SURFACE WATER QUALITY
AND HYDROLOGY
ASSESSMENT

DENDROBIUM AREA 3B SUBSIDENCE MANAGEMENT PLAN
SURFACE AND SHALLOW GROUNDWATER ASSESSMENT

for

BHP BILLITON ILLAWARRA COAL

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ECOENGINEERS Pty Ltd
9 Sunninghill Circuit
Mount Ousley NSW
Australia 2519
Tel: 61 2 4227 4174 Fax: 61 2 4227 5154
www.ecoengineers.com
ABN 74 078 666 510

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EXECUTIVE SUMMARY

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BHP Billiton, Illawarra Coal (IC) proposes to continue its underground mining operations at Dendrobium Mine, located in the Southern Coalfield of New South Wales, by extracting coal from the Wongawilli Seam using longwall mining techniques in Area 3B.

As a Condition of the Dendrobium Mine Development Consent, Subsidence Management Plan (SMP) Approval is required for Area 3B prior to longwall extraction from this area. The proposed Area 3B, comprising Longwalls 9 - 18, is located approximately 20 km west of Wollongong.

Development of Area 3B commenced June 2011 with longwall coal extraction planned to commence January or February 2013.

Surface Hydrology Assessment

The hydrologic impacts of mining longwalls directly under the Sandy Creek catchment (Dendrobium Areas 2 and 3A) have been studied closely since early 2008 and assessed systematically following the completion of Longwall 5 (Area 2) in December 2009 and the completion of Longwall 6 (Area 3A) in March 2011. As a result, a good understanding of the surface and shallow groundwater hydrologic system in the area has emerged.

Hydrologic studies to date have confirmed there is no deep aquifer in the bulk of the Hawkesbury Sandstone within Dendrobium Area 3A and hence the same is expected for Area 3B. Surface and near-surface groundwater hydrologic systems are likely to be well separated from any longwall mine workings by a number of claystone units as well as relatively tight sandstone strata.

These studies, reported in the Area 2 Longwall 5 and Area 3A Longwalls 6 and 7 End of Panel Reports, have shown that baseflows of the draining streams, which may be expected to be most affected by mine subsidence-related effects, are generally provided by semi-confined hillslope aquifers contained in weathered sandstone slopes, soil catenas and swamps. These hillslope aquifers do not appear to be directly connected to any deep water-bearing strata. From baseflow hydrologic recession analysis, characteristic times of non-linear response (‘reservoir coefficients’) of these hillslope aquifers have been shown to range from a few months up to a few decades. This is consistent with water ages determined through tritium analysis of waters flowing out of Sandy Creek and waters in Lake Cordeaux.

Hydrologic studies have indicated that there was no evidence that the overall Sandy Creek Catchment (located just east of Dendrobium Area 3B) or any of its sub-catchments suffered any significant permanent net loss of water to deep (unrecoverable) storages due to longwall mining by Longwall 5 (Area 2).

One instance of fracturing of a first and second order creek bed (the so-called ‘Fern Tree Creek’ of ~8% of the whole Sandy Creek Catchment) and a temporary diversion of water into the creek bedrock occurred over a period of about 6 months only with subsequent self remediation strongly evident by about 9 months after being mined under.

Similarly, hydrographic monitoring and catchment and sub-catchment modelling of the mining of Area 3A carried out thus far, with Longwalls 6 and 7 completed and the final Longwall 8 nearing completion has shown no hydrologic evidence for any deep (unrecoverable) permanent loss to deep storage(s).

One instance of fracturing of a first order creek bed (the so-called SC10C comprising <10% of the whole Sandy Creek Catchment) and a temporary diversion of water into the creek bedrock occurred in November 2011. A preliminary hydrologic assessment conducted recently for the period April – June 2012 due to the triggering of a Level 2 TARP for Swamp 15b i.e. prior to an End of Panel report has also shown strong evidence for significant self remediation and a much lesser impact than had occurred in the steeper Fern Tree Catchment during the mining of Area 2 Longwall 5.

Longwalls in Area 3B have been designed to not mine under major creeks such as Wongawilli Creek and Lake Avon (see below). The setbacks have been designed, by *a priori* subsidence modelling, to avoid subsidence impacts at Wongawilli Creek other than “minor impacts” (such as minor fracturing, iron staining and minor impacts on water flows, water levels and water quality). Due to the proposed standoffs of Area 3B longwalls it is not expected that any significant fracturing and sub-bed flow diversions will occur in Wongawilli Creek or that there will be detectable, permanent losses of outflows from this catchment.

Subsidence Induced Erosion Issues

Ground movements caused by mine subsidence may increase erosion and loss of soil materials through rock falls, or cracking in surface soils. Rock falls and surface soil cracking occurred as the result of mining Dendrobium Areas 1, 2 and 3A.

Monitoring and inspection by IC and its consultants for Dendrobium Mine shows there has been no evidence of sustained subsidence-induced erosion of the valley slopes of Sandy Creek or Wongawilli Creek and its tributaries during the four year period since commencement of mining of Longwall 5 in December 2008, including during the most recent ‘La Nina’ high rainfall period since May 2010.

Cliff lines associated with Wongawilli Creek and its tributaries in Area 3B are no larger than those that have been previously mined under in Dendrobium Areas 1, 2 and 3A. Slopes are no steeper or more extensive than those that have been previously mined under in Areas 1, 2 and 3A. Soil landscape types are closely similar to those previously encountered in upper Wongawilli Creek. Based on that experience no significant erosive effects on water quality from the mining of Area 3B are expected.

Streambed Fracturing Effects

Subsidence caused by longwall mining beneath creeks and riverbeds can produce a complex suite of physico-chemical effects. Hydrological measurements, visual observations and water quality monitoring over past years in the Southern Coalfield indicate the principal effects are:

1. Compressive and tensile failure fracturing of bedrock leading to increased permeability and storage, possibly reduced surface flows over the undermined stretch of the watercourse, especially at the low end of the flow rate regime and more rapid draining of pools in no and low flow situations.
2. Diversion of stream flows through the fractured bedrock leading to loss of surface flows and potential loss of catchment yield if a connection to a deep storage was established.
3. Oxidative dissolution of accessory marcasite within freshly fractured bedrock water pathways, leading to release of sulfuric acid and iron, manganese,

nickel and zinc and re-emergence of more acidic water of lower pH, lower redox potential, lower dissolved oxygen concentrations and high concentrations of the above metals.

4. Leaching of aluminium from kaolinite by acidic water flowing through the fracture network.

It has been demonstrated that, subject to predictive subsidence modelling, if adequate standoffs from the sides or ends of longwalls from major watercourses are provided, avoidance of the above-described hydrologic and geochemical effects can be almost achieved. Recent examples of such major reductions in impact include Appin Area 3 Longwalls 301 and 302 adjacent to Cataract River, Appin Area 7 Longwalls 701 to 703 adjacent to the Nepean River, and West Cliff Area 5 Longwalls 29 through 34 adjacent to the Georges River. During the mining of Dendrobium Area 3A, Longwalls 6 and 7 were offset from Sandy Creek by 90 – 225 m and Wongawilli Creek by 130 – 370 m. The rationale for this was described in detail in the supporting report by Mine Subsidence Engineering Consultants (MSEC, 2007).

A comparable approach has been adopted for Area 3B in Report No. MSEC311 (Revision D) (MSEC, 2012) in support of the Dendrobium Area 3B SMP wherein the potential impacts along Wongawilli Creek were reduced by adopting setbacks of the finished ends of longwalls limits from the Creek such that:

- a maximum predicted valley closure of 200 mm would generally occur at mapped rockbars and riffles; and
- maximum predicted conventional tensile strains would generally not exceed 0.5 m/m and;
- maximum predicted conventional compressive strains would not exceed 2 mm/m,

so that potential Creek main channel bed fracturing effects will be minimized in a manner was consistent with the approach adopted in MSEC Report No. MSEC404 which supported the BHPBIC Bulli Seam Operations Part 3A Application.

MSEC (2012) predicts that maximum tensile strains greater than 0.5 mm/m may be of sufficient magnitude to result in cracking in the beds of (say) tributary creeks. They also predict compressive strains greater than 2 mm/m may be of sufficient magnitude to result in the topmost bedrock buckling and fracturing, which can induce surface cracking in the beds of some drainage lines.

All the pre- and post mining monthly Wongawilli stream chemistry data up to the date when Longwall 8 passed beneath the eastern ridge and out of the Wongawilli Catchment was reassessed for this Area 3B SMP report. Thus this assessment already takes into account the entire period during which Longwalls 6, 7 and 8 were mined beneath the Wongawilli Creek Catchment.

There is no evidence of any statistically significant change in any key water quality parameters at Wongawilli Creek site WWM3 just downstream of Longwall 6 (and also further downstream of Longwall 7) nor any further downstream at site WWL2.

These data indicate that; if there has been any fracturing in Wongawilli Creek adjacent to Longwalls 6 and 7 or in any of the minor eastern tributaries of the Creek lying over Longwalls 6 and 7 it has been minor and not of sufficient extent to result in a significant change in downstream water quality.

Ferruginous Springs

Induction of ferruginous springs as a consequence of mining-related subsidence has been identified as a longwall mining-related effect in the Southern Coalfield in sub-catchments of the Nepean, Cataract and Georges River, most notably the likely cause of:

- The large and long-lived 'SW2 Spring' (Appin Area 3) in Cataract River just west of Back Gully Creek.
- The moderately large and long lived 'Pool 11 Spring' (West Cliff Area 5) in Georges River.

Mining-related subsidence can have the effect of delaminating erosion surfaces and bedding planes within and between strata. These effects are predicted to occur preferentially along the interfaces between materials with different elastic properties. It is now recognised that subsidence as a consequence of longwall mining can result in dilation and an interfacial permeability enhancement of variable duration at the sub-horizontal interface between sub-cropping Hawkesbury Sandstone and an overlying Wianamatta Shale or Mittagong Formation-based type of outcrop.

A substantial portion of Area 3B is mantled by outcropping Mittagong Formation-based clay-rich soils occupying several catchments at the 1 – 2 km^2 scale, some of which drain via steep (10 – 20%) slopes with sandstone outcrops southwest to the Native Dog Creek Arm of Lake Avon. It is therefore considered that shallow ferruginous springs might be induced in the slopes of some sub-catchments over Area 3B.

Such an effect, if it does occur, is likely to be largely aesthetic rather than posing any adverse impact on stream ecology due to the relatively short length, high gradients and aeration coefficients applying in the ephemeral creeks potentially involved.

Notwithstanding, specific water quality monitoring sites have been proposed for this part of Area 3B to provide early detection and ongoing assessment of this potential effect. Drainage of Mittagong Formation-based landscape type to the northwest of tributaries of Donalds Castle and Wongawilli Creeks occurs over much longer distances of far lower slopes and there are numerous intervening upland swamps. It is considered unlikely that springs would be induced in this area and if they were, would be likely to occur around the margins of swamps or upslope of swamps or their effects be largely attenuated by those landscape features.

Swamps

There are 13 swamps mapped within Area 3B. Upland swamps can be differentiated into (at least) two types, which would usually be expected to exhibit distinctly different types of potential susceptibility to the effects of mine subsidence as follows:

i. Valley in-fill swamps are those which fringe, and have arisen from, sand accumulation along well defined streams where there is a potential for scour of the sandy substrate of the swamp(s) above a certain stream power and erosive resistance threshold. The changes in grade that may result from mine subsidence are only likely to induce excessive shear in relatively low gradient swamps. Therefore the swamps at risk from scour and erosion as a result of longwall mining are those where the stream is of a high order (i.e. high flow and low gradient), has poor vegetation condition (e.g. from drying and/or bushfire damage), and the longwalls lie perpendicular to the long axis of the swamp.

ii. Headwater swamps occur within broad scale, relatively low slope creek or tributary headwater areas. A significant body of evidence indicates that most, if not all headwater swamps are ‘embedded’ in a broader scale ‘hillslope aquifer’ which provides the excess of precipitation over evapotranspiration (ET) which sustains them i.e. they are predominantly groundwater fed over the long term (including through droughts).

Valley in-fill swamps at risk from scour and erosion as a result of longwall mining are typically those lying well down the stream where there is sufficient upstream catchment to potentially provide high stream power. The only downstream valley in-fill swamp identified in Area 3B which is considered possibly susceptible to scour effects enhanced by changes in grade due to mine subsidence identified by the original Area 3 SMP Landscape Impact Assessment prepared by Cardno Forbes Rigby (2007) is Swamp DEN05.

While it is considered unlikely, on the basis of past experience and the Cardno Forbes Rigby (2007) Landscape Impact Assessment, that mine subsidence-induced scour effects would affect these swamps detailed monitoring and assessment will be undertaken during periods when longwalls in Area 3B mine beneath them.

Fracturing due to subsidence effects may become physically detectable at a central drainage line rock shelf or knick points in headwater swamps, but such fracturing is likely to coincide with sandstone that *already* contains naturally, well weathered bedding planes and cross fractures due to the long period of exposure and weathering of such features. Therefore it is predicted that further subsidence induced bedrock fracturing below these swamps is unlikely to be significant in terms of geochemical and/or hydrologic impacts.

While it is considered unlikely on the basis of past experience that mine subsidence-induced hydrologic effects would adversely affect these headwater swamps and more particularly the substantial hill slope aquifers in which they are generally likely to be embedded, detailed monitoring and assessment will be undertaken during any period in which longwalls in Area 3B approach or mine under them.

Water Quality Impacts on Water Supply Reservoirs

Any impacts to Lake Avon would likely be restricted to a possible erosive export of fine sands and clays and/or ferruginous precipitates near the mouths of minor creeks designated LA2, LA3, LA4 and LA5 during the mining of Area 3B. These creeks are all remote from the Lake’s dam off-take and outflows. Any impact zones would be localised to around the point of input to the Lake and would be unlikely to have any significant impact on local freshwater ecology and would be undetectable in the bulk water supply quality.

Based on past experience from Wongawilli and Native Dog Creeks which were directly mined under by Elouera Colliery, and where some creek bed fracturing did occur, it is also considered highly unlikely that there would be any adverse effect on bulk drinking water supply quality in Lake Avon. Nevertheless detailed monitoring of all streams draining to Lake Avon will be conducted on a monthly basis during the entire period of Area 3B development and extraction and for a subsequent period of up to two years.

Water Monitoring and Management Plan

A Water Monitoring and Management Plan ('WMMP') incorporating detailed provisions for hydrographic and water quality data collection and interpretation has been prepared as **Appendix A** of this report. This will be incorporated into the Dendrobium Area 3B SMP which guides management and monitoring protocols for the area.

The proposed hydrographic monitoring and hydrologic assessment aspect of the Plan is based on the model developed during the mining of Area 2 Longwall 5 and all Area 3A longwalls for the detection of near surface hydrologic impacts of mine subsidence, both within creek lines and in the broader sub-catchments. Details of the hydrologic theory and modelling forming the basis of the proposed assessment approach are given in **Appendix B**.

Water quality-related field studies will concentrate in the first instance on regular visitations to main channel water quality/flow sites, main channel vicinity sand apron piezometers, upland piezometers within, surrounding and downstream of swamps. These would be monitored for identifiable impacts to the surface and for all key water quality parameters on a monthly basis for the duration of mining and an appropriate time following mining.

A key aspect of the WMMP deals with the early detection, and subsequent investigation and assessment of upsidence effects within tributaries. Properly sampled, and analyzed, geochemical data is very sensitive and has invariably proven to be the most reliable early indicator of the onset of any subsidence-related water effects. The main channel monitoring sites have been sited just within and downstream of confluences with tributaries. Reasons for adopting this monitoring philosophy are as follows:

1. A baseline database of sufficient quality to confirm or modify the pre-established TARPs requires a large and relatively long dataset which in turn mandates that a water quality site be wet or flowing most regularly when visited. Main channels have the more persistent baseflow and hence provide more regular monthly samples.
2. Main channel monitoring is required to monitor drinking water supply quality.
3. Main channel sites are more amenable to (relocatable) instrumentation and automatic sampling, utilization of which is seen as a desirable trend.

If geochemical effects are detected just downstream of a confluence but not at the main channel upstream site and these effects are judged to be possibly a consequence of tributary sub-catchment subsidence-related effects, further investigation of the sub-catchment water quality and hydrology would then be initiated.

Tributary investigations would be based on a staged response strategy, as follows:

1. Collection of water quality data from pools and storm flows within the tributary for assessment against TARPs.

2. Deployment of a suite of shallow piezometers within and outside of swamps to gauge changes in the extent and/or vertical thickness of the hillslope aquifer(s) over the active longwalls and their close monitoring.

Water Quality Trigger Action Response Plans (TARPs) proposed for Area 3B will be finalized from the statistical baseline dataset obtained prior to the commencement of mining of any longwall in Area 3B at any particular water quality monitoring site or upstream of it.

Three-tiered Water Quality TARPs proposed for Area 3B (see **Section A6** below) will be established from baseline data obtained prior to the commencement of mining of any longwall in Area 3B. A decline in water quality as a result of mining will be measured as a statistically significant change in water quality parameters during/after mining compared to pre-mining water quality, or a statistically significant change in water quality adjacent to or downstream of mining when compared to upstream water quality.

TARPs will include Lake Avon monitoring sites (LA1 off Native Dog Creek; LA2/3_S1 off Creeks LA2 and LA3; LA4_S2 off Creek LA4; LA5_S2 off Creek LA5) and the Cordeaux River at its confluence with Wongawilli Creek (WWL2 Lower Wongawilli Creek adjacent to Fire Road 6) in accord with the mining consent.

In all cases a Trigger for Action shall not be confirmed until a series of validating checks have been made. These checks shall be:

1. Cross checking of potentially triggering field water quality parameters against equivalent values at the immediately upstream/downstream monitoring sites.
2. Checking for the occurrence of triggering field water quality parameter values over two or more consecutive monitoring periods.
3. Comparison of field parameters with concurrent levels of key laboratory water parameters (where applicable) i.e. sulfate, filterable Fe, filterable Zn, filterable Ni or filterable Mn.

However, the proposed TARPs may need to be revised following collection of additional baseline data.

In the event that future water monitoring shows that there have been significant hydrologic or aquatic ecotoxic effects within any specific Area 3B sub-catchments then it is possible that some management and mitigation measures may be required. Management measures may involve alterations to the key design criteria for future mining layouts (i.e. adaptive management). Some potential water quality management and mitigation measures compatible with the Metropolitan Special Catchment Area are described in **Appendix A, Section A8.**

1. INTRODUCTION

BHP Billiton Illawarra Coal (IC) proposes to continue its underground coal mining operations at Dendrobium Mine, which is located in the Southern Coalfield of New South Wales, by extracting coal from the Wongawilli Seam in Dendrobium Area 3B using longwall mining techniques. IC has already successfully undertaken longwall mining in Areas 1 and 2 and is currently mining in Area 3A. Dendrobium Colliery is one of three operating underground mines managed by IC south of Sydney, the other two mines being Appin Colliery and West Cliff Colliery.

Approval to mine Area 3 at Dendrobium Colliery was granted by the Minister for Planning in 2001. Since that initial approval, the desired layout of Area 3 has changed following the accumulation of improved geological and environmental impact information.

In 2007, IC applied to modify the approval for Dendrobium Mine (in terms of the Area 3 footprint) pursuant to section 75W of the Environmental Planning and Assessment Act 1979; and submitted a Subsidence Management Plan (SMP) for part of Area 3 denoted by IC as Area 3A.

An Environmental Assessment was completed to support the proposal to modify the footprint of Area 3 and that assessment was prepared by Cardno Forbes Rigby (‘Cardno’) in consultation with a number of specialist sub consultants.

That team included Ecoengineers Pty Ltd (‘Ecoengineers’) who prepared a Surface Water Quality and Hydrology Impact Assessment for the proposed mining in Dendrobium Area 3A (for which a mining layout was defined) and Areas 3B and 3C (for which a mining layout was not fully defined due to uncertainty regarding the area’s geology).

The modification to the original Area 3 Consent covering Area 3A was approved 8 December 2008. Since that time Longwall 6 of Area 3A has been mined with no significant surface water quality or hydrologic impacts (Ecoengineers, 2011) and Longwall 7 is nearing completion (refer **Figure 1.1**).

As a Condition of the Dendrobium Mine Development Consent, SMP Approval is now required for Area 3B prior to longwall extraction from this area. The proposed Area 3B, comprising Longwalls 9 - 18, is located approximately 20 km west of Wollongong. Area 3 lies within the Metropolitan Special Catchment Area, which is a special declared area controlled by the Sydney Catchment Authority ('SCA'). The water storages in the Metropolitan Special Area provide the sole supply for the Macarthur and Illawarra regions and the townships of Campbelltown, Camden, Bargo, Picton, Thirlmere, Tahmoor, The Oaks, Buxton and Oakdale, and provide approximately 20% of the supply to the Sydney Metropolitan Area, via the Prospect Reservoir. The Metropolitan Catchment Area has been defined as an area of environmental sensitivity for the purposes of the SMP approval process.

This Surface Water and Shallow Groundwater Assessment is required to provide a general surface water hydrologic and water quality Impact Assessment for all major creeks, their tributaries, swamps and shallow aquifers in Area 3B.

It is also necessary to consider and assess downstream and ‘far field’ effects within Lake Avon in accordance with the requirement to treat the Metropolitan Catchment Area as an area of environmental sensitivity.

This assessment is based upon past experience by Ecoengineers and other consultants in the investigation and assessment of water quality, hydrologic and aquatic ecological effects in relation to longwall mining in the Illawarra Region over the last 15 years.

Ecoengineers was commissioned by Olsen Environmental Consulting Pty Ltd on behalf of IC in late 1999, to study the mining proposals, to prepare a water impact assessment for the proposed Longwalls 1 to 18 at Dendrobium Mine, and to identify and prepare detailed water related assessments for all major infrastructure associated with coal extraction and mine dewatering for Area 1, ventilation infrastructure above the longwalls, the transport and emplacement of coal wash and safe discharge of excess mine water in support of the Dendrobium EIS (Ecoengineers, 2000).

Subsequently, the Dendrobium Commission of Inquiry ('CoI') considered a number of water related matters such as the hydrologic and water quality effects of mine subsidence generated by the then Elouera Colliery longwall mining on Wongawilli Creek and on swamps which are also pertinent to the planned Dendrobium Area 3 (Office of the Commissioners of Inquiry for Environment and Planning, 2001). Ecoengineers produced specific papers for IC and also a standalone submission to the Dendrobium CoI which, amongst other matters, also dealt in broad terms with water related matters associated with Area 3 (Ecoengineers, 2001).

This report has been prepared to support the SMP application to mine the proposed Longwalls 9 to 18 in Area 3B of the Mine. This requires the Impact Assessment address the same issues as for the wider Area 3 but also requires that there be a focus on specific site features within, and adjacent-to, the SMP Area which has been defined by the finalized longwall layout of Area 3B by Mine Subsidence Engineering Consultants (‘MSEC’) which has been commissioned by IC to study the mining proposal, to identify natural features, and to prepare subsidence predictions for Area 3B.

Water quality, geomorphological and ecological studies and assessments previously conducted in relation to IC’s Elouera Mine to the immediate south of Dendrobium Area 3B, the Dendrobium Area 3A General SMP Area and their environs have been drawn upon in the preparation of this report.

A number of natural features have been identified in the vicinity of the proposed longwalls, including in particular a major creek (Wongawilli Creek) running north-south along the entire eastern side of Area 3B, a creek (Donalds Castle Creek) arising over the northern three proposed longwalls containing upland swamps, and the Native Dog Creek Arm of Lake Avon - a Sydney Catchment Area storage on the south east side of Longwalls 13 through 18, as well as a number of other upland swamps, cliff lines and steep slopes.

The proposed layout of Area 3B, together with surface topography, watercourses and swamps is shown in **Figure 1.1** below. The Area 3B General SMP Area is based on MSEC, 2012 (see **Figure 1.2**).

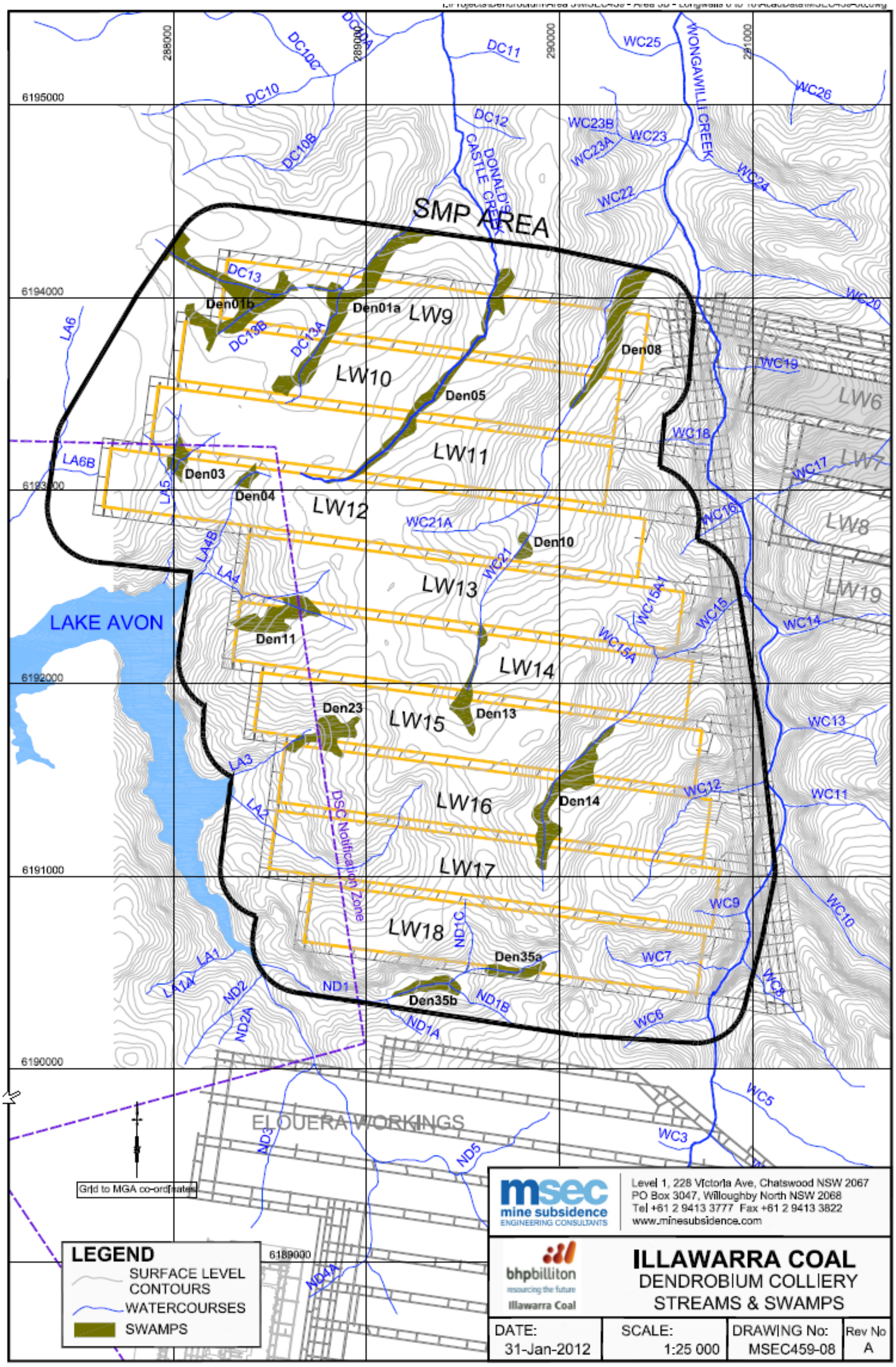


Figure 1.1: Proposed layout of Longwalls 9 to 18 in Dendrobium Area 3B together with surface topography, watercourses and associated upland swamps

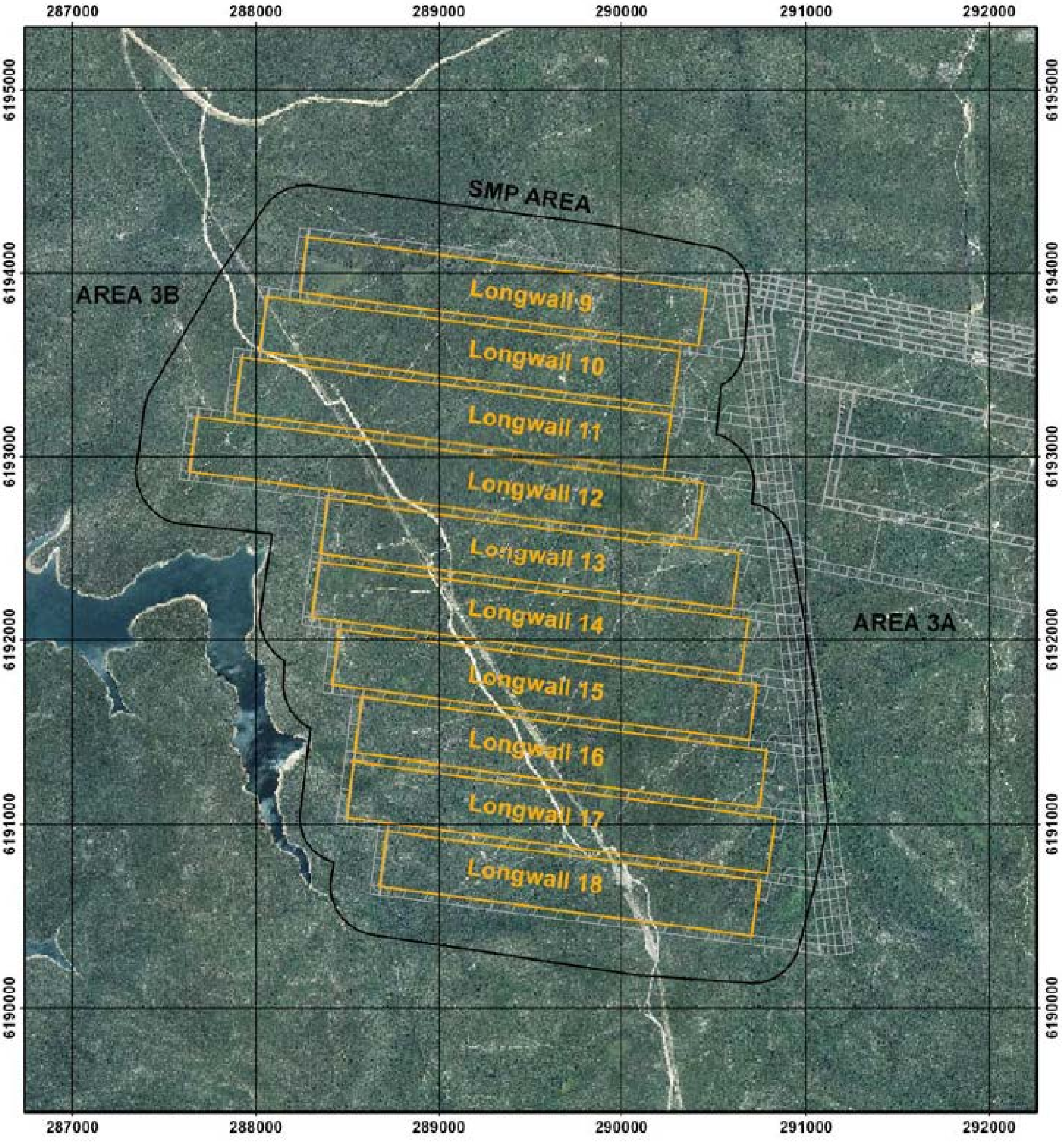


Figure 1.2: The location of Proposed Area 3B Longwalls 9 – 18 within the General Study Area for Area 3B

The Consent for Dendrobium requires the preparation of a Watercourse Impact Monitoring, Management and Contingency Plan to the satisfaction of the Director-General. Each such Plan must:

(a) demonstrate how the subsidence impact limits in conditions 1 - 3 (of the Consent) are to be met;

(b) include a monitoring program and reporting mechanisms to enable close and ongoing review by the Department and DPI of the subsidence effects and impacts (individual and cumulative) on Wongawilli Creek, Sandy Creek and Sandy Creek Waterfall;

(c) include a general monitoring and reporting program addressing surface water levels, water flows, water quality, surface slope and gradient, erodibility, aquatic flora and fauna (including Macquarie Perch, any other threatened aquatic species and their habitats) and ecosystem function;

(d) include a management plan for avoiding, minimising, mitigating and remediating impacts on watercourses, which includes a tabular contingency plan (based on the Trigger Action Response Plan structure) focusing on measures for remediating both predicted and unpredicted impacts;

(e) address third and higher order streams individually but address first and second order streams collectively;

(f) be prepared in consultation with DECC, SCA and DPI;

(g) incorporate means of updating the plan based on experience gained as mining progresses;

(h) be approved prior to the carrying out of any underground mining operations that could cause subsidence impacts on watercourses in the relevant Area; and

(i) be implemented to the satisfaction of the Director-General.

A comprehensive report has been prepared by MSEC (see MSEC 2012) on the assessment of mine subsidence in relation to Area 3B for which the longwall layout and mining domain has been defined by IC.

The General Study Area is as shown in **Figure 1.1** above. The General Study Area may be taken to be approximately the area within which water related impacts (hydrologic and/or geochemical) may be expected to be detectable if they occur.

This report draws on some of the key findings published in the following reports to which, where relevant, cross reference should be made.

- Surface Water Quality and Hydrology Assessment to Support the SMP Application for Dendrobium Area 3 (Ecoengineers, 2007).
- Landscape Impact Assessment (Cardno Forbes Rigby, 2007).
- Flora and Fauna (including Species Impact Statements) (Biosis Pty Ltd, 2007).
- Aquatic Assessment (The Ecology Lab Pty Ltd, 2007).

This assessment should be read in conjunction with the other specialist assessment prepared to support the Dendrobium Area 3B SMP. **Appendix A** provides a Water Monitoring and Management Plan ('WMMP') for the Area 3B SMP. Note the WMMP covers Area 3B only. The monitoring program of the Plan presented herein was based on an initial design goal directed towards providing, in the short term, the most comprehensive baseline hydrographic, soil moisture, shallow piezometric and stream water quality database for Area 3B prior to the planned commencement of Longwall 9 in January or February 2013.

1.1 RELEVANT STUDIES AND REPORTS

1.1.1 Water Quality Studies for Elouera and Delta Collieries

Between 2001 and 2006, IC commissioned Ecoengineers to carry out monthly water quality monitoring campaigns at a significant number of sites in both Wongawilli and Donalds Castle Creeks. Those studies were made in connection with water and environmental monitoring for Longwalls 5 through 10 of the Elouera Colliery and more recently Longwalls 14 and 17 for Delta Colliery beneath and adjacent to upper Wongawilli Creek. This monitoring also provides baseline water quality data in respect of the proposed future mining of Dendrobium Area 3.

In addition, throughout that period, IC also conducted similar water quality monitoring of a number of sites in Native Dog Creek which had been previously undermined and was subject to continued extraction of Elouera Longwalls 1 to 10.

Where Longwalls 1 to 7 of Elouera Colliery (located only 1 – 2 km to the southwest and south of Area 3B) directly mined beneath Native Dog and Wongawilli Creeks between February 1993 and September 2001, fracturing of the (Hawkesbury Sandstone) strata in the base of the creeks resulted in upsidence and dilation of the strata and the creation of voids beneath the beds of the creeks. Fracturing of the surface rocks allowed flow of surface water in the creeks to be redirected into the dilated bedrock strata. The depth of cover beneath the creeks for the Elouera longwalls was typically 280 – 310 m with a void width of about 185 m.

Permanent and semi-permanent pools in some sections of these creeks were drained of surface water during low flow and no flow conditions due to the occurrence of the surface fractures at these locations. Where pools were themselves not completely drained by the above effects they were also subjected to ecotoxicological stresses from flow of geochemically altered sub-bed diverted waters into them. This sub-bed diverted water had had the opportunity to induce accelerated weathering of accessory marcasite (a form of iron sulfide) in freshly fractured (unweathered sandstone) bedrock, inducing ecological impacts in the pools resulting from:

1. Reduced pHs (i.e. increased acidity), in some cases reaching as low as 3.0.
2. Dissolved Oxygen (DO) depletion by oxidation of ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions released.
3. Possible ecotoxic effects from other accessory heavy metals released from the marcasite, being Mn, Nickel (Ni) and Zinc (Zn) (from marcasite) and Aluminium (Al) (from kaolinite).

4. Possible ‘smothering’ of pool boulder and bed surfaces downstream with heavy precipitates of Fe and Mn oxyhydroxides.

IC engaged Ecoengineers to prepare summary and assessment reports on those water quality monitoring programs (Ecoengineers, 2003; 2004a, b; 2005a, b, c; 2006, 2007a, c).

This monitoring and assessment record of water quality monitoring over a 7 year period constitutes a very substantial database on baseline chemistries of local major creeks and of the geochemical effects of directly longwall mining beneath them.

1.1.2 Hydrologic Studies for the Elouera Colliery EMP

In the first half of 2001, discussions were held between IC and SCA regarding the various sorts of flow measuring devices that could be deployed within catchment areas to monitor the possible hydrological effects of longwall mining-induced subsidence. SCA agreed to permit the installation of temporary staff gauges in selected semi-permanent pools to measure pool levels and to derive pool volumes. IC and its consultants were also authorized to make periodic manual measurements of flow at selected locations. However, deployment and use of more standard flow gauging devices such as V notch or rectangular weirs, Cippoletti weirs or Parshall flumes for continuous measurement of flow in watercourses was not approved by SCA at that time.

After consultation between IC and various consultants it was decided to purchase and deploy a number of small fixed-in-place ultrasonic Doppler flow meters which could be dyna-bolted to the sandstone bedrock. These meters accumulate flow data with onboard data loggers and in this case were powered via cable by a battery recharged by solar cells. The cells were mounted securely on firmly founded galvanized steel posts located well outside and above the main creek channel.

Ultrasonic Doppler flow meters were first deployed within the catchments of Native Dog Creek, Wongawilli Creek and Donalds Castle Creek in 2002. It was soon found that placement of ultrasonic Doppler flow meters in natural creek channels requires a careful choice of location and careful measurement of the immediately upstream cross section trapezoid. These flow meters are also subject to obscuration of the upstream-pointing ultrasonic beam by accumulations of organic debris. Coverage of the hydrostatic water level pressure sensor (which simultaneously measures flow depth) by debris was also an issue (Ecoengineers, 2006b).

Notwithstanding these difficulties, a tentative hydrologic analysis of a number of periods of creek flow data collection made using the Starflow Doppler flow meters in Lower Native Dog and Donalds Castle Creeks over 2002 - 2003 was subsequently presented in a review report which made recommendations for improved future hydrologic work (Ecoengineers, 2006b).

The outcomes of the data analysis and modelling presented in that report were used to develop and propose to SCA an improved approach to hydrographic monitoring and hydrologic modelling-based assessment for future application to the landscape mined under by Longwall 5 in Dendrobium Area 2 and subsequent longwalls.

In 2007 SCA agreed to permit installation of nine hydrographic gauging stations based on water level logging pressure transducers located behind ‘natural’ rockbar flow controls or very low constructed weirs (capable of being dismantled at some later time) and a pluviometer in Dendrobium Areas 2 and 3A.

These were installed by Hydrometric Consulting Services (HCS) for IC in sub-catchments of Sandy Creek between November 2007 and April 2008. In addition, two gauging stations (designated WWU and WWL – the latter just north of Fire Road 6) were permitted to be established in Wongawilli Creek respectively upstream and downstream of the proposed Area 3A longwalls and one was also established in Upper Donalds Castle Creek just north of Fire Road 6 (designated DCU).

Two gauging stations had to be repositioned due to the failure of low weirs during major storm events in early 2008, but all stations remain operational to the present time.

These gauging stations record instantaneous flow rates every 15 minutes, compute average flow rates (ML/day) every six hours and subsequent data treatment enables estimation of daily flows, subject to the limitation that each of these gauging stations measures stream flow up to some rating curve limit dictated by the size and location of each controlling rock bar, above which storm flows overtop the rock bar and may also flow around the rock bar and gauging is either inaccurate or no longer occurs, producing unusable intervals or even gaps in the outflow records for each catchment.

