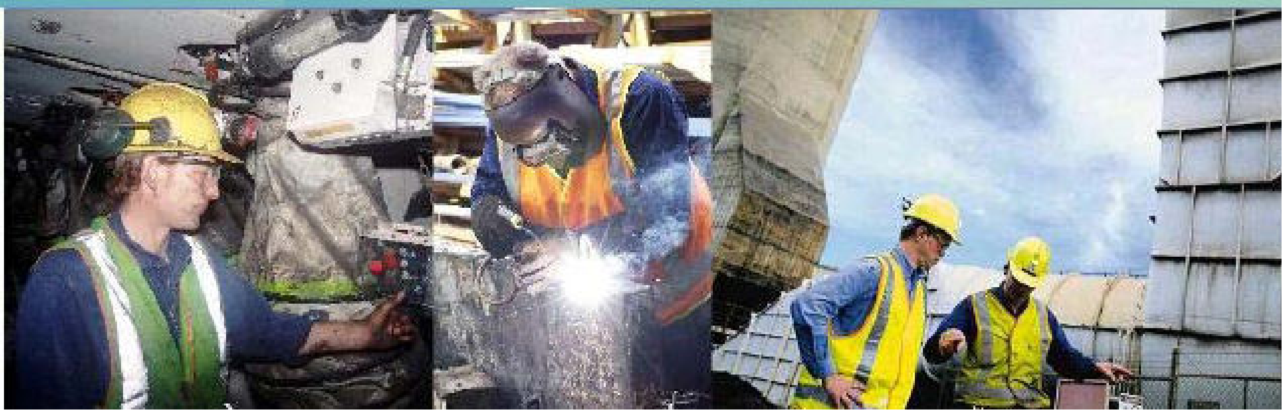
Dendrobium Mine

# Health and Safety Management System

# Management Plan



# Groundwater Management Plan

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# Dendrobium Colliery Area 3B SMP

# Groundwater Management Plan

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# 1. INTRODUCTION

## 1.1 Purpose

The Groundwater Management Plan has been prepared to comply with the Dendrobium Consent with respect to groundwater management issues. The revised Dendrobium Consent, dated 8 December 2008, requires a Groundwater Monitoring Plan under Schedule 3(13) of the consent. Specifically Schedule 3(13) of the consent is provided below.

13. The SMPs prepared under condition 7 must include a Groundwater Monitoring Program, which must include:
    (a) proposals to develop a detailed regional and local groundwater model, with special reference to flows to and from nearby water storages;
    (b) detailed baseline data to benchmark the natural variation in groundwater levels, yield and quality;
    (c) groundwater impact assessment criteria;
    (d) a program to monitor the impact of the development on:
    - groundwater levels, yield and quality (particularly any potential loss of flow to, or flow from, SCA water storages);
    - coal seam aquifers and overlying aquifers; and
    - groundwater springs and seeps; and

    (e) consideration of the requirements of the latest version (or subsequent replacement) of SCA's The Design of a Hydrological and Hydrogeological Monitoring Program to Access the Impacts of Longwall Mining in SCA Catchment.

# 2. MONITORING AND REPORTING

## 2.1 Aim of Monitoring Program

The groundwater monitoring program has been developed from the baseline study in accordance with the Dendrobium Consent and in consultation with relevant stakeholders. The aim of the monitoring program is to:

- Monitor groundwater levels and quality, commencing at least one year prior to mining affecting the groundwater system.
- Project potential groundwater changes during mining (short term) and post-mining (long term) with particular attention given to the affect of changes to groundwater regime, impact on the catchment yield and interaction with the stored waters.
- Identify hydraulic characteristics of overlying and intercepted groundwater systems, and determine changes to groundwater systems due to coal extraction and dewatering operations.
- Report any pumping tests and groundwater/surface water simulation studies.
- Collect water level data from all agreed groundwater-monitoring locations.

A number of exploration drill holes with hydro-geological information were available in the area to define the groundwater regime. A number of these holes had been monitored for some years. This information is supplemented by detailed near surface and deeper aquifer investigations required to monitor groundwater impacts between the mining and the Reservoirs. The relevant plans associated with this monitoring are the:

- BHPB, 2012. *Dendrobium Mine, Avon and Cordeaux Reservoir DSC Notification Areas, Management Plans.*

The Groundwater Monitoring Program is generally consistent with the SCA's The Design of a Hydrological and Hydrogeological Monitoring Program to Access the Impacts of Longwall Mining in SCA Catchment.

## 2.2 Hydraulic Characteristics of Groundwater

Hydraulic characteristics of overlying and intercepted groundwater systems are being determined by a number of shallow and deeper groundwater investigations. The data from these investigations is used to identify changes to groundwater systems due to coal extraction and dewatering operations.

## 2.3 Baseline Ground Water Monitoring

Water levels and quality are measured and logged with routine downloads made to a central database for analysis. Status reports and maintenance of the sites is conducted at regular intervals to rectify any identified issues. Data recovery, storage and reporting comply with NATA-accredited procedures.

A series of piezometers are installed and completed to varying depths to monitor groundwater. This includes overburden sequences that would be subsided by mining, including those that may influence ecosystems and/or dam safety. Secondary impacts from the installation and maintenance of monitoring bores are assessed and approved by SCA prior to installation.

*Area 1*

The shallow groundwater baseline study in Area 1 commenced with an initial site inspection to identify areas where potential groundwater monitoring bores could be established. Groundwater monitoring bores were installed in association with surface water monitoring sites. This ensures any link between surface and shallow groundwater impacts are recorded. The sites selected capture significant features within streams and are located within the predicted impact zone and reference sites. Subsidence predictions have been reviewed for the monitoring sites identified.

There was limited deep groundwater baseline monitoring available in three exploration holes in Area 1. Additional piezometers were installed to monitor the mining impact in consultation with the DSC.

*Area 2, 3A & 3B*

The baseline study for Area 2, 3A and 3B is an extension of the program developed for Area 1. Additional groundwater bores have been established with accurate absolute datum levels and these would be regularly verified in areas where subsidence may occur. Groundwater level is recorded at each of these additional stations with water quality analysis conducted at selected sites within the catchment. The groundwater component requires a number of bores to adequately define the slope of the groundwater and any potential impacts of subsidence. The monitoring program is similar to that of the Kembla Creek and DSC programs for Area 1. Groundwater is monitored for levels and in shallow holes water quality using down hole water level and conductivity temperature and depth (CTD) sensors. Recently some holes have been fitted with low volume displacement pumps at key horizons to enable water sampling for detailed analysis.

## 2.4 Monitoring Shallow Groundwater Levels and Quality

*Area 1 – Shallow Groundwater Monitoring*

Monitoring of groundwater levels and quality associated with Kembla and Goondarrin Creeks commenced in 2003 and was completed in 2009, two years after mining was completed in Area 1. Eleven boreholes were hand-augured to refusal with a maximum depth reached of 6 m. Four of the boreholes contained water at the time of installation, while the remainder were moist or completely dry.

Ten of the 11 boreholes had pressure transducer instrumentation to provide continuous measurement of the groundwater level. Where holes had reliable groundwater levels water quality instrumentation was installed. It is important for water to be in the holes to reduce the possibility of damage to the instrumentation.

Pool water levels were monitored to determine any increased interaction between surface and groundwater from subsidence. The water level in each bore was measured to a datum common with the surface water level recordings. Data was transferred to a central database to enable processing. Groundwater level and quality changes are good indicators of potential impacts and data from monitoring could provide design specifications for any pool mitigation and rehabilitation programs, though none were required. This monitoring was concluded in 2009 and **Figure 2.1** shows the locations of the monitoring sites

*Area 2 – Shallow Groundwater Monitoring*

Groundwater monitoring is undertaken in Area 2 with a number of monitoring stations developed between the mining area and Lake Cordeaux. There are 13 auger holes instrumented with piezometers installed in Area 2 as shown in **Figure 2.2**.

***Area 3A - Shallow Groundwater Monitoring***

Three shallow piezometers were initially installed on the eastern part of Area 3A in the SC10 sub-catchment of Sandy Creek in the vicinity of Swamp 15b.

In addition, 49 new auger holes have been installed in Area 3A in swamps and hillslope aquifers. These installations have been undertaken in consultation with key stakeholders and appropriate approvals from the SCA. The monitoring include a series of seventeen holes in the southern arm of SC10 in and around Swamp 15a, twenty holes in Swamp 15b, five holes in Swamp 12 and seven holes in other locations (see **Figure 2.3**).

The first stage of instrumentation involves establishing piezometers in 18 of the boreholes, including 12 holes for the first stage of extraction and three control piezometers for Swamp 15a.

The piezometers measure groundwater level continuously on a one hourly frequency.

The location of the Area 3A monitoring sites is shown in **Figure 2.3**.

***Area 3B - Shallow Groundwater Monitoring***

Due to the size of Area 3B, instrumentation will be installed progressively, focussing on the earlier longwalls. 23 new auger holes have been installed in swamps and hillslope aquifers in Area 3B. An additional 12 boreholes are planned to be installed in Longwalls 9 and 10 as a result of consultation with key stakeholders.

The location of the Area 3B monitoring sites is shown in **Figure 2.3**.

