the statistical analysis as there is no downstream water quality change. To demonstrate this, comparative cumulative frequency graphs, which use the Flow-Based Sub-Sample Threshold for both the pre- and post-development cases, must be provided. As meeting the pollutant percentile concentrations for TP generally also meets the requirements for TSS, cumulative frequency analysis is not required for TSS. Cumulative frequency is also not applied to gross pollutants.

A third criterion is provided in the WaterNSW standards (2012); however, it only applies to developments where the catchment is more than 70% impervious. This is not the case for the catchments that will discharge to the environment (SB03 and SB04, which are 57% and 44% impervious respectively). As such, this criterion does not apply.

To assess the reduction of baseflow on surface water quality, the relevant ANZECC and ARMCANZ, and ADW guidelines (as per the *National Water Quality Management Strategy Guidelines* (ANZECC & ARMCANZ (2000) and NHMRC (2016)) and water quality objectives recommended by *Healthy Rivers Commission into the Hawkesbury-Nepean River* (HRC 1998) will be used as criteria to compare against both baseline surface water quality and groundwater quality data.

iii Flooding

Changes to the flood regime may affect local land users within and next to the project area. The following acceptability criteria are used to assess the flooding impact at different land uses (for flooding events up to the 100 year ARI):

- Flood level:

  - Buildings – less than 50 mm increase in flood level (afflux) if the building is already flooded and no new flooding of buildings not currently flooded due to proposed works unless owner's consent is obtained;

  - Public roads/rail – less than 100 mm afflux if the road/rail is already flooded and no new flooding of public roads/rail that are not currently flooded; and

  - Private properties – less than 250 mm afflux.

- Flood velocity:
  - No increase in velocity above a threshold of 1.5 m/s, where existing conditions velocities are below the threshold. No more than a 10% increase in velocity where existing conditions velocities are above this threshold.

These criteria have been developed with the consideration of the Wingecarribee Local Environment Plan (WSC 2010), the *Australian Rainfall and Runoff – A guide to flood estimation* (IEA 1987), *Floodplain Development Manual* (DIPNR 2005), and *Practical Consideration of Climate Change* (DECC 2007).

9.3.2 Groundwater

> *AR 13: A detailed assessment against the NSW Aquifer Interference Policy (2012) using DPI Water's assessment framework.*

The project has been assessed in detail against the minimal harm thresholds defined in the AIP, and DPI Water's assessment framework has been completed and is included in Appendix C. The assessment framework table has been cross-referenced with the relevant sections in this document. This is in accordance with the Minister's requirements for approval and administration of the WMA 2000. Impacts to groundwater are assessed via the consideration of high priority groundwater dependent ecosystems, high priority culturally significant sites, and landholder bores.

The AIP divides groundwater sources into 'highly productive' or 'less productive' based on the yield (>5 L/s for highly productive) and water quality (<1,500 mg/L total dissolved solids for highly productive). Thresholds are set in the AIP for the different groundwater sources for the different minimal impact considerations.

Based on DPI Water's mapped areas of groundwater productivity in NSW (NOW 2012b), the project is considered to be within 'highly productive' porous and fractured rock source. The applicable minimal harm considerations are shown in Table 9.1.

Cumulative variation in the water table and/or pressure head decline criteria in the AIP are for 'post-water sharing plan' variations only. The cumulative assessment has been conducted and results are also included in this document. However, for the assessment of impacts as per the AIP, the project influenced drawdown (only) is relevant. Other stresses within the system (eg landholder bore pumping and Berrima Colliery drainage) were present 'pre-water sharing plan' and are considered relatively constant; their influences on the groundwater systems are therefore excluded from the assessment under the AIP.

Table 9.1 Minimal impact criteria for 'highly productive' porous rock water source

Water table	Water pressure	Water quality
1. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. A maximum of a 2 m decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply	1. A cumulative pressure head decline of not more than a 2 m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. 2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

Notes: Source: AIP 2012.

1. 'post-WSP'– refers to the period after the first WSP in the water source begins, including the highest pressure head (allowing for typical climatic variations) within the first year after the first WSP begins.

2. 'Appropriate studies' on the potential impacts of water table changes greater than 10% are to include an identification of the extent and location of the asset, the predicted range of water table changes at the asset due to the activity, the groundwater interaction processes that affect the asset, the reliance of the asset on groundwater, the condition and resilience of the asset in relation to water table changes and the long-term state of the asset due to these changes.

3. All cumulative impacts are to be based on the combined impacts of all 'post-water sharing plan' activities within the water source.

9.4 Cumulative impacts

Cumulative water-related impacts have been assessed for the project within the following context:

- existing pre-project cumulative drawdown of existing works(baseline);
- cumulative drawdown of the project and of existing works (project plus baseline);
- the drawdown interference of the project only (ie removing other existing impacts); and
- the drawdown influence of the project, and due to other existing works and potential future projects in planning process.

For surface water, the Berrima Rail Project is the only relevant additional project to consider for cumulative impacts.

For groundwater, the existing works include landholder bore pumping and the Berrima Colliery. The groundwater model considers the combined baseline (landholder pumping and Berrima Colliery and the project effects, as well as the effects of the project only (ie not including baseline landholder pumping and the Berrima Colliery). The AIP assessment criteria require proponents to consider post water sharing plan impacts. As the landholder pumping and Berrima Colliery effects are already considered as part of the baseline, the project's influence has been used for assessment against the AIP criteria.

As described in Chapter 5 of the *Hume Coal Project EIS* (EMM 2017a), a number of industrial, extractive and manufacturing facilities occur in the locality. The proposed or recently approved developments in the region include:

- Berrima Cement Works (Mod 9 use of waste derived fuels);
- New Berrima Clay/Shale Quarry;
- Green Valley Sand Quarry; and
- Sutton Forest Quarry.

However, there are no water-related aspects of these projects that would contribute to cumulative drawdown or water quality changes for the project. For the surface water assessment the only relevant project that is considered as part of the cumulative assessment is the Berrima Rail Project (EMM 2017d), which has been considered both independently and cumulatively with the project in the *Berrima Rail Project Environmental Impact Statement* (EMM 2017d).

For groundwater, there are no potential future projects in the planning process that would influence the assessment of the project.

10 Surface water assessment

This chapter outlines the results of the impact assessments undertaken for project-related impacts to surface water resources and water users.

SEAR 1: As assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources, having regard to the EPA's, DPI's and Water NSW requirements and recommendations.

SEAR 2: An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.

AR 4: Analysis of impacts of groundwater interference and drawdown on water quality, water flow and aquatic and riparian environments within and downstream of all waterways within the proposal area.

AR 14: Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, wetlands, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.

AR 20: Assessment of whether the activity may have a significant impact on water resources, with reference to the Commonwealth Department of Environment Significant Impact Guidelines.

AR 21: If the activity may have a significant impact on water resources, then provision of information in accordance with the Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals, including completion of the information requirements checklist.

AR 22: A detailed assessment of riparian and watercourse impacts, particularly with respect to watercourse crossings. The project should be designed to minimise impacts on watercourses and riparian land, and must have regard to the Department of Primary Industries' Guidelines for Controlled Activities on Waterfront Land – in particular the guideline on watercourse crossings.

AR 29: The EIS should take into account the following policies (as applicable):
· NSW Guidelines for Controlled Activities on Waterfront Land (NOW, 2012)
· NSW Aquifer Interference Policy (NOW, 2012)
· Risk Assessment Guidelines for Groundwater Dependent Ecosystems (NOW, 2012)
· Australian Groundwater Modelling Guidelines (NWC, 2012)
· Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals (IESC, 2014)
· Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments - impacts on water resources (Australian Govt. 2014)
· NSW State Rivers and Estuary Policy (1993)
· NSW Wetlands Policy (2010)
· NSW State Groundwater Policy Framework Document (1997)
· NSW State Groundwater Quality Protection Policy (1998)
· NSW State Groundwater Dependent Ecosystems Policy (2002)
· NSW Water Extraction Monitoring Policy (2007)
· Groundwater Monitoring and Modelling Plans - Information for prospective mining and petroleum exploration activities (NOW, 2014)
· NSW Code of Practice for Coal Seam Gas Well Integrity (DTIRIS 2012)
· NSW Code of Practice for Coal Seam Gas Fracture Stimulation (DTIRIS 2012)

AR 45: *Assessment of predicted impacts on the following:*

- *flow of surface water (including floodwater), sediment movement, channel stability, and hydraulic regime*
- *water quality*
- *flood regime*
- *dependent ecosystems*
- *existing surface water users*
- *planned environmental water and water sharing arrangements prescribed in the relevant water sharing plans*

AR 58: The results of any models or predictive tools used.

AR 59: Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users, including information on:

- *Any proposed monitoring programs, including water levels and quality data. Reporting procedures for any monitoring program including mechanism for transfer of information*
- *An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal*
- *Identification of any nominal thresholds as to the level of impact beyond which remedial measures or contingency plans would be initiated (this may entail water level triggers or a beneficial use category)*
- *Description of the remedial measures or contingency plans proposed*
- *Any funding assurances covering the anticipated post development maintenance cost, for example on-going groundwater monitoring for the nominated period*

AR 62: A detailed description of all potential impacts on the watercourses/riparian land

AR 63: A detailed description of all potential impacts on the wetlands, including potential impacts to the wetlands hydrologic regime; groundwater recharge; habitat and any species that depend on the wetlands

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 69: The EIS must assess the impacts of the development on water quality, including:
a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction.
b. Identification of proposed monitoring of water quality.

AR 70: The EIS must assess the impact of the development on hydrology, including:

- *a. Water balance including quantity, quality and source.*
- *b. Effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas.*
- *c. Effects to downstream water-dependent fauna and flora including groundwater dependent ecosystems.*
- *d. Impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (eg river benches).*
- *e. Changes to environmental water availability, both regulated/licensed and unregulated/rules-based sources of such water.*
- *f. Mitigating effects of proposed stormwater and wastewater management during and after construction on hydrological attributes such as volumes, flow rates, management methods and re-use options.*
- *g. Identification of proposed monitoring of hydrological attributes.*

AR 75: If WQO's cannot be met for the project, demonstrate that all practical options to avoid water discharge have been implemented and outline any measures taken to reduce the pollutant loads where a discharge is necessary. Where a discharge is proposed, analyse the expected discharges in terms of impact on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm.

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 82: An assessment of the relevant impacts of the action on water resources including:
- a description and detailed assessment of the nature and extent of the likely direct, indirect and consequential impacts, including short term and long term relevant impacts
- a statement whether any relevant impacts are likely to be known, unpredictable or irreversible, and analysis of the significance of the impacts
- any technical data and other information used or needed to make a detailed assessment of the impacts

AR 85: The assessment of impacts should include information on:
- any substantial and measureable changes to the hydrological regime of the water resource, for example a substantial change to the volume, timing, duration or frequency of ground and surface water flows
- the habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the water resource being seriously affected
- substantial and measureable change in the water quality and quantity of the water resource – for example, a substantial change in the level of salinity, pollutants, or nutrients in the wetland; or water temperature that may adversely impact on biodiversity, ecological integrity, social amenity or human health

10.1 Water quantity

10.1.1 Introduction

Surface water quantity assessment results are presented and discussed in detail in Appendix F (WSP PB 2016c). The results and impact assessment are summarised in the following sections.

Flow and yield impacts have been assessed for the following two climate sequences:

- Climate sequence 58 (1946 to 1964) – wettest sequence: maximum volume of water treated and discharged to Oldbury Creek of the 107 realisations simulated in the water balance model.
- Climate sequence 103 (1991 to 2009) – driest sequence: lowest simulated rainfall-runoff volume of the 107 realisations simulated in the water balance model.

10.1.2 Project activities with potential to affect surface water flows

AR 3: Analysis of impacts of subsidence upon water flow within and downstream of all waterways within the proposal area.

The natural flow regimes of Medway Rivulet, Oldbury Creek and their tributaries are highly disturbed; the catchments have been extensively cleared for agriculture and multiple instream storages, which impede the natural flow, have been constructed along the length of the streams. The project has the potential to further impact on the flow regime of local streams due to:

- reduction in catchment area and runoff associated with the water management system for the project;
- releases from selected stormwater basins (SB03 and SB04) following containment of the first flush within the water management system; and
- interception of natural baseflow to streams associated with depressurisation of groundwater systems during underground mining.

These activities are discussed further in the following sections.

The underground mine workings will result in negligible impacts on the flow and geomorphology in overlying catchments. Worst case estimates of subsidence associated with the proposed low impact, first workings mining method predict ‘imperceptible’ surface disturbance due to mining, with predicted settlement of less than 20 mm (EMM 2017e; Mine Advice 2016). Such disturbances are low enough in magnitude as to not affect streamflow regimes or geomorphology.

The mine water management system is detailed in Section 2.3.2, and is summarised as:

- runoff from undisturbed areas will be diverted around or away from the infrastructure and remain within the natural catchment;
- surface water runoff from disturbed areas will be collected in stormwater basins (SBs) and mine water dams (MWDs) and reused as much as possible as part of the operational demands; or
- runoff from disturbed areas not in direct contact with coal (SB03 and SB04 catchments) may be discharged to Oldbury Creek after first flush and water quality criteria have been met;
- water in excess of operational needs will be pumped underground into the sealed void areas; and
- excess water on site (likely in last few years of mining) to be treated by the provisional WTP at MWD08 before controlled release at Oldbury Creek. The water balance (Section 8.2) demonstrates that this is unlikely to be required and, therefore, this scenario has not been assessed.

i Reduction in catchment area

Containment and reuse of water from operational areas of the project will result in a reduction in catchment area and runoff to local streams. A reduction in runoff has the potential to alter the flow regime of the stream.

The catchment areas associated with the project storages are provided in Table 10.1. The reduction in catchment area for Medway Rivulet sub-catchment (not including Oldbury Creek) is estimated to be 26.6 ha, which represents 0.2% of the catchment area to its confluence with Wingecarribee River. A reduction in catchment area for Oldbury Creek is estimated to be 67.6 ha, which is 5.0% of the total catchment area. The Medway Rivulet and Oldbury Creek sub-catchments are shown on Figure 2.4.

Table 10.1 Reduction in catchment areas associated with project dams and basins

Dam/ basin	Description	Dam / basin catchment area (ha)	Existing area drains to (pre-project)	Total catchment area (ha)	% reduction in catchment area
SB03	Captures runoff from administration and workshop area	5.91	Medway Rivulet (including Wells Creek and Belanglo Creek sub-catchments, not including Oldbury Creek sub-catchment)	10,909	0.2%
SB04	Captures runoff from mine road and conveyor embankment	14.73			
MWD05	Captures runoff from north of Medway Rivulet – overland conveyor no. 1	0.64			
MWD06	Captures runoff from south of Medway Rivulet – conveyor portal	2.69			
MWD07	Captures runoff from ventilation shaft pad dam	2.60			
SB01	Captures runoff from product stockpile area	26.36	Oldbury Creek	1,355	5.0%
SB02	Captures runoff from CPP and ROM areas	22.64			
MWD08 (provisional)	Stores water before treatment and release to Oldbury Creek	0.27			
PWD	Stores water pumped from SBs and MWDs and underground mine sump dewatering	18.28			
Total Medway Rivulet catchment (including Oldbury Creek)		94.12	Medway Rivulet and Oldbury Creek	12,264	0.8%

ii Discharge from SB03 and SB04 to Oldbury Creek

The water balance model developed for the project (Section 8.2) was used to predict the volume of discharge from SB03 and SB04, once first flush criteria have been met. Details of the releases from SB03 and SB04 are presented in Appendix D (WSP PB 2016a). Annual releases are expected to be in the range of 29 ML to 31 ML from SB03 and 38 ML to 41 ML from SB04 during years with high rainfall. Annual releases are expected to be less than 1 ML during years with low rainfall.

iii Depressurisation of groundwater systems from underground mining

The conceptual model for the project area infers that drainage lines receive baseflow from groundwater (Chapter 7). In dry conditions, where surface rainfall and runoff is insufficient to sustain substantial flow, the smaller tributaries will receive groundwater as baseflow in persistent unconnected or connected pools. Groundwater systems are depressurised as a result of water inflows during underground mining. As a result, drainage lines, although still receiving baseflow, may receive a decreased rate of baseflow and experience an overall reduction in streamflow/water level in pools. This will be particularly noticeable during low flows, or dry conditions.

Rates of reduction in baseflow have been calculated from the numerical groundwater model; the results are presented in Section 11.1.3.

10.1.3 Flow impacts

Flow duration curves for the wet and dry climate scenarios in the Medway Rivulet sub-catchment (excluding the Oldbury Creek sub-catchment) are presented in Figure 10.1. The flow duration curves for the operation case include:

- reduction in catchment area associated with the project water management system basins and dams; and
- reduction of baseflow to Medway Rivulet and its tributaries as a result of underground mining.

The flow duration curves on the right in Figure 10.1 include low flow discharges from the Moss Vale sewage treatment plant (STP) located on Whites Creek for both the existing and operation cases. The STP discharges are approximated at 2.3 ML/day based on effluent data provided by Wingecarribee Shire Council.

The results show that with constant low flow discharges from the Moss Vale STP, the flow regimes in Medway Rivulet for the existing and operation cases are similar. If the constant discharges from the Moss Vale STP are excluded, changes in the low flow regime below about 5 ML/day may occur and the number of no flow days may increase by approximately 20% under the wet climatic scenario and by about 30% under the dry climatic scenario. Yield impacts for Medway Rivulet are discussed in Section 10.1.3.

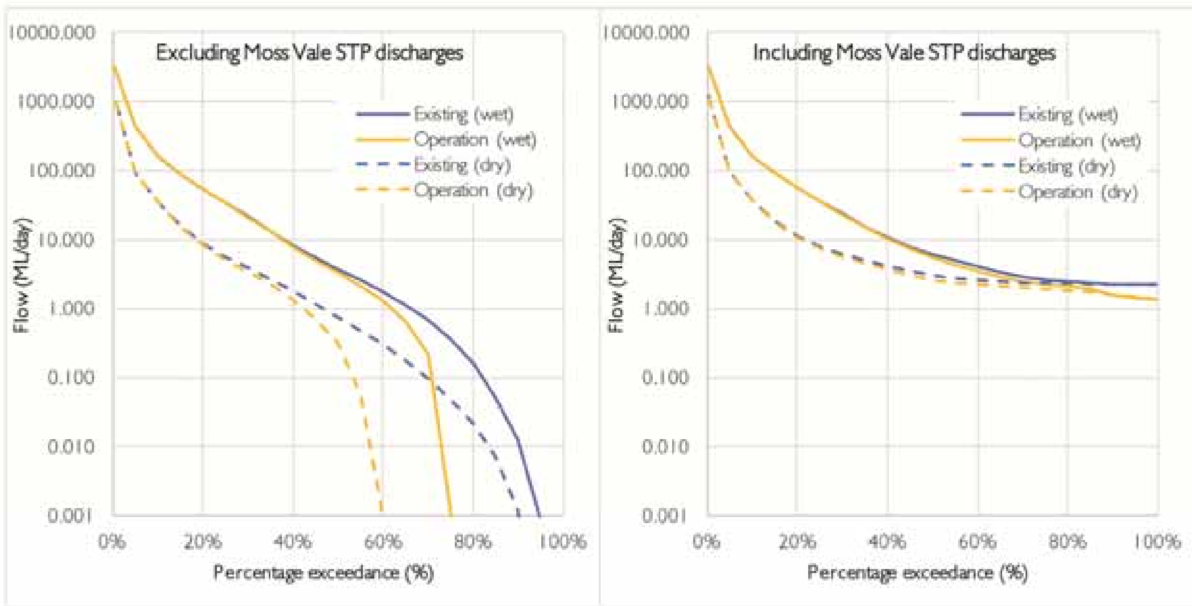


Figure 10.1 Flow duration curves for Medway Rivulet for wet and dry climate sequences

Flow duration curves for the wet and dry climate scenarios in Oldbury Creek are presented in Figure 10.2. The flow duration curves for the operation case include:

- reduction in catchment area associated with the project water management system basins and dams;
- discharge of water from SB03 and SB04 after the first flush; and
- reduction of natural baseflow to Oldbury Creek as a result of underground mining.

The flow duration curves for Oldbury Creek with and without constant low flow discharges from the Berrima STP are approximately the same. This is because discharges from the Berrima STP to Oldbury Creek are low, at about 0.2 ML/day.

The results show that alteration of the flow regime in Oldbury Creek during operation of the mine will be minor compared to pre-mining conditions, with discharges from SB03, SB04 to some extent offsetting changes to flow associated with a reduction in catchment for project storages and interception of baseflow associated with depressurisation of groundwater systems. Flow modification in Oldbury Creek is discussed in Section 5.4.2.2.

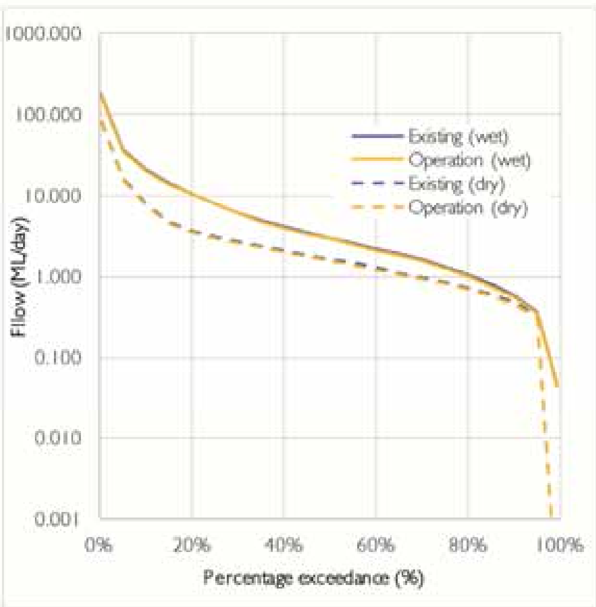


Figure 10.2 Flow duration curves for Oldbury Creek for wet and dry climate sequences

10.1.4 Yield impacts

i Medway Rivulet Management Zone and Medway Dam

The change in streamflow due to the project, with and without STP discharges, has been estimated for wet and dry climate sequences to assess the change in surface water yield for:

- the Medway Dam catchment.
- the Medway Rivulet catchment, excluding the Oldbury Creek sub-catchment.
- the Oldbury Creek sub-catchment.
- the Medway Rivulet Management Zone.

The catchments are shown in Figure 2.4 and results are shown in Table 10.2. The results indicate that under wet conditions, the project will result in a 0.8% reduction in yield for the Medway Rivulet Management Zone, and under dry conditions the project will result in a 1.4% reduction in yield. Locally, yield will be greater in the Oldbury Creek sub-catchment, with up to a 4.1% reduction in yield under wet conditions and up to a 4.2% reduction in yield under dry conditions.