It is also noted that where streams are ephemeral (i.e. their baseflows decline to zero) this also produces gaps in the hydrographic record which cannot be modelled. There are occasional dropouts in data collection due to electronic failures of the water level transducer (‘Diver’) used to monitor water levels behind the flow control point (or structure) or of its onboard data storage.

HCS also established a pluviometer (HCS rainfall gauging station 300027) for gauging daily rainfalls at a central location within Area 3. This is designated the Dendrobium Area 3 Centroid Rainfall Station (‘CRS’). It is noted that monthly rainfall samples have also been collected at this station and radioanalysed for tritium since January 2010. The consequences of that are outlined further in **Section 1.1.8** below.

1.1.3 Water Quality Studies for Longwalls 5 (Area 2) and 6, 7 and 8 (Area 3A)

Since 2004, Ecoengineers has been engaged by IC to study, review and report on the results of water quality testing undertaken on water bodies above and adjacent to mining carried out at Dendrobium Mine.

Monthly visitations to water quality monitoring sites have been conducted since mid-May 2001. During the monthly field campaigns, each site in Areas 2 and 3A is monitored for pH, EC, DO and ORP by the Ecoengineers Field Team, and the collection of samples for detailed laboratory analysis undertaken. For each mining area, an extensive pre-mining dataset (see Table 1.1) has been obtained to provide baseline water quality data. Monitoring of surface waters continued on a monthly basis during and immediately after the mining of each longwall.

IC commissioned Ecoengineers to assess chemical and ecological impacts of longwall mining on surface water bodies in Dendrobium Mining Areas 2 and 3A during pre-mining baseline periods and during active longwall extraction. The most recent and most relevant End of Panel Reports compiled by Ecoengineers were those for Longwall 5 (Area 2) and Longwalls 6 and 7 (Area 3A).

No discernible impacts on the water quality of Lake Cordeaux or the creeks in Area 2 (Ecoengineers, 2010) or the creeks of the Sandy Creek Catchment and

Wongawilli Creek in Area 3A (Ecoengineers, 2011) occurred as a consequence of the Longwalls 3, 4, 5, 6 and 7 mining operations.

1.1.4 Hydrologic and hydrogeologic studies for Longwalls 5, 6 and 7 End of Panel Reports

Rainfall data obtained at the Dendrobium Area 3 Centroid Rainfall Station established on 1 November 2007 and stream flow data collected from 1 January 2008 has used to determine key hydrologic performance parameters for the Greater Sandy Creek Catchment area, some 6 subcatchments of the Greater Sandy Creek Catchment, the Upper Wongawilli Creek Catchment, the Greater and Lesser Wongawilli Creek Catchment areas (the latter defined as the Upper Catchment subtracted from the Greater Catchment) and Upper Donalds castle Creek catchment, and the two relevant Sandy Creek sub-catchments (SC10 and SC101A) under both baseline pre-mining, mining and post-mining conditions for Area 2 Longwall 5 and Area 3A Longwalls 6 and 7 (Ecoengineers, 2011).

This was done using the Free University of Amsterdam RUNOFF2005 small catchment hydrologic model (Van der Griend et al., 1985, 1986, 2002, 2003; Seyhan and Van der Griend, 1997) which we proposed in Ecoengineers (2006b) and previously used successfully for assessing stream hydrologic impacts of the mining of Area 2 Longwall 5 (Ecoengineers, 2010a).

Baseline hydrologic model parameters were then used to ‘test model’ observed rainfall and stream flow data from the period during and immediately after the mining of Longwall 6 to determine if unrecoverable flow losses to deep groundwater, stream diversions or any other hydrologic impacts were discernible as a result of mining Longwall 6, especially during the low flow and base flow conditions where mining impacts may be expected to be most evident (if present).

Acceptable Nash-Sutcliffe goodness-of-fit parameters (E) generally in excess of 80% generated by the same model (with the same key parameter magnitudes) when modelling both baseline and post-mining stream flows for each of the above catchments indicated there had been no changes, particularly under the most critical base flow conditions to the hydrology of any of these catchment or sub-catchments as a result of the mining of Longwall 6.

It was found that there was no evidence that the mining of Longwall 6 had any discernible impact on either the hydrologic performance of Wongawilli or Sandy Creek catchments or the various local sub-catchments of Sandy Creek which Longwall 6 had mined under (Ecoengineers, 2011).

Groundwater level records for 10 shallow piezometers were also closely compared with the daily rainfall as measured at the Dendrobium Area 3 Centroid Rainfall Station during and after the Longwall 6 mining period. These comparisons showed the mining of Longwall 6 did not appear to have any noticeable adverse effect on local groundwater levels in and around Swamps 15a, 15b, 12 and 16 (Ecoengineers, 2011).

Further examination of the local shallow groundwater level piezometer records was made by plotting the cumulative rainfall mass residual derived from the physically nearest regional long term monthly rainfall record (Upper Cordeaux Dam No. 2 site; 1982 – 2011) located only 4.2 km southeast of the centre of Area 3A and the Dendrobium Area 3 Centroid Rainfall Station monthly rainfall record (from June 2008) on all the shallow water level graphs.

Comparison of the shallow groundwater levels record with the cumulative monthly rainfall mass residual indicated that the general decline in water levels and the drying out ('flat lining') of most piezometers after the end of the Longwall 6 mining period was a consequence of the general drying of the Dendrobium Area 3A area over the period June 2008 to March 2010 which in turn had followed the wetting of the area from October 2006 through May 2008 (after local cessation of the Millenium Drought in September 2006).

The mining of Longwall 7 apparently resulted in a lowering of some piezometers within the mined-under area, particularly in the small 0.817 km^2 catchment SC10C which contains Swamp 15b, around November 2011. The impact was identified in the Longwall 7 End of Panel Report (Ecoengineers, 2012a) but there was insufficient hydrographic data available to conduct a detailed hydrologic assessment for the post December 2011 period.

A preliminary hydrologic assessment conducted recently for the period April – June 2012 due to the triggering of a Level 2 TARP for Swamp 15b i.e. prior to an End of Panel report for Longwall 8 has shown strong evidence for a mining impact as well as significant self remediation. The impact was a much lesser impact than had occurred in the steeper Fern Tree Catchment during the mining of Area 2 Longwall 5. The effect will be further assessed in the forthcoming Longwall 8 End of Panel Report.

1.1.5 Swamps associated with Elouera/Delta Collieries

Swamps numbered 18 and 19 in the IC numbering system in the headwaters of Native Dog Creek Catchment have been the subject of a number of studies due to suggestions that they had been subject to mine subsidence related damage, in particular erosive scour.

These studies have been reported in a number of IC reports and consultant's reports to IC of which the most important to the swamp-related matters addressed in this document are: Horsley, 2003; IC, 2004a, b, 2006; Earth Tech Engineering, 2005, 2006, Cardno Forbes Rigby, 2007.

There are also numerous other journal papers and publications relevant to the understanding of the uplands swamps of the Woronora Plateau e.g. Young, 1986a, 1986b, Keith, 1993; Mooney, 1994; Cary and Morrison, 1995; Hatton and Evans, 1998; Dept. of Land and Water Conservation (DLWC), 2002; DEC, 2006; Tomkins and Humphreys, 2006; Humphreys and Tomkins, 2007; Tomkins et al. 2007.

1.1.6 Swamps associated with Area 3A Longwall 6

Four upland swamps were recognised as being at risk of damage caused by subsidence related to the mining operations in Dendrobium Area 3A (including Longwall 6). These swamps were identified in the Dendrobium Area 3A Swamp Impact, Monitoring, Management and Contingency Plan (Good *et al.* 2010) as:

- Swamp 12, Pool 3.
- Swamp 15a, Pool 10A (also referred to as SC10 Pool 10A).
- Swamp 15b, Pool 0 (also referred to as SC10C Pool 0).
- Swamp 16, Pool 2.

Water quality studies conducted on these swamps during the pre, post and active mining periods in Dendrobium Area 3A Longwalls 6 and 7 were reported in Ecoengineers, 2011 and 2012.

Prior to, during and following the extraction of Longwall 6, it was found that there were no observable impacts occurring at Swamps 12, 15a or 15b in relation to water chemistry, hydrology or surface cracking.

However, at Swamp 16, very minor increases in sulfate (SO_4) concentrations and sharp increases in filterable iron and manganese occurred concurrently with low ORP TARP exceedances during the mining of Longwall 6.

It is noted that, at the time this water quality effect was first observed (30 August 2010), the face of Longwall 6 was some 1.2 km WSW of Swamp 16. It was also noted that Swamp 16 does not lie over Longwall 6 but rather lies over the development roadway to its north known as West Mains ‘E’ Heading.

Field inspections by the IC Environmental Field Team found no visual subsidence-related impacts to Swamp 16 and have not reported any further notable decreases in ORP since November 2010. It was therefore unclear whether these ORP TARP exceedances in August – November 2010 were mining-related.

1.1.7 Impacts on Wongawilli Creek during the extraction of Longwall 7

Mining of Longwall 7 in Dendrobium Mining Area 3A commenced on 4 May 2011. The western portion (starting end) of the longwall mined beneath the Wongawilli Creek catchment until approximately 27 July 2011 when the face of the longwall moved into the area below the Sandy Creek catchment.

For the purpose of this report, an assessment was made from the available water chemistry data to check for the occurrence of potential mining related impacts on Wongawilli Creek. The baseline periods comprised all data collected prior to the commencement of Longwall 6 extraction (9 February 2010). These data were then compared with all data obtained between this date and the 27 July 2011 (when Longwall 7 mining passed out of the Wongawilli Catchment) making up the mining period.

Five monitoring sites along Wongawilli Creek were included in the assessment due to their proximity to the mining activity. These sites were the upstream locations WWU4, WWM1 and WWM2, and the downstream sites WWM3 and WWL2. **Table 1.1** below shows the long term average of key water quality parameters obtained during the baseline and mining period for each of the five monitoring sites mentioned above.

The data presented in **Table 1.1** indicates that there have not been any significant changes to water quality in Wongawilli Creek since mining commenced in Dendrobium Area 3A. This is evident not only when comparing baseline and mining period data for each monitoring site, but also when comparing upstream and downstream sites.

1.1.8 Swamp 1 Dendrobium Area 2

BHP Billiton Illawarra Coal (‘BHPBIC’) engaged Ecoengineers Pty Ltd (‘Ecoengineers’) to conduct a hydrogeologic assessment on Swamp 1 in Dendrobium Mine Area 2 in partial response to a letter from the Acting Director

Environmental Sustainability, NSW Dept. of Trade and Investment, Resources and Energy data 22 November 2011.

A marked reduction in water levels seen in three Swamp 1 piezometers D1-1, D1-2 and D1-3 shortly after these piezometers were undermined by Longwall 4 around 9 – 17/06/08 with no restoration of any groundwater in them until 25/11/08, 16/01/09 and 01/10/08 respectively, with further pickup of groundwater in the first half of 2009, could possibly be ascribed to mine subsidence effects arising from their undermining by Longwall 4.

However, other evidence, namely:

1. the declining but still continuing presence of groundwater in the shallowest piezometer D1-4 after Longwall 4 mined directly adjacent this site on or about 04/06/08 (which it is noted preceded the dates of undermining of piezometers D1-1 through D1-3 by 5 – 13 days);
2. the stable and continuing presence of groundwater in the shallowest piezometer D1-4 after Longwall 5 mined directly adjacent to this site on or about 15/08/09; and
3. the continuation of high groundwater levels in piezometer D1-5 after Longwall 4 mined adjacent to this site on 31/05/08;
4. the lack of any ‘proximity effect’ on shallow groundwater levels in piezometer D4-1 from the mining of Longwall 4 directly adjacent to this site in the first half of 2008;
5. the continued observation of groundwater outflow from the downslope end of the swamp right through June 2008 up until late November 2008; and
6. the behaviour of piezometers D1-1, D1-2 and D1-3 after June 2008 in which the highest piezometer in the landscape with the shallowest pre-mining groundwater levels (D1-3) recovered some groundwater with the least lag time, an effect which appears contrary to that expected for mine subsidence-induced near surface fracturing,
7. showed that any apparent evidence for a possible hydrogeologic undermining effect in Swamp 1 piezometers during and immediately after June 2008 was highly equivocal.

The breaking of the Millennium Drought in early 2007, and the relatively wet period which applied from early 2007 through to early 2008 would have ensured that all Swamp 1 shallow piezometers were installed during a period when local shallow groundwater levels would have been markedly higher than average by typically ~100 – 150 mm (allowing for ET).

The cumulative residual rainfall curve based on the 30-year rainfall record at the Upper Cordeaux Dam No. 2 weather station only 2.15 km from the lowest down gradient drainage point of Swamp 1 showed that, after February 2008, there was evidently a resumption of the well-known regional and Eastern Australian long term drying trend (e.g. Rancic et al. 2009; Russell et al. 2010) for ~2.5 years which lasted through to about September 2010 and which was characterised by an eventual accumulated rainfall deficit over long term average conditions by up to ~600 mm.

This would have meant a net fall in shallow ground water levels between about February 2008 i.e. from <u>before</u> the undermining of Swamp 1 by Longwalls 4 and 5 and September 2010 of about 600 mm - noting a fall from a rainfall surplus of ~350 mm to a deficit of ~650 mm would translate, after allowance for ET, into a groundwater deficit of the order of ~300 mm.

On balance, the piezometric, rainfall and 2008-9 field inspection evidence tended to support our conclusion that some observations of groundwater decline around June 2008 are only coincidentally aligned with the local undermining by Longwall 4 at that time and were more likely due to a strong trend of a declining cumulative rainfall residual i.e. a declining local groundwater resource from early to mid-2008 onwards (Ecoengineers, 2011b).

Monitoring of the Swamp 1 groundwater levels has continued since our report in November 2011 and at this stage Ecoengineers has not had the opportunity to assess this data.

1.1.9 Swamp 15b Dendrobium Area 3A

Following a triggering of the Level 2 TARP indicating mine subsidence-related near-surface water loss effects from within and around Swamp 15b, Dendrobium Area 3A, BHP Billiton Illawarra Coal ('BHPBIC') engaged Ecoengineers to conduct an independent review of the monitoring program and to provide advice on any Corrective Management Actions (CMAs) considered necessary. BHPBIC are to inform relevant technical specialists of the impacts and seek their input to a review of the monitoring program and suggest any CMAs that may be appropriate. Key government agencies are also invited to provide feedback on monitoring programs and CMAs. The results of these reviews and assessments will be reported by BHPBIC to key stakeholders. Monitoring and reporting of Longwall 8 impacts will continue as described in the SMP, including an End of Panel Report early in 2013 following the planned completion of the longwall in December.

To those ends Ecoengineers (2012) have now conducted that review and provide below some technical discussion of the monitoring and management of detected impacts on the basis of:

1. The supplied BHPBIC Field Team report 'Dendrobium Area 3A Longwall 8 Impact Report 120912' including all photos and graphs therein.
2. The supplied BHPBIC Field Team follow-up report 'Dendrobium Area 3A Longwall 8 Impact Report 200912' including all photos, tables and graphs therein.
3. Our pre-existing knowledge of the established monitoring programs required by the SMP – specifically the local shallow piezometric and draining stream surface water quality monitoring programs.
4. Discussions on the piezometric monitoring held with Mr. Andrew Gurba of AGurba Pty Ltd who installed, maintains and collects data from the piezometric monitoring program.
5. Discussions on the fracturing observations and on the general field observations with Mr. Luke Pascot leader of the BHPBIC Field Team.
6. Examination of additional data collected by the BHPBIC Field Team and supplied to us – specifically dielectric soil moisture monitoring, field photographs, especially of pools and water quality data.

As part of that review Ecoengineers (2012a) conducted some preliminary hydrologic modelling of the small catchment SC10C (0.817 km^2) in which Swamp 15b resides for the 63 day valid flow gauging period 10 April 2012 to 11 June 2012.

They found that the pre-mining hydrologic model established prior to the mining of both Longwalls 6 and 7 over a total of 297 days including equivalent modelling over a total of 118 days up to 3 December 2011 i.e. slightly after Longwall 7 passed beneath still applied quite well for the above period with a goodness of fit of 75.2% - only slightly below the accepted norm of 80.0%.

Although there is still evidence of some minor loss of water into deeper storage which did not report to the gauging station, based on a comparison of model-simulated evapotranspiration (ET) for the 10 April 2012 to 11 June 2012 with a measure of ET by the independent CSIRO Land and Water method (Zhang et al. 1999, 2001, 2004, 2007) it was only about 3.2% of total precipitation – well within measurement error.

By way of comparison the rate of loss was estimated, using the same criterion to be about 9.3% of precipitation for the 118 day period to 3 December 2011 so there is evidence that by April 2012 any effect of mine subsidence-induced fracturing leading to loss of surface water or shallow groundwater outflow from the catchment was already undergoing self-amelioration.

This is a similar pattern to that which was observed with the small Fern Tree Creek (‘FTC’) catchment mined under by Area 2 Longwall 5 in December 2008/January 2009 where, by late 2009, the alteration of catchment behaviour (increased loss to deep storage) had largely disappeared presumably due to relaxation and closure of sub-bed fracturing and infilling with clays, silt and organic matter (Ecoengineers, 2010).

1.1.10 Implications of BHPBIC Tritium Monitoring Program

Tritium, a beta-emitting isotope of hydrogen with a 12.32 year half-life is widely used in hydrological investigations for timescale below about 100 years. A peak in production of tritium in the atmosphere around 1960 due to atmospheric nuclear weapons testing has enabled a method for useful determination of the fractions of a water which are ‘younger’ than or ‘older’ than approximately 50 years in terms of when it fell as rainfall (Leibundgut and McDonnell, 2000).

Data from ANSTO, Lucas Heights has been accumulated for 29 pooled monthly rainfall samples from the Area 3 Centroid Rainfall Station established over the centre of Dendrobium Area 3 i.e. from January 2010 up to and including April 2012, except for May 2010 as that month was too dry to provide a sample large enough for tritium radioanalysis. Samples collected in August and September 2012 are currently undergoing radioanalysis at ANSTO.

Mean monthly rainfall tritium level in this local Area 3A rainfall has so far ranged between 1.04 and 3.51 TU giving, presently, a rainfall volume-weighted average of 1.979±0.044 Tritium Units (‘TU’; n=29).

These are true monthly volumetrically-weighted averages as the rainfall collector used is too big to overflow during any one month. It is noted the simple unweighted average tritium level is a fairly similar 2.164±0.718 TU.

The present volume-weighted average tritium value of 1.979±0.044 TU (n=29) for local rainfall at the Dendrobium Area 3 Centroid Rainfall Station established and maintained by HCS is similar-to, <u>but is now significantly different-from</u> the average tritium level value we have for nearby Lake Cordeaux surface waters (i.e. for both Cordeaux and Sandy Creek Arms; 1.772±0.199 TU; n=37) but is not (yet) significantly different to Lake Avon surface waters possibly due to the small number of tritium determinations made thus far for Lake Avon (1.849±0.171 TU; n=7) and a somewhat different provenance of tritium in rainfall.

The actual percentage of modern surface water (from rainfall) possibly appearing locally in shallow groundwaters as estimated from tritium (regardless of its source) has become increasingly more precise and reliable due to the large number of determinations now to hand and the correct volumetric weighting for rainfall depth (mm).

The body of tritium data for (both) Lake Cordeaux and Lake Avon now shows that water in both of these lakes very probably contains a minor but significant fraction of groundwater of the order of 10% which originated as rainfall in excess of 50 years ago.

For Lake Cordeaux this fraction is better known due to the larger number of determinations and is of the order of 10.5±9.8% at the one standard deviation level i.e. it is also significantly different to zero.

This observation is confirmed by an extensive suite of tritium analyses we have obtained for the lower end of Sandy Creek (1.695±0.205 TU; n=17) which also indicates that water flowing out of the Sandy Creek catchment into Lake Cordeaux (Sandy Creek Arm) contains significant shallow groundwater more than 50 years old in an estimated proportion of 14.9±10.8% i.e. it too is significantly different to zero.

This also accords with the observation that water in the Sandy Creek Arm of the Lake also contains groundwater more than 50 years old in the estimated proportion of 13.7±7.8% again significantly different to zero.

Assuming that rainfall entering Lake Avon as catchment outflows also has a mean tritium concentration close to the mean level of 1.979±0.044 TU found at the Dendrobium Area 3 Centroid Rainfall Station rainfall then the water in Lake Avon would also have about 7% water older than 50 years.

These data are interpreted to mean that groundwater travelling slowly through hillslope aquifers in the (largely) outcropping Hawkesbury Sandstone of the Sandy Creek catchment provides a small but significant proportion of total outflow from the Sandy Creek catchment which is more than 50 years old because some minor part of the recharge to groundwater takes that long to reach the draining stream. It is expected that the Wongawilli and Donalds Castle Creek Catchments will be no different.

It is very important to realize that this phenomenon of ‘extended detention’ of (initially modern water) as it passes down through the hillslope aquifers of these landscapes does place some sort of natural limit on just how precise *per se* can be an hydrologic assessment of ‘catchment performance’ pre- and post-mining and on supposed water balances constructed from hydrographic data spanning at most a few months.

The tritium data clearly shows that, by definition, such water balances do rely – up to a limit of about 10 – 15% on the assumption that ‘old water’ passing through the hillslope aquifer (groundwater) part of the local landscapes is simply being continually pushed out by ‘younger water’ in a nearly volumetrically constant manner.

Given the natural variability of Recharge (= Precipitation, P minus Evapotranspiration, ET) on monthly to annual timescales and long events like droughts etc., this may not always be a particularly reliable assumption.

1.1.11 Southern Coalfield Inquiry

On 6 December 2006, the NSW Government established an independent Inquiry into underground coal mining in the Southern Coalfield and appointed an Independent Expert Panel to conduct the Inquiry.

The Inquiry was established because of concerns held by the government over both past and potential future impacts of mining-induced ground movements on significant natural features in the Southern Coalfield. These concerns first surfaced in the community in 1994 when the bed of the Cataract River suffered cracking and other impacts caused by mine-related subsidence from the underlying Tower Colliery workings. Sections of the local and broader community had continued to express concerns at further subsidence-related impacts associated with this and other coal mines in the Southern Coalfield.

Given the community concerns and changes in the planning system, the Government announced the inquiry to provide a sound technical foundation for assessment under Part 3A (and other regulatory and approval processes) and long term management of underground mining in the Southern Coalfield by both the Department of Planning (DoP) and the Department of Primary Industries (DPI) and other key agencies such as the Office of Environment and Heritage (OEH), the Sydney Catchment Authority (SCA) and the Department of Water and Energy (DWE)).

The terms of reference required the Panel to focus its examination on the subsidence-related impacts of underground mining on ‘significant natural features’. These features were defined as ‘rivers and significant streams, swamps and cliff lines.’ Other natural features, for example plains, plateaus and general landforms, and any impacts of subsidence on infrastructure, buildings or other structures were not within the Panel’s terms of reference.

In considering impacts on rivers, significant streams and swamps, the Panel was asked to place particular emphasis on ‘risks to water flows, water quality and aquatic ecosystems’.

The reference to water flows and water quality was considered to relate not only to ecosystem functioning but also to reflect the water catchment values of large sections of the Southern Coalfield, which contains a number of water supply catchments, dams and other water supply assets. The reference within the terms of reference to ‘aquatic ecosystems’ was considered by the Panel to also include groundwater dependent ecosystems.

The Panel comprised the following members:

- Professor Bruce Hebblewhite (Chair, subsidence expert);
- Emeritus Professor Jim Galvin (subsidence expert);
- Mr. Colin Mackie (groundwater expert);

- Associate Professor Ron West (aquatic ecologist); and
- Mr. Drew Collins (economist).

One of the key findings of the Panel was the fact that there was no scientific evidence or argument to support the view that an absolute "one size fits all" protective buffer region should be applied for protection of significant natural features from adverse subsidence impacts from underground mining. A number of community groups argued that a 1 km wide buffer, below which no mining was permitted, should be applied to all rivers in the Southern Coalfield. However the basis for either the 1 km figure, or the universal application of a single measure was not substantiated. For example, simple variations in depth, not to mention mining widths, seam thicknesses, and structural geology features all contribute to some degree of variability in the surface extent of any adverse subsidence impacts.

The Southern Coalfield Panel Report made a number of recommendations for future research, especially relating to mine subsidence behaviour; prediction techniques; monitoring and surface fracture remediation:

The coal mining industry and Government should undertake additional research into the impacts of subsidence on both valley infill and headwater swamps. This research should focus on the resilience of swamps as functioning ecosystems, and the relative importance of mining-induced, climatic and other factors which may lead to swamp instability. The coal mining industry should undertake additional research into means of remediating stream bed cracking, including:

- crack network identification and monitoring techniques;
- all technical aspects of remediation, such as matters relating to environmental impacts of grouting operations and grout injection products, life spans of grouts, grouting beneath surfaces which cannot be accessed or disturbed, techniques for the remote placement of grout, achievement of a leak-proof seal and cosmetic treatments of surface expressions of cracks and grouting boreholes;
- Administrative aspects of remediation, in particular, procedures for ensuring the maintenance and security of grout seals in the long term.
- The coal mining industry should escalate research into the prediction of non-conventional subsidence effects in the Southern Coalfield and their impacts and consequences for significant natural features, particularly in respect of valley closure, upsidence and other topographic features.

However, the Inquiry did not investigate in any significant way water quality impacts, or their specific geochemical issues or the water quality-related ecological impacts of longwall mining in the Southern Coalfield. Consequently it did not consider any methods of management and mitigation.

Table 1.1: key water quality parameters obtained at five monitoring sites along Wongawilli Creek. Baseline data collected prior to the commencement of Longwall 6 mining (2 February 2010) and the mining period includes data collected between 9 February 2010 and 27 August 2012.

			Field pH	Field EC	DO	Turbidity	ORP	Filt. SO4	Cl	Filt. Fe	Total Fe	Filt. Mn	Total Mn	Filt. Ni	Filt. Zn
			pH Unit	µS/cm	%	NTU	mV	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
WWU4	**Baseline**	**Mean**	4.95	79.7	93.1	0.4	446	5.7	20.2	0.09	0.23	0.103	0.101	0.005	0.024
		St. Deviation	0.49	21.1	7.4	0.3	67	4.8	4.3	0.07	0.41	0.093	0.104	0.006	0.025
		Count	65	65	31	6	6	74	48	65	74	65	74	75	75
	Mining Period (9/2/10-27/8/12)	**Mean**	5.51	85.7	91.1	0.3	404	5.8	18.2	0.07	0.15	0.088	0.092	0.009	0.036
		St. Deviation	0.36	13.4	7.5	0.4	42	3.1	2.5	0.05	0.11	0.019	0.022	0.002	0.009
		Count	32	32	32	32	32	32	32	32	32	32	32	32	32
WWL2	**Baseline**	**Mean**	5.73	92.6	86.4	0.7	380	3.0	25.5	0.35	0.60	0.045	0.050	0.001	0.006
		St. Deviation	0.56	21.5	7.1	0.3	126	1.2	3.9	0.28	0.39	0.025	0.032	0.000	0.004
		Count	80	81	33	8	8	95	55	85	93	85	94	95	95
	Mining Period (9/2/10-27/8/12)	**Mean**	5.64	94.1	81.7	0.7	375	2.2	23.2	0.27	0.60	0.044	0.050	0.001	0.008
		St. Deviation	0.46	11.5	11.4	0.8	45	0.9	3.5	0.32	0.37	0.015	0.015	0.001	0.004
		Count	31	31	31	31	31	31	31	31	31	31	31	31	31
WWM1	**Baseline**	**Mean**	5.39	98.4	52.5	1.8	356	4.1	23.3	0.59	1.91	0.081	0.165	0.003	0.018
		St. Deviation	0.43	18.2	25.2	1.5	106	2	2.7	0.69	2.25	0.040	0.307	0.001	0.006
		Count	23	23	23	7	13	18	18	18	18	18	18	18	18
	Mining Period (9/2/10-27/8/12)	**Mean**	5.29	90.2	68.8	0.5	376	3.3	20.4	0.22	0.58	0.053	0.067	0.003	0.019
		St. Deviation	0.37	13.1	15.1	0.8	50	1	3.8	0.35	0.65	0.020	0.049	0.001	0.008
		Count	42	42	41	31	42	31	31	31	31	31	31	31	31
WWM2	**Baseline**	**Mean**	5.42	96.1	65.1	2.7	358	3.6	23.2	0.57	1.10	0.064	0.069	0.002	0.015
		St. Deviation	0.44	12.4	18.9	3.9	82	2.0	2.6	0.71	1.28	0.023	0.032	0.001	0.006
		Count	22	22	22	7	12	18	18	18	18	18	18	18	18
	Mining Period (9/2/10-27/8/12)	**Mean**	5.46	92.4	71.5	1.1	375	2.9	21.9	0.40	0.75	0.052	0.076	0.002	0.013
		St. Deviation	0.43	10.3	16.4	2.1	52	1	3.0	0.57	0.91	0.017	0.081	0.001	0.003
		Count	43	43	42	31	43	31	31	31	31	31	31	31	31
WWM3	**Baseline**	**Mean**	5.65	101.7	54.7	3.7	354	3.2	24.2	0.39	1.67	0.207	0.220	0.003	0.012
		St. Deviation	0.51	15.1	19.1	4.4	79	1.9	2.9	0.33	1.34	0.199	0.205	0.001	0.005
		Count	22	22	22	7	12	18	18	18	18	18	18	18	18
	Mining Period (9/2/10-27/8/12)	**Mean**	5.62	91.0	67.9	1.0	374	2.3	20.9	0.46	0.80	0.099	0.106	0.002	0.012
		St. Deviation	0.49	10.7	17.5	1.1	54	0.9	2.7	0.46	0.41	0.078	0.081	0.000	0.003
		Count	44	44	42	31	44	31	31	31	31	31	31	31	31

2. CLIMATE, GEOLOGY, SOILS & WATER QUALITY ISSUES

2.1 RAINFALL

Long-term rainfall records (> 20 years) in the vicinity of Area 3B have been obtained from the weather stations located at Browns Road (located within Area 3B), Upper Cordeaux Dam Number 2 (which lies about 6.5 km east of the Browns Road weather station), and 'Cordeaux Quarters' (located at the modern Cordeaux Dam site about 7 km north-north east of Browns Road weather station).

Table 2.1 below shows the average monthly rainfall recorded at each station since 1981 i.e. over the last 30 years. Note that n = the number of individual fully logged months used to compute average monthly rainfalls.

Table 2.1: Mean Monthly and Annual Precipitation in General Area

	Average Precipitation (mm)		
Month	**Browns Road**	**Cordeaux Dam No. 2**	**Cordeaux Quarters**
Jan	96.4±57.0 (n=26)	118.2±75.7 (n=29)	87.4±51.2 (n=25)
Feb	142.5±114.4 (n=26)	196.7±169.4 (n=28)	114.6±86.5 (n=25)
Mar	117.6±80.3 (n=27)	165.3±112.1 (n=28)	96.2±65.8 (n=27)
Apr	113.6±169.4 (n=27)	132.2±179.7 (n=27)	94.4±141.2 (n=28)
May	92.8±79.4 (n=28)	116.3±99.4 (n=28)	86.6±76.9 (n=27)
June	100.1±118.3 (n=28)	127.1±148.4 (n=29)	83.8±102.1 (n=28)
July	67.6±60.8 (n=27)	73.8±72.5 (n=28)	61.4±54.9 (n=27)
Aug	81.0±142.2 (n=26)	119.9±213.6 (n=27)	89.4±156.1 (n=27)
Sept	66.0±56.0 (n=27)	84.9±71.7 (n=29)	65.2±54.8 (n=28)
Oct	96.8±120.1 (n=26)	121.9±134.9 (n=29)	89.8±100.5 (n=27)
Nov	112.6±94.2 (n=25)	122.2±82.0 (n=30)	90.8±61.0 (n=25)
Dec	80.8±68.8 (n=25)	102.7±99.1 (n=30)	81.9±60.8 (n=25)
Year	**1167.9±232.1**	**1481.4±291.7**	**1041.5±202.4**

To identify long-term trends in the local rainfall record, the cumulative monthly rainfall residual mass was calculated based on the long-term rainfall record obtained from Browns Road, Cordeaux Dam Number 2 and Cordeaux Quarters.

The cumulative monthly rainfall residual mass was calculated by subtracting the actual monthly rainfall (recorded at the corresponding rainfall station) from the long-term regional monthly average rainfall (for the same rainfall station).

Transforming the data in this way functions as a low pass filter by removing rainfall variations resulting from seasonal changes and individual high precipitation events (see **Figures 2.1, 2.2** and **2.3** below).

For the Browns Road rainfall station on Fire Road 6A (within Area 3B), the result of the transformation indicates a recent recovery in shallow groundwater recharge since November 2010, relative to the available long term historical record.

As can be seen in **Figures 2.2** and **2.3** below this recent recovery is also mirrored at the other two regional rainfall stations both closer to the Illawarra Escarpment (i.e. Upper Cordeaux Dam No. 2) and more remote (from the Browns Road station) the Cordeaux Quarters rainfall station (i.e. the modern Cordeaux Dam constructed in 1926). The Cordeaux Quarters cumulative monthly rainfall residual curve (Figurer 2.3) has be highlighted in pink as this is the curve which we believe, from various checks, best represents average conditions within Dendrobium Area 3 as a whole.

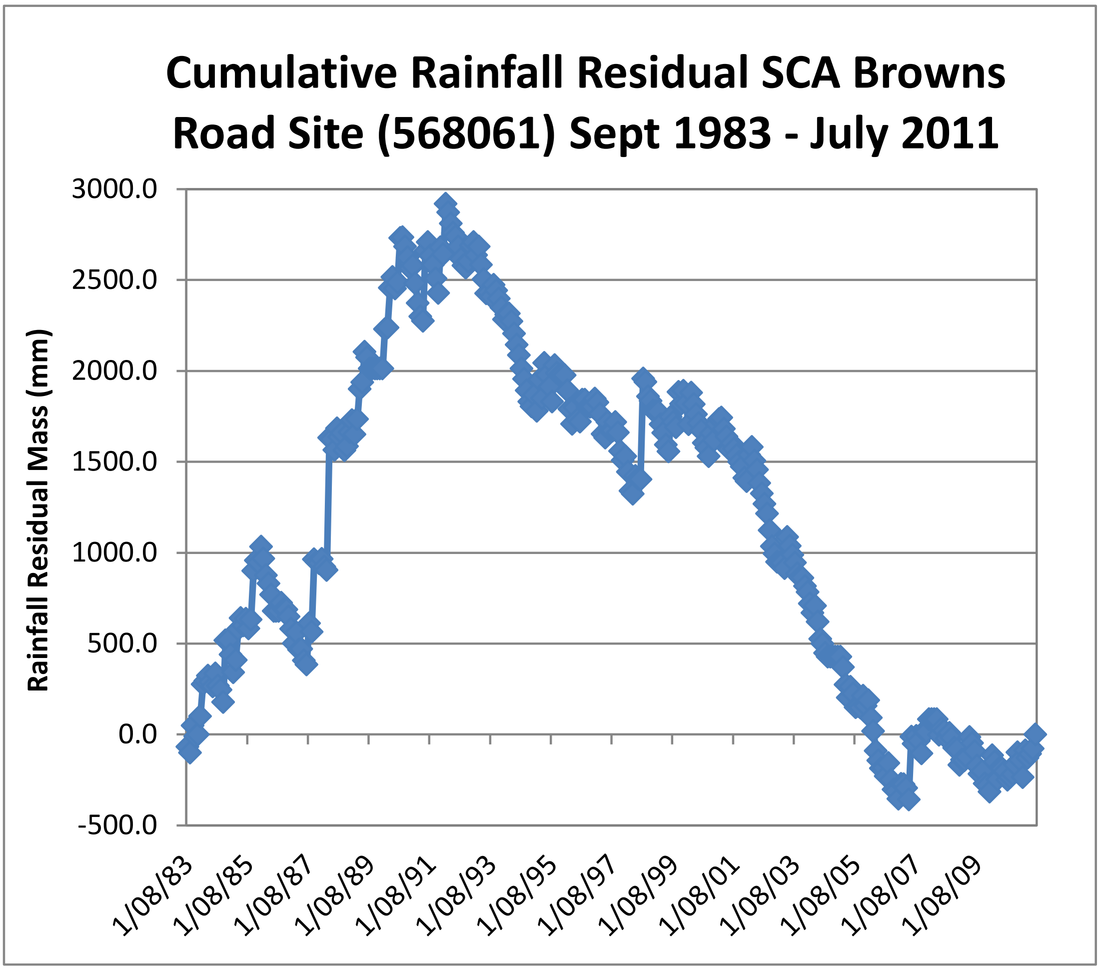


FIGURE 2.1: CUMULATIVE RAINFALL RESIDUAL MASS PLOTS CALCULATED FROM DATA OBTAINED FROM THE SCA BROWNS ROAD RAINFALL STATION

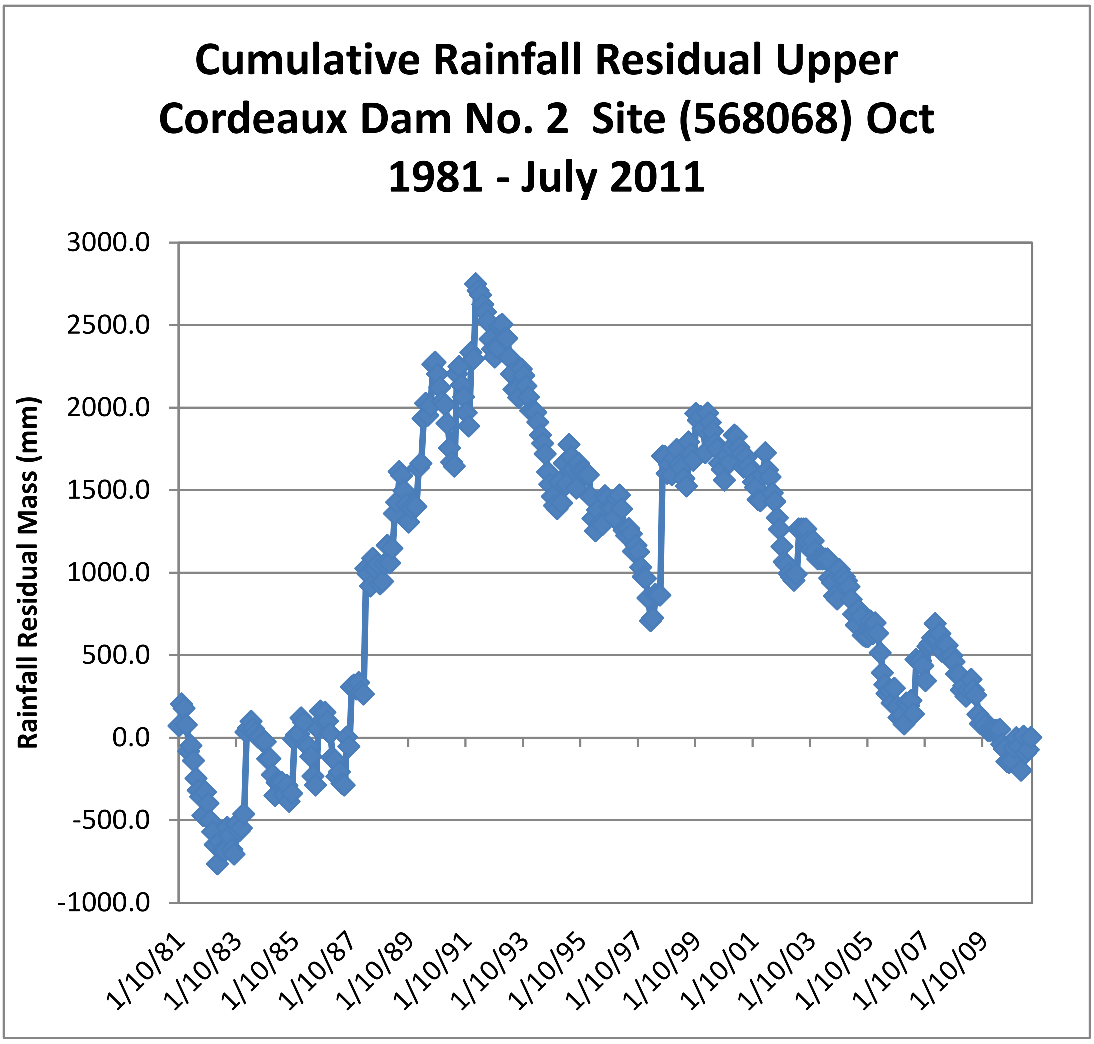


FIGURE 2.2: CUMULATIVE RAINFALL RESIDUAL MASS PLOTS CALCULATED FROM DATA OBTAINED FROM THE UPPER CORDEAUX DAM NO. 2 RAINFALL STATION

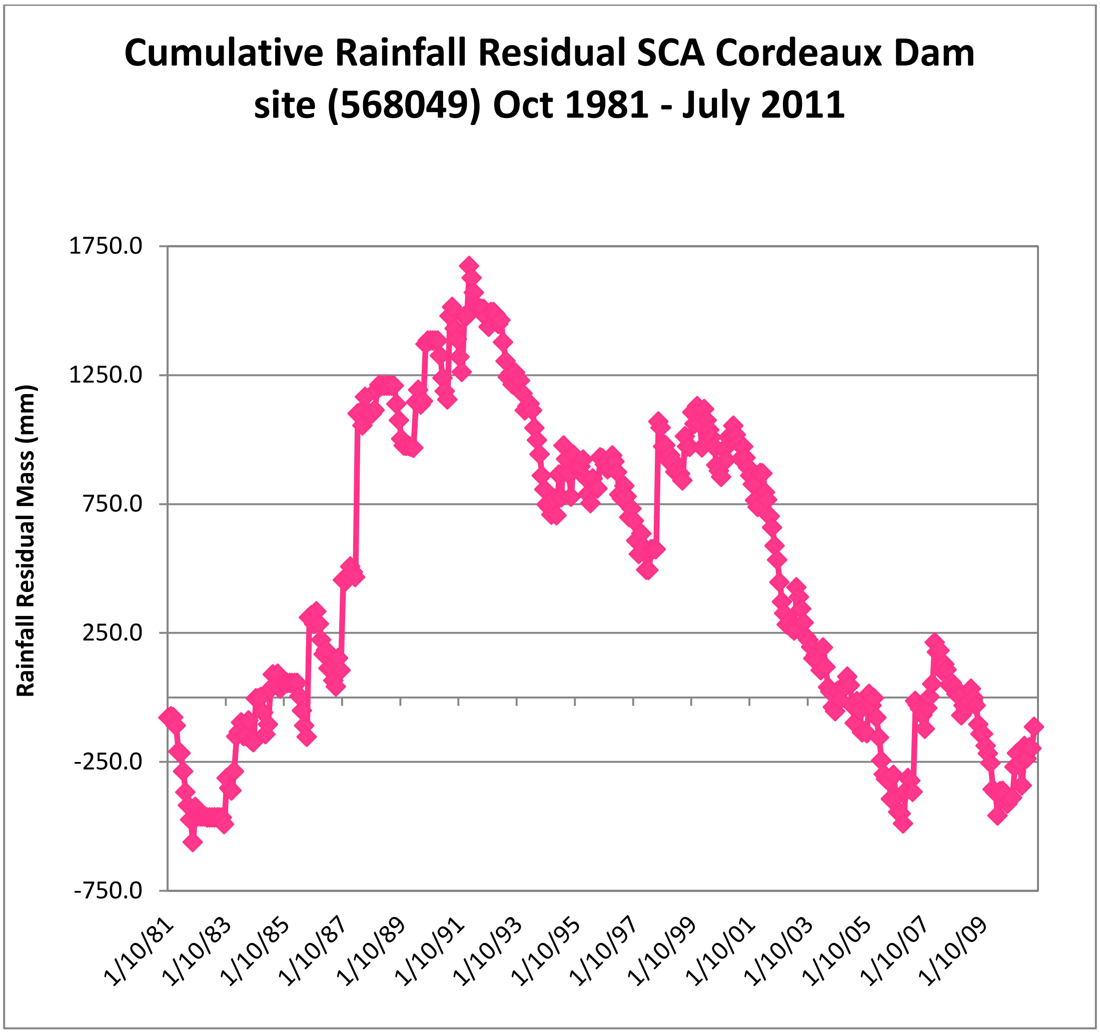


FIGURE 2.3: CUMULATIVE RAINFALL RESIDUAL MASS PLOTS CALCULATED FROM DATA OBTAINED FROM THE SCA CORDEAUX QUARTERS (MODERN CORDEAUX DAM) SITE RAINFALL STATION

2.2 LOCAL GEOLOGY

Area 3B geology mainly comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods, which have been intruded in places by igneous syenites. The major sedimentary units in Dendrobium Area 3B are, from the surface down:

- The Mittagong Formation;
- The Hawkesbury Sandstone.
- The Narrabeen Group.
- The Eckersley Formation.