## 2.5 Deep Groundwater Monitoring

Dendrobium uses deep groundwater monitoring to understand the groundwater regime in the stratigraphic units between the mining horizon, in the Wongawilli Seam, and the outcrop stratigraphy in Avon and Cordeaux Reservoirs. Dendrobium uses borehole packer tests, piezometers and pumps to establish strata permeability, groundwater levels and water quality in conjunction with in-mine monitoring of water quantity and quality data. The monitoring data is used to:

- identify the pre-mining groundwater regime,
- model the groundwater and prepare impact assessments,
- monitor the mining impacts on groundwater, provide a basis for Triggered Action Response Plans
- assure government that the mining impacts are within prediction and acceptable.

The monitoring consists of a significant database of piezometric pressures within the rockmass coupled with the measurement of the water balance within Dendrobium Mine.

**Table 2.0 – Dendrobium Deep Groundwater Monitoring**

| Area | Boreholes | Piezometers | Pumps |
|---|---|---|---|
| 1 | 12 | 66 | 0 |
| 2 | 24 | 126 | 1 |
| 3A | 21 | 142 | 21 |
| 3B | 34 | 168 | 5 |

The monitoring has been developed on an 'area by area basis', this has enabled new technology like multiple piezometer strings and low volume displacement pumps sealed into boreholes to be introduced as the new technology is proven.

In Area 1 and 2 the monitoring was heavily focussed on the area between the extraction area and the Reservoir in order to justify that mining was acceptable near the Reservoir. The monitoring in Area 3 has been designed to provide more general groundwater data in addition to the monitoring near the Reservoir.

The sites of all monitoring boreholes are shown in **Figure 2.1**, **Figure 2.2** and **Figure 2.3** for Area 1, 2 and 3 respectively.

***Area 1 and 2 – Deep Groundwater Monitoring***

Early groundwater monitoring investigations involved installation of a single piezometer in a limited number of exploration boreholes. At the time of the commencement of Longwall extraction in Area 1 in 2005, multi level piezometer strings were utilised to monitor the impacts of mining. The Area 1 program monitors the hydrogeological conditions within the rockmass between the Kembla Creek arm of Cordeaux Reservoir and the Area 1 longwall goaf. The Area 2 program monitors the hydrogeological conditions within the rockmass between the Cordeaux River arm of Cordeaux Reservoir and the Area 2 longwall goaf. The monitoring concentrates on the performance of the groundwater in the Scarborough Sandstone as it is the aquifer that has limited outcrop in the Reservoir and is intersected by the goaf. Additional monitoring is in place to understand the groundwater behaviour within and around the Cordeaux Crinanite at the southern end of Area 2. The monitoring in Area 1 and 2 was developed to meet the requirements of the Dams Safety Committee.

In Area 1 groundwater monitoring was conducted at four sites refer **Table 2.1**.

**Table 2.1 – Area 1 Deep Groundwater Boreholes**

| Site | Description | Monitor |
|---|---|---|
| 1 | 3 inclined boreholes drilled from underground S1655, 1656 and 1588 (Dendrobium DDH 42, 43 & 44) | Scarborough Sandstone |
| 2 | 2 inclined surface boreholes S1647b&c (Dendrobium DDH 45b & c) | Scarborough Sandstone |
| 3 | 2 inclined surface boreholes S1648a&b (Dendrobium DDH 46a & b) | Scarborough Sandstone |
| 4 | 1 vertical surface borehole S1557 (Dendrobium DDH 34) | Scarborough Sandstone |

*Notes - Monitoring in Hole S1588 has subsequently failed due to ground movement.*
*Monitoring in Hole S1655 &1656 has subsequently failed due to damage to cabling.*
*Monitoring in Hole S1647 & 1648 has subsequently failed due flooding of instrumentation.*

The piezometers installed from underground are read manually. The piezometers installed from the surface are logged hourly to a local datalogger which is downloaded monthly.

In Area 2 the groundwater monitoring was concentrated at five sites, refer to **Table 2.2** and **Figure 2.2** The methodology is similar to Area 1, however all monitoring has been offset further from the longwalls to ensure that the monitoring is not compromised by shearing of the piezometer strings associated with the formation of the goaf. All the monitoring was installed in boreholes drilled from the surface.

**Table 2.2 – Area 2 Deep Groundwater Boreholes**

| Site | Description | Monitor |
|---|---|---|
| 5 | 6 vertical boreholes S1576, 1712, 1713, 1714, 1849 & 1902 (Dendrobium DDH 37, 100, 51, 52, 53 & 80) | Cordeaux Crinanite and the margin |

| | | |
|---|---|---|
| 6 | 5 vertical boreholes S1650, 1651, 1652, 1847 & 1848 (Dendrobium DDH 48, 49, 50, 78 & 79) | Sedimentary lithology marginal to the Crinanite |
| 7 | 1 vertical borehole and 1 inclined borehole towards Longwall 3, S1833 & 1834 (Dendrobium DDH 74 & 75) | Sedimentary lithology |
| 8 | 1 vertical borehole and 1 inclined borehole towards Longwall 3, S1649 & 1832 (Dendrobium DDH 47 & 73) | Sedimentary lithology |
| 9 | 1 vertical borehole and 1 inclined borehole towards Longwall 3, S1830 & 1831 (Dendrobium DDH 71 & 72) | Sedimentary lithology |

*Regional groundwater is measured in 5 additional holes S1102, 1111, 1577, 1578 & 1723 (Kemira DDH23 & 25, Dendrobium DDH 38, 39, 60).*

*Note - Monitoring in Hole S1578 has subsequently failed due to ground movement associated with Longwall 3 extraction.*

In addition to the groundwater pressure monitoring undertaken by the borehole piezometers a borehole has been installed in Area 2 to enable groundwater samples to be collected for analysis. The pump in S1902 (Dendrobium DDH 94) samples water from the Scarborough Sandstone and a single piezometer monitors water pressure in the borehole.

All active piezometers in Area 2 are logged hourly and downloaded monthly. Water samples from Dendrobium DDH 94 are collected quarterly.

***Area 3A – Deep Groundwater Monitoring***

Dendrobium Area 3A groundwater monitoring is shown in **Figure 2.3**.

The groundwater monitoring programme for Area 3A is based on a regional approach to enable modelling and also monitoring of the barrier between Longwall 6 & 7 and the Sandy Creek arm of the Cordeaux Reservoir.

Regional monitoring includes early exploration drillholes S1106, 1388, 1587, 1719, 1720, 1738 & 1845 (Kemira DDH 24 and Dendrobium 29, 41, 56, 57, 61 and 77) which have single piezometers located in the Wongawilli Seam. Since 2006, multi level piezometers have been installed in 15 drillholes, S1867, 1870, 1871, 1878, 1879, 1885, 1887-1890, 1892, 1907, 1969, 1992 & 1994 (Dendrobium DDH 84-86, 91-93, 95-99, 103 and 118-120). The multi level piezometers primarily target the Hawkesbury, Bulgo and Scarborough Sandstones as well as the Bulli and Wongawilli Seams.

Six of the boreholes containing multiple piezometers are targeted to monitor the groundwater response between the longwalls and the Sandy Creek arm of the Reservoir, S1867, 1870, 1871, 1878, 1992 & 1994 (Dendrobium DDH 84, 85, 86, 91, 119 and 120). In addition to the previous monitoring a borehole has been installed to enable groundwater samples to be collected from the Scarborough and Bulgo Sandstone S1969 (Dendrobium DDH 118).

***Area 3B – Deep Groundwater Monitoring***

Dendrobium Area 3B groundwater monitoring is also shown in **Figure 2.3**.

The groundwater monitoring programme for Area 3B is based on a regional approach to enable modelling.

Regional monitoring includes early exploration drillholes S1579, 1739, 1755, 1758, 1800, & 1855 (Dendrobium 40, 62, 64, 65, 70 & 82) which have one or two piezometers located in the coal seams (Bulli & Wongawilli Seam). Since 2008, multi level piezometers have been installed in 14 drillholes, S1908, 1910, 1911, 1914, 1925 - 1927, 1929 – 1932, 2001, 2006 & 2009 (Dendrobium DDH 104 – 114, 125, 129 & 131)). The multi level piezometers target the Hawkesbury, Bulgo and Scarborough Sandstones as well as the Bulli and Wongawilli Seams, refer **Table 2.4**. Seam level piezometers have also been installed in an additional 12 drillholes.

