SURFACE WATER QUALITY
AND HYDROLOGY
ASSESSMENT

DENDROBIUM MINE AREA 3

for

CARDNO FORBES RIGBY PTY LTD

September 2007

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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	Signature:				Stephen A Short

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

BHP Billiton Illawarra Coal (IC) seeks to:

- apply 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
- submit a Subsidence Management Plan for part of Area 3 referred to by Illawarra Coal as Area 3A;

To support the submissions referred to above, IC has commissioned a Surface Water Quality and Hydrology Impact Assessment for the proposed mining in Dendrobium Area 3A (for which a mining layout is defined) and Areas 3B & 3C (for which a mining layout is not fully defined due to uncertainty regarding the area's geology).

Surface Hydrology Assessment

The hydrologic impacts of mining longwalls directly under Native Dog Creek and upper Wongawilli Creek in the vicinity of Area 3 have been studied since 2001 and a general understanding of the surface, shallow and deep groundwater hydrologic systems has emerged. All studies to date confirm there is no rdeep aquifer in the bulk of the Hawkesbury Sandstone within Dendrobium Area 3. Surface and near-surface groundwater hydrologic systems are believed to be well separated from any longwall mine workings by a number of well recognised aquicluding claystone units as well as relatively tight sandstone strata.

Prior hydrologic studies of Native Dog and Donald's Castle Creeks as reported in Ecoengineers (2006b) 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 connected to any deep water-bearing strata although there is some field evidence that they are more productive in a north-easterly direction towards Lake Cordeaux, consistent with the dip of the Nepean Monocline. From hydrographic recession analysis, characteristic times of response of these hillslope aquifers have been shown to range from a few years to in excess of 50 years. Tritium isotope evidence from Lakes Cordeaux and Avon confirms these lakes have significant fractions of water which have passed through such hillslope aquifers.

Those prior studies also suggested that there was no evidence that the overall Native Dog Creek catchment (located just south of Dendrobium Area 3B) suffered any significant net loss of water to deep (unrecoverable) storages due to longwall mining by Elouera Mine, despite significant instances of creek bed fracturing in this Creek and in Wongawilli Creek.

Longwalls in Area 3 will be sited well back from major creeks such as Sandy Creek and Wongawilli Creek to a distance that has been, and will be guided in future, by priori subsidence modelling, to avoid significant cracking and surface water loss in these creek beds. Due to the standoffs of Area 3 longwalls it is not expected that any significant fracturing and sub-bed flow diversions will occur in Sandy Creek or Wongawilli Creek or that there will be detectable losses of outflows from these catchments.

Subsidence Induced Erosion Issues

Ground movements caused by mine subsidence may increase erosion and loss of soil materials through rock falls, or fissure opening in cohesive surface soils. Minor

rock falls and surface soil cracking occurred as the result of mining Dendrobium Areas 1 and 2.

Monitoring and inspection by IC and its consultants for Elouera Mine shows there has been no evidence of sustained subsidence-induced erosion of the valley slopes of Wongawilli Creek and its tributaries during the past seven year monitoring period, even during the recent high rainfall period of the first 6 months of 2007. Cliff lines associated with Wongawilli Creek are no larger than those that have been previously mined under in Dendrobium Areas 1 and 2. Slopes are no steeper or more extensive than those that have been previously mined under in Areas 1 and 2 and 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 3 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 recent 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 mined under stretch of the watercourse, 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 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 from immediately downstream.
4. Leaching of aluminium from kaolinite by acidic water flowing through the fracture network.

It has been demonstrated that, subject to predictive 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 achieved. Recent examples of such reductions in impact include Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River and West Cliff Area 5 Longwalls 29 and 31 adjacent to Georges River.

Dendrobium Area 3A Longwalls 6 to 10 will not mine under Wongawilli or Sandy Creeks by distances 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 report by Mine Subsidence Engineering Consultants (MSEC, 2007). We understand this mine planning approach will also be employed for future mining in Areas 3B and 3C. On this basis we conclude it is unlikely that the mining of Area 3 will lead to significant Creek main channel bed fracturing and subsequent sub-bed diversion hydrologic and geochemical effects in Sandy Creek and Wongawilli Creek.

MSEC (2007) 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 the drainage lines.

There is some evidence from the local area that these predictions are relatively conservative. This is based on local experience over Longwalls 1 and 2 in Dendrobium Area 1 where, out of 6 main tributaries with Maximum Predicted Systematic Tilts, Maximum Predicted Tensile Strains and Maximum Predicted Compressive Strains along their channels of the order of 20, 4.0 and 9.0 mm/m respectively, only one (designated No. 22) exhibited fracturing. Geochemical studies also indicated the fracturing was minor and of limited duration. We infer from this that, while fracturing in Creek SC10 possibly has higher probability; the probability of a similar effect in Creek WC17/17A may be no more than about 15%.

Most of the baseflow in the lower Creek SC10 tributary of Sandy Creek (Banksia Creek) derives from Swamps 15A and 15B, which lie along relatively weakly incised tributaries. Field studies show that baseflows in Sandy Creek derive from outflows from significant hillslope aquifers on both the western (Area 3A) and eastern (Area 2) sides of the Creek and a broad un-mined southern area in Upper Sandy Creek. Mining under the SC10 (Banksia Creek) and SC7 (Cascade Creek) tributaries of Sandy Creek is likely to result in only marginal changes in several water quality parameters near their points of discharge into Lower Sandy Creek. Due to these broad scale sources of baseflow, downstream water quality impact is predicted to be insignificant.

Minor fracturing is also possible on the longer, more incised, high gradient tributaries of Wongawilli Creek in Area 3B e.g. creeks designated WC15 and 21, and possibly in Area 3C in the well incised creeks designated LC6 and LC7 of Area 3C which drain to Lake Cordeaux. It is considered any such fracturing is unlikely to cause significant downstream water quality impacts.

Ferruginous Springs

Induction of ferruginous springs as a consequence of upland subsidence has been identified over the last three years as a longwall mining-related effect in the Southern Coalfield in subcatchments 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; and
- 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 upland subsidence occurs as a consequence of longwall mining, delamination, dilation and an interfacial permeability enhancement may occur at sub-horizontal interface between a sub-cropping Hawkesbury Sandstone and an outcropping Wianamatta Shale sequence.

A substantial portion of Area 3B is mantled by Wianamatta 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. One or more ferruginous springs may be induced in 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 ephemeral creeks potentially involved and the substantial dilution and dispersion that would occur at the Lake Avon shoreline. Notwithstanding, specific water quality monitoring sites would be located in this part of Area 3B to provide early detection and ongoing assessment of this potential effect. Drainage of the Wianamatta Shale-based soil uplands to the northwest to tributaries of Donald's Castle and Wongawilli Creeks occurs over much longer distances of far gentler slopes and there are numerous intervening hanging 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 and their effects be largely attenuated by those landscape features.

Swamps

There are a number of large swamps within Area 3. These swamps have been mapped and are described as Swamps 1a to Swamp 35b. We believe it is important to 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. The first Type 1 or 'braided stream 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 prior drying and/or bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.
2. The second Type 2 or 'hanging swamps' occur within broad scale, relatively low slope creek or tributary headwater areas. A significant body of evidence indicates that most, if not all Type 2 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).

Type 1 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. Downstream Type 1 swamps 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) as Swamps 2, 5, 7, 8 and 15a. 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 it is recommended that monitoring and assessment be undertaken during period(s) when (and if) longwalls in Areas 3B and 3C mine beneath them.

Fracturing due to subsidence effects may become physically detectable at a central drainage line rock shelf or knick points in Type 2 swamps, but such fracturing is likely to be confined to 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 likely to be insignificant in terms of geochemical and/or hydrologic impacts. In our view, hydrologic effects on this type of swamp from longwall mining are only likely to be significant where longwall mining subsidence-related effects induce some significant hydrogeologic change to a broad scale subcatchment shallow hillslope aquifer.

While it is considered unlikely on the basis of past experience that mine subsidence-induced hydrologic effects would adversely affect these Type 2 swamps and more particularly the substantial hill slope aquifers in which they are generally likely to be embedded, it is recommended that frequent monitoring and assessment be undertaken during any period in which longwalls in Areas 3A, 3B and 3C approach or mine under them.

Several large upland swamps occur in the headwaters of creeks designated WC17 and SC10 (Banksia Creek) over Area 3A. Swamp 12 is of Type 2 and Swamps 15a and 15b of Type 1. Several creek flow and/or water quality monitoring sites are proposed for Area 3A, which lie immediately downstream (in Wongawilli Creek and Banksia Creek) from these swamps. Strongly differential rates of subsidence along these swamps are not expected with the exception of one or two locations in Swamp 15a near Longwall 9 Main Gate 9 and Longwall 10 Tailgate 10. Swamp 12 is largely offset from its draining stream and Swamps 15a and 15b lie in the headwaters of their draining streams. It is not expected these swamps would be susceptible to scour under high rates of runoff unless very significant fire damage or other prior major disturbance had occurred.

Water Quality Impacts on Water Supply Reservoirs

Any input of water-borne contaminants (to Lakes Avon and Cordeaux) 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) and LC6, LC7 and LC8 (Lake Cordeaux) during mining of Areas 3B and 3C respectively. These creeks are all remote from their respective dam off-takes and outflows. Such zones would be localised to around the point of input to the Lakes 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, it is also considered highly unlikely that there would be any adverse effect on bulk drinking water supply quality in the Lake Cordeaux or Lake Avon systems. It is concluded that the Area 3 development would be compatible with raw water supply quality standards for the Lake Cordeaux and Lake Avon systems.

Water Monitoring and Management Plan

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

The proposed hydrographic monitoring and hydrologic interpretation of the Plan is considered best practice for the detection of potential near surface hydrologic impacts of mine subsidence, both within creek lines and in the broader subcatchments. Detail of the hydrologic theory and modelling and assessment approach proposed are given in **Section 2.6 and Appendix B** of this report.

It is proposed water quality-related field studies concentrate in the first instance on regular monthly visitations to main channel water quality/flow sites, main channel vicinity sand apron piezometers, upland piezometers not within, but surrounding and downstream of hanging 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.

Secondary and principal water quality TARPs initially adopted for Area 3A would be those previously established for Dendrobium Area 2, namely pH declines of 1.5 and 2.0 pH units, Electrical Conductivity increases of 50 and 100 µS/cm and Oxidation Reduction Potential declines of 150 and 200 mV. These would be reviewed following collection of additional baseline data. Additional water quality monitoring sites will be established for obtaining baseline data well prior to the mining of Areas 3B and 3C (in that order).

A key aspect of the Plan deals with the early detection, and subsequent investigation and assessment of upsidence effects within tributaries. It would be non-productive and unsafe to establish *a priori* regularly visited water quality monitoring sites within tributaries until evidence was detected for geochemical change in a main channel. Properly sampled, and analysed, geochemical data is very sensitive and has invariably proven to be the most reliable early indicator of the onset of subsidence-related water effects. The location of main channel monitoring sites would sited be downstream of confluences with key 'candidate' mined under 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 which are judged to be possibly a consequence of tributary subcatchment subsidence-related effects, investigation of the subcatchment water quality and hydrology would then be initiated. It is proposed 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; and
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; and if necessary
3. deployment of portable Doppler flow meters to a gauging site above the confluence of the tributary and creek main channel to obtain quantitative flow data through several storm events for hydrologic assessment.

In the event that future water monitoring shows that there has been significant hydrologic or aquatic ecotoxic effects within Area 3 catchments then it is possible that some management and mitigation measures may be required. Management measures may simply 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. Some potential water quality management and mitigation measures believed to be compatible with the Metropolitan Special Catchment Area are identified.

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 Area 3 using longwall mining techniques.

IC has previously extracted Longwalls 1 and 2 in Area 1 at the mine and has approval to extract Longwalls 3 to 5 in Area 2 at the mine. An application to extend the length of Longwall 5 and to add a further longwall (LW5A) in Area 2 has been submitted for approval. At the time of this report IC is extracting Longwall 3.

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 Impact Assessment report has been commissioned by Cardno Forbes Rigby on behalf of IC to provide the water-related (near-surface hydrologic and water quality) component to the Environmental Assessment required for the revised Area 3 footprint under Section 75w of the Environmental Planning and Assessment Act.

This requires the assessment provide a general surface water-related hydrologic and water quality Impact Assessment for all major creeks, their tributaries, swamps and shallow aquifers in Area 3.

It is also necessary to consider and assess downstream and ‘far field’ effects within Lake Cordeaux and Lake Avon, in accord 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 more than 10 years.

Ecoengineers Pty Ltd (‘Ecoengineers’) was commissioned by Olsen Environmental Consulting Pty Ltd on behalf of IC in late 1999, to study the mining proposals, to prepare water-related impact assessments for the proposed Longwalls 1 to 18 at Dendrobium Mine, and to identify and prepare detailed water related assessments for all 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 Pty Ltd., 2000).

In addition, the Dendrobium Commission of Inquiry 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 support specific papers for IC and also a standalone submission to the Dendrobium Commission of Inquiry which, amongst other matters, also dealt with water-related matters associated with Area 3 Ecoengineers Pty Ltd., 2001).

Numerous published, public domain water quality, geomorphological and ecological studies and assessments previous conducted in relation to:

- IC Elouera Mine to the immediate southwest of Dendrobium Area 3; and
- the General SMP Areas of Dendrobium Areas 1 and 2 ,

and their adjacent environs, have been drawn upon in the preparation of this report.

This report also supports the Subsidence Management Plan (SMP) application to mine the Longwalls 6 to 10 in Area 3A at 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 from the finalized longwall layout of Area 3A.

Consent for Dendrobium Area 3A will require a Water Monitoring and Management Program to be in place within one year of the commencement of longwall mining. It is required that the Program shall include the following activities:

- A surface water budget of streams that may be affected by subsidence so that any loss of water can be predicted and quantified.
- Relationships of water levels to ecological processes such as fish migration within streams and between Lake Cordeaux and streams subject to mining subsidence.
- Description of the water quality and flow characteristics of streams that may be affected by subsidence.
- Hydraulic characteristics of overlying and intercepted groundwater systems, and changes to ground/surface water due to coal extraction and dewatering operations.

A comprehensive report has been prepared by Mine Subsidence Engineering Consultants Pty Ltd (MSEC, 2007) on the assessment of mine subsidence in relation to Area 3 and more particularly Area 3A for which the longwall layout and mining domain has been defined by BHPIC.

The MSEC (2007) report refers to a General Study Area for Area 3 as a whole and, for Area 3A only a General SMP Area.

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

The following pertinent reports have also been prepared concurrent with this one:

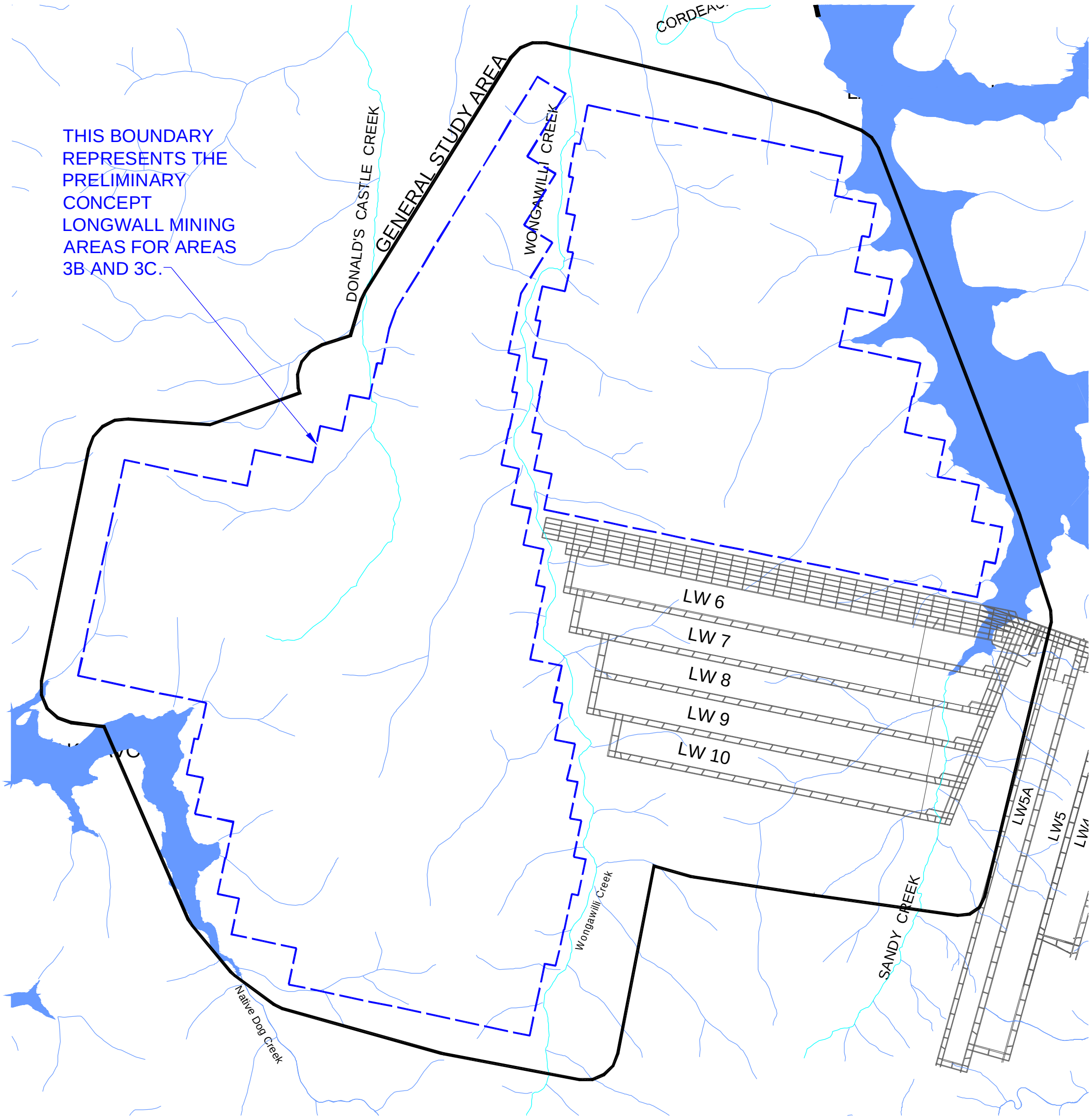
- Landscape Impact Assessment: Cardno Forbes Rigby, 2007;
- Flora and Fauna (including Species Impact Statements): Biosis Pty Ltd, 2007; and
- Aquatic Assessment: The Ecology Lab Pty Ltd, 2007,

This report draws on some of the key findings published in the Cardno Forbes Rigby, 2007, Biosis Pty Ltd, 2007 and The Ecology Lab, 2007 reports to which, where relevant, cross reference should be made.

We provide in **Appendix A** a Water Monitoring and Management Plan for the Area 3 SMP. This Plan covers principally the Area 3A stage of the development and will require some extension for the applications to mine the future longwalls in Areas 3B and 3C. The monitoring program of the Plan presented is based on a design philosophy primarily directed towards providing, in the short term:

1. a comprehensive baseline hydrographic database for Area 3A; and
2. a comprehensive baseline water quality database for Area 3A ; and
3. a hydrographic infrastructure for the whole of Area 3.
4.

FIGURE 1.1: GENERAL STUDY AREA AND MAXIMUM LONGWALL MINING DOMAINS OF AREA 3.



1.1 RELEVANT PRIOR WATER-RELATED 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 monthly campaigns at a significant number of sites in both Wongawilli Creek and Donald's Castle Creeks. Those studies were made in connection with the water-related environmental monitoring of the mining beneath and adjacent to Upper Wongawilli Creek of longwalls 5 through 10 of the IC-owned Elouera Colliery and more recently Longwalls 14 and 17 for Delta Colliery, the new name for Elouera Colliery. They were also carried out to provide baseline water quality data in respect of the proposed future mining of Dendrobium Area 3.

In addition, throughout that period, IC itself conducted similar water quality monitoring of a number of sites in Native Dog Creek, itself also mined under previously and during monitoring by Elouera Longwalls 1 through 10.

Where Longwalls 1 to 7 of Elouera Colliery directly mined beneath Native Dog and Wongawilli Creeks between February 1993 and September 2001 only 1 – 2 km to the southwest of Area 3, 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 low 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 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 the sub-bed diverted waters into them. This sub-bed diverted water had the opportunity to induce accelerated weathering of accessory marcasite (a form of iron sulfide) in the freshly fractured bedrock, inducing ecological impacts in the pools resulting from:

1. reduced pHs (i.e. increased acidity), in some cases reaching 3.0;
2. DO depletion by oxidation of the ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions released;
3. possible ecotoxic effects from other accessory heavy metals released from the marcasite, being Mn, Ni and Zn and Al from kaolinite; and
4. possible 'smothering' of pool boulder and bed surfaces downstream with precipitated iron and manganese hydrous oxides.

IC engaged Ecoengineers to prepare all summary and assessment reports on those water quality monitoring programs (Ecoengineers Pty Ltd., 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 direct longwall mining beneath them.

1.1.2 Hydrologic Studies for Elouera Colliery EMP

In the first half of 2001 discussions were held between Illawarra Coal 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. The SCA agreed to permit the installation of temporary staff gauges in selected semi-permanent pools to measure pool levels and so derive pool volumes. IC and its consultants were also authorized to make periodic manual measurements of flow at selected locations. The deployment and use of 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 the SCA.

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 Donald’s Castle Creek in 2002. Placement of ultrasonic Doppler flow meters in natural creek channels requires a careful choice of location and careful prior 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 pressure sensor (which simultaneously measures flow depth) by sand and similar debris can also be an issue.

Notwithstanding these difficulties, a comprehensive hydrologic analysis of a number of periods of creek flow data collection made using the Starflow Doppler flow meters in Lower Native Dog and Donald’s Castle Creeks over 2002-2003 was presented in Ecoengineers Pty Ltd, 2006b.

The outcomes of the data analysis and modelling presented in that report, described in more detail in **Section 2.6** below have been used to guide the approach to hydrologic monitoring and assessment for Area 3 generally and specifically as required by the monitoring Conditions of Consent which would be required for Area 3A listed in **Section 1.1** above.

1.1.3 Studies of Swamps

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) damage.

These studies have been reported in a number of IC internal reports and consultants reports to IC of which the most important to the swamp-related matters addressed in this document are: Horsley, 2003; BHPIC, 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; Hatton and Evans, 1998; Dept. of Land and Water Conservation (DLWC), 2002; Dept. of Environment and Conservation (DEC), 2006; Tomkins and Humphreys, 2006; Humphreys and Tomkins, 2007; Tomkins et al. 2007.

2. GEOMORPHOLOGIC, HYDROLOGIC & GEOCHEMICAL ISSUES

2.1 LOCAL GEOLOGY

Area 3 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 3 are, from the top down:-

- 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.