The Narrabeen Group contains the Newport Formation (sometimes referred to as the Gosford Formation), the Bald Hill Claystone, the Bulgo Sandstone, the Stanwell

Park Claystone, the Scarborough Sandstone, the Wombarra Shale and the Coalcliff Sandstone.

The Eckersley Formation contains sandstones, shales and minor coal seams and forms the upper section of the Illawarra Coal Measures. The Bulli Seam lies directly above the Eckersley Formation and the Wongawilli Seam lies directly below it.

The sandstone units vary in thickness from a few metres to as much as 120 metres. The major sandstone units are interbedded with other rocks and, though shales and claystones are quite extensive in places, the sandstones predominate.

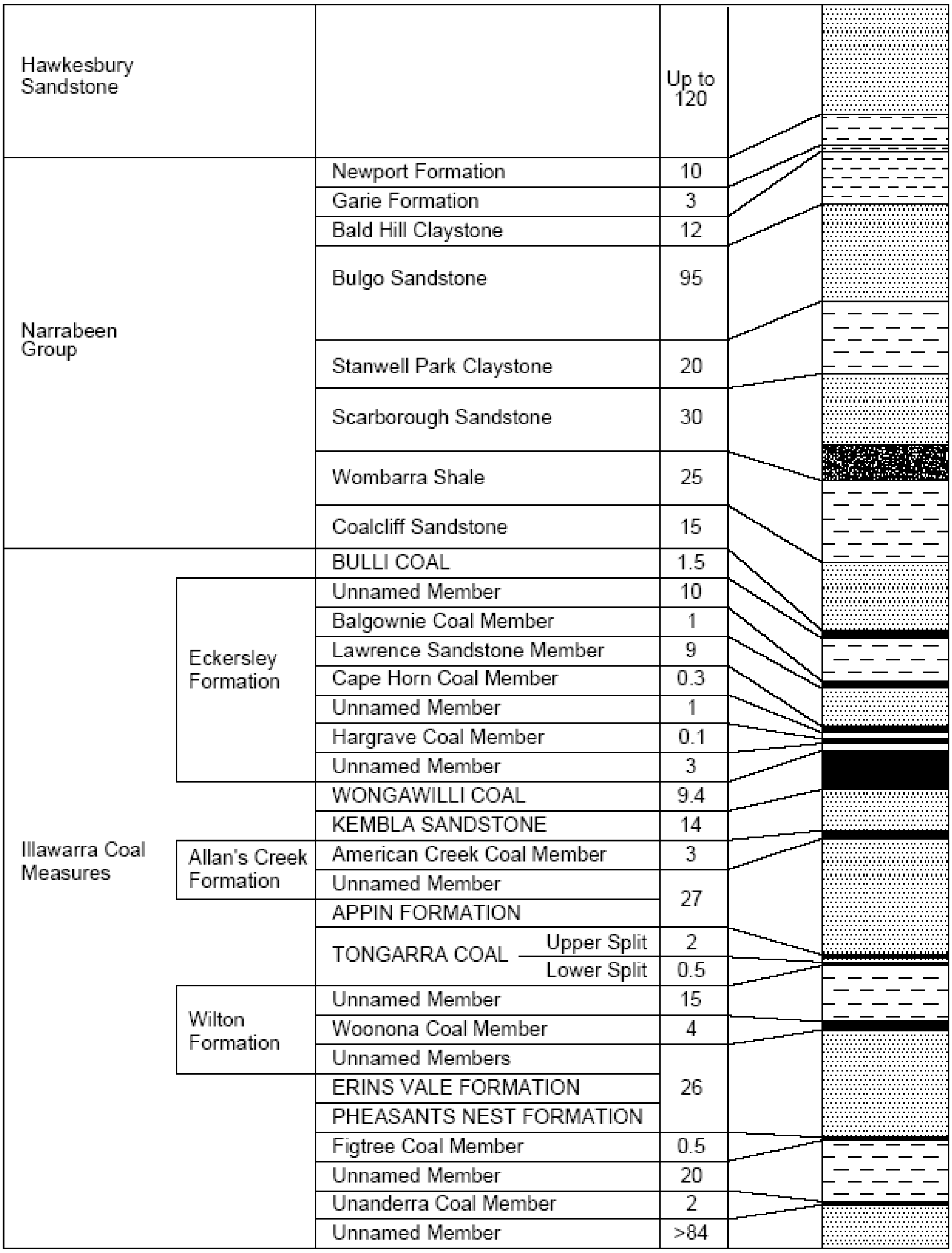
A generalised sedimentary stratigraphic section with indicative strata thicknesses is shown in **Figure 2.1** below (Williams, 1979).

Area 3B is situated between the dissected Woronora and Illawarra Plateau, physiographic landscape units drained by numerous creeks and rivers, which extend south from Sydney in a ramp like structure, the dominant outcropping rock formation being the Triassic Age Hawkesbury Sandstone although a significant fraction of the upland landscape is mantled by the residual weathered material derived from intercalated shale and sandstones of the Mittagong Formation (refer **Figure 2.9**).

The sandstone units of the important Hawkesbury Sandstone Formation are typically comprised of mainly medium to coarse quartz grains bound by secondary quartz cement which sometimes contains up to about 4% of a manganiferous siderite, with a clay matrix of variable proportion dominated by kaolinite, which can completely fill the intergranular space.

Petrographic studies have found that unweathered to weakly weathered sandstone may contain about 0.5% of iron sulfide, principally present as marcasite, a dimorph of pyrite, with minor solid solution incorporation of nickel and intercalation of sphalerite (zinc sulfide) and hauerite (manganese sulfide) (Deer et al. 1992).

The Sandstone has been subject to lateritization and the depth of weathering can be profound, especially from ridgelines, as well as highly variable but generally reduces with depth below the surface. Weathering effects range from superficial which leads to colour changes due to siderite and marcasite alteration to iron oxides to a complete loss of aggregation. The degree of weathering and porosity changes are controlled by a number of physical factors and do not necessarily graduate downwards (Standard, 1969; Herbert and Helby, 1980).



Hawkesbury Sandstone			Up to 120
Narrabeen Group		Newport Formation	10
		Garie Formation	3
		Bald Hill Claystone	12
		Bulgo Sandstone	95
		Stanwell Park Claystone	20
		Scarborough Sandstone	30
		Wombarra Shale	25
		Coalcliff Sandstone	15
Illawarra Coal Measures		BULLI COAL	1.5
	Eckersley Formation	Unnamed Member	10
		Balgownie Coal Member	1
		Lawrence Sandstone Member	9
		Cape Horn Coal Member	0.3
		Unnamed Member	1
		Hargrave Coal Member	0.1
		Unnamed Member	3
		WONGAWILLI COAL	9.4
		KEMBLA SANDSTONE	14
	Allan's Creek Formation	American Creek Coal Member	3
		Unnamed Member	27
		APPIN FORMATION	
		TONGARRA COAL Upper Split	2
		Lower Split	0.5
	Wilton Formation	Unnamed Member	15
		Woonona Coal Member	4
		Unnamed Members	26
		ERINS VALE FORMATION	
		PHEASANTS NEST FORMATION	
		Figtree Coal Member	0.5
		Unnamed Member	20
		Unanderra Coal Member	2
		Unnamed Member	>84

FIGURE 2.1: GENERALISED LOCAL STRATIGRAPHIC SECTION

2.3 GEOMORPHOLOGY

Figure 2.2 below shows the surface water features and layout of Area 3B. It identifies the overall boundary of Area 3B, the major creeks and tributaries and their catchments in and adjacent to the Area.

The nomenclature for identifying all un-named creeks and tributaries of the named creeks being Wongawilli Creek, Native Dog Creek and Donalds Castle Creek is also presented <u>and these identifiers are subsequently used throughout this report</u>.

The eastern area is broadly sited on a plateau dissected by a number of relatively shallow sub-catchments draining either into Cordeaux River via Wongawilli Creek or Donalds Castle Creek or five other individual un-named ephemeral creeks draining directly to the southern end of Lake Avon.

The largest watercourse within the Study Area is Wongawilli Creek which is located between Area 3A (which is currently being mined) and Area 3B and crosses the western side of the proposed Area 3C downstream to the north east. Wongawilli Creek generally flows in a northerly direction and drains into the Cordeaux River approximately 700 m north of the maximum footprint for Area 3C.

The central area and eastern part of Area 3B is dominated by the Creek, a large, well-incised, permanently flowing stream which dissects Area 3 south to north and also has numerous well-incised tributaries.

The headwaters of Wongawilli Creek are located along a drainage divide separating surface runoff and shallow groundwater outflow runoff from Native Dog Creek and Lake Avon to the west.

The natural gradient of Wongawilli Creek within the Area 3B SMP Area (excluding Waterfall WC-WF54) generally varies up to around 75 mm/m with a maximum natural gradient of 200 mm/m occurring just downstream of Waterfall WC-WF54. The average natural gradient of Wongawilli Creek is approximately 10 mm/m (MSEC, 2011).

Proceeding northwards towards the northern boundary of Area 3, numerous tributary sub-catchments lying west and east of Wongawilli Creek are all founded in sedge-dominated, flatter, basin like upland plateau along the confining ridges and grading towards the main channel of the Creek into deep gullies which in their basal steeper sections contain numerous outcrops, minor vertical drops and blocky scree slopes.

Ephemeral tributaries and the main channel of another stream, Donalds Castle Creek, also drain the north western part of Area 3B through a weakly incised plateau. Donalds Castle Creek catchment on this plateau is characterised by low topography, upland swamps and a numerous local unconfined shallow hillslope aquifers. Much of the local soil is derived from weathering of shale-rich Mittagong Formation and is more clayey and of lower permeability than residual soils developed purely on Hawkesbury Sandstone outcrop.

The south western area drains directly to Lake Avon via five small ephemeral creeks designated Native Dog Creek tributary No. 1 (‘ND1) and LA2, LA3, LA4 and LA5.

The geomorphology of tributary sub-catchments in Area 3B is typically characterized by upland plateau and a series of ‘benches’ comprised of catenary hill slopes and swamps enclosed in roughly crescent-shaped cliff lines.

The extreme upstream (southern) end of the catchment consists of a ridge containing a thin sandy soil profile accumulated on a generally dome shaped outcrop. This outcrop exhibits pronounced eluviation (removal) of the sandstone's kaolinite clay cement and is typically white and friable (Hazelton and Tille, 1990).

Drainage is to the north east and south west down slopes with little evidence of surface drainage channels. This is consistent with headwater hillslope aquifer zones and overland sheet flow during extreme storm events.

The upper reaches of Donalds Castle Creek are located in the northern part of Area 3B and in the western part of the proposed Area 3C. The headwaters of the creek will be directly undermined by the Area 3B proposed Longwalls 9 to 12.

Tributaries associated with Donalds Castle Creek (DC13) will also be undermined by the proposed longwalls in the northern region of the Area 3B SMP area (Longwalls 9 and 10). This Creek also flows in a northerly direction and ultimately drains into the Cordeaux River.

The natural gradient of the Donalds Castle Creek within the Study Area varies between a minimum of 10 mm/m and a maximum of 100 mm/m, with an average natural gradient of 30 mm/m (MSEC, 2012).

Wongawilli, Sandy and Donalds Castle Creeks are generally permanently flowing streams with small base flows and increased flows for short periods of time after each significant rain event.

Beds of the creeks are typically formed within Bulgo Sandstone, which overlies the Stanwell Park Claystone; however there are small sections of the headwaters of these creeks which are formed within the Hawkesbury Sandstone.

Wongawilli and Donalds Castle Creeks have been defined as areas of environmental sensitivity for the purposes of the SMP approval process.

Three distinct channel types may be recognised in the main channel uplands, and in the tributaries of Wongawilli and Donalds Castle Creek Catchments:

1. Narrow indistinct overgrown channels associated with low sedge/ heath type vegetation cover and a relatively thick sandy riparian soil profile. The streambed consists of weathered bedrock and/or sandy materials. This is the situation in which valley infill swamps may be found (refer **Section 2.3**).
2. Rock platforms of variable width which are usually smooth except for minor depressions on joint planes and occasional potholes. These platforms normally grade to a thinly vegetated sandy soil on both sides and usually exhibit the effects of chemical deposition of hydrated iron oxides. This deposition ranges from a slight colouration of the surface strata to intense replacement of the rock fabric.
3. Channels that are erosive into cross-bedded sandstone and exhibit a rough riffle like surface usually with accumulations of boulders and other sediments. These channels are usually bounded by solid rock outcrop.

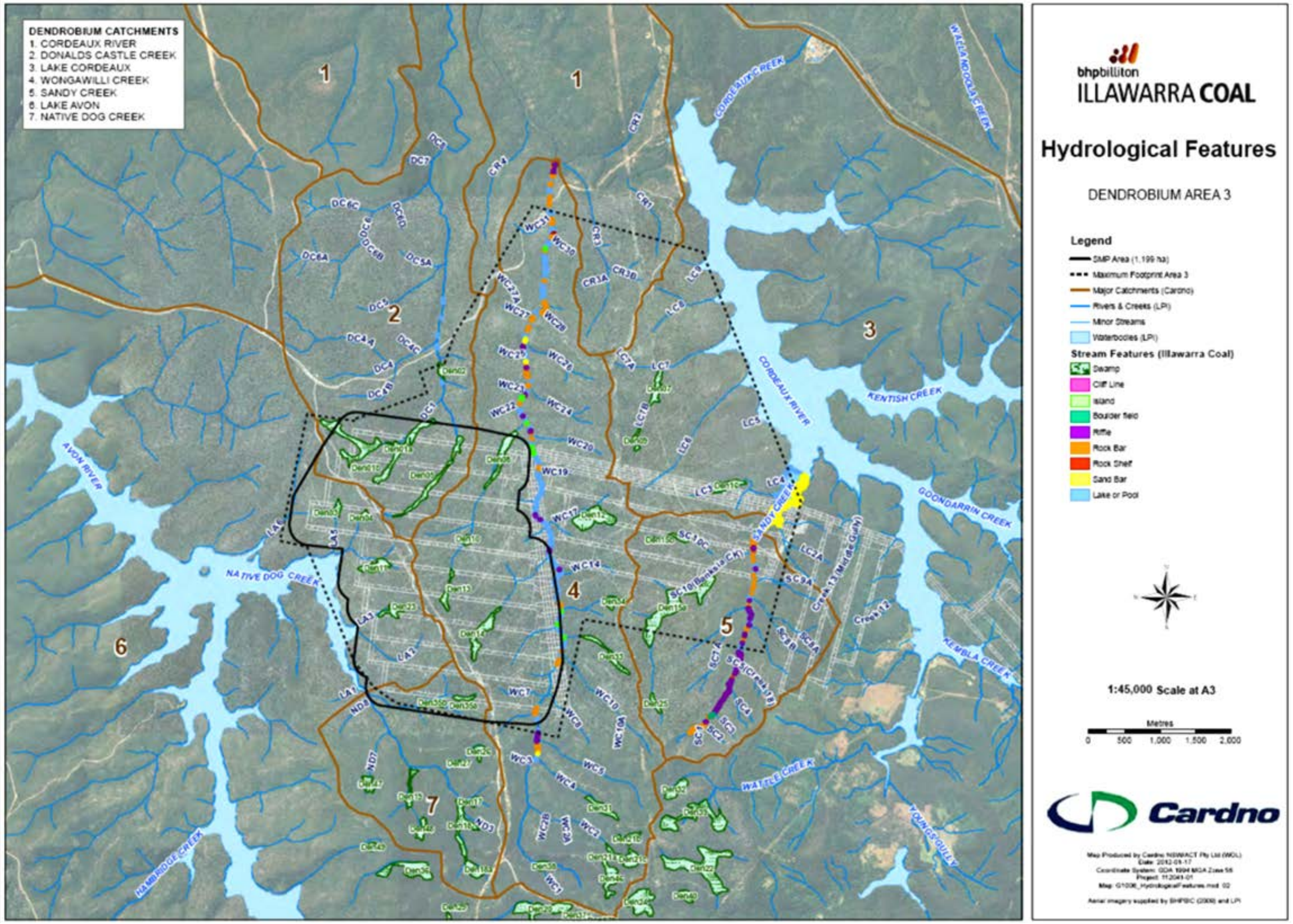


FIGURE 2.2: MAJOR CREEKS, TRIBUTARIES AND MAJOR CATCHMENTS WITHIN AND ADJACENT TO DENDROBIUM AREA 3

A number of semi-permanent pools may be found within the channels of these drainage lines and creeks. The mechanisms of pool stability are variable and uniquely depend on local stratigraphy, structure and gradient. Pools range from:

- Simple water accumulations in a depression in an impermeable bedrock shelf (analogous to a bathtub) that is fed by direct precipitation, seepage or flood events; to
- The other extreme which occurs within eroded sections of sandy sediment and a free water surface that is dependent on the local groundwater regime for stability.

A number of distinct pool types can be recognised:

1. Shallow, usually linear, small pools located in depressions formed by joint systems or cross-bedding and sometimes associated with potholes. Accumulated water is usually less saline than that in surrounding pools and probably has little interaction with the local groundwater system.
2. Linear pools associated with narrow erosion channels in sandy soil profiles. The soil profile is usually vegetated with heath/sedge like species. The downstream end is usually associated with a low rock bar or outcrop.
3. Larger pools constrained by a rock bar on the downstream end. These rock bars are usually significantly undercut by erosion and exhibit signs of chemical weathering.
4. Larger pools constrained mainly by sediments on the downstream end. The sediments may extend for a considerable distance downstream and are associated with valley infill channels described above.

These features are consistent with the observations of channel and pool morphology in Wongawilli Creek and its tributaries and in greater Donalds Castle Creek.

Pools within unconsolidated (sandy) sediments are in a state of equilibrium between water in (from a higher part of the phreatic groundwater surface either upstream or laterally) and water out (flowing down the phreatic surface). These pools are usually embedded in a valley infill or braided stream swamp (refer **Section 2.5** below).

Most bedrock pool levels and associated riffle complexes rely on equilibrium between excess water in and minimal water out. If the water inflow is less than the outflow then the pool level declines. The nature of this equilibrium is ultimately dependent on the position of the pool on the overall stream gradient.

Many pools in the streams are permanent and naturally develop at the creek rock bars and at the sediment and debris accumulations. The locations of stream features in the Wongawilli and Donalds Castle Creek catchments are shown in **Figures 2.3, 2.4** and **2.5**.

Such pools are important ecologically as they constitute the only viable aquatic ecosystems within these catchments. Hydrologically, apart from tree canopy water storage which is comparatively minor, they also constitute the only important depression storages i.e. storages holding water against the force of gravity in these catchments.

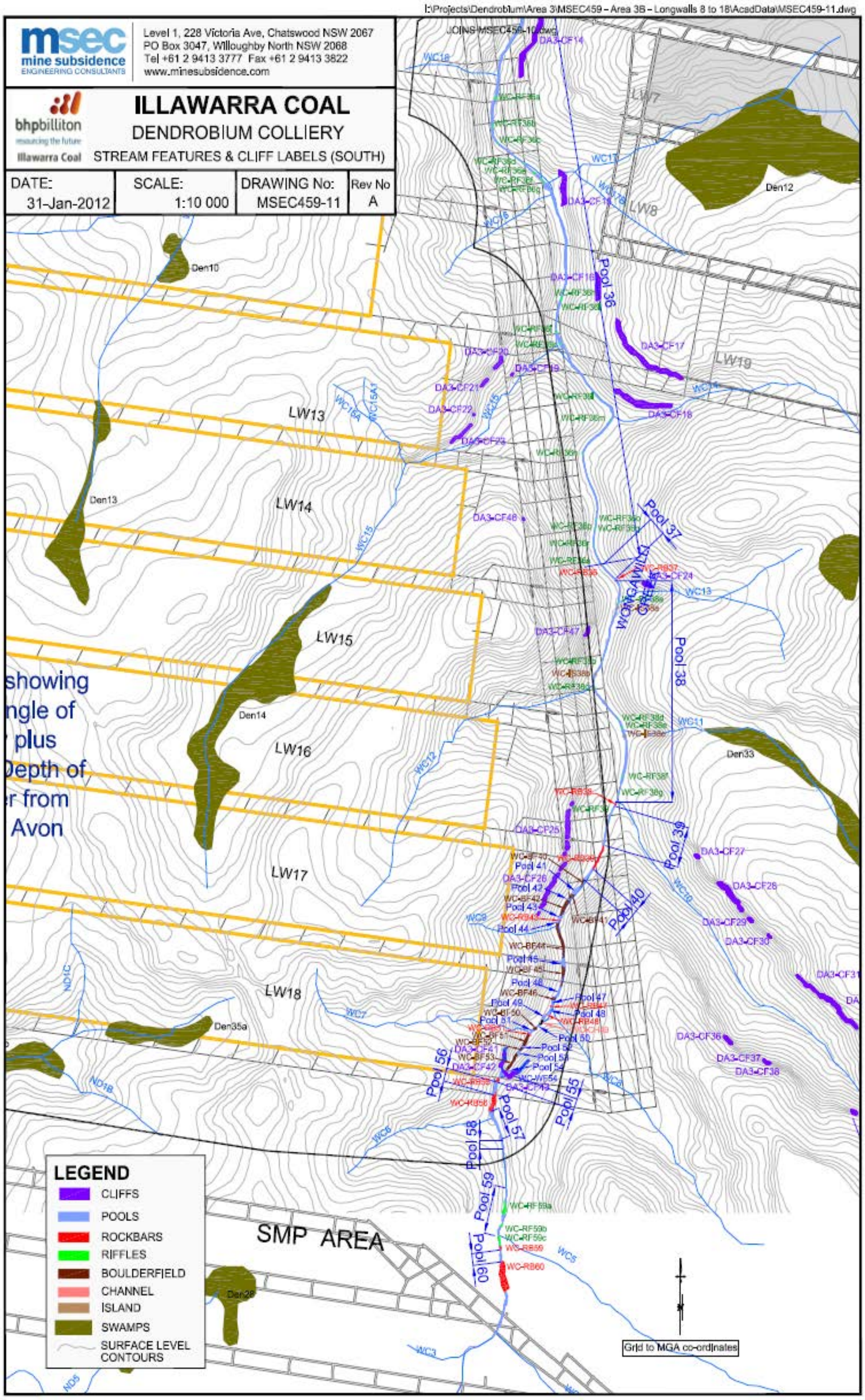


FIGURE 2.3: STREAM GEOMORPHIC FEATURES ALONG WONGAWILLI CREEK SOUTH

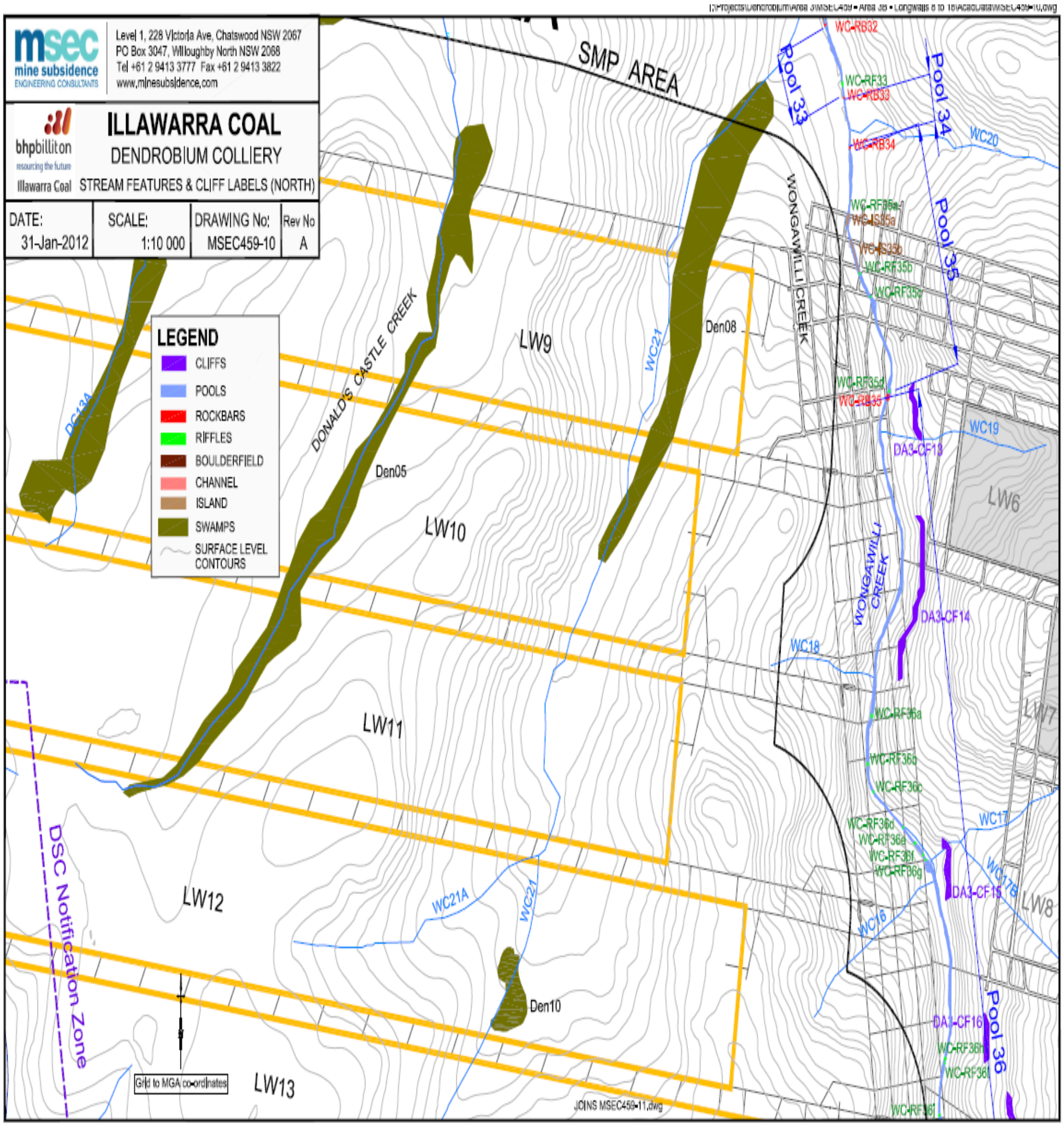


FIGURE 2.4: STREAM GEOMORPHIC FEATURES ALONG WONGAWILLI CREEK NORTH

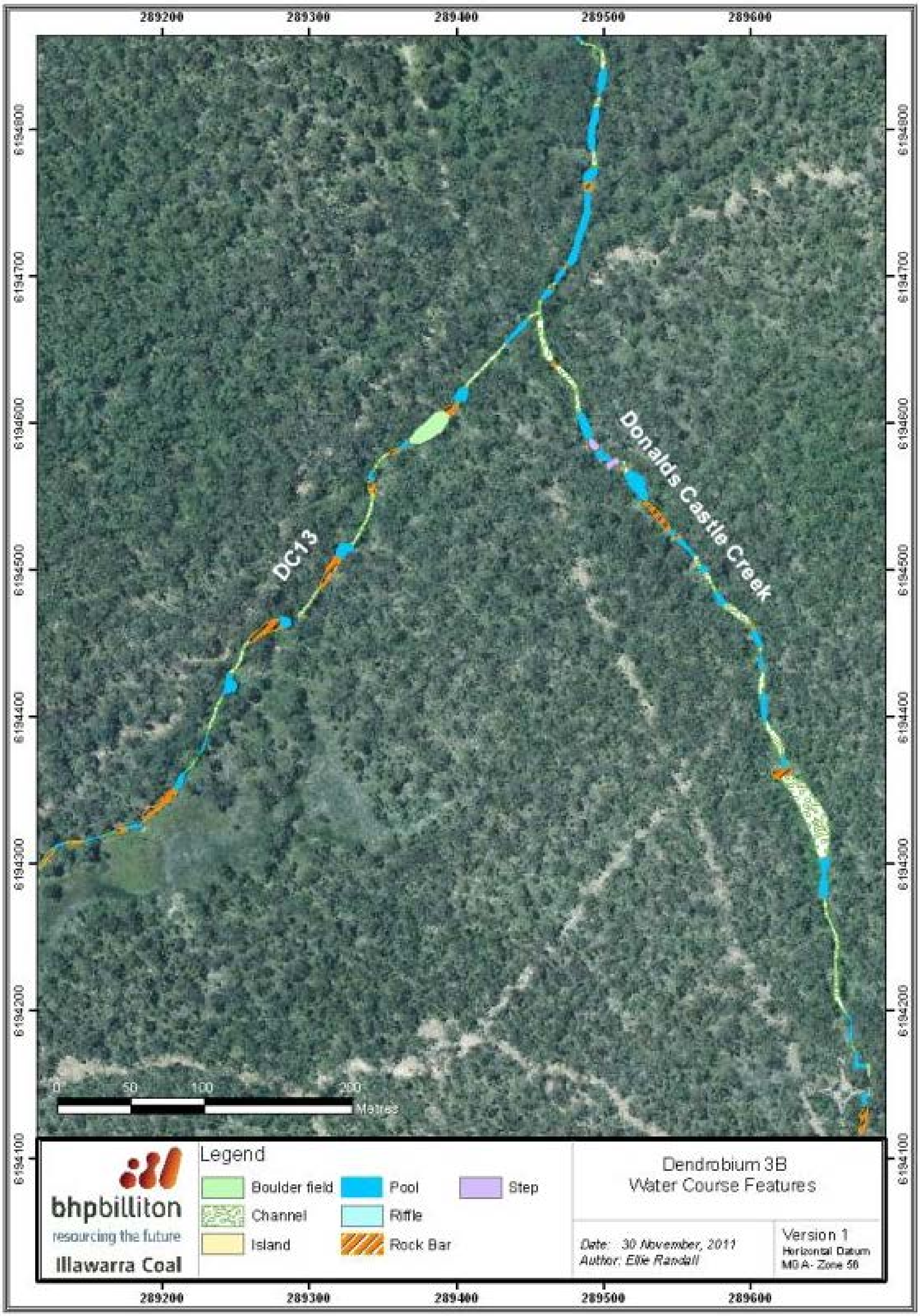


FIGURE 2.5: STREAM GEOMORPHIC FEATURES ALONG UPPER DONALDS CASTLE CREEK

The surface topography of Dendrobium Area 3B and the proposed longwalls within the Area 3B SMP Area are shown in **Figure 2.6** below, taken from MSEC, 2011.

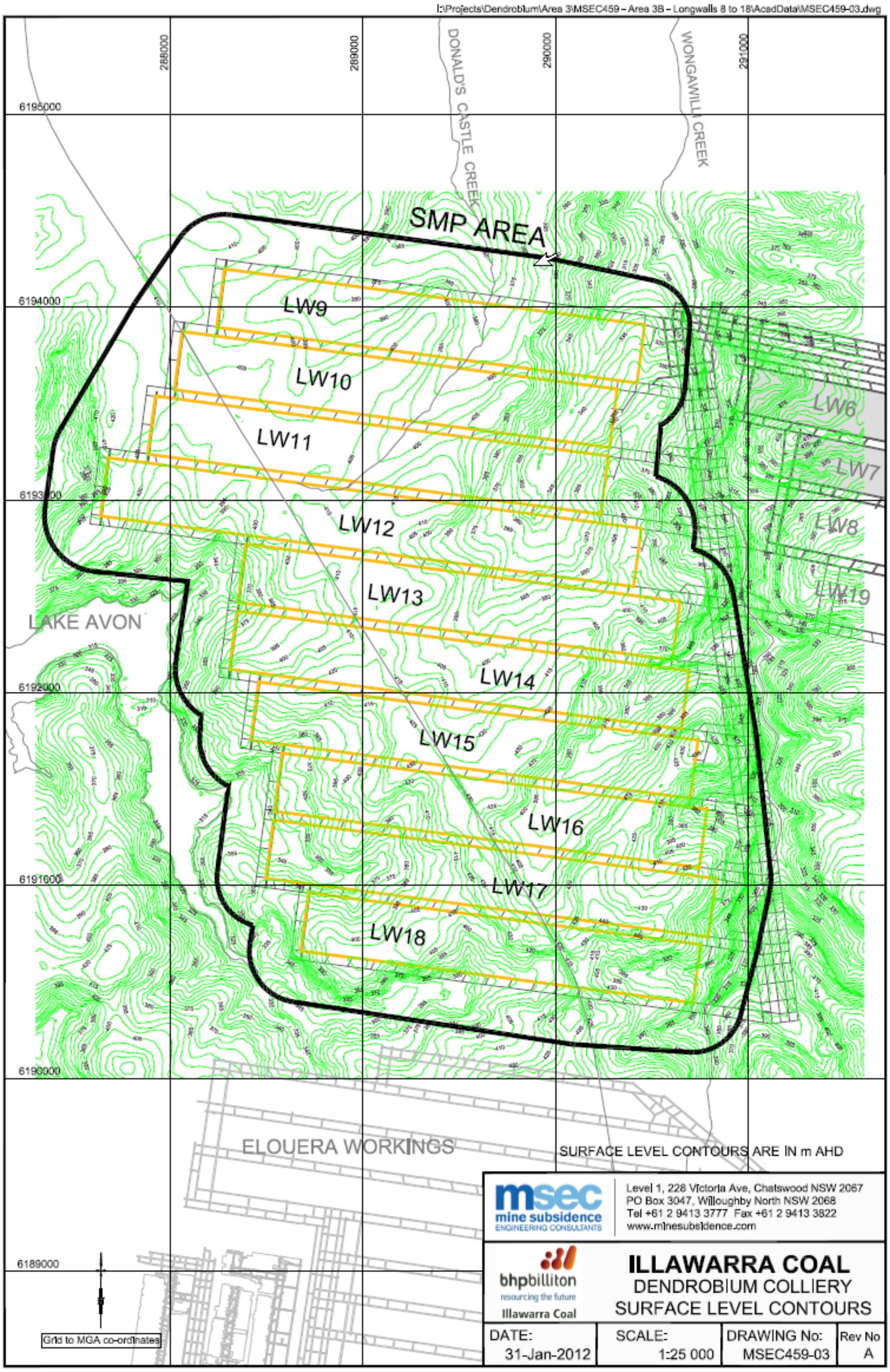


FIGURE 2.6: SURFACE CONTOURS IN AREA 3B GENERAL SMP AREA

Dendrobium Area 3B comprises Longwalls 9 to 18. Area 3B does not longwall mine directly beneath Lake Avon. The commencing ends of Longwalls 11 to 18 are located within the Dams Safety Committee (DSC) Notification Area for Lake Avon, the boundary of which is designated by the purple dashed line in **Figure 2.7**.

The longwalls lie a minimum distance of 230 m east (Longwall 16) of the Native Dog Creek arm of Lake Avon at their closest point to the full supply level of the reservoir (MSEC, 2012). The longwalls are also located west of Wongawilli Creek, which is a distance of 75 metres away at its closest point (to Longwall 18).

Figure 2.7 below taken from MSEC (2012) also shows the general layout of the ten longwalls of Area 3B indicating the extent of the General SMP Area.

The Area 3B longwalls largely underlie an undulating plateau draining eastward to Wongawilli Creek, northward to Donalds Castle Creek and westward to Native Dog Creek and Lake Avon. A number of natural landscape features (tributary creeks of the above draining small valleys and swamps) have been identified in the vicinity of the proposed longwalls which, in so far as they relate to water quality issues are described in detail in **Section 3** of this report.