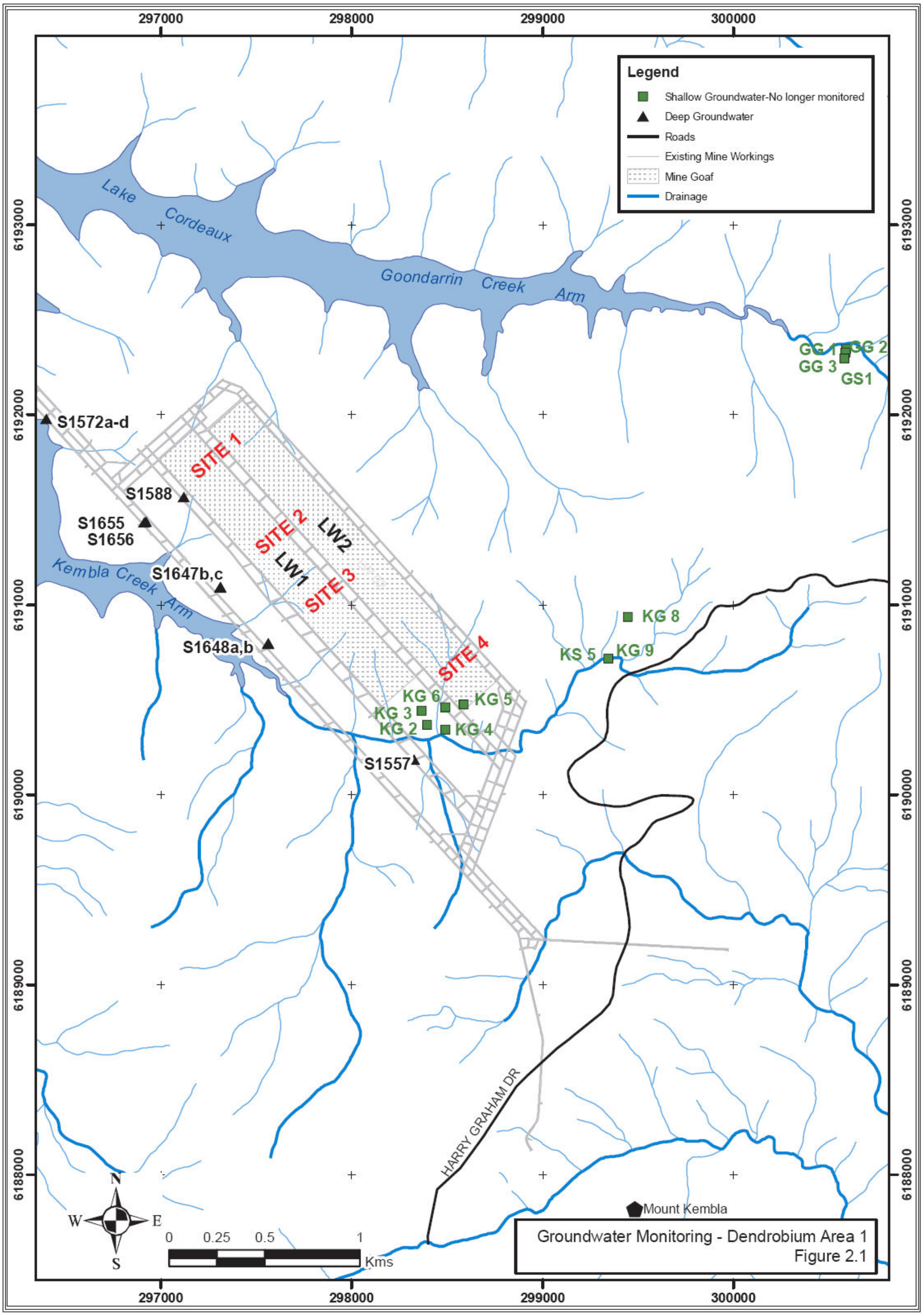
Table 2.3 – Area 3A Deep Groundwater Boreholes

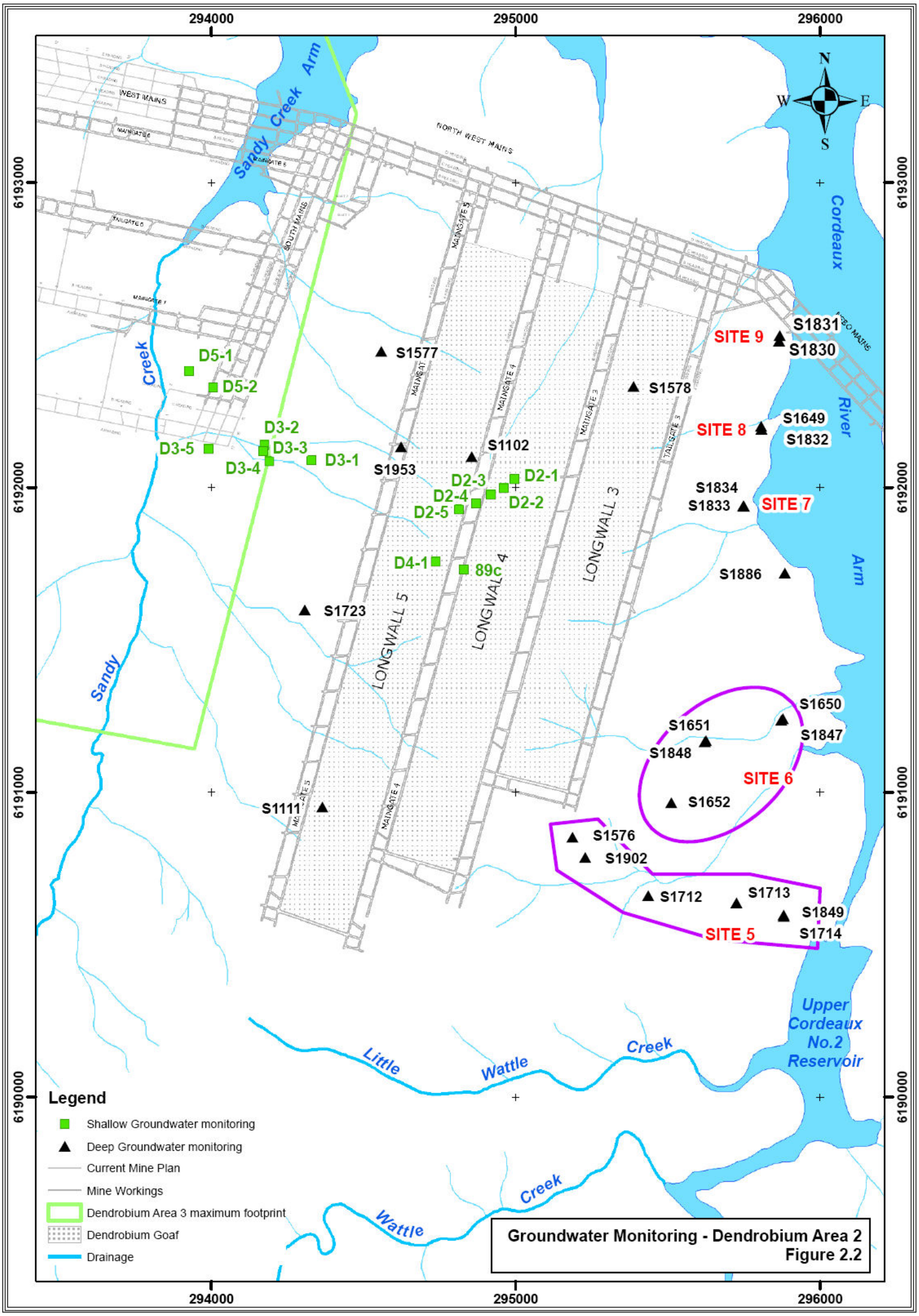
| Borehole | Piezometers located in Stratigraphic Unit | | | | | | | | Total Piezometers |
|---|---|---|---|---|---|---|---|---|---|
| | Hawkesbury Sandstone | Bald Hill Claystone | Bulgo Sandstone | Scarborough Sandstone | Wombarra Shale | Coalcliff Sandstone | Bulli Seam | Wongawilli Seam | |
| S1106 | | | | | | | | 1 | 1 |
| S1388 | | | | | | | | 1 | 1 |
| S1587 | | | | | | | | 1 | 1 |
| S1719 | | | | | | | | 1 | 1 |
| S1720 | | | | | | | | 1 | 1 |
| S1738 | | | | | | | | 1 | 1 |
| S1845 | | | | | | | 1 | 1 | 2 |
| S1867 | 2 | | 3 | 2 | 1 | 1 | 1 | 1 | 11 |
| S1870 | 3 | | 3 | 2 | 1 | 1 | 1 | 1 | 12 |
| S1871 | 3 | | 3 | 2 | 1 | 1 | 1 | 1 | 12 |
| S1878 | | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 11 |
| S1879 | 3 | | 3 | 3 | 1 | | 1 | 1 | 12 |
| S1885 | 3 | | 3 | 3 | 1 | | 1 | 1 | 12 |
| S1887 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1888 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1889 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1890 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1892 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1907 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1969 | 3 | | 3 | 3 | | | 1 | 1 | 12 |
| S1992 | 1 | | 3 | 3 | | | 1 | | 8 |
| S1994 | 1 | | 3 | 3 | | | 1 | | 8 |