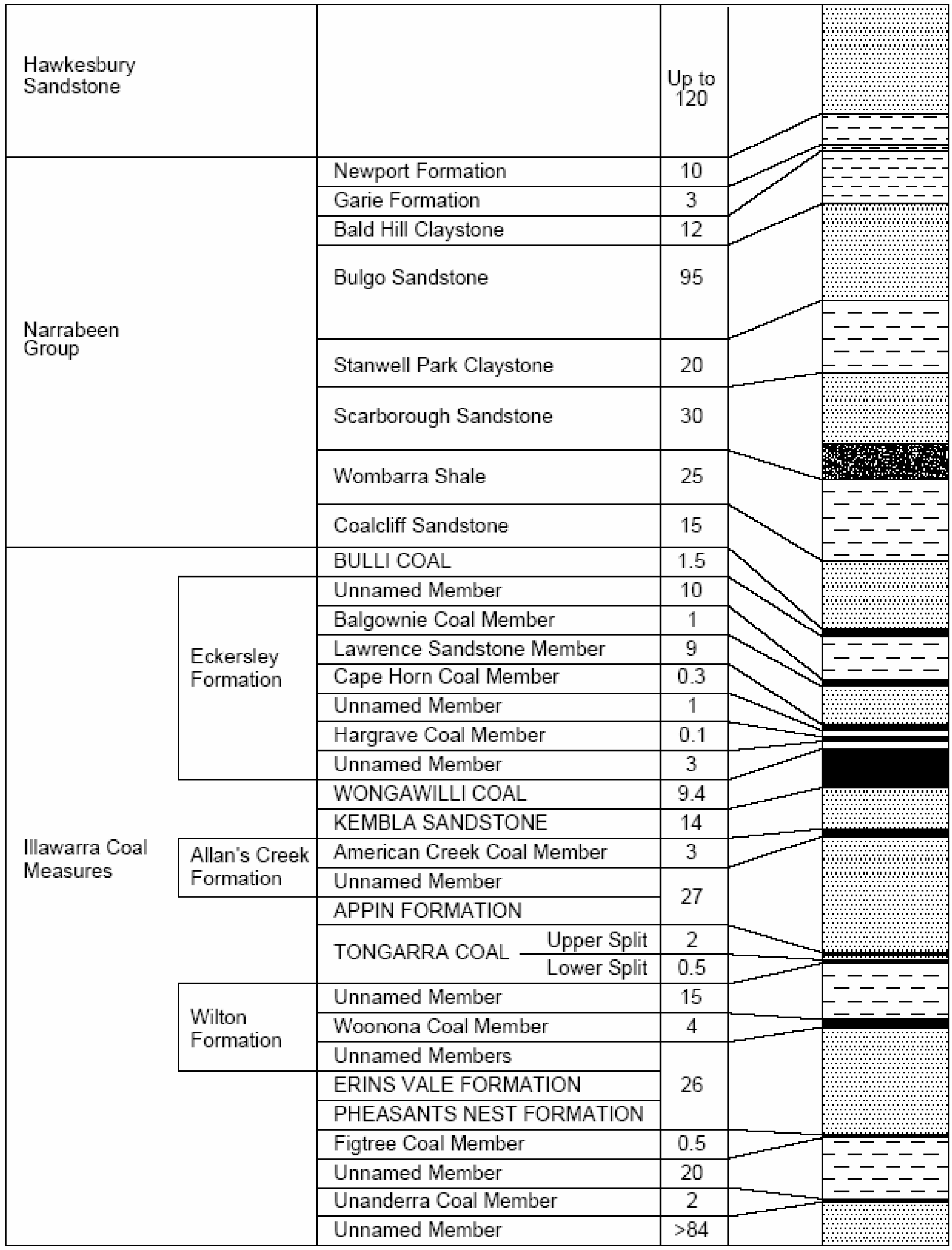
A generalised sedimentary stratigraphic section with indicative strata thicknesses is shown in **Figure 2.1** below (Williams, 1979).

Area 3 is situated between the dissected Woronora and Illawarra Plateaux, 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.

The sandstone units of the Hawkesbury Sandstone Formation are typically comprised of mainly medium to coarse quartz grains bound by a 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. We have found in petrographic studies that unweathered to weakly weathered sandstone may contain about 0.5% of iron sulfide, principally marcasite with minor solid solution incorporation of nickel and intercalation of sphalerite (zinc sulfide) and hauerite (manganese sulfide).

The Sandstone has been subject to lateritisation and the depth of weathering can be profound as well as highly variable. 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 change is controlled by a number of physical factors and is not necessarily graduated downwards (Standard, 1969; Herbert and Helby, 1980)

FIGURE 2.1: GENERALISED LOCAL STRATIGRAPHIC SECTION



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

2.2 CATCHMENT GEOMORPHOLOGY

Figure 2.2, provided courtesy of Cardno Forbes Rigby, shows the water-related layout of the entire Area 3. It identifies the overall boundary of Area 3, the major creeks and tributaries and their catchments in and adjacent to the Area.

The nomenclature for identifying all un-named tributaries of the major creek is also presented and these identifiers are subsequently used throughout this report.

The eastern area is broadly sited on a plateau dissected by a number of relatively shallow subcatchments draining either into Lake Cordeaux via Sandy Creek or eight other individual un-named ephemeral creeks draining directly to the western side of Lake Cordeaux.

The central area is dominated by Wongawilli Creek, a large, well-incised, permanently flowing stream which dissects Area 3 south to north and also has numerous well-incised tributaries. Wongawilli Creek drains to Cordeaux River downstream of Cordeaux Dam.

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 total length of Wongawilli Creek within the general Study Area is approximately 8.6 km. The natural gradient of the creek excluding the cascade in the south of Area 3B varies between a minimum of less than 1 mm/m and a maximum of 200 mm/m, with an average natural gradient of approximately 10 mm/m.

The natural gradient of Wongawilli Creek within the Area 3A SMP Area varies between a minimum of less than 1 mm/m and a maximum of 25 mm/m, with an average natural gradient of approximately 4 mm/m.

Proceeding northwards to the northern boundary of Area 3, numerous tributary subcatchments lie west and east of the Creek all founded in sedge-dominated, flatter, basin like upland plateaux along the confining ridges and grading towards the main channel of the Creek into deep gullies which in their basal steeper section that contains numerous outcrops, minor vertical drops and blocky scree slopes.

Ephemeral tributaries and the main channel of another major stream, Donald’s Castle Creek, also drain the northwestern part of Area 3 through a weakly incised plateau. The Donald’s Castle catchment is characterised by low topography, substantial upland swamps and a local unconfined shallow hillslope aquifer.

The south western area drains directly to Lake Avon via four small ephemeral creeks.

The basic geomorphology of tributary subcatchments in Area 3 is invariably characterized by upland plateaus and a series of ‘benches’ comprised of catenary hill slopes and swamps enclosed in roughly crescent-shaped cliff lines.

The largest watercourse within the Study Area is Wongawilli Creek which is located between Areas 3A and 3B and crosses the western side of Area 3C. The creek is located 110 metres west of the commencing end of Longwall 6, at its closest point to the proposed longwalls in Area 3A.

The headwaters of Wongawilli Creek are located in a drainage divide separating surface precipitation from Native Dog Creek and Lake Avon to the west, Upper Cordeaux River Catchment to the south and Sandy Creek to the east. The Creek is constrained by a north west ridge and a long north ridge extending to Cordeaux Dam.

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 down slopes with no evidence of surface drainage channels. This is consistent with headwater hillslope aquifer zones and overland sheet flow during extreme storm events.

Sandy Creek is partly located within Area 3A and crosses the eastern sides of the General Study Area and Area 3A SMP Area. The creek is located 85 metres east of the finishing ends of Longwalls 8, 9 and 10 at its closest point to the proposed longwalls in Area 3A. The creek generally flows in a northerly direction and drains into an arm of Lake Cordeaux at a waterfall site located 250 metres east of Longwall 7. The total length of Sandy Creek within the General Study Area is approximately 2 km.

The natural gradient of the Creek within the Study Area, upstream of the waterfall, varies between a minimum of less than 1 mm/m and a maximum of 60 mm/m, with an average natural gradient of 10 mm/m. The natural gradient of Sandy Creek within the Area 3A General SMP Area varies between a minimum of less than 1 mm/m and a maximum of 30 mm/m, with an average natural gradient of approximately 10 mm/m.

The upper reaches of Donalds Castle Creek are located in the northern part of Area 3B and in the western part of Area 3C. The headwater of the creek is located 1.4 km west of the commencing end of Longwall 6, at its closest point to the proposed longwalls in Area 3A. The creek generally flows in a northerly direction and drains into the Cordeaux River approximately 3.4 km north of the general Study Area.

The natural gradient of the creek within the Study Area varies between a minimum of 10 mm/m and a maximum of 150 mm/m, with an average natural gradient of 30 mm/m.

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.

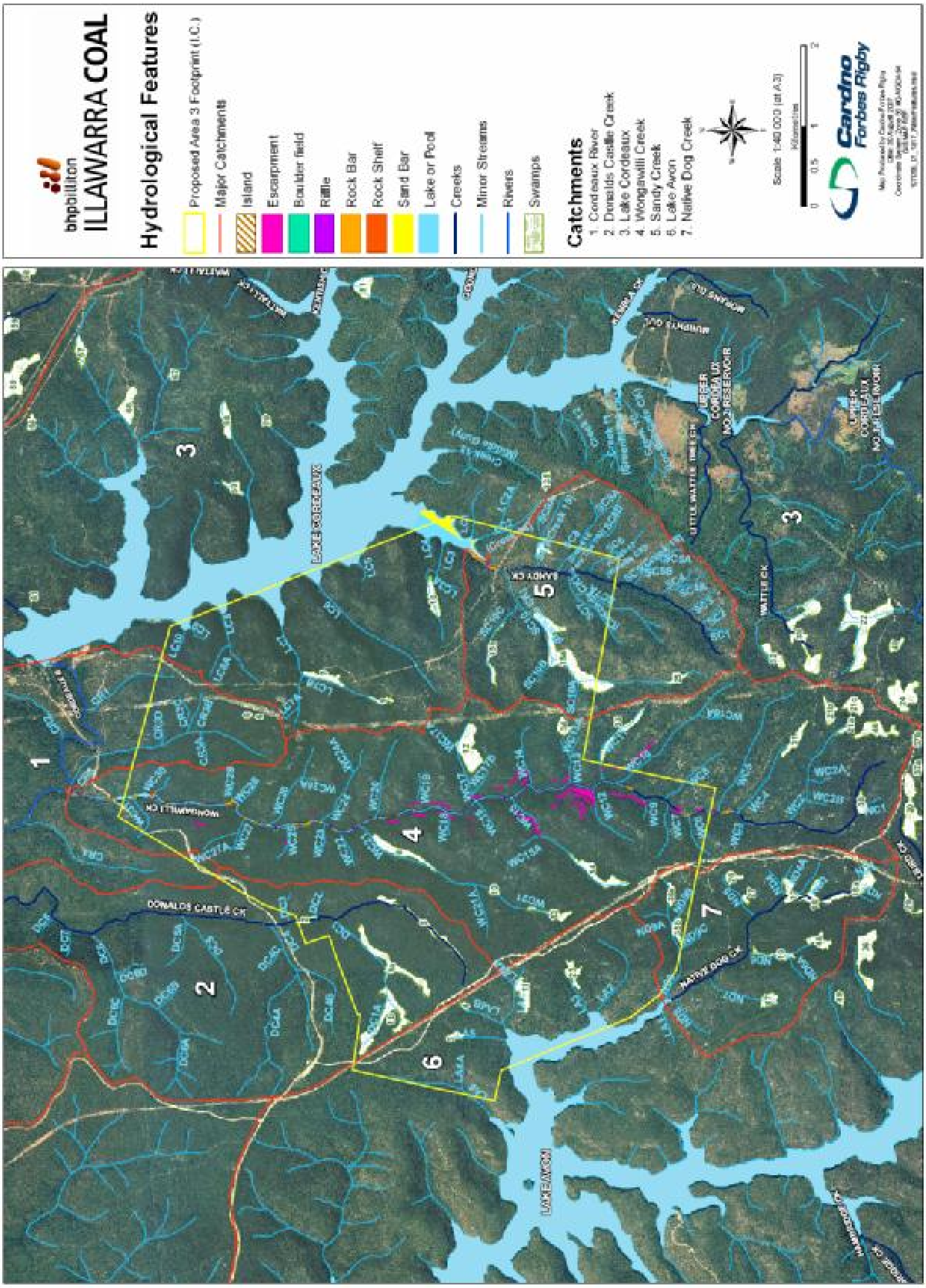
The beds of the creeks are formed within the Bulgo Sandstone, which overlies the Stanwell Park Claystone, however, there are small sections of the headwaters of these creeks which are formed within the Hawkesbury Sandstone.

Wongawilli, Sandy 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, Donald’s Castle and Sandy 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 Type 1 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 dependent 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 Type 1 channels described above.

These features are consistent with the observations of channel and pool morphology in Banksia Creek, Cascade Creek, Sandy Creek, Wongawilli Creek and its tributaries and in greater Donald’s 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 swamp of the type which we have arbitrarily described as braided stream swamps or Type 2 swamps as distinct from ‘hanging swamps’ or Type 1 swamps which we contend are hydrologically relatively distinct from Type 1 (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 which are shown in Drawings Nos. MSEC311-08 to MSEC311-10 reproduced below with permission as **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

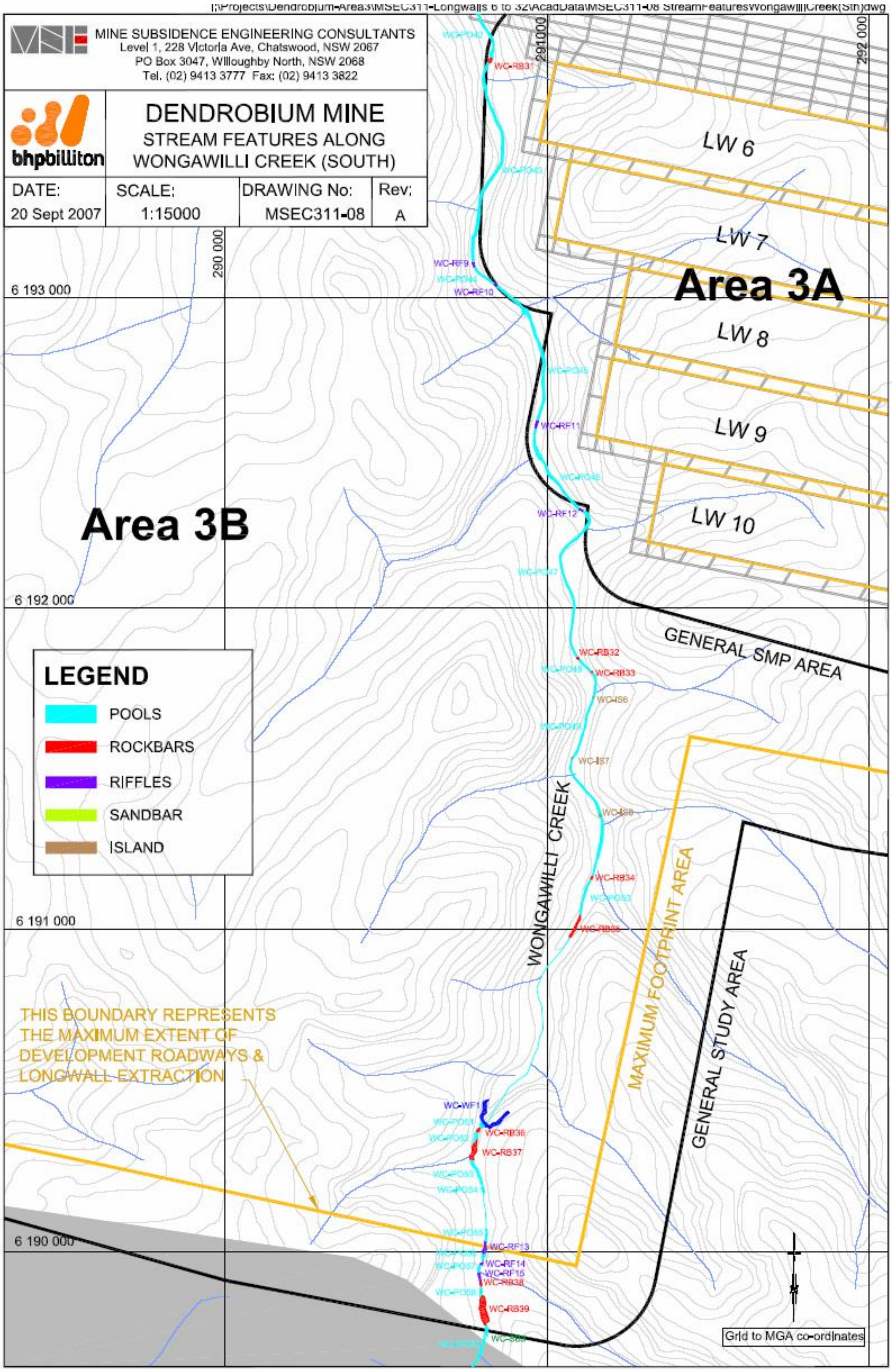


FIGURE 2.4: STREAM GEOMORPHIC FEATURES ALONG WONGAWILLI CREEK NORTH

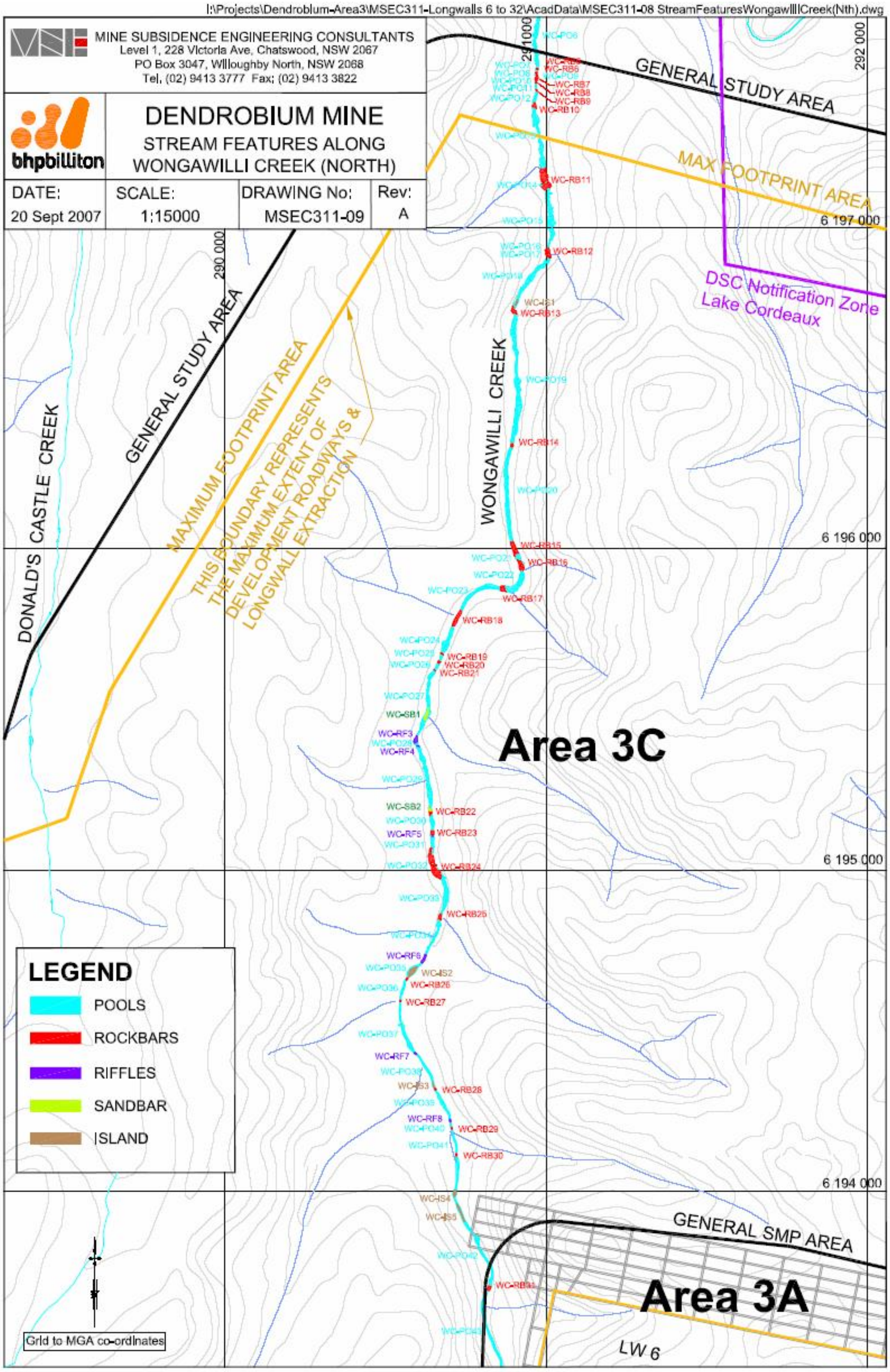
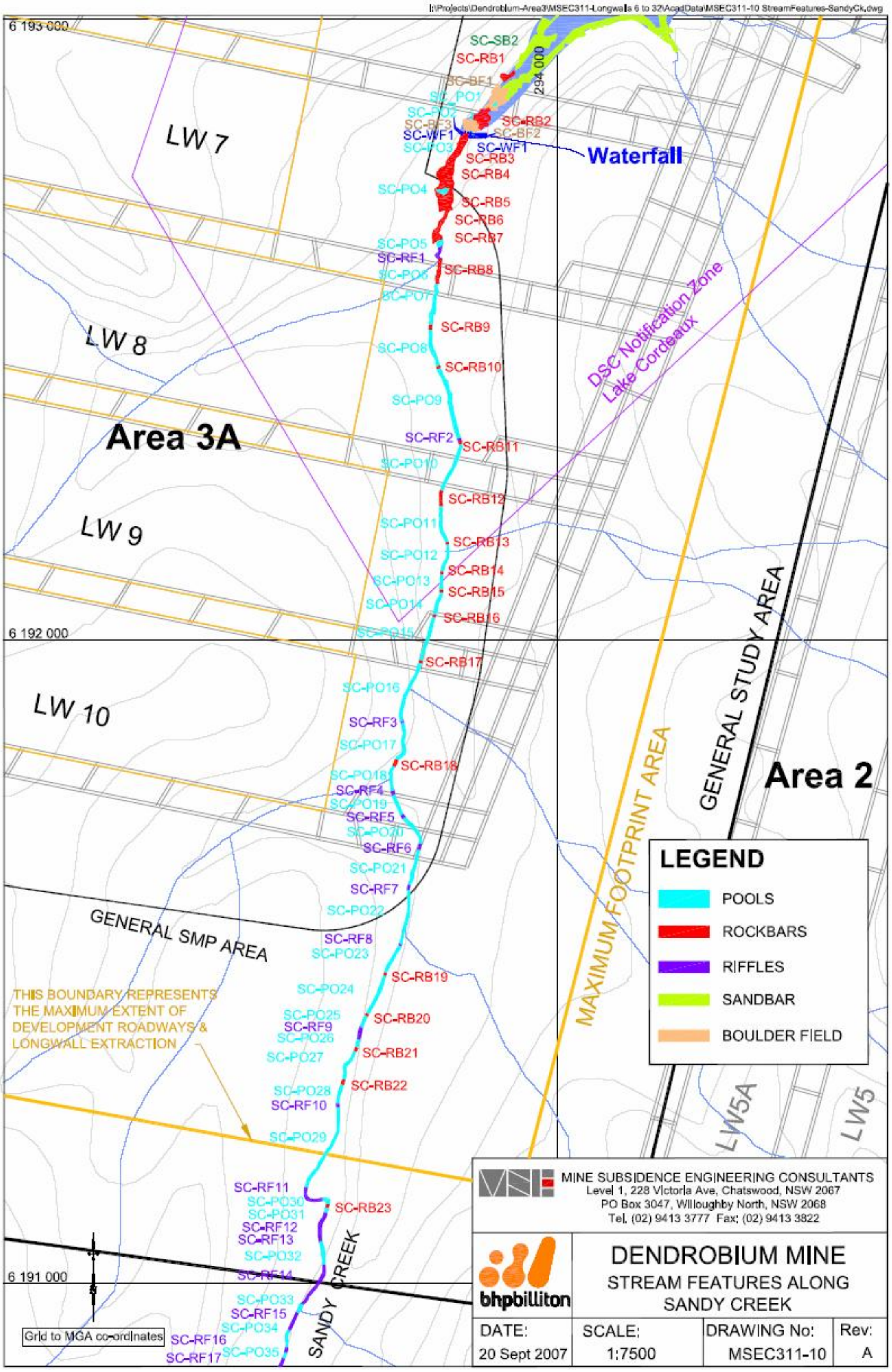
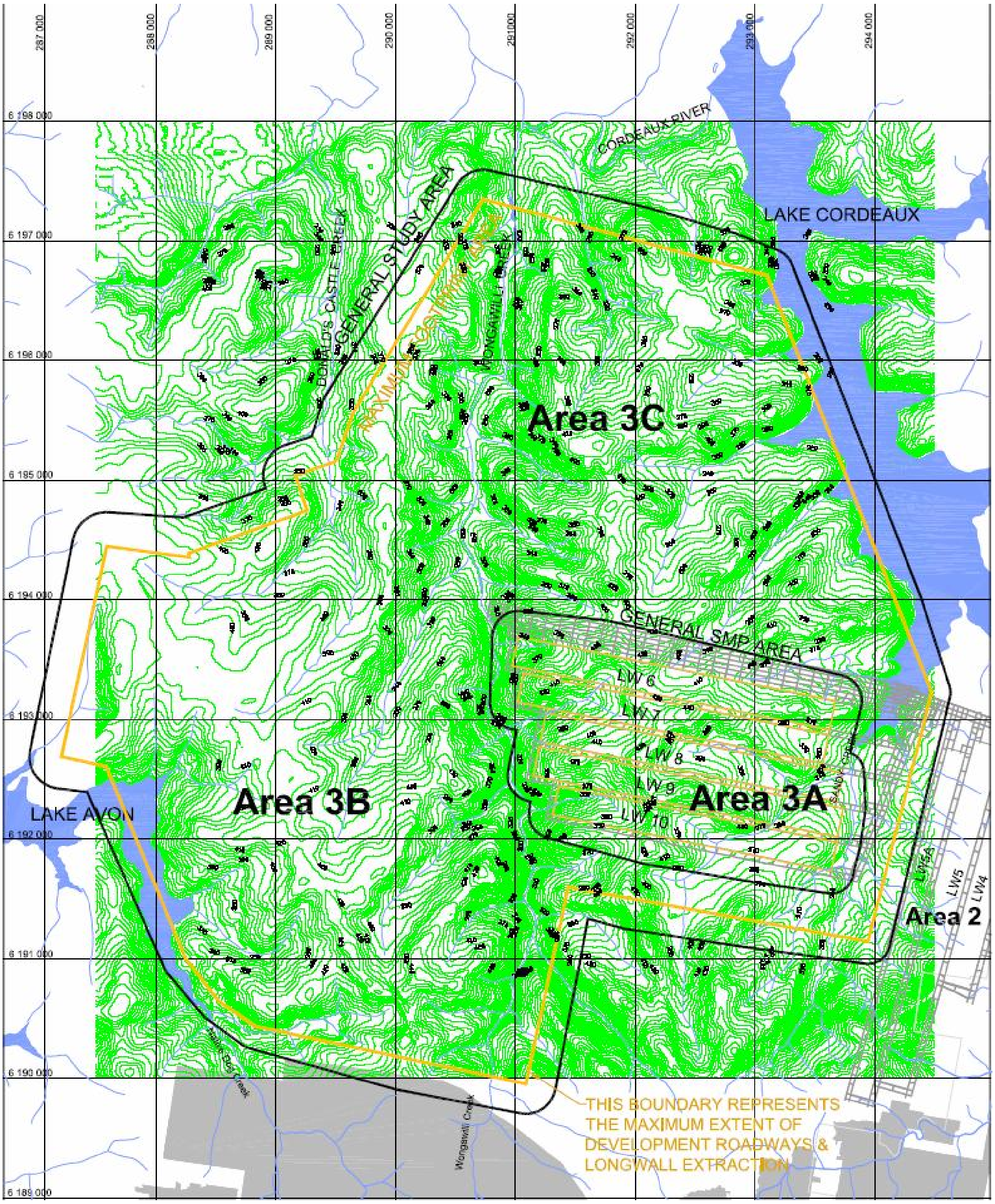


