8. Groundwater

The potential impact of the Wallarah 2 Coal Project on the regional groundwater system was identified as an issue of concern to the community and discussed at length during the Independent Strategic Inquiry into coal mining in the Wyong Local Government Area. The potential for the W2CP to impact on the groundwater system is discussed in this chapter.

8.1 Scope

Mackie Environmental Research Pty Ltd (MER) was commissioned by W2CP in 2006 to consolidate existing groundwater studies undertaken by various consultants, in order to assess the likely impacts of mining on groundwater systems and to provide advice in respect of future measurement and monitoring of aquifer conditions. The report, contained in Appendix B, provides details of the previous studies as well as a separate assessment of the current project proposal. The assessment has involved detailed computer based simulations undertaken by MER to assess the likely impacts arising from proposed mining operations. This report is summarised in this Chapter.

The Independent Strategic Inquiry into Coal Mining in the Wyong Local Government Area was held during the second half of 2007. This inquiry dealt specifically with the potential implications of underground mining on the Gosford Wyong Water Supply Scheme. Although the Inquiry was not specifically about the W2CP, the final report confirms that with the appropriate safeguards, the extraction of coal by longwall methods deep beneath the Jilliby Jilliby Creek alluvials will not compromise the Gosford Wyong Water Supply Scheme.

The Inquiry report sets out a number of key recommendations which have been adopted in both the project itself and the level of assessment undertaken.

8.2 Existing Groundwater System

Three principal domains of groundwater have been identified within the region – the unconsolidated alluvial aquifers hosted within the Yarramalong and Dooralong valleys and coastal areas, the shallow weathered rock zone, and the more regional sedimentary rocks and coal measures including the Wallarah –Great Northern (WGN) Seam.

The unconsolidated alluvial deposits host a variable aquifer system whose water storage and transmissivity characteristics vary across the valley areas. The underlying Narrabeen Group is regarded as an aquifer only in the shallow weathered zone or in areas where secondary permeability has been induced through jointing and stress relief at shallower depths, more generally within the Terrigal Formation. For the greater part however, strata within this group of rocks are considered to be aquitards (very poor groundwater transmission characteristics) or aquicludes (impermeable).

The groundwater flow regime is shown diagrammatically in Figure 8.1.

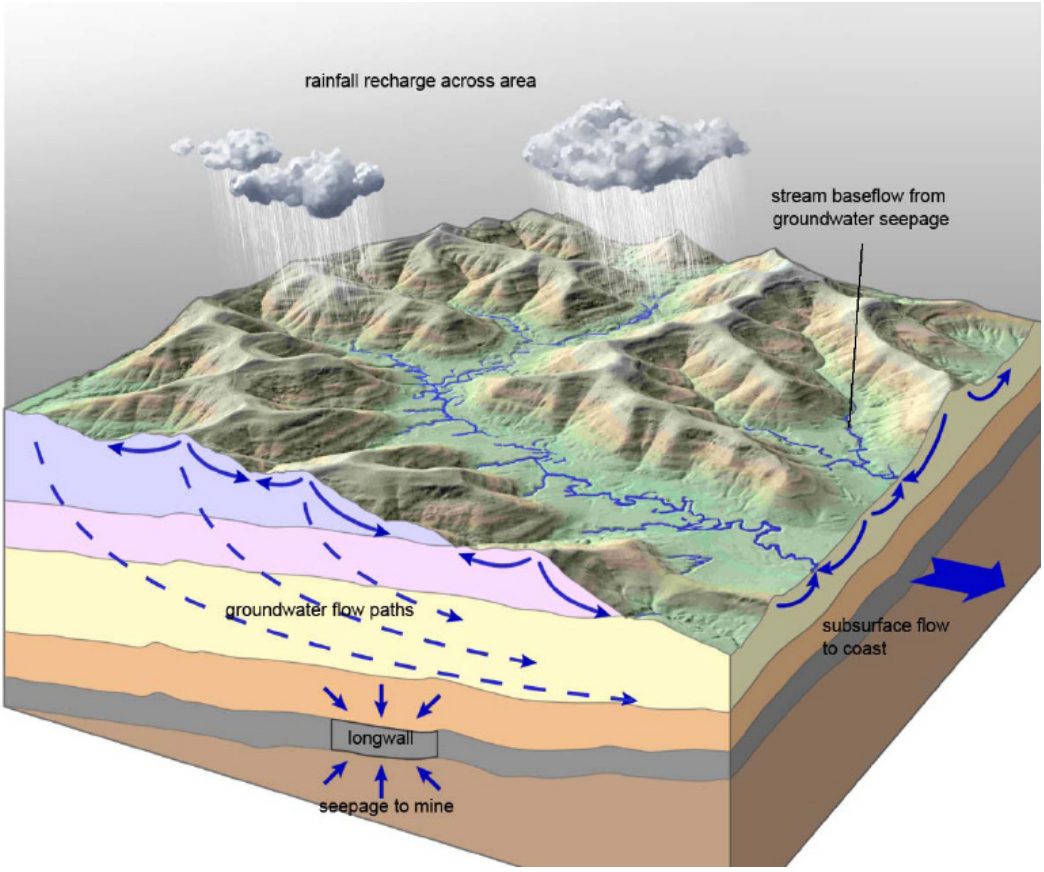

Figure 8.1 Simplified Representation of Groundwater Systems in the Region

8.2.1 Existing Bores and Wells in the Region

Groundwater resources are occasionally exploited for water supply by bores and wells. In order to determine the locations of existing bores and wells, a records search was conducted on the NSW Office of Water (NOW) database. This database contains all registered structures and includes both pumping bores and wells in use, and exploration/test wells which may have been completed as monitoring bores.