Table 2.4 – Area 3B Deep Groundwater Boreholes

| Borehole | Piezometers located in Stratigraphic Unit | | | | | | | | Total Piezometers |
|---|---|---|---|---|---|---|---|---|---|
| | **Hawkesbury Sandstone** | **Bald Hill Claystone** | **Bulgo Sandstone** | **Scarborough Sandstone** | **Wombarra Shale** | **Coalcliff Sandstone** | **Bulli Seam** | **Wongawilli Seam** | |
| S1579 | | | | | | | | 1 | 1 |
| S1739 | | | | | | | | 1 | 1 |
| S1755 | | | | | | | 1 | 1 | 2 |
| S1758 | | | | | | | 1 | 1 | 2 |
| S1800 | | | | | | | 1 | 1 | 2 |
| S1855 | | | | | | | 1 | 1 | 2 |
| S1908 | 2 | | 3 | 1 | | | 1 | 1 | 8 |
| S1910 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1911 | 3 | | 3 | 2 | 1 | 2 | | 1 | 12 |
| S1914 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1925 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1926 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1927 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1929 | 2 | | 2 | 2 | | | 1 | 1 | 8 |
| S1930 | 3 | | 3 | 3 | 1 | | 1 | 1 | 12 |
| S1931 | 1 | 1 | 3 | 2 | | | 1 | 1 | 9 |
| S1932 | 4 | | 3 | 3 | | 1 | | 1 | 12 |
| S1995 | | | | | | | 1 | 1 | 2 |
| S1998 | | | | | | | 1 | 1 | 2 |
| S1999 | | | | | | | 1 | 1 | 2 |
| S2000 | | | | | | | 1 | 1 | 2 |
| S2001 | 3 | | 3 | 2 | | | 1 | 1 | 10 |
| S2002 | | | | | | | 1 | 1 | 2 |
| S2003 | | | | | | | 1 | 1 | 2 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| S2004 | | | | | | | 1 | 1 | 2 |
| S2006 | 3 | | 3 | 2 | | | 1 | 1 | 10 |
| S2007 | | | | | | | 1 | 1 | 2 |
| S2009 | 3 | | 3 | 2 | | | 1 | 1 | 10 |
| S2013 | | | | | | | 1 | 1 | 2 |
| S2070 | | | | | | | 1 | 1 | 2 |
| S2071 | | | | | | | 1 | 1 | 2 |
| S2078 | | | | | | | 1 | 1 | 2 |
| S2126 | | | | | | | 1 | 1 | 2 |


Legend
Shallow Groundwater-No longer monitored
Deep Groundwater
Roads
Existing Mine Workings
Mine Goaf
Drainage
Lake Cordeaux
Goondarrin Creek Arm
Kembla Creek Arm
SITE 1
SITE 2
SITE 3
SITE 4
LW1
LW2
S1572a-d
S1588
S1655
S1656
S1647b,c
S1648a,b
S1557
KG 2
KG 3
KG 4
KG 5
KG 6
KG 8
KG 9
KS 5
GG 1
GG 2
GG 3
GS1
HARRY GRAHAM DR
Mount Kembla
0 0.25 0.5 1 Kms
N S E W
297000 298000 299000 300000
6188000 6189000 6190000 6191000 6192000 6193000
Groundwater Monitoring - Dendrobium Area 1
Figure 2.1




Groundwater Monitoring - Dendrobium Area 2
Figure 2.2

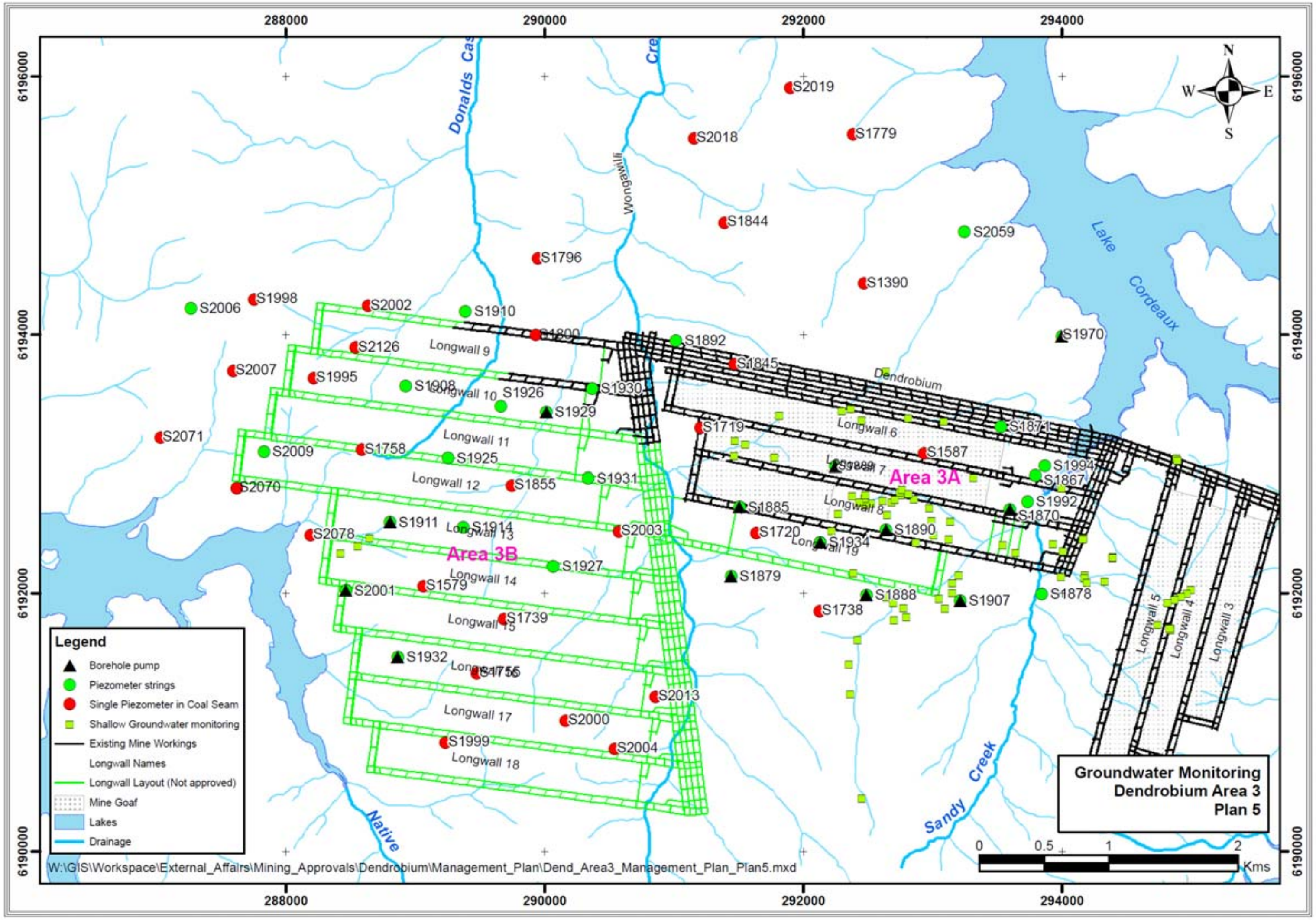



**Figure 2.3 – Groundwater Monitoring Area 3**

## 2.6 Underground (Mine) Water Monitoring

### 2.6.1 Underground (Mine) Water Balance

The principal component of the underground monitoring program is the use of a "water balance" to quantify total inflows and outflows in relation to defined mining areas. **Figure 2.4** shows the current mine (Area 1, 2 and 3A) and the adjacent workings in the Wongawilli Seam. The procedure, *Mine Water Balance* (DENP0049) has been developed to document the mine water monitoring and balance. The water balance is a tool used to quantify the water make associated with mining. Water is transferred into, around and out of the mine by three mechanisms pumping, ventilation air and water taken out of the mine with the coal.

**Mine Water Flow (Pumping)**
A total of 15 flow meters are currently being utilised for the daily water balance calculations. These monitor the real time water flow and store the daily totals to a data file. Values recorded in this data file are checked and included in the daily water balance.

**Water in the Ventilation Air**
Water is removed from the mine in exhaust air. Intrinsically safe hygrometers are installed in intake and return airways around the mine. The units monitor wet and dry temperature which in conjunction with the air velocity and cross sectional area at the site determine volume of moisture carried out of the mine in the ventilation air. The readings are recorded on the mine monitoring system every minute. Daily cumulative values are checked and included in the daily water balance.

**Water in the Coal**
Water is removed from the mine with the 'Run of Mine' coal. A microwave analyser monitors moisture in real time on the ROM belt. The ROM coal moisture in conjunction with in-situ coal moisture, obtained from coal sampling, and the coal tonnage, allows the water removed from the mine with the ROM coal to be calculated. Daily cumulative values are checked and included in the daily water balance.

Dendrobium calculates a daily mine water balance (outflow – inflow). In addition to the overall mine balance a balance is prepared for each mining area (Area 1, 2 and 3). Additional balances can be calculated for smaller areas of the mine, based on monitoring for each active gateroad.

Additional manual data is collected on an as needs basis.

The results of the water balance are reviewed internally and reported to the DSC, SCA, I&I, NOW and DOP each month.

### 2.6.2 Underground (Mine) Water Sampling and Analysis

The other principal component of the management of inrush and inflow relates to the sampling and analysis of mine waters. By comparing the composition of underground waters with reference samples from known sources, the source of the water entering the mine can be determined. This allows for better quantification of any risk to the mine, mine personnel and the environment.

Water quality monitoring of underground waters is being conducted as per The *Underground Water Sampling and Analysis Procedure* (DENP0048). The results of the water sampling are reviewed by Ecoengineers and reported to the DSC, SCA, I&I, NOW and DOP each month.

Dendrobium currently conducts routine analysis of water samples taken from underground workings, inter-seam boreholes, flooded adjacent mine workings, as well as surface stored waters and boreholes for base comparison. The “water fingerprint” is used to identify discrete water sources.

The *Underground Water Sampling and Analysis Procedure* (DENP0048) outlines the “water fingerprinting” sampling and analysis methodologies. Water is analysed for chemistry, algae and hydrogen isotopes...

The water balance for the mine is used in conjunction with the water fingerprinting to initiate triggers within the Triggered Action Response Plan (TARP) of the Groundwater Management Plan (and the DSC Contingency Plan).