FIGURE 2.5: STREAM GEOMORPHIC FEATURES ALONG SANDY CREEK



The surface topography of the whole of Dendrobium Area 3 and the proposed longwalls and the General SMP Area for Area 3A only which have been finalized are shown in **Figure 2.6** below, taken from MSEC, 2007.

FIGURE 2.6: SURFACE CONTOURS IN AREA 3 AND AREA 3A GENERAL SMP AREA



Dendrobium Area 3A comprises Longwalls designated 6 through 10. Area 3A does not longwall mine directly beneath Lake Cordeaux. Area 3A is located to the south and west of the Sandy Creek Arm of Lake Cordeaux which lies a distance of 400 m to the east at its closest point (eastern end Longwall 6). The longwalls are also located west of Sandy Creek, which is a distance of 85 metres away at its closest point (to Longwall 9).

Figure 2.7 below taken from MSEC (2007) shows also shows the general layout of the five longwalls of Area 3A indicating the extent of the General Subsidence Management Plan (SMP) Area which is taken to be the 35^0 angle of draw (MSEC, 2007). The predicted vertical limit of surface subsidence, taken as the 20 mm subsidence contour, lies within the 35^0 angle of draw.

The Area 3A longwalls largely underlie an undulating plateau draining eastward to Sandy Creek and westward to Wongawilli Creek. A number of natural landscape features (tributary creeks of Sandy and Wongawilli Creeks 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.

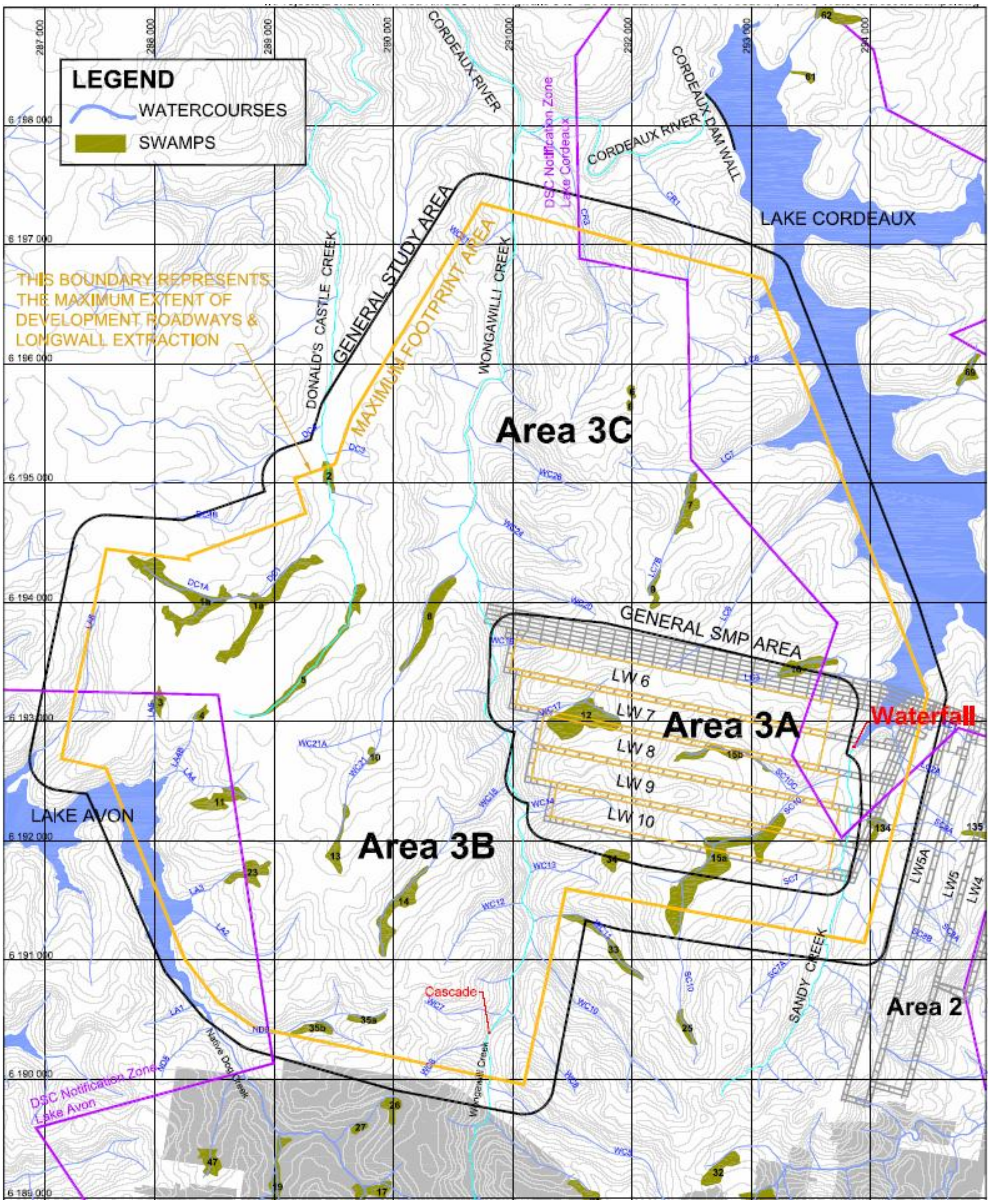
The surface of the Area 3A General SMP Area consists largely of a ridged and undulating plateau oriented north-south (dipping generally to the north) lying transversely over all Longwalls 10 through 6, terminating at its northern end by two major gullies containing Creeks LC3 and LC6 draining to Lake Cordeaux.

The plateau is transversely dissected along its western and eastern sides by two steep gullies draining to Wongawilli Creek (Creeks WC14 and WC17) draining into Wongawilli Creek and by relatively low slope gullies on its eastern side to Sandy Creek (Banksia and Cascade Creeks).

The surface of the land within the Area 3A General SMP Area is undulating to hilly, with levels varying from a low point of approximately 340 m AHD, in drainage lines near the eastern perimeter of the SMP Area, to a maximum of approximately 420 m AHD, along the central ridgeline of the plateau above Fire Road 6F.

The proposed Area 3A longwalls are also partly located within the Dams Safety Committee Notification Area for Lake Cordeaux the boundary of which is designated by the magenta line in **Figure 2.7**.

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



2.3 SOILS

Almost the entire surface of Area 3 is founded on highly weathered Hawkesbury Sandstone outcrop and Sandstone derived-soils. A single ridgeline in the west of the Area between Wongawilli Creek catchment and the Native Dog Creek Arm of Lake Avon is partly mantled by Wianamatta Shale-derived soils overlaid on Hawkesbury Sandstone.

Figure 2.8 below provides a surface soil map of Area 3. The legend identifies the five major soil landscape types which appear in Area 3 as described in DNR (2006) as being the:

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%; and
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 Pty Ltd., 2003, 2004a, b, 2005a, b, c, 2006, 2007a, c).

FIGURE 2.8: SOIL LANDSCAPES OF AREA 3

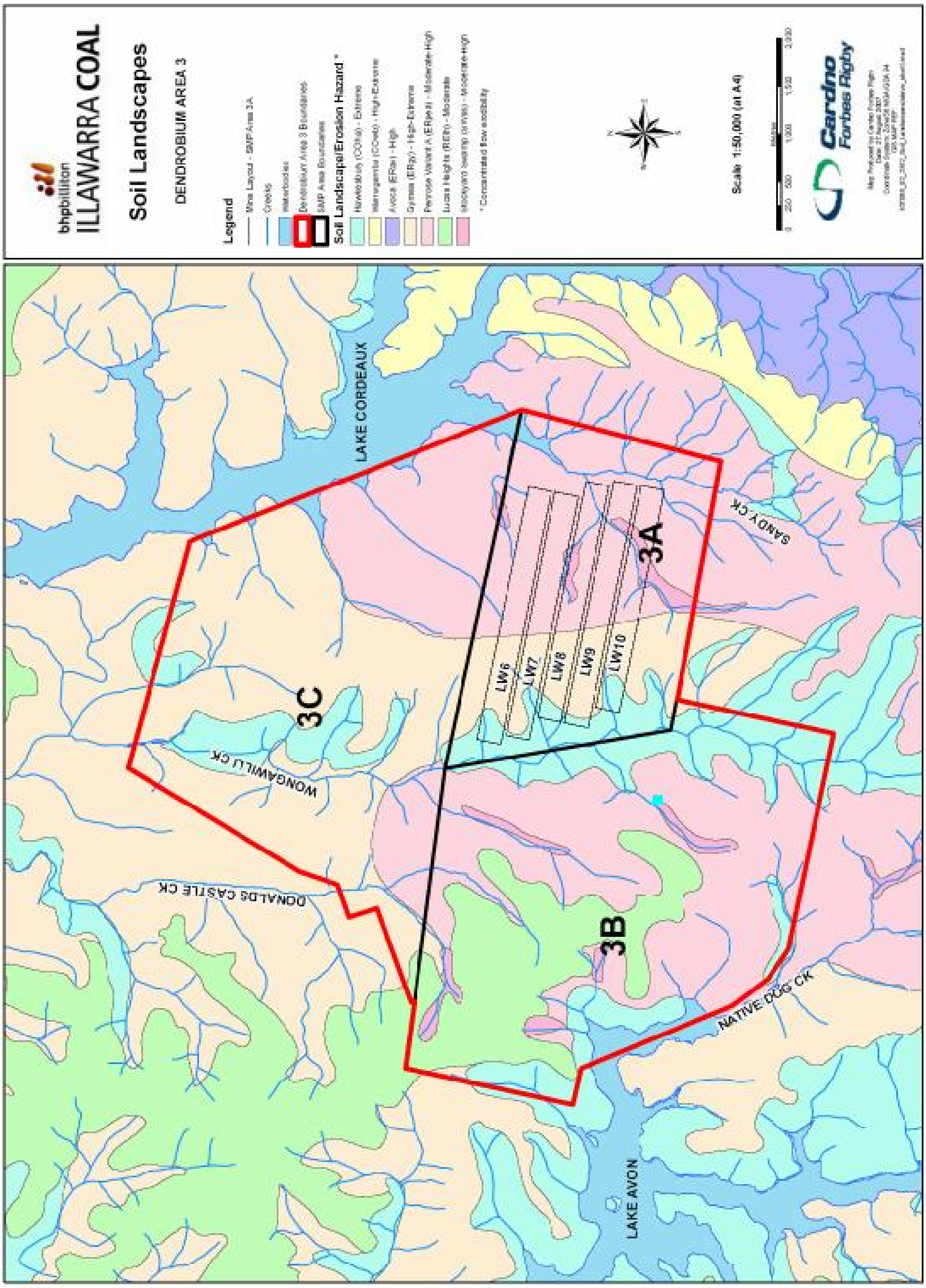
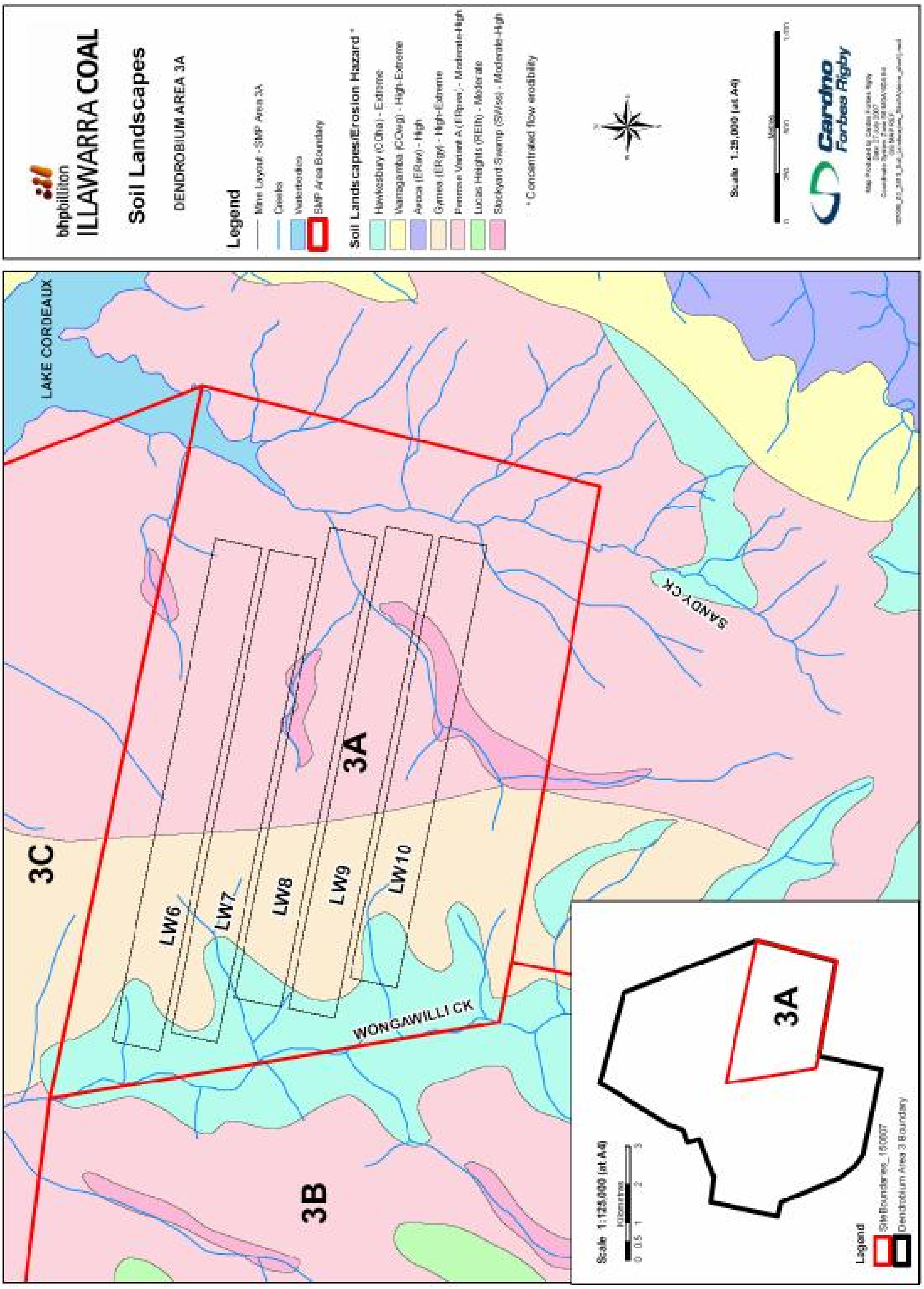


Figure 2.9 below provides a surface soil map of Area 3A.

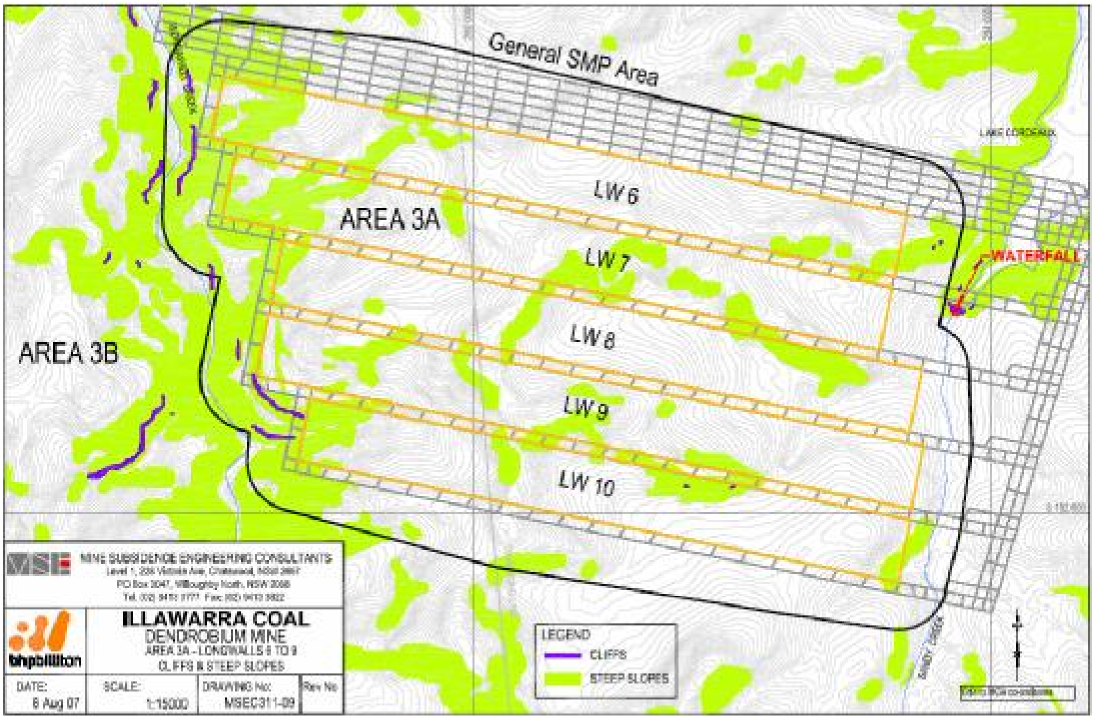
FIGURE 2.9: SOIL LANDSCAPES OF AREA 3A



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 from MSEC (2007) identifies the cliffs and steep slopes in the Area 3A General SMP Area and adjacent to it.

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



It can be seen that there significant areas of steep slopes along the western side of Area 3A where the soils are of the Hawkesbury soil landscape type. These areas are very similar to those in Upper Wongawilli Creek mined under by Longwalls 1 though 7 of Elouera Colliery.

2.4 NEAR-SURFACE HYDROGEOLOGY

Almost all of the central plateau and ridgelines over Areas 3A and 3C 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 downgradient.

Springs or seeps deeper on the gullies would be 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.

Due to the large size of the major creek catchments it is expected that shallow groundwater movements would be extensive and evident throughout Area 3. In the Woronora Plateau zones of shallow seepage, clearly associated with the local stratigraphy can often be correlated laterally for distances in excess of 500 m (J. Wood, IC, pers. comm.).

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 bedding planes and natural fractures of the Sandstone.

On the basis of prior hydrologic modelling studies of Native Dog and Donald's Castle Creek catchments it is believed that such hillslope aquifers will be very common within Area 3 (Ecoengineers 2006b). The basic systematic features of such hillslope aquifers are discussed in detail in **Appendix B**.