The surface of the Area 3B SMP Area consists largely of a ridged and undulating plateau oriented north-south (dipping generally to the northeast) lying transversely over all Longwalls 9 to 18, terminating at its northern end by two major gullies containing Donalds Castle Creek and Wongawilli Creek tributary WC21.

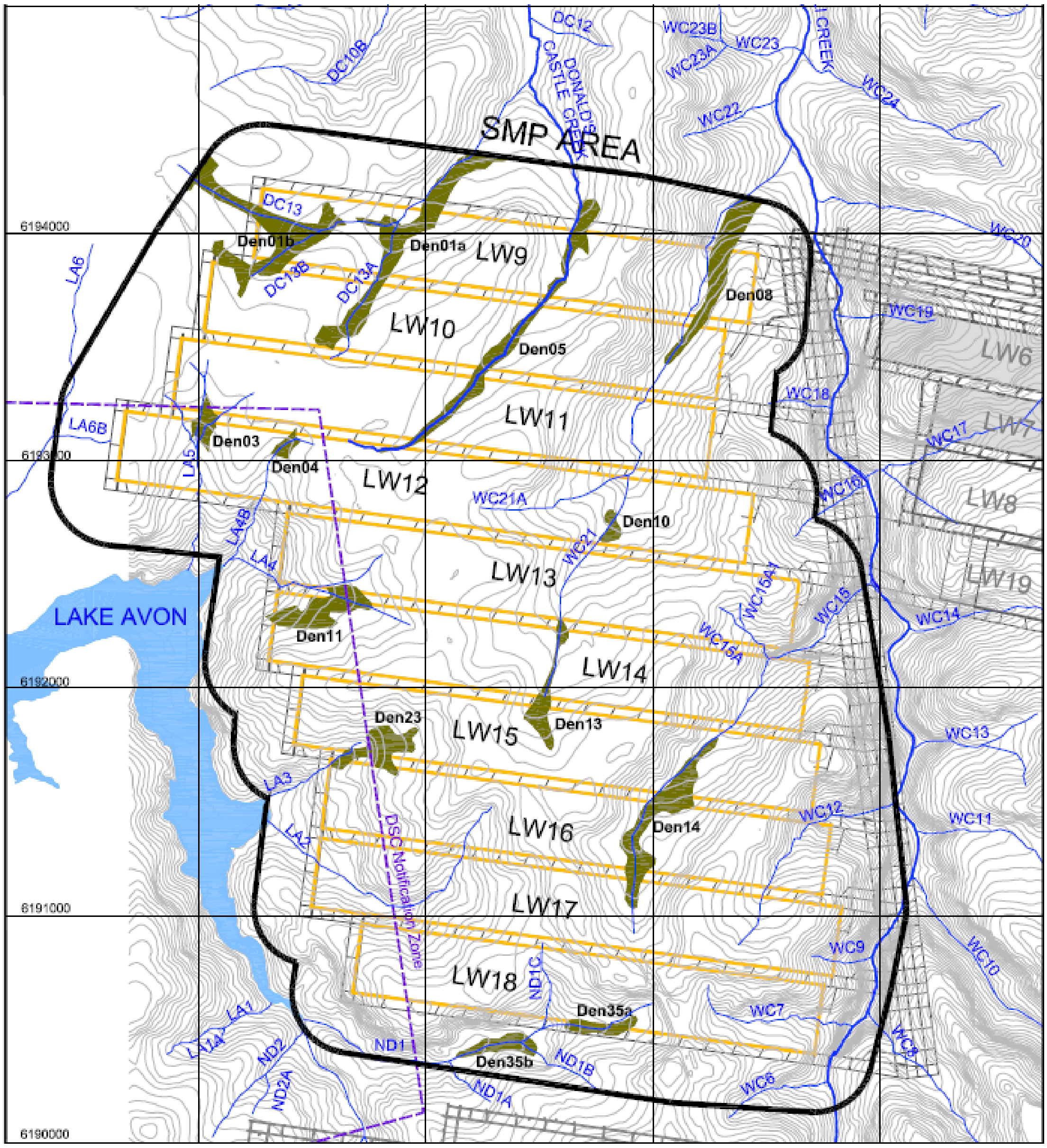


FIGURE 2.7: AREA 3A SHOWING PARTICULAR NEAR AND FAR FIELD SURFACE WATER FEATURES

2.4 SOILS

Almost the entire surface of Area 3B is founded on highly weathered Hawkesbury Sandstone outcrop and Sandstone derived-soils. The ridge and uplands in the west of the Area between Wongawilli Creek catchment and the Native Dog Creek Arm of Lake Avon are partly mantled by Mittagong Formation-derived soils (overlaid on Hawkesbury Sandstone).

The five major soil landscape types which appear in Area 3B (**Figure 2.8**) as described in DNR (2006) are:

1. Penrose Variant A (code ERpea) type developed on the moderately steeper 10 – 20% slopes of Hawkesbury Sandstone.
2. Hawkesbury (code COha) type developed on very steep slopes of Hawkesbury Sandstone of greater than 25% within creek main valleys and lower sections of tributaries.
3. Lucas Heights (code REh) developed on gentle undulating crests, ridges and plateaus of slope <10% on Wianamatta Shale or Mittagong Formation (the latter being a thin mixed sandstone/shale sequence lying between the Wianamatta Shales and Hawkesbury Sandstone) derived soils.
4. Gymea (code ERgy) developed on Hawkesbury Sandstone undulating to rolling low hills with local relief 20 – 80 m and moderately steep slopes of 10 – 25%.
5. Stockyard Swamp (code SWss) developed on flat low relief areas of Hawkesbury Sandstone of slopes generally <2%.

Colluvial soil landscapes formed on Hawkesbury Sandstone develop on steep slopes and ridges and are generally classified as belonging to the Hawkesbury soil landscape group. These are characterised as discontinuous Lithosols, yellow earths, localised red and yellow podsols and siliceous sands (Hazelton and Tille, 1990).

Erosional landscapes developed on Hawkesbury Sandstone are classified as belonging to the Penrose Variant A or Gymea soil landscapes groups. These form on valley side slopes (10 – 25% slope) with narrow to wide outcropping sandstone rock benches (Hazelton and Tille, 1990; DNR, 2006). Soils developed in this landscape are characterised as yellow earths, earthy sands, siliceous sands and leached sands. Sandy clay and medium clay occurs as subsoil on shale bedrock. These soils types are generally shallow and highly permeable with a high soil erosion hazard.

The clay component of these soils types reflect the variable lithology of the Hawkesbury Sandstone where up to 20% of the rock mass is comprised of clay matrix and localised, discontinuous outcroppings of shale lenses (Herbert and Helby. 1980).

Penrose Variant A, Hawkesbury and Gymea soil landscapes are all considered to produce soil pHs that are strongly (pH 4.0) to slightly acid (pH 6.0). This is consistent with the general pHs of the major creeks which have exhibited natural pHs in the strongly (pH 4.0) to moderately acid (pH 5.5) ranges (Ecoengineers, 2003, 2004a, b, 2005a, b, c, 2006, 2007a, c). **Figure 2.9** below provides a surface soil map of Area 3B.

It is noted that Hawkesbury and Gymea soil landscapes are considered to have Extreme and High to Extreme erosion susceptibilities to concentrated flows respectively and it is in slopes where these soils occur where any mine subsidence effects on slope stability such as cracking may be expected to lead to sheet erosion after bush fire or rilling and gully erosion on unprotected tracks and fire roads.

Figure 2.10 below from MSEC (2012) identifies the cliffs and steep slopes in the Area 3B General SMP Area and adjacent to it.

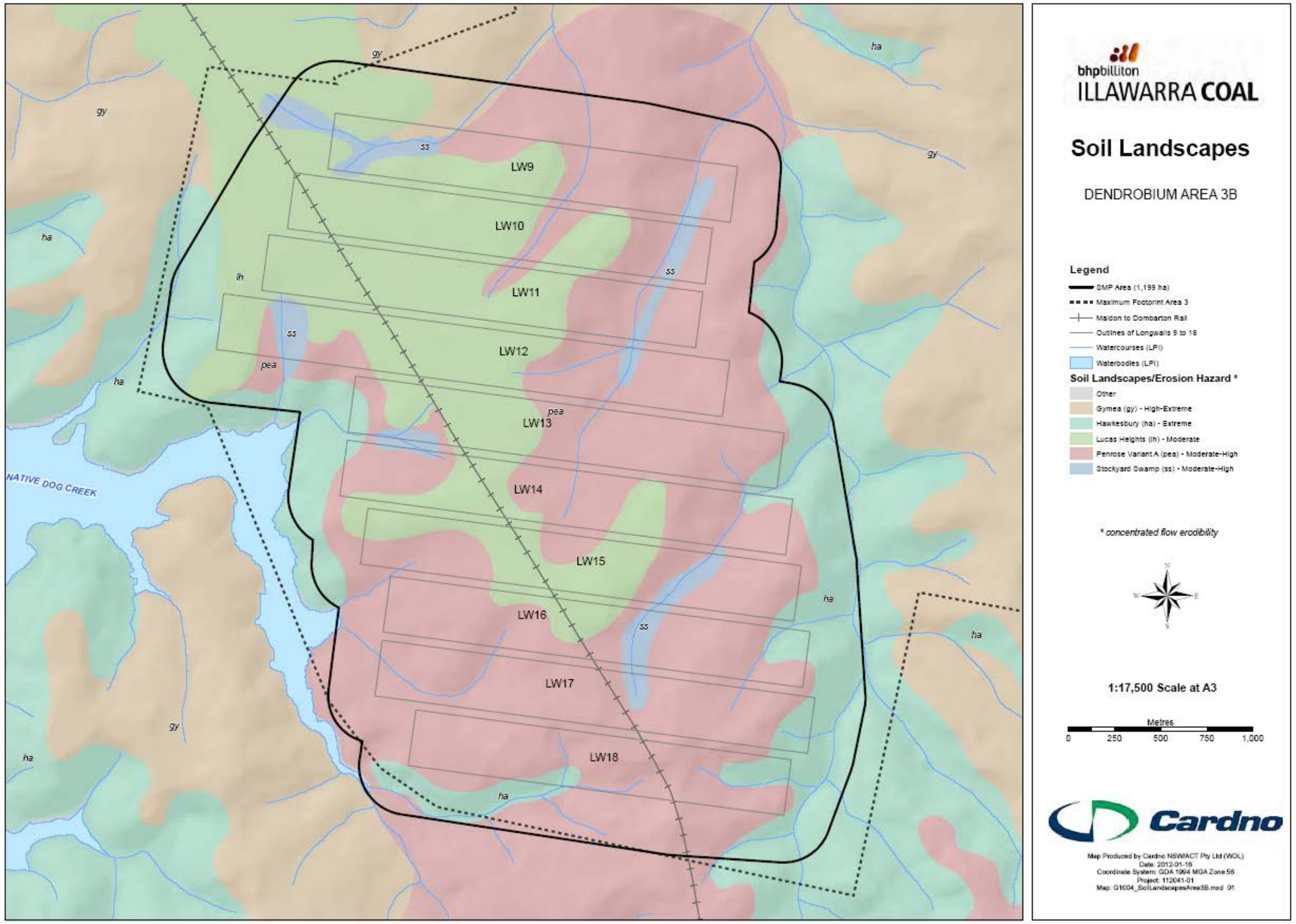


FIGURE 2.9: SOIL LANDSCAPES OF AREA 3B

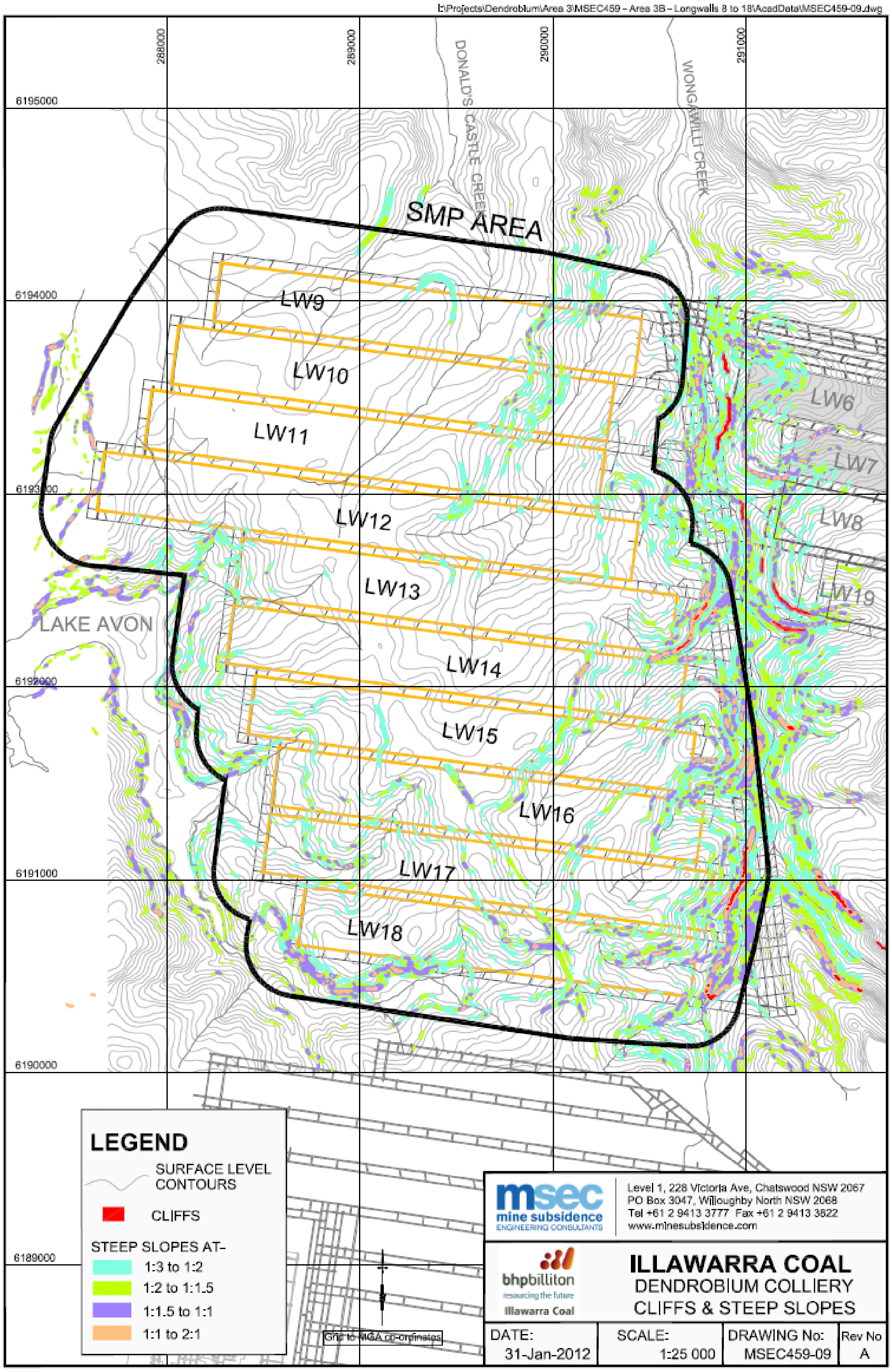


FIGURE 2.10: CLIFFS AND STEEP SLOPES IN THE ENVIRONS OF AREA 3A

It can be seen that there are significant areas of steep slopes along the western side of Area 3B draining to Lake Avon where the soils are of the Lucas Heights soil type developed on Mittagong Formation shales.

2.5 NEAR-SURFACE HYDROGEOLOGY

Almost all of the central plateau and ridgelines over Area 3B and the dissecting gullies and upper slopes are based on Hawkesbury Sandstone outcrop. The Sandstone consists of intercalated fine to very coarse grained sandstone beds, usually separated by bedding planes and paleo-erosion surfaces. Minor siltstone and mudstone bands and lenses are often recognised in outcrop.

The highest permeabilities are expected in a horizontal direction, usually along bedding planes. Vertical migration is dependent on the local vertical permeability (variable through the Hawkesbury) and on the horizontal surface area of ‘leakages’ between adjacent stacked strata but is not insignificant, particular closer to the edges of cliff lines and benched escarpments where vertical fracturing causing by tilt effects causing natural valley closure, perhaps enhanced by past tectonic events provides vertical conduits for groundwaters migrating down gradient.

Springs or seeps deeper on the gullies are expected to be concentrated in areas of outcrop of palaeoerosion surfaces or bedding planes within the Lower Hawkesbury or between the Hawkesbury, Newport and Garie Formations. These seeps identify zones of higher horizontal permeability. Springs or seeps are usually associated with pronounced deep chemical weathering, chemical precipitation and deposition and the formation of cavernous zones within cliff line features.

Where perched water storages appear to exist, they are most likely to be hydraulically supported by a broader scale semi-confined (unconfined above, confined below) hillslope aquifer or groups of such shallow aquifers residing in the soils developed on Hawkesbury Sandstone, and in bedding planes and natural fractures of the Sandstone.

Numerous hydrological modelling exercises for Area 3A Longwalls 6, 7 and 8 Wongawilli Creek, and Donalds Castle Creek catchments (see **Table 3.1**) for the purposes of establishing pre-mining baseline hydrologic characteristics and then subsequently for assessing hydrologic effects of mining indicate hillslope aquifers are very common within Area 3B (Ecoengineers 2006b, 2010b, 2011 and 2012a)).

Please refer to **Appendix B** for a detailed explanation of this reasoning. The basic systematic mathematical features of such hillslope aquifers and how they relate to hydrologic modelling of the catchments are discussed in detail in **Appendix B**, **Sections B3 and B4.**

Hydraulic gradients in any hillslope aquifers within Area 3B will invariably be:

- along the western side of Area 3B southwest towards Lake Avon;
- in the headwaters of Donalds Castle Creek towards the north, and
- within sub-catchments of Wongawilli Creek towards the main channel of the Creek.

Issues surrounding deep groundwaters within Areas 3A and 3B were investigated, assessed and reported by Heritage Computing (2011) and Coffey Geotechnics (2012) respectively.

Those studies found that Hawkesbury Sandstone groundwater heads were generally unaffected by the mining of Longwall 6 or concurrent development headings. There was one exception at Bore S1889 (DEN97) over Area 3A Longwall 7 where 25 m drawdown in the lower Hawkesbury Sandstone was observed during the passage of Longwall 6, but the head in the upper Hawkesbury Sandstone was unaffected.

2.6 SWAMPS

The surface area above the proposed Dendrobium Area 3B coal extraction is characterised by a series of drainage basins separated by steep ridges. These basins drain into Wongawilli Creek, Donalds Castle Creek and directly into Lake Avon. A knowledge of the interaction between the water infiltration mechanisms of the surface sediments (on ridges, slopes and depressions), the water storage capacity of the sediments and the water transmission properties of the sediments, the underlying strata and the surface water system is essential to an understanding of any potential surface effects of longwall mining beneath this area. The measurement of local free water pressure within the sediments is a practical method of monitoring these properties and potential changes in these properties.

Swamps in Area 3 have been mapped and numbered by IC. **Figure 2.11** below**,** courtesy of Cardno Forbes Rigby, shows the general layout of the entire Area 3, and identifies all key swamps within Area 3 in the context of the creek tributary drainage lines with which they are associated. IC's simple numbering system for identifying the swamps is used throughout this report.

Upland swamps of the Woronora Plateau are well known to be resilient ecosystems of the landscape. They have been shown in some cases to contain sediments dating from the Late Pleistocene and throughout the Holocene which provide a carbon-14 record of the history of swamp development spanning in excess of 10,000 years. Analysis of the sedimentary record in three such swamps was undertaken as part of a collaborative research project between Macquarie University and SCA to determine the depositional and erosional chronology, develop an understanding of swamp dynamics and assess the causes or triggers of erosion including the current episode of erosion seen in several swamps (Tomkins and Humphreys, 2006).

Tomkins and Humphreys (2006) found that the swamps are formed through the accumulation of sands sourced from the catchment combined with the growth of organics, tending to peat at various times, and are governed by high water tables and moist conditions. The swamps appear to grow and blanket the surrounding hillslopes masking the underlying bedrock and/or colluvium.

Infilling of swamps is in some cases occasionally interrupted by brief periods of erosion. Erosion appears to commence through the formation of scour pools in the swamp surface which can become progressively channelized to form a continuous gully. Swamps on the Woronora Plateau also show evidence of event-based erosion via the formation of scour pools in the surface which can become progressively channelized to form continuous gullies dissecting the swamps.

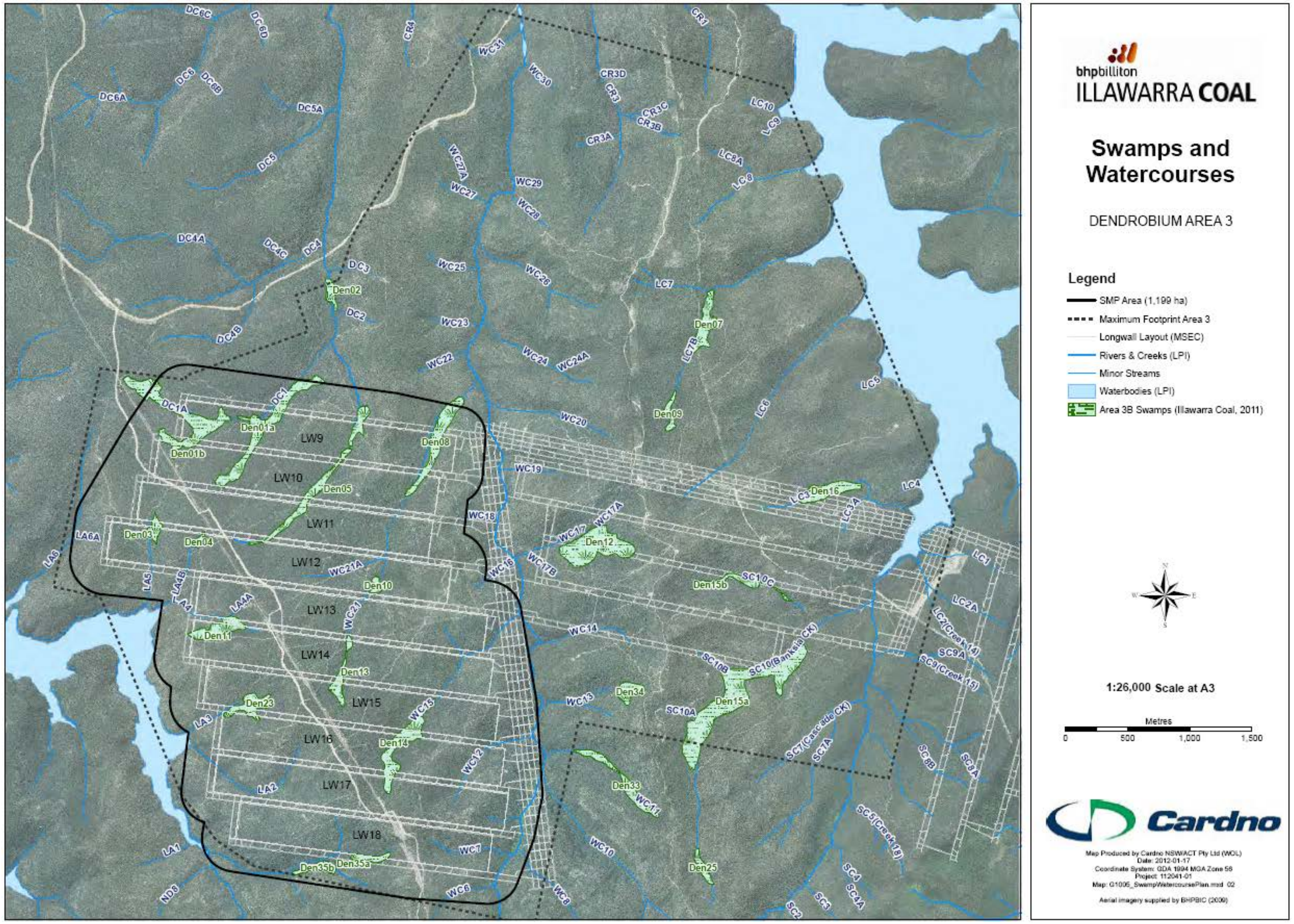


FIGURE 2.11: MAPPED SWAMPS IN AREA 3

However, the controls on formation of scour pools are still unknown. Once the scour pools are formed, the dominant erosional processes are knick point retreat (through over-steepening in the swamp surface or channel bed), linking of scour pools to form a continuous gully and, undercutting and collapse of the gully sidewalls leading to widening. Sediment generated through gully erosion is deposited on the swamp surface downstream as a sand splay or transported beyond the swamp.

Gully erosion removes a narrow slice of sediments, rather than the whole swamp, but nonetheless can result in the rapid release of a large volume of sediments into the reservoirs downstream. The formation of the scour pools is a critical indicator of likely future gully erosion in the swamps. The trigger(s) and controlling factors of the scour pools including intrinsic thresholds are unknown but warrant further investigation. Extreme rainfall events (>700 mm of rainfall over several days), were considered a likely trigger of the scour pools.

The events in the modern record, however, occurred after formation of the scour pools and in some cases after commencement of gullying in the swamps so Tompkins and Humphreys (2006) concluded that it is not possible to draw any firm conclusions on thresholds of rainfall magnitude or intensity which would induce scour.

This finding would appear to be at odds with the findings of Earth Tech (2005) who found from a literature review that scour and incision may be initiated in fully vegetated, intact swamps of this type when shear stress exceeds about 240 N/m^2 and stream velocities exceed about 2.2 m/s.

Earth Tech (2005) also showed that these swamps will most likely remain intact if shear stresses of 200 N/m^2 are not exceed in events up to and including the 100-year ARI event. The change in grade that might result from mine subsidence is higher (as a percentage) in relatively low gradient swamps and this may conceivably induce excessive shear in these circumstances.

Therefore the swamps at risk from scour and erosion as a result of longwall mining are those in which the stream is of a high order (i.e. high flow and low gradient), have poor vegetation condition (e.g. from bushfire damage), and where the longwalls lie perpendicular to the long axis of the swamp.

Tomkins and Humphreys (2006) concluded that wildfires can lead to further erosion in swamps where gully erosion is already underway. At least two of the swamps they investigated (which are not in Area 3) showed knick point retreat following the 2001/2002 fires despite relatively low magnitude rainfall events. The sensitivity of the swamps to erosion after fire suggested that the fire has a significant effect on surface roughness and runoff velocities. This is in contrast to un-eroded swamps where the scorched vegetation can recover more quickly given favourable growing conditions.

They also concluded that human disturbance in the catchment, particularly direct physical disturbance as had occurred by drilling operations on Flying Fox Creek in the Avon Catchment, was an important trigger of erosion of swamps.

Tomkins and Humphrey (2006) have stated that; “dewatering of swamps through mine subsidence may play a role in increasing the sensitivity of swamps to external forces such as fires and extreme rainfall events”.

The surface above the proposed coal extraction is composed largely of weathered Hawkesbury Sandstone outcrop and a variable cover of sandy sediment derived from it. The Hawkesbury Sandstone is composed of quartzose to lithic sandstones deposited originally in a fluvial environment. Individual strata are characterised by cross-bedding and localised erosion zones. Lateral correlation of individual strata is difficult. Weathering is an in-situ process that is accelerated by wetting and drying cycles within the intact rock. Weathering of the original matrix is the major process with lithic and clay particles weathered and dissolved. This process produces soluble products that are incorporated into the water system. These products are detected by water quality sampling within routine surface water study programs. Dissolved iron (and other) salts are transported within reducing conditions within the subsurface and are typically precipitated by oxidation when subjected to mixing with groundwater high in dissolved oxygen or on contact with the atmosphere.

Accumulations of carbonaceous material (peat) are a product of *in situ* accumulation of vegetable matter and/or vegetable matter washed from the slopes into depressions during rain events. Vegetable matter is converted into carbonaceous material by chemical processes requiring a wet and reducing environment. Carbonaceous material is invariably mixed with inorganic debris, usually sand, and more rarely, silt or mud size fragments.

It is postulated that the sediment cover can be subdivided into:

1. Broad ridge lines with a variable sediment cover, usually characterised by *in situ* weathering and an indistinct contact with the underlying unweathered rock. These zones provide infiltration and recharge vertically to the underlying rock strata and laterally to the hillslope sediment system.
2. Erosive zones composed of outcrop with a thin sandy cover in places. These zones are characterised by steep slopes and are mainly zones of direct run off.
3. Hillslopes and hillslope depressions exhibiting *in situ* weathering, shallow sediment cover, fluctuating water table with transport of free water immediately above bedrock allowing both recharge to, and discharge from, the underlying bedrock. These zones are characteristically composed of red/orange mottled material (oxidation) with an indistinct contact with underlying rock.
4. Areas marginal to depressions (upland swamps). These areas are subject to a fluctuating water table and therefore periodic oxidising conditions.
5. Sediment accumulations within depressions (upland swamps). This environment is mainly wet and is characterised by:
    a. carbonaceous accumulations;
    b. eluviation of clay material producing zones of clean (usually) quartzose sand with some small pebbles and distinct zones of finer clay rich material;
    c. a distinct sediment base and (often) iron oxide accumulation within the upper veneer of the underlying bedrock.

The sequence is usually part of a series of inter-fingering lobes of sediment that are difficult to correlate laterally. Auger holes provide a local section through a complex 3D sequence.

Monitoring of shallow groundwater levels allows for the indirect monitoring of water storage and transmission parameters within the saturated part of hillslope/upland swamp complexes. Shallow groundwater monitoring can be carried out prior to coal extraction to provide catchment baseline data, during longwall extraction to identify potential changes in these parameters due to mining activity and for a period following mining to show any recovery of the system if impacts were observed. This permits an understanding of hillslope water transmission, water storage and instantaneous and long term water yield to be gained.

The employment of a shallow groundwater monitoring program is also useful for identifying the contribution of storage/seepage from the Hawkesbury Sandstone ridge strata, providing insight into the location of potential future monitoring points to identify water quality changes and to further investigate the role of carbonaceous material/peat in the long term water storage and baseflow characteristics of upland swamps.

There is a large body of work and conclusions from the numerous studies of upland swamps on the Woronora Plateau (e.g. Young, 1986a, b; Keith, 1993; Mooney, 1994; Cary and Morrison, 1995; DLWC, 2002; Tomkins and Humphrey, 2006; Keith et al., 2006; Ross, 2009 etc.).

Before discussing this issue, it is first necessary to clearly differentiate upland swamps into (at least) two types, which would usually be expected to exhibit distinctly different types of potential susceptibility to the effects of mine subsidence as follows:

1. Valley infill swamps lie within well defined streams where there is a potential for scour of the sandy substrate of the swamp(s) above a certain stream power threshold. The changes in grade that may result from mine subsidence are only likely to induce excessive shear in relatively low gradient swamps. Therefore the swamps at risk from scour and erosion as a result of longwall mining are those in which the stream is of a high order i.e. high flow but low gradient, has poor vegetation condition e.g. from bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.
2. Headwater swamps occurs within broad, relatively low slope areas e.g. upper Donalds Castle Creek area in Area 3B, in which the available evidence shows substantial unconfined hillslope aquifers occur within the Hawkesbury Sandstone and play a significant role in sustaining the swamps and the hydrology of the catchment in which they are located.

The available data indicates that the hydrologic setting of the swamps can be summarised as:

- Fire is a major and relatively frequent disturbance of these swamps and is an important factor in their diversity, structure and floristics (Keith, 1991; Mooney, 1994; Cary and Morrison, 1995; Keith et al., 2006 2007).
- Many have significant topographic and hence piezometric gradients.
- Sporadic excesses of precipitation over evapotranspiration (ET) proportionally sustain these swamps long-term (Hatton and Evans, 1998).
- While the swamps of the form seen today perhaps existed since the Late Pleistocene (Tomkins and Humphrey, 2006), they are located on Triassic sandstone terrain subjected to the weathering effects of numerous wet

glacial and dry interglacial cycles throughout the Pleistocene and far wetter conditions than either the Pleistocene or Holocene in the Late Pliocene. Such weathering invariably leads to loss of the cementing siderite, fine quartz and kaolinite in the Sandstone and other permeability-increasing effects. It has been claimed that swamps can be 'dewatered' through one or more 'fractures' of their bases e.g. induced by mine subsidence. This is largely based on a view that swamps have essentially impermeable bases. This has never been proven by one or more quantitative water budget study over the last 25 years or so. Headwater swamps are unlikely to be 'dewatered' or 'desiccated' through any fracturing of bedrock beneath the swamp because these swamps do not actually reside on a widely unweathered 'impermeable base' (e.g. Ross, 2009). It has been demonstrated that a headwater swamp, namely Swamp 18A above Elouera Colliery Longwalls 9 and 10 is sustained by groundwater seepage into it from a local unconfined aquifer based on four paleo-erosional surfaces in the surrounding Sandstone (IC, 2004). Catchment water balances which accurately account for evapotranspiration (ET) and non-linear groundwater responses, even for catchments down to the <1 km^2 scale containing significant swamps confirmed the substantial permeability of such terrain (Ecoengineers, 2010, 2011, 2012).

- Broad zones of desiccation or dieback in well vegetated upland swamps of either type subject to mining induced subsidence were not detected anywhere in the Woronora Plateau over a period of drought and several major wild fires (Earth Tech, 2003).
- Extensive water quality monitoring within and immediately downstream of swamps in recent years, including in locations where longwalls which mined directly under headwater swamps, has also never detected any geochemical effects from mining subsidence within or immediately down gradient of swamps of either type indicative of the cracking of a 'tight' impermeable sandstone bedrock which by definition should contain unweathered marcasite and hence release low pH water with elevated levels of sulfate, nickel and zinc upon fracturing (Ecoengineers, 2006a, 2007a, d, 2010b, 2011a, 2011b, 2012a).

2.7 CATCHMENT HYDROLOGY

Nine hydrographic gauging stations were installed by HCS for IC in the sub-catchments of the Wongawilli Creek, Donalds Castle Creek and Sandy Creek catchment areas in Dendrobium Area 3 between November 2007 and April 2008.

Two gauging stations had to be repositioned and reconstructed due to the failing of small weirs during major storm events in early 2008 but all stations remain operational to the date of this report.

Of relevance to both Area 3A and 3B are two HCS gauging stations which monitor outflows from sub-catchments of the Wongawilli Creek catchment thereby providing:

- Greater Wongawilli Creek Catchment (WWL; HCS gauging station number 300022 located at Fire Road 6), which has a catchment area of 20.026 km^2;

- Upper Wongawilli Creek Catchment (WWU; HCS gauging station number 300024), which has a catchment area of 3.211 km^2, and
- Lesser Wongawilli Creek Catchment (i.e. WWL flows minus WWU flows; HCS station numbers 300022 and 300024, respectively), which has an effective catchment area of 20.026 – 3.211 = 16.815 km^2.

Area 3B has also had another pre-existing HCS gauging station since December 2007 which is located just north of Fire Road 6 which monitors outflows from Upper Donalds Castle Creek (DCU; HCS gauging station number 300023) with a catchment area of 6.219 km$^{2.}$

These gauging stations record instantaneous flow rates every 15 minutes and computes average flow rates (ML/day) every six hours. The data is then converted into daily flows using the usual HYDSTRA hydrographic data management utility software.

It is important to appreciate each of these gauging stations measures stream flow only up to some upper flow limit of validity dictated by the size and location of each controlling rock bar or small weir, above which high storm flows overtop and/or pass around the rock bar or weir. Flow rates above that limit are equivalent to gaps in the monitoring record, by definition forcing the necessarily continuous RUNOFF2005 modelled period to terminate before them and/or commence after them.

It is also important to note that where streams are ephemeral (i.e. their base flows decline to zero) this also produces data gaps in the hydrographic record, again forcing the RUNOFF2005 modelled period to terminate before them and/or commence after them.

HCS also installed the ‘Dendrobium Area 3 Centroid Rainfall’ pluviometer (HCS station 300027) in October 2007 and this has been providing daily rainfall data since 1 November 2007 as well monthly rainfall tritium data since January 2010.

Hydrologic modelling is undertaken in catchments before, during and after mining for the purpose of comparison and assessment of the hydrologic effects of mine subsidence. As with Longwall 5 Area 2 and Longwalls 6, 7 and 8 in Area 3A the hydrologic modelling and assessment proposed for Dendrobium Area 3B will focus on quantitative assessment of the significance of any changes in:

1. The reservoir coefficient describing the sum of detained overland flow and temporarily perched interflow or return flow (known collectively as ‘quickflow’) through catchment soils.
2. The unconfined (above) groundwater reservoir coefficient contributing to baseflow.
3. A catchment water balance over some defined period of assessment.

The groundwater reservoir is modelled in terms of a generalised hydrologic equation for a groundwater reservoir that takes into account the time-variable nature of resistance to drainage. This enables catchments that had potentially been affected by longwall mining to be correctly compared with other similar, unaffected catchments over defined periods according to a mathematical framework. This in turn enables estimation of the magnitudes of key hydrologic parameters and allow assessment of their possible change over time e.g. as associated with repressurisation, sealing or in-filling of any fracture network or man-made remedial effects.

The RUNOFF2005 hydrologic model which has been used for the hydrologic assessments of the impacts of above-noted longwalls (Ecoengineers, 2006b, 2010, 2011, 2012) will also be employed for the proposed longwalls of Area 3B.

A detailed description of the adopted hydrologic modelling framework and discussion of the key issues relating to monitoring-for, detection and assessment of hydrologic effects of longwall mining in Dendrobium Area 3 is given in **Appendix B**.

2.8 BASELINE WATER QUALITY CONTEXT

The pHs of upland streams within Hawkesbury Sandstone in the Study Area (and more widely) are invariably well below the default trigger value of 6.5 for upland rivers in southeast Australia given in the national water quality guidelines (ANZECC/ARMCANZ, 2000). This has been consistently confirmed by:

- long term monitoring of Native Dog and Wongawilli Creeks during the mining of Elouera Colliery just south of the Area 3B General Study Area (Ecoengineers, 2003, 2004a, 2004b, 2005, 2006a) and also
- studies for the General SMP Area for Dendrobium Area 2 (Manly Hydraulics Laboratory, 2006; The Ecology Lab, 2006a); and also
- studies for the General SMP Area for Dendrobium Area 3A (Ecoengineers, 2011).

These low pHs arise naturally as a consequence of equilibration of the waters with atmospheric carbon dioxide, with silicic acid derived from dissolution of silica and from the leaching of small concentrations of low molecular weight organic acids from peats and other sources of dead plant organic matter, particularly in swamps.

In addition, it has been found that levels of dissolved aluminium (Al) are usually in excess of the default trigger value for the protection of 95% of all aquatic species at pHs >6.5 for freshwater ecosystems in the national water quality guidelines (i.e. 0.055 mg/L (55 μg/L; ANZECC/ARMCANZ, 2000)).

However, for pHs <6.5 a low reliability trigger value for Al for protection of 95% of all aquatic species in freshwater ecosystems has been set at 0.8 μg/L i.e. approximately 1μg/L on ecotoxicological grounds (ANZECC/ARMCANZ, 2000).

Aluminium is generally only ecotoxic in its cationic forms (Tessier and Turner, 1995). Measured sulfate (SO_4), and Dissolved Organic Carbon (DOC) levels in these creeks indicate that there would invariably be insufficient levels of SO_4, and fulvic and humic acids (i.e. the natural high molecular weight organic acids that go to make up part of the DOC to form sufficient complex species with cationic Al to significantly ameliorate its ecotoxicity).

Comparison with the established ecotoxicity literature indicates the dissolved Al levels at most Elouera Colliery headwater baseline sites, including Upper Wongawilli Creek (i.e. excluding only the downstream Donalds Castle Creek site DCL3 and the Lake Avon Native Dog Creek Arm site LA1) and even in downstream permanent pools would invariably be ecotoxic to a large number of species, especially benthic macroinvertebrates, the juvenile stages of some amphibians and many fish species, which had not evolved to tolerate such acidic, soft water, containing relatively high dissolved Al concentrations (Tessier and Turner, 1995).