Table 10.2 Yield impacts for Medway Rivulet

Catchment	Included sub-catchments	Impact due to	Yield impact	
			Wet climate sequence	Dry climate sequence
Medway Dam	Medway Rivulet Wells Creek	Reduction in catchment area due to project storages (SB03, SB04, MWD05, MWD06 and MWD07) Intercepted baseflow for Medway Rivulet (scaled to catchment area) and Wells Creek	0.5%	0.9%
Medway Rivulet at the confluence with Wingecarribee River (excluding Oldbury Creek)	Medway Rivulet Wells Creek Belanglo Creek	Reduction in catchment area due to project storages (SB03, SB04, MWD05, MWD06 and MWD07) Intercepted baseflow for Medway Rivulet, Wells Creek and Belanglo Creek	0.6%	1.1%
Oldbury Creek	Oldbury Creek	Reduction in catchment area due to project storages (SB01, SB02, MWD08 and PWD) Releases from SB03 and SB04 after a first flush Intercepted baseflow for Oldbury Creek	4.1%	4.2%
Medway Rivulet Management Zone		Reduction in catchment area due to project storages (SB01, SB02, SB03, SB04, MWD05, MWD06, MWD07, MWD08, and PWD) Releases from SB03 and SB04 to Oldbury Creek after a first flush Intercepted baseflow for Medway Rivulet, Wells Creek, Belanglo Creek and Oldbury Creek	0.8%	1.4%

ii Lower Wingecarribee River Management Zone and Warragamba Dam

Results from the yield assessment indicate that under wet conditions, the loss of baseflow will result in a 0.1% reduction in yield for the Lower Wingecarribee River catchment, and under dry conditions the loss of baseflow will result in a 0.2% reduction in yield. Refer to Section 8.3 for method.

The Medway Rivulet Management Zone (Figure 2.4) is upstream of the Lower Wingecarribee River Management Zone. Under wet conditions, the project will result in a 0.8% reduction in yield for the Medway Rivulet Management Zone, and under dry conditions the project will result in a 1.4% reduction in yield. These changes in the Medway Rivulet Management Zone would produce negligible changes in flow downstream in the substantially larger Lower Wingecarribee Management Zone.

iii Lower Wollondilly and Bundanoon Creek Management Zones

Reduction in yield in the Lower Wollondilly and Bundanoon Creek Management Zones could occur as a result of reduction in baseflow. Results from the yield assessment are shown in Table 5.3 below. The results indicate that under wet and dry conditions, the project would result in up to a 0.0004% reduction in yield for the Lower Wollondilly River Management Zone and no reduction in yield in the Bundanoon Creek Management Zone.

Table 10.3 Reduction in yield due to reduction in baseflow – Lower Wollondilly and Bundanoon Management Zones

Water Management Zone	Catchment area (ha)	Reduction in yield	
		Wet conditions	Dry conditions
Lower Wollondilly River	265,763	0.0001%	0.0004%
Bundanoon Creek	31,947	None	None

10.2 Surface water quality

AR 73: Estimate the chemical composition and load of chemical and physical stressors and toxicants in any discharge with ANZECC 2000 trigger values for the various environmental values of the waterway.

AR 77: Demonstrate that the proposed measures to capture and treat water impacted by the proposal will have no impact on water quality within the Wingecarribee River.

AR 78: Specifically address clauses 9(1) and (2) and 10(1) of State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011. In particular, the EIS must describe and justify how the development would have a neutral or beneficial effect on water quality.

10.2.1 Introduction

Surface water quality assessment results are presented and discussed in detail in Appendix E (WSP PB 2016b). The results and assessment are summarised in the following sections.

10.2.2 Project activities with potential for water quality variation

During the project's construction and rehabilitation phases, the following activities that have the potential to vary water quality:

- earthworks, which have the potential to cause erosion and sedimentation of local waterways;
- use of vehicles and heavy machinery, storage of fuels, oils and lubricants and equipment maintenance, which have the potential to cause hydrocarbon contamination of local waterways; and
- a construction camp, which has the potential to contaminate local waterways with general waste and sewage.

The construction and rehabilitation phases of the project will be short-term and the potential variation in surface water quality can be suitably managed through the preparation and implementation of site environmental management plans (discussed in Chapter 13); these have not been assessed in this report. Sediment dams required during construction will be designed in accordance with the *Managing Urban Stormwater– Soils and Construction– Volume 2E Mines and Quarries* (DECC 2008) and managed under a Soil and Water Management sub-plan (which incorporates sediment and erosion control measures).

During the project's operation phase, most project activities will be managed as part of the mine water management system. Refer to Section 2.3.2 and 10.1.2 for further details.

During the project's operation phase, project activities outside the mine water management system with the potential to vary water quality include:

- vehicle and heavy machinery movements on access roads, resulting in potentially contaminated runoff to local waterways (TSS and hydrocarbons);
- operation of the WTP, if required (water balance modelling demonstrates treatment and release of water will not be required);
- ongoing resource definition activities along with geotechnical and engineering testing and fieldwork for detailed design; and
- depressurisation of the groundwater systems during underground mining resulting in a reduction in baseflow to streams and possible increased concentrations in some constituents.

Potential impacts to surface water quality associated with the first three activities listed above can be suitably managed through implementing a project-specific environmental management plan (discussed in Chapter 13).

The following project activities have been further assessed for resulting in potential water quality variation:

- discharge from SB03 and SB04 (when first flush and water quality criteria are met) to Oldbury Creek;
- runoff from access roads outside of the mine water management system; and
- depressurisation of groundwater systems from underground mining.

The change in the surface water salt balance as a result of the project is expected to be negligible, as the project is predicted to be a zero discharge site for most of the time. Releases to Oldbury Creek would only occur during times of high flow from post-first flush releases from SB03 and SB04 during times of high rainfall. As such, the changes in salt balance have not been considered further.

i Discharge from SB03 and SB04 to Oldbury Creek

The results of the MUSIC modelling undertaken to assess the potential TSS and nutrient loads and concentrations in Oldbury Creek show discharge will be in accordance with the NorBE criteria (Section 8.4.1).

Results indicate a significant reduction of more than 10%, and therefore acceptable within NorBE criteria, of the mean annual TSS and nutrient loads for the operations phase compared with the existing situation (Table 10.4). This reduction is due to the smaller area of the agricultural catchment draining to Oldbury Creek during operation.

Cumulative frequency plots of TN and TP concentrations in runoff to Oldbury Creek for the existing (runoff from SB01, SB02, SB03, SB04, MWD08, and PWD catchments) and operation (runoff from SB03 and SB04 catchments) scenario are shown in Figure 10.3 and Figure 10.4. The results indicate that pollutant concentrations for the operational scenario are equal to or lower than the existing scenario between the 50^{th} and 98^{th} percentiles, and are therefore compliant with NorBE criteria.

Table 10.4 Mean annual loads in Oldbury Creek during existing and operation scenarios, and NorBE criteria

Parameter	Mean annual load		% reduction	NorBE criteria
	Existing (Oldbury Creek receives runoff from future SB01, SB02, MWD08, and PWD catchments)	Operation (Oldbury Creek receives releases from SB03 and SB04)		
TSS (kg/yr)	25,500	4,130	84%	≥10% reduction
TP (kg/yr)	125	8	93%	≥10% reduction
TN (kg/yr)	483	61	87%	≥10% reduction
Flow (ML/yr)	149	20	86%	-

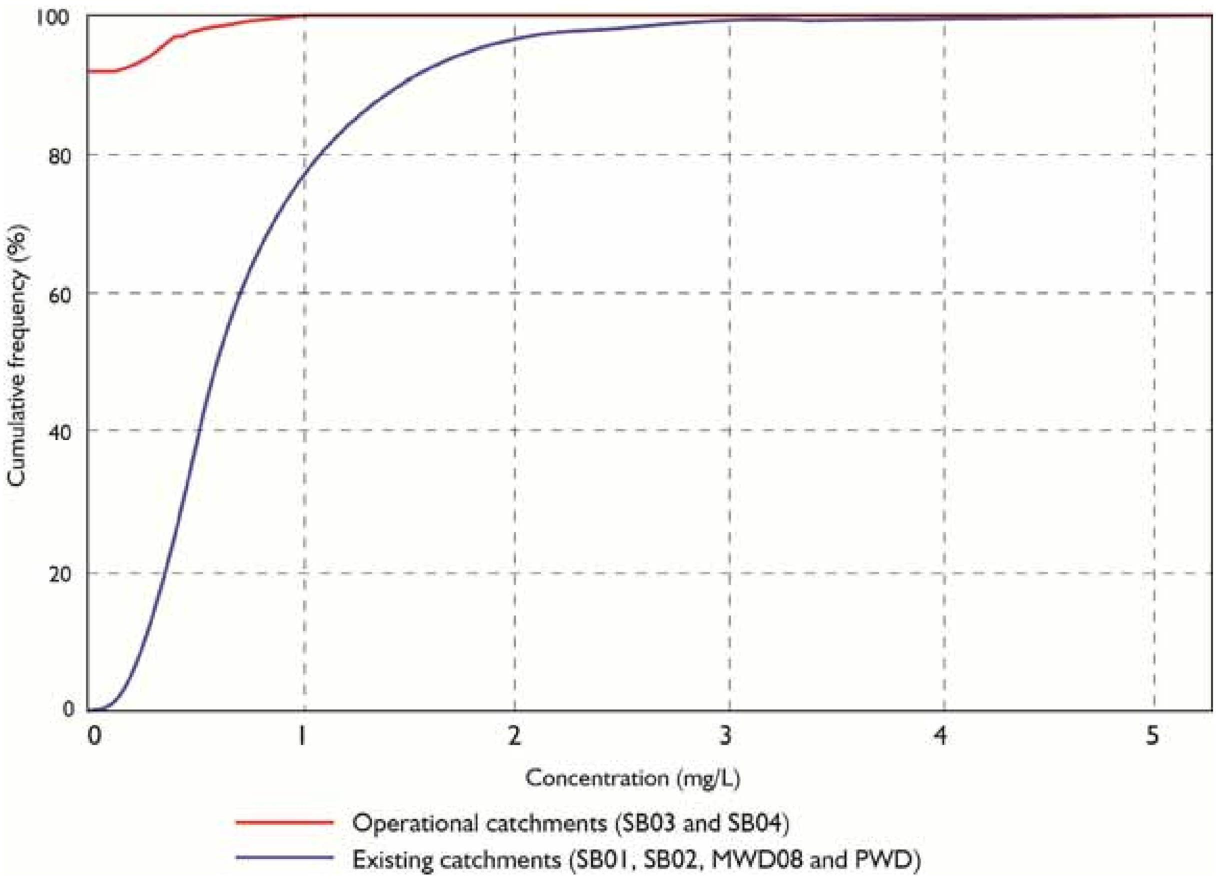


Figure 10.3 Cumulative frequency graph for stormwater discharge to Oldbury Creek – TP

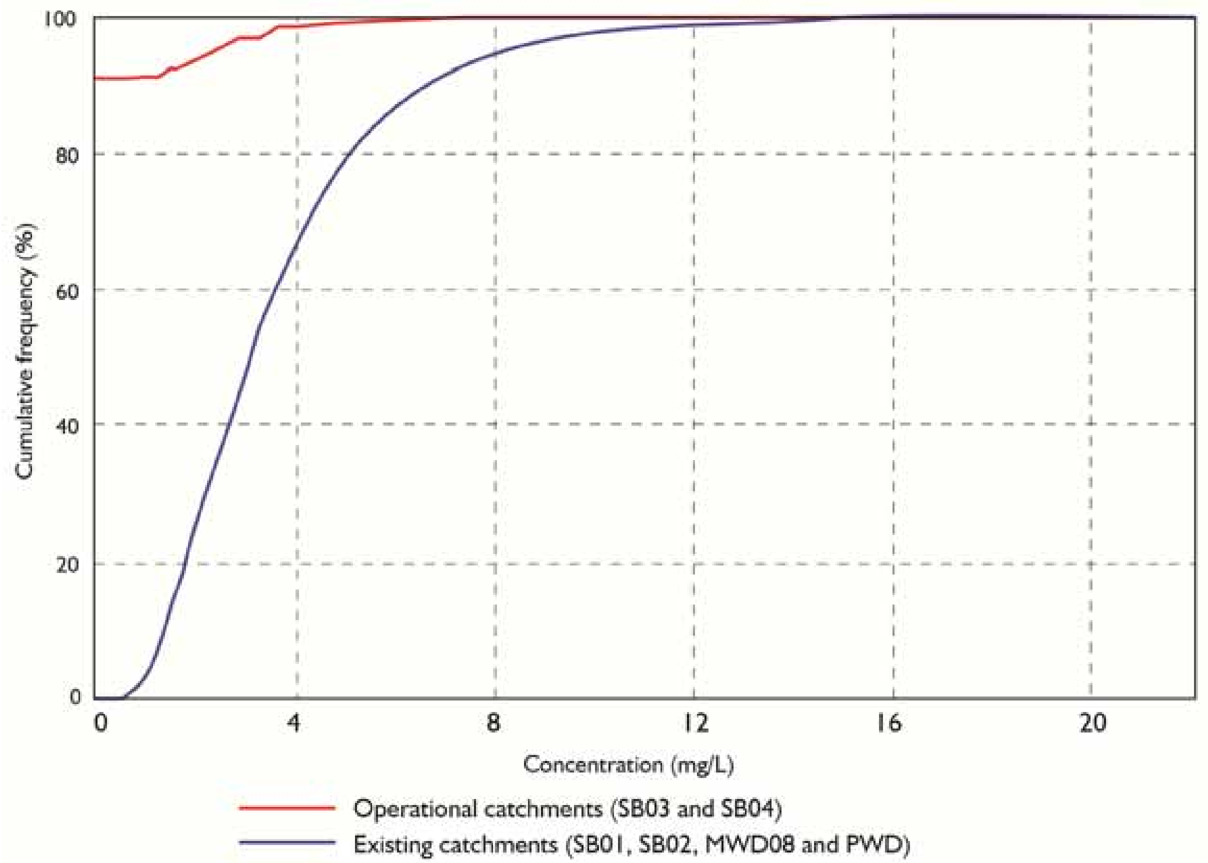


Figure 10.4 Cumulative frequency graph for stormwater discharge to Oldbury Creek – TN

Although the first flush is expected to remove most potential contaminants from the catchment, some contaminants may still be present in the runoff collected in SB03 and SB04 after first flush has been captured (and pumped to the PWD). While the risk of coal contact in these catchments is expected to be minimal, this potential source of contamination has still been assessed. Based on comparing a coal and reject leachate test with baseline water quality results from the natural catchment, the contaminants that could be at elevated concentrations are: calcium, magnesium, sulphate, aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, zinc, and lower pH. Preferred levels of mean concentrations of key indicator parameters (pH, TDS, TSS, and Oil and Grease) in SB03 and SB04 have been proposed (refer to Table 8.4). These contaminants would be monitored at SB03 and SB04 as part of the routine monitoring program and the levels managed, with the option to treat before release where required. Testing for TDS and pH will be undertaken to inform decisions on whether to release water. As such, water quality effects are expected to be negligible.

ii Mine access roads

The results of MUSIC modelling to assess the potential changes of runoff from the two mine access roads outside the water management system indicate that, with vegetated swales used as a treatment measure, NorBE criteria will be met.

Results indicate a significant reduction of 10% or more, and therefore acceptable within NorBE criteria, of the mean annual TSS and nutrient loads for the operations phase compared with the existing situation (Table 10.5). The reduction is achieved through providing vegetated swales to treat the road runoff. To meet the NorBE criteria, the swales must be 730 m and 500 m long for the sealed road catchment and the unsealed road catchment, respectively.

A sample of the cumulative frequency plots of TN and TP concentrations for the existing and operational scenarios are shown in Figure 10.5 and Figure 10.6. The results indicate that pollutant concentrations for the operational scenario are equal to or lower than the existing scenario between the 50th and 98th percentiles, and are therefore compliant with NorBE criteria.

Table 10.5 Mean annual loads from access road catchments during existing and operation scenarios, and NorBE criteria

Catchment	Parameter	Mean annual load			% reduction (no swales)	% reduction (with swales)	NorBE criteria
		Existing	Operation	Operation with swale treatment			
Sealed road northern catchment (3.07 ha)	TSS (kg/yr)	1250	3940	215%	410	-67%	≥10% reduction
	TP (kg/yr)	3.77	6.79	80%	1.55	-59%	≥10% reduction
	TN (kg/yr)	19.7	31.6	60%	17.5	-11%	≥10% reduction
Sealed road middle catchment (0.99 ha)	TSS (kg/yr)	413	580	40%	176	-57%	≥10% reduction
	TP (kg/yr)	1.18	1.06	-10%	0.484	-59%	≥10% reduction
	TN (kg/yr)	5.9	31.6	2%	5.2	-10%	≥10% reduction
Sealed road southern catchment (0.56 ha)	TSS (kg/yr)	357	413	16%	189	-47%	≥10% reduction
	TP (kg/yr)	0.846	0.735	-13%	0.442	-48%	≥10% reduction
	TN (kg/yr)	4.02	3.73	-7%	3.53	-12%	≥10% reduction
Unsealed road (1.32 ha)	TSS (kg/yr)	276	7,240	79.1	-2,523%	71%	≥10% reduction
	TP (kg/yr)	1.19	3.32	0.454	-179%	62%	≥10% reduction
	TN (kg/yr)	6.66	14	5.79	-110%	13%	≥10% reduction

Notes: 1. A negative % reduction implies an increase in mean annual load.

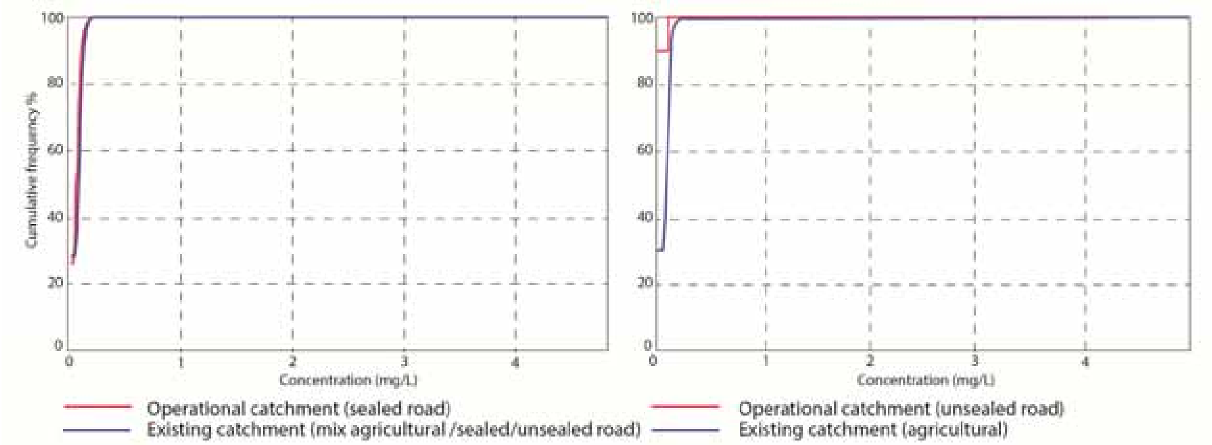


Figure 10.5 Cumulative frequency graph for access roads (sealed northern catchment and unsealed) – TP

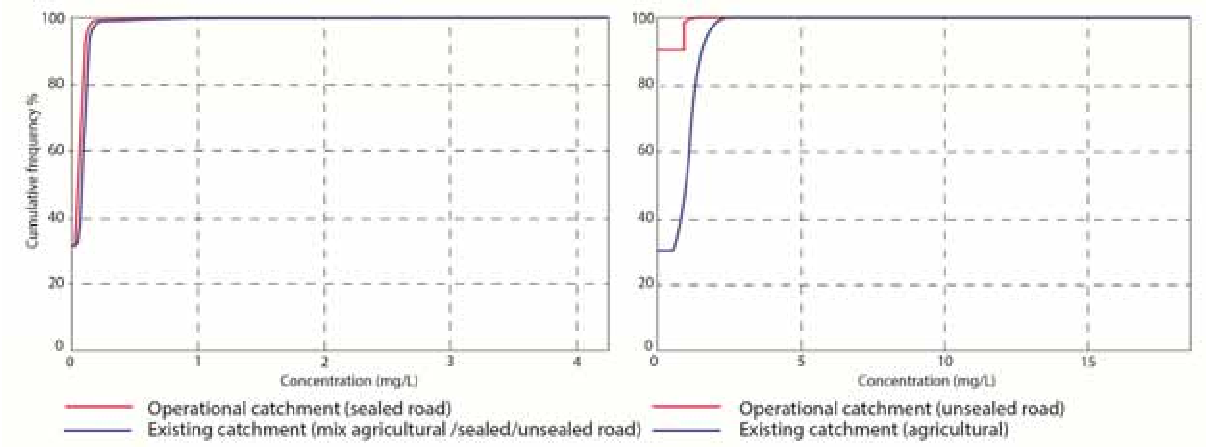


Figure 10.6 Cumulative frequency graph for access roads (sealed northern catchment and unsealed) – TN

iii Depressurisation of groundwater systems from underground mining

Numerical groundwater modelling predicts that baseflow in drainage lines will be decreased as a result of the underground mining activities depressurising groundwater systems. This is discussed in detail in Section 11.1.3 and Appendix E (WSP PB 2016b). A reduction in baseflow will result in reduced loadings in all parameters. However, some contaminant concentrations may increase as a result of reduced baseflow. This occurs where concentrations in groundwater are lower than surface water (ie reduction in baseflow results in less dilution of surface water concentrations). On the other hand, some contaminant concentrations may decrease as a result of decreased baseflow where concentrations in groundwater are higher than surface water (ie reduction in baseflow results in less total contaminant mass present in streamflow). In this latter case, surface water quality would be improved with a reduction in baseflow.

Comparison of baseline groundwater and surface water results indicates most contaminants (monitored analytes) were generally higher in concentration in groundwater than in surface water; ie a reduction in baseflow would improve surface water quality. However, nitrate, phosphorus, calcium, sodium, sulphate, and aluminium were generally higher in surface water than groundwater; ie a reduction in baseflow would increase concentrations of these contaminants.

Increases in contaminant concentrations would not necessarily have a detrimental effect on the beneficial use of the surface water. Comparison of 80^{th} percentile baseline surface water quality results with the relevant ANZECC, ADW, and HRC guidelines indicates that:

- nitrate results were below and calcium, sodium, sulphate results were well below guideline values, and, therefore, changes in these concentrations are unlikely to affect the beneficial use of the surface water;
- phosphorus results exceeded the HRC guideline value; and
- aluminium results exceeded the guideline values for aquatic ecosystems and, in some locations, the ADW guidelines, but not the guidelines for irrigation or livestock.