Figure 8.2 provides the results of the records search and identifies 61 bore/well locations within a 5 km zone of the mine footprint including only 12 locations situated within the proposed mine footprint. More distant bores are located mainly to the south of Yarramalong Road or clustered in the Yarramalong and Forest Park areas.

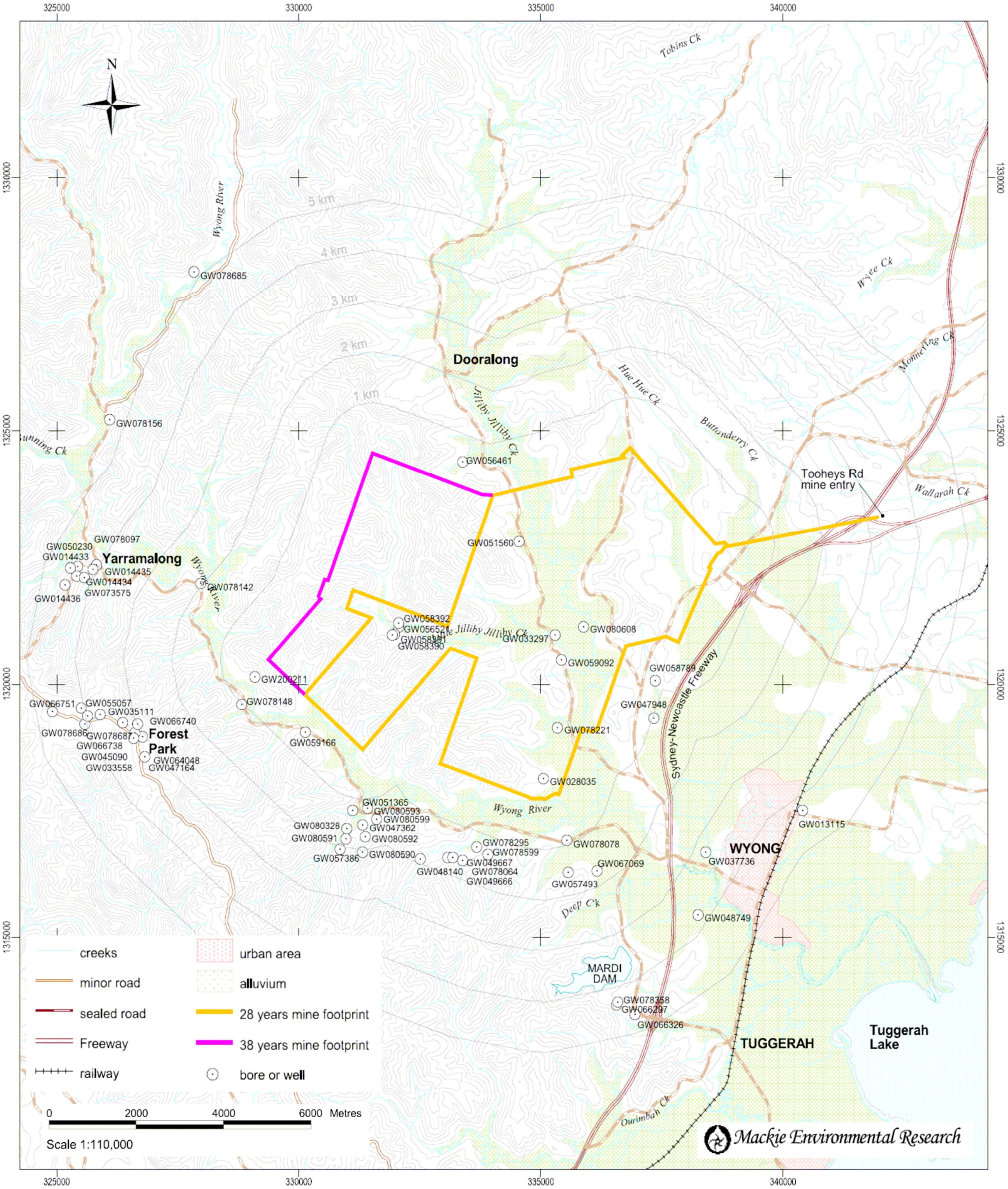

Figure 8.2 Location of Registered Bores and Wells

An overview of bore construction information indicates that most locations draw groundwater from the hard rock areas (Narrabeen Group) rather than the alluvial areas. Yields are variable but generally low, and water qualities vary from fresh to brackish.