## 2.7 Monitoring Procedures to Address Inflows from Cordeaux Reservoir

Procedures developed to address water inflows from the Cordeaux Reservoir or from an unknown source, which may include surface inflows, fall into the following three categories.

**Monitoring** - Principal and Secondary Monitoring Controls monitor the surface and underground environment to detect any abnormal inflow. Monitoring procedures are aimed at detecting the ingress of water, identifying when surface water is a component of an inflow, and the presence or behaviour of the potential water conduits outlined previously, that may influence the potential for water to be lost from the storage area as a consequence of mining.

**Principal Monitoring Controls** are the primary means of defining and initiating a response to abnormal water inflows. This control is the combination of continuous underground water balance determinations related to the Dendrobium Mining Areas coupled with the regular sampling and analysis of water quality to provide the data that establishes trigger levels and responses related to defined levels of dam water inflow to the workings.

**Secondary Monitoring Controls** – are monitoring resulting in triggers that alert mine management to the potential for an abnormal inflow and that initiate low level alarms within the Principal Monitoring TARP. They are the Monitoring components used to provide early warning of a potential abnormal water inflow to the workings and that may activate a Level 1 Principal Monitoring Alarm or significant components of the response to this. These are inseam drilling results, groundwater monitoring, subsidence monitoring, surface water monitoring (including rainfall monitoring), underground site water balance and quality monitoring and visual inspections of underground workings.

**Pumping** – Pumping provides time for assessment to be conducted and/or the appropriate response to be initiated without adverse effect on mining operations, and

**Remedial** – Measures designed to correct an unacceptable inflow from any source but most specifically from the Avon & Cordeaux Reservoirs.

### 2.7.1 Principal Monitoring Controls

Principal Monitoring Controls are the primary means of defining and initiating a response to abnormal water inflows. These include underground (mine) water balances and underground water sampling and analysis.

***Underground (Mine) Water Sampling and Analysis***

The Principal Monitoring Control in the management of abnormal inflow potential relates to the regular sampling and analysis of various waters coupled with ongoing underground water balances. By comparing the composition of underground waters with reference samples from known sources, the Review Team are able to determine the source of any water entering the mine based on expert analysis and advice, and thereby are able to quantify the risk to the Avon and Cordeaux Reservoirs as well as to the mine and mine personnel. However, in the event of an abnormal inflow of defined, significant magnitude that cannot be explained by recent events such as heavy rainfall, the Mine will not await the results of water sampling and analysis before taking the appropriate remedial action as defined within Section 4.

Dendrobium Mine personnel conduct routine analysis of water samples taken from underground workings and flooded adjacent mine workings. Ecoengineers (Dr S Short) sample stored waters and streams for base comparison. The water “fingerprints” are used to identify discrete water sources and identify if underground water contains a component of dam or surface water.

Monthly water samples are taken from the mine’s main discharge point(s) and from non-active longwall zones. Weekly water samples are taken (if water is present) in the longwall zone currently being mined and from the water pumped from the goaf. This data is inputted to the computer monitoring system so that the proportion of dam water in the mine’s discharge is known at any time based on the last sample results. A fundamental control related to a Level 2 Principal monitoring trigger being activated is to increase the mine discharge water sampling and analysis frequency to weekly and to expedite the analysis and reporting of results. It is, however, unlikely that the analysis and reporting of results can be achieved in less than two weeks.

Samples of water inflowing to the working faces and selected discharge sites are obtained and analysed for chemical composition and algal content by NATA approved laboratories strictly according to the procedure for *Underground Water Sampling and Analysis* (DENP0048). The Planning Manager is responsible for the standards and frequency of the normal sampling programme defined within that procedure as well as for expediting samples related to any reported or suspected abnormal inflow or in response to any other ‘trigger’ defined in Section 4.

On the basis of Water Balance and Water Analyses conducted as each longwall progresses, Mine Management will regularly project the total inflow for the completed longwall block based on the data available at that time. The relationship between actual flow (Ml of dam water/day/m) and the length (metres) of extracted longwall will be used to forecast/predict total inflows for the block. Though the alarms relating to defined trigger levels in the Principal Monitoring TARP (Section 4) relate to actual inflows at any point in time, the Review Team will take appropriate remedial action whenever the <u>projected</u> total dam water inflow reaches a trigger level i.e. well before actual trigger levels are reached. By this action, it is anticipated that the <u>actual</u> dam water inflow will never reach a trigger level requiring a larger scale and more immediate response.

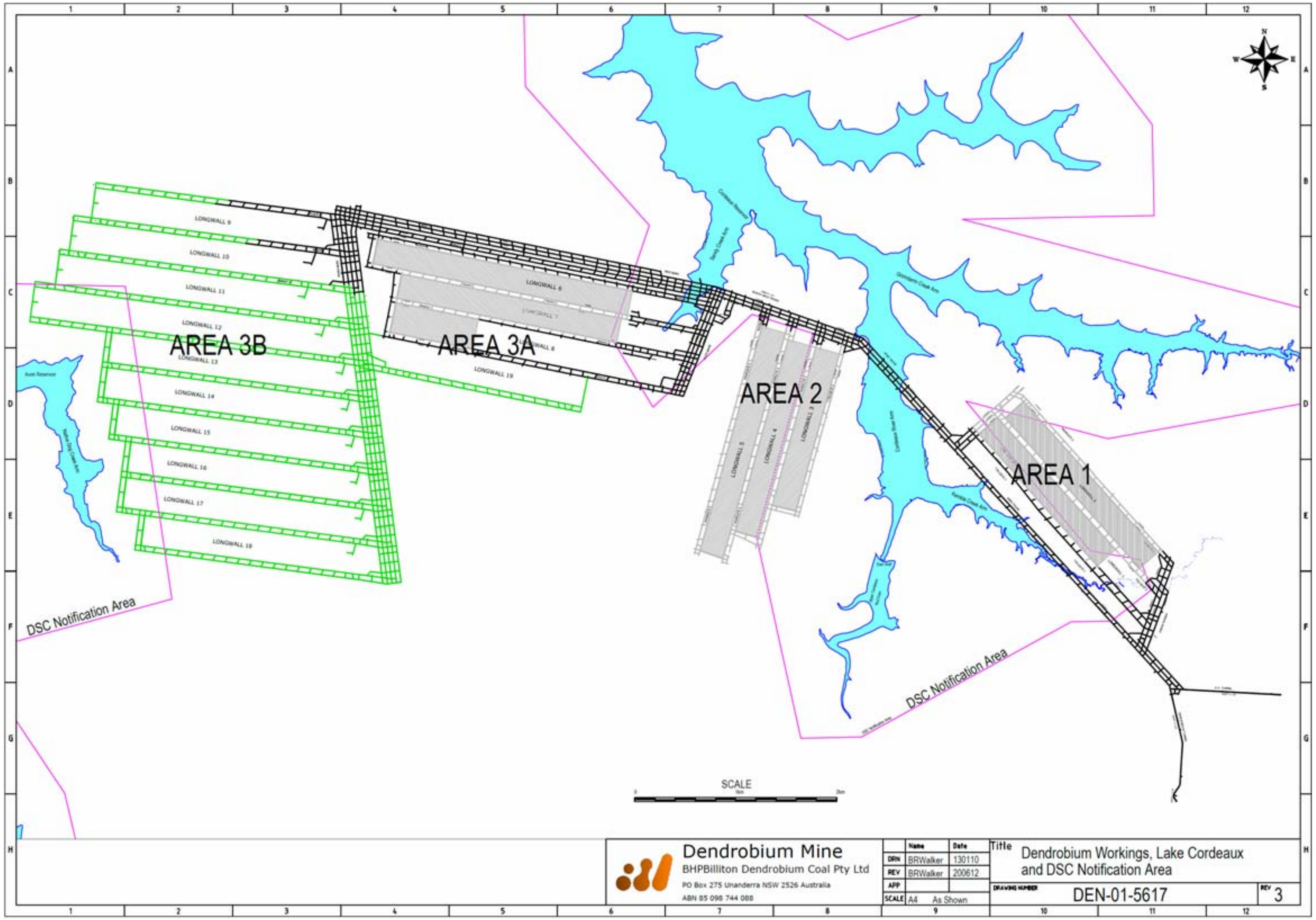



**Figure 2.4 - Relationship between Lake Avon and Cordeaux, the DSC Notification Area and the Dendrobium Mining Area**

### 2.7.2 Secondary Monitoring Controls

Secondary Monitoring Controls result in triggers that alert mine management to the potential for an abnormal inflow and that initiate low level alarms within the Principal Monitoring TARP. They include

- Inseam drilling,
- Visual inspections of workings,
- Surface water balance and
- Groundwater monitoring.

Details of the secondary monitoring controls are outlined in the DSC Notification Area Management Plans and information on the groundwater monitoring is provided below.

***Groundwater Monitoring***

Groundwater monitoring is a Secondary Monitoring Control undertaken to determine and assess hydrogeological conditions within the rockmass between the Avon & Cordeaux Reservoirs and the Wongawilli Seam longwall extraction in Areas 1, 2, 3A and 3B.

This monitoring aims to detect groundwater flow from stored water and provide verification of the results of hydrological modelling. The monitoring increases the confidence in the barrier both during and following extraction.