A key feature of the baseline studies undertaken in Area 3 was that the diversity and abundance of aquatic species would undoubtedly be very significantly constrained by the relatively low pH and significant levels of dissolved Al. The depauperate nature of benthic fauna in local headwater catchments in the Cordeaux and Avon Special areas has been confirmed in previous and recent studies (e.g. The Ecology Lab, 2007).

By comparison, the national default trigger value for Zn for protection of 95% of all aquatic species is 0.008 mg/L (8 μg/L).

If great care is taken to eliminate sources of Zn contamination in sampling, which are common as Zn is often associated with the surfaces of plastic and rubber products due to the very common use of zinc stearate, or in admixture with calcium stearate as a mould release agent, mean concentrations of filterable Zn in almost all Elouera EMP baseline water sites were found to lie at, or around 0.008 mg/L (range 0.006 – 0.024 mg/L).

This has also been confirmed for Wongawilli Creek (see **Table 1.1)????).**

However, it is likely that speciation modeling (e.g. Parkhurst and Appelo, 1999), or methods of direct measurement of cationic Zn (e.g. ion selective electrode, anodic stripping voltammetry) would show that the appropriately summed ecotoxic cationic Zn^{2+}, $ZnOH^{+}$, and $ZnCl^{+}$ species would not, in general, sum to over 0.008 mg/L at these sites, despite the relatively fresh nature of these waters (Tessier and Turner, 1995), unless pHs were below 5.5.

It is concluded that, of the two metals: Al and Zn, Zn is usually the less (potential or actual) ecotoxic metal present at local baseline sites.

This conclusion would not necessarily be valid where the underlying lithology was not of a sedimentary quartz lithic sandstone type of course e.g. where shales or shale-based soils such as those derived from Wianamatta Shale or Mittagong Formation outcropped.

3. HYDROLOGIC AND WATER QUALITY IMPACTS

With respect to Dendrobium Area 3B, the key questions in relation to surface water quality and flow are whether mining subsidence effects will adversely affect:

1. Hydrologic productivity of the Cordeaux River and Avon headwater sub-catchments contained within Area 3B.
2. The ecological integrity of the streams, swamps or the Lake due to changes in water quality.
3. Raw water quality for drinking water supply purposes.

Further, if any such effects arise, significant or otherwise, whether they attenuate with time and over what timescale(s) and/or are amenable to prediction and avoidance prior to mining or amenable to an environmentally sensitive remediation during and post-mining.

3.1 BASELINE AND POST-MINING HYDROLOGY

Figure 3.1 below shows the sub-catchments and associated HCS flow gauging station numbers for the Wongawilli Creek catchment area. The HSC flow gauging station for Donalds Castle Creek (also shown in **Figure 3.1**) is located in the upper sub-catchment, just downstream of Swamp Den 02.

The catchment transects shown in **Figure 3.1** below were inserted to enable determination of a range of hillslope aquifer lengths extending from a confining ridgeline to the main channel draining stream (refer **Appendix B, Section B4**).

Key hydrologic RUNOFF2005 model-derived parametric data from each of the pre-mining baseline periods in 2008 and 2009 and for post-mining periods in 2010 and 2011 for these catchments with respect to the mining of Area 3A Longwalls 6 and 7 are shown in Table 3.1.

Please note that for the Greater Wongawilli and Lesser Wongawilli catchments ET_{CSIRO} (Zhang et al. 1999, 2001, 2004) was calculated for 100% forest cover. For Sandy Creek catchment ET_{CSIRO} was calculated for 75% heathland + 25% forest cover.

These data were comprehensively discussed and assessed in the End of Panel reports for Dendrobium Area 3A Longwalls 6 and 7 (Ecoengineers, 2011, 2012).

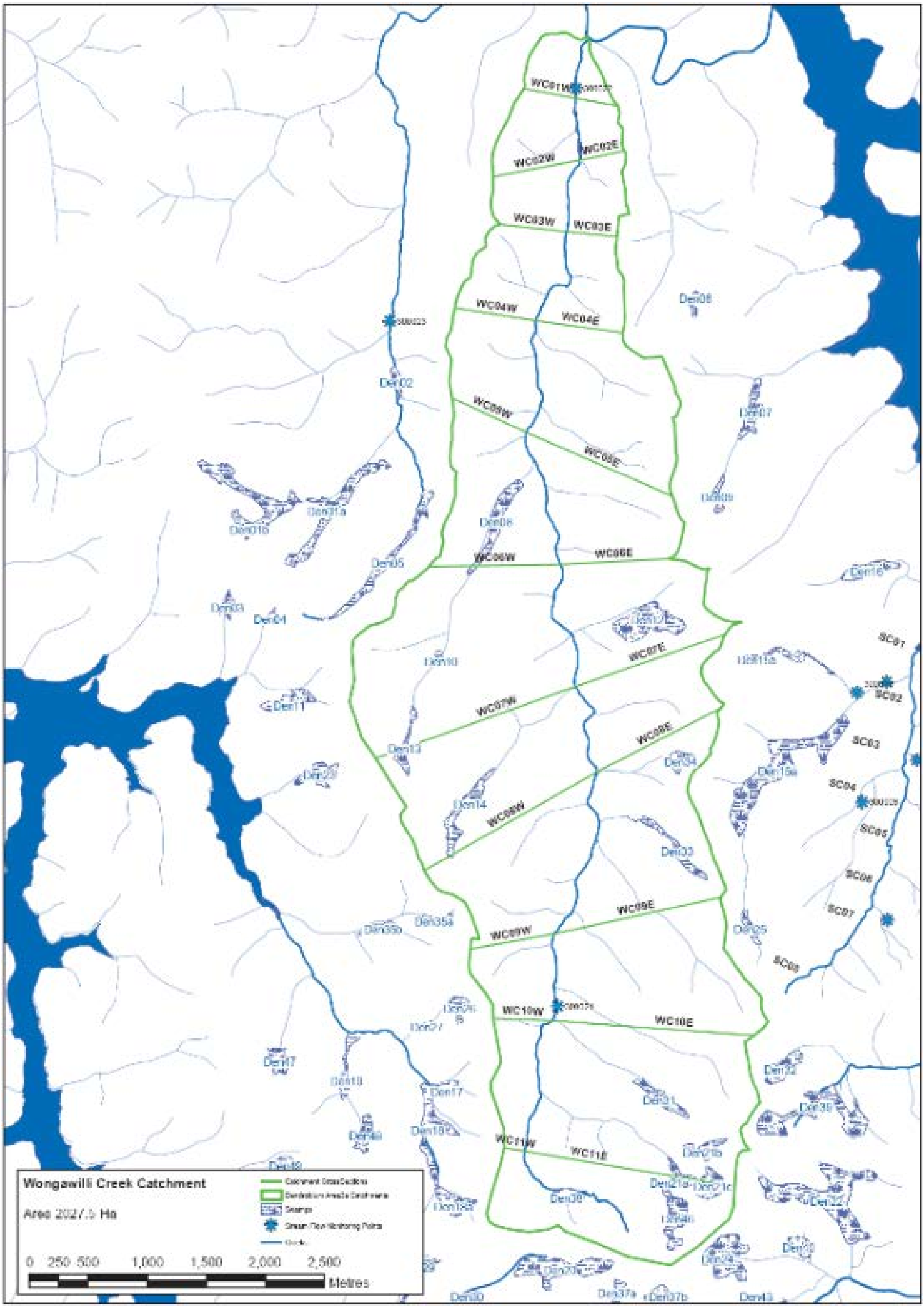


FIGURE 3.1: GREATER AND LESSER WONGAWILLI CREEK CATCHMENTS AND UPPER DONALDS CASTLE CREEK GAUGING STATIONS

Table 3.1: Hydrologic Impact Assessment Longwall 7 pre-mining (🟩) and mining period (🟧) Wongawilli Creek and Donalds Castle Creek Catchment Areas

	Periods of Valid Gauged Flows	Model Duration	Quick-flow J_d (days)	Baseflow system				Alpha	N-S goodness-of-fit; E (%)	P_{obs} (mm)	Q_{obs} (mm)	Averages (mm/day)				Pobs-weighted ΔET_{CSIRO} - ETsim (mm/day)	Mean ΔET ± 1 st.dev (mm/day)
				A	B	J_{bmin} (days)	J_{bmax} (days)					Q_{sim}	Soil store dS'_{sim}	ET_{sim}	ET_{CSIRO}		
Greater Wongawilli Creek (WWL) 20.026 km²	15/06/08 - 05/09/08	83	4.812	0.085	0.681	20.4	71.5	0.627	92.7	131.5	23.30	0.283	-0.066	**1.387**	**1.585**	**0.168**	**0.015**
	25/06/09-25/11/09	153	4.812	0.085	0.681	17.1	104.0	0.627	90.2	192.0	25.70	0.170	-0.132	**1.211**	**1.238**	**0.033**	**0.162**
	12/12/10-18/03/11	96	4.812	0.085	0.681	14.3	72.5	0.627	86.0	142.5	14.70	0.180	-0.100	**1.608**	**1.439**	**-0.155**	
	19/04/11-30/05/11	40	4.812	0.085	0.681	32.8	53.1	0.627	87.2	44.0	8.21	0.193	-0.073	**0.980**	**1.063**	**0.057**	**0.011**
	11/10/11-22/11/11	42	4.812	0.085	0.681	11.0	34.2	0.627	87.9	85.0	17.96	0.415	-0.230	**1.840**	**1.825**	**-0.020**	**0.041**
	22/12/11-23/01/12	32	4.812	0.085	0.681	12.7	30.6	0.627	91.9	64.0	12.37	0.377	-0.188	**1.811**	**1.806**	**-0.005**	
Lesser Wongawilli Creek (WWL-WWU) 16.814 km²	09/06/09-15/11/09	134	4.795	0.110	0.669	13.7	75.2	0.627	80.3	138.0	36.96	0.246	-0.111	**0.895**	**0.998**	**0.103**	**0.041**
	12/06/10-01/10/10	111	4.795	0.110	0.669	14.3	58.0	0.627	80.2	181.0	30.75	0.273	-0.121	**1.479**	**1.520**	**0.054**	**0.068**
	12/12/10-14/02/11	52(12-65)	4.795	0.110	0.669	29.5	58.8	0.627	83.1	96.0	10.82	0.208	-0.104	**1.708**	**1.662**	**-0.032**	
	20/04/11-29/05/11	38	4.795	0.110	0.669	35.7	54.2	0.330	80.0	43.5	6.90	0.173	-0.061	**1.003**	**1.075**	**0.047**	**0.068**
	28/08/11-01/11/11	40	4.795	0.110	0.669	11.8	33.9	0.627	82.5	64.5	20.25	0.486	-0.116	**1.242**	**1.504**	**0.252**	**0.174**
	21/12/11-25/01/12	35	4.795	0.110	0.669	13.1	33.9	0.627	89.8	93.5	15.14	0.429	-0.083	**2.336**	**2.268**	**-0.095**	
Greater Sandy Creek (SCL) 7.771 km²	16/03/08-01/10/08	198	1.446	0.008	0.999	1.1	39.4	0.095	82.6	469.5	135.74	0.810	0.011	**1.550**	**1.838**	**0.624**	**0.211**
	08/06/10-23/08/10	76	1.446	0.008	0.999	5.6	53.2	0.095	80.8	105.0	25.5	0.339	-0.212	**1.255**	**1.246**	**-0.004**	**0.357**
	22/03/11-23/05/11	59 (3-63)	1.446	0.008	0.999	3.1	42.8	0.095	96.6	76.0	28.11	0.503	-0.345	**1.108**	**1.148**	**0.014**	
	30/05/11-24/08/11	83	1.446	0.008	0.999	0.3	32.2	0.095	93.7	309.5	157.90	1.569	-0.151	**2.267**	**2.356**	**0.112**	**0.064**
	08/09/11-17/11/11	70	1.446	0.008	0.999	3.8	38.3	0.095	80.3	184.5	37.43	0.660	0.031	**1.944**	**1.965**	**0.016**	**0.068**

3.2 SUBSIDENCE-INDUCED EROSIONAL EFFECTS

Ground movements caused by mine subsidence may increase erosion and loss of soil materials through rock falls, or fissure opening in cohesive surface soils. Rock falls and surface soil cracking have occurred as the result of mining Areas 1, 2 and 3A.

Steep slopes and cliff lines occur along either side of the main channel of Wongawilli Creek and in several short un-named drainage lines on each side of the Creek. These tributary streams are short, have high average gradients and the steep slopes in their small catchments are relatively close to the Creek. Their catchments are founded on Hawkesbury Sandstone and soils are of the high to extremely erosive Hawkesbury and Gymea landscape types. Natural export of fine sand and non-dispersible kaolinite clay into the Creek is likely to be occurring, especially during and following intense storm events.

Slopes, cliff lines and soil types identified within Area 3B are very similar to those typical of the upstream stretch of Wongawilli Creek where Elouera Longwalls 1 through 6 crossed under the Creek between February 1993 and September 2001. That area was subject to significant denudation of the landscape caused by the intense fires which swept the area in late 2001 and continued burning through most of January 2002.

Monitoring and inspection by IC and its consultants over the subsequent seven years of those areas of Upper Wongawilli Creek (which had been mined under by Longwalls 1 through 6 of Elouera Mine) shows there were episodes of extreme erosion only from the newly fire-bared ground during intense storm periods in February 2002 and again in February, April and May 2003. This is consistent with the known ‘Extreme’ concentrated flow erodibility of the Hawkesbury soil landscape type which characterizes the steeper slopes of Wongawilli Creek (and end slopes of some of its tributaries).

Nonetheless, there has been no evidence of sustained subsidence-induced erosion of the valley slopes of Wongawilli Creek and its tributaries during the subsequent seven year monitoring period, even during the recent relatively high rainfall periods of the first 6 months of 2007 and the second 6 months of 2010.

It is expected some minor erosion will occur due to mine subsidence-induced slope stability effects during the mining of Area 3B.

These erosive effects are likely to impact steep slopes draining the western side of Area 3B to the Native Dog Creek Arm of Lake Avon. The steep slopes of those catchments are of the extremely erodible Hawkesbury, moderate to highly erodible Penrose and high to extremely erodible Gymea soil landscapes.

The intensity of these effects would be increased if wildfires were to pass through areas of steep slope which had recently undergone slope stability effects before revegetation of sites of soil opening had occurred.

Such occurrences would be relatively isolated, would have only minor, localised impacts on lower sections of creeks or at the shorelines of Lake Avon and should be generally indistinguishable from the suite of similar localised effects that occur naturally.

Given that:

- Dendrobium Area 3B longwalls will not mine directly under the main channel of Wongawilli Creek;

- the cliff lines and slopes of the area are no more extreme than those extensively mined under further south by Elouera Longwalls 1 through 6 over an eight year period between February 1993 and September 2001; and
- the general absence of significant erosive effects in Dendrobium Areas 1, 2 and 3A,

it is highly unlikely that the mining of Area 3B would lead to any deleterious effects on aquatic ecology or water quality through erosive effects induced by cliff or surface instabilities resulting from mine subsidence.

3.3 STREAM BED FRACTURING EFFECTS

Strains due to differential subsidence, leading to 'upsidence' and 'valley closure' caused by longwall mining beneath incised creeks and riverbeds can produce a complex suite of physico-chemical effects. Hydrological measurements, visual observations and water quality monitoring over recent years in the Southern Coalfield indicate these effects are:

1. Compressive or tensile (strain) failure fracturing of the Hawkesbury Sandstone bedrock leading to increased permeability and storage, possibly reduced surface flows, especially at the low end of the flow rate regime and more rapid draining of defined pools in no and low flow situations.
2. Diversion of stream flows through the fractured bedrock leading to loss of surface flows and potential loss of catchment yield to deep aquifer storage. This effect has been described in our previous reports as 'sub-bed diversion' (Ecoengineers, 2003, 2004a, b, 2005b, c, 2006b, 2007c).
3. Dispersion of small quantities of kaolinite from freshly fractured unweathered sandstone in the bedrock and its re-emergence from the bedrock immediately downstream of upsidence-affected areas. This effect has only been detected visually, occurs very early in the fracturing sequence, does not significantly affect downstream turbidities at anywhere near the levels that natural rainfall/runoff events cause and decays very rapidly.
4. Oxidative dissolution of accessory marcasite (a form of pyrite, FeS_2) within freshly cracked groundwater pathways, leading to release of sulfuric acid (H_2SO_4), dissolved iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn) and re-emergence of more acidic water of lower pH, lower redox potential (Eh) and dissolved oxygen (DO) concentrations and higher concentrations of the above metals from the bedrock immediately downstream of upsidence-affected areas. It has been shown that this process potentially has the (worst case) capacity to inject up to an approximate maximum of 100 moles sulfuric acid (H_2SO_4) (~10 kg) per day into a local watercourse (Ecoengineers, 2003, 2004a, b, 2005).
5. Increased concentrations of dissolved Al in water emerging immediately downstream of fracturing-affected areas due to the dissolution of Al from kaolinite in the walls of flow paths conducting acidic water through the fractured bedrock.

It has been demonstrated that, subject to predictive modelling, if adequate offsets from the sides or ends of longwalls from major watercourses are provided, avoidance of the above-described 'upsidence-related' hydrologic and geochemical effects may be achieved.

Examples of such reductions in impacts achieved include:

- Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River.
- West Cliff Area 5 Longwalls 31 to 33 adjacent to Georges River.

- Dendrobium Area 3A Longwalls 6 to 10,which do not mine under Wongawilli or Sandy Creeks by a distance in the range from 130 – 370 m for Wongawilli Creek and 90 – 225 m for Sandy Creek. The rationale for this is described in detail in the companion report by Mine Subsidence Engineering Consultants (MSEC, 2012).

However, it is considered possible that minor fracturing will occur at rockbars, rock shelves and nick points along tributary creek beds. MSEC (2012) predicts that maximum tensile strains greater than 0.5 mm/m may be of sufficient magnitude to result in cracking in the beds of the drainage lines. They also predict that compressive strains greater than 2 mm/m may be of sufficient magnitude to result in the topmost bedrock buckling and fracturing, which can induce surface cracking in the beds of the drainage lines.

Water quality monitoring sites have been recommended on the basis of a means of isolating and assessing such occurrences to determine if remedial action is required.

3.4 UPLAND SUBSIDENCE EFFECTS

3.4.1 Swamp Dewatering and Geochemical Effects

Valley infill swamps at risk from scour and erosion as a result of longwall mining are typically those lying well down the stream where there is sufficient upstream catchment to potentially provide high stream power.

The only downstream valley infill swamp identified in Area 3 which are considered possibly susceptible to scour effects enhanced by changes in grade due to mine subsidence have been identified by Cardno Forbes Rigby (2007) in their Landscape Impact Assessment as Swamps Den02, Den05, Den07, Den08 and Den5a. Of these, Swamps Den02, Den05 and Den08 are associated with watercourses present in Dendrobium Area 3B.

While it is considered unlikely, on the basis of past experience that mine subsidence-induced scour effects would affect these swamps, it recommended that these swamps are subject to frequent assessment during the period when longwalls in Areas 3B mine beneath them.

As noted in **Section 2.5** above, the overwhelming body of evidence indicates that headwater swamps are embedded in hillslope aquifers and are supported by groundwater i.e. they are groundwater dependent ecosystems (DLWC, 2002). It is noted that:

1. Adverse hydrologic effects e.g. broad or even discrete zones of dessication in well vegetated upland swamps of either type which have been subject to mining induced subsidence have not been detected anywhere in the Woronora Plateau over 10 years of close study, a period encompassing six years of drought and several major wild fires (Earth Tech, 2003).
2. One headwater swamp, namely Swamp Den18A above Elouera Colliery Longwalls 9 and 10 is demonstrably sustained by groundwater seepage into it from a local unconfined aquifer based on four clearly recognisable paleo-erosional surfaces within the surrounding Sandstone (IC, 2004).
3. Extensive water quality monitoring within and immediately downstream of swamps in recent years, including longwalls which mined directly under headwater swamps has not detected any geochemical effects e.g. lowered pH, increased dissolved sulfate, increased dissolved nickel and zinc from mining subsidence beneath or immediately down gradient of swamps of either type indicative of the cracking of 'tight' impermeable sandstone bedrock which by definition contains unweathered marcasite (Ecoengineers, 2006, 2007a, b, 2010, 2012).

It follows that hydrologic and/or geochemical effects on headwater swamps from longwall mining are therefore only likely to be significant where longwall mining subsidence-related effects have induced some significant change, not so much to an individual rock shelf or knick point because this will have no significant geochemical or ecological effect on the upgradient or down gradient portions of the swamp, but to a broad scale hillslope aquifer in which the swamp is embedded.

Detection of such a change requires:

1. Deployment of a wide area network of shallow piezometers both within and outside of swamps to gauge changes in the extent and/or vertical thickness of the hillslope aquifer(s) over the proposed or active longwalls.
2. Local stream hydrologic modelling to detect significant mining induced changes in the storativity and/or hydraulic elasticity of the baseflow-contributing local aquifer.

It is proposed to put hydrographic and pluviometric monitoring stations in place in Area 3B to enable modelling and assessment along the lines described in **Sections 2.6** and **3.1 above**.

3.4.2 Ferruginous Springs

An effect of induction of ferruginous springs as a consequence of subsidence has been observed before in the Southern Coalfield in sub-catchments of the Nepean, Cataract and Upper Georges Rivers.

In terms of the likely mechanism giving rise to such springs, it is known that where broad scale subsidence occurs as a consequence of mining, delamination, dilation and hence permeability enhancement is likely along the sub-horizontal interface between the sub-cropping Hawkesbury Sandstone and outcropping Wianamatta Shale sequences (Hazelton and Tille, 1990).

It is known that mining-related subsidence can have the effect of delaminating erosion surfaces and bedding planes within and between strata. These effects are predicted to occur preferentially along the interfaces between materials with different elastic properties.

This in turn is likely to facilitate the increased detention and storage of infiltrating meteoric waters within the shale and close to the shale/sandstone interface. The water stored at the shale/sandstone interface subsequently drains down gradient in the direction of a local creek or river. In some cases it can then travel down natural or induced vertical cracks and along widened bedding planes in the sandstone and subsequently appear as well-defined springs.

The common link in the induction of these springs seems to be:

- proximity to a creek line which experiences some change in slope induced by subsidence-induced tilt, although the slope change need not be significant by comparison with the natural slope of the creek ; and
- mantling of the upper catchment of the creek by Wianamatta Shale soils or possibly alternating shale and fine grained sandstone of the Mittagong Formation.

Detailed geochemical investigations have shown such ‘ferruginous upland spring’ waters have:

1. A very distinctive geochemical signature characteristic of leaching of salts stored (marine- derived) Wianamatta Shale clay soils. Specifically, the following is observed: a very high magnesium/calcium (Mg/Ca) mole ratio of +3.6 – +5.0 (noting it is +5.2 in seawater), a very low strontium/calcium mole ratio (Sr/Ca) of 0.004 – 0.009 (noting it is 0.009 in seawater), a narrow log bromide/chloride (log(Br/Cl)) mole ratio of -2.85 – -2.95 (noting it is -2.81 in seawater), a narrow log boron/chloride (log(B/Cl)) mole ratio of -11 - -18 (noting it is -12 in seawater), and a narrow log sulfate/chloride (log(SO_4/Cl)) mole ratio of typically -1.3 – 2.0 (noting it is -1.3 in seawater). In other words, these waters

have the signature of a marine shale soil profile subsequently modified only by cation exchange (for sodium, Na, potassium, K, Ca, Mg and Sr), adsorption (for B) and Fe and Mn oxide dissolution effects during percolation.

2. Depending upon the depth of shale such waters often exhibit characteristically elevated levels of dissolved Fe and Mn typically ranging from 0.2 – 40 mg/L and 0.1 – 2 mg/L respectively. Due to the well known high concentrations of disseminated Fe and Mn oxides (after siderite and rhodochrosite) in weathered Wianamatta Shales (which gives them their distinctive brick red through dark maroon colours), reductive dissolution of those oxides ('bleaching') has occurred in the subsoil storage under the influence of so-called Fe and Mn dissimilatory bacteria (typically *Geobacter* species) that are well known to oxidize percolating dissolved organic matter (DOM) and, in that same biogeochemical process, use such oxides as their terminal electron acceptors (TEAs; Lovley and Phillips, 1986).
3. As distinct from the oxidative dissolution of marcasite that can occur in freshly fractured Hawkesbury Sandstone, the reductive dissolution (bleaching) of disseminated Fe and Mn oxides in the Wianamatta Shales does not increase SO_4 concentrations and does not produce acidity and hence lowering of pH *in situ* (although this will be created at emergence into the open air of such waters). Hence these waters generally maintain constant SO_4 concentrations (albeit higher the greater the depth of shale and extent of salts leaching involved) and generally have near neutral to only weakly acidic pHs when properly sampled *in situ* or immediately upon emergence and if not subsequently passed through bulk fractured sandstone.

That significant water storage at the Wianamatta/Hawkesbury interface can occur and be pronounced has now been indicated by:

- water yields recovered from various shallow boreholes drilled in the Southern Coalfield on plateau mantled with shale (i.e. those drilled just into the upper layers of the Hawkesbury);
- periodic longwall mining-induced seepages into Cataract Tunnel; and
- emergence of highly visible ferruginous springs into the upper Georges and Cataract Rivers.

Longwall mining induced subsidence effects on shale-mantled upland catchments in the Southern Coalfield might generate ferruginous springs from upland catchments at a maximum recharge/discharge rate of about 0.4 mm/day and a mean recharge/discharge rate of about 0.2 mm/day. This would generate average flows of the order of 0.2 ML/day and maximum flows of the order of 0.4 ML/day per km^2 of catchment (Ecoengineers, 2005a).

When a spring of this 'Wianamatta Shale-type water' emerges into the open air it tends to immediately react with the oxygen in the air or dissolved in the water of the creek or river it may flow into. This results in the precipitation of Fe and Mn hydrous oxides, generating acidity.

Fe and Mn oxidation and precipitation of hydrous oxides creates acidity through the reactions:

$2Fe^{2+} + 0.5O_2 + 5H_2O \Rightarrow 2Fe(OH)_3 + 4H^+$

$Mn^{2+} + 0.5O_2 + H_2O \Rightarrow MnOOH + 2H^+$

Where such springs flow directly into ephemeral or low flow creeks, their relatively low alkalinity in Area 3B will be insufficient to ensure that the generation of acidity through the oxidation of the dissolved Fe and Mn does not produce pHs low enough to cause ecotoxic effects.

In summary:

1. Ferruginous springs can be highly visible due to the voluminous precipitation of oxidised ferruginous material.
2. Increased inflows of saline waters into local creeks as a consequence of increasing infiltration into, and interflow through local Wianamatta Shale soils and outcrops due to mine subsidence-related effects (e.g. shearing) are a potential aquatic ecological stressor on local aquatic ecosystems (ANZECC/ARMCANZ, 2000), unless the waters in these creeks can be demonstrated to already receive Wianamatta Shale-derived waters of a comparable salinity level.
3. As the reduced iron and manganese load in the spring water is oxidised, and if it discharges to a creek, it discharges all dissolved oxygen (DO) in the creek water at and immediately downstream of the point of entry to the creek. This can have significant ecotoxic effects both due to the reduction in DO and due to a smothering effect in the creek bed (ANZECC/ARMCANZ, 2000).

Unless such a springs or springs are detected, detained, diverted or treated in some way within the catchment within it as they arose, then creek waters containing significant concentrations of dissolved Fe and Mn could also pass either indirectly or directly into Lake Avon (as occurred with the Cataract River and Upper Georges River). This in turn again creates a significant consumption of dissolved oxygen at the point of entry which has the potential to discharge DO from the water, and cause bed smothering of the immediate area.

A substantial portion of Area 3B is mantled by shale-based Mittagong Formation soils (Lucas Heights type) occupying several catchments at the 1 – 2 km^2 scale. These drain via steep (10 – 20%) slopes with sandstone outcrops southwest into the Native Dog Creek Arm of Lake Avon (refer **Figure 2.8** in **Section 2.3** above) or into the northwest tributaries of Upper Donalds Castle Creek over much longer distances with far gentler slopes.

For those springs which were intercepted by Swamps Den01a, Den01b, and Den05 in the Upper Donalds Castle Creek area and Swamps Den08, Den10 and Den13 in Wongawilli Creek tributary WC21 and Swamp Den14 in tributary WC15, this would offer a much longer flow path for aeration and amelioration of any generated acidity.

Any effect (of one or more ferruginous springs) would therefore most likely be localised to the slopes of the southwest-draining catchments over Area 3B. Such an effect, if it does occur is likely to be largely aesthetic rather than posing any adverse impact on stream ecology due to the relatively short length and high gradients of the creeks potentially involved and the substantial dilution and dispersion that would occur at the confluence with Lake Avon. Water quality monitoring sites will be located in this part of Area 3B to provide early detection and ongoing assessment of this potential effect.

4. CONCLUSIONS

4.1 PREDICTED IMPACTS ON BULK RAW WATER SUPPLY QUALITY

From five years of monitoring there has been no evidence of significant effect in the short or long term on either bulk raw water quality or even drinking water quality in the Native Dog Creek Arm of Lake Avon, despite Native Dog Creek being directly undermined by Elouera Colliery longwalls, causing creek bedrock fracturing.

Due to the standoffs from Wongawilli Creek of the Area 3B longwalls, it is not expected any significant fracturing and sub-bed flow diversions will occur in Wongawilli Creek to alter flows or water quality other than minor impacts. Due to the substantial distance downstream it is predicted there will be no reduction (other than negligible reduction) in the quality or quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek.

Due to the standoffs from Lake Avon of the Area 3B longwalls, it is not expected there will be a reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Avon. In addition, due to the substantial size of the Lake Avon system, it is predicted that there will be no measurable reduction in the quality or quantity of water in Lake Avon resulting from surface water or groundwater inflows.

Based on past experience from Wongawilli and Native Dog Creeks which were directly mined under by Elouera Colliery longwalls, it is also considered highly unlikely that there would be any adverse effect on bulk drinking water supply quality in the Lake Avon or Cordeaux River (into which Donalds Castle and Wongawilli Creeks discharge) systems.

Any water-borne inputs to Lake Avon and Cordeaux River would likely be restricted to a possible erosive export of fine sands and clays and/or ferruginous precipitates near the mouths of minor creeks designated LA2, LA3, LA4 and LA5 (Lake Avon) during mining of Area 3B.

These creeks are all remote from their respective dam off-takes and outflows. Such zones would be localised around the point of input to the Lake and would be unlikely to have any detrimental effect on local freshwater ecology and unable to affect the bulk water supply quality.

4.2 PREDICTED IMPACTS ON STREAM HYDROLOGY AND ECOLOGY

4.2.1 Impacts on Catchments Hydrology and Productivity

The hydrologic impacts of mining longwalls directly under Native Dog Creek and upper Wongawilli Creek in the vicinity of Dendrobium Area 3 have been studied since 2001 and a general understanding of the surface and shallow groundwater hydrologic systems has emerged.

There is no recognised deep aquifer in the bulk of the major outcropping Hawkesbury Sandstone in this area. Baseflows of the draining streams are provided by semi-confined hillslope aquifers in weathered sandstone slopes and swamps which do not appear to be connected to any deep water bearing strata and are insulated from the mine workings by a number of well recognised aquicluding claystone units as well as relatively tight sandstones.

Stream flow monitoring subject to a quantitative hydrologic assessment as reported in Ecoengineers (2011 and 2012) have indicated there was no evidence that the overall Wongawilli Creek catchment (partly located within Dendrobium Area 3B) suffered any significant net loss of water to deep (unrecoverable) storages due to longwall mining of Longwall 6 or 7 in Dendrobium Area 3A.

Due to the standoffs from Wongawilli Creek of the Area 3B longwalls, it is not expected any fracturing resulting in sub-bed flow diversions will occur in Wongawilli Creek to alter flows such that there will be detectable losses of outflows from this catchment.

4.2.2 Predicted Subsidence Induced Erosion Impacts

Slopes, cliff lines and soil types identified within Area 3B are similar to those typical of the upstream stretch of Wongawilli Creek where Elouera Longwalls 1 to 6 crossed under the Creek between February 1993 and September 2001. That area was subject to significant denudation of the landscape caused by the intense fires which swept the area in late 2001 and continued burning through most of January 2002.

Monitoring and inspection by IC and its consultants over the past seven years of those areas of Upper Wongawilli Creek which had been mined under shows there were episodes of erosion from the newly fire-bared ground during intense storm periods in February 2002 and again in February, April and May 2003.

This is consistent with the known concentrated flow erodibility of the Hawkesbury soil landscape type of the steeper slopes of Wongawilli Creek and end slopes of its tributaries.

Nonetheless, there has been no evidence of sustained subsidence-induced erosion of the valley slopes of Wongawilli Creek and its tributaries during the subsequent seven year monitoring period, even during the recent high rainfall ‘La Nina’ period since May 2010.

It is expected minor erosion will occur due to mine subsidence-induced slope stability effects during the mining of Area 3B. The erosion effects are likely to impact steep slopes draining the western side of Area 3B to the Native Dog Creek Arm of Lake Avon. The steep slopes of those catchments are of the extremely erodible Hawkesbury, moderate to highly erodible Penrose and high to extremely erodible Gymea soil landscapes.

The intensity of these effects would be increased if wildfires were to pass through areas of steep slope which had recently undergone slope stability effects before revegetation of sites of soil opening had occurred.

Such occurrences would be relatively isolated, would have only minor, localised impacts on lower sections of creeks and negligible impact on Lake Avon and Wongawilli Creek and should be generally indistinguishable from the suite of similar localised effects that occur naturally.

Given that:

- Dendrobium Area 3B longwalls will not mine directly under the main channel of Wongawilli Creek; and
- the cliff lines and slopes of the area are similar to those extensively mined under further upstream by Elouera Longwalls 1 through 6 over an eight year period between February 1993 and September 2001 with those slopes also mantled by Hawkesbury soil landscapes,

it is highly unlikely that the mining of Area 3B would lead to any deleterious effects on aquatic ecology through erosive effects induced by cliff or surface instabilities resulting from mine subsidence.

4.2.3 Predicted Streambed Fracturing Impacts

It is well known that subsidence caused by longwall mining beneath creeks and riverbeds can also produce a complex suite of physico-chemical effects.

It has been demonstrated that, subject to predictive subsidence modelling, if adequate standoffs from the sides or ends of longwalls from major watercourses are provided avoidance of the described ‘upsidence-related’ hydrologic and geochemical effects may be achieved. Recent examples of such reductions in impact include Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River, Longwalls 701 to 704 of Appin Area 7, adjacent to the Nepean River, and West Cliff Area 5 Longwalls 29 to 34 adjacent to Georges River.

Dendrobium Area 3B Longwalls 9 to 18 will not mine under Wongawilli Creek by distances in the range from 75 – 500 m. The rationale for this is described in detail in the report by MSEC (2012).

MSEC (2012) predicts that maximum tensile strains greater than 0.5 mm/m may be of sufficient magnitude to result in cracking in the beds of the drainage lines. They also predict that compressive strains greater than 2 mm/m may be of sufficient magnitude to result in the topmost bedrock buckling and fracturing, which can induce surface cracking in the beds of the drainage lines.

It is possible minor fracturing may occur at rockbars, rock shelves and knick points along tributary creek beds for Area 3B.

However, there is some evidence from the local area that these predictions are relatively conservative based on local experience over Longwalls 1 and 2 in Dendrobium Area 1 where, of eight tributaries of the order of 20 mm/m maximum predicted systematic tilts, 4.0 mm/m maximum predicted tensile strains and 9.0 mm/m maximum predicted compressive strains along their channels, only one tributary (No. 22) exhibited fracturing resulting in surface flow diversion. Geochemical studies indicated that fracturing within the tributaries of Dendrobium Area 1 was minor and of limited extent. No fracturing was observed in Kembla Creek, within Dendrobium Area 1 due to the setback of the mining from the Creek.

4.2.4 Predicted Ferruginous Springs Impacts

Mining subsidence beneath upland plateau areas can also produce a complex suite of physicochemical effects. Induction of ferruginous springs as a consequence of subsidence has been identified over the last three years as a longwall mining-related effect in the Southern Coalfield in sub-catchments of the Nepean, Cataract and Upper Georges River, most notably by being the likely cause of:

- The large and long-lived ‘SW2 Spring’ in Cataract River just west of Back Gully Creek.
- The moderately large and long lived ‘Pool 11 Spring’ in Upper Georges River.

Mining-related subsidence can have the effect of delaminating erosion surfaces and bedding planes within and between strata. These effects are predicted to occur preferentially along the interfaces between materials with different elastic properties. Where broad scale upland subsidence occurs as a consequence of longwall mining, delamination, dilation and hence interfacial permeability enhancement is likely along the sub-horizontal interface between a sub-cropping Hawkesbury Sandstone and an outcropping shale-based sequence.

Increased detention and storage of infiltrating meteoric waters within the shale and close to the shale/sandstone interface in effect creates or enhances a perched aquifer. The stored water subsequently drains down gradient in the direction of the nearest local creek or river. It may then travel down natural or valley closure-induced vertical cracks and widened bedding planes in the Sandstone to in valley walls. Mine subsidence-induced storage at the Wianamatta/Hawkesbury interface is common and is recognised by:

1. Water yields recovered from various shallow boreholes drilled in the Southern Coalfield on plateau mantled with shale (i.e. those drilled just into the upper layers of the Hawkesbury).
2. Periodic longwall mining-induced seepages into Cataract Tunnel.

3. The above-noted emergence of highly visible, long lived ferruginous springs into the upper Georges and Cataract Rivers.

Longwall mining induced subsidence effects on shale-mantled upland catchments in the Southern Coalfield, <u>may</u> therefore occasionally generate discrete ferruginous springs from upland catchments at a <u>mean</u> recharge/discharge rate of about 0.1 mm/day and <u>maximum</u> discharge rate of about 0.4 mm/day thus generating average flows of the order of 0.1 ML/day and maximum flows of the order of 0.4 ML/day per km^2 of catchment. Peak flows arrive sometime after peak rainfall due to the hydraulic residence time of the subsidence-induced perched aquifer e.g. average hydraulic residence time of the shallow aquifer driving the Cataract Gorge SW2 Spring appears to be of the order of six weeks.

A substantial portion of Area 3B is mantled by Mittagong Formation shale-based soils occupying several catchments at the 1 – 2 km^2 scale which drain via steep (10 – 20%) slopes with sandstone outcrops southwest to the Native Dog Creek Arm of Lake Avon. Drainage of the Wianamatta Shale-based soil uplands to the northwest to tributaries of Donalds Castle and Wongawilli Creeks occurs over much longer distances of far gentler slopes and there are numerous intervening upland swamps. It is considered unlikely that springs would be induced in this area and if they were they would be likely to occur around the margins of swamps or upslope of swamps and be largely attenuated by these landscape features.

However, it is possible one or more ferruginous springs might be induced in the slopes of the small, steep southwest-draining catchments over Area 3B draining towards Lake Avon.

Such an effect, if it does occur is likely to be largely aesthetic rather than posing any adverse impact on stream ecology due to the relatively short length and high gradients of the creeks potentially involved and the substantial dilution and dispersion that would occur at the confluence with Lake Avon.

Nevertheless, it is recommended that water quality monitoring sites be located in this part of Area 3B to provide early detection and ongoing assessment of this potential effect.

4.2.5 Predicted Swamp-Related Impacts

There are a number of swamps within Area 3. These swamps have been mapped and are described as swamps Den01a to Den35b (**Figure 1.2**).

Upland swamps can be differentiated into (at least) two types, which would usually be expected to exhibit distinctly different types of potential susceptibility to the effects of mine subsidence as follows:

1. Valley infill swamps are those which fringe, and have arisen from sand accumulation along well defined streams where there is a potential for scour of the sandy substrate of the swamp(s) above a certain stream power threshold. Swamps at risk from scour and erosion as a result of longwall mining are those in which the stream is of a high order i.e. high flow and low gradient, has poor vegetation condition e.g. from bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.