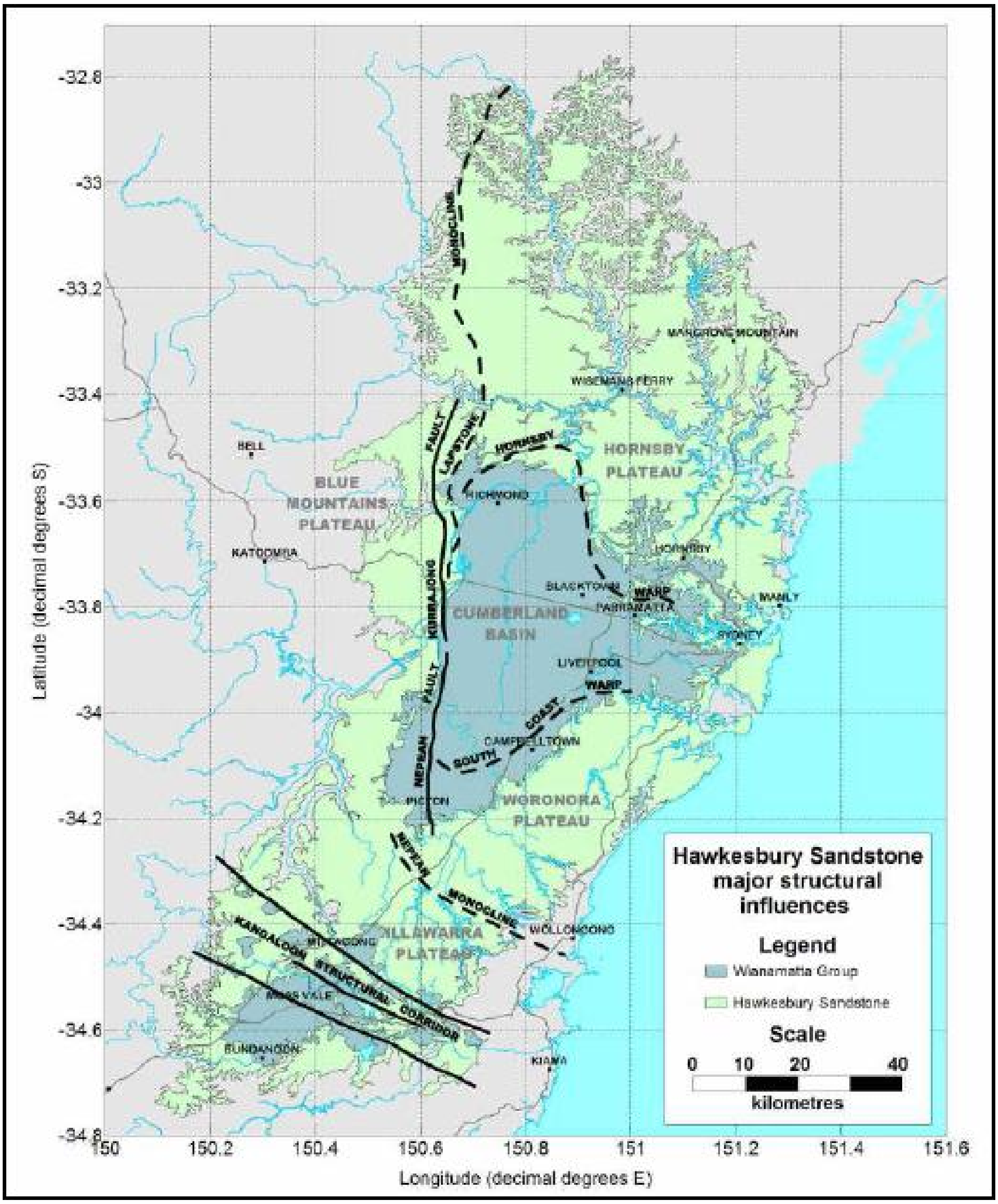
Lateral hydraulic gradients in any hillslope aquifers within Area 3B will invariably be southwest towards Lake Avon, in the headwaters of Donald's Castle Creek towards the north, within subcatchments of Wongawilli Creek towards the main channel of the Creek, in the east towards Lake Cordeaux and over most of Area 3A towards Sandy Creek.

The possible presence of the Nepean Monocline (which marks the boundary between the Woronora and Illawarra Plateaux) dipping from southwest of Area 3A northeast towards Lake Cordeaux, suggests that regionally within Area 3, most deeper groundwaters contained within the beddings of Hawkesbury Sandstone would probably be directed north towards Lake Cordeaux and Lower Cordeaux River as can be seen in **Figure 2.11 below.**

This inference is consistent with recent field observations of seepages from hillslope aquifers in the area of proposed Dendrobium Area 3A which appear to be significantly more productive in the subcatchments flowing towards Lake Cordeaux than in Wongawilli Creek subcatchments lying on the eastern side of the Creek (J. Wood, pers. comm.).

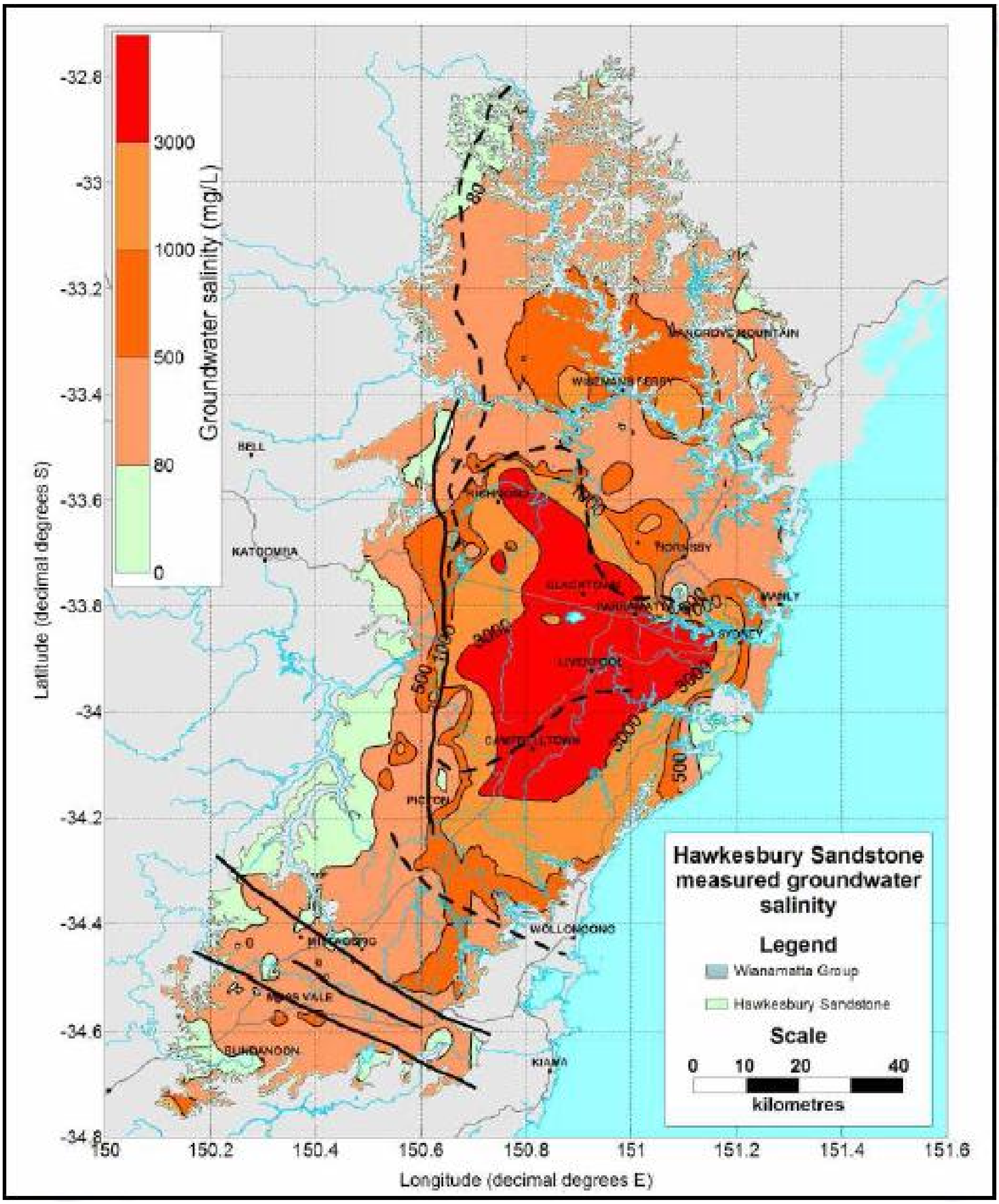
The Nepean Monocline is a branch of the Mount Tomah Monocline which extends from Warragamba in a north to south direction down to about Tahmoor before swinging towards the coast to Avondale Mine then east northeast to Port Kembla. There is possibly some confusion in the following **Figures 2.7 and 2. 8**, presented at a recent conference on the hydrogeology of the Sydney Basin, between these two monoclines and to whether the Nepean Monocline extends further east of the Avon River lineament.

FIGURE 2.11: HAWKESBURY SANDSTONE MAJOR REGIONAL STRUCTURAL INFLUENCES



Limited data on the salinities of regional Hawkesbury Sandstone ground waters in Area 3 seem to confirm that deeper Hawkesbury Sandstone groundwaters in Area 3 do flow north towards Lake Cordeaux and Lower Cordeaux River and then meander north along the Nepean River valley or south toward the eastern end of Lake Avon as shown in the following **Figure 2.12**.

FIGURE 2.12: HAWKESBURY SANDSTONE MAJOR REGIONAL GROUNDWATER SALINITY ZONATION



Airlift yields north-south through Area 3 within and adjacent-to the zone of moderate salinity (500 – 1000 mg/L) shown in **Figure 2.12 above** have been reported to be a moderate 1 – 5 L/s indicating that the Sandstone's aquifer properties have been improved by:

- expansion of planes of weakness within the rock mass due to pressure relief effects;
- significant fracturing due to tectonic uplift; and perhaps a

- solution enhancement of intergranular and fracture porosity due to the general lack of overburden except for some thinly overlain shale over parts of the monocline over a long period of weathering under cyclic conditions of recharge.

Issues surrounding deep groundwaters within the vicinity of the proposed Area 3A longwalls are being investigated, assessed and reported by Gutteridge Haskins and Davey (GHD Geotechnics, 2007). The question of whether there is any existing evidence to suggest a loss of shallow groundwaters or stream flows to a deep aquifer in the Hawkesbury (or below it) as a result of longwall mining is addressed in a summary of our hydrologic studies in the area and are described in **Section 2.6** below.

2.5 SWAMPS

Swamps in Area 3 have been mapped and numbered by IC. **Figure 2.13, below,** courtesy of Cardno Forbes Rigby, shows the general layout of the entire Area 3, and identifies all known 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 sediment storage features in the landscape. They have been shown to contain sediments dating from the Late Pleistocene and throughout the Holocene which provide a record of the history of swamp development spanning thousands of years. Analysis of the sedimentary record in three 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.

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 results 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 warrants 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) conclude 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 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 velocity exceeds about 2.2 m/s.

Earth Tech (2005) have also shown 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. The change in grade that may result from mine subsidence is only likely to induce excessive shear in relatively low gradient swamps.

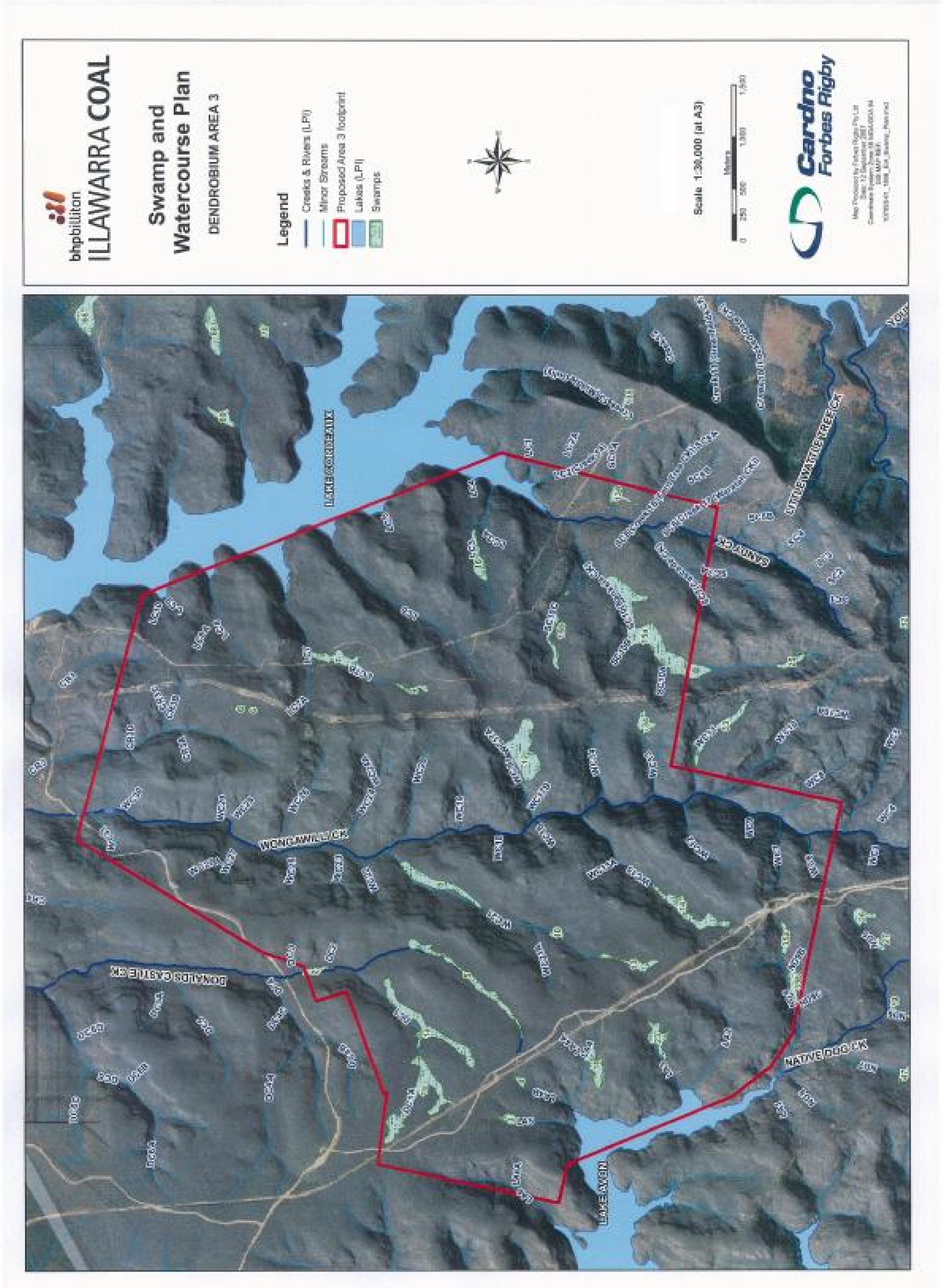
Therefore the swamps at risk from scour and erosion as a result of longwall mining are those in which the stream is of a high order i.e. high flow and low gradient, has poor vegetation condition e.g. from prior bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.

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 2001-2 fires despite very 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 vegetation is scorched but quickly recovers.

They also concluded that human disturbance in the catchment, particularly direct physical disturbance such as at Drillhole Swamp on Flying Fox Creek on the Avon Catchment had been found to be 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”.

FIGURE 2.13: MAPPED SWAMPS IN AREA 3



We accept the overwhelming body of findings obtained from the numerous studies of upland swamps in the Woronora Plateau (Young, 1986a, b; Keith, 1993; Dept. of Land and Water Conservation (DLWC), 2002; Tomkins and Humphrey, 2006 etc).

However, we believe the view that some swamps can be 'dewatered' through one or 'ruptures' of their bases is significantly misplaced.

Before discussing this issue further, it is first necessary to 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. The first type ('Type 1') or 'braided stream swamps' those which 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 prior bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.

2. The second type ('Type 2') of 'hanging swamp' occurs within broad, relatively low slope areas e.g. upper Donald's 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 belief that Type 2 swamps can be 'dewatered' through fracturing of an 'impermeable base' (e.g. DLWC, 2002) appears to be based on an entrenched view of their hydrologic setting following Young (1982) that; in upland swamps, the geomorphological processes that underpin their hydrological functions are relatively well understood, and they are typically found on the floors of low gradient valleys on <u>impermeable</u> substrates in high-rainfall catchments. However, this is not actually generally true for the following reasons:

1. Fire is a major and relatively frequent disturbance of these swamps and is an important factor in their diversity, structure and floristics (Keith, 1991) yet even Young (1982) noted that no changes could be detected in swamp margins in the Cataract and Cordeaux Catchments in high resolution aerial photographs taken over the duration of 26 years between 1951 and 1977. This period was characterised by a major wild fire in 1968.

2. It is now known that many such swamps have significant gradients.

3. While the swamps of the form seen today only perhaps existed since the later Pleistocene (Tomkins and Humphrey, 2006), they are located on Triassic sandstone terrain which has been 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. The notion that the Hawkesbury Sandstone bedrock terrain in which these swamps are essentially 'embedded' is invariably impermeable is thus unreasonable. Whole of catchment regional water balances will be presented in the next **Section 2.6** which clearly demonstrate the substantial permeability of such terrain.

4. If the bases of these swamps were truly impermeable then it should have been possible at some time over the last 25 years to demonstrate a water balance for an individual small swamp by establishing boundary conditions, gauging rainfall and outflow and measuring evapotranspiration (ET) using *in situ* lysimeters. No such quantitative water balance study has been published.
5. An excess of precipitation over evapotranspiration (ET) proportionally sustains these swamps (Hatton and Evans, 1998). It can be shown by macroscopic water balance considerations that this is probably due to a significant fraction of precipitation on the Woronora Plateau penetrating to depths of over 2 m into the underlying weathered sandstone too quickly to be subject to ET processes (refer **Section 2.6.3**).
6. Adverse hydrologic effects e.g. broad or even discrete zones of dessication in well vegetated upland swamps of either type which have subject to mining induced subsidence have not been detected anywhere in the Woronora Plateau over 10 years of close study, a period encompassing 6 years of drought and several major wild fires (Earth Tech, 2003).
7. It has been explicitly demonstrated that a major Type 2 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 palaeo-erosional surfaces in the surrounding Sandstone (IC, 2004)
8. Extensive water quality monitoring within and immediately downstream of swamps in recent years, including longwalls which mined directly under Type 2 swamps has never detected any geochemical effects from mining subsidence beneath or immediately downgradient of swamps of either type indicative of the cracking of a 'tight' impermeable sandstone bedrock which by definition should contain unweathered marcasite and therefore release low pH water with elevated levels of sulfate, nickel and zinc upon fracturing (Ecoengineers Pty Ltd., 2006, 2007a, b).

2.6 CATCHMENT HYDROLOGY

The prime purpose of hydrologic calibrations of mined under catchments should be for the purpose of comparison and assessment of the hydrologic effects of mine subsidence <u>on a rational, quantitative, peer-reviewable basis</u>. Therefore the structure of the hydrologic model should focus primarily 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 quickflow runoff coefficient for any defined antecedent precipitation; and
3. the unconfined (above) groundwater reservoir coefficient contributing to baseflow; and
4. a catchment water balance over some defined period of assessment.

The groundwater reservoir must be 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 would enable catchments that had potentially been affected by longwall mining to be correctly compared with other similar, unaffected catchments over defined periods according to an unambiguous mathematical framework. This in turn would enable estimation of the magnitudes of key hydrologic parameters and allow assessment of their possible alteration over time e.g. as associated with 'self-healing' or man-made remedial effects, to be evaluated.

2.6.1 Previous Hydrographic Study Locations and Durations

An assessment of hydrographic flow data from the mined under Native Dog Creek and an adopted control of greater Donald's Castle Creek in the general area of Dendrobium Area 3 was completed in 2006 (Ecoengineers, 2006b). This provided valuable information about how best to approach the requirement to perform future assessments of the possible impact(s) of mine subsidence on catchment hydrology and productivity

Figure 2.15 identifies the flow gauging sites which were previously employed in the Native Dog, Wongawilli Creek and Donald's Castle Creek Catchments in the general area as referred-to in **Section 1.2.3.**

FIGURE 2.15: LOCATIONS OF PRIOR FLOW GAUGES IN AND ADJACENT TO AREA 3

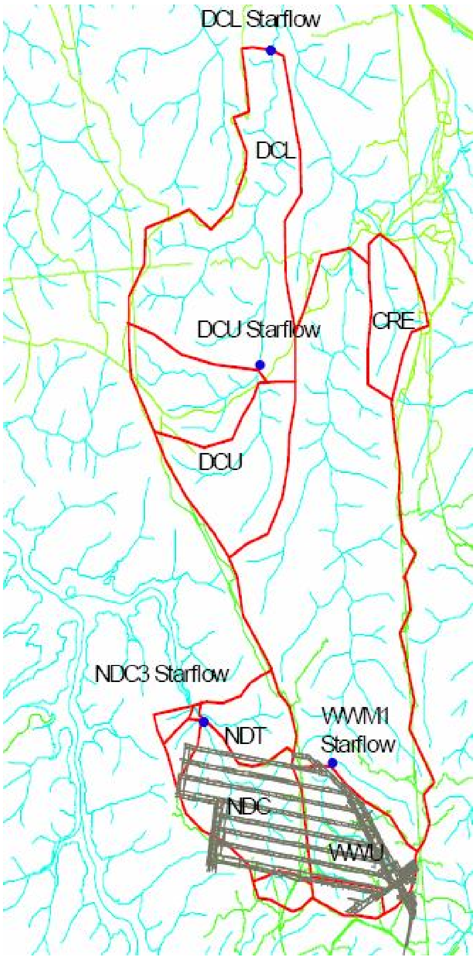


Table 2.1 below identifies the flow gauging sites used, the periods and durations of reliable gauging achieved, and noting that on other occasions the flow zone was found to be blocked by debris or else the Starflow Doppler flowmeter was not functioning correctly.

Table 2.1 also lists the total rainfalls recorded at the Cordeaux Colliery pluviometric site over those durations and the total runoff volumes measured by the Starflow meters and loggers for those durations. Note that NDC3 denotes Native Dog Creek site 3 and DCL3 denotes Lower Donald's Castle Creek site 3.

TABLE 2.1: PERIODS OF FLOW GAUGING AT NATIVE DOG CREEK AND DONALD'S CASTLE CREEK AND TOTAL RAINFALLS AND OUTFLOW MEASURED FOR GAUGED PERIODS.

Catchment	Gauging Sites	Area (km^2)	Period	No. of days flow gauged	Total Rainfall (mm)	Measured Total Outflow (mm)	Total Outflow (% of total rainfall)
Native Dog Creek	NDC3	3.96	22/05/03-03/06/03	13	67.5	3.0924	4.58
Native Dog Creek	NDC3	3.96	28/02/03-16/04/03	48	91.5	1.6532	1.81
Donald's Castle Creek	DCL3	13.44	15/09/02-28/09/02	12	10	0.2395	2.40
Donald's Castle Creek	DCL3	13.44	09/03/03-06/05/03	59	154.5	1.0749	0.70

The Starflow ultrasonic Doppler flow meters were most closely monitored, maintained and cross checked with manual spot measurements during the critical period between 1 January 2003 and 20 June 2003.

This interval coincided with the period when the geochemical effects of the mining of the Elouera longwalls appeared to be most pronounced in Native Dog Creek as clearly shown by the data presented in **Table 2.2**.

TABLE 2.2: GEOCHEMICAL DATA FOR NATIVE DOG CREEK BEFORE AND AFTER FEBRUARY - APRIL 2003 FLOW GAUGING PERIOD

Site	Date	pH	EC (µS/cm)	SO_4 (mg/L)	Total Fe (mg/L)	Total Mn (mg/L)	Total Al (mg/L)	Filt. Ni (mg/L)	Filt. Zn (mg/L
NDC2A	20/06/2002	5.50	162	49	0.30	2.94	0.55	0.109	1.26
NDC2A	19/09/2002	4.29	288	94	1.10	5.94	1.08	0.469	6.33
NDC2A	18/03/2003	3.70	570	263	4.10	3.36	29.3	1.15	7.85
NDC2A	15/04/2003	3.53	865	405	7.55	7.92	53.7	1.82	10.6
NDC2A	21/05/2003	3.19	521	124	11.1	2.85	1.60	0.827	5.06
NDC2A	12/06/2003	3.95	297	79	2.30	2.69	4.31	0.452	2.81
NDC2A	14/07/2003	4.32	210	51	0.90	2.50	2.53	0.296	2.05
NDC2A	18/12/2003	4.31	172	35	1.50	2.19	0.92	0.182	1.14

2.6.2 Adopted Hydrologic Model

After evaluation of various models, RUNOFF2005 was selected for the conceptual analysis and synthesis of runoff hydrographs by non-linear optimization methods for our previous hydrologic studies as being most useful for the assessment of possible longwall mining-related hydrologic effects. This model was developed by Prof. Adriaan Van De Griend of the Free University of Amsterdam and co-workers over many years of study of conceptually similar European alpine headwater catchments.

The RUNOFF model was developed on the basis (as are most other modern models e.g. Institution of Engineers, Australia, 1998) of a schematic representation of hydrogeological conditions, related to the structure of soil and hydrogeologic formations and catchment topographical features.