8.2.2 Groundwater Occurrence in Unconsolidated Valley Sediments

Groundwater contained within the valley infill and coastal plain sediments occurs within a mixed but typical sequence of gravels, sands, silts and clays. Measurements of groundwater levels at specific alluvial monitoring bores / wells installed some years ago for environmental assessment purposes, have indicated an overall saturated thickness ranging from 2 m to more than 30 m. While there has been limited potential for continued groundwater monitoring in recent years due to the restricted access to the WACJV monitoring sites imposed by particular landowners, there have been several years of measurement of water levels and water quality parameters undertaken in this saturated zone across the WACJV owned monitoring bore network throughout the Yarramalong and Dooralong Valleys. With the recent purchase by the WACJV of a strategically located property in the Dooralong Valley, monitoring of groundwater will recommence in March 2010.

Water level measurements support relatively shallow depths to groundwater in the order of 1 to 5 m, with seasonal oscillations evident in all observation bores due to natural rainfall recharge. These shallow depths and natural seasonal groundwater level movements (in alluvial lands) are also consistent with observations in the Mandalong Valley to the north of the project area.

Historical pH measurements indicate a range from 5.5 to 7.5 for coastal locations and 5.2 to 11.8 for valley deposits, although the high pH of 11.8 probably reflects the influence of grouting in specific boreholes. Salinity measured as total dissolved solids (TDS) supports a fresh to saline quality groundwater in upland areas (200 to 9100 mg/l) and moderately fresh to highly saline quality groundwater in lowland and coastal areas (500 to >20,000 mg/l).

Deeper groundwater in the alluvial areas may be more brackish or saline than shallower groundwater as a consequence of slow upward leakage of brackish groundwater from the deeper hardrock aquitards in inland areas. Shallower groundwater may be fresh or weakly brackish in some areas.

Hydraulic properties of the unconsolidated alluvial deposits, while sparsely measured due to restricted access to test locations, generally reflect a silty clayey alluvium with low hydraulic conductivities (low permeabilities). Locally, these conductivities are likely to vary due to the nature of the unconsolidated materials and the depositional environment.

Hydraulic conductivities of shallow sand deposits situated in coastal areas to the east, while untested, are expected to be higher than the alluvial deposits within the Dooralong and Yarramalong valleys. Table 8.1 provides a general summary of expected properties.

Table 8.1 Estimates of Hydraulic Conductivity for Shallow Unconsolidated Aquifers

	Hydraulic Conductivity (m/day)	Drainable Porosity (%)
Valley Alluvium – Gravels	10 – 50	25 – 35
Valley Alluvium – Sands	1 – 20	20 – 40
Valley Alluvium – Silts	0.01 – 1	20 – 35
Valley Alluvium – Clays	<0.0001 – 0.01	1 – 10
Coastal Sands	0.5 – 40	20 – 40
Mixed Valley Infill – Sand, Silt, Clay	0.1 – 5	20 – 30

8.2.3 Groundwater Occurrence in Hardrock Strata

Groundwater within the Narrabeen Group of rocks occurs predominantly as interstitial storage in pore spaces. The groundwater is derived from sustained recharge by rainfall infiltration through the shallow weathered zone into the underlying clastic rocks over geologic time.

Recharge in topographically high areas sustains an elevated water table that is constrained mostly by surface drainage systems flanking these high areas. That is, the water table is intercepted by local drainages which act to relieve pressures by either conveying seeped groundwater down slope to the Wyong River and Jilliby Jilliby Creek, or by evapotranspirational losses through vegetation along these same drainages when surface flows subside. As a result, the water table (phreatic surface) tends to be a subdued reflection of topography with flow paths initiated in elevated areas (often along topographic divides) and ending beneath the major drainages or along the coastline.

Groundwater flow rates within the hardrocks (hard bedrock) are very low due to the low hydraulic conductivities of the strata. Relatively higher rates of flow are expected within sandstones while much lower rates of flow will prevail within claystones and shale strata.

There is potential for groundwater exchange between strata via fractures and micro cracks which introduce secondary permeability if they are connected. However, it is extremely difficult to establish the occurrence, frequency and connectivity of these fractures since they are mostly vertical or sub vertical and consequently are less likely to be intersected by exploration boreholes than fractures that occur at shallow angles. Core inspections and borehole permeability testing undertaken as part of the current study suggest the hardrock strata are infrequently fractured and therefore likely to exhibit low secondary permeability. Where observed in core, the fractures are often clean and without alteration or secondary mineralisation implying negligible movement of groundwater along these features.

Groundwater within the hardrock strata may be differentially pressurised through structural features or bedding planes, especially in areas of higher topographic relief. When such conditions are encountered during drilling, groundwater levels may rise and sustain an artesian flow at the surface.