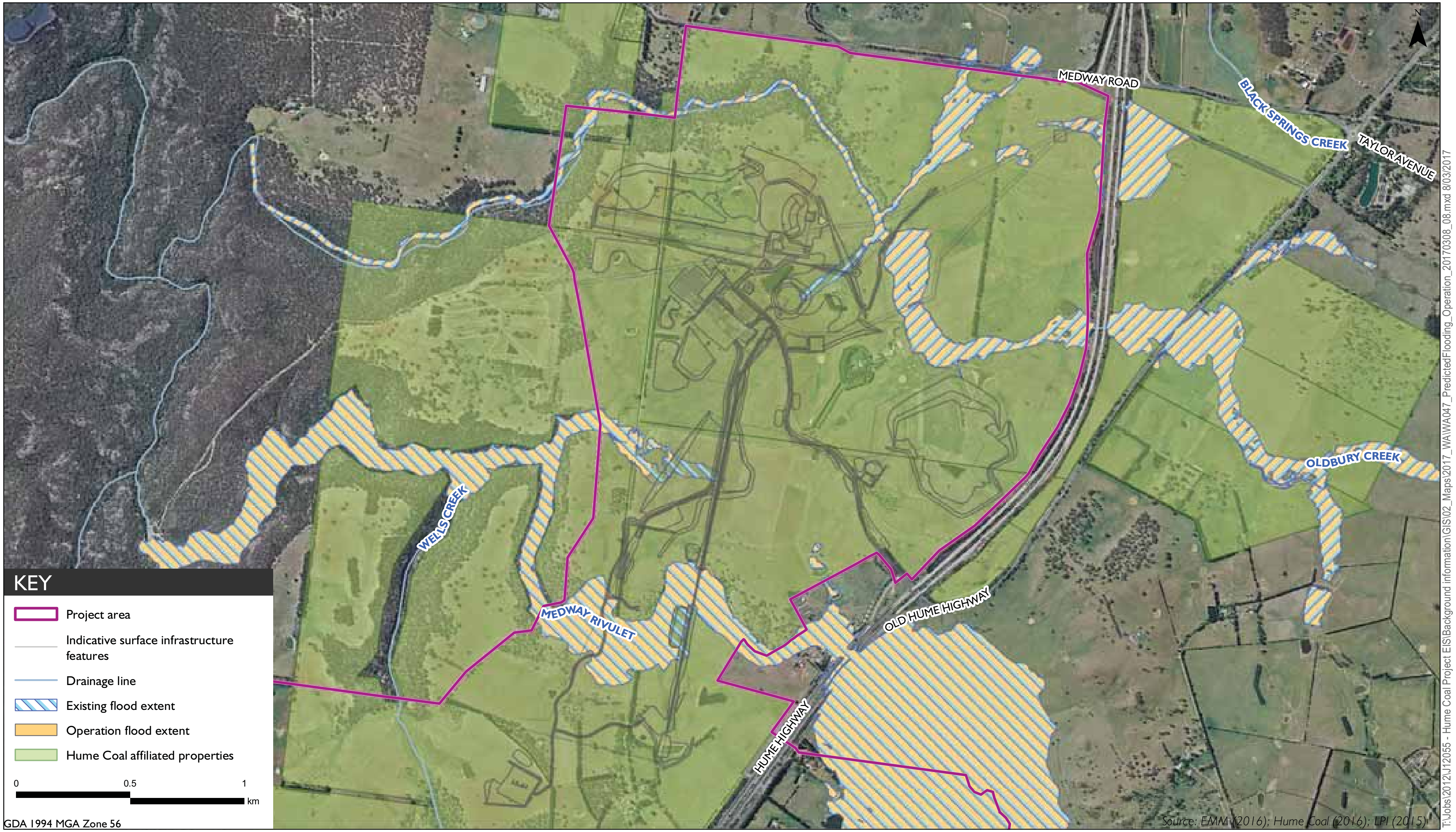
Increases in aluminium concentrations are unlikely to affect the beneficial use for irrigation and livestock use within the project area. Although phosphorus concentrations are higher in surface water than groundwater, there is little difference between the two in most cases. Minor increases in concentrations of phosphorus as a result of reduction in baseflow are, therefore, unlikely to significantly alter the beneficial use of the surface water.

10.3 Flood regime

SEAR 3: An assessment of the potential flooding impacts of the development.

10.3.1 Flood extent

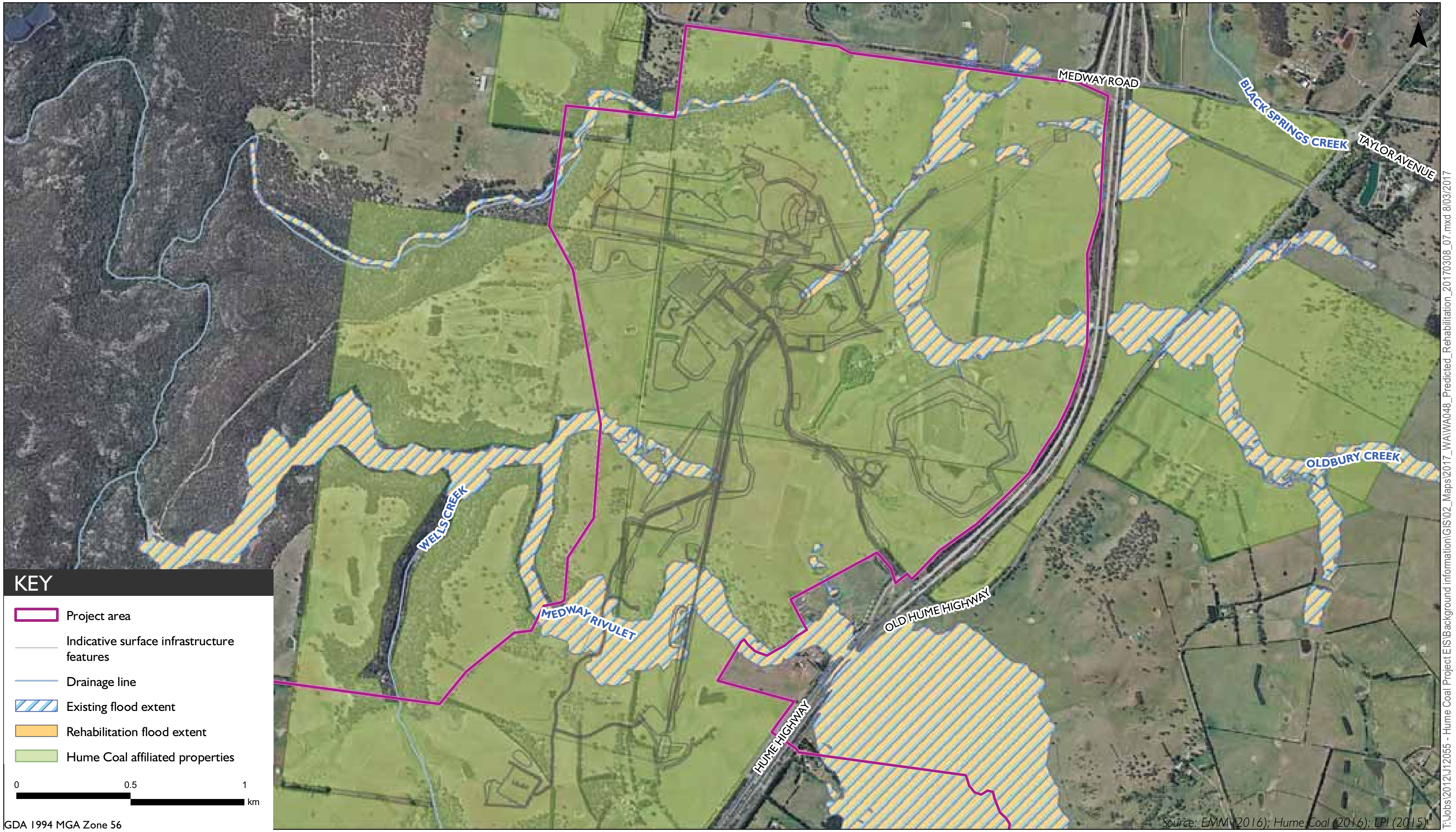
The predicted maximum flood (PMF) extents for the 100 year ARI event are shown comparing the existing, and operation, and the existing and rehabilitation project phases in Figure 10.7 and Figure 10.8, respectively. Predicted flood extents comparing the 5 year and 20 year ARI and PMF for existing, operation, and rehabilitation scenarios are included in Appendix G (WSP PB 2016d). Results of the hydrologic modelling indicated there will be minor change in the 100 year ARI flood extents for the operation phase compared to the existing, pre-project, situation. Changes in flood extents following mine rehabilitation, compared to the existing situation, are only predicted in the area where SB02 will be located during mine operation.



Predicted flooding extent (1 in 100 year) – operation

Hume Coal Project
Water Assessment

Figure 10.7



Predicted flooding extent (1 in 100 year) – rehabilitation

Hume Coal Project
Water Assessment

Figure 10.8

EMM HUMECOAL

10.3.2 Flood levels

Changes in flood levels (afflux) between the existing and operation phase, and between the existing and rehabilitation phase have been assessed for cross sections generated from the hydrologic model. The selected cross sections are located across areas of interest, including privately owned land, locations where existing roads cross streams, and locations where new infrastructure is proposed to cross streams. Detailed results for the 5 year, 20 year, and 100 year ARI, and PMF extents are included in Appendix G (WSP PB 2016d).

The predicted affluxes for the operation phase are within the assessment criteria presented in a 9.3.1iii, with the exception of localised afflux values of up to 340 mm in Oldbury Creek on land owned by Hume Coal between the PWD and SB02. The areas with predicted localised afflux values greater than the assessment criteria have been considered in the design of the surface infrastructure area and water management system, so that flood levels are effectively managed without impacts on project infrastructure or surrounds.

The predicted affluxes for the rehabilitation phase are negligible and considered acceptable, with reference to the assessment criteria presented in a 9.3.1iii, for land outside of Hume Coal's ownership. The difference noted above between PWD and SB02 will be reduced during the rehabilitation stage, however, a localised afflux of up to 400 mm remains downstream of the instream storage on Oldbury Creek (Hume Coal owned land).

10.3.3 Flood velocities

Infrastructure crossing streams, including bridges and culverts, can change the velocity of stream flow local to the infrastructure. An increase in the velocity of streamflow can cause erosion and scour of bed sediments and impact on surface water quality and the stability of instream structures.

Peak velocities downstream of new infrastructure crossing streams in the flooding assessment study area (refer to Section 1.6) are shown in Appendix G (WSP PB 2016d). Peak velocities are presented for the following new infrastructure:

- the conveyor crossing Medway Rivulet to transport coal from the conveyor drift to the administration and workshop area;
- the road crossing Medway Rivulet to provide access between the conveyor drift and ventilation shaft and the administration and workshop area, which includes 17 box culverts; and
- the embankment at the downstream end of the instream storages on Oldbury Creek, which will be raised and used to provide access between the CPP area and the train load out facility. The embankment will have an access road, a conveyor to transport coal and poles for electricity lines.

The project will not include any structures that pose significant obstruction to or constriction of flood flows. Peak velocities are expected to increase locally around the conveyor piers and box culverts and scour protection measures will need to be implemented.

The changes in peak velocities presented in Appendix G (WSP PB 2016d) are for cross-sections immediately downstream of the new infrastructure. Changes in peak velocity are in the range ± 0.3 m/s. The results show that the change in velocity at these downstream locations is minor and considered acceptable, with reference to the assessment criteria presented in a 9.3.1iii.

10.4 Cumulative impacts

AR 18: Assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.

The proposed Berrima Rail Project is upstream of the project in the Oldbury Creek catchment (Figure 1.2).

Surface water flows will not be influenced by construction, operation or rehabilitation of the Berrima Rail Project. The Berrima Rail Project will not take water from streams, discharge water to streams or cause groundwater impacts that would decrease baseflow to streams. In addition, the rail infrastructure for the Berrima Rail Project will not reduce the volume of flow because culvert structures will be built where the rail crosses waterways. Cumulative impacts to flow and bed and bank stability associated with the Hume Coal and Berrima Rail projects is predicted to be negligible. Refer to the Berrima Rail Project EIS (EMM 2017d).

The surface water quality assessment for the Berrima Rail Project indicates that with appropriate management plans and treatment measures in place (ie swales), the water quality in Oldbury Creek will not be influenced by constructing, operating, or rehabilitating the Berrima Rail Project. Cumulative changes to surface water quality associated with the Hume Coal and Berrima Rail projects will therefore be negligible. Refer to the Berrima Rail Project EIS (EMM 2017d) for details of the surface water assessment.

The cumulative impacts of the project and Berrima Rail Project were assessed in the Oldbury Creek catchment where infrastructure from both projects is located. Refer to Appendix G for assessment (WSP PB 2016d). Comparison of the 100 year ARI flood extents shows that changes in flood extent during operation will occur:

- upstream of where the rail line crosses Oldbury Creek south west of Berrima Cement Works;
- just upstream of the Hume Highway on a tributary of Oldbury Creek; and
- near the rail loop.

The majority of changes in flood extent occur on land owned by Hume Coal or Boral. The increased flood extent upstream of the Hume Highway is minor.

Around the rail loop, the Hume Highway and around Berrima Cement Works disturbance are all only related to the rail infrastructure. Downstream near the project these works are not relevant. Similarly, localised flooding caused by the project does not contribute to these areas upstream that are affected by the rail infrastructure. Therefore, both projects do not have a cumulative impact on flooding in Oldbury Creek. Further details of the flooding effects of the Berrima Rail Project are addressed in the Berrima Rail Project EIS.

10.5 Predicted impacts on surface water users, drainage lines and riparian land

The possible predicted effects on sensitive surface water users, as defined in Section 9.1, are described below. In summary:

- Surface water users and stream environments:
  - Changes to flow for licensed and basic rights users due to the reduction in catchment area and reduction in baseflow are predicted to be minor or negligible in the Medway Rivulet and Oldbury Creek, with the assumption that Moss Vale STP continues low flow discharge in the Medway Rivulet tributary. Changes in yield for licensed and basic rights users due to the reduction in catchment area and reduction in baseflow are predicted to be minor or negligible. As per the *Significant impact guidelines* (DoE 2013), surface water flow and yield changes are considered **insignificant**.
  - Stream bank erosion changes can be mitigated via an erosion and sedimentation control plan. This is further discussed in Section 10.5.1. As per the *Significant impact guidelines* (DoE 2013), these changes are considered **insignificant**.
  - Where predicted, water quality changes as a result of discharges from SB03 and SB04 can be mitigated by the implementation of discharge limits and criteria; releases that will occur are predicted to be compliant with NorBE criteria. With provision of vegetated swales, runoff from access roads outside of the water management system is predicted to be compliant with NorBE criteria. Potential increases in contaminants in surface water flow as a result of reduction in baseflow are predicted to be within the appropriate guideline values or are relatively minor increases to an already elevated baseline situation, and are not predicted to alter the beneficial use of the resource. As per the *Significant impact guidelines* (DoE 2013), surface water quality changes are considered **insignificant**.
  - Changes in flood levels as a result of the project for land not owned by Hume Coal are considered acceptable with reference to the assessment criteria. Changes to flood peak velocities are considered acceptable with reference to the assessment criteria. As per the *Significant impact guidelines* (DoE 2013), flooding changes are considered **insignificant**.

Predicted effects to the remaining users defined in Section 9.1 (including "watercourses, drainage lines, creeks, and swamps that receive baseflow") are discussed in Section 11.4.

Potential impacts to users associated with changes in the flow regime that have been assessed include:

- erosion of stream banks associated with an increase in stream energy and bank full flow events (due to water releases from SB03 and SB04, and the WTP, if required);
- decreased access for water users associated with a decrease in streamflow (due to reduced catchment area and intercepted baseflow); and
- decreased availability of water for instream and riparian ecosystems associated with a decrease in streamflow (due to reduced catchment area and intercepted baseflow).

Decrease in streamflow associated with project storage catchments and decrease in baseflow as a result of underground mining has the potential to decrease streamflow available to instream ecosystems and overbank flows and flooding available to riparian ecosystems. Potential ecological impacts associated with the predicted changes in flow regime and sedimentation has been assessed in the *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c).

10.5.1 Stream bank erosion

Drainage lines identified as prone to erosion are located upstream of the surface infrastructure area (refer to drainage lines identified as 'laterally unconfined valley setting', 'partly-confined valley setting', and 'laterally unconfined' in Figure 5.2). Whereas, next to and downstream of the surface infrastructure area, Medway Rivulet and Oldbury Creek are in confined valley settings and the channels are bedrock controlled.

During the project's operational phase, the risk of stream bank erosion would be low and could be managed by appropriate mitigation measures. Discharges to Oldbury Creek would occur in a reach classified as 'confined valley setting – occasional floodplain pockets' (Figure 5.2). Discharge would occur as piped outflows from SB03 and SB04 (combined) and from the WTP if required, into or just upstream of the existing instream storage north of the PWD. Scour protection will be required at the discharge outlets and potentially reinforcement of the existing spillways following assessment. Downstream, the channel is bedrock controlled and the risk of stream bank erosion due to this discharge is considered negligible.

During construction and rehabilitation, an erosion and sedimentation control plan, developed in accordance with Landcom (2004) and DECC (2008) guidelines, will be prepared to manage and mitigate potential erosion and sedimentation induced by the project so as not to adversely affect the surrounding environment. With the implementation of this plan, erosion and sedimentation changes during the construction and rehabilitation phases are expected to be minimal. Temporary erosion and sedimentation control measures include: sediment basins, sediment fences, diversion banks, check dams, batter chutes, temporary culverts, and scour protection. This is discussed further in Chapter 13.

Based on the above, the predicted changes to stream banks as a result of erosion induced by the project are considered **insignificant**.

10.5.2 Reduced access for water users

i Flow

Decreased streamflow associated with reduced catchment size and reduction of baseflow due to underground mining has the potential to reduce access to surface water for downstream water users. As discussed in Section 5.5, downstream of the surface infrastructure area, Medway Dam is the only licensed user in the Medway Rivulet; although the associated treatment plant was operated for town water supply it is not currently being used. Landholders with basic water rights are located downstream and upstream of the surface infrastructure area. There is potential for a reduction in streamflow in the Medway Rivulet.

The potential for a low flow regime is mainly attributable to the interception of baseflow associated with underground mining depressurising groundwater systems. The interception of baseflow in the Medway Rivulet catchment will decrease to less than 0.1 ML/day 17 years after mining begins (Figure 11.2) and will decrease to 0 ML/day 38 years after mining begins as groundwater levels recover (Coffey 2016b).

Based on the information above, licensed and basic rights flow changes are predicted to be minor or negligible.

The reduction in low flows in the Medway Rivulet catchment if discharges from the Moss Vale STP do not occur has the potential to decrease the connectivity of pools and increase the potential for pools to dry out. This has the potential to affect access for landholders with basic water rights. However, the Moss Vale STP discharges are likely to continue throughout the mining operations and therefore impacts on access for landholders with basic water rights are unlikely (refer to Figure 10.1). The potential impacts to instream ecosystems associated with these predicted changes are discussed in the *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c).

ii Yield

Under wet conditions, the project will result in up to a 0.5% reduction in surface water yield in the Medway Dam catchment, and under dry conditions the project will result in up to a 0.9% reduction in yield. These values represent the approximate reduction in yield to Medway Dam. Hume Coal will hold water access licences (WALs) to account for these reductions in streamflow.

The numerical groundwater model for the project (Coffey 2016b) indicates that under existing (pre-mining) conditions, Medway Dam loses about 0.5 ML/day to underlying aquifers. The model predicts that during operation of the mine, losses from Medway Dam to underlying groundwater systems will increase to 0.6 ML/day (ie an increase of 0.1 ML/day). These additional losses from Medway Dam over the life of the project are about 36.5 ML/year. Hume Coal will hold WALs to account for these losses from the dam (refer to Chapter 12). For comparison, annual evaporation from Medway Dam is estimated to be about 100 ML/year (refer to Section 2.1.3).

Locally, changes to yield will be largest in the Oldbury Creek sub-catchment, with up to a 4.1% reduction in yield under wet conditions and up to a 4.2% reduction in yield under dry conditions. Most of the creek where this impact would occur is fronted by land owned by Hume Coal, and downstream of it, the creek geomorphology is typically confined valleys. As such, the effect on basic rights use is expected to be minimal or negligible. There are no licensed users on Oldbury Creek other than on Hume Coal property.

The Medway Rivulet Management Zone (Figure 2.4) is upstream of the Lower Wingecarribee River Management Zone. Under wet conditions, the project will result in a 0.8% reduction in yield for the Medway Rivulet Management Zone, and under dry conditions the project will result in a 1.4% reduction in yield. These changes in the Medway Rivulet Management Zone would produce negligible effects downstream in the substantially larger Lower Wingecarribee Management Zone.

Based on the information above, changes in yield for licensed and basic rights users due to the reduction in catchment area and reduction in baseflow are predicted to be minor or negligible.

11 Groundwater assessment

This chapter outlines the results of the impact assessments for project-related impacts to groundwater resources and water users.

SEAR 1: As assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources, having regard to the EPA's, DPI's and Water NSW requirements and recommendations.

SEAR 2: An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.

AR 2: A groundwater assessment to determine the likelihood and associated impacts of groundwater accumulating and subsequently discharging from the workings post cessation of mining, including consideration of the likely controls require to prevent or mitigate against these risks as part of the closure plan for the site.

AR 14: Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, wetlands, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.

AR 20: Assessment of whether the activity may have a significant impact on water resources, with reference to the Commonwealth Department of Environment Significant Impact Guidelines.

AR 21: If the activity may have a significant impact on water resources, then provision of information in accordance with the Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals, including completion of the information requirements checklist.

AR 29: The EIS should take into account the following policies (as applicable):
· NSW Guidelines for Controlled Activities on Waterfront Land (NOW, 2012)
· NSW Aquifer Interference Policy (NOW, 2012)
· Risk Assessment Guidelines for Groundwater Dependent Ecosystems (NOW, 2012)
· Australian Groundwater Modelling Guidelines (NWC, 2012)
· Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals (IESC, 2014)
· Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments - impacts on water resources (Australian Govt. 2014)
· NSW State Rivers and Estuary Policy (1993)
· NSW Wetlands Policy (2010)
· NSW State Groundwater Policy Framework Document (1997)
· NSW State Groundwater Quality Protection Policy (1998)
· NSW State Groundwater Dependent Ecosystems Policy (2002)
· NSW Water Extraction Monitoring Policy (2007)
· Groundwater Monitoring and Modelling Plans - Information for prospective mining and petroleum exploration activities (NOW, 2014)
· NSW Code of Practice for Coal Seam Gas Well Integrity (DTIRIS 2012)
· NSW Code of Practice for Coal Seam Gas Fracture Stimulation (DTIRIS 2012)

AR 45: *Assessment of predicted impacts on the following:*
- *flow of surface water (including floodwater), sediment movement, channel stability, and hydraulic regime,*
- *water quality*
- *flood regime*
- *dependent ecosystems*
- *existing surface water users*
- *planned environmental water and water sharing arrangements prescribed in the relevant water sharing plans*

AR 50: The predicted impacts of any final landform on the groundwater regime.

AR 58: The results of any models or predictive tools used.

AR 59: Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users, including information on:
- *Any proposed monitoring programs, including water levels and quality data. Reporting procedures for any monitoring program including mechanism for transfer of information*
- *An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal*
- *Identification of any nominal thresholds as to the level of impact beyond which remedial measures or contingency plans would be initiated (this may entail water level triggers or a beneficial use category)*
- *Description of the remedial measures or contingency plans proposed*
- *Any funding assurances covering the anticipated post development maintenance cost, for example on-going groundwater monitoring for the nominated period*

AR 66: Detailed modelling of potential groundwater volume, flow and quality impacts of the presence of an inundated final void (where relevant) on identified receptors specifically considering those environmental systems that are likely to be groundwater dependent.

AR 69: The EIS must assess the impacts of the development on water quality, including:
a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction.
b. Identification of proposed monitoring of water quality.

AR 75: If WQO's cannot be met for the project, demonstrate that all practical options to avoid water discharge have been implemented and outline any measures taken to reduce the pollutant loads where a discharge is necessary. Where a discharge is proposed, analyse the expected discharges in terms of impact on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm.

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 82: An assessment of the relevant impacts of the action on water resources including:
- a description and detailed assessment of the nature and extent of the likely direct, indirect and consequential impacts, including short term and long term relevant impacts
- a statement whether any relevant impacts are likely to be known, unpredictable or irreversible, and analysis of the significance of the impacts;
- any technical data and other information used or needed to make a detailed assessment of the impacts

AR 85: The assessment of impacts should include information on:
- any substantial and measureable changes to the hydrological regime of the water resource, for example a substantial change to the volume, timing, duration or frequency of ground and surface water flows
- the habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the water resource being seriously affected
- substantial and measureable change in the water quality and quantity of the water resource – for example, a substantial change in the level of salinity, pollutants, or nutrients in the wetland; or water temperature that may adversely impact on biodiversity, ecological integrity, social amenity or human health

11.1 Numerical groundwater model predictions

Detailed results of the numerical groundwater model are included in Appendix I (Coffey 2016b). A summary of results is included in the following sections.