The model uses analytical solutions which were derived for the behaviour of groundwater discharge in terms of a time-variable drainage resistance (Kraijenhoff Van de Leur, 1958; De Zeeuw, 1979). This led to a general equation of the drainage resistance as a function of groundwater discharge which is not restricted to areas with an unconsolidated ‘Dupuit-Boussinesq aquifer’. This physically-based equation was then implemented in a simple, non-distributed conceptual runoff model for the analysis of continuous time series of runoff in the presence of intermittent rainfall (Van de Griend and Seyhan, 1985; Van de Griend et al., 1986; 2002).

The model treats the catchment as a whole and does not differentiate the catchment spatially into different spatial runoff source areas.

Similar models which essentially derive from different configurations of the Dupuit-Boussinesq aquifer were subsequently derived in the United States (e.g. Brutsaert and Lopez, 1998) and also more recently in Australia (e.g. Sloan, 2000).

The RUNOFF model, now available as a very mature 2005 version refined over more than 20 years, is considered appropriate for this particular application (Van de Griend et al., 2003) because of the following important factors:

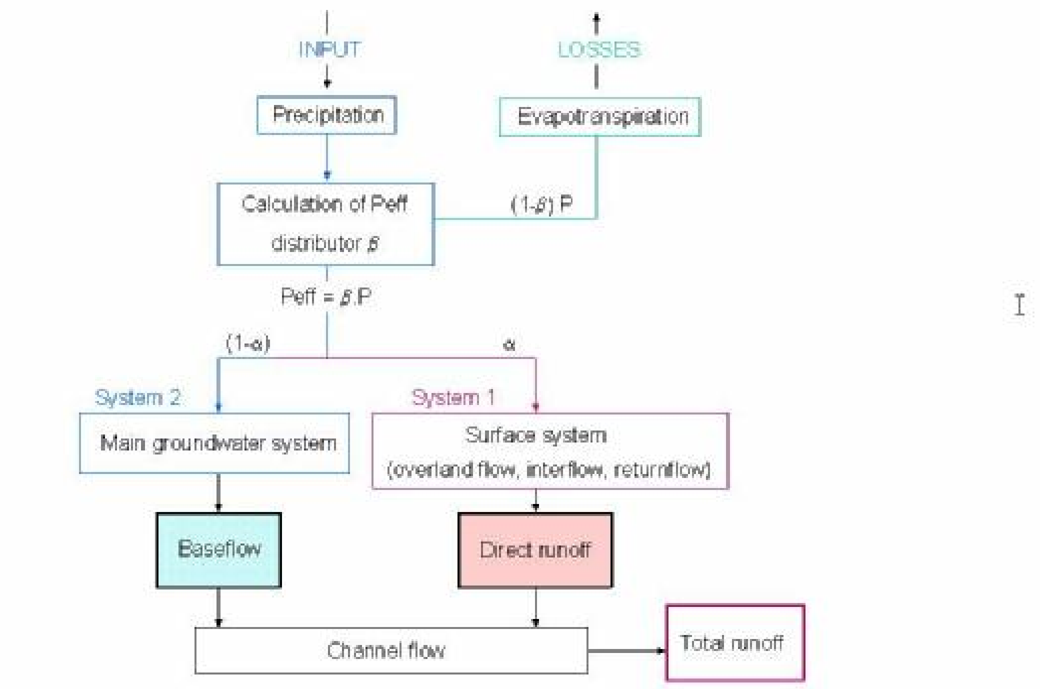
1. These subcatchments are likely to contain a groundwater system that is not only possibly affected by longwall mining-related effects but regardless, is

likely to naturally display time-variable drainage resistance (e.g. due to increasing resistance with depth below bedrock and/or decreasing bed slope and/or increasing travel distance). Numerous studies have shown that models which ignore the time-variable nature of drainage resistance often lead to significant errors in the analysis and prediction of both baseflow and direct runoff.

2. The model provides a straightforward, easily understood set of stream system parameters by non-linear optimization procedures working solely on the flow hydrograph.
3. The model is parsimonious, being neither too simplistic nor too complex for the intended application but most importantly, is mathematically defensible in its parametric characterization of the critically important groundwater (baseflow) system. In particular, it enables determination of the reservoir coefficient (otherwise known as a time of response) range for the groundwater system. This may then be directly input, together with other physical catchment parameters and recharge rates, into the Australian numerical aquifer model FLOWTUBE (Dawes et al. 1997, 2001) for improving understanding of the physical characteristics of, and possible effects on, the catchment groundwater system.
4. The model has the valuable ability to subject its derived hydrologic parameters to statistical sensitivity analysis. Very few commercial surface hydrologic models provide this facility although it is standard with most groundwater models.

Figure 2.14 gives the schematic layout of the catchment hydrological cycle that is the basis of the RUNOFF2005 model used to assess preliminary hydrographic flow data obtained from Native Dog and Donald's Castle Creeks model (Van de Griend et al. 2002).

FIGURE 2.14: SCHEMATIC REPRESENTATION OF THE CATCHMENT HYDROLOGICAL CYCLE FORMING THE BASIS OF THE RUNOFF MODEL



The following list defines the hydrologic parameters input-to or output-from the model and identifies their common symbols as they are used and discussed in this report. Pobs = observed precipitation (rainfall) daily or over the model simulation period (units of mm/day or mm/total simulation period)

β = beta = fraction of P entering catchment. Note that if all water entering the catchment eventually appears as outflow and none is lost to deep storage then the long term β equals the long term runoff coefficient.

ETsim = model simulated evapotranspiration (units of mm/day or mm/year). Therefore ETsim = $(1-\beta)$Pobs

Peff = effective precipitation i.e. precipitation entering catchment (i.e. Peff = βP) (units of mm/day or mm/total simulation period).

Peff(t) = $\beta(t) * P(t)$ where P(t) is the precipitation during interval t. and where $\beta(t)$ is a time-dependent parameter to relate the effective precipitation Peff to the Antecedent Precipitation Index (API) according to: $\beta(t) = 1 – \exp[-\gamma(API(t)]$ where:

γ = gamma = a catchment-specific fitting parameter (units of 1/mm) that determines the exponential dependence of β on API(t). Note that the value of $\beta(t)$ is also specific to the length of the time interval used and that:

Antecedent Precipitation Index API(t) = [API(t-1) + P(t)](K-API) where K-API is a pre-defined dimensionless model parameter which can be changed optionally. It is based on daily rainfall totals i.e. normalized to ‘daily intervals’ but automatically recalculated by the model for the actual interval duration. Default value for K-API = 0.75. It can be seen that K-API and gamma are the means by which the model adjusts Peff for the pre-existing wetness of the catchment.

α = alpha = fraction of Peff entering catchment leading to direct runoff (i.e. overland flow and interflow and returnflow).

$1 – \alpha$ = fraction of Peff entering catchment main groundwater system and not reporting to the direct runoff system.

Qobs = actual total volumetric flow past the gauging point daily or over the model simulation period (units of mm/day or mm/total simulation period).

Qsim = simulated total volumetric flow past the gauging point daily or over the model simulation period (units of mm/day or mm/total simulation period).

Qd = simulated volumetric flow past the gauging point contributed by the catchment surface system daily or over the model simulation period (units of mm/day or mm/total simulation period).

Jd = reservoir coefficient of the catchment direct runoff system (units of days).

The reservoir coefficient can be regarded as the bulk recession time constant or timescale of response for the direct runoff system as a whole. The direct runoff system, also sometimes called the quickflow system is taken to be that which produces overland flow and interflow and return flow (i.e. throughflow) from water perched in soils, talus rubble, swamps etc immediately following rain. If only overland flow is involved then the reservoir coefficient is a functional measure of the *time of concentration* of the catchment. *It is assumed, as do most common models, that the quickflow system drains with a constant drainage resistance.*

In the RUNOFF2005 model Jd is defined in line with modern modelling conventions as the e-folding time (1/e) for quickflow i.e. within the time span of Jd, (1-exp(-1)) = 0.63 = 63% of the equivalent Instantaneous Rainfall (event) leaves the catchment so it is defined slightly differently to the older-style peak rainfall to peak runoff time of concentration.

ΔS' = change in storage of all catchment storages (i.e. for both systems) which drain freely under forces of gravity. Examples of these are: soil or swamp saturated zones, fractured outcrop or bedrock, slope talus rubble. This parameter is positive if the direct runoff (quickflow) system is being net recharged and negative if being net discharged (over the simulation period).

Jb = reservoir coefficient of the principal catchment groundwater system.

The reservoir coefficient can be regarded as the bulk recession time constant for the aquifer as a whole and has been long identified as the *aquifer response time*, *time-scale of response* or *hydrologic response time* (Terzaghi and Peck, 1948; Glover and Balmer, 1954; Kraijenhoff van de Leur, 1958; Domenico and Miflin, 1965; Gelhar and Wilson, 1974; Birtles and Wilkinson, 1975; Erskine and Papaioannou, 1997; Manga, 1999; Rassam et al. 2004; Knight et al. 2005).

This parameter varies with drainage resistance and therefore will not be fixed but will cover a range of values which the RUNOFF2005 model attempts to estimate. For a non linear time-variable drainage resistance, the reservoir coefficient Jb = A/Q^{B} where A and B are dimensionless constants fitted by a non-linear optimization technique.

ΔS'' = storage change of all catchment storages which hold water against the forces of gravity. Examples of these are: soil or swamp unsaturated zones, depression storages (e.g. permanent pools) and canopy storage in trees. This parameter is positive if these storages are being net recharged and negative if being net discharged (over the simulation period). Over medium (typically one month or more) to long simulation periods ΔS'' is generally assumed to zero or negligible in terms of other storage changes in the catchment.

τ = tau = translation time though a short linear channel to the gauging point.

Water Balance = ∑P = ∑Qsim + ∑ET + ΔS

where ΔS = ΔS' + ΔS''

E = Nash-Sutcliffe (model efficiency parameter (Nash and Sutcliffe, 1970) defined as follows:

$$E = 1 - \frac{\sum(Q^{t}obs - Q^{t}sim)^{2}}{\sum(Q^{t}obs - Q^{m}obs)^{2}}$$

where Q^{t}obs = observed flow at time t

Q^{t}sim = model simulated flow at time t; and

Q^{m}obs = mean of the observed flow values over entire simulation period

2.6.3 Evapotranspiration and Infiltration

As well as the usual tests for goodness of fit, in order to operate any hydrologic model in such a way that it produces an accurate water balance, it is necessary to estimate beforehand, with reasonably precision, the mean daily ET that would have operated over the gauging/modelling periods and to ensure model outcomes are consistent with that. As ET is the major closure term in making a catchment water balance, we reviewed very closely just how ET operates in the relatively pristine areas of the Woronora Plateau.

Hounam (1961) reported that evaporation from a non-standard tank located at Cataract Dam (elevation 293 m) averaged 785 mm over a 31 year period. This implies that long term actual ET from the local catchments should not exceed about 0.9 x 785 = 706 mm.

However, the Bureau of Meteorology national map for Annual Areal Actual Evapotranspiration for the period 1960 – 1991 indicates that the Woronora Plateau catchments under study should have a lower mean annual ET in the 500 – 600 mm/year range, refer:

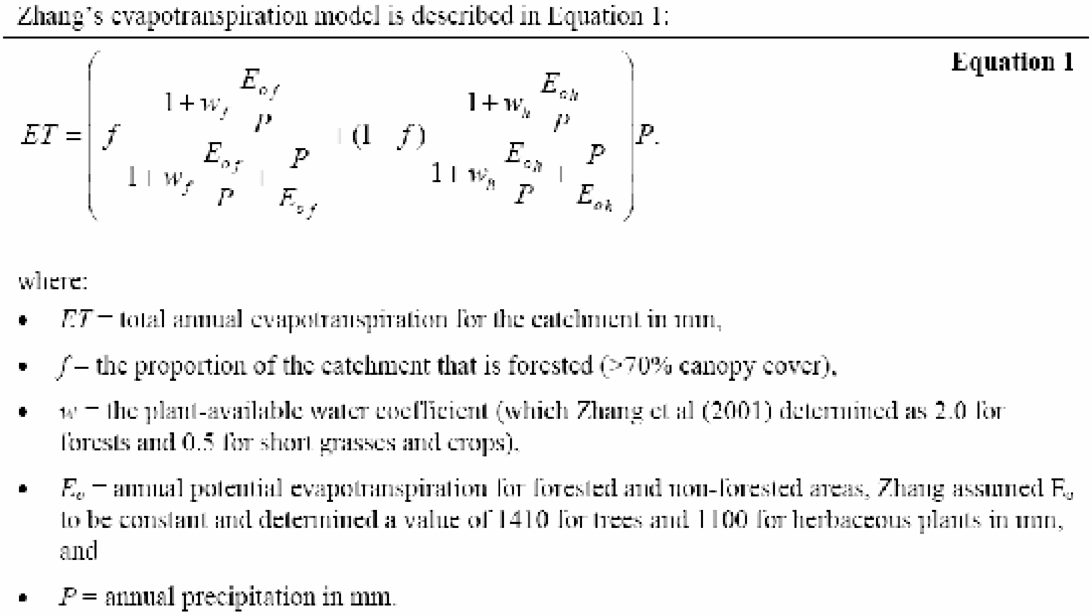
http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/evapotrans/et.html

Zhang et al. (2001) studied over 250 catchments worldwide, of which 96 were within Australia, covering a wide range of soil and climate types.

Zhang et al's model is based on empirical measurements from catchments with the following characteristics:

- rainfall is the dominant form of precipitation (not irrigation);
- slopes of catchments are gentle; and
- soil depth is relatively thick (>2 m).

Zhang et al. (2001) found, following on from extensive earlier studies, that mean annual ET_a may be well predicted from mean annual precipitation (P_a) using an equation which takes into account the proportion of woody vegetation (trees, shrubs) and proportion of grasses and low herbaceous species covering the 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 Zhang et al. (2001) algorithm shown above is now used widely in Australia and elsewhere for the prediction of mean annual evapotranspiration at a coarse geographic scale (e.g. Dowling et al. 2004) using the following values for w:

- 2 for plantations, native forests and woodland
- 1 for native shrub lands and heath lands (including swamps), horticultural trees and shrubs and perennial crops;
- 0.5 for annual crops, pasture and native grasslands; and
- 0.1 for bare ground and built-up areas.

Table 2.3 summarizes the results of a literature search we conducted on published long term hydrologic information relating to macroscopic water balances for regional near-coastal catchments founded mostly on weathered sandstone terrain.

Table 2.3 also lists the range of estimated values, for values of f, the proportion of catchment covered by forest (>70% canopy) ranging from 0 – 0.7 (noting some catchments such as Nepean have significant areas of farmland), for mean annual ET_a using the Zhang et al. (2001) equation shown above.

On the basis of examination of satellite imagery, the rural Mongarlowe, Corang and Kangaroo River catchments were assumed to be a mix of native forests/woodland (w = 2) and pasture/native grasslands (w = 0.5), and all others being largely national park (Endrick) or SCA areas (Avon, Cordeaux, Cataract, Nepean) a mixture of native forests/woodland (w = 2) and native heath lands (w = 1.0).

Table 2.3 shows that:

1. the Mongarlowe and Kangaroo River catchments exhibited the highest mean annual ET consistent with a 0.23 (23%) forest cover (>70% canopy) in each catchment, a value for the proportion of forest which appears likely to be an underestimate from inspection of satellite photographs of these catchments; and
2. <u>all other catchments</u> exhibit a significant <u>deficit</u> between the difference between mean annual rainfall and mean annual runoff which is significantly smaller than an estimated mean annual ET using the Zhang et a. (2001) formula, <u>even</u> a minimum ET estimated on the basis that the catchments contained no forest and are entirely covered in native heath land - which is patently not true.

TABLE 2.3: BASIC CLIMATIC INFORMATION FOR REGIONAL NSW NEAR-COASTAL CATCHMENTS LARGELY FOUNDED ON SANDSTONES

Catchment	**Area (km^2)**	**Years of Record**	**Mean Annual Rainfall (mm) P_a**	**Mean Annual Runoff (mm) Q_a**	**Mean Annual ET_a $=P_a-Q_a$ (mm)**	**Est. ET for f = 0 - 0.7 (mm)**	**Closest Est. ET (mm) to Mean Annual ET (f)**
Mongarlowe[a]	130	1950 - 1972	950	290	660	614 - 753	660 (0.23)
Corang[a]	166	1979 - 1986	650	230	420	492 - 567	492 (0.0)
Endrick[a]	210	1970 - 1979	880	645	235	649 - 731	649 (0.0)
Kangaroo River[a]	330	1970 - 1990	1570	725	845	763 - 871	846 (0.23)
Avon[b]	141	1961 - 1996	1122	565	557	741 – 793	741 (0.0)
Cordeaux[b]	90	1961 - 1996	1218	689	529	770 - 829	770 (0.0)
Cataract[b]	130	1961 - 1996	1192	776	416	762 - 896	762 (0.0)
Nepean[b]	320	1961 - 1996	927	346	581	670 - 759	670 (0.0)

a. Baki (1993); Boyd and Baki (1998)
b. Thyer and Kuczera (2000)

It can only be concluded that, with the possible exception of the Mongarlowe and Kangaroo River catchments, for all other NSW coastal Triassic and Permian sandstone-based catchments listed above in **Table 2.3** (including in particular the Cordeaux and Avon catchments of the Woronora Plateau in which Area 3 is located) a significant fraction of precipitation ultimately reporting as runoff at the gauging points must have rapidly infiltrated the soils and rock outcrops and passed to a depth below which water is no longer accessible for ET processes.

The absolute minimum fast infiltration to groundwater in this way for the Corang and Endrick catchments appears to be about 72 and 414 mm/year respectively, although the records are relatively short at 8 and 10 years respectively and hence these estimates are relatively imprecise for the long term.

However, the absolute minimum fast infiltration to groundwater in this way for the Avon, Cordeaux, Cataract and Nepean catchments lies in a narrower range being about 184, 241, 346 and 89 mm/year respectively, and the records are relatively long at 36 years in all four cases (Thyer and Kuczera, 2000).

This is strong, broad scale, water balance evidence for the Woronora Plateau Triassic sandstone terrain, which has been subjected to the weathering effects of numerous wet glacial and dry interglacial cycles throughout the Pleistocene and far wetter conditions in the Late Pliocene, being a relatively permeable landscape.

Equivalent behaviour where some not-insignificant fraction of total precipitation rapidly infiltrates to depth without being subject to ET processes has been measured in sandy catchments elsewhere in Australia (e.g. Petheram, 2003).

It is therefore inferred that for the Avon, Cordeaux, Cataract and Nepean catchments constituting most of the Woronora Plateau;

1. for any annual rainfall above a maximum available fraction of total annual rainfall, annual ET is naturally limited to a maximum value due to some rainfall penetrating to >2 m depth; and consequently
2. if all water which infiltrates too rapidly to be susceptible to ET does ultimately report to the gauging point then long term average deficit between rainfall and runoff should approach that maximum value of ET; and
3. for rainfall below that maximum available fraction of total annual rainfall, i.e. under drought conditions, annual ET may be expected to be proportionately reduced in magnitude (due to water stress on plants) approximately in accord with the relationship published by Zhang et al., 2001.

For the Avon and Cordeaux catchments, and adopting a 0.7 (70%) forest vegetation cover (>70% canopy) in each catchment, we can calculate from the Zhang et al. (2001) formula that the approximate minimum available annual rainfall to produce near-maximum annual ETs in accord with the observed long term differences between mean annual rainfalls and runoffs gauged at the dams (i.e. values of 557 and 529 mm; mean 543 mm; **Table 2.3**), should be 657 and 606 mm respectively. These have a mean value of 632 mm.

We infer this value (~632 mm) would approximate the lower limit on annual rainfall in Area 3 below which water stress on vegetation would be expected to naturally lead to a reduced annual ET.

Over calendar 2002, annual rainfall measured at Cordeaux Colliery was 516 mm, indicative of the drought that applied in the region over 2001 – 2002 and implying there would have been water stress on vegetation.

However, for the 12 month period 1 July 2002 through 30 June 2003 (which included the IC Native Dog and Donalds Castle Creek stream flow gauging periods), total rainfall was 725 mm and for calendar 2003 total rainfall was 856 mm.

These data indicate that over the period September 2002 to June 2003 in which IC's initial flow gauging of these catchments occurred, annual rainfall (~725 mm) was significantly in excess of the estimated minimum annual rainfalls (657 and 606 mm respectively) required to produce near-maximum annual ETs in the Avon and Cordeaux catchments.

In calculating best fit *Model Water Balances* for the target Native Dog and control greater Donald's Castle Creek catchments, our hydrologic model was therefore optimized to fit the observed hydrographs until ET over the study periods became adequately close to the mean of the observed long term difference between mean annual rainfall and mean annual runoff for the Lake Cordeaux and Lake Avon catchments i.e. 543±54 mm/year (i.e. 1.34 – 1.63 mm/day).

Provided annual rainfall in the area does no fall into severe drought below about 632 mm, this is a reasonable range to invariably adopt (or expect) for annual or daily ET in Area 3 to provide an acceptable ET closure term on model water balances.

2.7 BASELINE WATER QUALITY CONTEXT

The pHs of all upland streams within Hawkesbury Sandstone within the Special Metropolitan Areas are all 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 confirmed by long term monitoring of streams in the local area (Ecoengineers Pty Ltd., 2003, 2004a, 2004b, 2005a, 2005b, 2006a), and has also for the General SMP Area for Dendrobium Area 2 (Manly Hydraulics Laboratory, 2006; The Ecology Lab, 2006a).

These low pHs arise naturally as a consequence of equilibration of the waters with silicic acid derived from dissolution of silica and 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 only ecotoxic in its cationic forms (Tessier and Turner, 1995). Measured SO_4 and Dissolved Organic Carbon DOC levels in these creeks indicate that there would invariably be insufficient levels of sulfate (abbrev. 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 complex species with cationic Al, which would 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 these baseline sites studied 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 the benthic fauna in local headwater catchments in the Cordeaux and Avon Special areas has been confirmed by previous and recent studies (e.g. The Ecology Lab, 2007).

In 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 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 0.004 – 0.018 mg/L).

It is likely that speciation modeling, 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 generally the very much less (potential or actual) ecotoxic metal present at baseline sites. This conclusion would not be valid where the underlying lithology was not of a sedimentary quartz lithic sandstone type.

3. HYDROLOGIC AND WATER QUALITY IMPACTS

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

1. the ecological integrity of the streams, swamps or the lakes due to changes in water quality; and/or
2. raw water quality for drinking water supply purposes in Lake Cordeaux, Cordeaux River or Lake Avon;
3. the hydrologic productivity of the Lake Cordeaux and Avon headwater subcatchments contained within Area 3; and
4. 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 CATCHMENT HYDROLOGY EFFECTS

The following section describes in some detail the outcomes of our previous flow monitoring and hydrologic modelling of data obtained from the sites labelled NDC3 Starflow and DCL Starflow (also known as DCL3) identified in **Section 2.6.3** above.

3.1.1 Outcomes of the Prior Hydrologic Assessment

Time lags between peaks in rainfall and outflow by quickflow for both Native Dog Creek and greater Donald’s Castle Creek catchments were found to be of the order of 0.9 – 4.2 days, inclusive of creek line channel travel times, but still of the order of 0.4 – 2.7 days after subtraction of estimated channel travel times.

Estimates of Time of Concentration (t_c) for purely overland flow from these two catchments were only of the order of 0.05 – 0.08 days, i.e. very much smaller than the lag times evident from the storm hydrographs (Institution of Engineers Australia, 1998).

This indicates that outflow from the direct runoff (quickflow) systems of both catchments is dominated by processes involving interflow and return flow (i.e. quickflow) and true overland flow is a relatively small contributor to drainage from the direct runoff (quickflow) systems of both of these catchments.