The WGN coal seam, like most seams throughout the coalfields, is identified as the main aquifer at depth in so far as it offers enhanced groundwater storage and transmission characteristics through the presence of cleating, although the seam is only weakly cleated. Historically, mining operations at other locations have preferentially depressurised and dewatered the seam with loss of pressure extending over significant distances in advance of mining (≥1 km) and ultimately inducing vertical leakage and pressure losses within overlying and underlying strata.

In general, water quality data reflects fresh to brackish waters throughout the area. Salinity measured as total dissolved solids (TDS) ranges from 1,800 to 7,500 mg/l, while pH values range from 6.3 to 7.6. Improved quality groundwater may be expected within shallow hardrock systems (<30 m depth) in some areas of elevated topography where stress relief induced by weathering, may have generated secondary aquifers with higher rates of flushing, particularly down joints and fractures, and along bedding shears.

8.2.4 Regional Piezometric Surface

The predicted piezometric surface is a subdued reflection of topography with flow directions generally away from topographic highs and towards the Yarramalong and Dooralong Valleys, and subsequently towards the coast.

Rates of groundwater flow are governed by the prevailing piezometric surface and the hydraulic properties of respective strata. The velocities of flow within the hard rock system (Terrigal Formation) are calculated to be very low and in the range from 0.036 to 3.6 mm/year, based on the hydraulic conductivities used in numerical modelling of the aquifer system.

In contrast to the hard rocks, the alluvial aquifers associated with the Wyong River and Jilliby Jilliby Creek (and other significant drainages) act as more dynamic flow systems with rainfall recharge penetrating the sandy and silty aquifer materials. This infiltration mechanism sustains a groundwater flow regime towards the drainage paths where creek bank and river bed seepages eventually discharge groundwater to the river or creeks as base flow. Velocities of groundwater flow within the alluvium are calculated to range from less than 36 to 3600 mm/year.

It is important to note that the regional hard rock groundwater system below the water table is in fact a complex three dimensional flow regime which varies depending upon depth and location of the measurement.

Highest groundwater elevations are predicted in the Forest Park area where piezometric heads of more than 250 m AHD are calculated in the shallower hard rock system while the deep WGN seam is predicted to exhibit piezometric heads of the order of +160 m AHD at the same area. Downwards flow from the surface through the deeper strata can be inferred from the head difference.

8.3 Potential Groundwater Impacts

Proposed mining would induce change to the local groundwater environment. Potential impacts arising from the development include:

- ❒ Reduction in regional hard rock aquifer pressures;
- ❒ Leakage of groundwater from shallow alluvial aquifer systems to deeper systems;
- ❒ Change in shallow aquifer system storage induced by subsidence;
- ❒ Loss of groundwater yield at existing bore locations;
- ❒ Change in groundwater quality; and
- ❒ Impact on groundwater dependent ecosystems.

8.3.1 Groundwater Investigations

Proposed longwall mining in the WGN seam will generate a pressure loss regime within the deep rock strata. Coal panel extraction will initially depressurise the seam and goaf. This depressurisation will then migrate upwards through overburden strata via subsidence induced cracking or bedding parting and via pore spaces in the hard rock matrix. Zero pore pressures are predicted to migrate above extracted panels, to the lower part of the Tuggerah Formation about 220 m above the coal seam. This will in turn generate pressure loss gradients within the remaining part of the Tuggerah Formation and in parts of the overlying Patonga Claystone. Since the hard rocks are basically stratified aquicludes or aquitards, there are no identifiable adverse impacts within the hard rock system. The impact of this on the groundwater is shown diagrammatically on Figure 8.3.