11.1.1 Inflows to mine

The average yearly inflow to the mine sump is 440 ML/yr and 1,157 ML/yr to the sealed underground void.

Inflows to the sump occur over a period of 19 years until the end of mining. Inflows to the void, however, continue after this period and through the recovery of the groundwater system. The model predicts that the drawdown as a result of the project will return to pre mining conditions within 72 years from commencement of mining. The water table largely recovers to 2 m drawdown or less over most of the area within 60 years after the start of mining.

Modelled annual inflows to the sump and the void are shown in Figure 12.1.

The model results indicate that inflow to the Hume Coal mine workings is sourced mainly from groundwater systems. There is a small volume from intercepted baseflow and an even smaller volume of loss predicted from surface water storage (Medway Dam).

The predicted maximum rate of release of groundwater from groundwater storage, and the respective percentage contribution from each source, as a result of the project is shown in Table 11.1. The vast majority of groundwater inflow to the mine is sourced from the Nepean Management Zone 1; which is to be expected given the project area is entirely within this management zone of the water source.

The rate of predicted baseflow reduction as a result of the project is discussed in Section 11.1.2 below, and the source of this is groundwater. Surface water leakage from Medway Dam is predicted to be at an average of 36.5 ML/yr.

Table 11.1 Maximum rate of release of groundwater from groundwater storage

Groundwater source	Maximum rate of release of groundwater from groundwater storage (ML/day)[1]	Percentage contribution to mine inflow
Nepean Management Zone 1 (NMZ1)	5.206	99.14%
Nepean Management Zone 2 (NMZ2)	0.003	0.06%
Sydney Basin South (SBS)	0.042	0.8%

Notes: 1.Not including baseflow reduction (refer to Table 11.2).

2. The peak daily inflows are not calculated on a yearly time step, and therefore do not necessarily correlate to a peak annual flow.

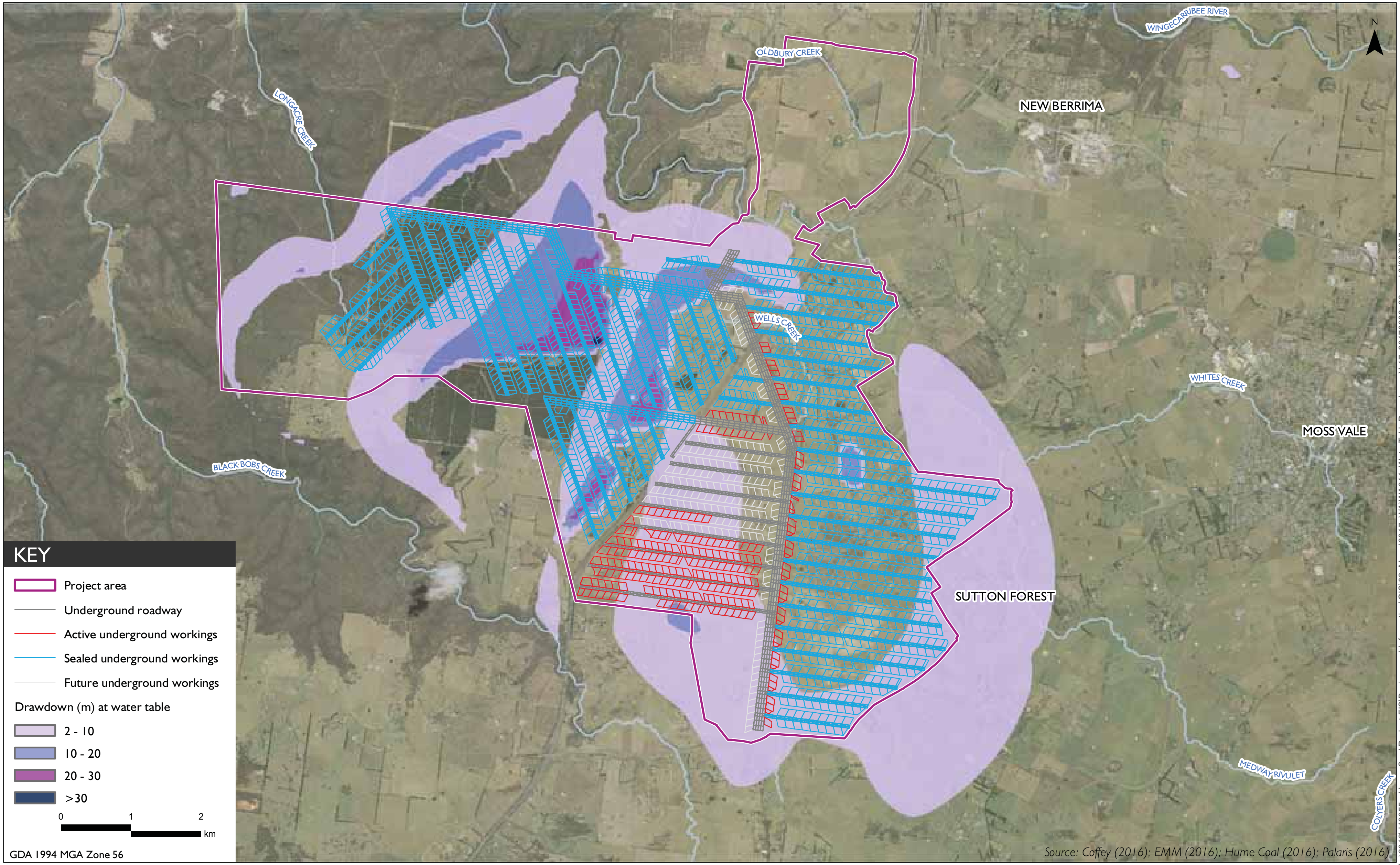
11.1.2 Groundwater levels

Changes to groundwater pressures and water levels were modelled for both the project drawdown influence only and total drawdown (the project plus drawdown effects of existing landholder bore pumping and Berrima Colliery drawdown). The project only simulation was used to determine the bores where drawdown exceeded 2 m interference as stipulated in the Aquifer Interference Policy (AIP).

Maps of the project only and total water table drawdown for each consecutive year of mining and 30, 40 and 50 years since the start of mining are included in Appendix M. The zone affected migrates according to the location of active mine working areas. As shown in the images in Appendix M, the depressurisation effects of the mine are somewhat compensated by rainfall recharge in the western part of the project area, and, in combination with the regional easterly dip in hydraulic conductivity. The maximum project drawdown of about 45 m of the water table is attained in year 17, but is localised in a small zone (about less than 0.25 ha) above the western part of the mine workings. The zone where the water table is affected by 2 m or more total drawdown extends to a maximum of 2 km beyond the mine footprint to the south-east in year 17 (Figure 11.1).

Injection of water into the sealed void greatly decreases the amount of depressurisation above the mine workings. Half of the affected bores recover from the project drawdown by 43 years after mining begins; and all bores recover from the project drawdown by 72 years after mining begins. The recovery time for the project (ie 72 years for bores) is significantly less than some mines in the Hunter Valley and Gunnedah Basin, with some having recovery times in excess of 1,000 years, and many not recovering to pre mining conditions at all (as is the case for some open cut mines with final voids where groundwater continues to be taken).

Refer to Section 11.4 for further discussion on impacts to landholder bores.



T:\Jobs\2012\J12055 - Hume Coal Project EIS\Background information\GIS\02_Maps\2017_WA\WA044_WaterTableDrawdown_Yr17_20170308_08.mxd 8/03/2017

Project induced groundwater table drawdown at Year 17 of mining

Hume Coal Project
Water Assessment

Figure 11.1

EMM HUMECOAL

11.1.3 Changes to surface water flow

The groundwater model indicates that under existing (pre-mining) conditions, Medway Dam loses about 0.5 ML/day to the groundwater system (pre-mining). The model for the project predicts that during operation of the mine, losses from Medway Dam to groundwater will increase to an average of about 0.6 ML/day. These additional average losses from Medway Dam over the life of the project are therefore 0.1 ML/day (36.5 ML/year).

The maximum rates of baseflow reduction as a result of the project for each water source are shown in Table 11.2. The Lower Wingecarribee River and Medway Rivulet surface water sources have been subdivided into smaller catchments for the purpose of this assessment (Figure 8.5). The model results indicate no reduction in baseflow for the Upper Wingecarribee River, Black Bobs Creek, or Nattai River due to the project.

The maximum rates of baseflow reduction are not consistent throughout the mining period. The times taken to reach the maximum rate for each water source are shown in Table 11.2 For example, the rate of baseflow reduction at the Medway Rivulet water source only exceeds 0.9 ML/day for a portion of one year (during the 11th year after mining begins). Figure 11.2 shows the predicted rate of baseflow reduction over time for each water source based on model predictions. A sharp decline in baseflow reduction occurs after 17 years of mining, to less than 0.1 ML/day, when much of the mine is sealed and groundwater levels start to recover.

The Lower Wingecarribee River and the Medway Rivulet surface water sources are predicted to have the highest sustained rates of baseflow reduction; although, most creeks and watercourses would see recovery towards pre-mining baseflow conditions by around year 18 (Figure 11.2).

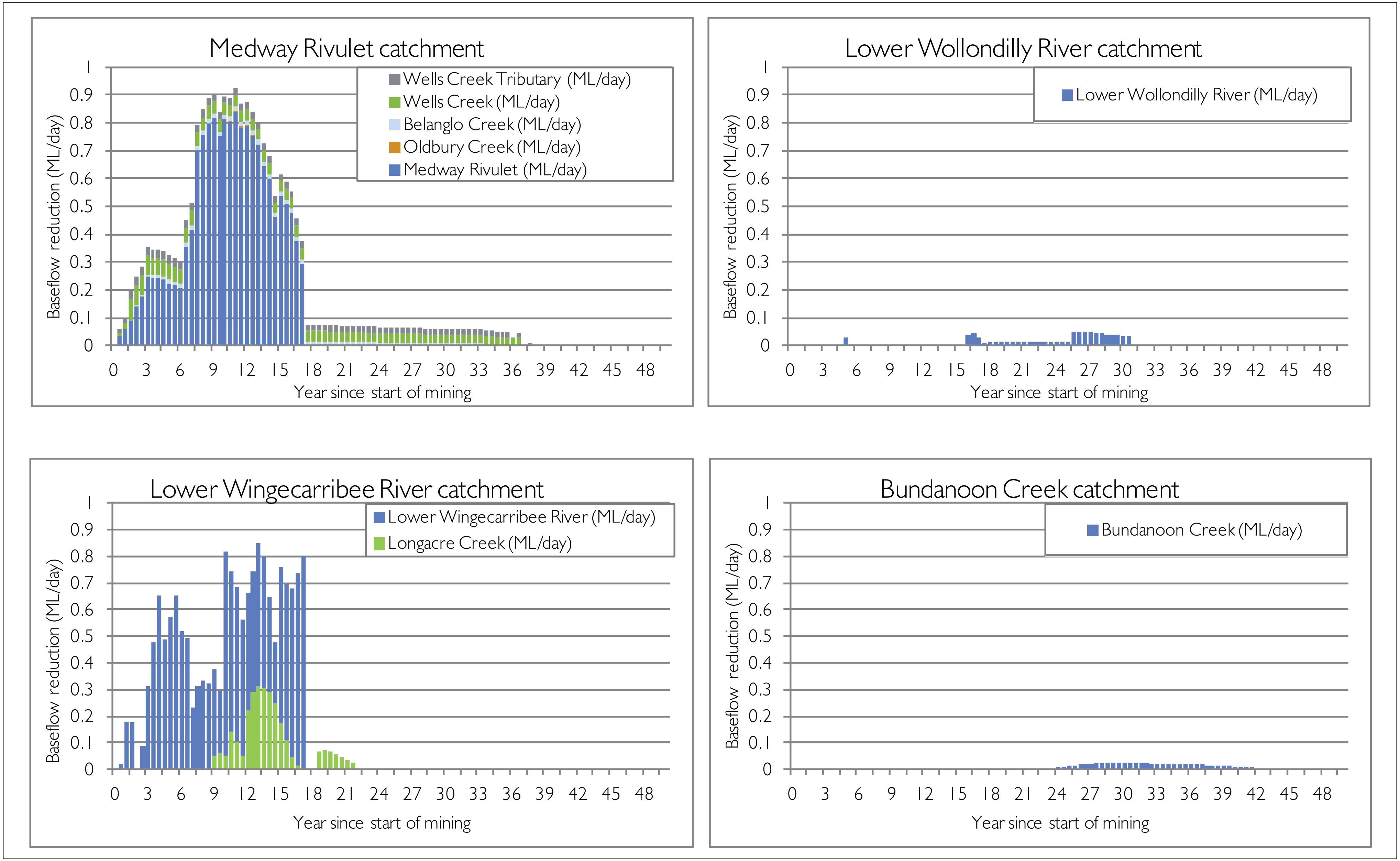
The average Medway Rivulet baseflow rate estimated from baseline monitoring data is 3.3 ML/day at SW04 during average rainfall conditions (Coffey 2016b). This is about three times larger than the predicted maximum rate of baseflow reduction (0.9 ML/day). The model results suggest the reduction in baseflow in the Medway Rivulet will be a minor proportion of the total baseflow and is, therefore, unlikely to influence other users of the surface water source, during a range of climate conditions (Coffey 2016b).

The predicted drawdown in the groundwater regime due to the mine would extend beyond the 22 years of mining activities but would decrease progressively, mitigated by rainfall and runoff.

Table 11.2 Maximum rate of baseflow reduction from surface water sources

Surface water source	Corresponding groundwater source	Maximum rate of baseflow interception (ML/day)		Time to maximum rate (years since start of mining)
		Whole source	Tributary	
Upper Wingecarribee River	NMZ1	0		-
Lower Wingecarribee River (whole source)		0.849		13
Lower Wingecarribee River excluding Black Bobs and Longacre Creeks	NMZ1, NMZ2		0.800	17
Black Bobs Creek	NMZ1		0	-
Longacre Creek	NMZ1		0.311	13
Medway Rivulet (whole source)		0.927		11
Medway Rivulet excluding Oldbury, Belanglo, and Wells Creeks, and Wells Creek tributary	NMZ1		0.841	11
Oldbury Creek	NMZ1		0.002	11
Belanglo Creek	NMZ1		0.017	9.5
Wells Creek	NMZ1		0.075	1.5
Wells Creek tributary	NMZ1		0.033	1.5
Lower Wollondilly River	NMZ1	0.050		26
Nattai River	NMZ1, NMZ2	0		-
Bundanoon Creek	SBS	0.024		28

Notes: NMZ1– Sydney Basin Nepean Groundwater Source Nepean Management Zone 1.
NMZ2 – Sydney Basin Nepean Groundwater Source Nepean Management Zone 2.
SBS – Sydney Basin South Groundwater Source.



Predicted baseflow reduction rates for surface water sources

Hume Coal Project

Water Assessment

Figure 11.2

11.2 Groundwater quality

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

AR 53: An assessment of the potential for groundwater contamination (considering both the impacts of the proposal on groundwater contamination and the impacts of contamination on the proposal).

AR 73: Estimate the chemical composition and load of chemical and physical stressors and toxicants in any discharge with ANZECC 2000 trigger values for the various environmental values of the waterway.

Groundwater quality assessment results are presented and discussed in detail in Appendix K. The results and impact assessment are summarised in the following sections.

11.2.1 Effects of induced leakage from Wianamatta Group to Hawkesbury Sandstone

The groundwater numerical model was used to quantify the simulated flow of groundwater from the low permeability Wianamatta Group shale to the upper Hawkesbury Sandstone. Simulations were run for a 100 year time period, both with and without the influence of the project's activities, to provide a baseline groundwater flux in the absence of the project influences and with mining.

The baseline migration of groundwater with higher salinity from the Wianamatta Group shales to the upper Hawkesbury Sandstone was consistently around 11.1 ML/day for the entire simulation period. This rate for comparison is equivalent to a very small rainfall event of 0.04 mm per day.

Including the project's activities, an incremental increase in the vertical flow was predicted between years 1 and 74, peaking in the year 14.5 time step at 12.1 ML/day, or a 1 ML (9%) increase above the baseline conditions. For comparison an additional 1 ML/day of groundwater migration from the Wianamatta Group shale to the Hawkesbury Sandstone is equivalent to a rainfall event of 0.004 mm per day. The incremental flow over the simulation period is presented in Figure 11.3.

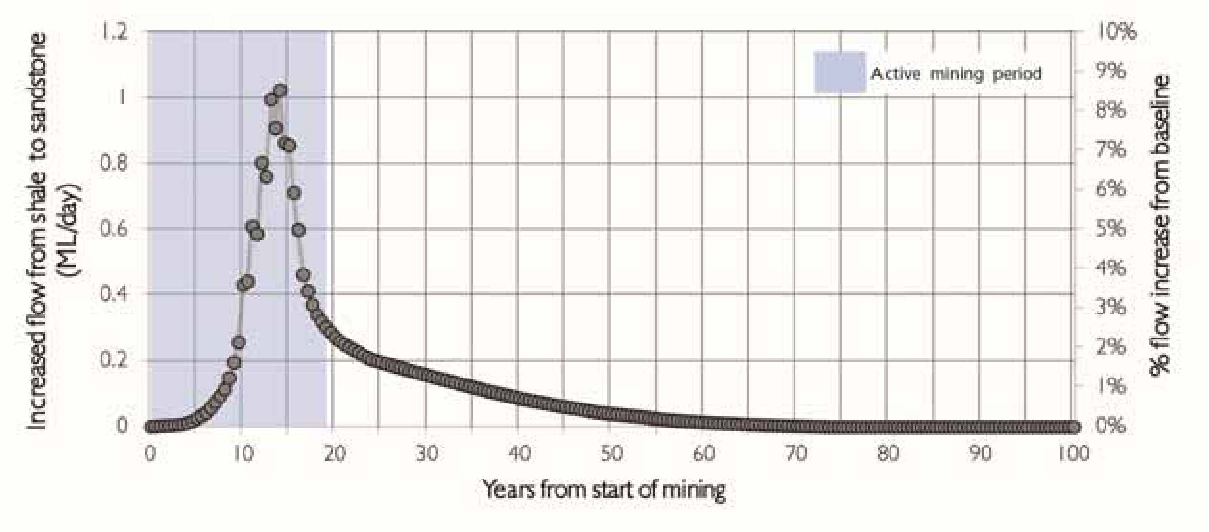


Figure 11.3 Predicted increase in groundwater flow from Wianamatta Group shale to upper Hawkesbury Sandstone due to mining

The temporary increase in groundwater flow from the shale to the upper Hawkesbury Sandstone could result in an increased solute (salt) load in the upper water bearing formations within the affected portion of the Hawkesbury.

The potential influence of the temporary increase in vertical groundwater migration, over about thirty years, should be considered in the context of the baseline conditions. There is currently an 11.1 ML/day flux of groundwater between these two formations due to existing downward vertical hydraulic gradients. The downward gradients are attributable to the effects of mounding in recharge areas and depressurisation from discharge as baseflow or from escarpment faces, as well as the ongoing depressurisation/dewatering effects of the Berrima and Loch Catherine mine voids to the north.

Water quality data from the multi-level monitoring bores, installed in areas where the shale outcrops, was reviewed to assess whether the shale influences the baseline salinity of the underlying Hawkesbury Sandstone. In all cases, the water quality in Hawkesbury Sandstone bores installed beneath areas of shale outcrop were characterised by low TDS conditions (typically below 1,000 mg/L). Bores installed in areas of Hawkesbury Sandstone outcrop generally exhibited slightly lower TDS values, but all were within the range of very low to low EC with respect to the ANZECC and ARMCANZ (2000) irrigation criteria, and consistent with 'good quality' drinking water according to the TDS criteria in the ADWG (NHMRC 2016). In addition, TDS concentrations were generally either stable or increasing with depth at each monitoring location. Whereas, the opposite distribution would be expected if the downward flow of shale groundwater were imparting a significant water quality effect on the underlying Hawkesbury Sandstone.

A mixing model was used to assess solute concentrations that would result from mixing different proportions of Wianamatta Group and Hawkesbury Sandstone groundwater, considering average groundwater quality from the two formations. With respect to the potential to diminish the beneficial uses of the Hawkesbury Sandstone groundwater resource, EC and also, therefore, TDS were the most sensitive parameters, as the other analytes were generally substantially below the relevant beneficial use criteria even when a high proportion of shale groundwater was considered in a mixing scenario. The mixing analysis indicated that a ratio consisting of >40% Wianamatta Group shale groundwater would be required to produce a mixed TDS value that exceeds 900 mg/L (the threshold at which groundwater is considered 'poor quality' from a drinking water perspective). The same ratio would result in groundwater considered to be suitable for irrigation of 'moderately tolerant crops', from an EC perspective.

The flux model results were also used to estimate salt load transferred (ie salt balance) from the Wianamatta Group shale to the underlying Hawkesbury Sandstone. Under baseline conditions, the groundwater flux from the shale to the sandstone was 11.1 ML/day, with an average TDS of 1,700 mg/L. Therefore, the baseline salt transfer under pre-mining conditions equates to 18,870 kg/day, or 6,887,550 kg/year. Under conditions influenced by mining, the increase in salt flux is proportional to the increase in groundwater flux, peaking at 7,497,790 kg/yr at the Year 14.5 time step (or 9% above baseline conditions). Over the full 74-year period during which the model results indicated an incremental increase in groundwater flux from mining influences (including the post-mining recovery period), the net increase in salt flux from the Wianamatta Group shale to the Hawkesbury Sandstone is 1.3% above baseline conditions.

Given groundwater flow between the Wianamatta Group shale and underlying Hawkesbury Sandstone increases by 9% within a limited period, and the current baseline flux has not significantly affected the underlying Hawkesbury Sandstone water quality, it is considered unlikely a material change to Hawkesbury Sandstone groundwater quality with the potential to reduce the beneficial uses of the groundwater resource would occur as a result of the additional mining-induced flux.

11.2.2 Water quality effects of co-disposed reject

Laboratory tests (kinetic leachate columns (KLC)) were completed on physical representative samples of reject material (RGS 2016) and groundwater to assess the potential change to groundwater quality resulting from groundwater interaction with co-disposed reject material emplaced in the void. The results of column leaching tests were selected from columns considered to best represent the expected subsurface conditions: simulated mine reject material generated from cores recovered from the project area, leached with groundwater obtained from the Wongawilli Seam, as would occur in within the backfilled mine void.

Data from two columns were considered; one with mine reject material only and one with reject material amended with limestone as an additional alkalinity source (which represents the proposed process for the project). The results were compared to baseline water quality for the Hawkesbury Sandstone and Wongawilli Seam to assess whether leaching from mine reject material could result in degrading the beneficial use status of the groundwater resources.

The results of the unamended column leaching test indicated leachate water quality exceeded one or more of the beneficial use criteria for a number of parameters that were generally also exceeded in the baseline groundwater quality; although the magnitude of the exceedance was substantially larger for certain metals in the leachate results. The final leachate pH of the unamended column was relatively low, indicating that acid generation was a potential concern.

The leachate quality from the limestone amended reject material was very favourable. pH was close to neutral throughout the test and leachate analyte concentrations were acceptable for most beneficial use criteria, including many that were originally exceeded in the baseline groundwater quality. Accordingly, the assessment indicates that limestone amendment of the reject material before emplacement in the mine void is likely to produce leachate that is indistinguishable from natural groundwater quality, and is considered unlikely to change the beneficial use status of the groundwater resources.

11.2.3 Seepage from stockpile runoff

The results of the assessment are summarised in Appendix K, including the water quality criteria for the foreseeable beneficial uses of groundwater in the study area, the results of the KLC tests for the limestone-amended and the unamended columns, and the average groundwater quality for the Hawkesbury Sandstone, calculated from the baseline monitoring data.