2. Headwater swamps occur within broad scale, relatively low slope creek or tributary headwater areas.

As previously noted, some past commentary on swamps and mining promoted the view that headwater swamps are ‘perched’ on impermeable bedrock. However, a significant body of direct and circumstantial evidence, (summarized in **Section 2.5** above) shows that most, if not all headwater swamps are ‘embedded’ in a broader scale hillslope aquifer or aquifers which provides the required excess of precipitation over evapotranspiration (ET) that sustains them.

For this reason Woronora Plateau headwater swamps are Groundwater Dependent Ecosystems (DLWC, 2002).

Valley infill swamps at risk from scour and erosion as a result of longwall mining are typically those lying well down the stream where there is sufficient upstream catchment to potentially provide high stream power. The only downstream valley infill swamp identified in Area 3B which is considered possibly susceptible to scour effects enhanced by changes in grade due to mine subsidence is Den05 (CRF, 2007). While it is considered unlikely, on the basis of past experience, that mine subsidence-induced scour effects would affect this swamp it is recommended frequent assessment is undertaken during mining in Area 3B.

Fracturing due to subsidence effects might sometimes become physically detectable at a central drainage line rock shelf or knick points in headwater swamps, but such fracturing is likely to coincide with sandstone that already contain, naturally, well weathered bedding planes and cross fractures due to the long period of exposure of such features. In this case further fracturing is likely to only enhance an existing conductance and transmission capability rather than create total loss of water from a swamp.

Hydrologic and/or geochemical effects on this type of swamp from longwall mining are only likely to be significant where longwall mining subsidence-related effects have induced some significant change, not so much to an individual rock shelf or knick point as this will have no significant impact on the upgradient or down gradient portions of the swamp, but to a broad scale hillslope aquifer. To detect these changes it is recommended the deployment of a wide area network of shallow piezometers within and outside of swamps to gauge changes in the extent and/or vertical thickness of the hillslope aquifer(s) over the proposed longwalls.

A number of shallow piezometers have already been established in Dendrobium Area 3B for hillslope aquifers in the Upper Donalds Castle Creek and catchments draining directly to Lake Avon.

It is recommended that shallow piezometers be installed within the Area 3B sub-catchment areas encompassing Swamps Den01a, Den01b, Den05 and Den09, Den10 and Den13. Installation should be staged so that data collected from initial installations can inform the site of subsequent installations.

4.3 WATER MONITORING AND MANAGEMENT PLAN OUTLINE

A Water Monitoring and Management Plan ('WMMP') incorporating detailed provision for surface water quality and hydrographic monitoring and the interpretation of data from those programs have been prepared as **Appendix A** of this report. This will be incorporated into the Dendrobium Area 3B SMP which guides management and monitoring protocols for Dendrobium Mine. The proposed programs comprising the Plan are:

1. A pre-mining baseline and post-mining stream hydrographic monitoring, hydrologic modelling and assessment program, the theoretical base, modelling and assessment approaches of which were designed after flow gauging studies of the nearby Native Dog and Donalds Castle Creeks and were described in detail in the Elouera EMP Stage 1 hydrology 2006 report. The degree of hydrographic monitoring and hydrologic interpretation in the proposed monitoring plan is much more detailed than previously undertaken and is appropriate for the detection of potential near surface hydrologic impacts of mine subsidence. The rationale and methodology for the data analysis have been described in full in **Sections 2.6, 3.1** and **Appendix B.**

2. It is recommended that shallow piezometers be established in those upland areas where a significant unified hillslope aquifer potentially susceptible to subsidence occurs and where large swamps or families of swamps occur.
3. Pre-mining baseline and post-mining field water quality monitoring and laboratory analysis program will be conducted based on the long term study of water quality of the nearby Native Dog, Wongawilli and Donalds Castle Creeks since late 2001. It is proposed that a three-tiered Water Quality TARP be established for Area 3B from pre-mining baseline data obtained prior to the commencement of mining of any longwall in the mining domain. A decline in water quality as a result of mining will be measured as a significant change (>2 standard deviations from the pre-mining mean) in water quality parameters during/after mining compared to pre-mining water quality, or a significant change in water quality (>2 standard deviations from the pre-mining mean) adjacent to or downstream of mining when compared to upstream water quality. TARPs for Lake Avon and the Lower Wongawilli Creek monitoring site (adjacent to Fire Road 6) will be in accord with the specific performance criteria in the mining consent. Water quality TARPs are described in **Appendix A, Section A6**.
4. As all proposed longwalls are set back from the main channels of creeks, a key aspect of the monitoring plan deals with the early detection, and subsequent investigation and assessment of any upsidence effects within tributaries. For this reason it is recommended that water related field work concentrate in the first instance on regular visitation to main channel water quality/flow sites, main channel vicinity sand apron piezometers, upland piezometers not within but surrounding and downstream of headwater swamps.

Properly sampled, and analyzed, geochemical data is very sensitive and invariably has proven to be the most reliable early indicator of the onset of subsidence-related water effects and of their magnitude.

In the first instance water quality studies should focus on sites located within the main channels of Donalds Castle and Wongawilli Creeks, with main channel monitoring sites located just downstream of confluences with mined under tributaries. The reasons for adopting this philosophy are as follows:

1. A baseline database of sufficient quality to confirm or modify the pre-established TARPs requires a large and relatively long dataset which in turn mandates that a water quality site be wet or flowing most regularly when visited. Main channels have the more persistent baseflow and hence provide more regular monthly samples for verifying compliance with TARPs. Otherwise, a lot of time would be wasted visiting too many sites which would often be dry (i.e. no baseflow) and requiring a lot of (two-person due to safety considerations) dense bush/swamp penetration on foot for very little (data) return for effort and a consequence increase in occupational health and safety risk.
2. There is also a long term commitment to main channel monitoring to monitor drinking water supply quality.
3. Main channel sites are more amenable to instrumentation and automatic sampling.

If geochemical effects are detected just downstream of a confluence but not at the main channel upstream site which are judged to be possibly a consequence of subsidence-related effects, detailed field investigations of the tributary sub-catchment's water quality and hydrologic behaviour would then be initiated. These tributary investigations would involve:

1. Collection of further water quality data from pools and storm flows within the tributary for assessment.

2. Closer monitoring of the suite of shallow piezometers sited within the sub-catchment and if necessary installation of more piezometers.

The proposed water quality, hydrographic and piezometric monitoring sites are appropriate for assessing the potential hydrologic and water quality effects of Dendrobium Area 3B and enabling rapid back tracking to any suspected sites or areas affected by mine subsidence effects, such as tributary sub-catchments. These sites would be visited and monitored monthly for all key parameters in a coherent, well-defined and consistent program for the duration of mining of Area 3B and an appropriate number of years thereafter.

In the event that future water monitoring shows that there have been significant hydrologic or aquatic ecotoxic effects within Area 3B catchments then it is possible that some management and mitigation measures may be required. It is recommended that management measures considered include alterations to the disposition of the area of extraction of a current longwall or agreed modifications to the orientation and/or disposition of succeeding longwalls. Potential water quality management and mitigation measures compatible with the Metropolitan Special Catchment Area are identified and briefly discussed in **Section A8** of **Appendix A**.

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APPENDIX A:
AREA 3B WATER MONITORING AND MANAGMENT PLAN

A1 MONITORING OBJECTIVES AND STRATEGY

The Dendrobium Area 3B Water Monitoring and Management Plan (‘WMMP’) is intended to provide for the reporting of mining impacts. The Plan has been developed with regard to previous experience of longwall mining in the Southern Coalfield in general and the mining of the earlier Elouera Colliery longwalls and in the 7 years in Dendrobium Mine Areas 1, 2 and 3A.

The WMMP is also required to comply with the Dendrobium Mine Development Consent, and the Department of Trade and Investment’s SMP Guidelines and the reporting requirements set out therein.

Monitoring objectives are to provide the maximum possible data flow pertaining to the following key effects:

1. Upland subsidence causing fracturing and dilation of upland bedrock increasing subsurface porosity, and possibly draining pools in ephemeral watercourses, causing broad scale depression of shallow groundwater levels in hillslope aquifers or desiccating swamps and affecting their ecological integrity.
2. Valley closure causing stream bed upsidence and stream bed fracturing in permanent streams or high flow frequency ephemeral streams and possibly leading to sub-bed diversion and/or stream acidification effects and release of metals which could cause watercourse ecological effects or degradation of Bulk Water Supply quality.
3. Valley closure causing strata dilation possibly leading to enhance perched water storages and the induction or exacerbation of ferruginous springs which could cause downstream ecological effects or degradation of Bulk Water Supply quality.
4. Broad catchment scale mine subsidence effects possibly causing permanent or semi-permanent loss of major stream productivity (in reporting to Cordeaux River or Lake Avon) over annual or greater timescales.

The core monitoring strategy is to answer and report on relevant questions of magnitude and degree of persistence of the above effects within the appropriate timescales.

To pursue these objectives, and to follow this strategy, requires a comprehensive Plan enabling effective and widespread application of soil moisture determination, shallow groundwater piezometric data collection, stream recessional and base flow hydrography, rainfall and related weather data gathering, field water quality monitoring, sampling and laboratory water quality analysis.

To implement the core monitoring strategy the WMMP’s constituent programs must apply before, during and after mining of Area 3B.

To implement the core monitoring strategy the WMMP must ensure that the data collected enables effective and defensible assessment of the magnitude and persistence of the key effects, and must also implement objectives of best practice science enabling optimal parameter selection and the collection of the high quality data.

To implement the core monitoring strategy the WMMP’s monitoring objectives and methodology must be set out in defined programs providing clear and adequate practical objectives and adequate implementation detail for each major class of study technique. These programs are set out in this Plan.

To implement the core monitoring strategy the WMMP's monitoring programs must provide data of an adequate quality and a clear understanding of data limitations. This requires that data quality assurance and controls be in pace and that all data is subject to adequate statistical treatment where required.

The WMMP must also provide timely and defensible assessment and reporting. This partly requires the application of geochemical and hydrologic modelling. The specific issue of modelling and rapid assessment reporting is addressed in the following section.

Findings from assessment of the climatic, soil moisture, shallow piezometric, hydrographic and hydrologic and water quality monitoring programs will be reported on the following occasions and for the reasons given:

1. Whenever TARPs are triggered, mandating notification of government agency stakeholders and in some cases activation of expert review of the monitoring data.
2. In the Annual Environmental Management Report (AEMR).
3. In the End of Panel Report for each longwall.
4. As requested by DP&I and/or Mineral Resources.

A2 ASSESSMENT TIMING, MODELLING AND TARP REPORTING

The hydrographic monitoring and the hydrologic assessment methodology builds on lessons learnt from earlier hydrologic modelling assessments in the local area (Areas 2 and 3A). It is designed to provide a 'best practice' approach to the detection of significant hydrologic impacts of mine subsidence, within swamps and creek lines and with respect to hydrologic performance of the catchment.

Hydrologic modelling and assessments in the area have used the Free University of Amsterdam alpine headwater catchment non-linear hydrologic model RUNOFF2005 (Ecoengineers, 2006b). This model has been successfully used for the Native Dog, Sandy Creek, Wongawilli and Donalds Castle Creek Catchments (and subcatchments) and also at coal mine sites both in the Southern Coalfield and elsewhere (Ecoengineers Pty Ltd., 2006b, 2007b, 2010a, 2010b, 2011, 2012a, and 2012b).

Use of the RUNOFF2005 model enabled quantitative detection and description of a short term (6 – 9 month) disruption to the hydrologic performance of a minor subcatchment of Sandy Creek arising from the mining of Area 2 Longwall 5, with the model showing that a restoration to 'normal' hydrologic performance (within acceptable parametric precision) subsequently occurred.

Hydrologic assessment will continue to be based on application of the RUNOFF2005 model as frequently as circumstances require (refer **Appendix B**).

In the first instance, hydrographic and water quality monitoring would be based on sites located within the main channels of the principal creeks (Wongawilli and Donalds Castle) as well as some key tributaries (e.g. tributaries flowing directly to Lake Avon). The reasons for adopting this monitoring plan are as follows:

1. A baseline database of sufficient quality to confirm or modify the pre-established TARPs requires a large and relatively long dataset which in turn mandates that a water quality site be wet or flowing most regularly when visited.
2. Main channels have the more persistent baseflow and hence provide more regular monthly samples. Otherwise, a lot of time would be wasted visiting too many sites which would often be dry (i.e. no baseflow) and requiring a considerable amount of time expended on (two-person due to safety considerations) dense bush/swamp penetration on foot for very little (data) return for effort and a substantial increase in occupational health and safety risks.
3. There is also a long term commitment to main channel monitoring to monitor drinking water supply quality.
4. Main channel sites are more amenable to instrumentation and automatic sampling.

A finding of a significant catchment water balance discrepancy as defined in the relevant TARP will result in assessment and checking for an explanation for the event. This might require installing automatic stream water sampling equipment to check for a significantly varying tritium level in the catchment outflow (refer **Section 1.1.10**).

Numerous studies in the area conducted since September 2001 have shown that field monitoring of pH, Electrical Conductivity (EC), Oxidation Reduction Potential (ORP; Eh) and/or dissolved oxygen (DO) and Turbidity provides extremely sensitive and timely means of detecting and providing quantitative assessment of effects such as the initial stages of creek bed fracturing, pool drainage or induction of ferruginous springs.

Three-tiered Water Quality TARPs proposed for Area 3B (see **Section A6** below) will be established from baseline data obtained prior to the commencement of mining of any longwalls in Area 3B. A decline in water quality as a result of mining will be measured as a significant change in water quality parameters during/after mining compared to pre-mining water quality, or a significant change in water quality adjacent to or downstream of mining when compared to upstream water quality.

TARPs for Lake Avon monitoring sites (LA1 off Native dog Creek; LA2/3_S1 off Creeks LA2 and LA3; LA4_S2 off Creek LA4; LA5_S2 off Creek LA5) and the Cordeaux River at its confluence with Wongawilli Creek (WWL2 Lower Wongawilli Creek adjacent to Fire Road 6) will be consistent with the performance criteria in the mining consent.

In all cases, a Trigger for Action shall not be confirmed until a series of validating checks have been made. These checks shall be:

1. Cross checking of potentially triggering field water quality parameters against equivalent values at the immediately upstream/downstream monitoring sites.
2. Checking for the occurrence of triggering field water quality parameter values over two or more consecutive monitoring periods.

3. Comparison of field parameters with concurrent levels of key laboratory water parameters (where applicable) i.e. sulfate, filterable Fe, filterable Zn, filterable Ni or filterable Mn.

The proposed TARPs may be revised with the agreement of DP&I and Mineral Resources following collection of additional baseline data. Additional water quality monitoring sites will be established for obtaining baseline data well prior to the mining of Area 3B.

To maximize data returned for effort expended water-related field work will concentrate, in the first instance, on regular monthly field campaigns to main channel water quality/flow sites, and tributary catchment piezometers installed in and around swamps. However, as all proposed longwalls are set back from the main channels of creeks, a key aspect of the WMMP deals with the early detection, and subsequent investigation and assessment of any upsidence effects within tributaries.

Properly sampled, and analyzed, geochemical data is very sensitive and invariably has proven to be the most reliable early indicator of the onset of subsidence-related water effects.

A staged response plan triggered by main channel exceedances of water quality TARPs would be activated as described in more detail in **Section A6** below to investigate possible subsidence-related effects within tributaries.

Detailed laboratory chemical analysis for major cations and anions, key total and filterable trace metals and dissolved organic carbon (DOC) enables rapid geochemical modelling and assessment of biogeochemical processes occurring and their likely timescales (Ecoengineers Pty Ltd., 2003, 2004a, b; 2005; 2006a, b; 2007a). This involves use of the United States Geological Survey ('USGS') model for aqueous chemical speciated, batch reaction, one-dimensional transport and inverse geochemical model PHEEQC (Parkhurst and Appelo, 1999).

PHREEQC (version 2) is the most popular model for investigating aqueous chemical speciation, batch reactions, one-dimensional reactive transport and inverse geochemical calculation (Parkhurst and Appelo, 1999) to provide the following services:

- Inverse modelling of suspected causally-linked water quality pairs. This involves taking a 'Water A' composition and a 'Water B' and testing probabilistically whether Water B can derive from Water A by interaction with the known lithology of (say) fractured weathered or unweathered Hawkesbury Sandstone.
- Accurate quantification of the magnitude of sub-bed diversion geochemical effects if they should arise. It is noted this has been done many times before and extensively discussed and reported on by Ecoengineers.
- Properly identify source waters where/when required e.g. whether ferruginous springs are contributing to downstream tributary flows.

A3 WATER QUALITY MONITORING SITES

Preliminary monitoring sites were selected for watercourses that overly the location of proposed longwalls in Area 3B and within the Area 3B General SMP Area.

Areas of focus included upland swamps and stream features permitting monitoring sites to be established (i.e. pools and rockbars). Site access was also considered.

Monitoring will be carried out in Creeks LA4 and LA5, WC21, DC13 and Donalds Castle Creek during both the pre-mining baseline period and at least during mining of Longwalls 9 to 14 to provide early detection of possible ferruginous springs.

Potential sites suitable for water quality monitoring and flow gauging were chosen following consultation with Ecoengineers, the BHPBIC Environmental Field Team and HCS.

Field validation of potential monitoring sites was conducted by experienced personnel from Ecoengineers, BHPBIC Environmental Field Team and HCS. Following the examination of the areas of interest, a number of sites were identified as being potential water quality monitoring sites. However, few sites were found to be suitable for stream flow gauging.

Figure A3.1 and **A3.2** show the location of the (preliminary) suite of Area 3B water quality which will be monitored by Ecoengineers and the BHPBIC Environmental Field Team, respectively, as well as:

- The position of Area 3B Longwalls 9 to 18.
- The position of watercourses located within the Dendrobium Area 3B mining domain.
- The location of the 13 upland swamps mapped within the Area 3B SMP Area.

Installation of a centrally located rainfall monitoring station (pluviometer) has been established in accord with this Plan. Its location is indicated in **Figure A4.1** as a purple circle.

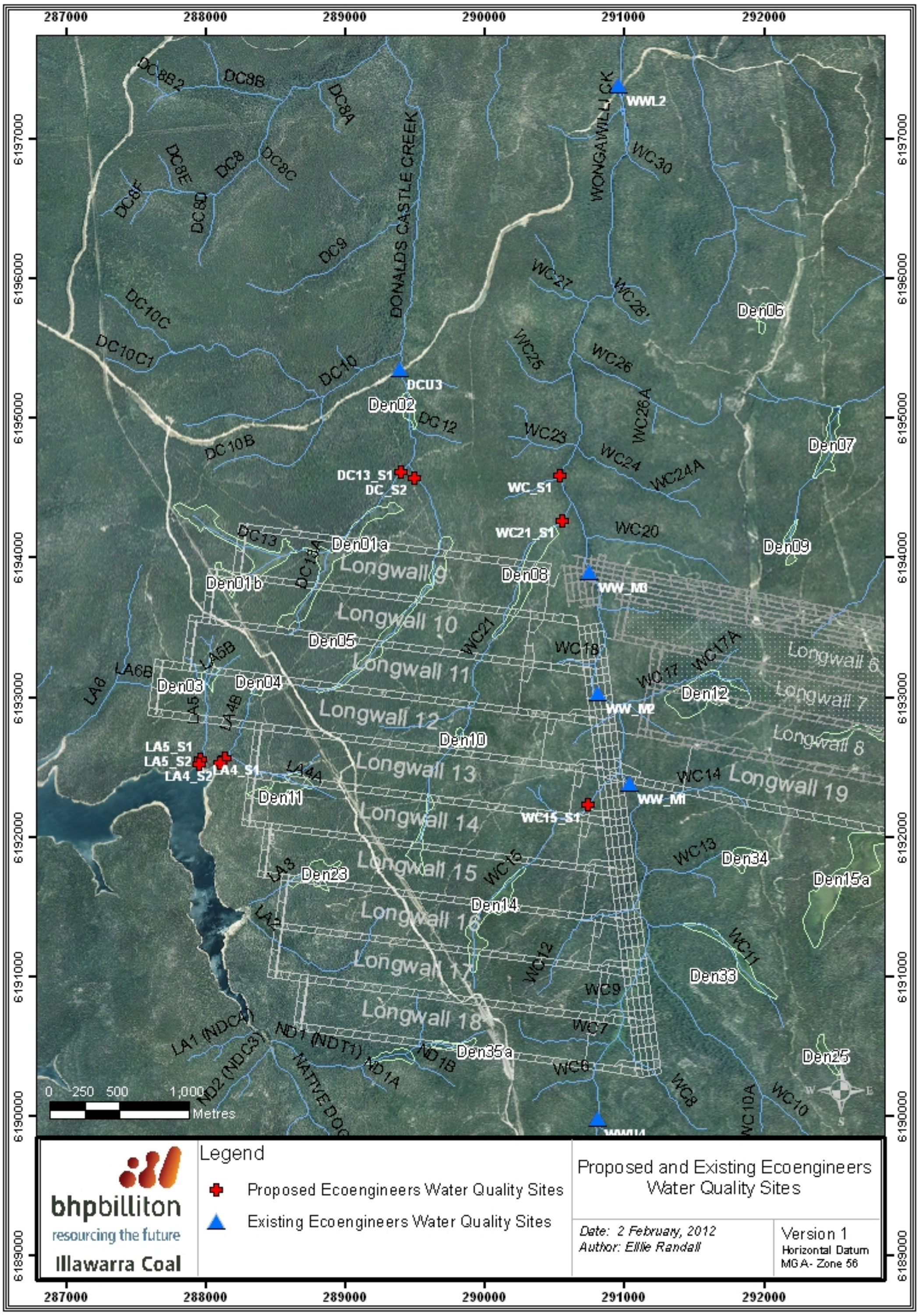


FIGURE A3.1: DENDROBIUM AREA 3B PROPOSED AND EXISTING WATER QUALITY SITES TO BE MONITORED BY ECOENGINEERS

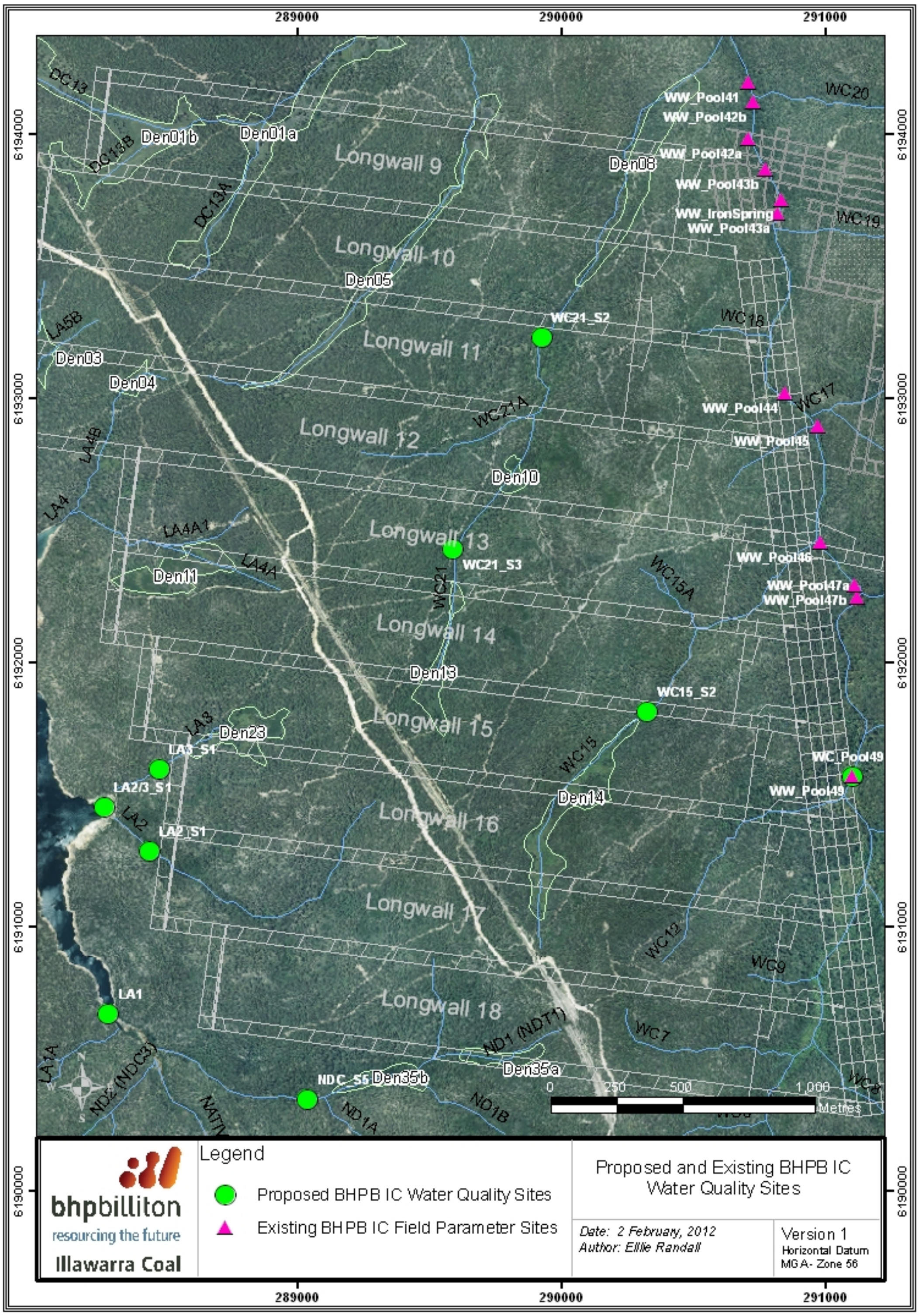

289000
290000
291000
6194000
6193000
6192000
6191000
6190000
DC13
DC13B
Den01b
Den01a
Longwall 9
DC13A
Longwall 10
Den05
WW_Pool41
WW_Pool42b
WC20
Den08
WW_Pool42a
WW_Pool43b
WW_IronSpring
WW_Pool43a
WC19
LA5B
Den03
Den04
WC21_S2
Longwall 11
WC18
WW_Pool44
WC17
WW_Pool45
Longwall 12
WC21A
LA4B
Den10
LA4
LA4A1
LA4A
Den11
Longwall 13
WC21_S3
WC21
WC15A
WW_Pool46
WW_Pool47a
WW_Pool47b
Longwall 14
Den13
WC15_S2
Longwall 15
LA3
Den23
LA3_S1
LA2/3_S1
WC15
WC_Pool49
WW_Pool49
Den14
LA2
LA2_S1
Longwall 16
Longwall 17
WC12
WC9
LA1
Longwall 18
ND1 (NDT1)
WC7
Den35a
LA1A
ND2 (NDC3)
NDC_S6
Den35b
ND1B
ND1A
0
250
500
1,000
Metres
WC8
bhpbilliton
resourcing the future
Illawarra Coal
Legend
● Proposed BHPB IC Water Quality Sites
▲ Existing BHPB IC Field Parameter Sites
Proposed and Existing BHPB IC Water Quality Sites
Date: 2 February, 2012
Author: Ellie Randall
Version 1
Horizontal Datum
MGA - Zone 56

FIGURE A3.1: DENDROBIUM AREA 3B PROPOSED AND EXISTING WATER QUALITY SITES TO BE MONITORED BY BHPBIC ENVIRONMENTAL FIELD TEAM

A description and photographic record of the proposed sample sites is provided where available.

Unnamed Creeks

LA2

LA2_S1

Sheet flow enters stream pool (7m x 4m x 0.2m deep) over upstream rockbar. There is good mixing of waters in to the pool. This section of the stream has a sandstone base with incised bedding planes. There is a good water level benchmark at the end of the pool. This site is suitable to be used for water quality monitoring and sampling.

 **Photo 1:** LA2_S1 looking upstream at rockbar.	 **Photo 1:** LA2_S1 looking across stream at pool.

 **Photo 3:** LA2_S1 looking downstream to end of pool.	 **Photo 4:** LA2_S1 looking upstream at outflow point.

LA4

LA4_S1 (288138, 6192567)

A possible water quality monitoring and sampling site. Sheet flow from upstream flows over a narrow upstream channel (up to1.5m wide) before cascading into a pool (3m x 1.5m x 0.2m deep) with good mixing. The channel has a sandstone base with incised bedding planes and sediment/vegetated banks. Water flow continues downstream over a series of steps before entering a boulder field. No substantial pools were present upon field inspection, however the pool upstream of the steps could be used for water quality monitoring and sampling. This site is not suitable for flow gauging.

Photo 8: LA4_S1 looking upstream at channel.

Photo 9: LA4_S1 looking downstream at pool

Photo 10: LA4_S1 looking across stream at pool.

LA5

LA5_S1 (287992, 6192663)

Water flows from upstream and enters a pool from an upstream rockbar and step section. The pool is 10m x 7m x 0.5m deep with organic matter as a substrate. A deep overhang exists under the rock step. There is good mixing of the water in the pool which flows out through a downstream boulder field. A flow gauging point could not be established at this site, however it is suitable for water quality monitoring and sampling.

Photo 11: LA5_S1 looking across at pool and inflow.

Photo 12: LA5_S1 looking across at pool.

Photo 13: LA5_S1 looking upstream at pool.

Donalds Castle Creek

DC_S2 (289526, 6194548)

At the time of the field inspection, there was good flow over an upstream rockbar resulting in a well-mixed downstream pool (15m x 7m x 1.5m deep with a sediment base). The banks of the pool are vegetated. An iron seep adjacent to the upstream rockbar/pool inflow was noted. The presence of the iron spring detracts from the suitability of this site to be used as a water quality monitoring site. Site DC_S3 (below) could be used as an alternative to this site.

Photo 17: DC_S2 looking upstream at rockbar.

Photo 18: DC_S2 looking across stream at rockbar.

Photo 19: DC_S2 looking downstream at pool.

Photo 20: DC_S2. Iron seep adjacent to pool inflow.

DC13

DC13_S1 (289319, 6194510)

Sheet flow over an upstream rockbar enters into a downstream pool which is 10m x 7m x 1.5m deep. The pool substrate is a combination of sediment and leaf litter. There is good mixing of the inflow at the south eastern corner of the pool. A flow gauging point could not be established at this site, however it is suitable for water quality monitoring and sampling. This is also a potential site for a water level benchmark.

 **Photo 23:** DC13_S1 looking upstream at rockbar.	 **Photo 24:** DC13_S1 looking downstream at rockbar.
 **Photo 25:** DC13_S1 looking downstream at pool.	

Wongawilli Creek

WC_S1 (290590, 6194441)

There is a large upstream pool (30m x 7m x1.5m deep) at this site. Downstream, the flow converges and overtops a rockbar on the western side. The channel is 3m wide and up to 0.3m deep with a sediment bank on the western side. This site is not ideal as a flow point; however it offers the best option for this stretch of the watercourse. The downstream pool is suitable for use as a water quality monitoring and sample site.

Photo 29: WC_S1 looking upstream at rockbar.

Photo 30: WC_S1 looking across stream at rockbar.

Photo 31: WC_S1 looking downstream at pool.

WC15

WC15_S1 (290859, 6192931)

The upstream pool (8 m x 5 m x 0.2 m deep) flows (sheet flow) over a rockbar with good mixing into a downstream pool. The downstream pool is 5 m x 5 m x 0.3 m deep and would serve as a suitable water quality monitoring and sample site. It is noted that access to this site is difficult.

 **Photo 35:** WC15_S1 looking upstream at rockbar and pool.	 **Photo 36:** WC15_S1 looking downstream at pool.

WC15_S2 (290323, 6191815)

Upstream sheet flow overtops a rockbar before entering a well-mixed pool. The pool is 5 m x 5 m x 0.4 m deep with a sandstone base. A flow gauging site could not be established, however this site is suitable for use as a water quality monitoring and sample site.

This pool is currently part of the IC Environmental Field Team’s monitoring run for Swamp Den14. A water level benchmark is currently in place with historical water level data available.

Photo 37: WC15_S2 looking upstream at rockbar.

Photo 38: WC15_S2 looking downstream at rockbar and pool.

WC21

WC21_S1 (290555, 6194270) and WC21_S2 (290534, 6194255)

Both sites have the potential to be used as water quality monitoring and sampling sites. There is good mixing of inflow as it passes over rockbars and in to the pools. Both pools have a sandstone base with pockets of sand. Site WC21_S1 appears to be the better option as a monitoring site due to the potential for a water level benchmark to be established.

Photo 39: WC21_S1 looking upstream at rockbar.

Photo 40: WC21_S1 looking across stream at rockbar.

Photo 41: WC21_S1 looking across stream at inflow to pool.

Photo 42: WC21_S1 looking downstream at pool.

Photo 43: WC21_S2 looking upstream at rockbar.

Photo 44: WC21_S2 looking across stream at rockbar.

Photo 45: WC21_S2 looking downstream at pool.

WC21_S3 (290497, 6194232)

Small upstream pool is 8m x 1.2m and up to 0.6m deep at the lower end. The flow channel is ~1m wide and ~0.5m deep with an incised bedding plane. Two smaller outflow points direct flow over the downstream rockbar. While not ideal, this site has the potential to be used as a flow gauging point.

Photo 46: WC21_S3 looking upstream at rockbar.

Photo 47: WC21_S3 looking across stream at channel.

 **Photo 48:** WC21_S3 looking across stream at channel.	

A4 HYDROGRAPHIC AND CLIMATE MONITORING PROGRAM

Approximately five flow monitoring stations have been installed within Wongawilli and Donald Castles Creeks (and some of their tributaries) to more accurately measure stream flow for appropriate periods encompassing an adequate number of storm events through rising, peak and recessional stages of the storm hydrographs. In addition, a weather station has been installed within Area 3B to maintain an accurate rainfall record for the region.

The monitoring program will aim to characterise catchment hydrologic performance during the pre, during and post mining operations. All proposed monitoring structures and sites have been installed following approval from SCA.

Where it is possible to do so, natural rockbars have been used as flow control structures. Where it is not possible to use natural rockbars as flow controls, flow control structures have been installed to facilitate accurate flow measurements. Noting that stream waters in Area 3B are naturally relatively acidic, flow control structures were constructed of materials (i.e. polyvinyl chloride pipe) which do not have the potential to leach aluminium, nickel or zinc into the downstream flows.

All flow monitoring stations will aim to accurately characterise flows within the streams at low flows i.e. baseflows where the potential for mining-induced impacts are likely to be most apparent and most necessary to quantify.

An initial rating and measurement program will be undertaken in response to a number of rainfall events during the pre-mining period in order to develop a robust understanding of the stream flow dynamics, particularly at low flows. Repeated routine manual stream flow measurements will be made at each new site which, together with the cross-sections, will enable the derivation of rating tables. The delivery of these tables is dependent on weather patterns but interim tables should be available within six months of installation.

The basis for flow monitoring at these sites will be water levels measured by an industry standard enclosed pressure transducer-type water level gauges with onboard data logging (e.g. Schlumberger 'Micro Diver' type or In-situ Inc., 'MiniTroll' types).

All the proposed sites are subject to a build-up of leafy material, sticks etc. This build-up will result in the pool levels becoming artificially high and therefore affecting the level/flow relationship. The stations will be serviced and data downloaded on a monthly basis, including routine clearing of the controls and obtaining flow measurements to verify or modify the flow rating tables. Level data collected over this period will then be converted to flow using the aforementioned derived rating curve.

A central rainfall gauging and weather station (pluviometer) has been installed and will be operated for the duration of the program.

Data will be edited, archived and disseminated using the software HYDSTRA. This is currently the preferred software for the hydrometric industry with SCA utilising it for data management and reporting. Data shall be delivered to BHPBIC in MS Excel 2007/2010 importable format.

Daily stream flow and rainfall data shall be available upon demand within seven days of each download, and following the derivation of the flow rating curves, daily flow and rainfall data shall be made available to BHPBIC on a monthly basis.

After the collection of sufficient stream flow data during the pre-mining phase, level sensors and flow control structures shall remain in place during the mining and post-mining phase and be inspected periodically for maintenance purposes.

Post-mining hydrographic monitoring campaigns will be undertaken sequentially after mining of each longwall in Dendrobium Area 3B to characterise the responses of the catchment to several rainfall events (with an emphasis on low flow conditions with the range of validity of the rating curve). Hydrographic monitoring is likely to be required throughout Area 3B mining and post mining monitoring period.

All equipment used in the construction or operation of the stream flow monitoring program will be removed at the completion of the program.

The locations of the flow monitoring sites are set out in **Table A4.1** and are displayed in **Figure A4.1**.

Table A4.1: Proposed (red) and existing Locations of Hydrographic and rainfall monitoring sites in Dendrobium Area 3B

Monitoring Location	Proposed Site Identifier	Easting (MGA)	Northing (MGA)	Catchment
Upper Donalds Castle Creek	DC13_S1	289397	6194613	Donalds Castle Creek
Upper Donalds Castle Creek upstream of DC_S1	DC_S2	289496	6194574	Donalds Castle Creek
Wongawilli Creek	WC21_S1	290555	6194270	Wongawilli Creek
Wongawilli Creek	WC_S1	290539	6194591	Wongawilli Creek
Wongawilli Creek Middle	WC15_S1	290743	6192232	Wongawilli Creek
Unnamed Creek LA4	LA4_S1	288138	6192567	Lake Avon
Upper Donalds Castle Creek	DCU3	289398	6195573	Donalds Castle Creek
Lower Wongawilli Creek	WWL2	290977	6197548	Wongawilli Creek
Upper Wongawilli Creek	WWU4	290803	6189783	Wongawilli Creek
Area 3B Weather Station	3BWS	288458	6192012	Full Area 3B Weather Station

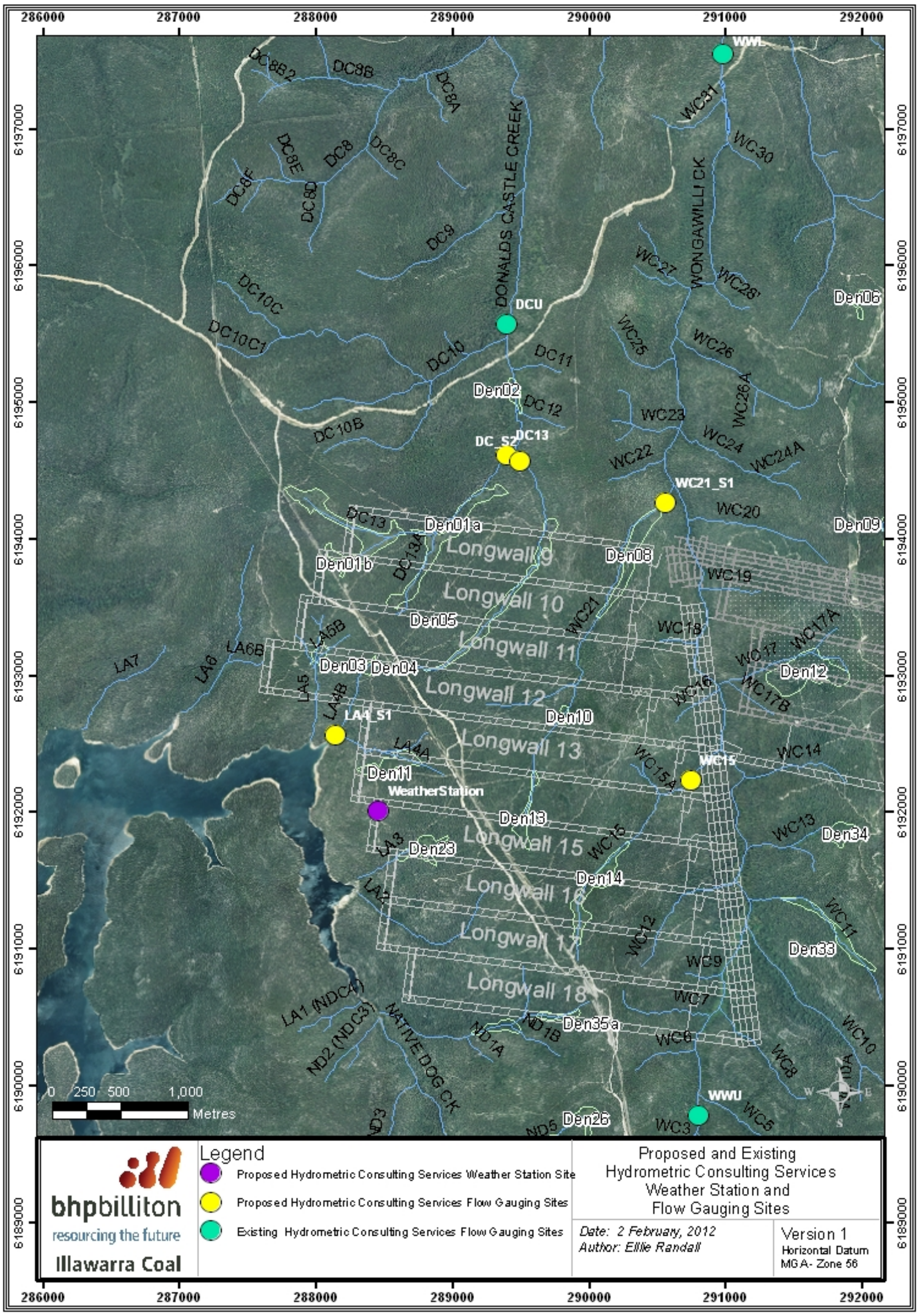


FIGURE A4.1: PROPOSED AND EXISTING HYDROMETRIC CONSULTING SERVICES WEATHER STATION AND FLOW GAUGING SITES IN DENDROBIUM AREA 3B.