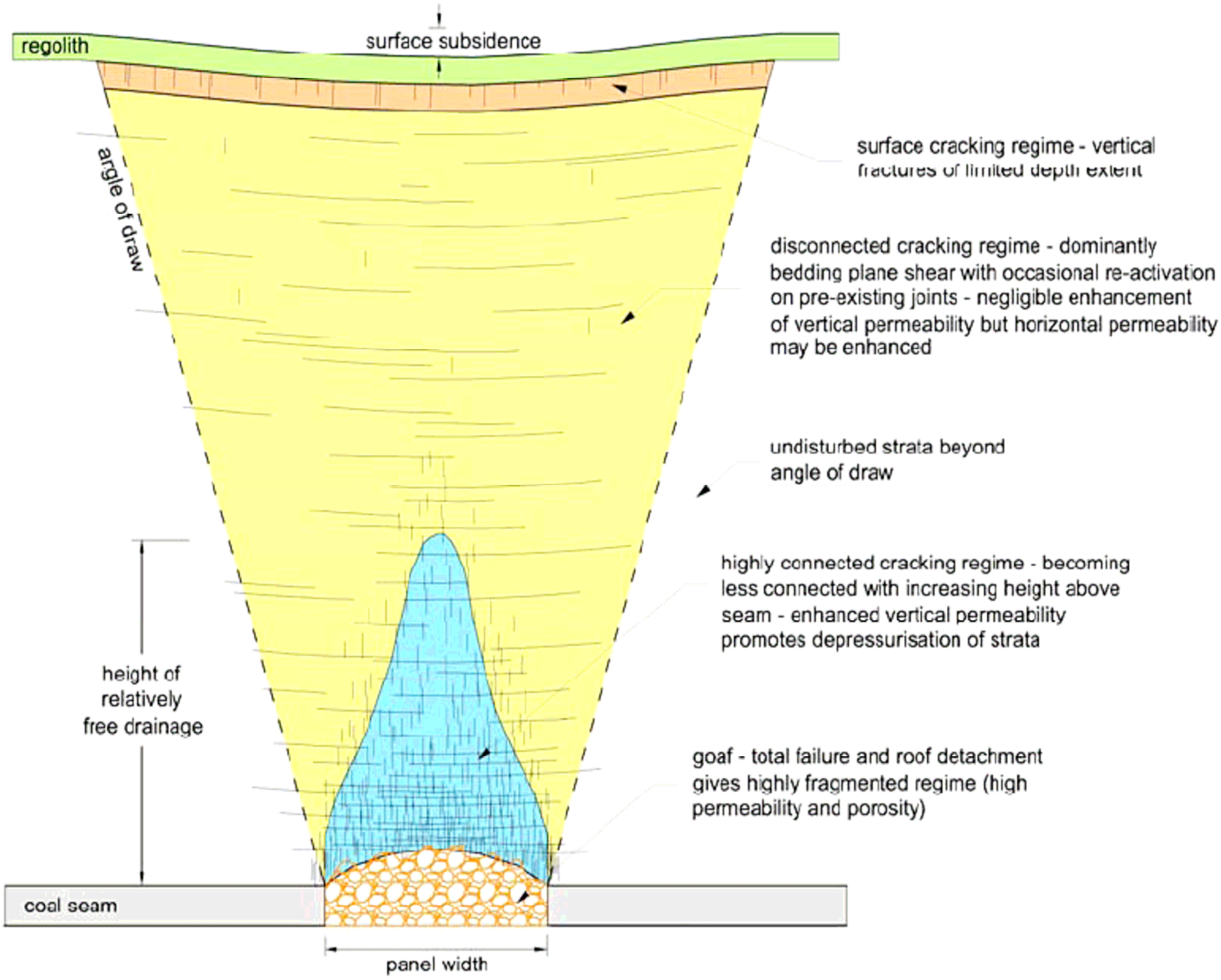

Figure 8.3 Groundwater Impacts

The pressure loss envelope will generate seepage to the mine workings and to goaf. The seepage rate is predicted to rise from about 0.1 ML/day during initial decline construction, to approximately 2.5 ML/day during mining. The predicted seepage to mining operations is considered to be low and manageable.

Loss of pressure within the hard rock strata has the potential to induce leakage from shallower alluvial systems in the long term. This leakage could occur via intergranular permeability or via induced vertical fracturing arising from subsidence. In respect of intergranular permeability, the potential downwards leakage flux from shallow aquifer systems has been calculated to be less than 2 millilitres (ml) per day per square metre of land surface – a rate that is small and easily balanced by recharge from rainfall which is estimated at 130 ml/day per square metre assuming 4% of annual rainfall. Loss of storage in shallow aquifers through this mechanism is therefore considered to be negligible.

In respect of subsidence induced fracturing, SCT (1999) have conducted simulations of the failure regime and determined that cracking above goafed zones would not exhibit continuity to surface. Instead, a significant zone of 100 to 400 m thickness would remain devoid of connected cracking and tend to isolate any shallow and surficial subsidence cracking from the deeper cracked and caved zones. Under these conditions the calculated leakage rates noted above are unlikely to rise. Loss of storage attributed to connective cracking is therefore expected to be negligible.

8.3.2 Shallow Storage Changes Arising From Subsidence

A change in the shallow system groundwater storage will accompany the subsidence process. The change would be of a transient nature and would occur through either temporary filling of tensile cracking storage that would be mainly located around the perimeter of longwall panels (at the surface), or readjustment of groundwater levels to changed surface geomorphology brought about by subsidence.

Adjustment due to filling of crack storage is predicted to be relatively minor. However, re-equilibration of local water levels within the unconsolidated strata would exhibit a variable impact depending upon location. The Yarramalong Valley sediments are predicted to remain generally unaffected except in areas immediately south-west of longwalls LW11S to LW16S where the alluvium is in proximity to the panel footprint.

In contrast, the Dooralong and Hue Hue valley sediments are located above panels scheduled for extraction over the mine life and as such, local aquifers and contained water tables would undergo a more substantial fall in elevation as areas subside. However a rebound in the water table would then occur as subsided areas re-equilibrate to adjacent unsubsided areas. The rate of recovery would depend largely upon climatic conditions with slower rebound occurring during drought periods when local tributaries exhibit low or no flow, and a more rapid rebound occurring during wet periods.