The monitoring consists of measuring and recording piezometric pressures. The assessment of any flow direction and quantity through the rockmass (i.e. from the reservoir to the longwall extraction) will involve measurement of head from the piezometer strings. When combined with permeability calculations from packer testing during drillhole advance and comparison with predicted piezometric pressures, this will enable determination of any flow.

These determinations will be used as one of the inputs to reconciliation of the source of groundwater reporting to the mine workings.

The Planning Manager is responsible for the conduct and assessment of regular groundwater monitoring and for the initiation of the appropriate actions as defined by Section 4 in the event that monitoring indicates that defined ‘trigger’ levels have been reached.

### 2.7.3 Pumping

Dendrobium has an established mine dewatering system. The current system has 152L/s capacity.

### 2.7.4 Remediation

Remedial measures to control inflows to the mine are discussed in Section 5 Corrective Management Actions and include grouting and sealing techniques.

## 2.8 Monitoring of Groundwater Springs and Seeps

Groundwater springs and seeps are monitored via the Landscape Management Plan outlined in the Subsidence Management Plan. Should they be identified through visual inspections and water quality monitoring that will occur as part of the surface water monitoring program, also outlined in the SMP and Watercourse Impact, Monitoring Management and Contingency Plan.

# 3. GROUNDWATER MONITORING PROGRAM & MODELLING

Illawarra Coal has engaged Dr Noel Merrick, Heritage Consulting to advise on the Groundwater Monitoring & Modelling for the Dendrobium mine. Coffey Geotechnics has prepared a detailed regional groundwater model.

A regional groundwater flow numerical model has been developed to simulate mining of panels in Dendrobium Mine Areas 1, 2, 3A, and 3B. The model was developed using MODFLOW-SURFACT Version 3, distributed by Hydrogeologic, Inc. (Virginia, USA). It is an advanced version of the standard USGS MODFLOW algorithm and is able to simulate variably saturated flow. The software can accommodate unsaturated zones at depth, as are developed during longwall mining. MODFLOWSURFACT is operated within the Visual Modflow (Version 2009) pre- and post-processing environment, developed by Schlumberger Water Services.

The active model area covers 770km2, refer Figure 3.1, within a window of 34km east-west by 39km north- south. The south eastern portion of the model area traverses the Illawarra Escarpment. The model boundary has been selected so that the hydraulic heads in the model are setup by rainfall recharge and groundwater sinks at the extremities of the model area (in conjunction with interior boundary conditions such as mines and rivers). This eliminates difficulties associated with the uncertainty in, and control of, groundwater fluxes to or from constant head or general head boundaries on the boundary of the model area. The model grid comprises 15 layers with 225 columns and 239 rows. Cell dimensions are 50m by 50m over Longwalls 3 to 8 in Areas 1 and 2, and Longwalls 13 to 18 in Area 3B (the ones which approach Lake Avon), expanding to 100m by 100m over the remaining Dendrobium longwalls (mined and proposed), then expanding to 200m by 200m at the extremities of the model area. The finer grid is placed where detail is required during model calibration and predictive simulations.

Fifteen model layers are used to represent lithological contrasts and mining-induced stratigraphic changes. These layers and their average thicknesses are listed in Table 1. The crinanite intrusion is present in the model in Layers 2 to 5. The Hawkesbury Sandstone is represented by two layers to handle the large natural vertical hydraulic gradients present within it, and to allow assignment of the height of the collapsed zone for panels of 300m width.

The Model was calibrated in two stages. Stage 1 targets comprised 141 pre-(Dendrobium)mining hydraulic head measurements from 22 monitoring sites, providing an average of about 7 measurements down the profile at each site. This characterised the critical vertical hydraulic head gradients.
Stage 2 targets comprised:

- Hydrographs from 94 piezometers at 21 monitoring sites at the Dendrobium Mine, over the period of mining of LW3 to LW6. This represents an average of nearly 5 piezometers, located throughout the vertical profile, at each site. These sites are listed in Appendix A.
- Measured inflows to Dendrobium Mine.
- Estimated baseflow to lakes and rivers in the model area northwest of the Illawarra Escarpment.
- Measured inflows to surrounding full extraction mines.

Calibration results indicate that the numerical model parameters are simultaneously consistent with measured aquifer properties, surface discharges (baseflow to rivers), and deep discharges (inflow to mines). This provides the model with a significant level of reliability, and greatly reduces uncertainty in model results. The calibrated model has been used as the basis for a predictive model that simulates mining in Area 3B. Figure 3.2 shows the measured and predicted groundwater inflow to the existing Area 1, 3 & 3A workings. Figure 3.3 shows the predicted groundwater inflow to the proposed Area 3B workings.

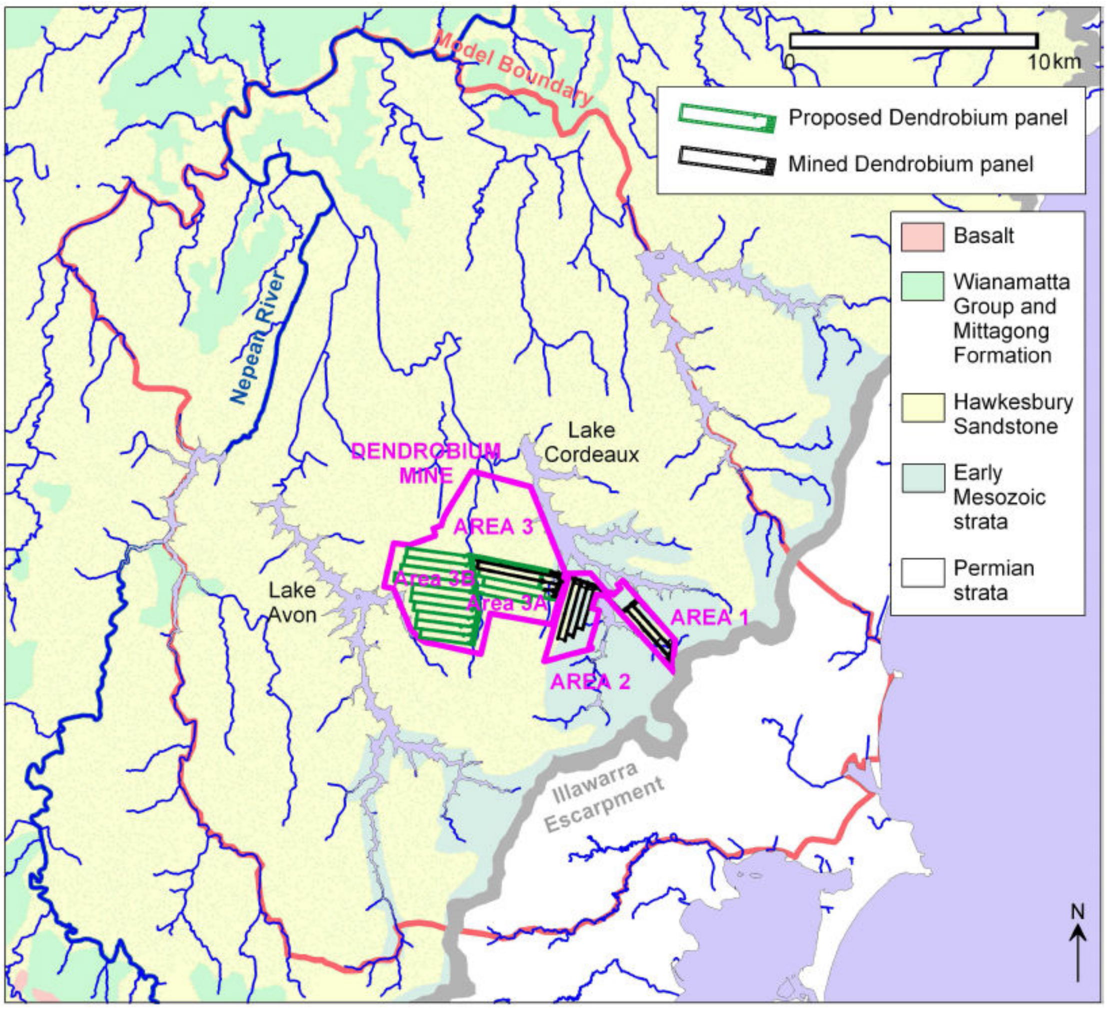



Figure 3.1 - Regional groundwater model extent (red border)