The existing and proposed hydrographic monitoring sites are briefly described in more detail as follows. Site coordinates are given in the MGA (Map Grid of Australia) 1994 system.

Lower Wongawilli Creek (WWL)

- LOCATION: Fire Road 6.
- ACCESS: Enter bush prior to crossing at yellow ribbon on a tree. Proceed about 90 degrees to road until the creek.
- MAP CO-ORDINATES: 290977E, 6197548N
- CONTROL: Rock and boulder bar with three sections of flow. Two of the sections will be sealed with cement stabilised sandbags to afford a good single section natural rock control. No obstruction to fish passage will occur. An increased pool water depth will occur upstream of this control.
- INSTRUMENTATION: Located approx. mid pool on the right bank. Install Diver water level logger housing on existing solid rock with suitable brackets. A stainless steel dyna-bolt will be installed as a benchmark gauge on stream bank rock.

Upper Donald Castle Creek (DCU)

- LOCATION: Downstream of road crossing on Fire Road 6.
- ACCESS: Enter bush prior to crossing, at about the last corner in the road and walk at 90 degrees to the road until the creek.
- MAP CO-ORDINATES: 289398 E, 6195573 N
- CONTROL: Natural rock bar that would be best if enhanced with small cement stabilised sandbag wall on right bank to afford and single well defined control. No obstruction to fish passage will occur.
- INSTRUMENTATION: Located approx. 10m downstream of top of pool, in a very deep pool. Diver water level logger housing on existing bedrock. A stainless steel dyna-bolt will be installed as a benchmark gauge on stream bank rock.

Wongawilli Creek upstream site (WWU4)

- LOCATION: Wongawilli Creek, and downstream of Elouera Mine workings.
- ACCESS: Proceed along fire trail to Browns Rd pluviometer; continue past until a fenced-in borehole with a yellow ribbon on a tree opposite. Enter railway ‘line’ and opposite is another yellow ribbon on a tree – enter the bush here.
- MAP CO-ORDINATES: 290803 E, 6189783 N
- CONTROL: Natural rock bar, no work to be undertaken.
- INSTRUMENTATION – Located approx. 10m u/s of control on the rockbar. Diver water level logger housing bolted to existing solid rock. A stainless steel dyna-bolt is installed as a benchmark gauge on stream bank rock.

Upper Donalds Castle Creek Tributary DC13 (DC13_S1)

- LOCATION: Upper Donalds Castle Creek
- ACCESS: Access via the track linking Fire Road 6 and Fire Road 6A, through a rehabilitated cleared area (old seismic track).
- MAP CO-ORDINATES: 289397E, 6194613N
- CONTROL: Good control on rockbar
- INSTRUMENTATION: A water level gauging station will be installed at this location.

Upper Donalds Castle Creek upstream of DC_S1 (DC_S2)

- LOCATION: Upper Donalds Castle Creek
- ACCESS: Access via the track linking Fire Road 6 and Fire Road 6A, through a rehabilitated cleared area (old seismic track) following the pink flagging tape.
- MAP CO-ORDINATES: 289496E, 6194574N
- CONTROL: The control is partially blocked by a tree which will require clearing prior to installation of gauging station.
- INSTRUMENTATION: A stainless steel instrument housing can be deployed on the left bank and secured to the existing rock shelf.

Wongawilli Creek Tributary WC21 (WC21_S1)

- LOCATION: Wongawilli Creek Tributary WC21
- ACCESS: Site can be accessed via the track linking FR6 and FR6A. The track is not cleared or properly marked. It is anticipated that safe access to the site will be provided by IC prior to the installation of the gauging station.
- MAP CO-ORDINATES: 290555E, 6194270N
- CONTROL: The site consists of a rockbar control and a pool.
- INSTRUMENTATION: A stainless steel upright housing, secured to the rock shelf, can be deployed on the right bank.

Wongawilli Creek (WC_S1)

- LOCATION: Wongawilli Creek
- ACCESS: This site is downstream of WC21_S1 however there is currently no marked or cleared track. It is anticipated that safe access to the site will be provided by IC prior to the installation of the gauging station.
- MAP CO-ORDINATES: 290539E, 6194591N
- CONTROL: The site has a substantial pool and controlling rockbar, however a large tree has fallen on the left bank at the control which will need to be removed.
- INSTRUMENTATION: A stainless steel housing, secured to a rock 10 m upstream of the control, can be deployed on the right bank.

Unnamed Tributary LA4 (LA4_S1)

- LOCATION: Unnamed creek draining to Lake Avon.
- ACCESS: Site access can be gained from FR6A, following an old seismic track and walking through unmarked bush. Minor clearing of the track and marking will be required prior to installation of equipment.
- MAP CO-ORDINATES: 288138E, 6192567N
- CONTROL: A control can be created through the construction of a low profile concrete wall (approximately 200 mm high) installed across one of the ‘steps’ between the pools at this site. This will provide a good monitoring pool of 300 mm deep and 10 m long.
- INSTRUMENTATION: Instrumentation will be installed in an upright stainless steel housing secured to the rock bed of the creek.

Wongawilli Creek Tributary WC15 (WC15_S1)

- LOCATION: Mid-Wongawilli Creek at the bottom end of the major tributary denoted WC15.
- ACCESS: Access along an old seismic line is difficult with the track requiring some clearing and adequate marking to allow safe access to the site.
- MAP CO-ORDINATES: 290743E, 6192232N
- CONTROL: A reasonable pool and rockbar control exists.
- INSTRUMENTATION: A stainless steel housing could be secured to the sloping rock shelf on the right bank.

Area 3B Weather Station

- LOCATION: Large rock outcrop off western side of Fire Road 6A adjacent to Borehole DEN125
- ACCESS: Proceed along Fire Road No. 6A road until rock platform; walk up to near the top, the rainfall monitoring site is behind the low scrub.
- MAP CO-ORDINATES: 288458, 6192012
- HOUSING: Stand with ‘round’ on both ends and bolted to rock. Shield and locking bar required.
- INSTRUMENTATION: a Campbell’s Scientific weather station on a 3 m tripod mast.

Additional site information

- All steel products will be manufactured of stainless steel or (above the general water level) hot dipped galvanised to ensure lasting performance.
- Timber weirs will be constructed from treated pine timber, bolted to stainless steel pipe uprights with stainless steel u-bolts. Galvanised ‘stays’ will be installed on the downstream sides of uprights using Downy fittings to secure the weir against flood damage. Consequently only high flow waters will be potentially exposed to the galvanised surfaces.

- Diver housings will either be bolted to existing bedrock by use of stainless steel dyna-bolts or, where this is not possible, secured to the bank using star-pickets driven through tabs welded to the housing.
- Weirs will be sealed on the upstream edge by the use of cement stabilised sandbags, while a downstream apron will be similarly constructed to prevent undermining of the weir.
- The stainless steel weirs will be secured to bedrock with stainless steel dyna-bolts and sealed with underwater mastic, with the sides supported by cement stabilised sandbags.
- Where stated gauge plates will be installed in the creek or where this is impractical, a stainless steel dyna-bolt will be installed in bedrock from where the water level will be measured.
- All instrumentation will be locked using a brass padlock.
- Cross-sections of each control will be obtained to assist in rating table development.
- All monitoring equipment and control structures will be removed at the end of the monitoring program.

A5 SOIL MOISTURE AND GROUNDWATER MONITORING PROGRAM

A5.1 Soil Moisture Monitoring

Shallow moisture measuring probes based on the frequency domain (capacitive) technique of soil dielectric permittivity measurement has been in operation in Area 3A since early 2010 (Stacheder et al. 2009).

The model currently used is the Micro-Gopher type originally marketed by Soil Moisture Technology. This is a portable device inserted typically once or twice a month into pre-installed narrow PVC guide tubes extending up to 1000 mm below ground. Estimates of soil moisture are made at 100 mm intervals down to the maximum depth of the guide tube.

The soil moisture monitoring program within Area 3A has been extended into Area 3B.

Installation of new guide tubes into appropriate tributary sub-catchments has already occurred throughout Area 3B as indicated in **Figure A5.1**.

A5.2 Shallow Groundwater Monitoring

The current piezometer-based shallow groundwater monitoring program within Area 3A has been extended into Area 3B.

Installation of new shallow piezometers in appropriate tributary sub-catchments has already occurred throughout Area 3B as indicated in **Figure A5.1**.

1. The holes were drilled with a hand auger into weathered rock. The resulting holes will be approximately 70 mm in diameter. Deeper holes which encounter coarse running sand under saturated conditions may not be able to be completed to bedrock. Where hand held augers can't be completed to refusal, small hand held motor powered drills will be used.

2. Access to identified auger locations will be gained from the closest established track. All equipment is to be hand carried to site.
3. Holes will be logged to identify major sediment changes. Samples may be archived if necessary. A photo record of all subsections will be maintained.
4. Holes will be completed with 50 mm diameter PVC standpipes and screened over an appropriate basal interval. Under saturated conditions in coarse sand, it may not be possible to install the screen to the full depth. A geotextile 'sock' will be used to protect from sediment ingress during the screened interval. The upper annulus is to be supported with an inert mechanical device (e.g. cotton rag). No cement or other chemical based materials were used in the installation.
5. A data logger protection enclosure, a data logger (Sigra) and a sensitive downhole piezometer transducer will be fitted to selected standpipes. It is noted that these loggers are capable of remote radio download and that the logger batteries are charged by solar cell located on the cap of the enclosure. Some additional holes may be fitted with Greenspan downhole instruments which are manually downloaded.
6. Auger holes shall remain until all effects of mining are successfully recorded. The holes will be remediated at the end of the monitoring period.

Proposed shallow piezometer locations are shown in **Figure A5.1** below.

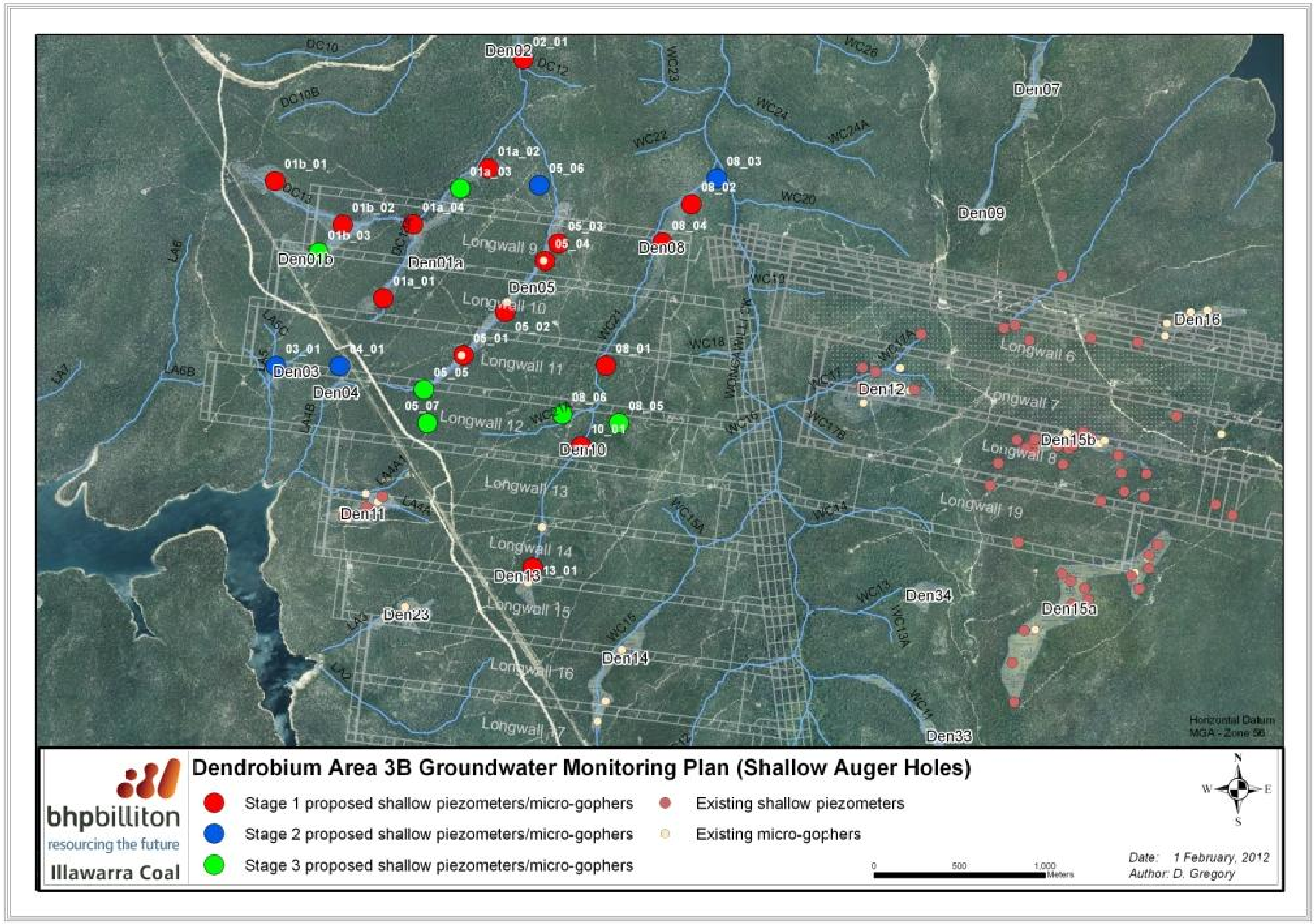


FIGURE A5.1: MOISTURE PROBE SITES AND SHALLOW GROUNDWATER PIEZOMETERS IN DENDROBIUM AREA 3B.

TABLE A5.1: LOCATIONS OF SHALLOW GROUNDWATER PIEZOMETERS IN AREA 3B

Bore No	Easting	Northing	Groundwater Level Sensor	Comments	Neutron Moisture Probing	Stage
01a_01	288660	6193583	Yes	Headwater	No	1
01a_02	289275	6194343	Yes	Intermediate headwater	No	1
01a_04	288832	6194014	Manual readings	Intermediate headwater	No	1
01b_01	288025	6194268	Yes	Headwater	No	1
01b_02	288420	6194013	Yes	Intermediate headwater	No	1
02_01	289480	6194983	Yes	Channel	No	1
05_01	289130	6193248	Yes	Headwater	Yes	1
05_02	289375	6193503	Yes	Headwater	Yes	1
05_03	289685	6193903	Yes	Intermediate headwater	Yes	1
05_04	289608	6193801	Yes	Headwater	Yes	1
08_01	289965	6193188	Yes	Channel	No	1
08_02	290465	6194133	Yes	Channel	No	1
08_04	290295	6193907	Manual readings	Channel	No	1
10_01	289817	6192717	Yes	Intermediate headwater	Yes	1
13_01	289534	6192006	Yes	Headwater	Yes	1
03_01	288029	6193187	Manual readings	Headwater	No	2
04_01	288404	6193187	Manual readings	Headwater	No	2
05_06	289575	6194243	Manual readings	Hillslope	No	2
08_03	290615	6194283	Manual readings	Hillslope	No	2
01a_03	289112	6194224	Manual readings	Channel	No	3
01b_03	288281	6193850	Manual readings	Intermediate headwater	No	3
05_05	288898	6193048	Manual readings	Intermediate headwater	No	3
05_07	288917	6192852	Manual readings	Hillslope	No	3
08_05	290040	6192852	Manual readings	Intermediate headwater	No	3
08_06	289709	6192904	Manual readings	Intermediate headwater	No	3

A6 HAWKESBURY SANDSTONE GROUNDWATER MONITORING PROGRAM

As with Dendrobium Mine Areas 1, 2 and 3A, a program has already been put in place by Geosensing Pty Ltd on behalf of IC for the installation of shallow to deep multi-level groundwater piezometers in Area 3B.

Since the development of Area 2, these programs have also included the installation of separate boreholes situated a few metres away from some piezometers which are fitted with low flow bladder pumps located within packed-off intervals of various strata which had been shown, during drilling, to have significant water-bearing capacity.

The sampling pumps provide for periodic sampling of *in situ* groundwater from various strata above any longwall. It is noted that groundwater sampling with such pumps provides samples collected in accord with low flow sampling guidelines (USEPA, 1996.)

Figure A5.2 below shows the suite of 13 monitoring bores with multi-level piezometers and four monitoring bores with multi-level groundwater sampling pumps which have been installed in Hawkesbury Sandstone (HBSS) only.

It is proposed that HBSS groundwater levels in particular and some groundwater qualities particularly close to Lake Avon (i.e. boreholes EDEN111, 114 and 125; with baseline sample from EDEN106) will be assessed at the End of Panel reporting stages as part of the overall surface water and shallow groundwater assessments conducted for those End of Panel Reports.

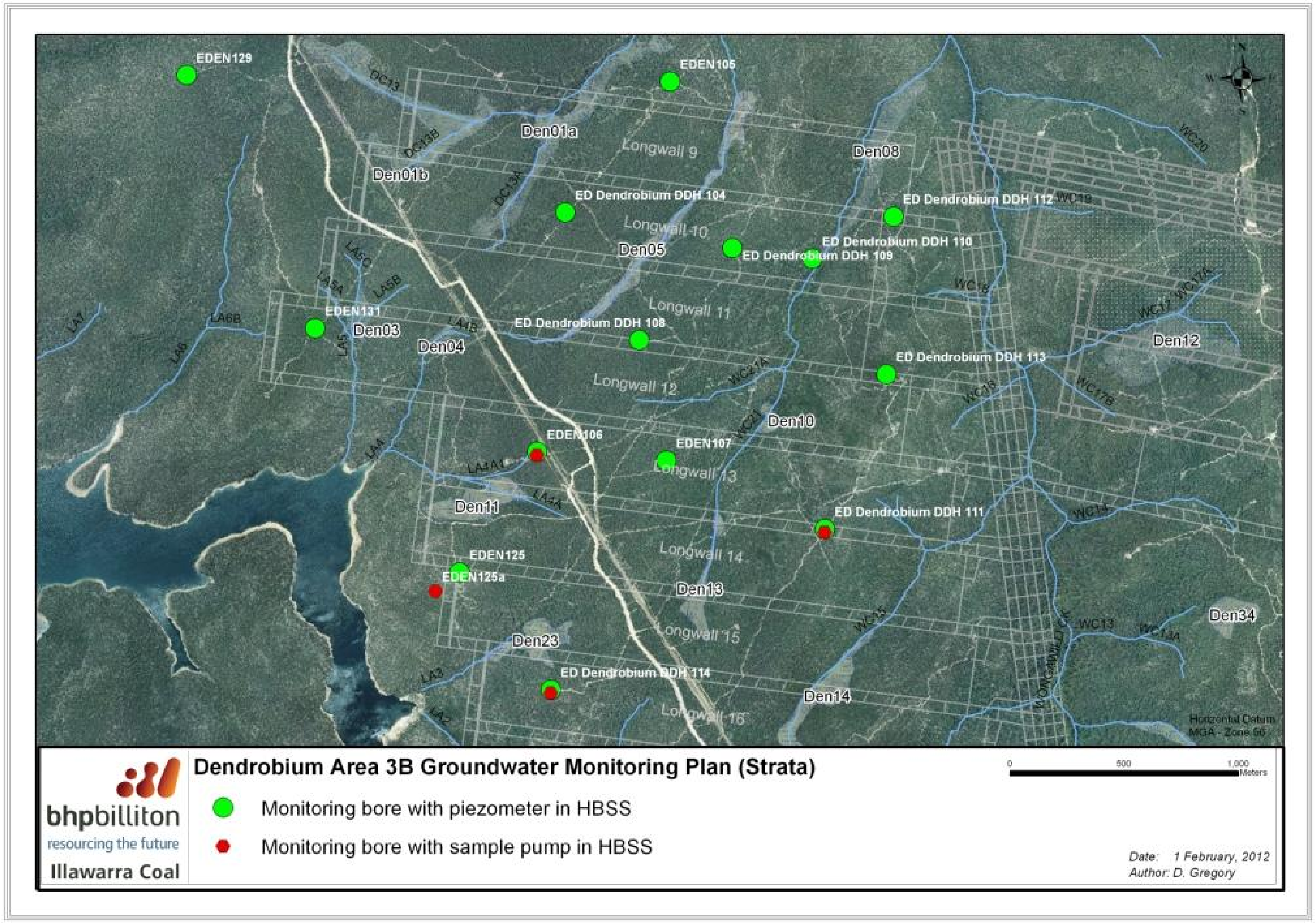


FIGURE A5.2: HAWKESBURY SANDSTONE PIEZOMETERS AND GROUNDWATER SAMPLERS IN DENDROBIUM AREA 3B

A7 WATER QUALITY MONITORING AND TRIGGERS

The proposed locations of the water quality monitoring sites and their identifiers are described in **Table A6.1** (for sites monitored by Ecoengineers) and **Table A6.3** (for sites monitored by IC Environmental Field Team). These locations may be identified on the area map in **Figure A6.1**. An effort has been made to ensure that flow and water quality monitoring sites are integrated wherever possible.

Proposed field and laboratory analytical parameters and monitoring frequencies at the proposed Area 3B water quality monitoring sites are listed in **Table A6.2** and **Table A6.4** for Ecoengineers and IC Environmental Field Team monitored sites, respectively.

Three-tiered Water Quality TARPs proposed for Area 3B (**see Table A6.5**) will be established from baseline data obtained prior to the commencement of mining of any longwall in Area 3B. A decline in water quality as a result of mining will be measured as a statistically significant change in water quality parameters during/after mining compared to pre-mining water quality, or a statistically significant change in water quality adjacent to or downstream of mining when compared to upstream water quality. The proposed triggers for action are as follows:

Level 1

- A temporary (two to four months) change in water quality following the onset of mining at any site in which any field water quality parameter (i.e. pH, EC, ORP or DO) changes by more than two standard deviations from the mean established for the baseline monitoring period.

Level 2

- An ongoing (more than four month duration) change in water quality following the onset of mining at any site where any single field water quality parameter (i.e. pH, EC, ORP or DO) deviates by more than two standard deviations from the mean established for the baseline monitoring period.
- The simultaneous shift by more than two standard deviations from the means established for the baseline monitoring period of any two or more field water quality parameters (i.e. pH, EC, ORP or DO) immediately after the onset of mining at any site.
- The simultaneous increase by more than two standard deviations from the mean established for the baseline monitoring period of any two or more key monthly monitored laboratory parameters (i.e. sulfate, filterable Fe, filterable Zn, filterable Ni or filterable Mn) as determined from any targeted investigation or during an End of Panel reporting stage.

Level 3

- A change of more than two standard deviations from the mean established for the baseline monitoring period in the inshore water quality of Lake Avon i.e. at the four designated Lake monitoring sites (LA1, LA2/3_S1, LA4_S2 and LA5_S2) or at the downstream Wongawilli Creek site (WWL2) adjacent to Fire Road 6 (such that a water quality impact might occur at the Wongawilli Creek/Cordeaux River confluence as a result of mining).

In all cases, a Trigger for Action shall not be confirmed until a series of validating checks have been made. These checks shall be:

- Cross checking of potentially triggering field water quality parameters against equivalent values at the immediately upstream/downstream monitoring sites.
- Checking for the occurrence of triggering field water quality parameter values over two or more consecutive monitoring periods.
- Comparison of field parameters with concurrent levels of key laboratory water parameters (where applicable) i.e. sulfate, filterable Fe, filterable Zn, filterable Ni or filterable Mn.

TABLE A7.1: ECOENGINEERS PROPOSED (RED) AND EXISTING WATER QUALITY MONITORING SITES

Monitoring Location	**Site Identifier -Water Quality/Site Identifier - Flow**	**Easting (MGA)**	**Northing (MGA)**	**Catchment (sub-catchment)**	**Site Type**
Upper Wongawilli	WWU1	291347	6187987	Wongawilli	Baseline
Upper Wongawilli	WWU4	290803	6189783	Wongawilli	Baseline
Mid-Wongawilli	WWM1	291102	6192297	Wongawilli	Area 3B Longwalls 12-18
Mid-Wongawilli	WWM2	290787	6193041	Wongawilli	Area 3B Longwalls 11-18
Mid-Wongawilli	WWM3	290767	6193885	Wongawilli	Area 3B Longwalls 9-18
Lower Wongawilli	WWL2	290977	6197548	Wongawilli	Far field impact (Areas 3A, 3B)
WC21 Tributary	WC21_S1	290555	6194270	Wongawilli	Area 3B Longwalls 9-14
Mid-	WC_S1	290539	6194591	Wongawilli	Near field impact

Wongawilli Creek					(Areas 3A, 3B)
WC15 Tributary	WC15_S1	290743	6192232	Wongawilli	Area 3B Longwalls 13-17
Upper Donalds Castle Creek	DC_S2	289498	6194755	Upper Donalds Castle	Area 3B Longwalls 9-11
DC13 Tributary	DC13_S1	289397	6194613	Upper Donalds Castle	Area 3B Longwalls 9 and 10
Unnamed Creek LA4	LA4_S1	288138	6192567	Lake Avon	Area 3B Longwalls 12-14
Lake Avon off Creek LA4	LA4_S2	288105	6192529	Lake Avon	Area 3B Longwalls 12-14
Unnamed Creek LA5	LA5_S1	287957	6192535	Lake Avon	Area 3B Longwalls 11 and 12
Lake Avon off Creek LA5	LA5_S2	287956	6192518	Lake Avon	Area 3B Longwalls 11 and 12

TABLE A7.2: PROPOSED (RED) AND EXISTING FIELD AND LABORATORY WATER QUALITY PARAMETERS AND MONITORING FREQUENCY

Site Identifier	Analytes	Sampling Frequency	Trigger
WWU1	Field pH, EC, ORP, DO, Turbidity. All lab. analytes except algae	Monthly	Presence of water in pool
WWU4/WWU	Field pH, EC, ORP, DO, Turbidity. All lab. analytes except algae	Monthly	Active flow
WWM1	Field pH, EC, ORP, DO, Turbidity. All lab. analytes except algae	Monthly	Active flow
WWM2	Field pH, EC, ORP, DO, Turbidity. All lab. analytes except algae	Monthly	Active flow
WWM3	Field pH, EC, ORP, DO, Turbidity. All lab. analytes except algae	Monthly	Active flow
WWL	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow
WC21_S1	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow

WC_S1	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow
WC15_S1	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow
DC13	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow
LA4_S1	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow
LA4_S2	Field pH, EC, ORP, DO, Turbidity. All lab analytes incl. algae	Monthly	Active flow
LA5_S1	Field pH, EC, ORP, DO, Turbidity. All lab analytes except algae	Monthly	Active flow
LA5_S2	Field pH, EC, ORP, DO, Turbidity. All lab analytes incl. algae	Monthly	Active flow

Note: All lab. analytes = Lab check of pH & EC, Na, K, Ca, Mg, Filt. SO_4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, TKN, NH_3-N, NO_x-N, TP, Algae (ID and Counts). APHA/AWWA/WEF (1998); DEC (NSW) (2004).

TABLE A7.3: BHPBIC ENVIRONMENTAL FIELD TEAMS PROPOSED (RED) AND EXISTING WATER QUALITY MONITORING SITES

Monitoring Location	Site Identifier - Water Quality/Site Identifier - Flow	Easting (MGA)	Northing (MGA)	Catchment (sub-catchment)	Site Type
Mid-Wongawilli	WW_Pool41	290705	6194192	Wongawilli Creek	Area 3B Longwalls 9-18
Mid-Wongawilli	WW_Pool42a	290708	6193980	Wongawilli Creek	Area 3B Longwalls 9-18
Mid-Wongawilli	WW_Pool42b	290728	6194117	Wongawilli Creek	Area 3B Longwalls 9-18
Mid-Wongawilli	WW_Pool43a	290816	6193699	Wongawilli Creek	Area 3B Longwalls 9-18
Mid-Wongawilli	WW_Pool43b	290774	6193865	Wongawilli Creek	Area 3B Longwalls 9-18
Mid-Wongawilli	WW_Pool44	290847	6193016	Wongawilli Creek	Area 3B Longwalls 11-18
Mid-Wongawilli	WW_Pool45	290969	6192892	Wongawilli Creek	Area 3B Longwalls 11-18
Mid-Wongawilli	WW_Pool46	290979	6192452	Wongawilli Creek	Area 3B Longwalls 13-18
Mid-Wongawilli	WW_Pool47a	291118	6192247	Wongawilli Creek	Area 3B Longwalls 13-18
Mid-Wongawilli	WW_Pool47b	291109	6192293	Wongawilli Creek	Area 3B Longwalls 13-18
Mid-Wongawilli	WW_Pool49	291101	6191569	Wongawilli Creek	Area 3B Longwalls 15-18
Mid-Wongawilli	WW_IronSpring	290831	6193751	Wongawilli Creek	Area 3B Longwalls 9-18
Mid-Wongawilli	WC_Pool49	291101	6191569	Wongawilli Creek	Area 3B Longwalls 15-18
Lake Avon off Native Dog Creek	LA1	288285	6190673	Native Dog Creek	Area 3B Longwall 18

Lake Avon off Creeks LA2 and LA3	LA2/3_S1	288268	6191456	Lake Avon	Area 3B Longwalls 15-17
Unnamed Creek LA2	LA2_S1	288440	6191287	Lake Avon	Area 3B Longwalls 16 and 17
Unnamed Creek LA3	LA3_S1	288479	6191597	Lake Avon	Area 3B Longwalls 15 and 16
WC15 Tributary	WC15_S2	290323	6191815	Wongawilli Creek	Area 3B Longwalls 15-18
WC21 Tributary	WC21_S2	289924	6193231	Wongawilli Creek	Area 3B Longwalls 11-18
WC21 Tributary	WC21_S3	289590	6192429	Wongawilli Creek	Area 3B Longwalls 13-18
Native Dog Creek ND1	NDC_S5	289039	6190349	Native Dog Creek	Area 3B Longwall 18

TABLE A7.4: PROPOSED (RED) AND EXISTING FIELD AND LABORATORY WATER QUALITY PARAMETERS AND MONITORING FREQUENCY

Site Identifier	Analytes	Sampling Frequency	Trigger
WW_Pool41	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WW_Pool42a	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WW_Pool42b	Field pH, EC, ORP, DO. All lab analytes except algae	Monthly	Active flow
WW_Pool43a	Field pH, EC, DO, ORP. All lab. analytes except algae	Monthly	Active flow
WW_Pool43b	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WW_Pool44	Field pH, EC, ORP, DO. All lab analytes except algae	Monthly	Active flow
WW_Pool45	Field pH, EC, DO, ORP. All lab. analytes except algae	Monthly	Active flow
WW_Pool46	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow

WW_Pool47a	Field pH, EC, ORP, DO. All lab analytes except algae	Monthly	Active flow
WW_Pool47b	Field pH, EC, DO, ORP. All lab. analytes except algae	Monthly	Active flow
WW_Pool49	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WW_IronSpring	Field pH, EC, ORP, DO. All lab analytes except algae	Monthly	Active flow
WC_Pool49	Field pH, EC, DO, ORP. All lab. analytes except algae	Monthly	Active flow
LA1	Field pH, EC, DO, ORP. All lab. analytes incl. algae	Monthly	Active flow
LA2/3_S1	Field pH, EC, DO, ORP. All lab. analytes incl. algae	Monthly	Active flow
LA2_S1	Field pH, EC, ORP, DO. All lab analytes except algae	Monthly	Active flow
LA3_S1	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WC15_S2	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WC21_S2	Field pH, EC, ORP, DO. All lab analytes except algae	Monthly	Active flow
WC21_S3	Field pH, EC, DO, ORP. All lab. analytes except algae	Monthly	Active flow
NDC_S5	Field pH, EC, DO, ORP. All lab. analytes except algae	Monthly	Active flow

Note: All lab. analytes = Lab check of pH & EC, Na, K, Ca, Mg, Filt. SO_4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, TKN, NH_3-N, NO_x-N, TP, Algae (ID and Counts). APHA/AWWA/WEF (1998); DEC (NSW) (2004)

A7.5: DENDROBIUM AREA 3B WATERCOURSE 'TRIGGERS FOR ACTION'

Aspect	Trigger	Action
CREEKS AND DRAINAGE LINES		
WATER QUALITY – Wongawilli Creek and Lake Avon		
Area 3B: **Wongawilli Creek** Reduction in water quality within Wongawilli Creek as a result of mining - measured as: • Reduced water quality during/after mining compared to before mining • Reduced water quality adjacent/downstream of mining compared to upstream. Trigger for Action will not be confirmed until a series of validating checks has been made. These checks include: • cross checking of potentially anomalous field water quality parameters against equivalent values at the immediately upstream/downstream monitoring sites, • checking for the occurrence of anomalous results over two or more consecutive monitoring periods, and • the comparison with levels of key laboratory parameters (where applicable)	***Impact Level 1**** Temporary (2 – 4 months) change (>2 standard deviations from the mean as calculated for the baseline monitoring period) at the same site of any field water quality parameter (i.e. pH, EC, ORP or DO) after the onset of mining.	• Continue monitoring program • Report impacts to key stakeholders • Undertake targeted investigations: o Review laboratory analysis results when available o Review tributary water quality and observational monitoring • Summarise impacts and Report in the End of Panel Report and AEMR
	Impact Level 2* Ongoing (> 4 months) change (>2 standard deviations for the mean as calculated from the baseline monitoring period) at the same site of any field water quality parameter (i.e. pH, EC, ORP or DO) after the onset of mining. The simultaneous change (>2 standard deviations from the mean as calculated for the baseline monitoring period) at the same site of any two or more field water quality parameters (i.e. pH, EC, ORP or DO) after the onset of mining. The simultaneous increase (>2 standard deviations from the mean as calculated for the baseline monitoring period) at the same site of any two or more key monthly monitored laboratory parameters (i.e. sulfate, filterable Fe, filterable Zn, filterable Ni or filterable Mn) as determined from any targeted investigation or during an 'End of Panel' reporting stage.	• As above • Review monitoring program • Notify OEH, DP&I, DPI, SCA, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visits with stakeholders as requested • Collect laboratory samples within 2 weeks and analyse for: o pH, EC, major cations, major anions, Total Fe, Mn & Al o Filterable suite of metals • Develop site CMA in consultation with key stakeholders and seek any approvals required. CMAs available are described in **Appendix A, Section A8**. • Completion of works following approvals • Issue CMA report within 1 month of works completion • Review the relevant TARP and Management Plan in consultation with key stakeholders

Aspect	Trigger	Action
	Impact Level 3* Change (>2 standards deviations from the mean as calculated for the baseline monitoring period) in the quality of water inflows to Lake Avon or the Cordeaux River at its confluence with Wongawilli Creek as a result of mining.	• As above. • Additional sampling in Lake Avon and/or Cordeaux River in consultation with SCA. • Review mine design criteria in consultation with DP&I and DPI.

* These may be revised in consultation with DP&I and DPI and other key stakeholders following analysis of natural variability within the pre-mining baseline data.

A8 QUALITY ASSURANCE AND QUALITY CONTROL PROGRAM

The water quality monitoring programs for both surface waters and Hawkesbury Sandstone groundwaters shall be operated strictly in accord with international Standard Methods (APHA/AWWA/WEF, 1998), State guidelines (DEC (NSW), 2004), and with national i.e. National Association of Testing Authorities guidelines and specifications and industry best practice with respect to quality assurance and quality controls.

All sample containers for laboratory water analysis must be those supplied by the testing laboratory specifically for the particular purpose. No other type of bottle may be used. No bottle may be used which does not have a label asserting that the container is ‘fit for purpose’ for the type of sample collected therein.

All sample labels must be fully filled-in with respect to date and location and that shall include an identification of the sampler. If the label has a checking box that shall be checked as appropriate. No bottles may be cleaned and reused by those conducting the field collections.

No sampling shall be conducted in a manner that results in the concurrent expelling of preservative contained within the sample bottle. Samples shall be collected in an order which blocks contamination of any subsequent sample by any accidentally expelled preservative.

Every batch of surface i.e. stream or pool or groundwater quality samples of 9 or more shall also contain, alternately at least one field blank or one replicate as the 10th sample.

Field Blanks must be made using the particular type of demineralized and decontaminated water supplied by the testing laboratory for that purpose. No other type of demineralized water may be used. The Field Blanks shall not be identified as a blank but shall be labelled Q1 or Q2 to indicate it is a quality control sample.

Replicates shall be collected at least once per 18 samples and Field Blanks shall be collected at least once per 18 samples. Replicate shall not be collected repeatedly at the same site and shall be rotated through all sites during the course of a year or so.

Water samples for laboratory checks of pH, EC and major cations shall always be collected with no headspace in the sample, chilled as soon as possible and transported to the testing laboratory in that state. Groundwater samples for C1 – C4 hydrocarbon gases (methane, ethane etc.) shall always be collected with no headspace in the sample, chilled as soon as possible and transported to the testing laboratory in that state.

All surface and groundwater water quality samples sent to a laboratory for any form of testing shall be accompanied, with one copy in each and every Eskie by a full and complete Chain of Custody (CoC) sheet which identifies that chain of transfer between individual persons to the laboratory, the nature of the testing, the appropriate order number and quotation number and all relevant address and contact details for consignment tracking and the reporting of results.

All service companies providing contracted services which form part of this WMMP i.e.:

- installation, maintenance and data retrieval from hydrographic flow gauging stations and weather stations;
- installation, maintenance and data retrieval from soil moisture probes;
- installation, maintenance and data retrieval from shallow piezometers;
- installation, maintenance and data retrieval from deep piezometers in Hawkesbury Sandstone;
- installation, maintenance and operation of low flow bladder pumps for obtaining groundwater samples,

are expected to maintain individual company Quality Assurance and Control Programs to ensure best practice conduct, excellence and high quality of data gathered.

Each service company shall provide and maintain documentation of such a Program including the recording of all internal checks and tests in accord with best practice. Evidence of such a Program and documentation of all checks and tests shall be made available to BHPBIC upon demand at any time.

A9 MANAGEMENT AND MITIGATION PROGRAM

In the event, considered by Ecoengineers to be unlikely, that future water monitoring shows that there has been significant hydrologic or aquatic ecotoxic effects within any Area 3B catchments then it is possible that some management and mitigation measures may be required.

Management measures may involve alterations to the disposition of the area of extraction of a current longwall or agreed modifications to the orientation and/or disposition of succeeding longwalls.

Where SCA is the controlling authority of a public land, above ground management and mitigation works are subject to approval from the SCA to enter the land to undertake any works therein.

SCA land is described as Schedule 1 or Schedule 2 land where Schedule 1 refers to land immediately surrounding the water storage and Schedule 2 lands are areas surrounding storages in which the SCA has a major management interest. In these areas, approval to access these areas to undertake works must be sought from the SCA. For any works on SCA land there is a requirement for compliance with the SCA Water Supply Catchment Special Areas Standard Conditions for Entry (SCA, 2001). These requirements ensure strict limits are placed on any impacts associated with undertaking rehabilitation works on SCA land.