Calculations indicate between 55 and 75% of rebound could be expected within about 6 months of subsidence occurring (for the expected range in alluvial aquifer hydraulic properties and assuming very low rainfall recharge). The subsided alluvial areas would retain an increase in overall groundwater storage as a result of the increased saturated thickness. The depth to the water table would reduce by an amount equivalent to or less than the average subsidence in a given area.

8.3.3 Loss of Groundwater Yield at Existing Bore Locations

Loss of pressures induced by mining within the deep hardrock strata is not predicted to affect any existing bores due to the very low leakage fluxes that are estimated by numerical modelling of the aquifer systems.

There are 12 bores located within the subsidence zone (refer to Table 8.2) that may exhibit a minor loss of yield as groundwater levels initially fall then rebound as a result of subsidence induced strata displacement. Groundwater levels may fall by up to 1.3 m but for average conditions, 55% to 75% recovery is expected to occur within six months. Such displacement is unlikely to affect borehole yield in a measureable way. However, some bores in these same locations could be susceptible to mechanical damage (through subsidence) and may need to be repaired or re-drilled if damaged.

Table 8.2 NOW Registered Bores/Wells within Proposed Mine Footprint

Bore	Coordinates (AMG)		Depth (m)	Aquifers/ Yield (L/s)	Water Depth (m)	Water Quality	Bore Geology
	E	N					
GW028035 20BL021424 P	348750	6318275	30.5	19.8-25.2m/1.26	7.60	good	0.04-4.8 Clay 4.8-6.7 S/S 6.7-18.3 Clay 18.3-20.4 S/S 20.4-24.4 Sh 24.4-30.5S/S
GW033297 20BL026199 W,D	348930	6321110	19.8	17.6-19.7/0.25	4.60	nil	0.00-10.66 Clay 10.66-11.88 S/S 11.88-17.67 Sh 17.67-19.81 S/S
GW051560 20BL11142 4 F,S	348160	6322940	33.0	28.0/5.0	13.0	nil	0.0-19.0 Clay 19.0-33.0 S/S
GW05652120 BL122843D,S	345687	6321210	45.0	nil	nil	nil	0.0-8.0 Clay 8.0-25.0 S/S 8.0-25.0 Sh 25.0-44.0 S/S 44.0-45.0 Sh
GW05839020 BL127954 D	345575	6321050	0.00	nil	nil	nil	nil
GW05909220 BL135236 D,S	349070	6320630	38.0	24.0-25.0/1.26	15.0	salty	0.0-16.0 Clay 16.0-38.0 Sh S/S
GW07822120 BL166822 1	349022	6319270	60.0	28.9-30.0/0.13	26.0	fresh	0.0-16.5 Clay 16.5-28.9 Mud 28.9-42.6 Cong 42.6-53.0 Mud 53.0-60.0 Cong
GW08060820 BL169008 D,S	349520	6321281	48.0	41.0-45.0/0.40	3.20	nil	0.0-36.0 Sands 36.0-48.0 Sh
GW078609	348866	6323656	32.0	nil	nil	nil	0.0-6.0 soil/clay 6.0-30.0 s/s 30.0-32.0 mudstone
GW200505 D,S	350914	6322022	54.0	26.4-26.9 48.5-49.3	nil	fresh	0.4-4.9 clay 4.9-6.5 gravel 6.5-26.4 clay 26.4-26.9 clayey gravel 26.9-31.4 clay 31.4-49.3 cong 49.3-50.1 clay 50.1-54.0 cong
GW058391 D	345728	6321244	nil	nil	nil	nil	nil
GW058392	345802	6321461	nil	nil	nil	nil	nil

"nil" = no recorded data, S/S = sandstone, Sh = shale/claystone, Cong = conglomerate
D, S, F, I, W, P denotes authorized purpose: Domestic, Stock, Farm, Irrigation, Waste disposal, Poultry

8.3.4 Change in Groundwater Quality

It is unlikely that any measurable change in groundwater quality will be observed in hardrock strata as pressures decline. Localised change in salinity may be observed in deep caved zones as groundwaters contained within different stratigraphic horizons of hardrock units mix with fragmented materials in goaf. This mine water will be treated within the mine water management system.

Similarly, it is unlikely that any measurable change in water quality will be observed in the shallow unconsolidated alluvial aquifer systems. Subsided areas will retain a shallower water table that will be replenished from drainage systems and rainfall recharge. The depth to the water is predicted to remain generally more than 2 m. Active flushing of salts by recharge processes will continue.

It is possible that surface cracking of hardrock strata in elevated areas may initiate localized redirection of surface flows in some drainages leading to fresh water-rock hydrochemical interactions and the potential for ferruginous staining downstream of the cracking. This process is observed in some subsided drainages within Hawkesbury Sandstone areas of the southern coalfields (south of Sydney). Candidate drainages within the W2CP project area include the upper reaches of Little Jilliby Jilliby Creek. The Terrigal Formation hosting these drainages is not known to have historically generated natural iron springs and the potential is therefore considered to be low.

8.4 Groundwater Mitigation Measures

Mitigation measures for any identified negative impacts beyond those predicted, may include replacement of water supply or relinquishment of groundwater or surface water allocations in order to account for leakage losses from the alluvial aquifers.