The main observations are as follows:

- In all cases, the final EC values from the KLC tests were below the average baseline EC values of Hawkesbury Sandstone groundwater. The results suggest that leachate from the three column scenarios would have a negligible influence on natural groundwater quality.

- The results for KLC 10, the unamended column (no limestone added), indicated that acid is generated through exposure to atmospheric oxygen and flushing with oxidised water. The final pH value of 4.7, was slightly lower than even the slightly acidic pH value of the natural Hawkesbury Sandstone groundwater (pH average of 5.3). The lower pH evidently also resulted in mobilising certain metals in the leachate. About half of the metals analysed exceeded one or more of the beneficial use assessment criteria.

- The results for KLC 16 and 18, with 1% and 2% limestone amendment respectively, indicated the limestone had enough buffering capacity to manage the acid generated though water-reject contact. The pH values remained close to neutral throughout the test, and the column leachate analytical results were similar to or more favourable than the native groundwater quality, with respect to exceeding water quality criteria. The final sample from KLC 16 presented an equivalent beneficial use status to the Hawkesbury Sandstone groundwater. The final sample from KLC 18 only exceeded the selenium criterion because the limit of recording was higher than the criterion; all other analytes are below the various assessment criteria.

The results of the limestone-amended KLC tests indicated that the expected water quality resulting from rainfall infiltration into the reject stockpile presents a negligible risk to the baseline beneficial uses of Hawkesbury Sandstone groundwater resource.

11.2.4 Summary of groundwater quality impacts

With regard to the requirements of the AIP in relation to groundwater quality, it is not anticipated that the project activities will lower the beneficial use category of the groundwater source beyond 40 m from the mining zone, provided the mitigation measures discussed in Chapter 13 are implemented. Cumulative changes to groundwater quality are not anticipated as a result of mining activities.

11.3 Cumulative impacts

AR 18 Assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.

As discussed in Section 9.4, there are no potential future projects in the planning process that would influence the assessment of the project. Therefore, no additional cumulative groundwater impacts are predicted.

The existing drawdown within the groundwater system includes landholder bore pumping and the Berrima Colliery mining effects. The groundwater model considers the combined drawdown of landholder pumping and Berrima Colliery mining and the project, as well as the project. The AIP assessment criteria require proponents to consider post water sharing plan impacts. As the landholder pumping and Berrima Colliery impacts are already considered as part of the baseline, the project only case has been assessed against the AIP criteria.

With reference to the NSW State Groundwater Quality Protection (1998), cumulative groundwater quality changes due to the project are assessed to be negligible and there are also no potential future projects in the planning process.

11.4 Predicted impact on groundwater users

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

AR 76: The impacts of groundwater flows, including changes in the water table configuration through such things as new dam construction, re-routing of waterways, groundwater behavioural changes, and changes to the catchment areas that feed to or away from the Hume Highway. Any change in the water table has the potential to affect the structural integrity of the Hume Highway.

The possible predicted effects on sensitive groundwater users, as defined in Section 9.1, are described below. In summary:

- High priority ecosystems that rely on groundwater (GDEs listed in a water sharing plan):
  - there are **no predicted impacts** to GDEs as a result of the project.
- Ecosystems that potentially rely on groundwater:
  - potentially groundwater dependent ecosystems are considered to have facultative (opportunistic) dependency on groundwater. Where water table drawdown is predicted to occur, the ecosystems are expected to be able to adapt and, therefore, influence would be minimal. As per the *Significant impact guidelines* (DoE 2013), this impact is considered **insignificant**.
- Watercourses such as creeks, drainage lines, and swamps that receive baseflow:
  - baseflow reduction is expected to occur in most drainage lines near the project. The rate of reduction is not constant over time. The maximum rate of reduction is expected to be a minor proportion of the total baseflow. The impact on baseflow has been assessed (WSP PB 2016b and 2016c) and is expected to be minimal on surface water uses during a range of climatic conditions. As per the *Significant impact guidelines* (DoE 2013), this impact is considered **insignificant**.
- Private landholder bores and associated infrastructure:
  - groundwater quality changes in landholder bores are considered negligible based on assessments of potential increased flow from poorer water quality groundwater systems and solute transport assessments on co-disposed rejects to be emplaced underground. As per the *Significant impact guidelines* (DoE 2013), this impact is considered **insignificant**.
  - 93 landholder bores on 71 properties will be directly impacted by 2 m or more of temporary drawdown over a period of 72 years as a result of the project. If total impacts are considered, then 109 bores on 84 properties are impacted by 2 m or more. Four of these bores are predicted to be intersected by the mine workings. As per the *Significant impact guidelines* (DoE 2013), this impact is considered **significant**.

In addition, the predicted change to the water table was assessed for influence on the Hume Highway. Based on the water table drawdown maps presented in Appendix M, drawdown on the Hume Highway is expected to be negligible given the amount of water table drawdown is typically less than 10 m. In addition, subsidence impacts as a result of mining and dewatering are predicted to be negligible or imperceptible to built and natural features at surface (Hume Coal Project Hazard and Risk Assessment (EMM 2017e; Mine Advice 2016)). The predicted depressurisation of groundwater systems as a result of underground mining is not predicted to influence the Hume Highway either as new dam construction, re-routing of waterways, groundwater behavioural changes (eg flow), and changes to the catchment areas associated with this highway.

11.4.1 Ecosystems that rely or potentially rely on groundwater

Although terrestrial vegetation, Long Swamp, and Stingray Swamp were identified as potentially affected GDEs by the project (EMM 2017c), the groundwater model drawdown predictions indicated these swamps and associated vegetation will not be influenced by the project.

Terrestrial vegetation has been classified as having a facultative (opportunistic) dependence on groundwater. Facultative (opportunistic) ecosystems will use groundwater during droughts (ie when surface water is not available), but exist without groundwater most of the time. Long Swamp and Stingray Swamp have been classified as having a facultative (proportional) dependence on groundwater (EMM 2017c). Facultative (proportional) ecosystems take a proportion of their water requirements from groundwater; however, there is no absolute threshold for groundwater availability below which ecosystem structure or function is impaired, and can respond to changes in groundwater.

Long Swamp is assessed to be a valley infill swamp, which is likely to source water from perched groundwater above the regional water table and also potentially from the water table. Although the water table is predicted to be shallow at Long Swamp (Figure 6.18), it is at least 6 km from the maximum extent of drawdown predicted by the numerical model. Drawdown of the water table upstream of this location is not predicted to impact Long Swamp. Therefore, it follows that Temperate Highland Peat Swamps and the threatened species it supports at Long Swamp would not be impacted by the project.

Stingray Swamp is assessed as a headwater swamp, which is likely to rely on perched groundwater sourced from local rainfall and runoff, and is not connected with the regional water table. As such, no drawdown-related impacts from the Hume Coal Project are predicted to occur at Stingray Swamp.

The *Hume Coal Project Biodiversity Assessment Report* (EMM 2017c) assessed the potential effects of predicted groundwater drawdown on potential terrestrial vegetation GDE locations. The assessment compared areas where the pre-mining water table is 10 mbgl or less (the assumed average eucalypt root depth limit) against the predicted maximum project impact drawdown from the water table. The assessment took into consideration the ecosystem's level of dependence on groundwater. Accordingly, no influence is expected to ecosystems identified if periods of prolonged drought are not experienced during mining.

11.4.2 Watercourses, creeks, drainage lines, and swamps that receive baseflow

Baseflow reduction is expected to occur in most drainage lines within near the project. The rate of reduction is not constant over time. The maximum rate of reduction is expected to be a minor proportion of the total baseflow (Section 11.1.3 and Appendix I (Coffey 2016b)). As such, the impact of reduction in baseflow is expected to be minimal on watercourses, drainage lines, and swamps during a range of climate conditions.

11.4.3 Landholder bores

Predictive simulations were used to quantify the potential impact for registered landholder bores under two scenarios:

- total drawdown effects, including the existing stresses of Berrima Colliery and landholder pumping as well as the project effects; and
- the effects of the project only (not including the existing stresses).

Impacts to landholder bores have been assessed against the AIP requirements of a maximum 2 m decline cumulatively at any water supply work for 'post-water sharing plan' variations. The project only effects have been used for assessment against the AIP. However, results for both scenarios are presented below, in Table 11.3, and in Appendix I (Coffey 2016b). The predicted bore water levels at each bore over time are plotted in hydrographs in Appendix O. With reference to the AIP, 93 landholder bores (not including Hume Coal owned bores) on 71 properties are predicted to be subject to a drawdown of 2 m or more as a result of the project.

Table 11.3 Summary statistics of landholder bore impacts – comparing project and total drawdown exceeding AIP criteria

	Project drawdown	Total drawdown
	Project drawdown only	Project, landholder pumping and Berrima Colliery drawdown
Number of bores impacted	93[1]	109[1]
Maximum drawdown range	2–80 m	2–84 m
Median maximum drawdown	12 m	14 m
Number of landholders (properties) with impacted bores	71	84
Average time for a bore to recover by 75% since impact begins	23 years	33 years[2]
Time until all impacted bores recover, after mining starts	72 years	(not all bores will recover from total drawdown due to impacts from landholder pumping and Berrima Colliery)
Number of bores predicted not to recover in 100 years after mining starts	0 bores	44 of 109 bores

Notes: *1. Not including bores located on properties owned by Hume Coal.*

2. Average calculated for bores where recovery is predicted within 100 years after mining starts and does not include bores where recovery to 2 m drawdown is not predicted to occur in this time frame.

The numbers referenced in this report do not include bores on land owned by Hume Coal. It should be noted the results in Appendix I (Coffey 2016b) include six bores on Hume Coal owned property, thus, the total number of affected bores above the AIP 2 m threshold is reported as 115. However, make good is not required for these eight bores, so they are not considered further in this assessment.

The magnitude and timing of the drawdown at each bore depends on its location and depth with respect to the mine workings. Shallower and/or remote bores are predicted to experience smaller drawdown than deeper and/or closer bores. For example, the maximum project drawdown in a bore is 80 m, and this is for a deep bore very close to the mined workings. The maximum project water table drawdown is 45 m.

The project is predicted to be responsible for 87% of the maximum total drawdown experienced by the bores. Appendix N shows project drawdown and total drawdown predicted at each affected bore after p mining begins.

If the total drawdown is considered, there are forty four (44) bores that are not predicted to recover to within 2 m within 100 years since the start of mining. Based on the model predictions, this slow recovery is due to ongoing effects from landholder pumping and not the project.

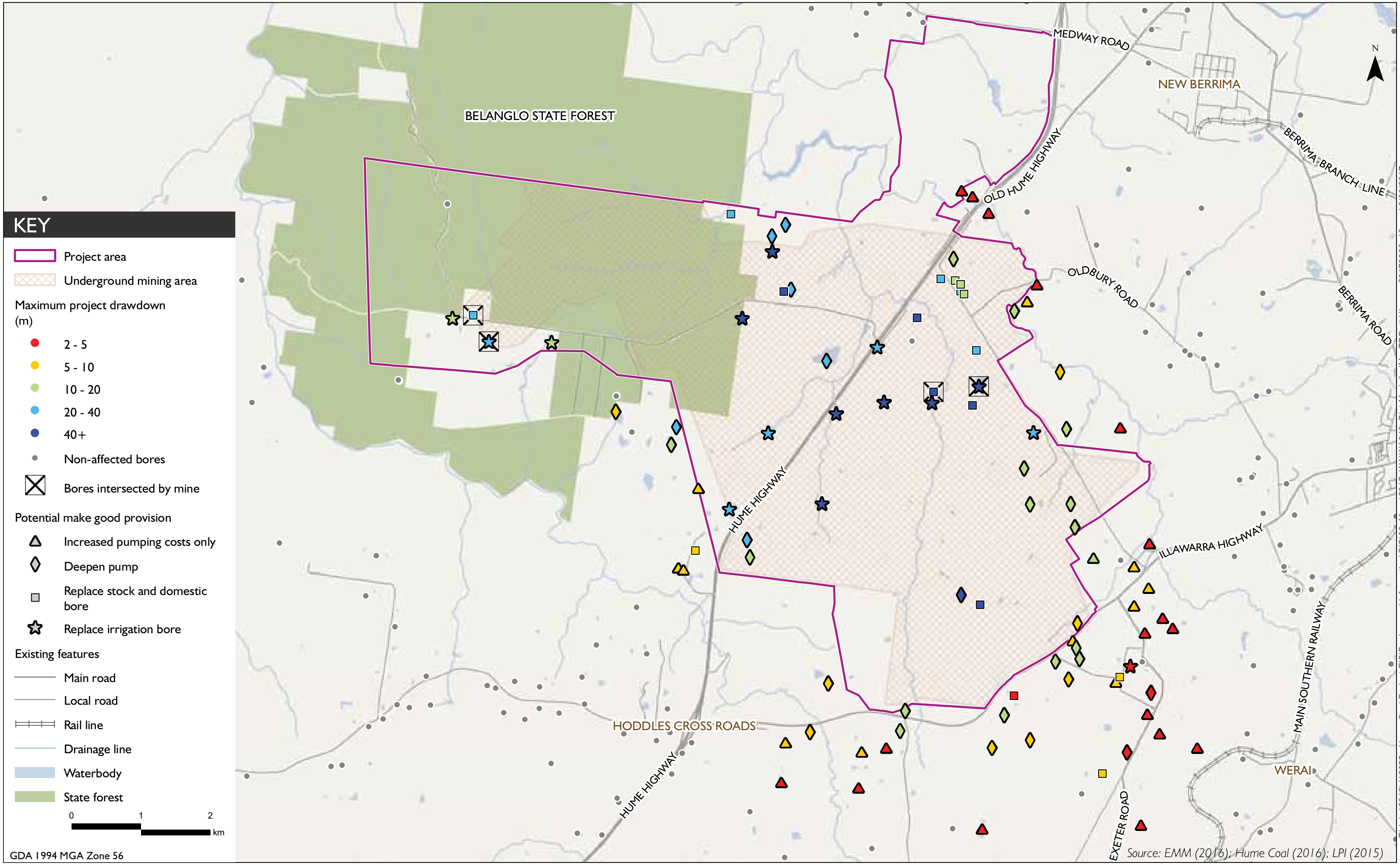
With reference to the AIP assessment criteria, 93 landholder bores (not including bores owned by Hume Coal) on 71 properties are predicted to be subject to a project drawdown of 2 m or more (Figure 11.5). Four bores are predicted to be intercepted by mining (Appendix I (Coffey 2016b) reports that five bores will be intercepted but it includes one bore on Hume Coal property). A histogram of the maximum project drawdown for the landholder bores is shown in Figure 11.4. The median project drawdown is predicted to be 12 m. The median duration of drawdown on the 93 affected bores is 36 years, with the maximum duration being 65 years; however, most of the recovery occurs much faster (Appendix N). Typically, a bore will recover by 75% within 23 years since it was first impacted.

The results of the 'make good' assessment are included in Appendix O. All bores having greater than 2 m drawdown are likely to be subject to increased pumping costs. About a third of those bores would not require bore pump intake deepening or replacement. Another third are assessed as potentially needing submersible pump intake depths repositioned for a certain period of time depending on the duration of drawdown. The final third are assessed as potentially requiring bore replacement of an alternative source of supply.

A table detailing the bore IDs, dates of construction, depths and assumed screened formation is also included in Appendix O.

With regard to the AIP requirements in relation to groundwater quality, it is not anticipated the project activities will result in a lowering of the beneficial use category of the groundwater source beyond 40 m from the activity, provided the mitigation measures discussed in the Section 13 are implemented. Cumulative impacts to groundwater quality are not anticipated as a result of mining activities.

Figure 11.4 Maximum project drawdown on landholder bores



Project drawdown and potential make good provisions

Hume Coal Project
Water Assessment

Figure 11.5

12 Water licences

This chapter provides a summary of the water licensing required for and already held by the project.

AR 8: Annual volumes of surface water and groundwater proposed to be taken by the activity (including through inflow and seepage) from each surface and groundwater source as defined by the relevant water sharing plan.

AR 9: Assessment of any volumetric water licensing requirements (including those for ongoing water take following completion of the project).

AR 10: The identification of an adequate and secure water supply for the life of the project.

AR 11: Confirmation that water can be sourced from an appropriately authorised and reliable supply. This is to include an assessment of the current market depth where water entitlement is required to be purchased.

AR 25: Demonstrate how the proposal is consistent with the relevant rules of the Water Sharing Plan including rules for access licences, distance restrictions for water supply works and rules for the management of local impacts in respect of surface water and groundwater sources, ecosystem protection (including groundwater dependent ecosystems), water quality and surface-groundwater connectivity.

AR 27: Provide an analysis of the proposed water supply arrangements against the rules for access licences and other applicable requirements of any relevant WSP, including:

- *Sufficient market depth to acquire the necessary entitlements for each water source*
- *Ability to carry out a "dealing" to transfer the water to relevant location under the rules of the WSP*
- *Daily and long-term access rules*
- *Account management and carryover provisions*

AR 32: Explanation of how the required water entitlements will be obtained (i.e. through a new or existing licence/s, trading on the water market, controlled allocations etc).

AR 34: Details on all bores and excavations for the purpose of investigation, extraction, dewatering, testing and monitoring. All predicted groundwater take must be accounted for through adequate licensing.

AR 38: Consideration of water allocation account management rules, total daily extraction limits and rules governing environmental protection and access license dealings.

AR 46: Any proposed groundwater extraction, including purpose, location and construction details of all proposed bores and expected annual extraction volumes.

AR 31: Details of the water supply source(s) for the proposal including any proposed surface water and groundwater extraction from each water source as defined in the relevant Water Sharing Plan/s and all water supply works to take water.

12.1 NSW Water legislation and policies for licensing water

Hume Coal is required to licence surface water and groundwater in accordance with the Aquifer Interference Policy (AIP), the WMA 2000, and the relevant statutory water sharing plans. This includes water taken for use as well as water intercepted and managed as a result of mining activities. Enough water access licences (WALs) must be held to account for water intercepted from all water sources (directly or indirectly).

The AIP specifies the project licence requirement needs to consider adjacent and overlying water sources. Should the project cause water to inflow and subsequently capture an adjacent water source, a licence for that volume is required from that adjacent water source. The numerical groundwater model predicts the total volume of water intercepted during mining and the ultimate sources of that water.

12.2 Modelled water inflows

12.2.1 Inflow to mine workings

A conventional underground mine (ie one where workings remain open over the mine life) would cause inflows to the active workings sourced from continually draining upgradient areas of the mine.

Conventional mining methods can be inefficient in their volume of groundwater intercepted, and often also result in the release of excess water to the environment at the surface. The project has a considered mine design that specifically addresses this water interception inefficiency by compartmentalising the mine into panels, and then promptly progressively sealing panels with water-retaining bulkheads. These design features minimise the removal of water from the groundwater source and minimises the volume of excess mine water released to the surface environment.

The project's compartmentalised water-efficient mine design results in most groundwater that would have otherwise flowed into the active mine remaining within the groundwater source.

The numerical groundwater model for the project (Coffey 2016b) predicts groundwater inflows into the different parts of the mine from the surrounding water sources, both to active areas of the mine, and to the sealed void. The model considers inflows during mining (years 1 to 19) and inflows post-mining until void spaces are completely filled (years 20 to 22).

Modelled groundwater inflow to the sump (active mine area) and the sealed void are illustrated in Figure 12.1. The volume of inflow to the active mining area (ie water that is physically taken) is represented in blue in Figure 12.1. The majority of groundwater that inflows into the sealed void remains within the groundwater source and is not physically taken this is represented in grey on Figure 12.1. A small volume of the inflow to void will be harvested in some years to make-up operational water supply in those years (refer to Section 2.3.1).

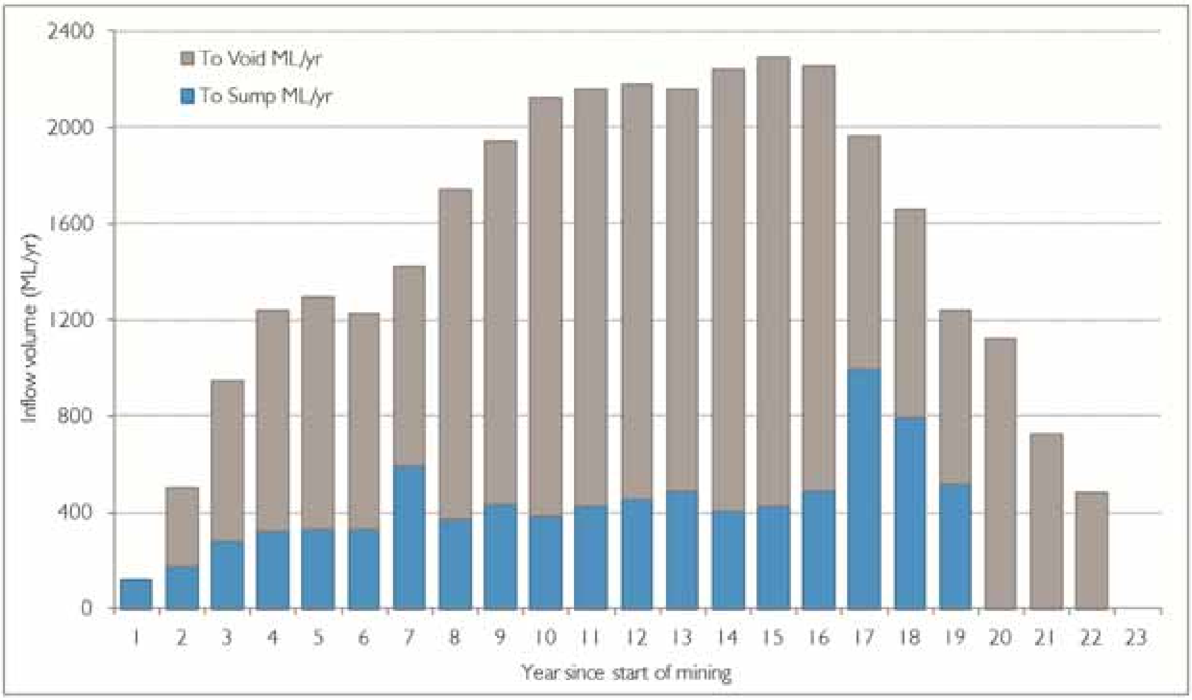


Figure 12.1 Expected inflow volumes over time

12.2.2 Source of water

Water that inflows to the mine sump and void is mainly sourced from the Nepean Management Zone 1 of the Sydney Basin Nepean Groundwater Source. However, there is some induced leakage of surface water from Medway Dam, and minor throughflow from Sydney Basin Nepean Management Zone 2, and the Sydney Basin South Groundwater Source.

The numerical groundwater model predicts that, during the mine's operation, leakage from Medway Dam to underlying groundwater systems will increase by 0.1 ML/day (refer to Section 11.1 and Appendix I (Coffey 2016b)). This additional leakage from Medway Dam is around an average of 36.5 ML/year. The throughflow from adjacent groundwater sources is estimated in the groundwater model; these values have been averaged, and then applied as a percentage to each yearly inflow. The throughflow from the Sydney Basin Nepean Management Zone 2 Groundwater Source and from the Sydney Basin South Groundwater Source is 0.01 and 0.80% of the overall inflow, respectively.

There is a time lag between taking water from the groundwater system at depth and a response in the overlying surface water. To off-set the time lag, and to account for all induced leakage from the overlying Medway Dam, the average volume of surface water intercepted is assumed to occur every year of mining, and until the void is full (year 22).

The remainder, and by far the majority, of the inflow to the mine sump each year is sourced from the Sydney Basin Nepean Groundwater Source – Nepean Management Zone 1.