Regardless of possible catchment specific scalar and geometric effects (refer **Appendix B**), the magnitude of the model alpha (α) parameter indicated that the proportion of effective precipitation (Peff) which enters the direct runoff (quickflow) system of these catchments is low, being estimated to be ≤25% from four model test cases considered. This implied that outflow from the direct runoff (quickflow) system must derive from precipitation which fell on the minor part of the catchment closest to drainage channels in gullies and the creek line.

It was known both from soil studies and from many inspections and sampling campaigns conducted by us in these catchments that in terms of soils profiles and the regolith (bedrock weathered zone), these appear very similar for the target Native Dog Creek and control greater Donald’s Castle Creek catchments.

For the mined-under Native Dog Creek catchment, both observed and model-simulated, area-normalized runoff (mm) from the direct runoff (i.e. quickflow) system

(1.02 mm from 91.5 mm of precipitation) was, proportionally greater by a factor of about 2.5 times than for the control greater Donald's Castle Creek catchment (0.67 mm from 154.5 mm of precipitation).

The direct runoff/quickflow system of Native Dog Creek catchment was also found to be about 60% faster than for Donald's Castle Creek catchment which drains significantly more slowly. This showed that, on an equivalent areal basis, the drainage resistance of the direct runoff (quickflow) system of Native Dog catchment is significantly less than that of greater Donald's Castle Creek catchment.

Therefore a possible effect (of mining) is an increased rate and volume of short term drainage of the Native Dog Creek catchment as indicated by an estimated direct runoff (quickflow) system reservoir coefficient Jd for the 3.96 km^2 catchment of 0.40 days. This is proportionately smaller than the estimated direct runoff (quickflow) system reservoir coefficient (Jd) for the 13.44 km^2 greater Donald's Castle Creek control catchment of about 2.73 days. Note these estimates do not include estimated channel travel times along the respected creek beds.

Baseflow recession in common catchment systems generally results from groundwater depletion, and moreover, most unconfined groundwater systems (aquifers) are usually located closest to the surface in the bases of valleys in unconsolidated sediments or deeply weathered bedrock.

The proportion of effective precipitation entering the groundwater systems of both catchments (1-α) as determined by modelling was therefore high (ranging from 80 – 98.5%). This implied that the outflow from the main groundwater system derives from precipitation which fell on, and hence recharged, the major part of the catchment i.e. the plateaus and hill slopes.

In the particular cases of both Native Dog and Greater Donald's Castle Creek catchments, it was considered that prolonged through flow in hillslopes was driving the delayed flow component. This phenomenon has been often observed and studied elsewhere before (e.g. Harr, 1977; Sklash et al., 1986).

This preliminary hydrologic analysis of the Native Dog and greater Donald's Castle Creek catchments strongly suggested that there was not a significant groundwater system associated exclusively with the creek bedrock or the bottoms of the valleys. The study showed that most of the recharge enters hillslope aquifers of each catchment and hence most, if not all, of the above-mentioned storage would:

- occur within those aquifers; but also therefore
- occur largely at elevation above the creek (while still being hydrogeologically connected to the creek bed).

This was consistent with detailed observations of these catchments made over the last 5 – 6 years (IC, 2004). The geomorphology of these catchments is characterized by upland plateaus and a series of 'benches' comprised of catenary hill slopes and swamps enclosed in roughly crescent-shaped cliff lines.

In the four test periods considered, the greatest degree of recharge of these 'hill slope aquifers' (i.e. 98.5% of effective precipitation) appeared to have occurred during the 59 day modeled period for greater Donald's Castle Creek catchment.

The available evidence suggested that while low baseflows may apply in greater Donald's Castle Creek some or most of the time, they appear to be systematically significantly smaller than for the mined-under Native Dog Creek.

This may be a consequence of subsidence related effects from mining under Native Dog Creek catchment. These effects could include ‘opening-up’ and ‘homogenizing’ vertical and horizontal flow paths in the catchment’s plateaux and hill slope-based groundwater system(s).

Alternatively it may simply have been a consequence of differing geomorphological characteristics between Native Dog Creek and Donald’s Castle Creek catchment.

Table 3.1 below compares the actual and modeled hydrologic behaviour of the mined under Native Dog Creek catchment and the reference greater Donald’s Castle Creek catchment during the period March – April 2003 when, as discussed in **Sections 1.2 and 1.3**, the geochemical evidence strongly suggested that the degree of fresh fracture opening of the bedrock in Native Dog Creek was at a maximum.

TABLE 3.1: ACTUAL AND MODELLED HYDROLOGIC BEHAVIOUR OF NATIVE DOG AND DONALD’S CASTLE CREEK CATCHMENTS FEBRUARY/MARCH – MAY 2003

Catchment	**Gauging Period**	**Days**	**Pobs (mm)**	**Qobs (mm)**	**Qsim (mm)**	**Jd (days)**	**ΔS’ (mm)**	**ETsim (mm/day)**	**Qb (mm/day)**	**Jb (years)**	**E (%)**
Greater Donald’s Castle Creek	09/03/03-6/05/03	59	154.5	1.07	1.02	2.60	75.47	1.345	0 – 0.01350	0 – 3.9	80.6
Native Dog Creek	26/02/03-15/04/03	48	91.5	1.65	1.58	0.40	14.09	1.639	0.01099 - 0.01212	26.5 – 29.4	86.8

The mined-under Native Dog Creek catchment exhibited a low but relatively constant baseflow from the groundwater system throughout the 48 day study period of the order of 0.011 - 0.012 mm/day. The greater Donald’s Castle Creek control catchment exhibited a much more variable groundwater-driven baseflow during the closely synchronous 59 day period ranging from zero to about 0.014 mm/day.

In the case of Native Dog Creek catchment, a shorter gauged period between 22 May 2003 and 3 June 2003 also exhibited an enhanced baseflow (0.067 – 0.072 mm/day) which could represent a period when an antecedent high rainfall/groundwater system recharge event became manifested in a much later ‘wave’ of baseflow flowing out of the groundwater system.

It was found that both the Native Dog and greater Donald’s Castle Creek catchment groundwater systems could be satisfactorily fitted by the RUNOFF 2000 model with a reservoir coefficient (Jb) of the groundwater system with an equation of the form $Jb = A/Qb^{0.67--1.00}$. This constrains the effective drainage distance (L) to being either constant or varying inversely with the average head above the drainage base, and 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).

The proportion of recharge (i.e. precipitation minus evapotranspiration) entering this groundwater system was invariably >75% of total recharge. By definition, this implied that the aquifer is typically located beneath at least 75% of the catchment i.e. the slopes, swamps and upland plateaux.

Mathematically, these observations all implied 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 idealised 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 fractured outcropping sandstone.

We carefully investigated the consequences of the baseflow characteristics of these catchments being driven by a hillslope aquifer by considering the scalar and geometric behaviour of an idealized hillslope aquifer system in these two catchments. Due to issues of mathematical complexity these considerations have described separately in **Appendix B**.

They showed that, in general, it is the geomorphic scalar features of the hillslope aquifers in the greater Donald's Castle Creek catchment which cause greater resistance to groundwater transmission, making it likely that the groundwater surface will intersect the land surface directly more frequently in these western sections of greater Donald's Castle Creek catchment, leading to discharge onto the land surface.

This in turn potentially returns some groundwater to the direct runoff/quickflow system. This is particularly the case if the travel path is not too long and if there is no opportunity for that water to re-enter the hillslope aquifer lower downslope. Where this is the case, such flows should appear in the creek as a later component of the direct runoff/quickflow system.

This provides a plausible explanation for why the best model fit for the 59 day period in March/May 2003 for Donald's Castle Creek catchment suggests a relatively large direct runoff/quickflow system reservoir coefficient of the order of 2.7 days and the overall hydrologic fit was visually and statistically poorer than for the Native Dog Creek Catchment study periods.

It also provided a specific reason as to why the 89.0 mm storm event between 9 and 12 March 2003, embedded in the 59 day rainfall/outflow record for this catchment was not preceded by a recognisable baseflow yet the recession curve that followed this four day storm event was characterised by a 'plateau' phase of near constant direct runoff/quickflow that lasted almost one month until about 7 April 2003.

In our view, this most likely results from a period of continuous 'daylighting' of groundwaters from an extensive thin, easily saturated hillslope aquifer in the south-western headwaters of the creek, an area which contains a number of large Type 2 swamps (refer **Figure 2.13**).

The Native Dog Creek catchment direct runoff/quickflow system apparently released water faster and in greater volume than Donald's Castle Creek catchment simply as a result of fundamental geometric and scalar differences between the two catchments.

It was concluded that greater Donald's Castle Creek is geomorphically and hydrogeologically insufficiently like Native Dog Creek catchment to be generally suitable as a control catchment for detecting changes in catchment hydrology possibly induced by longwall mining-based effects.

This is a key issue which needs to be understood and controlled in future comparative hydrologic studies of subcatchments within Area 3 when attempting to assess the hydrologic impact of longwall mining.

3.1.2 Prior Catchment Water Balances

Noting the assessment and *caveats* presented and discussed above, **Table 3.2** below shows an inferred Water Balance for the target and control catchments over a 47 day period from midday on 26 February 2003 to midday on 15 April 2003 for Native Dog Creek catchment and a 58 day period from midday on 9 March 2003 to midday on 6 May 2003 for greater Donald's Castle Creek catchment.

TABLE 3.2: MODEL WATER BALANCES FOR NATIVE DOG AND DONALD'S CASTLE CREEK CATCHMENTS FEBRUARY/MARCH – MAY 2003

Catchment	**Native Dog**	**Greater Donald's Castle**
Water balance period	Midday 28/02/03 – midday 16/04/03	Midday 09/03/03 – Midday 06/05/03
Days simulated	47	58
Rainfall (mm)	91.50	154.5
Total Outflow simulated (Total outflow observed) (mm)	1.58 (1.65)	1.02 (1.07)
Simulated change in soil and groundwater storages (mm)	14.09	75.47
Simulated change in depression storages etc (mm)	0.00	0.00
Simulated ET (mm) (mm/day)	75.83 (1.613)	78.01 (1.345)
Simulated (observed imbalance) (mm)	0.00 (-0.07)	0.00 (-0.05)

Table 3.2 above shows that:

1. within the expected degree of precision of the exercise (Nash-Sutcliffe goodness of fit parameter E ≥80%); and
2. assuming that a best fit ET must be within ±10% of 543 mm/y (1.487±0.149 mm/day) for both catchments (refer **Section 2.6.3 above**),

good water balances were achieved for both Native Dog and greater Donald's Castle Creek catchments for the gauged 47 day and 58 day periods respectively.

This suggested that at the mined-under Native Dog Creek NDC3 gauging site, over the 47 day study period (midday 28/02/03 – midday 16/04/03) and using greater Donald's Castle Creek hydrologic behaviour at nearly the same time as a control, particularly for the critical ET closure term on the balance, all water entering the Native Dog Creek catchment was recovered at the gauging point with a potential loss to deep storage of no more than the uncertainty in the model closure term estimates of daily ET (refer **Section 2.6.3**).

Therefore the uncertainty in the overall water balance is likely to be no more than about 1.613 – 1.488 = 0.125 mm/day (= 5.88 mm overall or 6.4% of the total precipitation).

On an area-equivalent basis, the water balance modelling also suggested that similar fractions of total catchment recharge (i.e. Pobs – ET) are inferred to have been stored in each catchment (Native Dog 90.0%; Donald's Castle 98.7%).

The rainfall and flow monitoring studies carried out by BHP Billiton Illawarra Coal in late 2002 and the 1st half of 2003, placed in a systematic and quantitative hydrologic context by appropriate modeling described above and in more detail in Ecoengineers (2006b) therefore suggest that:

- essentially all water was recovered at the downstream edge of the catchment at gauging site NDC3, north of the area of influence of the Elouera longwalls and upstream of the discharge point for Native Dog Creek to Lake Avon; and hence
- there was no evidence that the undermined Native Dog Creek catchment suffered any significant net loss of water to deep (unrecoverable) storages.

While substantial progress was made in this earlier study towards assembling a clear, realistic and systematic hydrological and hydrogeological model of local headwater catchments, this was for only a one-off study period, albeit conducted during a period of geochemically verified maximum creek bedrock fracturing. It is fully acknowledged that many more hydrographic and pluviometric field studies as well as hydrologic modelling and assessments are required to quantify the hydrological and hydrogeological effects of longwall mining, if any, in Dendrobium Area 3.

However, it is proposed that the approach established and described in **Sections 2.6 and 3.1** above and expanded further in **Appendix B** is an appropriate one to guide the design and implementation of the necessary 'best practice' hydrologic studies of Dendrobium Area 3.

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.

Minor rock falls and surface soil cracking occurred as the result of mining Areas 1 and 2.

Steep slopes and cliff lines occur along either side of the main channel of Wongawilli Creek and in several short un-named creeks on each side of the Creek. These tributary creeks 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 3A 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 past seven years of those areas of Upper Wongawilli Creek which had been mined under by Longwalls 1 through 6 of Elouera Mine at least monthly shows there were episodes of extreme 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 ‘Extreme’ concentrated flow erodibility of the Hawkesbury soil landscape type which characterise 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 past seven year monitoring period, even during the relatively high rainfall period of the first 6 months of 2007.

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

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 and the eastern side of Area 3C draining to Lake Cordeaux. 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.

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

Given that:

- Dendrobium Area 3 longwalls will not mine directly under the main channels of Sandy Creek, Wongawilli Creek or Donalds Castle Creek; and
- the cliff lines and slopes of the area are no more extreme than 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,

we conclude that it is highly unlikely that the mining of Area 3 would lead to any deleterious effects on aquatic ecology 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 Pty Ltd., 2005b, c; 2006b).
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.
5. Increased concentrations of dissolved aluminium (Al) in water emerging immediately downstream of fracturing-affected areas due to the dissolution of aluminium from kaolinite in the walls of flow paths conducting acidic water through the fractured bedrock.

3.3.1 Geochemical Impacts of Mining under Creek Beds

Detailed mapping of the downstream section of Native Dog Creek commenced in November 2001. At that stage Elouera Longwall 6 had extracted under the creek. Water was observed to be produced from the groundwater system in the vicinity of the “Coloured Pools” located 530m downstream of Maingate 6.

Ferruginous colouration and receding water levels were observed in Pool NDC2 located 420 m downstream of Maingate 6. Changes in water chemistry were noted in Pool NDC2a located 290 m downstream of Maingate 6. The Pool 201 complex is located 140 m downstream of Maingate 6. This complex was completely dry at the time of mapping. Complete drainage and ledge failure of Pool 210 located 50 m upstream of Maingate 6 was observed during this mapping. Detailed mapping extended from Lake Avon to the change in gradient upstream of Pool 210.

The extraction of Longwall 7 did not significantly change this pattern of observation. Pools such as NDC2A were completely dry during drought periods and Pool NDC2 held water for short periods after rainfall events. There was a trickle flow downstream of the coloured pools in all but extremely dry conditions.

These observations confirmed that the near surface strata were affected by compressive failure (mainly bedding plane shear) during the coal extraction process.

The most severe compressive failure was restricted to abrupt changes in creek bed elevation (and most competent strata) and was therefore concentrated at rock bars.

Minor leakage of rock bars was found to have the effect of depressing the local (unconfined) water table of the upstream flatter areas.

In 2005 an assessment and modelling of the potential magnitude of the above geochemical effects was conducted using data obtained over past years from lower Cataract River, from Bargo River and, in most detail, from Native Dog Creek.

These assessments were presented in a report in connection with the proposed development of Appin Colliery Area 3 near Cataract River (Ecoengineers Pty Ltd., 2005b), in a report in connection with the proposed development of West Cliff Colliery Longwalls 31 to 33 near Upper Georges River (Ecoengineers Pty Ltd., 2005c) and in recent reports on surface water effects of past longwall mining beneath Native Dog Creek catchment and the adjacent Wongawilli Creek catchment by Elouera Colliery for the period January 2005 – December 2006 (Ecoengineers Pty Ltd., 2006a, 7, 7a).

For those reports, a detailed study of the markedly fractured 2 – 3 m high rock bar at location NDC2A in upper Native Dog Creek was conducted. The assessment compared monthly flow measurements at an immediately downstream (site NDC3) and monthly chemistry sampling at upstream site NDC1, the rock bar site NDC2A and the downstream site NDC3 from the beginning of monitoring in mid March 2002 onwards.

Estimates of diverted sub-bed diversion flows through the Native Dog Creek NDC2A rock bar were found to be relatively accurate using the SO_4 concentration immediately downstream of the bar as a conservative tracer to site NDC3.

The study found the following:

1. The acid generation rate of the NDC2A rock bar was approximately dependent upon the rate of flow through the rock bar up to a maximum flow rate of about 0.1 ML/day.
2. *The highest observed rates of acid generation by the fractured rock bar occurred between March and May 2003*. The observed maximum daily mass of acid generated occurred on 21 May 2003 when the SO_4 concentration generated was 118 mg/L for an observed flow rate through the rock bar, back-calculated from a downstream flow meter at site NDC3, equivalent to 0.0791 ML/day. This is equivalent to a maximum H_2SO_4 generation rate of 97.2 moles/day. The pH of the diverted water on that day was also the lowest observed over the 12 month period at 3.16 (= field measurement; 3.19 laboratory sample check).
3. The acid generation rate of the rock bar then declined strongly over several years (Ecoengineers Pty Ltd., 2003; Ecoengineers Pty Ltd., 2004a, b; Ecoengineers Pty Ltd, 2005a).

To place the above outcomes in a regional context, it is useful to note that our subsequent Appin Area 3 study (Ecoengineers Pty Ltd., 2005b) also identified that:

1. early estimated maximum acid generation rates for discrete sub-bed flow diversion zones from the Lower Cataract River during the earliest monitoring period conducted by IC lay between 68 and 124 moles H_2SO_4/day; and
2. an estimate of maximum acid generation rates of comparable precision from data supplied to us by Tahmoor Colliery obtained from studies of the Bargo River also gave a maximum rate of approximately 100 moles H_2SO_4/day.

These estimates of maximum daily acid generation rate cover a relatively narrow range. This is an understandable outcome as there is good reason to expect that, for flows over about 0.1 ML/day through a freshly fractured network of a sub-bed flow diversion zone in Hawkesbury Sandstone, the rate of acid generation would be kinetically limited by:

1. average density of exposed marcasite grains in the freshly fractured Hawkesbury Sandstone; and
2. average cross sectional area, length and typical tortuosity of flow paths; and
3. dissolved oxygen content of the inflowing water.

It appears that this rate typically lies in the region of (say) 68 – 124 mole/day and the best available evidence to date suggests that it is very unlikely to be outside this range. A mean value of about 100 mole H_2SO_4/day would be a best estimate of the maximum rate of acid generation that would occur in any discrete sub-bed diversion zone.

In turn, this means that a maximum mass of marcasite of 50 moles/day is being dissolved and hence up to 36 moles/day of Fe is being released (but see below for estimated molar proportions of other included metals in marcasite).

This value appears to represents the maximum amount of acid that may be kinetically transferred to a sub-bed diversion flow of 0.1 ML/day or greater and that any sub-bed diversion flows (i.e. through the fracture network) that are greater than this will not increase the acid and metals load transferred to the water but will ameliorate their downstream effects through dilution.

It was found that the concentrations of filterable nickel (Ni) and zinc (Zn), known accessory metals in the marcasite, at pHs below that at which released Ni and Zn concentrations would have been reduced by adsorption onto precipitated hydrous Fe oxides showed relatively constant SO_4/Zn and SO_4/Ni mole ratios of 16±5 (n=13) and 100±19 (n=13) respectively (Ecoengineers Pty Ltd., 2005c). Note that errors here are expressed at the one standard deviation level.

These values for Ni and Zn are respectively, 16 and 96 within error and appear to be broadly consistent both with the known crystallography of marcasite and with recent literature on Ni, and Zn leaching in acid drainage derived from sedimentary quartz pebble-hosted spheroidal marcasites (Falconer and Craw, 2005). The average composition of local marcasite in the Native Dog Creek area (at least) therefore approximates to (say) $Fe_{0.854}Zn_{0.125}Ni_{0.021}S_{2.}$

We believe marcasite in Hawkesbury Sandstone within Dendrobium Area 3 is likely to have a generally similar composition. There was no significant correlation between manganese (Mn) and sulfate and it is inferred that most Mn would have been sourced from the dissolution of traces of rhodocrosite ($MnCO_3$) or manganiferous siderite (Fe/$MnCO_3$) in the sandstone as a consequence of the acid released though the dissolution of the marcasite.

In summary:

1. the estimated maximum daily rate of acid generation in any discrete sub-bed flow diversion zone is currently believed to be of the order of 100 mole H_2SO_4/day which is equivalent to 100 mole $CaCO_3$/day to completely neutralize it; and
2. prior 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.

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. Recent examples of reductions in impacts include Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River and West Cliff Area 5 Longwalls 31 to 33 adjacent to Georges River.

The Dendrobium Area 3A Longwalls 6 to 10 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, 2007).

We understand that this approach will also be the standard approach for future mining in Areas 3B and 3C.

We conclude that it is unlikely that the mining of Area 3 will lead to significant fracturing and subsequent hydrologic and/or geochemical effects within main channel creek beds of Sandy Creek, Wongawilli Creek and Donald’s Castle Creek

We cannot, however, rule out the possibility of some minor fracturing occurring at rockbars, rock shelves and nick points along tributary creek beds. MSEC (2007) predict 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.

With respect to Area 3A this may therefore possibly occur in the SC10 (Banksia Creek) tributary of Sandy Creek, particularly at the rock shelf over Main Gate 9 and Tailgate 10 and in the Creek WC17(A) tributary of Wongawilli Creek.

Noting that maximum tensile strain is the major element driving creek bed fracturing MSEC (2007) estimate that the Maximum Predicted Systematic Tilt, Maximum Predicted Tensile Strain and Maximum Predicted Compressive Strain along Creek SC10 and Creek 17/17A are 18, 4.5 and 9.4 mm/m and 10, 3.2 and 3.8 mm/m respectively.

However, there is some evidence from the local area that these predictions are relatively conservative.

Over Dendrobium Area 1 (Longwalls 1 and 2), only Tributary 22 of the main creek Kembla Creek exhibited creek bed fracturing as detected by our monthly geochemical monitoring of the pool at the confluence of Tributary 22 and Kembla Creek. The geochemical effects were relatively minor and of very limited duration. MSEC had previously estimated the Maximum Predicted Systematic Tilt, Maximum Predicted Tensile Strain and Maximum Predicted Compressive Strain along Tributary 22 to be 20, 4.0 and 9.0 mm/m.

However, there are seven other tributaries of upper Kembla Creek which were mined under by Longwalls 1 and/or 2 with similar Maximum Predicted Systematic Tilt, Maximum Predicted Tensile Strain and Maximum Predicted Compressive Strain along their channels as Tributary 22 and none of these were fractured.

We infer from this that while fracturing of Creek SC10 may have a probability exceeding 50%, the probability of a similar effect in Creek 17/17A may be as low as

10 – 15%. It is considered any such fracturing is unlikely to cause significant downstream water quality impacts.

Minor fracturing is therefore also possible in the longer, more incised, high gradient tributaries of Wongawilli Creek in Areas 3B and 3C and possibly in tributary creeks designated LC4 and LC of Area 3C which drain to Lake Cordeaux.

Water quality monitoring sites need to be carefully located to enable, on the basis of routine monthly campaigns a means of isolating and assessing such occurrence to determine if remedial action is required.

3.4 UPLAND SUBSIDENCE EFFECTS

3.4.1 Swamp Dewatering and Geochemical Effects

Type 1 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 Type 1 swamps 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 Impacts Assessment as Swamps 2, 5, 7, 8 and 15a.

While it is considered unlikely, on the basis of past experience, that mine subsidence-induced scour effects would affect these swamps it would clearly be prudent to target them for frequent assessment during the period if and when longwalls in Areas 3B and 3C mine across them.