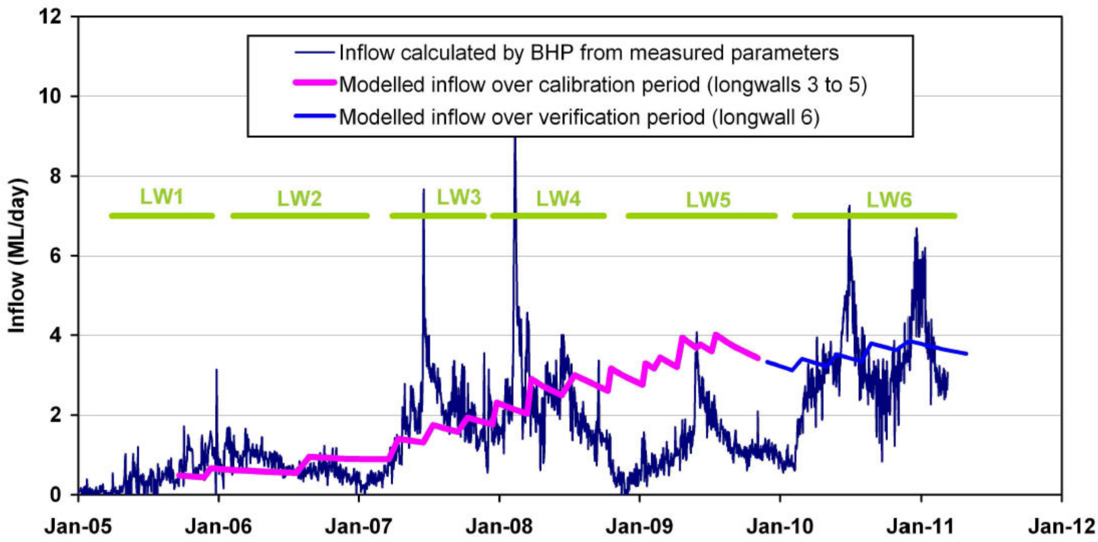



Figure 3.2 Measured & Predicted Groundwater Inflow

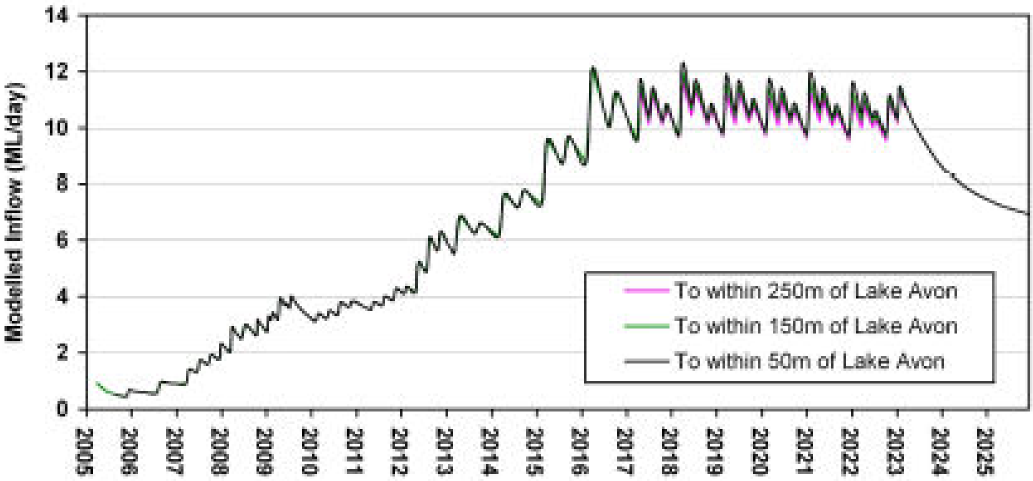



Figure 3.3 Predicted Groundwater Inflow (Area3B commences in 2013)

# 4. TRIGGER ACTION RESPONSE PLANS

## 4.1 Shallow Groundwater TARP

The TARP associated with shallow groundwater is part of the Swamp Management Plan and the Watercourse Management Plan.

## 4.2 Deep Groundwaters and Mine Water TARP

The components of surface and underground environmental monitoring serve to alert Mine Management that an abnormal water inflow problem may or does exist. Each has established triggers used to indicate a potential problem and initiate an appropriate response, but the fundamental means of determining the magnitude of any water inflow from the Cordeaux Reservoir and the further monitoring and/or remedial actions that need to be implemented is the Principal Monitoring Control i.e. Underground water balance and the water sampling and analysis results. This is the Principal monitoring TARP related to identifying, assessing and responding to abnormal water inflows into the mine.

Normal water inflow conditions have been defined as being ≤ 0.5ML/day of dam water inflow to the mine sustained over a seven day period to establish a statistically correct trend. All dam water inflow levels referenced within TARPs are based on this same statistical standard of being sustained over seven days. At 0.5ML/day of dam water, a Level 1 alarm will be activated on the SCADA system.

It should be noted that the Principal TARP represents actions to be taken as each defined trigger level is actually reached. On the basis of Water Balance and Water Analyses conducted as each longwall progresses, Mine Management will regularly project the total inflow for the completed longwall block based on the data available at that time. In practice, the Review Team will take appropriate remedial action whenever the projected total dam water inflow reaches a trigger level. By taking action in this pro-active manner, it is anticipated that the actual dam water inflow will never reach a trigger level requiring the larger scale and more immediate response required by the TARP.

**Figure 4.1** represents the Principal Response Flowchart. This describes the pre-determined process of decision making to be applied with respect to taking corrective actions.

Additional information on the relationship between the Secondary Monitoring TARPs and the Principal Monitoring TARP, and details of the Secondary TARPs, are found in the DSC Notification Area Contingency Plan.

The principal groundwater TARP is provided in **Table 4.1**.

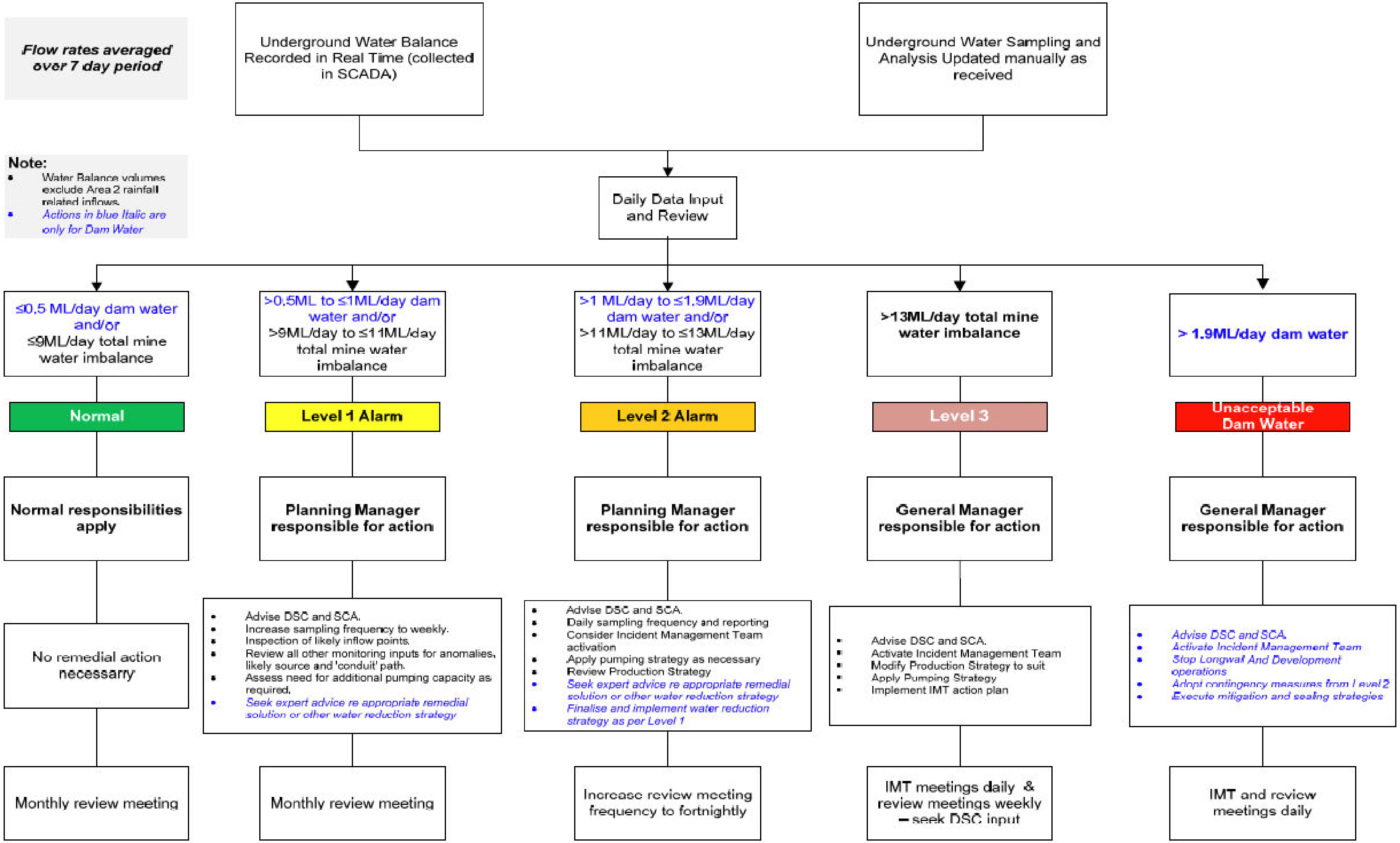



**Figure 4.1 Principal Response Flowchart**

At 1.9ML/day dam water– The General Manager will stop Longwall and Development operations following confirmation of this level. When remedial measures bring water inflows back below this level, Longwall and/or Development operations may resume. If unable to stem flows using other remedial measures, the General Manager will implement recovery of the Longwall and Development district and sealing of the areas according to the Mine Closure Plan provisions.