12.2.3 Intercepted baseflow

Baseflow is the component of streamflow that is groundwater. Baseflow is defined as the withdrawal of groundwater from storage and is part of groundwater recession inflow to the stream (Domenico & Schwartz 1990). Ephemeral streams are defined as those streams that do not flow continuously year round, and mainly flow following rain.

The groundwater level in the project area is generally higher than the beds of intersected streams for most of the stream length and for most of the time. Hence, the streams in the project area are classified as gaining streams and receive baseflow from groundwater (Figure 12.2, A and C). In much of the project area the drainage lines are also considered ephemeral.

Where groundwater extraction occurs (eg dewatering at an underground mine), depressurising groundwater systems may cause drawdown effects at interconnected surface water systems. The effects of extracted groundwater in a gaining stream can influence both the water table (lowered groundwater levels) and the surface water (decreased baseflow resulting in decreased streamflow, particularly during low flow periods) (Figure 12.2, B).

Should groundwater extraction continue to a point where the regional groundwater level falls below the stream height of overlying streams, a reversal of potential hydraulic gradient will occur and the stream will make a transition from gaining to losing (Figure 12.2, D). Once it becomes a losing stream, continued groundwater extraction will result in induced leakage from these overlying surface water features.

12.2.4 NSW approach to licensing intercepted baseflow

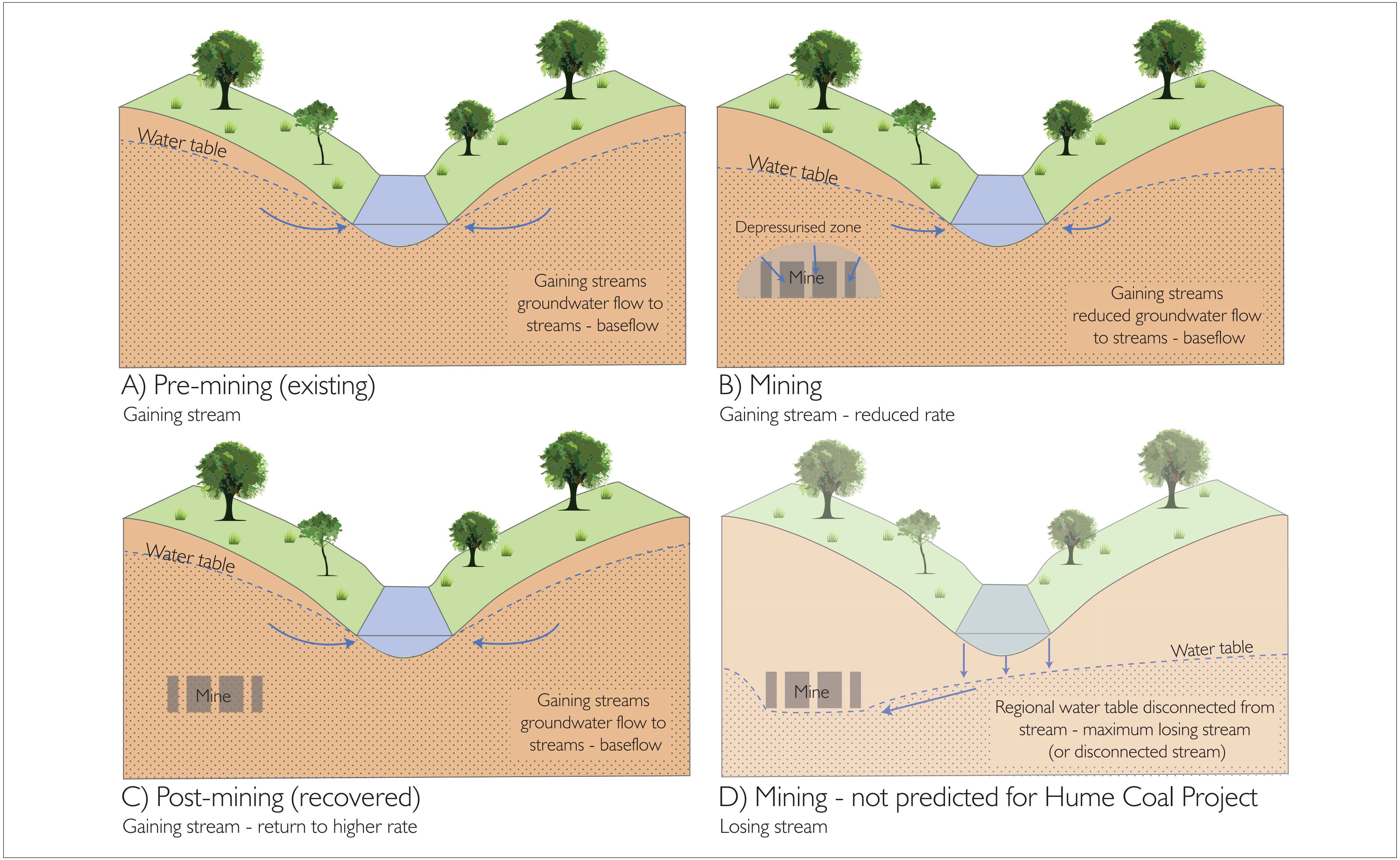
The sustainable limit for extraction has been defined for each water source in each water sharing plan (WSP) across NSW. This considers acceptable levels of regional impact for both groundwater and surface water users, including reduction of baseflow to streams regionally. Long-term average annual extraction limits (LTAAEL) set for individual surface and groundwater systems within the WSPs take into account potential reduction of baseflow should 100% of the LTAAEL be extracted.

Historically in NSW, water inflow to mines was always licensed solely as groundwater. Mining projects are required to determine the ultimate source of mine inflow and licence accordingly: Section 60 I (2) of the WMA 2000. In a gaining stream scenario this source is the groundwater.

The project will therefore licence:

- intercepted groundwater as groundwater;
- intercepted baseflow as groundwater; and
- leakage from surface water sources as surface water.

This aligns with the NSW Government AIP Fact Sheet 3 (NOW 2013a) that describes in detail the licensing of water. The fact sheet discusses and illustrates when surface water licences are required, and only discusses induced leakage from a stream; interception of baseflow is not described as requiring a surface water licence.



Schematic surface water – groundwater interaction during phases of mining

Hume Coal Project
Water Assessment

Figure 12.2

12.3 Required licence volumes

The project's mining method progressively seals off the mine void from the active mine workings with bulkheads, so that most groundwater that would have otherwise flowed into the mine is not extracted and pumped to the surface, but physically remains in the groundwater source and is available to other groundwater users.

The volume of water required to be licensed for the project is defined as the groundwater inflow to the sump that is physically handled by the mine's water management system, **plus** the groundwater inflow to the void, even though the majority of the groundwater in the void remains physically within the groundwater source.

Based on the results of the numerical groundwater model (Coffey 2016b) and the water balance model (WSP PB 2016a), the maximum volume required for licensing is 2,290.5 ML/yr in year 15, and for each individual source is:

- Nepean Management Zone 1 Sydney Basin Nepean Groundwater Source 2,235 ML/yr in year 15;
- Nepean Management Zone 2 Sydney Basin Nepean Groundwater Source 1 ML/yr from years 5 through to 18;
- Sydney Basin South Groundwater Source 18 ML/yr for years 14 through to 16; and
- Medway Rivulet Management Zone of the Upper Nepean and Upstream Warragamba Unregulated River Water Source 36.5 ML/yr for all years of mining and rehabilitation.

The yearly licence requirements are illustrated in Figure 12.3 and Table 12.1. The maximum volume required for licensing for each groundwater source as a portion of the LTAAEL is shown in Figure 12.4.

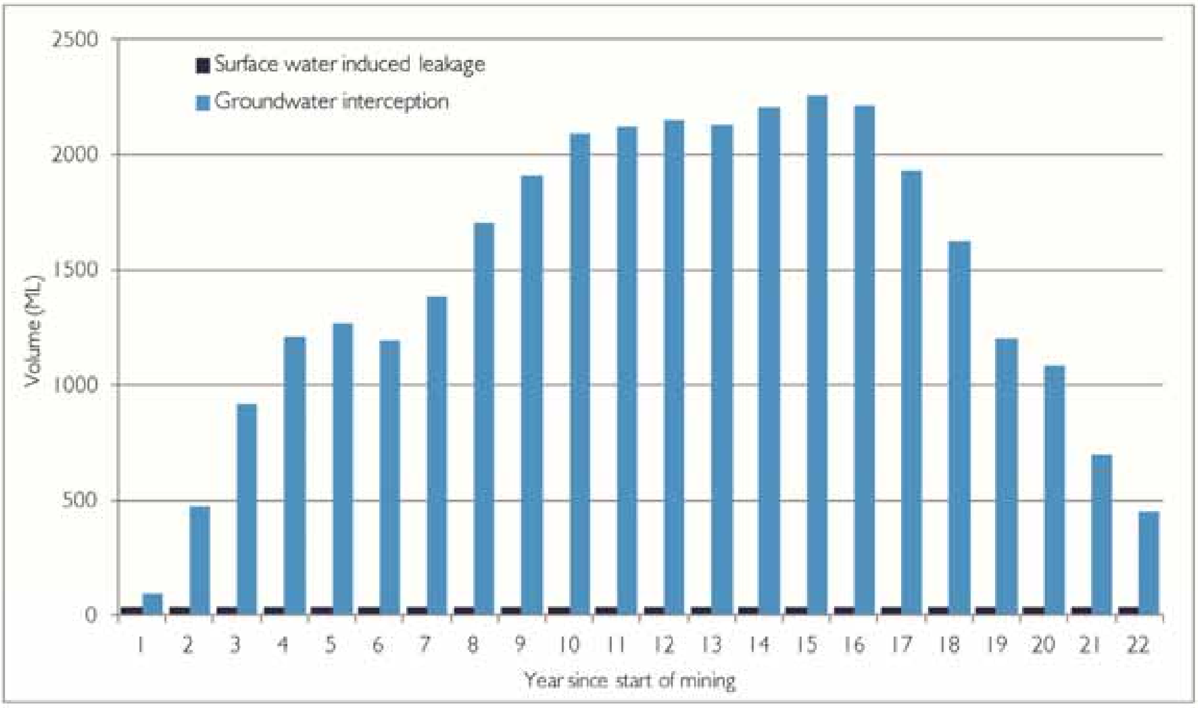


Figure 12.3 Yearly licence requirements

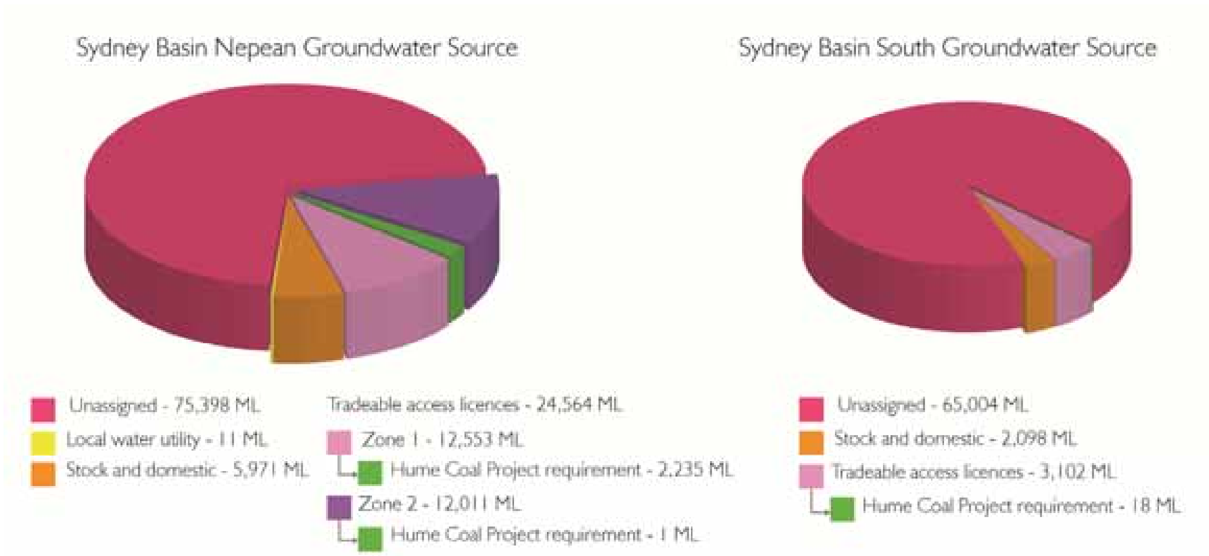


Figure 12.4 Project groundwater licence requirements as a portion of total LTAAEL in each groundwater source

Table 12.1 Required licence volumes from water sources

Year	Total take /induced leakage (ML)	Induced leakage Upper Nepean and Upstream Warragamba Water Source	Groundwater interception Sydney Basin South Groundwater Source	Groundwater interception Sydney Basin Nepean Groundwater Source	
		Medway Rivulet Management Zone (ML)	ML	Nepean Management Zone 2(ML)	Nepean Management Zone 1 (ML)
1	128.5	36.5	1	0	91
2	508.5	36.5	4	0	468
3	952.5	36.5	7	1	908
4	1247.5	36.5	10	1	1200
5	1301.5	36.5	10	1	1254
6	1232.5	36.5	10	1	1185
7	1423.5	36.5	11	1	1375
8	1741.5	36.5	14	1	1690
9	1946.5	36.5	15	1	1894
10	2123.5	36.5	17	1	2069
11	2157.5	36.5	17	1	2103
12	2181.5	36.5	17	1	2127
13	2160.5	36.5	17	1	2106
14	2244.5	36.5	18	1	2189
15	2290.5	36.5	18	1	2235
16	2254.5	36.5	18	1	2199
17	1968.5	36.5	15	1	1916
18	1657.5	36.5	13	1	1607
19	1242.5	36.5	10	1	1195
20	1124.5	36.5	9	1	1078
21	733.5	36.5	6	0	691
22	486.5	36.5	4	0	446
Maximum	**2290.5**	**36.5**	**18**	**1**	**2235**

For groundwater, carryover provisions in the plan provide for up to 10% carryover of unused account water from previous years, and up to 110% use from an account (provided the account water is there). For surface water, carryover provisions in the plan provide for 100% of entitlement, plus accrued allocations, over a three-year rolling period.

12.4 Licences currently owned by Hume Coal

Hume Coal currently holds 31 shares of unregulated river surface water in the Medway Rivulet Zone and 1,391 ML of groundwater share components for Sydney Basin Nepean Management Zone 1. Licence details are provided in Table 12.2, as at February 2017.

Table 12.2 Water licences currently held by Hume Coal

Water source	Approval		Water access licence (WAL)	Share component	Management zone	Purpose
Upper Nepean and Upstream Warragamba Unregulated River Water Source	10CA102776	Unregulated river	25665	14	Medway Rivulet Management Zone	
	10CA102875	Unregulated river	25630	17		
Total surface water				**31**		
Sydney Basin Nepean Groundwater Source	10CA111696	GW053331	24773	488	Nepean Management Zone 1	domestic, stock, irrigation
		GW031686				
		GW059306				
	10CA111712	GW057908	24908 & 24915	179		stock, irrigation, domestic
	10CA112150	GW106491	24938	100		irrigation
	10CA112196	GW108195	24765	120		irrigation
		GW108194				
	10WA109649	GW025588	0	0		stock
	10WA109694	GW031684	0	0		domestic
	10WA109707	GW031685	0	0		domestic
	10WA109708	GW031687	0	0		domestic
	10WA111035	GW109084	0	0		stock, domestic
		Other licences		504		
Total groundwater				**1,391**		

12.5 Mechanism used to secure sufficient water licences

Hume Coal has already secured in excess of 60% of the total licence requirement for the project, with a clear pathway for how the remaining licence volume will be secured to meet extraction requirements.

Trading of water from the Nepean Management Zone 1 is proposed to secure the majority of the remaining licence requirement. Application for water from the Nepean Management Zone 2 of the Sydney Basin Nepean Groundwater Source and from the Sydney Basin South Groundwater Source through controlled allocation order is proposed to secure adequate licence volumes held. An alternative option to secure this water is via the trading market.

Trading 5.5 ML of water from the Medway Rivulet Zone of the Upper Nepean and Upstream Warragamba Unregulated River Water Source is proposed to secure the remaining required licence volume for surface water. Water trading is required to be from within the same respective management zone, as water cannot be traded between different management zones. Table 12.3 summarises the secured and remaining required licence volumes for respective water sources and zones.

Table 12.3 Secured water licences

Water source	Management zone	Total volume required for project (ML/yr)	Volume currently held in licences (ML/yr)	Volume required (ML/yr)	Method for acquisition	Total available to trade in water source (ML/yr)
Sydney Basin Nepean	Nepean Management Zone 1	2,235	1,391 (62%)	844	Controlled allocation or trade	12,553[a]
	Nepean Management Zone 2	1	0 (0%)	1		50,000[b]
Sydney Basin South		18	0 (0%)	18	Controlled allocation or trade	69,892
Upper Nepean and Upstream Warragamba	Medway Rivulet Management Zone	36.5	31 (85%)	5.5	Trade	127[c]
Total		**2,290.5**	**1,422**	**868.5**		

Notes: *a. From an October 2016 search of the online Water Licence Register (town water supply volumes removed).*

b. Approximated for Zone 2 from the 99,658 ML of LTAAEL in the Metro Groundwater WSP and areas of Zones 1 and 2.

c. Town water supply volume of 900ML within this zone is removed.

12.6 Water market depth

The water market in the area has been deep enough that Hume Coal has already secured in excess of 60% of the required licence volume for the project to date. There is minimal remaining volume to be purchased or applied for via controlled allocation with the NSW Government.

Water trading in the area often happens without separating the water licence from the land. There have been 33 such transactions of land with accompanying water licence within the past two years within Nepean Management Zone 1 of the Sydney Basin Nepean Groundwater Source. The total volume of water involved in these transactions is 1,975 ML of groundwater. Of this, a total 1,383 ML were unrelated to the project.

Water licences are also traded separately from land in the area, and these are recorded on the NSW Water Licence Register. A number of groundwater share assignment of rights dealings (permanent trades) have occurred in the Sydney Basin Nepean Groundwater Source (Table 12.4). There have been no registered water allocation assignments (temporary trades) in the past three water years (July–June) for the Sydney Basin Nepean Groundwater Source.

Surface water assignment of rights dealings (permanent trades) that have been issued in the Upper Nepean and Upstream Warragamba Water Source over the past three years are shown in Table 12.5. There have been no registered water allocation assignments (temporary trades) in the past three water years for the Upper Nepean and Upstream Warragamba Water Source.

Table 12.4 Groundwater share assignment trades (permanent trades)

Assigned from WAL No.	Category	Assigned to WAL No.	Date transferred	Share (ML)	Price paid ($ per ML)
24925	Aquifer	36566	13-Nov-14	6	1,000
24802	Aquifer	37100	30-Oct-15	40	2,000
24809	Aquifer	37505	11-Mar-16	30	2,750
35537	Aquifer	37305	24-May-16	10	null
24865	Aquifer	37767	23-Nov-16	5	2,000
36487	Aquifer	36488	18-Jan-17	150	null
24941	Aquifer	40965	09-Feb-17	19	2,944.05
24915[a]	Aquifer	24915	June 2016	75	1,500

Notes: a. WAL 24915 was a property sale (ie not registered on the Land and Property Information database), but the water licence was independently valued.

Table 12.5 Surface water assignment trades (permanent trades)

Assigned from WAL No.	Assigned to WAL No.	Date transferred	Share (ML)	Price paid ($ per ML)
25717	25537	16-Sep-15	25	null
25744	25537	25-Sep-14	60	null

13 Monitoring, mitigation and management

This chapter provides a summary of the mitigation, proposed ongoing monitoring and management measures to be used to manage the potential environmental and social impacts of the project and validate the predictions of this assessment.

AR 2: A groundwater assessment to determine the likelihood and associated impacts of groundwater accumulating and subsequently discharging from the workings post cessation of mining, including consideration of the likely controls require to prevent or mitigate against these risks as part of the closure plan for the site.

AR 5: Fisheries NSW recommend the use of best practice sediment and erosion control, and water quality and stormwater management provisions to safeguard and mitigate impacts on water quality at the site and downstream. They also recommend inclusion of appropriate riparian corridors to provide a buffer between the development areas and adjacent waterways or natural drainage lines to provide protection to riparian and aquatic habitats.

AR 6: Details of ongoing monitoring programs to assess any impacts upon water quality, water flow and aquatic and riparian environments within and downstream of all waterways within the proposal area.

AR 7: Safeguards to mitigate any impacts upon water quality, water flow and aquatic and riparian environments within and downstream of all waterways within the proposal area during construction and ongoing operation of the proposed coal mine. In particular, provide details on proposals for erosion and sediment control (to be incorporated into a Construction Environmental Management Plan - CEMP) and proposed stormwater and ongoing drainage management measures. Water quality management for the project should be designed to achieve no net increase in pollutant run-off to receiving waters within the proposal site.

AR 13: A detailed assessment against the NSW Aquifer Interference Policy (2012) using DPI Water's assessment framework.

AR 16: Proposed surface and groundwater monitoring activities and methodologies.

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

AR 54: Measures proposed to protect groundwater quality, both in the short and long term.

AR 55: Measures for preventing groundwater pollution so that remediation is not required.

AR 56: Protective measures for any groundwater dependent ecosystems (GDEs).

AR 57: Proposed methods of the disposal of waste water and approval from the relevant authority.

AR 59: Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users, including information on:

- *Any proposed monitoring programs, including water levels and quality data. Reporting procedures for any monitoring program including mechanism for transfer of information*
- *An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal*
- *Identification of any nominal thresholds as to the level of impact beyond which remedial measures or contingency plans would be initiated (this may entail water level triggers or a beneficial use category)*
- *Description of the remedial measures or contingency plans proposed*
- *Any funding assurances covering the anticipated post development maintenance cost, for example on-going groundwater monitoring for the nominated period*

AR 59: A description of the design features and measures to be incorporated to mitigate potential impacts

AR 67: The measures that would be established for the long-term protection of local and regional aquifer systems and for the ongoing management of the site following the cessation of the project.

AR 69: The EIS must assess the impacts of the development on water quality, including:
a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction.
b. Identification of proposed monitoring of water quality.

AR 70: The EIS must assess the impact of the development on hydrology, including:

- *h. Water balance including quantity, quality and source.*
- *i. Effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas.*
- *j. Effects to downstream water-dependent fauna and flora including groundwater dependent ecosystems.*
- *k. Impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (eg river benches).*
- *l. Changes to environmental water availability, both regulated/licensed and unregulated/rules-based sources of such water.*
- *m. Mitigating effects of proposed stormwater and wastewater management during and after construction on hydrological attributes such as volumes, flow rates, management methods and re-use options.*
- *n. Identification of proposed monitoring of hydrological attributes.*

AR 74: Investigate options to reduce the levels of pollutants in the discharge of water to protect the environment from harm as a result of that pollution. Identify all practical measures to control or reduce pollutants in the surface or groundwater discharges. Identify preferred measures and their justification.

AR 75: If WQO's cannot be met for the project, demonstrate that all practical options to avoid water discharge have been implemented and outline any measures taken to reduce the pollutant loads where a discharge is necessary. Where a discharge is proposed, analyse the expected discharges in terms of impact on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm.