8.5 Groundwater Monitoring

A comprehensive groundwater monitoring program will be developed and maintained as part of the overall mine environmental monitoring. The program will commence in March 2010 with a series of bores constructed on company owned land in the Dooralong Valley. The program will be extended to include the previous monitoring bore network, bores on public land such as road reserves, private bores and wells in potentially affected areas (subject to negotiated access). New boreholes will be designed to also monitor vertical pressure distributions during development and mining, and monitoring of mine water seepage during the mine life.

Information gained from the monitoring program will be used to validate and verify model predicted seepage and depressurisation conditions outlined in this EA and the specialist consultant report appended (Appendix B). All data will be reviewed regularly as part of compliance procedures and alert protocols.

Water management monitoring will include:

- Measurement of groundwater levels, pore pressures and water quality (EC, pH and major ion species) within the existing W2CP regional network of monitoring bores and an expanded network;

- Measurement of rates of groundwater seepages and groundwater quality (EC and pH) within the mine water system;
- Compliance monitoring and measurement of water discharges including quality monitoring of major ions and specific rarer elements;

- Adoption of data transfer protocols to convey monitoring data from the mine to the relevant Regulatory Authorities; and

- Annual reporting as part of approvals and licensing conditions.

In addition to the above, the monitoring program will be subject to annual review by the environmental services group of W2CP and / or its appointed consultants.

8.6 Impact Verification

A groundwater monitoring program is planned to occur on land owned by the proponents of the W2CP and sites approved by the Department of Water and Energy (now Office of Water within DECCW). The program will commence in March 2010 and continue for the life of the operation. The initial approved sites are shown on Figure 8.4.

The monitoring program will determine the following parameters:

- Physical depressurisation of the shallow coal measures rock strata and potential indirect impacts on alluvial aquifer systems associated with the Dooralong and Yarramalong Valleys; and

- Changes to shallow groundwater storage induced by subsidence.

An accelerated decline in formation pressures in shallow strata beneath valley alluvium could signal a change in seepage rates. Future impact assessment criteria would therefore address the pressure regime within shallow strata near and beneath the alluvial lands. Leakage can be estimated by interpolation of the pressure/water table hydraulic gradients and calculation of the leakage flux from measured rock permeabilities. This estimate can also be reconciled with the volume of mine water pumped from proposed underground operations and establish both the strata hydraulic gradients and the rock mass permeabilities.

Eight road side monitoring bores have been approved and a further five drill sites have been chosen on company owned land within the Dooralong Valley. At each monitoring site a nested (bundled) set of piezometers will be constructed. The minimum requirement is a monitoring bore to be constructed in the 30 to 40 m thick alluvial system to measure any depressurisation in the alluvial aquifer and a second deeper piezometer to be completed approximately 20 to 25 m into the weathered basement sedimentary rock sequence. Depending on the results of drilling in the alluvium, a third piezometer may be required if semi-confined or confined hydrogeological conditions are encountered.