**Total Underground Water Balance Coupled with Sampling and Analysis**

| ***Flow rates averaged over 7 day period*** | CHARACTERISTICS OF LEVEL | POSSIBLE REASONS | ACTIONS | ACTION BY | NOTIFICATION |
|---|---|---|---|---|---|
| **NORMAL** | ≤ 0.5 ML/day reservoir water and ≤9ML/day total water imbalance | N/A | ▪ No remedial action necessary<br>▪ Monthly review meeting | **No Special Action Required** | None necessary |
| **Level 1** | > 0.5 to ≤1.0 ML/day reservoir water or >9 to ≤11ML total water imbalance and/or<br>Unacceptable secondary monitoring alarm | ▪ Intersection of 'conduit' to dam or stored water source<br>▪ Increased groundwater make<br>▪ Normal No.3 seam water 'make' | ▪ Advise DSC and SCA.<br>▪ Increase sampling frequency to weekly.<br>▪ Inspection of likely inflow points.<br>▪ Review all other monitoring inputs for anomalies, likely source and 'conduit' path.<br>▪ Assess need for additional pumping capacity as required.<br>▪ *Seek expert advice re appropriate remedial solution or other water reduction strategy.*<br>▪ Monthly review meeting | **Planning Manager** | ▪ Water Balance Review Team<br>▪ DSC and SCA (notification within 24 hours of confirmation) |
| **Level 2** | >1.0 to ≤1.9ML reservoir water or >11 to ≤13 ML/day total water imbalance | ▪ Intersection of 'conduit' to dam or stored water source<br>▪ Increased groundwater make | ▪ Advise DSC and SCA.<br>▪ Daily sampling and reporting frequency<br>▪ Incident Management Team (IMT) notification<br>▪ Apply pumping strategy as necessary<br>▪ Review Production Strategy<br>▪ *Seek expert advice re appropriate remedial solution or other water reduction strategy.*<br>▪ *Finalise and implement water reduction strategy as per Level 1*<br>▪ .Increase review meeting frequency to fortnightly. | **Planning Manager** | ▪ Water Balance Review Team<br>▪ DSC and SCA (immediately on confirmation) |
| **Level 3** | >13ML/day total water imbalance | ▪ Increased groundwater make | ▪ Advise DSC and SCA.<br>▪ Activate IMT<br>▪ Modify Production Strategy to suit<br>▪ Apply pumping strategy<br>▪ Implement IMT action plan<br>▪ IMT meetings daily & review meetings weekly – seek DSC input | **General Manager** | ▪ Water Balance Review Team<br>▪ IMT<br>▪ DSC and SCA (immediately on confirmation) |
| **Unacceptable Dam Water** | >1.9ML/day reservoir water | ▪ Intersection of 'conduit' to dam or stored water source | ▪ *Advise DSC and SCA.*<br>▪ *Activate IMT*<br>▪ *Stop Longwall and Development production*<br>▪ *Adopt contingency measures from Level 2*<br>▪ *Mobilise mitigation and sealing strategies*<br>▪ *IMT and review team meetings daily – seek DSC input* | **General Manager** | ▪ Water Balance Review Team<br>▪ IMT<br>▪ DSC and SCA (immediately on confirmation) |

▪ Note: Water Balance Volumes exclude Area 2 Rainfall related events

▪ *Actions in Blue Italic are only for Reservoir Water*

**Table 4.1 Principal TARP: Underground Water Balance coupled with Sampling and**

# 5. Corrective Management Actions

## 5.1 Grouting, PUR Injection and Similar Activities

The fundamental remedial strategy for addressing abnormal water inflows may take the form of one of a number of established engineered solutions for stopping or controlling water flows through strata. The application of a particular consolidation technique to any circumstance of abnormal water inflow to the mine from (or potentially from) the Avon or Cordeaux Reservoirs will be determined at the time by the decision of all stakeholders (BHPBIC, DSC and SCA) based on the advice of hydrogeologists and ground consolidation technical experts.

Some of the types of remedial actions available for gaining control of water inflows to the mine and their applications are summarised below.

**Table 5.1 – Possible Remedial Actions**

| Description of Flow Mechanism | Remedial Action | Injection Location |
|---|---|---|
| Disturbed or fractured ground | Concrete Blinding | Surface/ Underground |
| Regional water flows through porous/ fractured strata | Installation of grout curtains (cement based or chemical) | Surface/ Underground |
| Localised sealing of open fractures and joints | Polyurethane Resin (PUR) injection | Underground |

Illawarra Coal has used materials in ground control applications and some inflow control applications in the past and will apply these as appropriate to regain control of inflows should the need arise. Selection of the optimum application / combination of materials and techniques will depend on the nature and magnitude of the inflow, appropriate technical advice and on Review Team and stakeholder input.

Dendrobium Mine works closely with specialist ground support and polyurethane resin (PUR) injection company, Ground Consolidation. This company has considerable experience in the use of chemical injection techniques for consolidation of unstable and porous ground and in the use of such measures to control ground water flows. The expertise and equipment of Ground Consolidation are restricted to applications up to 30m from the access point and are the preferred option for localised water inflows.

The Ground Consolidation document "Dendrobium Mine – BHP Billiton Response Plan - Water Inrush" details the methodologies relating to grout and PUR-based solutions to localised anticipated water inflow situations. The document defines the capability of each product used for ground consolidation and water control, MSDS documents, technical specifications as well as case studies of applications where each product and sealing technique would be most effective. The Ground Consolidation document is part of the Contingency Plan (DENMP0049)

The application of a particular consolidation technique to any circumstance of more remote or extensive abnormal water inflow to the mine from (or potentially from) the Avon or Cordeaux Reservoirs will be determined at the time by the decision of all stakeholders (BHPBIC, DSC and SCA) based on the advice of technical experts. Pro-active responses based on projected inflows mean that action may be considered and planned at the time rather than relying on pre-planned scenarios. In addition to underground sealing of inflows zones it may be practical to undertake sealing works from the surface (depending on the specific environmental factors in relation to the proposed work). All such considerations should be assessed at the time.

Triggers that will initiate the decision to use such remedial techniques are defined in Section 4 though, with ongoing projections of dam water inflows over the entire longwall block based on the data available at any point in the progress of each longwall, the Review Team will take appropriate early remedial action that is anticipated to negate the need to ever activate the defined response to an actual Principal Monitoring trigger.

A store of PUR and grout materials (equipment and consumables) is maintained at Dendrobium and can be used to meet the requirements of this Plan. Further access to stocks of PUR and grout (held by BHPBIC at mine sites and by local contracting companies) are available at short notice (within 1 hour) to provide further stocks and an injection service to the mine. However, with the exception of localised occurrences, it is not considered to be necessary to maintain stocks of materials as these may be very circumstance-specific and, as a result of the time afforded by forward projection of inflows, their application and acquisition will not be matters of urgency.

The DSC Notification Area Management Plans, outlines the availability of PUR and Grout resources, drilling and pumping equipment both within and in close proximity to the Mine.

Ground Consolidation operators are on site to conduct strata support activities at the mine and are available to be rapidly deployed to water control activities if necessary. Dendrobium operators will be trained to conduct supporting activities for contract drillers and PUR injection personnel.

### 5.2 Sealing

The installation of mine seals to isolate Area 1 goaf was conducted as Longwall 1 and 2 was extracted. Each cut-through in Tailgate 1 and Maingate 2 was sealed for mine ventilation purposes. Subsequently Area 1 was sealed leaving only one heading in Tailgate 1 open as an intake roadway. Several seals contain monitoring, drainage and sampling facilities to allow water accumulation behind the seals to be monitored, sampled and managed while Areas 2 and 3 are mined.

Ventilation seals were progressively installed as Longwalls 3, 4 and 5 were extracted. Currently all the water from the Longwalls 3, 4 & 5 goaf reports to the Longwall 5 Maingate. Ventilation seals have progressively been installed as Longwalls 6, 7 and 8 were extracted. Currently all the water from the Longwalls 6, 7 & 8 goaf reports to the Longwall 6 tailgate.

The final sealing of the mine requires bulkheads to be installed that ensure that any reservoir water reporting to the mine, is controlled. The overall sealing strategy for mine water is contained in the Closure Plan.

Trigger mechanisms that will initiate the decision to abandon other remedial techniques and commence the installation of bulkheads either to isolate Area 1 or to seal the mine are defined in Section 4. Otherwise the sealing strategy for the Mine is an integral component of the Closure Plan.

# 6. REFERENCES

BHPB, 2012. Dendrobium Mine, Avon & Cordeaux Reservoirs DSC Notification Area, Management Plans. Rev 0 (DENMP0072)

BHPB, 2008. Dendrobium Mine, Inrush Management Plan. (DENMP0005),

BHPB, 2010. Dendrobium Mine, Water Balance Procedure (DENP0049),

BHPB, 2010. Dendrobium Mine, Underground Water Sampling and Analysis Procedure (DENP0048)

Heritage Consulting (2009) Dendrobium Colliery Groundwater Assessment: Mine Inflow Review, Conceptualisation and Preliminary Groundwater Modelling

Coffey Geosciences (2012) Groundwater Study Area 3B Dendrobium Coal Mine Numerical Modelling (GEOTLCOV24507AA-AB2).

# 7. DOCUMENT HISTORY

| | |
|---|---|
| July 2009 | Initial document |
| November 2009 | Revised to incorporate NSW Planning comments dated 11.11.09<br><br>Revised to incorporate changes from DSC Management Plans updated to include Area 3A. |
| April 2010 | Revised to incorporate revised Area 3A Mine Plan and final DSC Management Plans |
| October 2012 | Revised to incorporate Area 3B |