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 83: Information on proposed avoidance and mitigation measures to manage the relevant impacts of the action including:
- a description of the proposed avoidance and mitigation measures to address the impacts of the action
- assessment of the expected or predicted effectiveness of the mitigation measures
- the cost of mitigation measures;
- a description of the outcomes that the avoidance and mitigation measures will achieve:
- a description of the offsets proposed to address the residual adverse significant impacts and how these offsets will be established

13.1 Avoidance and mitigation

13.1.1 Introduction

The design of the mine layout and method, and the associated water management system, was iterative, with early results of surface water and groundwater modelling providing input into the mine design. The water management system was optimised via this iteration to minimise physical water interception and inflow, conserve and reuse water, minimise evaporation losses, and minimise discharge to surface water systems. As a result, a number of avoidance and mitigation measures have been incorporated into the overall project design.

The specific mitigation and avoidance measures adopted by the project, and related environmental and social benefits are presented in Table 13.1 are combined with management plans and measures and the monitoring regime (outlined in the following sections).

An additional mitigation measure to those discussed below that was considered in detail is to pump surplus water back into the Hawkesbury Sandstone. Injection of surplus water into the Hawkesbury Sandstone provides an excellent mitigation measure to minimise groundwater drawdown in landholder bores, and enhance recovery times following mining. However, a trial of this activity (ie injection into a water source) was unable to be licensed by DPI Water, and as such, this mitigation measure will not be included in the proposed project.

Table 13.1 Mitigation and avoidance measures and benefits

Mitigation measure	Environmental benefit	Social benefit
Diversion of runoff from undisturbed catchments back into natural system	Minimises unnecessary water capture. Reduces water volume to be stored.	Water remains available to other users.
In non-direct coal contact areas (ie sub-catchments with roads and building infrastructure only) non-contaminated water to be released to natural surface water systems following first flush	Minimises unnecessary water capture.	Water remains available to other users.
Underground mine footprint with considered design	The mine footprint has been considered and tested to minimise impacts to water assets. The mine footprint has been reduced from initial concept stage to achieve lower groundwater inflows.	Overall lower impact to surface and groundwater resources.
First workings mining method and design of barrier pillars – designed to have zero caving, negligible subsidence, and no surface cracking	Minimised structural deformation. Minimises both lateral and vertical extent of groundwater depressurisation (area affected by drawdown is a relatively small (Coffey 2016b)). Minimises duration of groundwater depressurisation. No surface water losses from cracking of stream beds. No structural changes to Hawkesbury Sandstone, therefore, no change to potential groundwater flow rates.	No losses from surface water systems due to cracking. Water therefore still available for surface water users.
Sealing of panels as mining progresses	Maintain greater volume of groundwater in natural groundwater source. Minimise the physical interception and inflow of groundwater to the mine's water management system. Allows groundwater system to commence recovery immediately after panel sealed (ie while active mining continues in other areas).	Provides more rapid recovery to overlying landholder bores that may be impacted.
Underground co-disposal of reject	Removes potential for runoff from permanent surface stockpiles into surface streams in high rainfall events.	
Addition of limestone to reject prior to co-disposal	Limestone neutralises the leachate quality of underground reject so that water is indistinguishable from the natural groundwater. No short or long-terms changes to water quality in or next to underground working or below reject stockpiles.	Landholders can access water within or next to the workings at the conclusion of mining without concerns over quality changes from current (pre-mining) quality.
Optimised water management regime	The water management for the site is optimised to: minimise water use, minimise physical water take and inflow of groundwater, conserve and reuse water, minimise evaporation losses, and minimise discharge to surface water systems.	Minimise impact to surface and groundwater resources.

Table 13.1 Mitigation and avoidance measures and benefits

Mitigation measure	Environmental benefit	Social benefit
Pump water into sealed panels - in excess of operational need	Provides for a more rapid recovery of groundwater levels following mining. Removes need to release excess water to surface water systems. Minimises evaporation losses from surface storages.	Provides more rapid recovery to overlying landholder bores that may be impacted.
Sufficient capacity in the primary water dam (PWD) to hold all water on site	Removes need to treat and release excess water to surface water systems.	Minimises water quality effects on users.
Clay lined PWD	Prevents seepage.	
Use of water from within the void as required for mine operations	Water from external source is not required for the mine, even in very dry climate sequences (other than potable water).	No additional draw on alternate water sources for project operation is required (other than potable water).
Scour protection measures downstream of the conveyor piers and box culverts in Medway Rivulet.	Water quality in Medway Rivulet is not impacted by erosion and sedimentation.	Water quality in Medway Rivulet is maintained for downstream users.
Install of vegetated swales along the two mine access roads outside the water management system. Swales will be 730 m and 500 m long for the sealed road catchment and the unsealed road catchment, respectively.	NorBE criteria will be met.	NorBE criteria will be met.

13.1.2 Make good provisions

Where predicted drawdown in bores are greater than the minimal Aquifer Interference Policy (AIP) impact criteria (refer to Section 3.2.2 and 9.3.2) and the perceived long-term viability of the water-dependent asset is compromised, then 'make good' provisions would be negotiated with the relevant landholder. Make good provisions for those landholder bores affected are proposed in Appendix O. As actual 'make good provisions' are not defined in the AIP or other NSW legislation, guidance has been sought from an AIP Fact Sheet 4 (NOW 2013b) and QLD make good guidelines (DEHP 2016). Strategies for make good provisions would be assessed case-by-case and would depend on the existing infrastructure, the degree of drawdown at each site and the outcomes of landholder consultation. Potential strategies and a desktop analysis of proposed measures are discussed in Appendix O.

13.2 Water management

13.2.1 Water Management Strategy

SEAR 4: A water management strategy, having regard to the EPA's, DPI's and WaterNSW requirements

The water management strategy for the project is based on diverting clean water around the mining disturbance areas, retaining water that lies within disturbed areas on-site for recycling and reuse, and replenishing groundwater into sealed voids to allow for increased recovery rate and reduced drawdown. The water management strategy also minimises evaporation losses by storing water excesses in underground voids to accelerate the groundwater recovery time and/or use in operations in very dry years.

The general principles guiding water management for the project are:

- maximise diversion of clean surface water flows around the mining operations;
- minimise the volume of imported water for site use by maximising recycling of mine-affected water, and minimising evaporation losses;
- harvest water only from within the active mining areas (basins, dams, and sump), and seal off mined-out panels so water into the void area does not enter the mine water management system;
- inject surplus water into the void (ie behind sealed bulkheads) to provide for a more rapid recovery of groundwater pressures and efficient storage of water in surplus years;
- avoid the discharge of water from site to surface water systems, with the exception of stormwater releases after first flush and water quality criteria are met;
- manage sediment affected water (ie not mine affected) within an Erosion and Sediment Control Plan;
- maximise injection of excess water into void to allow for increased recovery rate of groundwater systems;
- achieve NorBE for construction and operation activities;
- monitor and analyse results of monitoring for water resources;
- maximise protection of the environmental values of the receiving waters; and

- achieve and maintain regulatory compliance.

13.2.2 Management Plans

AR 81: The EIS should provide plans/protocols/procedures for:
- environmental management plan
- soils and water management plan
- spill management

Two main water management plans (WMPs) will be developed for the project, one for the construction phase (CWMP) and one for the operational phase (OWMP). The WMPs will be a sub-plan of the environmental management system. The WMPs will document the proposed mitigation and management measures for the approved project, and will include the surface and groundwater monitoring program, reporting requirements, spill management and response, water quality trigger levels, corrective actions, contingencies, and responsibilities for all management measures.

The WMPs will be prepared in consultation with DPI Water, EPA, WaterNSW, and the local council, and would consider concerns raised during the exhibition and approvals process for the project.

The WMPs will include details of the surface water and groundwater monitoring program, which will incorporate and update the existing monitoring network, monitoring frequencies and water quality constituents, and physical water take and pumping volumes between water storage structures (including the void, the sump, mine water dams and sediment basins). Reporting frameworks for the above will be prepared in accordance with licensing and agency requirements. Trigger levels for water quality parameters will be developed as part of the WMPs to assist in early identification of water quality trends. The monitoring program will be prepared in accordance with the approved project's environment protection licence (EPL), once enacted. Further details on the monitoring program are included in Section 13.3.

The WMPs will also identify erosion and sediment control measures to be implemented on site, which will be included as Soil and Water Management sub-plan (which incorporates the sediment and erosion control measures). The CWMP will account for the staging of construction and development works. Management measures will be designed in accordance with the relevant standards and best practice guidelines, including *Managing Urban Stormwater – Soils and Construction – Volume 2E Mines and Quarries* (DECC 2008). The WMPs will also identify requirements for storing fuels and other potential contaminants on site to minimise the risk of spill.

As part of the WMP, the water balance model will be reconsidered and optimised for water efficiency throughout all years of mining. The optimising of the water balance model will focus on more efficient operation and the water level in the PWD. It is expected these updates will result in minor changes to volumes of water required to be harvested from the void and therefore will not have material implications in the overall project assessment or licensing (impacts and licence requirements would be less under an optimised scenario).

The WMP will also provide a program for reviewing and updating the numerical groundwater model as more data and information become available; this program would include reporting requirements.

13.3 Monitoring and thresholds

The baseline water monitoring network and data gathered is extensive with up to four years of baseline hydrological data collected. The network has been developed with ongoing consultation with DPI Water. The water monitoring network is positioned to provide spatial coverage across the project area and beyond, investigate the major hydrological and hydrogeological environments, and monitor potentially sensitive features.

The baseline groundwater monitoring network consists of 54 groundwater monitoring bores at 22 nested locations, 11 vibrating wire piezometers (VWP) sensors in three bores, and three landholder bores. The baseline surface water monitoring network consists of 11 stream flow gauging locations and 24 water quality monitoring locations.

Baseline data will continue to be collected from this network throughout the life of the mine. Expansion of the network may be considered once the project starts construction and then operation, and may expand to include aspects such as:

- groundwater seepage monitoring next to the PWD;
- groundwater monitoring next to landholder bores predicted to be impacted by the project;
- shallow groundwater monitoring next to Medway Dam;
- water quality monitoring of mine water dams (including the PWD which receives recycled water) and sediment basins;
- water metering and recording of pumped volumes to/ from MWDs, SBs, PWD, sump and the void;
- real-time flow and water quality (TDS and pH) monitoring of the transfer pipe from SB03 and SB04 in accordance with the first flush threshold criteria;
- shallow groundwater monitoring in areas identified as having shallow groundwater and known ecosystems with possibly affected species;
- monitoring quality and metering the volume of water releases to Oldbury Creek from SB03 and SB04 or WTP (if required);
- monitoring water quality within temporary sediment basins during construction;
- monitoring quality of water in sump and the rate and quality of water injected into sealed voids; and
- additional surface water monitoring sites on Oldbury Creek (downstream of where releases from SB03 and SB04 will occur), and on Medway Rivulet downstream of the junctions with Wells Creek and Oldbury Creek.

The suite of water quality analytes (ie constituents) to be sampled and the frequency of sampling will be reviewed and updated in the WMPs developed for the project's construction and operation. Data loggers that currently monitor water levels will continue to operate. The ongoing development and expansion of the monitoring network will occur in consultation with WaterNSW and DPI Water, and as per the guidelines for the GMMP, which will evolve as the project progresses.

Thresholds levels have been proposed for the management of various water-related aspects of the project, and more will be proposed in monitoring plans as they are developed. Existing thresholds that have been identified are:

- achieving neutral or beneficial effect (NorBE) and water quality objectives for releases and changes in catchment water quality (refer to Appendix E (WSP PB 2016b));
- first flush criteria for releases from SB03 and SB04 following the first flush (refer to Appendix E);
- actual groundwater level changes within an agreed threshold of model predictions in virtual piezometers (refer to Appendix I (Coffey 2016b));
- water balance, and in particular physical water take and groundwater inflow contributions (refer to Chapter 12); and
- beneficial use of the groundwater system, which is classified as suitable for irrigation, not being compromised (refer to Appendix K).

In relation to post-closure water monitoring, there will be no ongoing water discharge from the mine workings as panels will be sealed progressively over the life of the mine. There will be no permanent surface reject emplacements and therefore no ongoing risk of leachate on the surface. All dams used as part of mine water management system will be rehabilitated upon cessation of operations and, unlike an open cut mine, there will be no surface voids and therefore no potential for evaporative concentration of salts in voids over time. Notwithstanding, Hume Coal will continue the water monitoring program post closure for a nominal period of five years, the cost of which will be accounted for in the mine's security deposit which will be required under the mining lease. The need for, and methodology of, ongoing water monitoring after mining has ceased will be confirmed during development of the detailed mine closure plan.

13.4 Management measures

Monitoring each component of the water management system would form the basis of how and when management responses are required. The monitoring network is fundamental to achieving effective management of project impacts and as such has been designed (and will continue to be designed) with this objective.

To help analyse monitoring data, triggers and thresholds will be developed to provide context when and what management measures are to be implemented.

Table 13.2 details the potential risks and respective management measures.

Table 13.2 Potential risks and management measures

Potential risk	Management measure
Proposed releases from SB03 and SB04 following first flush to Oldbury Creek are not consistent with achieving NorBE	Do not release, store in PWD instead. Water balance modelling demonstrates that PWD has enough capacity to contain all runoff from SB03 and SB04. Inject surplus water back into the Hawkesbury Sandstone (this is the preferred option to manage surplus water; however, to date DPI Water has been unable to licence this activity).
Drawdown in landholder bores is significantly larger than predicted	Consider if additional make good measures should apply to the bore to maintain existing water supply (refer to Appendix O). Analyse the model, and predictions and potential recalibration of the model using most recent data.
Higher than predicted sediment loads occur during construction and/or operation	Compliance with NorBE and the Soil and Water Management Sub-plan.
Groundwater inflow rates to the underground sump are higher than predicted	Consider options to seal voids as mining progresses at a rate faster than originally planned (ie the groundwater model allows for sealing within 12 months from cessation of mining in an individual panel) – sealing voids within 6 months or less from ceasing to mine a panel could reduce groundwater inflow to sump. Inject surplus water back into the Hawkesbury Sandstone (this is the preferred option to manage surplus water; however, to date DPI Water has been unable to licence this activity).
High rainfall and storm events coinciding with high groundwater inflow years, and PWD and sealed void are at or reaching capacity	Consider options to more rapidly fill void spaces. Consider options to commission WTP and MWD08, and treat and release excess water from PWD to Oldbury Creek. Inject surplus water back into the Hawkesbury Sandstone (this is the preferred option to manage surplus water; however, to date DPI Water has been unable to licence this activity).
Spills of petroleum products or other hazardous material	Comply with operating procedures relating to storing and handling of hazardous materials, including spill response plans. Avoid handling hazardous materials next to waterways. Immediately rehabilitate impacted area in line with relevant protocols.
Accumulation/concentration of potential contaminants in the PWD as a result of recycling water on site	Monitoring of water quality in the PWD will indicate if and when management measures need to be applied. Consider water management practices to reduce the volume of water needing to be recycled back into the PWD (ie optimise water efficiency in coal processing) Consider alternate options for water from coal processing (ie treatment/disposal off site
Acidification of sealed voids	Additional dosing of reject with limestone before underground emplacement. Consider filling and sealing individual voids more rapidly following mining.
Greater than predicted drawdown next to areas of shallow groundwater that ecosystems are potentially relying on	Assess ecosystem health, assess time for recovery of shallow groundwater at the location, consider to temporary irrigation to these systems until groundwater recovers to acceptable limits (ie the level at which the ecosystem can again access the groundwater).

13.5 Groundwater model validation

The groundwater model predictions would be validated by installing custom-designed groundwater monitoring sites at key selected virtual piezometers used in the model. Should sites be unsuitable (ie access restrictions), then the model will be re-run with additional virtual piezometers in accessible sites. The model can be regularly validated. Significant deviations from the predicted impacts will be investigated. Reporting on this is proposed annually. Model recalibration will be considered every two years (based on analysis of predicted versus actual impacts), and done as required.

Predicted impacts on landholder bores will be considered via monitoring these bores manually, and/or via installing dedicated monitoring bores next to key landholder bores.

14 Conclusions

This chapter summarises the project based on the findings of this water assessment.

Effective and efficient water management is essential to the project's operation. The mine design and associated water management system were developed iteratively, with early results of surface water and groundwater modelling providing input into the mine design. The resulting water management system and mine design (non-caving and progressively sealing panels) minimises physical water extraction and groundwater inflow, conserves and reuses water, minimises evaporation losses, and minimises discharge to surface water systems.

The effects on surface water resources as a result of the project will be minimal. A temporary 0.8% reduction in the catchment area of Medway Rivulet, in which the surface infrastructure area will be located, will occur as a result of constructing and operating the project.

Potential TSS and nutrient loads and concentrations in Oldbury Creek show discharge from sediment basins will be in accordance with the neutral or beneficial effect (NorBE) criteria. Swales can be used to provide an effective treatment system for runoff from access roads to meet the NorBE criteria for TSS and nutrients. The water balance model demonstrates that the PWD has enough capacity to contain all surplus water and treatment and release of water from the PWD is not required.

Changes in flood levels as a result of the project for land Hume Coal does not own are minor or negligible and considered acceptable with reference to the assessment criteria. Changes to flood peak velocities are considered acceptable with reference to the assessment criteria.

Groundwater inflows to the active mine sump area will occur throughout the operational mine life, and this water will be reused for mining operations with the excess pumped into the sealed void area to enhance the groundwater recovery time. The sealed void remains part of the groundwater source, with water available for other users.

The Aquifer Interference Policy (AIP) requires landholder bores affected by greater than 2 m drawdown as a result of the project are subject to 'make good' provisions. There are 93 private landholder bores on 71 properties that are predicted to drawdown 2 m or more as a result of the project.

A 'make good' assessment addressed the project's effects on these 93 bores. All bores affected by more than 2 m drawdown are likely to be subject to increased pumping costs. About a third of those affected bores would not require bore intake deepening or replacement. Another third are assessed as potentially needing submersible pump intake depths repositioned for certain periods of time, and the final third may require bore replacement or an alternative source of supply.

With regard to the AIP's groundwater quality requirements, the project is not anticipated to result in a lowering of the beneficial use category of the groundwater source beyond 40 m from the activity, provided the mitigation measures discussed in Chapter 13 are implemented.

Cumulative impacts to groundwater and surface water quality are not anticipated as a result of the project.

Monitoring the extensive surface water and groundwater network will continue. Monitoring each component of the water management system underpins if, how, and when management responses are required. Triggers and thresholds will be developed to provide context on if, how, and when management measures are required as part of the water management plan for the project.

Hume Coal has already secured in excess of 60% of the total water licence requirement for the project. The remaining volume required can be sourced by controlled allocation and via the trading market. The remaining licence volume will be secured so that all water taken is adequately licensed.

References

Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council (ANZECC and ARMCANZ) 2000, *Australian and New Zealand guidelines for fresh and marine water quality*.

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A, and Boronkay A, 2012, *Australian groundwater modelling guidelines*, Waterlines Report Series, Number 82, National Water Commission, Canberra.

Beca Pty Ltd (Beca) 2010, *Medway WTP Viability Study*. Prepared by Beca for Wingecarribee Shire Council.

Blevin, J et al. 2007, *Sydney Basin reservoir prediction study and GIS*. Project MR705, Report to NSW DPI and Macquarie Energy by FrOG Tech Pty Ltd.

Boughton, WC 1993, 'A Hydrograph-based Model for Estimating the Water Yield of Ungauged Catchments', paper presented at Hydrology and Water Resources Symposium, Newcastle, Australia, 30 June–2 July.

Bureau of Meteorology (BoM) 2012, Groundwater Dependent Ecosystem Atlas, viewed October 2016, www.bom.gov.au/water/groundwater/gde/.

Brunker, RL and Rose, G 1967, Sydney Basin 1:500,000 Geological Sheet, Geological Survey of NSW.

Coffey Geotechnics Pty Ltd 2016a*, Hume Coal Project Groundwater Assessment Volume 1: Data Analysis.* Prepared by Coffey for Hume Coal Pty Ltd. Appendix H.

2016b, *Hume Coal Project Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessmen*t. Prepared by Coffey for Hume Coal Pty Ltd. Appendix I

Commonwealth of Australia Department of the Environment (DoE) 2013*, Significant impact guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources*, Australian Government.

Department of Environment and Heritage Protection QLD (DEHP) 2016, Quick guide: make good obligations, viewed 15 November 2016, www.ehp.qld.gov.au/management/pdf/good-obligations-guide.pdf.

Domenico, PA and Schwartz, FW 1990, *Physical and Chemical Hydrogeology 2nd edition*, John Wiley & Sons, Chichester.

EMGA Mitchell McLennan Pty Ltd (EMM) 2015a, *Coastal porous rock rainfall recharge study*. Prepared by EMM for NSW DPI Water.

2015b, *Hume Coal Project, referral of proposed action*. Prepared by EMM for Hume Coal Pty Ltd.

EMM Consulting Pty Ltd (EMM) 2017a, *Hume Coal Project Environmental Impact Statement*. Prepared by EMM for Hume Coal Pty Ltd.

2017b, *Hume Coal Project Groundwater Monitoring and Modelling Plan*. Prepared by EMM for Hume Coal Pty Ltd.

2017c, *Hume Coal Project Biodiversity Assessment Report*. Appendix H of the *Hume Coal Project Environmental Impact Statement*. Prepared by EMM for Hume Coal Pty Ltd.

2017d, *Berrima Rail Project Environmental Impact Statement*. Appendix D of the *Hume Coal Project Environmental Impact Statement*. Prepared by EMM for Hume Coal Pty Ltd.

2017e, *Hume Coal Project Hazard and Risk Assessment Report*. Appendix P of the *Hume Coal Project Environmental Impact Statement*. Prepared by EMM for Hume Coal Pty Ltd.

2017f, *Hume Coal Project Land and Soil Assessment Report. Appendix F* of the *Hume Coal Project Environmental Impact Statement*. Prepared by EMM for Hume Coal Pty Ltd.

Environment Australia 2001, *A Directory of Important Wetlands in Australia, Third Edition,* Environment Australia, Canberra.

Fetter, CW 1994, *Applied hydrogeology, third edition*, Prentice-Hall, New Jersey.

Fletcher, T, Duncan, H, Poelsma, P, and Lloyd, S 2004, *Stormwater flow and quality, and the effectiveness of non-proprietary stormwater treatment measures – a review and gap analysis*. Prepared by Cooperative Research Centre for Catchment Hydrology, Monash University.

Geoscience Australia 2016, Sydney Basin, viewed 31 October 2016, www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/onshore-australia/sydney-basin.

Geosyntec Consultants Pty Ltd (Geosyntec) 2016. *Hume Coal Project Hydrogeochemical Assessment*. Prepared by Geosyntec for Hume Coal Pty Ltd. Appendix K.

Healthy Rivers Commission of NSW (HRC) 1998, *Independent inquiry into the Hawkesbury Nepean River system*.

Herbert, C and Helby, R (eds) 1980, *A guide to the Sydney Basin*, Department of Mineral Resources Geological Survey of New South Wales, Bulletin 26, Sydney.

Hume Coal Pty Ltd (Hume Coal) 2011, *Hume Exploration Project Review of Environmental Factors*. Prepared by Hume Coal Pty Ltd.

2012, *Hume Exploration Project Review of Environmental Factors Phase 2 Exploration Activities*. Prepared by Hume Coal Pty Ltd and EMGA Mitchell McLennan Pty Ltd.

2014, *Hume Exploration Project Review of Environmental Factors Phase 3 Exploration Activity*. Prepared by Hume Coal Pty Ltd.

Independent Expert Scientific Committee (IESC) 2015, *Information Guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals*, viewed 15 November 2016, www.iesc.environment.gov.au/system/files/resources/012fa918-ee79-4131-9c8d-02c9b2de65cf/files/iesc-information-guidelines-oct-2015.pdf.