With respect to possible remediation of the effects of excessive acid and metals generation through upsidence fracturing of stream bedrock and/or rock bars, liming of excessively acidic streams and rivers in Scandinavia, north eastern USA and south eastern Canada has been practiced and has been intensively studied since the early 1970s (Olem, 1991).

It is now very well understood and is generally the technique of first choice for aquatic ecosystem restoration under stress from acidification and heavy metals (Clayton et al. 1998; Appelberg and Svenson, 2001).

These treatments would be considered as a contingency measure and could use a granular agricultural grade limestone (calcium carbonate; $CaCO_3$) to treat any proven point of chronic emergence of acidic, Fe and Mn-rich upsidence-induced sub-bed diversion flows, especially if such pools were located within Donalds Castle Creek or Wongawilli Creek or say within 250 m of Lake Avon. Noting that:

1. the estimated maximum daily rate of acid generation in any discrete sub-bed flow diversion zone is of the order of 100 mole H_2SO_4/day which is equivalent to 100 mole $CaCO_3$/day to completely neutralise it; and
2. experience in Native Dog Creek over the nearby Elouera Colliery founded on closely similar Hawkesbury Sandstone terrain and at other mining-affected locations in the region shows that this maximum possible peak rate is not sustained for any more than a few months (Ecoengineers, 2003, 2004),

this load of acidity is only equivalent to a limestone demand of 10 kg $CaCO_3$/day or (say) one tonne for a three month period.

This could not possibly lead to any exceedance of the hardness and alkalinity limits for freshwaters in the National Water Quality Guidelines (ANZEC/ARMCANZ, 2000) or for Bulk Raw Water supply and hence would not adversely affect waters in Lake Avon.

Emplacement of limestone at any such location would:

1. provide a continual reactive surface for the neutralisation of excessive acidity;
2. encourage the localised precipitation of Fe and Mn hydrous oxides with consequent adsorptive removal of potential ecotoxic trace metals; and
3. increase the hardness of the water and encourage rapid settling of dispersed sodic 2:1 layer clays accelerating the rate of natural remediation of cracks in the bases of the pools.

It is noted that limestone is relatively insoluble except when pHs fall below about pH 8.0 and the dissolved products (calcium and carbonate alkalinity) are completely non-toxic, would have no effect on Bulk Water Supply quality and hence would not adversely affect waters in Lake Avon or Cordeaux River (into which Wongawilli and Donalds Castle Creek flow).

With respect to excessive precipitation of hydrous iron and manganese oxides and the consequent generation of local acidity (but not heavy metals) such as could occur through the induction of ferruginous springs, it is noted that this occurs as a result of reaction with atmospheric oxygen. This implies that; if the precipitation/acid generation effect occurs too far down slope from the spring and hence impacts on a pool or inshore ecosystem in Lake Avon, the location of the zone of maximal oxygen can be moved upslope closer to the spring source.

This would involve the deposition of heavy local sandstone rocks and boulders closer to the spring. This material could usually be obtained from local Hawkesbury Sandstone outcrops nearby and moved to the spring emergence point by manual labour. The effect of this would be to greatly increase turbulence and hence rates of oxygenation, precipitation of hydrous oxides and acid generation allowing natural effects downslope to play a greater role in amelioration of the effects of the spring.

Modification of drainage line and stream hydrology by deposition of boulders and local rock ‘rip rap’ and/or neutralisation with modest masses of limestone rock are accepted ‘green engineering’ methods widely employed worldwide in the mining and quarrying industries for improvement of environmental performance.

Such methodologies would not be environmentally incompatible with their potential deployment within SCA Special Areas in the event an adequate body of data obtained under the WMMP identified such mitigation measures were merited.

APPENDIX B:
HYDROLOGIC MODEL FRAMEWORK AND CONTEXT

B1 CATCHMENT HYDROLOGIC MODEL

The Free University of Amsterdam RUNOFF2005 hydrologic model was assessed six years ago as being most useful for the hydrologic assessment of these catchments (Ecoengineers, 2006). This is the last version released before the developer Prof. Adriaan Van der Griend retired. RUNOFF2005 model treats the catchment as a single similar unit and does not differentiate the catchment spatially into different spatial runoff source areas, i.e. it is a simple, parsimonious non-distributed hydrologic model particularly suitable for modelling small catchments from <1 km^2 up to about 25 km^2 which has been widely used though a number of versions in alpine areas in Europe for over 30 years (Van der Griend et al. 1985, 1986, 2002, 2003; Seyhan and Van der Griend, 1997).

Distributed models are primarily developed for forward modelling and usually cannot be used for model inversion due to the large number of (inter-dependent) parameters. A lumped parameter approach, applied to the proper scale of the issues of concern i.e. longwall scale gives better insight into the dynamic of the system than over-parameterized distributed models.

Figure B1.1 shows a schematic of the conceptual catchment hydrological cycle that is the basis of the RUNOFF2005 model used to assess hydrographic flow data (Van de Griend et al. 2002).

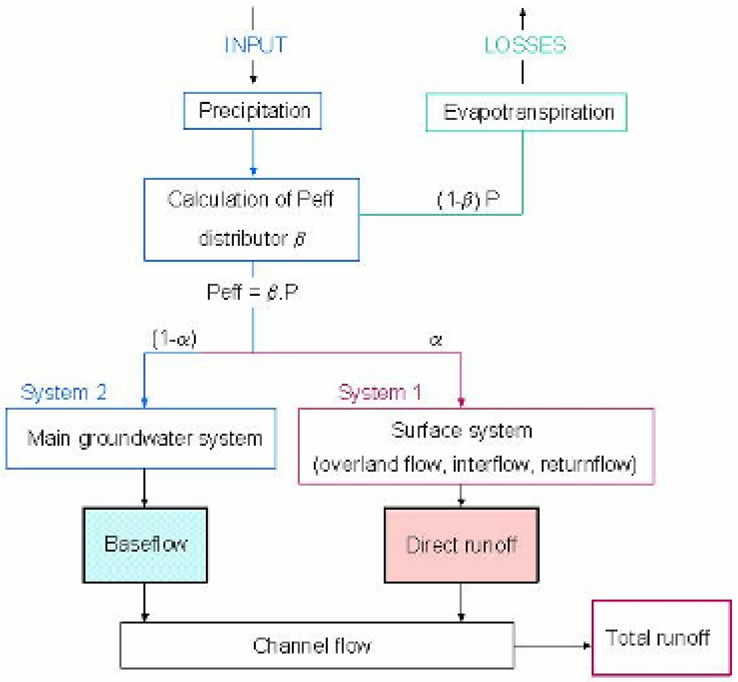


FIGURE B1.1: SCHEMATIC OF THE CATCHMENT HYDROLOGICAL CYCLE FORMING THE BASIS OF THE RUNOFF2005 Model.

In order to conduct model catchment calibrations for these catchments, all flow data is first converted from ML/day to mm per hourly interval, based on the respective catchment areas. Flow data is then converted to daily total discharge rates (mm/day) to remove an observed diurnal cycle in the 6 hourly data arising from the diurnal variation in evapotranspiration (ET).

The RUNOFF2005 model parameters are as follows:

- J_d = reservoir coefficient of the catchment quick flow (mostly direct runoff, plus some interflow and return flow) system (units of days). This is also known as the characteristic time of response or e-folding discharge time over which 1/e or 63% of the available quickflow outflows past the gauging point.
- J_b = reservoir coefficient of the principal catchment groundwater system (units of days). This is a characteristic time of response or e-folding discharge time over which 1/e or 63% of the available groundwater outflows past the gauging point. This parameter varies with drainage resistance and therefore covers a range of values which the RUNOFF2000 model attempts to reasonably estimate. For a non-linear time-variable drainage resistance, the reservoir coefficient $J_b = A/Q_b^{\mathbf{B}}$ where Q_b is purely groundwater outflow (baseflow) and A and B are dimensionless constants fitted by a standard non-linear optimization technique (Levenberg-Marquardt; Van der Griend et al. 2002).
- alpha (α) = fraction of P_{eff} entering catchment leading to quick flow (i.e. direct runoff, through flow, interflow and return flow). By definition the fraction 1 – α = is an estimate of the fraction of the area of the catchment which leads to infiltration of precipitation (rainfall) to groundwater.
- E(%) = Nash-Sutcliffe model efficiency 'goodness-of-fit' parameter (Nash and Sutcliffe, 1970)
- P_{obs} = observed precipitation (rainfall) daily or over the model simulation period (units of mm/day or mm/total simulation period)
- Q_{obs} = total volumetric flow past the gauging point daily or over the model simulation period (units of mm/day or mm/total simulation period).
- Q_{sim} = simulated total volumetric flow past the gauging point daily or over the model simulation period (units of mm/day or mm/total simulation period).
- dS' = change in storage of all catchment storages (i.e. for both quickflow and groundwater systems) which drain freely under the force of gravity. This parameter is positive if the storages are being net recharged and negative if being net discharged (over the simulation period).
- ET_{sim} = model simulated evapotranspiration (ET) (units of mm/day or mm/year).

B2 SIGNIFICANCE OF RECESSION AND BASEFLOW

Mine subsidence may produce effects of strata dilation and streambed upsidence which have the potential to cause loss of outflow during late stage recession and baseflow periods. During the rising stage, peak stage and early recession stages catchment outflows are invariably too high to be materially affected by mine subsidence-induced flow diversion or losses to deep storage.

A curved semi-logarithmic plot for recessions means that the storage-outflow relationship is non-linear. Such behaviour has long been known in many catchments worldwide (e.g. De Zeeuw, 1979; Erskine and Papaioannou, 1997; Manga, 1999; Wittenberg, 1999; Van der Griend et al. 2002; Troch et al. 2003; Brodie and Hostetler, 2005) and this invariably also occurs in the types of catchments under consideration in this region (Ecoengineers, 2006). For groundwater discharge from a shallow unconfined aquifer, there are three main reasons for this non-linearity (Van de Griend et al. 2002):

- In unconfined aquifers, a falling water table leads to a decreasing effective aquifer thickness (D) and thus to an increasing drainage resistance.
- Horizontal permeability (hydraulic conductivity; K) generally decreases with depth. In unconsolidated rock formations (e.g. Hawkesbury Sandstone) the permeability is strongly determined by bedding planes and interconnecting fractures which usually have a more open structure near the surface as a result of vertical pressure relief while in areas with pronounced relief, lateral pressure relief is directed towards the valleys and may be substantial.
- During prolonged baseflow recessions lower order tributary channels may run dry while only ultimately higher order channels continue their function as draining elements. This implies an increase in distance (L) between the effectively draining divides and/or channels.

Van der Griend et al (2002) specifically designed RUNOFF2005 (and earlier versions) to account for the most likely suite of relationships between the groundwater reservoir coefficient (J_b) and catchment groundwater discharge (Q_b) for different aquifer conditions and drainage conditions as shown in **Table B2.1**. Note c = some constant factor and x = some low single number.

TABLE B2.1 DEPENDENCE OF J_B ON CORE AQUIFER PROPERTIES

Aquifer Properties			
Mean aquifer thickness (D) in relation to actual effective thickness (h)	**Aquifer length to drainage channel (L)**	**Aquifer horizontal permeability (K)**	**Aquifer reservoir coefficient (J_b)**
constant	L = constant	K = constant	Jb = constant
D ~ h	L = constant	K = constant	Jb = $A/Q_b^{1/2}$
D ~ h	L = constant	K(h) = ch	Jb = $A/Q_b^{2/3}$
D ~ h	L α 1/h	K = constant	Jb = $A/Q_b^{1.00}$
D ~ h	L α $(1/(h)^x$	K = constant	Jb = $A/Q_b^{(2+x)/(x+2)}$
D ~ h	L α $(1/(h)^x$	K(h) = ch	Jb = $A/Q_b^{(2x+2)/(x+3)}$

During our hydrologic assessments of the Upper Wongawilli catchment (WWU; 3.211 km2) Lesser Wongawilli catchment (LLW minus WWU; 16.814 km^2) (Greater Wongawilli catchment (20.026 km^2), Upper Donalds Castle Creek (6.219 km^2) and Greater Sandy Creek catchment (7.771 km^2) it was found that all valid hydrographs (i.e. matching periods of daily flow not exceeding the limit of the rating curves with daily rainfall) for these largest catchments could be satisfactorily fitted by the RUNOFF2005 model using a reservoir coefficient (Jb) of the groundwater system with an equation of the form Jb = $A/Q_b^{\mathbf{0.667\text{--}1.00}}$ where Q_b is the baseflow discharge (Ecoengineers, 2011, 2012).

Mathematically, an exponent (of Q_b) in the range 2/3/ - 1 constrains aquifer hydraulic conductivity to being either constant or varying in simple linear ratio to the average head above the drainage base i.e. decreasing with depth (Van de Griend et al. 2002; refer **Table B2.1 above).**

There was no hydrologic indication that there was a major groundwater system associated exclusively with fractured bedrock or alluvial material in the bottoms of the valleys in Area 3B as this would require J_b to lie in the range of a constant (A) through to no more than $J_b = A/Q_b^{0.5}$ (Van de Griend et al. 2002; refer **Table B2.1**).

Baseline hydrologic modelling (see **Table 3.1 Section 3**) indicates that the greater Wongawilli Catchment reporting to WWL has an average direct runoff coefficient (alpha) of about 63% whereas the lesser/downstream Wongawilli Catchment) (WWL-WWU) has an average runoff coefficient of about 68%.

Thus the Upper Wongawilli Catchment reporting to WWU must have an average direct runoff coefficient significantly lower than 63%.

Baseline hydrologic modelling also indicates the reservoir coefficient (J_d) for the direct runoff/quickflow component has a value of approximately 4.812 days for the Greater Wongawilli Catchment and approximately 4.795 days for the Lesser/Downstream catchment area (WWL-WWU) i.e. a very similar value. These values do not include a minor main channel transit time of the order of 0.5 day.

Baseline hydrologic modelling also indicates that the groundwater system reservoir coefficient (J_b) for the base flow system of the Greater Wongawilli Catchment reporting to WWL (which includes the Upper Wongawilli Catchment reporting to WWU) only ranges, on average, over five model runs between ~12 and ~104 days whereas the reservoir coefficient (J_b) for the base flow system for the Lesser/Downstream Wongawilli Catchment reporting to WWL below WWU (i.e. WWL-WWU) ranges, on average, over five model runs from ~25 to ~279 days.

It was therefore concluded that it is throughflow within hillslope aquifers which is driving the delayed (groundwater) recessional flow and baseflow component. This phenomenon has often been observed and studied elsewhere (e.g. Harr, 1977; Sklash et al., 1986).

This conclusion is also consistent with the actual percentage of modern surface water (from rainfall) appearing locally in stream and lake waters as estimated from monthly rainfall tritium analyses obtained by BHPBIC over the last several years which have become increasingly more precise and reliable due to the large number of determinations now to hand and the correct volumetric weighting for monthly rainfall depth (mm).

The body of tritium data for (both) Lake Cordeaux and Lake Avon shows quite clearly that water in both of these lakes contains a minor but significant fraction of groundwater which originated as rainfall in excess of 50 years ago. For Lake Cordeaux this fraction is better known due to the larger number of determinations and is of the order of 10.5±9.8% at the one standard deviation level i.e. it is significantly different from zero.

This observation is confirmed by an extensive suite of tritium analyses we have for the lower end of Sandy Creek (1.695±0.205; n=17) which also indicates that water flowing out of the Sandy Creek catchment into Lake Cordeaux (Sandy Creek Arm) contains significant shallow groundwater more than 50 years old in an estimated proportion of 14.9±10.8% i.e. it too is significantly different from zero.

This also accords with the observation that water in the Sandy Creek Arm of the Lake also contains groundwater more than 50 years old in the estimated proportion of 13.7±7.8% again significantly different to zero.

These data are interpreted to mean that groundwater travelling slowly through hillslope aquifers in the (largely) outcropping Hawkesbury Sandstone of the Sandy Creek catchment provides a small but significant proportion of total outflow from the Sandy Creek catchment more than 50 years old. It is expected that the Wongawilli and Donalds Castle Creek Catchments are no different.

The conceptual and mathematical implications of this important conclusion are investigated further below in **Sections B3 and B4**.

It is useful to note this finding also means that base flow storage for the Lesser/Downstream Wongawilli Catchment reporting to WWL drains at a slower rate (i.e. persists longer) than expected from simple linear scaling-up of the base flow recession of the Upper Wongawilli Catchment (reporting to WWU) by e.g. the ratio of the areas of the upstream and downstream catchment areas because the hillslope aquifers are larger and longer in the Lesser/Downstream Wongawilli Catchment (refer **Figure 3.1).**

B3 SIGNIFICANCE OF EVAPOTRANSPIRATION

In order to operate any derived hydrologic model to produce an overall water balance, evapotranspiration (ET) must be used as the major closure term in making a catchment water balance. Therefore it is necessary to:

- estimate beforehand, with reasonable precision, the mean daily ET that would have operated over the gauging/modelling periods; and
- ensure model outcomes are consistent with that ET.

The Bureau of Meteorology ('BOM') national map for Annual Areal Actual Evapotranspiration for the period 1960 – 1990 suggests local regional catchments should typically have a long term mean annual actual ET in the 700 – 800 mm/year (1.92 – 2.19 mm/day) range:

http://reg.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp#maps

It is known that the index of dryness is the most significant variable in determining mean annual evapotranspiration. Forested catchments tend to show the highest ET and their dryness ratio (ET divided by precipitation) is most sensitive to changes in catchment characteristics for regions with an index of dryness around 1.0 (Zhang et al. 2001), which is the case for the Dendrobium Area 2 and Area 3 catchments.

At CSIRO Land and Water, Canberra, Zhang et al. (2001, 2004) found, following on from extensive earlier Australian studies e.g. Zhang et al. 1999, that mean actual annual ET_a may be well predicted (accounting for about 87% of the variance) from mean annual precipitation (P_a) using an equation which takes into account the proportions of woody vegetation (trees, shrubs, herbaceous species and grasses) covering a catchment as follows:

Zhang's evapotranspiration model is described in Equation 1:

Equation 1

$$ET = \left(f \frac{1 + w_f \frac{E_{of}}{P}}{1 + w_f \frac{E_{of}}{P} + \frac{P}{E_{of}}} + (1 - f) \frac{1 + w_h \frac{E_{oh}}{P}}{1 + w_h \frac{E_{oh}}{P} + \frac{P}{E_{oh}}} \right) P.$$

where:

- ET = total annual evapotranspiration for the catchment in mm,
- f = the proportion of the catchment that is forested (>70% canopy cover),
- w = the plant-available water coefficient (which Zhang et al (2001) determined as 2.0 for forests and 0.5 for short grasses and crops),
- E_o = annual potential evapotranspiration for forested and non-forested areas, Zhang assumed E_o to be constant and determined a value of 1410 for trees and 1100 for herbaceous plants in mm, and
- P = annual precipitation in mm.

The CSIRO Land and Water team's Zhang et al. (2001) paper has one of the highest citation indices in the field of catchment hydrology. The relationships described by the two parts of the above equation are very similar to the empirical curves proposed by Holmes and Sinclair (1986) for Victorian catchments.

The CSIRO Land and Water (Zhang et al. 1999, 2001, 2004, 2007) algorithm as shown above or minor variants of it are now used widely in catchment studies particularly in Australia but also worldwide for the prediction of mean annual ET, to a confidence level with a variance of about 95 – 97%, as an integral element of macroscopic catchment water balances at regional and local land use scale (e.g. Dowling et al. 2004; Keenan et al. 2004, Zhang et al. 2007) using the following values for w:

- 2 for forest plantations, native forests and mature woodland (>70% canopy);
- 1 for native shrub lands and heath lands (excluding swamps), horticultural trees, shrubs and perennial crops;
- 0.5 for annual crops, improved pastures and native grasslands; and
- 0.1 for bare ground and impervious built-up areas.

From the End of Panel report for Area 2 Longwall 5 (Ecoengineers, 2010), **Figure B3.1** below shows matches between the RUNOFF2005 model-simulated ETs (both pre- and post-mining) and the independent CSIRO-predicted ETs predicted on the basis of the CSIRO Zhang et al (2001) algorithm for seven local catchments being:

- the whole of the Sandy Creek Catchment (SCL) (pre- and post-mining);
- the Upper Sandy Creek sub-catchment (SCU) (pre-;
- the so-called Waratah Creek sub-catchment (WC);
- the so-called Fern Tree Creek sub-catchment (FTC),

and, the pre-mining baseline period other sub-catchments (of Sandy Creek Catchment) lying over the developing Dendrobium Area 3 being:

- the so-called Cascade Creek sub-catchment of Sandy Creek catchment (C1) now SC7;
- the so-called Banksia Creek sub-catchment (B1) of Sandy Creek catchment now SC10; and
- a sub-catchment of SC10 sub-catchment, the so-called Banksia Creek Tributary (BCT), now Creek SC10C, which contains the significant upland swamp Swamp 15b.

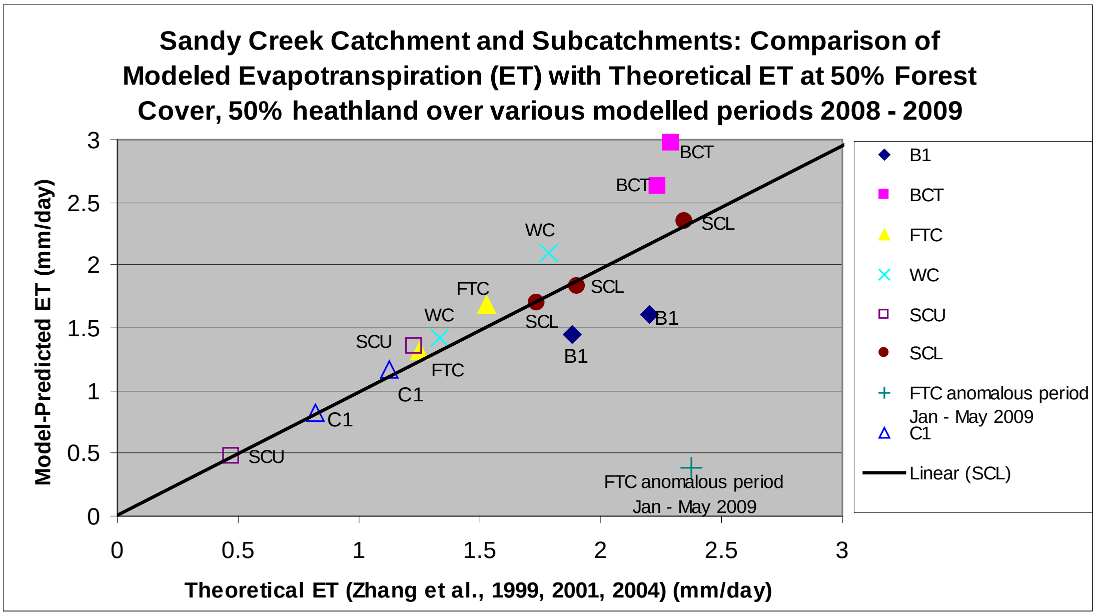


FIGURE B3.1: COMPARISON OF RUNOFF2005 MODELLED AND THEORETICAL ETS FOR GREATER SANDY CREEK CATCHMENT AND SIX SUB-CATCHMENTS.

In the cases of the Greater Sandy Creek Catchment (SCL; 7.771 km^2) and its smaller subcatchments Ecoengineers (2010) assumed that it was a mix of 50% native forest (>70% canopy cover) and 50% heath land with w = 2 and w = 1 respectively. For:

- three modelled periods for the Greater Sandy Creek Catchment (SCL); and for
- two modelled periods each for the Upper Sandy Creek (SCU), and the (Dendrobium Area 3A) subcatchment SC7 (‘Cascade Creek’) catchments,

model-predicted ETs were very close to that predicted theoretically by the Zhang et al. (2001) algorithm for an equivalent average rainfall over the modelled period.

This validated the hydrologic models’ determined ET values and their associated water balances.

For two modelled periods for the small (0.817 km^2) Creek SC10C (Banksia Creek Tributary) sub-catchment it could be inferred (on ET grounds) that the surface of the sub-catchment is comprised of a substantial upland swamp and evaporation from free water surfaces in swampland in this catchment occurred such that significant evaporation rates over and above that due to heath land and forest vegetation alone occurred during the gauged and modelled periods. We found that the ET behaviour of that small catchment approximated the case for a 100% forested catchment.

The precision of the RUNOFF2005 modelled hydrology and the model-predicted ETs for 10 modelled periods for the Greater Wongawilli Creek (WWL) and Lesser Wongawilli Creek (WWL - WWU) has also been validated against the CSIRO Land and Water, Canberra, Zhang et al. (1999, 2001, 2004) algorithm-predicted ET values for a catchment of 100% forest as shown in **Figure B2.2** below (Ecoengineers, 2011, 2012).

The Wongawilli Creek catchments exhibit about a 10% higher rate of ET than a fully forested catchment whereas the upper Donalds Castle Creek catchment exhibits about a 26% higher rate. Upper Donalds Castle Creek catchment has a significantly higher density of headwater upland swamps than Wongawilli Creek catchment (refer **Figure 2.11**).

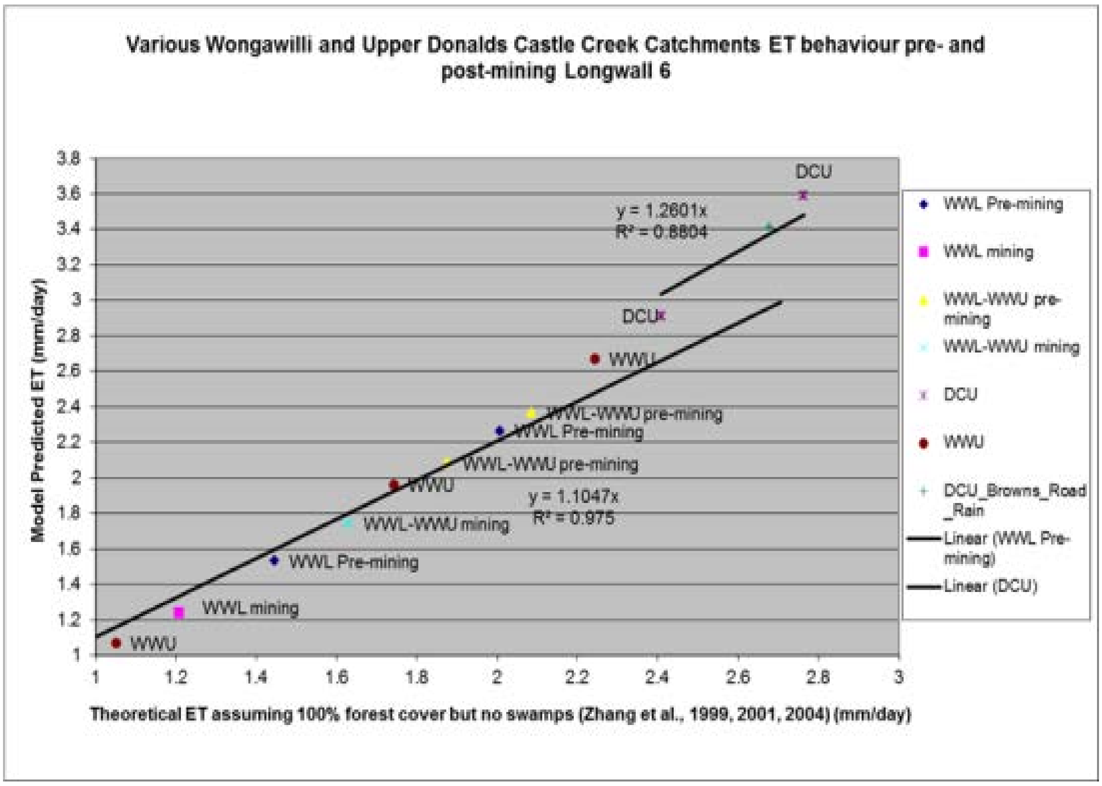


FIGURE B3.2: COMPARISON OF RUNOFF2005 MODELLED AND THEORETICAL ET FOR AREA 3B CATCHMENTS

Table B3.1 below compares the RUNOFF2005 model-predicted ETs for the various (separate) duration model runs used for the run shown in **Figure 2.16** above.

TABLE B2.1: EVAPOTRANSPIRATION (IN MM/DAY) PREDICTED BY THE RUNOFF2005 MODEL AND INDEPENDENTLY BY THE ZHANG ET AL (1999, 2001, AND 2004) CSIRO ALGORITHM FOR BASELINE PRE-MINING AND POST-MINING PERIODS OF WONGAWILLI CREEK

Modelling Period	Model Duration (days)	RUNOFF2005 predicted ET (mm/day)	CSIRO algorithm predicted ET (mm/day)
WWL pre-mining	83	1.387	1.482
WWL pre-mining	155	1.231	1.185
WWL post-mining	61	1.197	1.171
WWL post-mining	97	1.578	1.698
WWL post-mining	66	1.642	1.542
WWL-WWU pre-mining	71	1.510	1.475
WWL-WWU pre-mining	154	1.322	1.367
WWL-WWU post-mining	40	1.765	1.664
WWL-WWU post-mining	90	1.660	1.802
WWL-WWU post-mining	50	1.794	1.732
Duration-weighted Average (mm/day)		1.454	1.471

As can be seen in **Table B2.1** above, individual RUNOFF2005 model-predicted ETs and ETs computed by the CSIRO Zhang et al (2001) algorithm agreed well with the averages for greater and lower Wongawilli Creeks during both pre- and post-mining periods - differing by only 0.017 mm/day (i.e. 1.1%) on average.

Such insignificant differences in the ETs calculated independently by each method provide strong evidence that catchment modelling using RUNOFF2005 is a good basis for obtaining adequately precise catchment water mass balances over any possible model period, before, during or after mining.

B4 SIGNIFICANCE OF HILLSLOPE AQUIFERS

Mathematically, the findings discussed in **Section B1** all imply that the groundwater systems of these catchments involved in generating the baseflows in each creek, while still exhibiting non-linear variable drainage resistance may, to a first approximation, be idealized by a long, narrow triangular configuration i.e. a hillslope aquifer (or aquifers).

This 'hillslope aquifer' may be considered to generally have a maximum extent running from the groundwater divide at the ridgeline or midpoint of an upland plateau down to the creek. Saturated zones must be occurring in the weathered rocks of the plateaus, within the bases of the soil catena of the hill slopes, in the fractured sub cropping sandstone material underlying these and within weathered and/or fractured outcropping sandstone.

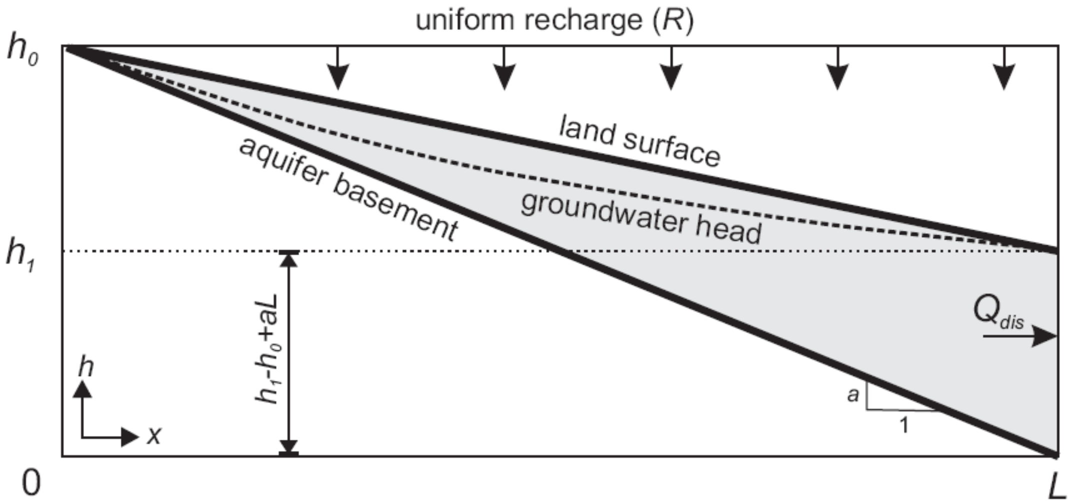
This led us to investigate conceptually the consequences to the critical (to discernment of mine subsidence-related effects) baseflow characteristics of these catchments being generally driven by a hillslope aquifer by considering the scalar and geometric behaviour of an extended idealized hillslope aquifer system in these two catchments.

This hillslope aquifer system was considered to be essentially two-dimensional, with no plan convergence/divergence. The system was considered to essentially have a uniform basement slope (a) over an effective aquifer length (L) (Aryal et al. 2003)) with an aquifer thickness of zero at the upper end, increasing monotonically to a thickness at the aquifer outlet (h_1-h_0 + aL).

The ground surface was considered to have a uniform ground surface drop (h_o-$h_{1)}$ where h_0 is the elevation at the upper end, and h_1 is the elevation at the aquifer outlet. To a first approximation, the aquifer may also be considered to be homogeneous, isotropic and unconfined, with a constant uniform bulk hydraulic conductivity (permeability) K. The aquifer is considered to receive a uniform recharge R and discharges at the boundary which is set at the ground surface of the creek. The total flux Q_{dis} to the outlet of this groundwater system is the key variable of interest.

Figure B4.1, reproduced from Walker et al (2005), provides an idealized picture of a hill slope aquifer.

FIGURE B4.1: IDEALISED HILLSLOPE AQUIFER CROSS SECTION



Walker et al. (2005) showed that the overall range of behaviours of the above idealized analogue of a aquifer system which slopes from a ridgeline down to a draining stream can be explained using two non-dimensional variables (B, G) where:

$$B = \frac{h_0 - h_1}{h_1 - h_0 + aL}$$

$$G = \frac{K(h_0-h_1)(h_1-h_0+aL)}{RL^2}$$

Increasing G corresponds to decreasing recharge, while increasing *B* corresponds to a steeper, thinner aquifer.

Aquifer properties such as elevation changes, flow length, aquifer transmissivity, and recharge can all be collapsed into a dependency upon B and G.

Walker et al. (2005) showed that the relationship between the aquifer's non-saturated volume, its recharge (and hence discharge) is approximately linear for the idealized groundwater analogue. They also showed that both the proportionality constant (E) for this relationship and the intercept at zero recharge (D) can be approximated with respect to the non-dimensional variable B.

The combination of this linearity and quasi steady-state catchment conditions leads to an exponential change (i.e. non-linear) in discharge with respect to time.

Their assumption of quasi steady-state was found to be valid by cross-checking using the CSIRO numerical catchment groundwater model FLOWTUBE (Dawes et al. 1997, 2001). Walker et al. (2000) found the relationship between aquifer saturated volume and 1/G appears to be linear for each value of B.

In terms of transient aquifer response to changes in recharge, instead of working with groundwater discharge (Q_{dis}), a normalized groundwater discharge function may be used. This function is associated with the response of the groundwater system and is given by the ratio of 'change in aquifer discharge' to 'change in recharge over the catchment'.

Due to the time delay between a change in recharge R_0 -> R, and a subsequent response in discharge, this functions starts at time = 0. As the aquifer responds towards a new equilibrium, the outputs should asymptote to the inputs, and hence the normalized discharge function should approach a value of 1. Because of these properties, the use of this function allows the comparison of the response of groundwater systems, regardless of catchment area and recharge rates.

For any catchment where recharge is uniform across the catchment (e.g. the idealized groundwater analogue), the normalized discharge function simplifies to the following form:

$D(t) = (Q_{dis} – LR_0)/((R-R_0 0)L)$

The discharge function (D(t)), and hence time response can be predicted in relation to various catchment characteristics.

Walker et al. (2000) have shown that, for an idealized groundwater system, this discharge function is exponential in shape with respect to time and the timescale associated with exponential behaviour is related to aquifer characteristics in a predictable manner. The solution to the discharge equation for a hillslope aquifer is thus:

$Q = RL – (R-R_0)L\exp(t/J_{\mathbf{b}})$ where

R = recharge over the period of interest

R_0 = recharge at time t = 0

L = length of the aquifer

J_b= the groundwater system reservoir coefficient (or e-folding characteristic time of response) i.e. *it is exactly equivalent to the RUNOFF2005 model groundwater reservoir coefficient* J_b.

To explore this relationship further, Walker et al (2005) also defined the following non-dimensional constants: E* and D*. These provide respectively; the slope and intercept of the relationship between aquifer saturated volume and 1/G. D^* is the saturated volume of the aquifer when there is no recharge (i.e. the aquifer volume below the level of the creek boundary condition). This can be shown simply as being:

$D^* = 1/(2(1+B)$

The relationship between B and E* was calculated for the idealized groundwater analogue. This was done by holding B constant for a range of recharge values (R), (thus changing values of 1/G). These values of 1/G were plotted against aquifer storage, and the slope of this line (E^*) was calculated. By solving the analytical solution for several B values, the relationship between B and E* was determined.

It was found that both E* and D* vary monotonically with B, with E* increasing and D* decreasing. This relationship is steeper for lower values of B (B<1), and flattens out for higher values of B. Walker at al. (2000) found two approximations for the E*(B) relationship in which:

1. A logarithmic regression gives a very reasonable fit across the range of values, although care should be used when dealing with very low values of B (i.e. B<0.1).
2. An approximation of E* in terms of B alone provides a reasonable fit, particularly for lower values of B (B<1) where $E^* \sim B/(2(1+B))$.

The groundwater characteristic timescale of response (Jb) is proportional to aquifer specific yield (S), also known as effective porosity, aquifer flow length (L), aquifer bulk lognormal mean horizontal permeability (K) and slope (S) of the aquifer unweathered basement as given by:

$$Jb = \frac{L^2SE^*}{K(h_o-h_1)}$$

$$\sim \frac{L^2SB}{K(h_0-h_1)2(1+B)}$$

$$= \frac{SL}{2Ka}$$

Lower values of B imply that the groundwater response time will be controlled by lateral pressure transmission. Higher values of B imply the groundwater response time will become dominated by hill-slope processes.

For a steeply sloping case (i.e. high B) the time-scale related to the discharge function becomes that for a sloping aquifer, while for a flat aquifer (i.e. low B) the timescale becomes that for a horizontal aquifer. The E*(B) parameter smoothly changes the time-scale to allow for the relative dominance of whichever of the two lateral groundwater processes are most important in any particular case.

The saturated volume of the aquifer is linear with respect to 1/G, so that as G becomes smaller, the saturated volume of the aquifer i.e. the resistance of the aquifer to recharge becomes larger, and hence the more likely it is that the groundwater surface will intersect the land surface. Where this occurs it leads to discharge at the surface.

By collapsing the number of parameters to two (B and G), these non-dimensional parameters show the correlation between all the independent aquifer parameters (K, h_1, h_0, L, S, R, R_0). They reveal the important emergent properties, such as the time-scale for groundwater response. This in turn shows the parameters explicitly and simplifies any sensitivity analysis.

One of the most important advantages of the non-dimensionalization carried out by Walker et al. (2000) is that it separates the scaling arguments from the geometric effects.

This allows prediction of how scaling effects (e.g. L, K, S, a) will impact on aquifer response time.

Geometric effects are likely to require more detailed site investigation and are harder to estimate, and are dealt with by the E*(B) parameter. The equation presented above illustrates this, as the time-scale is related to both scaling effects (e.g. S, L, K, h_0 and h_1), and geometric effects (E*).

Many of the scaling arguments can be captured for the broader landscape through an understanding of different types of groundwater systems and how these relate to common average bulk catchment characteristics (e.g. K, L).

However this is not the case for geometric effects. Geometric effects are more difficult to incorporate in a model without doing an intensive catchment investigation which is designed to capture variations in factors such as the hydraulic conductivity changes along the flow path.

In the absence of discharge to the land surface, the groundwater response time-scale will be related to L^2, 1/K, S, 1/d (where d is the thickness of the aquifer at the draining creek) or $1/\Delta h$.

There are obviously many complications relating to geometry (i.e. landscape topography) which will distort this time-scale, but for a given overall shape and properties, these basic mathematical scaling relationships will be preserved.

The idealized groundwater analogue described by Walker et al. 2005, and outlined above captures the important scalar parameters of actual, sloping hillslope aquifer systems. In the Woronora Plateau context, this provides a basis for beginning to analyze gross groundwater responses to changes in landscape behaviour such as those which may be induced by mine subsidence.