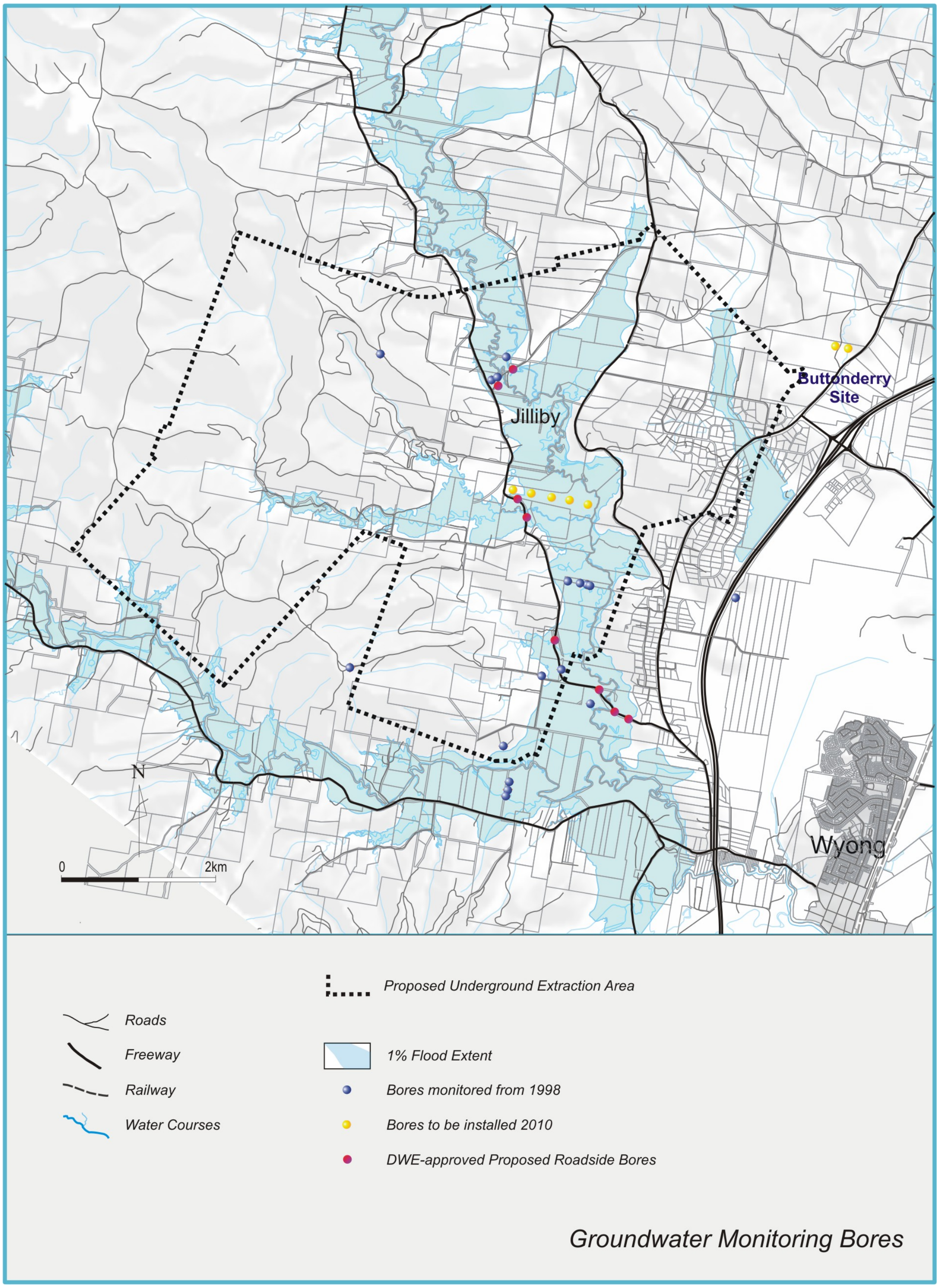

Figure 8.4 Initial Groundwater Monitoring Bores

Depressurisation monitoring may include:

- Construction of standpipe piezometers to augment measurement of pressures / water levels in shallow alluvium and underlying strata. As a minimum, the design will allow for isolation of bottom hole strata from mid hole and alluvial strata utilising combined standpipe and pore pressure transducer completions;

- Installation of vertical arrays of pore pressure transducers distributed within the Narrabeen Group of rocks (overburden) at a minimum of eight locations;

- Strata hydraulic conductivity measurement on rock core obtained at some of the above noted locations. Such measurement would comprise testing for matrix permeability and *insitu* testing for permeability over the piezometric intervals;

- Quarterly monitoring of water levels in all existing and new piezometers in the monitoring bore network; and

- Daily monitoring of water levels by installed auto recorders in selected existing and new piezometers in order to discriminate between oscillatory groundwater movements attributed to rainfall recharge, and longer term pressure losses related to mining.

Mine water seepage monitoring would include:

- Measurement of all water pumped underground and all mine water pumped to the surface on a daily basis. Measurement would be undertaken using calibrated flow meters or other suitable gauging apparatus;

- Routine monitoring of coal moisture content delivered from the working face in order to more accurately determine the underground water balance; and

- Routing monitoring of ventilation humidity.

Water quality monitoring would include:

- Quarterly monitoring of basic water quality parameters (pH and EC) in selected piezometers and pumped mine water. Such monitoring may provide early indication of mixing of shallow groundwaters with groundwaters in deeper strata. While this process is expected within the subsidence zone, it may not be evident within the wider piezometer network at the leakage levels predicted by groundwater monitoring;

- Six monthly measurement of total dissolved solids (TDS) and speciation of water samples in selected piezometers to support identification of mixing of groundwater types. Speciation should include as a minimum - major ions Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4 and elements including Al, As, B, Ba, F, Fe (total), Li, Mn, P, Se, Si, Sr, Zn; and

- Graphical plotting of basic water quality parameters and identification of trend lines and statistics including mean and standard deviation calculated quarterly. Comparison of trends with rainfall and any other identifiable processes that may influence such trends.

Impact verification analyses would include:

- Quarterly assessment for departures from identified monitoring or predicted data trends. The key data sets in this regard should be the mine water seepage rate calculated from the underground water balance, and the pressure monitoring data for multi level piezometers. If the average daily seepage rate exhibits an increase beyond the rate predicted (allowing for 0.5 ML/day additional transient storage depletion), or if consecutive pressure monitoring data over a period of six months exhibit an increasing divergence in an adverse impact sense from the previous data or from the established or predicted trend, then such departures should initiate further actions. These may include a need to conduct more intensive monitoring (including installation of additional piezometers) or to invoke impacts re-assessment and/or mitigative measures;

- Formal review of depressurisation of coal measures and comparison of responses with aquifer model predictions biennially. Expert review should be undertaken by a suitably qualified hydrogeologist; and

- Annual reporting (including a summary of all water level and water quality data) as part of the Annual Environmental Management Report (AEMR).