As noted in **Section 2.5** above, in our view the overwhelming body of evidence indicates that Type 2 swamps (‘hanging swamps’) are embedded in hillslope aquifers and are supported by groundwater (DLWC, 2002).

It is again 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 subject to mining induced subsidence have not been detected anywhere in the Woronora Plateau over 10 years of close study, a period encompassing 6 years of drought and several major wild fires (Earth Tech, 2003).
2. It has been explicitly demonstrated that a major Type 2 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 palaeo-erosional surfaces in 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 Type 2 swamps has never detected any geochemical effects from mining subsidence beneath or immediately downgradient of swamps of either type indicative of the cracking of a 'tight' impermeable sandstone bedrock which by definition contains unweathered marcasite (Ecoengineers Pty Ltd., 2006, 2007a, b).

It follows that hydrologic and/or geochemical effects on this second type of swamp 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; and also
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 3 to enable modelling and assessment along the lines described in **Sections 2.6 and 3.1.**. The proposed monitoring program is described in **Appendix A**.

3.4.2 Ferruginous Springs

An effect of induction of ferruginous springs as a consequence of upland subsidence has been observed before in the Southern Coalfield in subcatchments of the Nepean, Cataract and Upper Georges River, most notably by producing:

1. the very large, and long-lived ‘SW2 Spring’ in Cataract River just west of Back Gully Creek; and
2. the moderately large and moderately long lived ‘Pool 11 Spring’ in Upper Georges River.

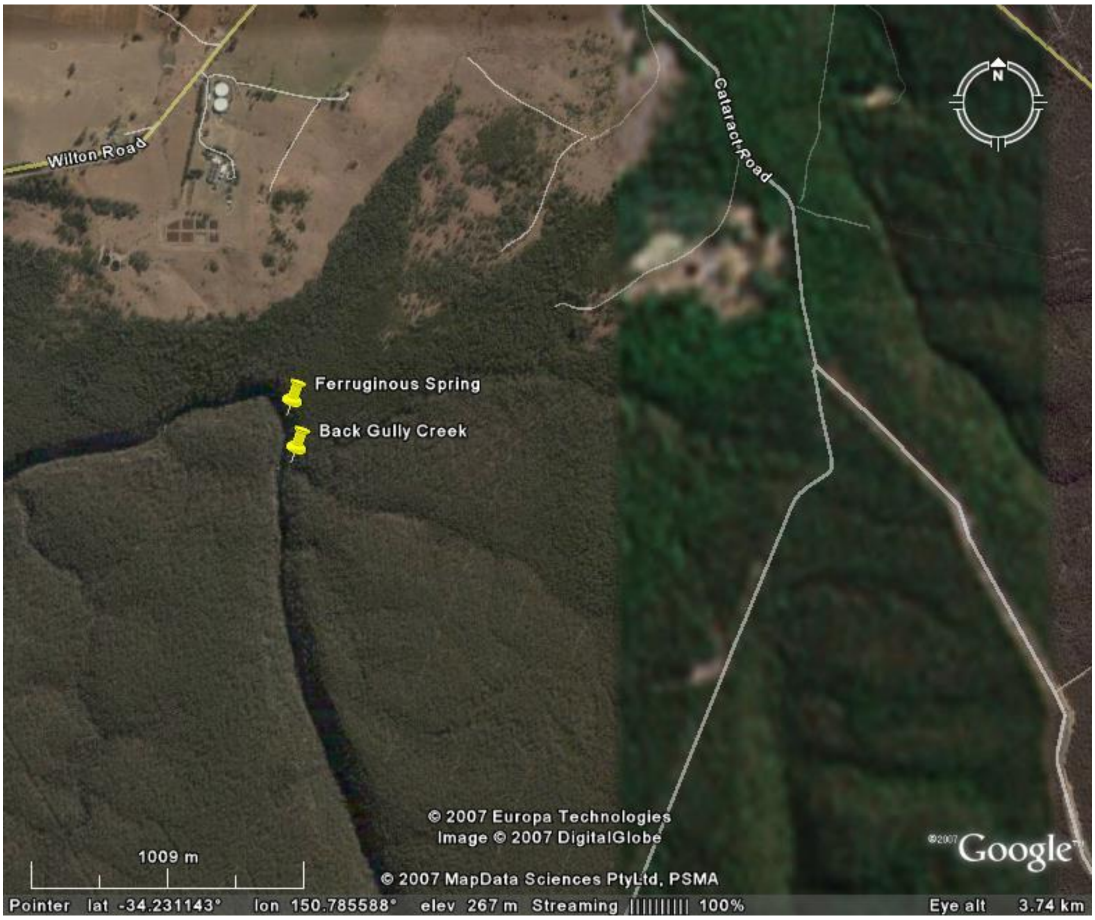
The Cataract Gorge SW2 Spring is presumed to have arisen some time in 1991 and continues to flow strongly to this day. It is estimated the spring obtains its water from a catchment of size in the range 1.0 – 2.0 km^2 mined under by Appin Longwalls 21B, 22B and 23 over the period March 1991 – March 1993.

The appearance of the spring, which has mature under canopy type rainforest tree species growing amidst masses of deposited iron oxides around and below the spring’s emergence point suggests that it has been a relatively stable feature since around that time i.e. a period of about 16 years. The following photograph shows the Cataract Gorge SW2 Spring.

FIGURE 3.1: SW2 SPRING CATARACT GORGE

The following picture shows the Back Gully Creek catchment from which the spring derives its water supply.

FIGURE 3.2: LOCATION OF CATARACT GORGE SW2 SPRING AND RELATED BACK GULLY CREEK CATCHMENT



The Georges River Pool 11 Spring arose in November/December 2000, was responsible for the long duration pollution with ferruginous material of the popular Marnyhes Hole, and only completely dried up in early 2006.

The following two photographs show the spring in January 2001 and the effect it was having on the River.

FIGURE 3.3: GEORGES RIVER POOL 11 SPRING JANUARY 2001

FIGURE 3.4: DOWNSTREAM GEORGES RIVER POOL 11 SPRING JANUARY 2001

The Pool 11 Spring lies in the centre of an area that was mined under by West Cliff Longwall 5A1 from May 1999 to January 2000 and by Longwall 5A2 from February 2000 until November 2000. Both of these longwalls mined across and under the River.

November 2000 was a relatively wet month of some 205 mm of rain, including a significant rainfall event occurring in the area in mid-November 2000 in which some 118 mm fell over a period of 11 days, with the bulk falling on 17 – 20 November. The preceding month of October was also relatively wet. Shortly thereafter the spring first appeared and discharged a considerable volume of ferruginous water into the river resulting in a heavy coating of hydrous Fe oxides down river for a distance of about 2 – 2.5 km.

It is inferred the spring derived its water from the (mined-under) portion (estimated to be about 0.2 km^2) of the 1.1 km^2 creek catchment flowing into the river nearby at Pool 12. The catchment providing the water supply for the spring occupied a significant portion of the urban area of Appin (Ecoengineers Pty Ltd., 2005b).

The spring in Georges River showed little evidence of decline in the four years after it was first identified but declined markedly in flow rate over late 2005 - 2006. It is unknown whether this was an effect of the drought and whether the relatively high rainfall conditions of the first 3 months of 2007 have restored its flows

The following photograph shows the (much diminished) Pool 11 Spring in March 2004.

FIGURE 3.5: GEORGES RIVER POOL 1 SPRING MARCH 2004

It is therefore inferred that such springs, if they arise, may be generated by a catchment of as little as approximately 0.2 km^2, are likely to have a lifetime of at least 5 years without significant diminution in intensity but may in fact be relatively permanent once instigated, depending upon the size of the catchment providing their water supply.

Significantly, a catchment size of the order of only 1 – 2 km^2 appears to be sufficient to confer a lifetime in excess of 10 years for such a spring.

In terms of the likely mechanism giving rise to such springs, it is now known that where broad scale upland 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 and would presumably be

This in turn apparently facilitates 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 downgradient 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:

- a 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 catchment of the creek by Wianamatta Shale soils.

Detailed geochemical investigations by us 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 iron (Fe) and manganese (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 rhodocrosite) 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 plateaux mantled with Shale (i.e. those drilled just into the upper layers of the Hawkesbury); and
- periodic longwall mining-induced seepages into the Cataract Tunnel; and by
- the emergence of highly visible ferruginous springs into the upper Georges and Cataract Rivers.

It has been estimated by us that 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 Pty Ltd., 2005a).

The Cataract Gorge SW2 Spring is presumed to have arisen some time in 1991 and continues to flow strongly. It is estimated the Spring obtains its water from a catchment size of about 0.3 – 0.7 km^2 being the northwest subcatchment of Back Gully Creek, directly mined under by Appin Longwalls 21B and perhaps part of 22B over the period March 1991 – March 1993.

The Pool 11 Spring lies in an area that was mined under by West Cliff Longwall 5A1 from May 1999 to January 2000 and by Longwall 5A2 from February 2000 until November 2000. Both of these longwalls mined under the River. It is estimated the spring derived its water from the mined-under diverted portion (estimated to be only about 0.2 km^2) of the 1.1 km^2 of catchment of the small creek flowing into the river nearby at Pool 12. The catchment providing the water supply for the spring occupied a significant portion of the urban area of Appin.

The following **Table 3.3** gives the major chemical characteristics of key examples of such water samples that have been analysed in the Southern Coalfield over the last eight years.

TABLE 3.3: WIANAMATTA SHALE WATERS OBSERVED IN SOUTHERN COALFIELD BOREHOLES AND SPRINGS

Sample Name	**Date**	**pH**	**EC µS/cm**	**Ca mg/L**	**Mg mg/L**	**Na mg/L**	**Filt. Fe mg/L**	**Filt. Mn mg/L**	**Cl mg/L**	**SO$_4$ mg/L**	**Mg/Ca M/M**
Georges River Borehole GRIP1	**12/05/99**	7.20	531	5.1	12	46	21.2	1.2	97	4	3.9
Georges River Borehole GRIP2	**12/05/99**	6.96	1301	4.4	11	240	21.8	0.64	130	14	4.12
Cataract Tunnel Seepage	**17/05/00**	7.07	9780	151	415	1450	<0.01	0.21	2930	171	4.53
Cataract Tunnel 404 Seepage	**22/06/01**	6.76	9230	118	354	1590	0.41	0.27	2980	146	4.95
Borehole Appin 72	**03/04/01**	7.80	9200	149	358	1360	0.01	0.30	2740	128	3.96
Borehole Appin 69	**08/08/01**	6.87	7360	147	319	1360	6.97	0.33	2760	130	3.58
Borehole Tower 22	**13/08/01**	6.65	5800	113	271	981	40.9	0.42	1930	166	3.95
Georges River Pool 11 Spring	**07/07/02 – 12/07/05 (n=13)**	7.79	1055	2.7	4.5	225	6.5	0.198	129	18	2.75
Cataract River Spring SW2	**19/07/05 – 04/04/07 (n=21)**	5.63	517	5.24	15.05	68.8	20.7	1.95	155	9.3	4.74

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 good alkalinity should generally be sufficient to ensure that the generation of acidity through the oxidation of the dissolved Fe and Mn is insufficient to produce pHs low enough to cause ecotoxic effects.

The only situation where this could potentially not apply is where such a spring flowed into a large stream or river where the existing water was very fresh i.e. of very low salinity and hence low alkalinity (Appelo and Postma, 1996).

In summary, we conclude that:

1. The ferruginous springs referred-to are very unsightly and highly visible due to the voluminous precipitation of oxidised ferruginous material and unless they arise in well wooded country in restricted areas are likely to be readily detected by the public.
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 has 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 were detected, detained and treated in some way within the catchment within it as they arose, then creek waters containing significant concentrations of dissolved ferrous and manganous 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 immediately area.

A substantial portion of Area 3B is mantled by Wianamatta 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 (refer **Figure 2.8 in Section 2.3** above).

Drainage of the Wianamatta Shale-based soil uplands to the northwest to tributaries of Upper Donald's Castle and Lower Wongawilli Creeks occurs over much longer distances with far gentler slopes. It is therefore considered that induction of ferruginous springs in this area is less likely. Even if such springs were to arise flows from them would also be intercepted by Swamps 1a, 1b, and 5 in the Upper Donalds Castle Creek area and Swamps 8, 10 and 13 in Wongawilli Creek tributary WC21 and Swamp 14 in tributary WC15, proving a much longer flow path for aeration and amelioration of the generated acidity.

Any such effect (of causation 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 Lake Avon shoreline.

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 IMPACTS ON BULK RAW WATER SUPPLY QUALITY

There is good evidence from over five years of monitoring that there has been no 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 substantial creek bedrock fracturing.

Due to the standoffs of Area 3 longwalls it is not expected any significant fracturing and sub-bed flow diversions will occur in Sandy Creek or Wongawilli Creek to alter bulk flows from these creeks or to significantly alter bulk water quality in the major sections of them.

Based on past experience from Wongawilli and Native Dog Creeks which were directly mined under, it is also considered highly unlikely that there would be any adverse effect on bulk drinking water supply quality in the Lake Cordeaux or Lake Avon systems.

Any input of water-borne contaminants (to Lakes Avon and Cordeaux) 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) and LC6, LC7 and LC8 (Lake Cordeaux) during mining of Areas 3B and 3C respectively.

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

4.2 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.

It is now known that there is no recognised deep aquifer in the bulk of the major outcropping Hawkesbury Sandstone in this area.

Baseflows of the draining streams are believed to be 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.

Rainfall and stream flow monitoring studies subject to a quantitative hydrologic assessment as reported in Ecoengineers (2006b) suggest that there was no evidence that the overall Native Dog Creek catchment (located just south of Dendrobium Area 3B) suffered any significant net loss of water to deep (unrecoverable) storages due to longwall mining by Elouera Mine, despite recognized instances of creek bed fracturing in this Creek and Wongawilli Creek.

It was inferred that the Native Dog Creek catchment direct runoff/quickflow system apparently released water faster and in greater volume than Donald's Castle Creek catchment simply as a result of fundamental geometric and scalar differences between the two catchments.

It was concluded that greater Donald's Castle Creek is geomorphically and hydrogeologically insufficiently like Native Dog Creek catchment to be generally suitable as a control catchment for detecting changes in catchment hydrology possibly induced by longwall mining-based effects.

This is a key issue which needs to be understood and controlled in future comparative hydrologic studies of subcatchments within Area 3 when attempting to assess the future hydrologic impact of longwall mining.

Longwalls in all areas of Area 3 will be sited well back from major creeks such as Sandy Creek and Wongawilli Creek to a distance that has been and will be guided in future by priori subsidence modelling, to avoid significant cracking in these creek beds. Due to the standoffs of Area 3 longwalls it is not expected that any significant fracturing and sub-bed flow diversions will occur in Sandy Creek or Wongawilli Creek or that there will be detectable losses of outflows from these catchments.

4.2.2 Subsidence Induced Erosion Impacts

Slopes, cliff lines and soil types identified within Area 3A are closely 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 past seven years of those areas of Upper Wongawilli Creek which had been mined under by Longwalls 1 through 6 of Elouera Mine at least monthly shows there were episodes of extreme 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 'Extreme' 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 past seven year monitoring period, even during the recent high rainfall period of the first 6 months of 2007.

It is expected minor erosion will occur due to mine subsidence-induced slope stability effects during the mining of Area 3. 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 and the eastern side of Area 3C draining to Lake Cordeaux. 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.

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

Given that:

- Dendrobium Area 3 longwalls will not mine directly under the main channels of Sandy Creek, or Wongawilli Creek; and
- the cliff lines and slopes of the area are no more extreme than 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,

we conclude that it is highly unlikely that the mining of Area 3 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 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. Hydrological measurements, visual observations and water quality monitoring over recent years in the Southern Coalfield indicate these effects are:

It has been demonstrated that, subject to predictive 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 and West Cliff Area 5 Longwalls 31 to 33 adjacent to Georges River.

Dendrobium Area 3A Longwalls 6 to 10 will not mine under Wongawilli or Sandy Creeks by distances 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. We understand this approach will also be the standard approach for future mining in Area 3.

We conclude that it is unlikely that the mining of Area 3 will lead to significant main channel creek bed fracturing and subsequent sub-bed diversion hydrologic and geochemical effects in Sandy Creek and Wongawilli Creek.

MSEC (2007) predict 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 therefore possible minor fracturing may occur at rockbars, rock shelves and knick points along tributary creek beds, for Area 3A particularly in and around Main Gate 9 and Tailgate 10 on the SC10 Creek tributary of Sandy Creek and in the WC17/17A tributary of Wongawilli Creek.

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 8 tributaries with Maximum Predicted Systematic Tilts, Maximum Predicted Tensile Strains and Maximum Predicted Compressive Strains along their channels of the order of 20, 4.0 and 9.0 mm/m respectively, only one tributary (No. 22) exhibited fracturing. Geochemical studies indicated the fracturing was minor and of limited duration.

We infer from this that while fracturing of Creek SC10 may have a probability exceeding 50%, the probability of a similar effect in Creek 17/17A may be as low as 10 – 15%. It is considered any such fracturing is unlikely to cause significant downstream water quality impacts.

Fracturing is also possible on the longer, more incised, high gradient tributaries of Wongawilli Creek in Area 3B e.g. creeks designated WC15 and 21, and possibly in Area 3C in the well incised creeks designated LC6 and LC7 of Area 3C which drain to Lake Cordeaux.

4.2.4 Ferruginous Springs Impacts

Mining subsidence beneath upland plateau areas can also produce a complex suite of physico-chemical effects. Induction of ferruginous springs as a consequence of upland subsidence has been identified over the last three years as a longwall mining-related effect in the Southern Coalfield in subcatchments 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; and
- the moderately large and long lived ‘Pool 11 Spring’ in Upper Georges River.

It is known 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 Wianamatta Shale 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 downgradient 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 plateaux mantled with Shale (i.e. those drilled just into the upper layers of the Hawkesbury);
2. periodic longwall mining-induced seepages into Cataract Tunnel; and by
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 which, in our view, <u>may</u> 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. Peaks flows arrive some time after peak rainfall due to the hydraulic residence time of the subsidence-induced perched aquifer e.g. average hydraulic residence time of the aquifer driving the Cataract Gorge SW2 Spring appears to be of the order of 6 weeks.

A substantial portion of Area 3B is mantled by Wianamatta 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 Donald's 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 may be induced in 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 Lake Avon shoreline.

Water quality monitoring sites should be located in this part of Area 3B just prior to mining to provide early detection and ongoing assessment of this potential effect.

4.2.5 Swamp-Related Impacts

There are a large number of swamps within Area 3. These swamps have been mapped and are described as Swamps 1a to Swamp 35b (**Figure 1.2**).

We believe it is important to 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:

3. Type 1 or 'braided stream 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. 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 and low gradient, has poor vegetation condition e.g. from prior bushfire damage, and the longwalls lie perpendicular to the long axis of the swamp.
4. Type 2 or 'hanging swamps' occurs within broad scale, relatively low slope creek or tributary headwater areas.

Even recent study reports may still exhibit an entrenched view that Type 2 swamps are 'perched' on impermeable bedrock. However, this is incorrect and a significant body of direct and circumstantial evidence, summarized in **Section 2.5** above clearly indicates that most, if not all Type 2 swamps are 'embedded' in a broader scale 'hillslope aquifer' which provides the excess of precipitation over evapotranspiration (ET) which proportionally sustains them. We conclude that Woronora Plateau Type 2 swamps are Groundwater Dependent Ecosystems in the same way as the hanging swamps of the Blue Mountains have long been recognised to be (DLWC, 2002).

Type 1 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 Type 1 swamps 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 CFR (2007) as Swamps 2, 5, 7, 8 and 15a.

While it is considered unlikely, on the basis of past experience, that mine subsidence-induced scour effects would affect these swamps it would be prudent to target them for frequent assessment during the period if and when longwalls in Areas 3B and 3C mine across them.

Fracturing due to subsidence effects might sometimes become physically detectable at a central drainage line rock shelf or knick points in Type 2 swamps, but such fracturing should be confined to sandstone that already contain, naturally, well weathered bedding planes and cross fractures due to the long period of exposure of such features and thus further fracturing should, in theory be inconsequential.

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 geochemical or ecological effect on the upgradient or down gradient portions of the swamp, but to a broad scale hillslope aquifer. Detection of change requires 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 or active longwalls.

Several shallow piezometers have already been established in Dendrobium Area 2 for hillslope aquifers on the eastern side of Sandy Creek. It is proposed that IC will also initially deploy relatively small numbers (say 3 – 5) of shallow piezometers within the Area 3A subcatchment areas encompassing Swamps 12 and 15a and the general area of Banksia and Cascade Creek catchments.

It is proposed that similar numbers would be progressively established over Area 3 wherever it is judged on geomorphic grounds that there is potential for a broad scale hillslope aquifer/upland swamp complex playing a significant role in the hydrology of the major local draining stream, i.e. specifically Sandy Creek, Wongawilli Creek or Donald’s Castle Creek.

In our view, the only other broad areas which would merit monitoring in this regard are:

- Swamp 12 and the Creek WC17 catchment of Wongawilli Creek (Area 3A);
- Swamps 10 and 13 and the subcatchments of Creeks WC21A and WC21 (Area 3B); and
- Swamps 1a and 1b and the Creek DC1 and Upper Donald’s Castle Creek sub-catchments which have been verified from our previous studies (Ecoengineers, 2006b) to provide a significant baseflow for Lower Donald’s Castle Creek (Area 3B).

While it is considered unlikely on the basis of past experience that mine subsidence-induced hydrologic effects would adversely affect these Type 2 swamps and more particularly the substantial hill slope aquifers in which they are likely to be embedded, it would be prudent to target them for frequent assessment during the period in which longwalls in Areas 3A, 3B and 3C approach or mine under them.

It is also noted that:

- There may be a future need to establish a hydrographic gauging station midway down Wongawilli Creek if shallow piezometer studies confirm a broad-based hillslope aquifer in the Creek WC21 subcatchment in order to make a hydrologic modelling assessment of its pre- and post-mining effects.
- Several large upland swamps occur in the headwaters of creeks designated WC17 and Banksia Creek over Area 3A. Swamp 12 is of Type 2 and Swamps 15a and 15b of Type 1. Several creek flow and/or water quality monitoring sites are proposed for Area 3A, which lie immediately downstream (in Wongawilli Creek and Banksia Creek) from these swamps.

Strongly differential rates of subsidence along these swamps are not expected with the exception of one or two location in Swamp 15a near Main Gate 9 and Tailgate 10 and hence it is considered unlikely that bedrock fracturing could occur at any but those two locations. Swamp 12 is largely offset from its draining stream and Swamps 15a and 15b lie at the headwater of their draining streams. It is not expected these swamps would be susceptible to scour under high rates of runoff unless very significant prior fire damage had occurred.

4.3 WATER MONITORING AND MANAGEMENT PLAN SUMMARY

A Water Monitoring and Management Plan incorporating detailed provision for water quality and hydrographic monitoring and the interpretation of data from that has been prepared as **Appendix A** of this report. This will be incorporated into the Dendrobium Area 3A Subsidence Management Plan (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 prior flow gauging studies of the nearby Native Dog and Donald's Castle Creeks and were described in detail in our 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 we believe now represents a best practice approach to the detection of potential near surface hydrologic impacts of mine subsidence. The rationale and methodology for the data analysis treatment have been described in full in **Sections 2.6, 3.1 and Appendix B.**
2. Small numbers of shallow piezometers will be established in those upland areas where a significant unified hillslope aquifer potentially susceptible to subsidence is believed to occur and where large swamps or families of swamps also occur.
3. Pre-mining baseline and post-mining field water quality monitoring and laboratory analysis program will be conducted based on the prior long term study of water quality of the nearby Native Dog, Wongawilli and Donald's Castle Creeks since late 2001. It is proposed that in the first instance, the secondary and principal water quality TARPs would be those previously established for Dendrobium Area 2, namely pH declines of 1.5 and 2.0 pH units, Electrical Conductivity increases of 50 and 100 µS/cm and Oxidation Reduction Potential declines of 150 and 200 mV. However, these may be revised following collection of an adequate body of baseline data. 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. We believe that water-related field work should concentrate in the 1st 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 hanging swamps.