Institution of Engineers, Australia (IEA) 1987, *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Volume 1, Engineers Australia, Barton, ACT.

Kalf, F 2016, KA Peer Review of Coffey Groundwater Modelling Assessment of the Hume Coal Project. Prepared by Kalf and Associates Pty Ltd for Hume Coal Pty Ltd.

Land and Property Information (LPI) 2014, *Digital topographic database*, NSW Spatial Data Infrastructure, NSW Government.

Landcom 2004, *Managing Urban Stormwater: Soils and Construction, 4th Edition, and Volume 2E Mines and Quarries (the Blue Book)*.

McLean, W and David, K 2006, *Review of Surface Water-Groundwater Interaction in the Nattai River Catchment.* Prepared by Parsons Brinckerhoff for Sydney Catchment Authority.

Merrick, N 2016, *Hume Coal Project Groundwater Impact Assessment Peer Review*. Prepared by HydroAlgorithmics Pty Ltd for Hume Coal Pty Ltd.

Mine Advice Pty Ltd, 2016, *Hume Coal Project: Environmental Impact Statement Subsidence Assessment. Appendix L* of the *Hume Coal Project Environmental Impact Statement*. Prepared for EMM Consulting Pty Ltd.

Moffit, RS 1999, *Southern Coalfield Regional Geology 1:100,000 Geology Map,* First edition, Geological Survey of New South Wales, Sydney.

Morton, FI 1983, 'Operational Estimates of Lake Evaporation', *Journal of Hydrology* 66(1-4), pp.77–100.

National Health and Medical Research Council and Natural Resource Management Ministerial Council (NHMRC) 2016, *2011 Australian Drinking Water Guidelines, Version 3.2.*

National Uniform Drillers Licensing Committee (NUDLC) 2012, *Minimum Construction Requirements for Water Bores in Australia Third edition,* Australian Government National Water Commission.

National Water Quality Management Strategy (NWQMS) 2013, *Guidelines for Groundwater Quality Protection in Australia,* Australian Government.

NSW Department of Land and Water Conservation (DLWC) 1997, *NSW State Groundwater Policy Framework Document*, NSW Government.

1998, *NSW State Groundwater Quality Protection Quality*, NSW Government.

2002, *NSW State Groundwater Dependent Ecosystem Policy* NSW Government.

NSW Department of Environment and Climate Change (DECC) 2008, Managing Urban Stormwater – Soils and Construction, Volume 2E Mines and quarries. State of NSW and Department of Environment and Climate Change.

2007, Practical consideration of climate change, version 1.0, NSW Government.

NSW Department of Environment, Climate Change, and Water NSW (DECCW) 2010, *NSW Wetlands Policy,* NSW Government.

NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) 2005, *Floodplain Development Manual, the management of flood liable land*, NSW Government.

NSW Department of Primary Industries Water (DPI Water) 2015a, Controlled allocation of aquifer access licences 2014 – frequently asked questions, viewed 21 November 2016, www.water.nsw.gov.au/water-management/water-availability/controlled-allocations/frequently-asked-questions.

2015b, PINNEENA Version 11.1 Groundwater Works database, NSW Government.

2016a, NSW Water Register, viewed 21 November 2016, www.water.nsw.gov.au/water-licensing/registers.

2016b, Continuous water monitoring network, viewed 21 November 2016, allwaterdata.water.nsw.gov.au/water.stm.

NSW Department of Primary Industries Office of Water (NOW) 2011a*, Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources*, NSW Government.

2011b, *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water*, NSW Government.

2011c, *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources – Background document*, NSW Government.

2012a, *NSW Aquifer Interference Policy, NSW Government Policy for the licensing and assessment of aquifer interference activities*, NSW Government.

2012b, Groundwater productivity in NSW, viewed 15 November 2016, http://www.water.nsw.gov.au/__data/assets/pdf_file/0008/547343/law_use_groundwater_productivity_nov_2012.pdf

2012c, Guidelines for Controlled activity approvals, viewed 16 November 2016, www.water.nsw.gov.au/water-licensing/approvals/controlled-activity/rights_controlled_fa.q.

2012d, *Risk Assessment Guidelines for groundwater dependent ecosystems, Volume 1 – the conceptual framework*, NSW Government.

2013a, *Aquifer Interference Policy Fact Sheet 3, accounting for water*, NSW Government.

2013b, *Aquifer Interference Policy Fact Sheet 4, assessing the impacts*, NSW Government.

2014, *Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum exploration activities*, NSW Government.

NSW Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) 2012a, *NSW Code of Practice for Coal Seam Gas Well Integrity*, NSW Government.

2012b, *NSW Code of Practice for Coal Seam Gas Fracture Stimulation*, NSW Government.

NSW Department of Water and Energy (DWE) 2007, *NSW Water Extraction Monitoring Policy*, NSW Government.

NSW EPA 2013, Stormwater first flush pollution, viewed 16 November 2016, http://www.epa.nsw.gov.au/mao/stormwater.htm.

NSW Natural Resources Department (DNR) 2006, 'Sydney Catchment Authority – Upper Nepean Catchment (Kangaloon – Detailed Pilot Investigation – Drilling and Pumping Tests, Volume 2. Prepared by DNR for Sydney Catchment Authority, Report No. 06-GL31A/4.

NSW Water Resources Council (WRC) 1993, *NSW State Rivers and Estuary Policy*, NSW Government.

O'Neill, C and Danis, C 2013, *The Geology of NSW, the geological characteristics and history of NSW with a focus on coal seam gas resources*. Prepared by Macquarie University for the NSW Chief Scientists' Office.

Parsons Brinckerhoff (PB) 2011, *Hume Coal Groundwater Monitoring and Modelling Plan*. Prepared by PB for Hume Coal Pty Ltd.

Queensland Government Department of Science, Information Technology, Innovation and the Arts (DSITIA) 2015, SILO climate data: data drill, viewed April 2016, www.longpaddock.qld.gov.au/silo/about.html.

RGS Environmental Pty Ltd (RGS) 2016, Hume Coal Project Geochemical Assessment of Mining and Waste Materials. Prepared by RGS for Hume Coal Pty Ltd.

Ross, J 2014, 'Groundwater Resource Potential of the Triassic Sandstone of the Southern Sydney Basin: an Improved Understanding', *Australian Journal of Earth Sciences*, 61, pp. 463–474.

Rust, B and Jones, B 1987, 'The Hawkesbury Sandstone south of Sydney, Australia: Triassic analogue for the deposit of a large, braided river', *Journal of Sedimentary Research*, 57(2), pp. 222–233.

Scheibner, E and Basden, H (eds) 1998, *Geology of New South Wales – Synthesis*, *Volume 2 Geological Evolution*, Geological Survey of New South Wales, Memoir (Geology), 13(2).

Sydney Catchment Authority (SCA) 2012, *Using MUSIC in Sydney's Drinking Water Catchments. A Sydney Catchment Authority Standard*, NSW Government.

2015, *Neutral or Beneficial Effect on Water Quality Assessment Guideline*, NSW Government.

Thomas, D, Biggin, A, Schmidt, P 2000, 'A palaeomagnetic study of Jurassic intrusive from southern New South Wales: further evidence for a pre-Cenozoic dipole low', *Geophysical Journal International*, 140, pp. 621–635.

Wahl, K and Wahl, T 1995, 'Determining the flow of Comal Springs at New Braunfels, Texas', *Proceedings of Texas Water 95,* August 16–17, 1995, American Society of Civil Engineers, San Antonio, Texas, pp. 77–86.

WaterNSW 2015, *Developments in the drinking water catchment – water quality information requirements*, NSW Government.

Wingecarribee Shire Council (WSC) 2010, Wingecarribee Local Environment Plan, viewed 21 November 2016, www.wsc.nsw.gov.au/development/wingecarribee-local-environmental-plan-wlep-2010.

WSP Parsons Brinckerhoff (WSP PB) 2016a, *Hume Coal Project Water Balance Assessmen*t. Prepared by PB for Hume Coal Pty Ltd. Appendix D.

2016b, *Hume Coal Project Surface Water Quality Assessment*. Prepared by PB for Hume Coal Pty Ltd. Appendix E.

2016c, *Hume Coal Project Surface Water Flow and Geomorphology Assessment*. Prepared by PB for Hume Coal Pty Ltd. Appendix F.

2016d, *Hume Coal Project Flooding Assessment*. Prepared by PB for Hume Coal Pty Ltd. Appendix G.

2016e, *Hume Coal Project Water Fieldwork and Monitoring Report*. Prepared by PB for Hume Coal Pty Ltd.

List of units

Unit	Description
$	Australian dollar
%	percent
°C	degrees Celsius
µm	micrometre
µS/cm	microsiemens per centimetre
ha	hectare
kg/yr	kilograms per year
L/s	litres per second
km	kilometre
km^2	square kilometres
m	metres
m/day	metres per day
m/year	metres per year
m^3/day	cubic metres per day
mAHD	metres Australian Height Datum
mbgl	metres below ground level
mbtoc	metres below top of casing
meq/L	milliequivalents per litre
mg/L	milligrams per litre
mh/L	milligrams per litre
ML	megalitres
ML/day	megalitres per day
ML/yr	megalitres per year
mm/day	millimetres per day
mm/hr	millimetres per hour
Mt	million tonnes
Mtpa	million tonnes per annum
pH	pH, unit of acidity and alkalinity

Abbreviations

Abbreviation	Description
ADWG	Australian Drinking Water Guidelines
AHD	Australian height datum
AIP	Aquifer Interference Policy 2012
ALS	Australian Laboratory Services
ANZECC and ARMCANZ	Australian and New Zealand guidelines for fresh and marine water quality
AR	Agency recommendation
ARI	Average recurrence interval
AWBM	Australian Water Balance Model
BOD	Biochemical oxygen demand
BoM	Bureau of Meteorology
BTEXN	Benzene, toluene, ethyl-benzene, and xylene
BTEXN	benzene, toluene, ethyl-benzene, xylene and naphthalene
CCL	Consolidated Coal Lease
CDFM	Cumulative deviation from the mean
CM	Coal measures
CPP	Coal processing plant
CWMP	Construction water management plan
DECC	Department of Environment and Climate Change NSW
DECCW	Department of Environment, Climate Change, and Water NSW
DEHP	Department of Environment and Heritage Protection (QLD)
DIPNR	Department of Infrastructure, Planning and Natural Resources NSW
DLWC	Department of Land and Water Conservation NSW
DNR	Natural Resources Department NSW
DO	Dissolved oxygen
DPI	Department of Primary Industries
DSITAI	Department of Science, Information Technology, Innovation and the Arts QLD
DTIRIS	Department of Trade and Investment, Regional Infrastructure and Services NSW
DWE	Department of Water and Energy NSW
EC	Electrical conductivity
EIS	Environmental Impact Statement
EP&A Act	Environmental Planning and Assessment Act
EPA	Environment Protection Authority
EPBC Act	Environment Protection and Biodiversity Conservation Act
EPL	Environment protection licence
EV	Environmental value
GDE	Groundwater dependent ecosystem
GMMP	Groundwater monitoring and modelling plan
HRC	Healthy Rivers Commission of NSW
ICM	Illawarra Coal Measures
IEA	Institution of Engineers, Australia

Abbreviation	Description
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
K	Hydraulic conductivity
Kh	Horizontal hydraulic conductivity
KLC	Kinetic leach column
Kv	Vertical hydraulic conductivity
LGA	Local government area
LPI	Land and Property Information NSW
LTAAEL	Long-term average annual extraction limit
MAR	Managed aquifer recharge
MLA	Mining Lease Application
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
MWD	Mine water dam
N	Nitrogen
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
NMZ1	Sydney Basin Nepean Groundwater Source Nepean Management Zone 1
NMZ2	Sydney Basin Nepean Groundwater Source Nepean Management Zone 2
NorBE	Neutral or beneficial effect
NOW	NSW Office of Water, now DPI Water
NSW	New South Wales
NUDLC	National Uniform Drillers Licensing Committee
NWC	National Water Commission
NWQMS	National Water Quality Management Strategy
OCP	Organochlorine pesticides
OEH	Office of Environment and Heritage
OPPP	Organophosphorus pesticides
ORM	Probabilistic rational method
OWMP	Operation water management plan
PAH	Polycyclic aromatic hydrocarbons
PMF	Predicted maximum flood
PMP	Probable maximum precipitation
POEO Act	*Protection of the Environment Operations Act 1997*
PWD	Primary water dam
QA/QC	Quality assurance/quality control
QLD	Queensland
RC	Riparian corridors
REF	Review of Environmental Factors
ROM	Run of mine
SB	Stormwater basin
SBS	Sydney Basin South Groundwater Source
SCA	Sydney Catchment Authority
SD	Standard deviation
SEARs	Secretary’s environmental assessment requirements
SEPP	State Environmental Planning Policy
SILO	Scientific information for land owners, a database of historical climate records for Australia

Abbreviation	Description
SST	Sandstone
STP	Sewage treatment plant
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TRH	Total recoverable hydrocarbons
TSS	Total suspended solids
VRC	Vegetated riparian corridors
VWP	Vibrating wire piezometer
WA 1912	*Water Act 1912*
WAL	Water access licence
WMA 2000	*Water Management Act 2000*
WMP	Water management plan
WR ply	Wongawilli Coal Seam ply
WRC	Water Resources Council NSW
WSP	Water sharing plan
WTP	Water treatment plant

Glossary of Terms

Acidity	Base neutralising capacity.
Alkalinity	Acid neutralising capacity.
Alluvium	Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on riverbeds, floodplains, and alluvial fans.
Alluvial aquifer	Permeable zones that store and produce groundwater from unconsolidated alluvial sediments. Shallow alluvial aquifers are generally unconfined aquifers.
Analytical model	Mathematical models that have a closed form solution, ie the solution to the equations used to describe changes in a system can be expressed as a mathematical analytic function.
Anion	An ion with a negative charge.
Anthropogenic	Occurring because of, or influenced by, human activity.
Annual Exceedance Probability (AEP)	The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year.
Annual Recurrence Interval (ARI)	The ARI is the average number of years between exceedances of a given rainfall depth for a given duration at a specific point location. The relationship between AEP and ARIs is: $$AEP = 1 - exp\left(\frac{-1}{ARI\ (years)}\right)$$ ARIs of greater than 10 years are very closely approximated by the reciprocal of the AEP.
Aquatic ecosystem	The stream channel, lake or estuary bed, water, and (or) biotic communities and the habitat features that occur therein.
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.
Aquitard	A low permeability unit that can store groundwater and also transmit it slowly from one formation to another. Aquitards retard but do not prevent the movement of water to or from adjacent aquifers.
Baseflow	The part of stream discharge that originates from groundwater seeping into the stream.
Bore	A structure drilled below the surface to obtain or monitor water from an aquifer or series of aquifers.
Borehole	A hole in the ground drilled by a drill rig for constructing a bore.
Boundary	A lateral discontinuity or change in the formation resulting in a significant change in hydraulic conductivity, storativity or recharge.
Cation	An ion with a positive charge – usually metal ions when disassociated and dissolved in water.
Confined formation	An aquifer that is overlain by low permeability strata. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Concentration	The amount or mass of a substance present in a given volume or mass of sample, usually expressed as microgram per litre (water sample) or micrograms per kilogram (sediment sample).
Conceptual model	A simplified and idealised representation (usually graphical) of the physical hydrogeologic and/or hydrologic setting and the hydrogeological understanding of the essential flow processes of the system. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, sources and sinks, and important aquifer flow and surface-groundwater interaction processes.

Confining layer	Low permeability strata that may be saturated but will not allow water to move through it under natural hydraulic gradients.
Contamination	Contamination is the presence of a non-natural compound in soil or water, or unwanted compound in chemicals or other mixtures.
Cross bedded	Characteristic bedding structure produced by the migration of bedforms with inclined depositional surfaces.
Discharge	The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.
Discharge area	An area in which there are upward or lateral components of flow in an aquifer.
Drawdown	The change in the groundwater head (level) as measured in a bore or at the water table. The groundwater level reflects the pressure of the groundwater at the depth the bore is open/screened. Drawdown refers to the change (lowering) in the groundwater level over time. Note that nearby monitoring bores with different screen depths would be subject to different drawdown.
Dyke	A sheet- like, near vertical minor igneous instruction that cuts across horizontal to gently dipping planar structures in the country rock
Electrical conductivity (EC)	A measure of a fluid's ability to conduct an electrical current and an estimation of the total ions dissolved. It is often used as a measure of water salinity.
Elevation	The height above a given level, often sea level (Australian Height Datum)
Fault	A fracture in rock along which there has been an observable amount of displacement. Faults are rarely single planar units; normally they occur as parallel to sub-parallel sets of planes along which movement has taken place to a greater or lesser extent. Such sets are called fault or fracture zones.
Fracture	Breakage in a rock or mineral along a direction or directions that are not cleavage or fissility directions.
Fractured rock aquifer	These occur in sedimentary, igneous and metamorphosed rocks that have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary rock aquifers.
Groundwater	The water contained in interconnected pores or fractures located below the water table in the saturated zone.
Groundwater dependent (or potentially dependent) ecosystems (GDEs)	Groundwater dependent ecosystems are communities of plants, animals and other organisms whose extent and life processes depend (or partially depend) on groundwater.
Groundwater flow	The movement of water through openings in sediment and rock within the zone of saturation.
Groundwater system	A system that is hydrogeologically more similar than different in regard to geological province, hydraulic characteristics and water quality, and may consist of one or more geological formations.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic gradient	The change in total hydraulic head with a change in distance in a given direction.
Hydraulic head	A specific measurement of water pressure above a datum. It is usually measured as a water surface elevation, expressed in units of length. In an aquifer, it can be calculated from the depth to water in a monitoring bore. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrochemistry	Chemical characterisation of water (both surface water and groundwater).
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Hydrology	The study of the occurrence, distribution, and chemistry of all surface waters.
Igneous	A rock that has solidified from molten or partially molten material (ie volcanic)

Infiltration	The downward flow of water from the land surface into and through the upper soil layers.
Interbedded	Deposited between units.
Jurassic	The middle geological time period of the Mesozoic era c. 208–145 million years ago.
Lithic	Formed of rock, either sedimentary or volcanic.
Major ions	Constituents commonly present in concentrations exceeding 10 milligram per litre. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulphate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.
MicroSiemens per centimetre (µS/cm)	A measure of water salinity commonly referred to as EC (see also electrical conductivity). Most commonly measured in the field with calibrated water quality meter.
Monitoring bore	A non-pumping bore, which is generally small in diameter and used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which groundwater can enter.
Numerical model	A model of groundwater flow in which the aquifer is described by numerical equations (with specified values for boundary conditions) that are usually solved in a computer program. In this approach, the continuous differential terms in the governing hydraulic flow equation are replaced by finite quantities. Computational power is used to solve the resulting algebraic equations by matrix arithmetic. In this way, problems with complex geometry, dynamic response effects and spatial and temporal variability may be solved accurately. It must be used in cases where the essential aquifer features form a complex system (ie high complexity models).
Outcrop	The area where a particular rock unit or formation occurs at surface.
Overburden	The rock units that are above a particular rock unit. Usually used in reference to the rock above the particular target mining unit (ie the coal seam).
Packer test	An aquifer test performed in an open borehole; the segment of the borehole to be tested is sealed off from the rest of the borehole by inflating seals, called packers, both above and below the segment.
Permeability	The property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. It is a measure of the relative ease of fluid flow under unequal pressure. The hydraulic conductivity is the permeability of a material for water at the prevailing temperature.
Permeability test	An aquifer test performed in a laboratory on a sample of aquifer rock (core) to determine the permeability. Liquid or gas is allowed to flow through at different rates and the inflow and outflow pressures are measured.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Permian	The youngest geological time period of the Palaeozoic era c. 290-245 million years ago.
pH	Potential of hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; and provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).
Porosity	The proportion of open space within an aquifer, comprised of intergranular space, pores, vesicles and fractures.
Porous rock	Consolidated sedimentary rock containing voids, pores or other openings (joints, cleats, fractures), which are interconnected in the rock mass and may be capable of storing and transmitting water.
Precipitation	(1) in meteorology and hydrology, rain, snow and other forms of water falling from the sky (2) the formation of a suspension of an insoluble compound by mixing two solutions. Positive values of saturation index (SI) indicate supersaturation and the tendency of the water to precipitate that mineral.

Pumping test	An aquifer test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the bore and the hydraulic characteristics of the aquifer.
Quaternary	The most recent geological period extending from about 2.5 million years ago to the present day.
Quartz arenite	A sandstone comprised of greater than 90% of detrital quartz, with limited amounts of other framework grains
Reach	An uninterrupted length of a stream, creek, or river.
Recharge	The process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Recharge area	A geographic area that directly receives infiltrated water from surface and in which there are downward components of hydraulic head in the aquifer. Recharge generally moves downward from the water table into the deeper parts of an aquifer then moves laterally and vertically to recharge other parts of the aquifer or deeper aquifer zones.
Recovery	The difference between the observed water level during the recovery period after pumping stopped and the water level measured immediately before pumping stopped.
Residence time	The time that groundwater spends in storage before moving to a different part of the hydrological cycle (ie it could be argued it is a rate of replenishment).
Salinity	The concentration of dissolved salts in water, usually expressed in electrical conductivity as total dissolved solids.
Salinity classification (Australia Water Resources s Council 1988)	Fresh water quality – water with a salinity <800 µS/cm. Marginal water quality – water that is more saline than freshwater and generally waters between 800 and 1,600 µS/cm. Brackish quality – water that is more saline than freshwater and generally waters between 1,600 and 4,800 µS/cm. Slightly saline quality – water that is more saline than brackish water and generally waters with a salinity between 4,800 and 10,000 µS/cm. Moderately saline quality – water that is more saline than brackish water and generally waters between 10,000 and 20,000 µS/cm. Saline quality – water that is almost as saline as seawater and generally waters with a salinity greater than 20,000 µS/cm. Seawater quality – water that is generally around 55,000 µS/cm.
Saturated zone	The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric pressure.
Screen	A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of aquifer or filter pack material.
Semi-confined formation	An aquifer overlain by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the leaky confining layer – also known as a leaky artesian or leaky confined aquifer.
Sill	A tubular or sheet-like igneous body from a few centimetres to hundreds of metres long.
Slug test	An aquifer test made either by pouring a small instantaneous charge of water into a well or by withdrawing a slug of water from the well.
Specific storage	Relating to the volume of water that is released from an aquifer following a unit change in the hydraulic head. Specific storage normally relates to confined aquifers.
Specific yield	The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Specific yield generally relates to unconfined aquifers. Gravity drainage may take many months to occur.

Standing water level (SWL)	The height to which groundwater rises in a bore after it is drilled and completed, and after a period of pumping when levels return to natural atmospheric or confined pressure levels.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to specific yield.
Stratigraphy	The depositional order of sedimentary rocks in layers.
Stygofauna	Animals that live in groundwater systems.
Surface water–groundwater interaction	This occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table next to the streambed is greater than the water level in the stream; and (2) streams lose water to groundwater through streambeds when the elevation of the water table is lower than the water level in the stream.
Tertiary	a geological time period of the Cenozoic era c. 65–1.6 million years ago.
Total Dissolved Solids (TDS)	A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). See also EC.
Transmissivity	The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Triassic	The oldest geological time period of the Mesozoic era c. 245–208 million years ago.
Unconfined formation	Also known as a water table aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of an unconfined aquifer.
Unconformity	A break in the stratigraphic record, representing a period of no deposition
Unsaturated zone	The rock, soil, sediments, or regolith between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.
Water quality	Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Water quality data	Chemical, biological, and physical measurements or observations of the characteristics of surface and ground waters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists.
Water table	The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.