It would be largely non-productive to establish *a priori* regularly visited water quality monitoring sites within tributaries until such time as evidence was detected for any geochemical change in a tributary. Properly sampled, and analysed, 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.

Based on extensive past experience in the area, it is believed that, in the first instance water quality studies should be based on sites still located within the three subcatchments (Sandy, Wongawilli and Donald’s Castle) main channels but always carefully locating main channel monitoring sites just downstream of confluences with key 'candidate' 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 - a trend we see developing over the next 5 years.

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, closer field investigations of the tributary subcatchment’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 against TARPs;
2. closer monitoring of the suite of shallow piezometers sited within the subcatchment and if necessary installation of more piezometers; and if deemed necessary
3. temporary deployment of one of the four relocatable Starflow Doppler flow meters held by IC to a gauging site above the confluence of the tributary and creek main channel to obtain quantitative flow data though several storm events for hydrologic assessment similar to the approach described in **Section 2.6.1**.

The proposed locations and numbers of routine water quality, hydrographic and piezometric monitoring sites as established by Hydrometric Consulting Services, IC and Ecoengineers are deemed satisfactory for assessing the potential hydrologic and water quality effects of Dendrobium Area 3A and enabling rapid back tracking to any suspected sites or areas affected by mine subsidence effects, such as tributary subcatchments. 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 3 and an appropriate number of years thereafter.

In the event that future water monitoring shows that there has been significant hydrologic or aquatic ecotoxic effects within Area 3 catchments then it is possible that some management and mitigation measures may be required. Management measures may simply 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. Some potential water quality management and mitigation measures believed to be compatible with the Metropolitan Special Catchment Area are identified in **Section A8** of **Appendix A**.

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APPENDIX A
PROPOSED DENDROBIUM AREA 3 WATER MONITORING AND MANAGEMENT PLAN

A1 INTRODUCTION

This proposed water monitoring plan, which incorporates provisions for, hydrographic and water quality monitoring has been prepared for incorporation into the Dendrobium Area 3A Subsidence Management Plan (SMP) which guides management and monitoring protocols for Dendrobium mine.

This is required to comply with the Dendrobium consent, and the DPI's SMP guidelines.

It is proposed to conduct monitoring programs before, during and after mining of Area 3. These programs are intended to provide catchment hydrologic and waterway geochemical assessments before and over the lifetime of Dendrobium Area 3.

A2 MONITORING PLAN DESIGN PHILOSOPHY

The current stream flow monitoring regime operated by IC within Dendrobium Area 2 has not been able to provide sufficiently accurate hydrographic data to confidently assess any mining-related change to catchment hydrologic stream flows within the Sandy Creek catchments, particularly under recessional and baseflow conditions.

Preliminary hydrologic monitoring in Native Dog and Donald's Castle Creek catchment and the preliminary development of hydrologic modelling of the data from that preliminary program has provided guidance on the way forward to addressing that deficiency.

Preliminary hydrologic modelling and assessment in the area was based on the use of the well-developed Free University of Amsterdam alpine headwater catchment non-linear parametric model RUNOFF2005, the use of which has now been well 'proofed' in the Native Dog and Donald's Castle Creek Catchments and at two coal mine sites in the Region with satisfactory outcomes (Ecoengineers Pty Ltd., 2006b; 2007b, d).

It is proposed that the hydrographic monitoring and hydrologic assessment of the monitoring plan should build on the lessons learnt from this ppreliminary hydrologic modelling assessment in the local area.

It is aimed to provide a level of hydrographic monitoring and hydrologic assessment much more detailed than previously undertaken, representing a 'best practice' approach to the detection of potential near surface hydrologic impacts of mine subsidence, both within creek lines and in the broader subcatchments. It is therefore proposed that hydrologic assessment would continue to be based on application of the RUNOFF2005 model.

However, it is also hoped optimized parametric outcomes of the RUNOFF2005 modelling of Banksia Creek, Cascade Creek, Upper and Lower Sandy Creek, Upper and Lower Wongawilli Creek and Upper Donald's Castle Creeks can be input to the CSIRO Land and Water hillslope aquifer model FLOWTUBE to properly assess water level data obtained from small numbers up to possibly whole networks of shallow piezometers distributed within in the Area 3 hillslope aquifers and hence also of the Type 2 swamps embedded in them (e.g. Dawes et al., 1997, 2001).

With respect to water quality monitoring, numerous studies in the area conducted since September 2001 have clearly shown that field monitoring of pH, Electrical

Conductivity (EC), Oxidation Reduction Potential (ORP; Eh) and/or dissolved oxygen (DO) provides extremely sensitive and timely means of detecting and providing quantitative assessment of such effects as the very earliest stages of creek bed fracturing or induction of ferruginous springs.

When this field monitoring is backed-up by detailed laboratory chemical analysis for major cations and anions, key total and filterable trace metals and dissolved organic carbon (DOC) this enables geochemical modelling and assessment which provides very detailed information on the biogeochemical processes occurring and their likely timescales (Ecoengineers Pty Ltd., 2003, 2004a, b; 2005a, b, c; 2006a, b; 2007a).

It is proposed that, in the first instance, the secondary and principal water quality TARPs adopted for Area 3A would be those previously established for Dendrobium Area 2, namely pH declines of 1.5 and 2.0 pH units, Electrical Conductivity increases of 50 and 100 µS/cm and Oxidation Reduction Potential declines of 150 and 200 mV.

However, these may be revised following collection of an adequate body of baseline data. More water quality monitoring sites will be established for obtaining baseline data well prior to the mining of Areas 3B and 3C (in that order).

It is also proposed that assessment of water quality data would be supported by geochemical modelling using, as it has been for some time, the United States Geological Survey (USGS) model PHREEQC (Parkhurst and Appelo, 1999) to provide:

- inverse modelling of causally-linked water quality pairs; and
- accurate quantification of the magnitude of sub-bed diversion geochemical effects if they should arise; and to
- properly identify source waters where/when required.

To maximize data returned for effort expended, we believe that water-related field work should concentrate, in the 1st instance, on regular monthly field campaigns to main channel water quality/flow sites, and tributary catchment piezometers not within but surrounding and downstream of hanging swamps.

It is noted that, in the first instance, hydrographic and water quality monitoring would be based on sites still located within the main channels of the principal creeks (Sandy, Wongawilli and Donald's Castle). The main 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.
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 trend we see developing over the next 5 years.

However, 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.

Properly sampled, and analysed, geochemical data is very sensitive and invariably has proven to be the most reliable early indicator of the onset of subsidence-related water effects. We are of the view that it would be largely non-productive to establish *a priori* regularly visited water quality monitoring sites within tributaries until such time as evidence was detected for any geochemical change in an upstream tributary.

A staged response plan triggered by main channel exceedances of water quality secondary TARPs would be activated as described in more detail in **Section A5** below to investigate possible subsidence-related hydrologic or water quality effects within tributaries.

The proposed data collection programs comprising the Plan are as follows:

1. A pre-mining baseline and post-mining stream hydrographic monitoring, hydrologic modelling and assessment program.
2. Establishment of small numbers of shallow piezometers in those upland areas where a significant unified hillslope aquifer, potentially susceptible to subsidence effects is believed to occur and where large Type 2 swamps or families of such swamps also occur.
3. A pre-mining baseline and post-mining field water quality monitoring and laboratory analysis program based on extension of the existing long term study of water quality conducted in the Native Dog, Wongawilli and Donald's Castle Creeks since late 2001 and extensively reported-on previously.

Three monthly water quality monitoring would also be carried out in Creeks LA1, LA2, LA3, LA4A and LA4B during the mining of Area 3B to provide early detection of the potential ferruginous springs effect.

The above catchment hydrologic, shallow groundwater and water quality monitoring and assessment programs will provide continuous water-related monitoring of the streams and subcatchments potentially affected by the mining of Dendrobium Area 3 and allow month-by-month assessment of the magnitude of any developing trends in overland and subsurface flow and water quality effects as a result of longwall the mining.

A3 PROPOSED MONITORING SITES (AREA 3A DEVELOPMENT STAGE)

Figure A1 below shows a map of Dendrobium Area 3 and its environs showing:

- the disposition of prior Elouera Mine longwalls 1 through 10; and
- the disposition of prior (mined under) Native Dog Creek catchment water quality monitoring sites NDC1, NDC2, NDC2A, NDC3 and NDC4; and
- the disposition of prior (partially mined under) Wongawilli Creek catchment water quality monitoring sites WWU1, WWU3, WWU4 and LLL2; and

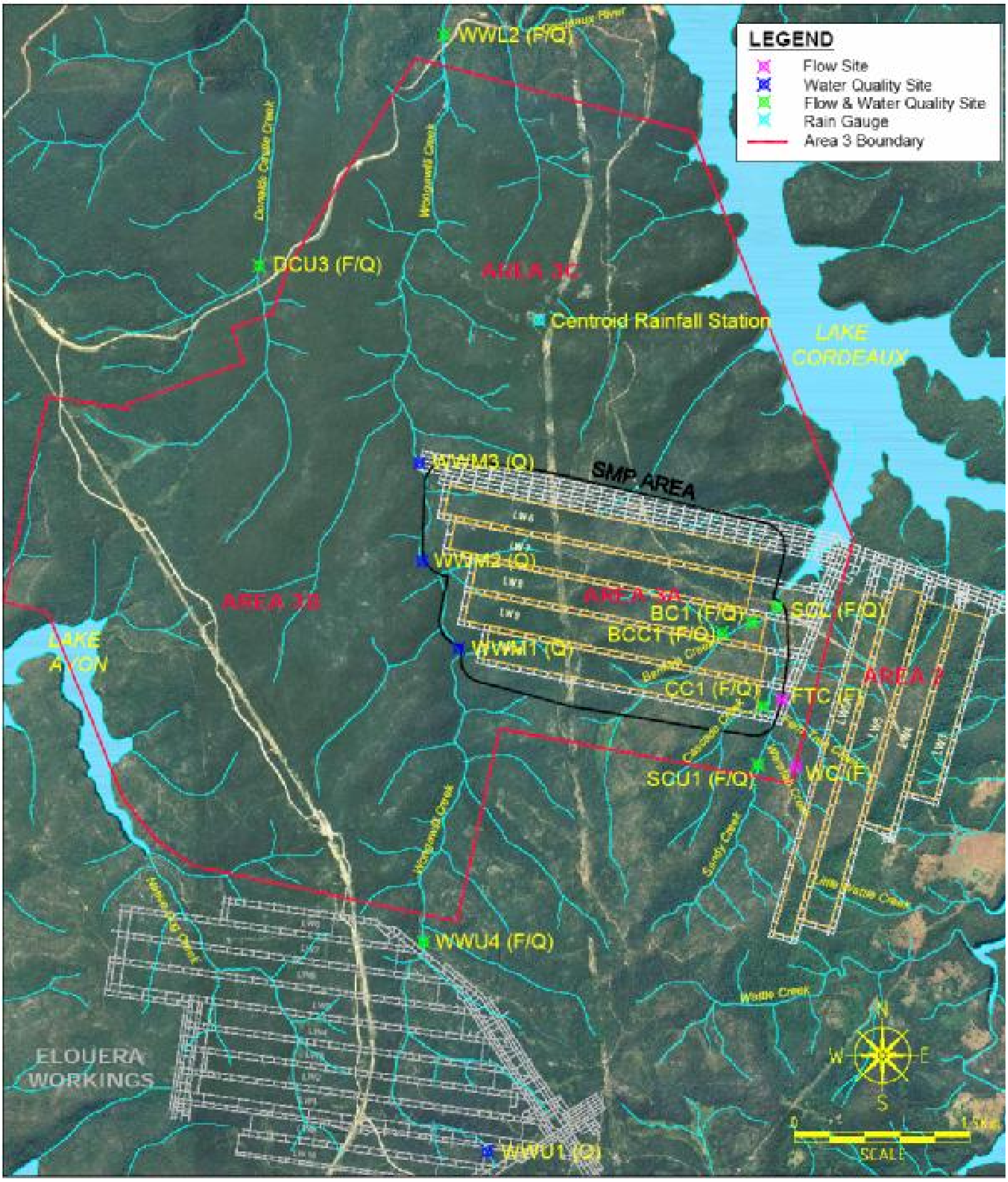
- the disposition of (control) Donald’s Castle Creek catchment water quality monitoring site DCU3.

A greater Donald’s Castle Creek catchment water quality monitoring site further to the north on lower Donald’s Castle Creek (designated DCL3) established in 2001 could not be shown on this figure as it lies too far to the north.

Figure A1 shows the proposed initial suite of Area 3 water quality and flow monitoring sites as well as a centrally located rainfall monitoring station (pluviometer) which would be established in accord with this Plan prior to the development of Area 3A.

Note that the approved longwalls 5A and 5B of Area 2 and the proposed longwalls of Area 3A are also shown.

FIGURE A1: DENDROBIUM AREA 3 PROPOSED WATER QUALITY AND FLOW MONITORING SITES (AREA 3A DEVELOPMENT STAGE)



A4 HYDROGRAPHIC MONITORING PROGRAM

To provide a suitable hydrographic monitoring program for Area 3, it is proposed that nine flow monitoring stations would be installed within the Sandy, 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. The monitoring program would aim to characterise catchment hydrologic performance during the pre, during and post mining operations.

IC have contracted Hydrometric Consulting Services HCS) to install, maintain and operate the stream flow monitoring (hydrographic) sites. HCS undertake similar work for the SCA and other mining companies who operate within the Sydney catchments. All proposed monitoring structures and site will be installed following approval from SCA.

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

All flow monitoring stations will aim to particularly accurately characterise flows within the streams at low flows i.e. baseflows where the potential for mining-induced impacts is 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 6 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 artificial 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 tables.

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

Data will be edited, archived and disseminated using the software HYDSTRA. This software is currently the preferred software for the hydrometric industry with SCA utilising it for data management and reporting. Data can be presented in a variety of formats including plots and tabulated outputs. Level and rainfall data will be available within 7 days of each download, and following the derivation of the flow rating tables, data will be presented as both level and flow.

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

As mining commences close to or under the Sandy and/or Wongawilli Creek catchments, flow monitoring will recommence. It may be appropriate to undertake flow monitoring in the 'during mining' phases on a campaign basis. This decision will be made on the basis of observational and other monitoring undertaken in the catchments in accordance with SMP approval requirements.

Post-mining hydrographic monitoring campaigns will be undertaken sequentially after mining ceases in Dendrobium Areas 2, 3A, 3B and 3C to characterise the responses of the catchment to several rainfall events (with an emphasis on low flow conditions). Hydrographic monitoring is likely to be applied periodically throughout the lifetime of Area 3. All equipment used in the construction or operation of the stream flow monitoring program would be removed at the completion of the program. At the conclusion of the monitoring program, all equipment and structures will be removed.

IC have not proposed a flow monitoring site in lower Sandy Creek due to the operation of the SCA flow monitoring site adjacent to the fire road above the Sandy Creek water fall. Timely provision of this data from the SCA to complete the data set will be requested. In return, data generated by this monitoring program will be provided to the SCA by Illawarra Coal on a mutually agreed basis.

The proposed locations of the flow monitoring sites are set out in **Table A1**.

TABLE A1: PROPOSED LOCATIONS OF HYDROGRAPHIC AND RAINFALL MONITORING SITES

Monitoring Location	Proposed Site Identifier	Easting (MGA)	Northing (MGA)	Catchment
Banksia Creek	BCC1	293608	6192516	Sandy
Tributary to Banksia Creek	BC1	293356	6192427	Sandy
Fern Tree Creek	FTC1	293868	6191857	Sandy
Waratah Creek	WC1	293988	6191278	Sandy
Wongawilli downstream	WWL	290977	6197548	Wongawilli
Donald Castle Creek	DCU	289398	6195573	Donald Castle
Wongawilli upstream	WWU	290803	6189783	Wongawilli
Sandy Creek upstream of Waratah Creek junction	SCU1	293664	6191303	Sandy
Cascade Creek	CC1	293708	6191802	Sandy
Centroid Rainfall Station	CRS	291790	6195106	Rainfall Station

The 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.

Banksia Creek

- LOCATION: First control upstream of crossing

- ACCESS DETAILS: Proceed along dirt track prior to arriving at the bridge at Sandy Creek. Upon reaching the first creek walk upstream to the first obviously good control.
- MAP COORDINATES: 293608 E, 6192516 N
- CONTROL: Natural rock control.
- INSTRUMENTATION: Located on left bank. Install 'Diver' water level logger in metal housing (60NB) with locking cap. Support stay/gauge in the creek to be installed by bolt to rock stream bed and banks. Photo 1 shows a similar installation in the Bargo River.

Tributary to Banksia Creek

- LOCATION: First creek up stream of Banksia site on the left bank
- ACCESS: Continue past Banksia site and walk upstream at first creek
- MAP CO-ORDINATES: 293356E, 6192427N
- CONTROL: Natural rock bar but very low flows. Recommend flow control enhancement with cement stabilised sandbags to create rateable flow control. A shallow pool approximately 150-300 mm depth will be created upstream of this control.
- INSTRUMENTATION: Located on left bank. Install Diver in metal housing (60NB) with locking cap. Support stay/gauge in the river to be installed by bolt to rock stream bed and banks.
- IMPACTS: The tributary to Banksia Creek is almost ephemeral with very low flow except during and immediately after heavy or prolonged rainfall events. It is unlikely that this tributary is significant for fish habitat or breeding. Several large waterfalls/drop off exist down stream in Banksia Creek. Negligible water quality impacts may be experienced during installation of cement stabilised sandbags.

Fern Tree Creek

- LOCATION: Creek across Sandy Creek Road where existing level gauge is installed
- ACCESS: Walk upstream to MHL level site – pool is immediately upstream.
- MAP CO-ORDINATES: 293868E, 6191857N
- CONTROL: Natural rock bar that should be enhanced on the left bank with 6 cement stabilised sandbags.
- INSTRUMENTATION: Located on right bank. Install Diver water level logger in metal housing (60NB) with locking cap similar to Photo 2. A stainless steel dyna-bolt will be installed as a benchmark gauge on stream bank rock.
- IMPACTS: The enhancement of the flow control with cement stabilised sandbags will not restrict fish passage upstream of the control site. Negligible water quality impacts may be experienced during installation of cement stabilised sandbags. Any such impact would be for a matter of a few hours at most.

Waratah Creek

- LOCATION: 2nd creek across Sandy Ck Rd where level gauge is installed

- ACCESS: 20 m upstream of road crossing
- MAP CO-ORDINATES: 293988E, 6191278N
- CONTROL: Rock and boulder section that will require installation of aluminium weir plate. The aluminium weir will be secured to bedrock with stainless steel dyna-bolts and sealed with underwater mastic, with the sides supported by cement stabilised sandbags. A shallow pool approximately 150-300 mm depth will be created upstream of this control.
- INSTRUMENTATION: Located on right bank. Install Diver water level logger in metal housing (60NB) with locking cap. Support stay/gauge in the river to be installed by bolt to rock stream bed and banks. .
- IMPACTS: Waratah Creek site is almost ephemeral with very low flow except during and immediately after heavy or prolonged rainfall events. It is unlikely that this tributary is significant for fish habitat or breeding. Several large waterfalls/drop off exist down stream in Sandy Creek. Negligible water quality impacts may be experienced during installation of cement stabilised sandbags. Any such impact would be for a matter of a few hours at most.

Wongawilli Creek

- LOCATION: Avon to Cordeaux Rd, downstream of crossing where gauge is located.
- 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.
- IMPACTS: No impacts are expected.

Donald Castle Creek

- LOCATION: Downstream of road crossing on Avon to Cordeaux Rd, where gauge is installed
- 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. Install Diver water level logger housing on existing bedrock (see Photo 2). A stainless steel dyna-bolt will be installed as a benchmark gauge on stream bank rock.

- IMPACTS: No impacts are expected.

Wongawilli Creek upstream site

- 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 to be bolted to existing solid rock. . A stainless steel dyna-bolt will be installed as a benchmark gauge on stream bank rock.
- IMPACTS: No impacts are expected.

Sandy Creek upstream of confluence of Sandy and Waratah Creeks

- LOCATION: Sandy Creek upstream of confluence of Sandy and Waratah Creeks
- ACCESS: Enter bush approx. 50m south of Waratah crossing at yellow ribbon on tree in depression on western side of road. Walk directly to creek.
- MAP CO-ORDINATES: 293664E, 6191303N. (Access point 293967E, 6191246N)
- CONTROL: Gravel bed that will require installation of timber weir with Cipolletti weir plate installed. Use 3 lengths of pine with 4 x 60NB uprights and supports with Downey fittings. See **Figure 4.3** for example similar structure on the Bargo River. Seal with cement stabilised sandbags. Install concrete apron.
- INSTRUMENTATION: housed in 3 m long Diver water level logger housing secured to the bank. Gauge to be installed.
- IMPACTS: The installation of this low timber weir will create an obstruction to fish passage during low flows. This may restrict the passage of small native fish within Sandy Creek. No Macquarie perch are present above the Sandy Creek waterfall immediately upstream of the Cordeaux reservoir. A pool approximately 300 mm deep will be formed upstream of the timber weir. Negligible water quality impacts may be experienced during installation of cement stabilised sandbags. Any such impact would be for a matter of a few hours at most.

FIGURE A.3: EXAMPLE OF TIMBER WEIR WITH CIPOLETTI WEIR PLATE INSTALLED

Cascade Creek

- LOCATION: upstream of confluence with Fern Tree Creek
- ACCESS: Enter bush approx. 35m south of Fern Tree crossing, find and follow pink ribbons. Cross the first creek and proceed to second creek.
- MAP CO-ORDINATES: 293708E, 6191802N
- CONTROL: Gravel bed that will require installation of timber weir with Cipolletti weir plate installed. Use 3 lengths of pine with 4 x 60NB uprights and supports with Downey fittings. Seal with cement stabilised sandbags Install concrete apron. (see Photo 3)
- INSTRUMENTATION: housed in 3m long Diver water level logger housing secured to the bank with star-pickets through welded tabs. Gauge to be installed.
- IMPACTS: The installation of this low timber weir will create an obstruction to fish passage during low flows. This may restrict the passage of small native fish within Bracken Creek. No Macquarie perch are present above the Sandy Creek waterfall immediately upstream of the Cordeaux reservoir. A pool approximately 300 mm deep will be formed upstream of the timber weir. Negligible water quality impacts may be experienced during installation of cement stabilised sandbags. Any such impact would be for a matter of a few hours at most.

Centroid Rainfall Station

- LOCATION: Large rock outcrop of western side of road to Sandy Ck
- ACCESS: Proceed along Sandy Creek road until rock platform; walk up to near the top, the rainfall monitoring site is behind the low scrub.
- MAP CO-ORDINATES: 291790E, 6195106N
- HOUSING: Stand with ‘round’ on both ends and bolted to rock. Shield and locking bar required.
- INSTRUMENTATION: tipping bucket rain gauge and data logger
- IMPACT: Nil.

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 SHALLOW GROUNDWATER AND TRIBUTARY MONITORING PROGRAM

It is proposed to extend the current piezometer-based shallow groundwater monitoring program within Area 2 into Area 3A.

One shallow piezometer has already been installed on the eastern part of Area 3A in the Banksia subcatchment of Sandy Creek in the vicinity of Swamp 15b. It is proposed to expand this number to a total of 3 – 5 piezometers.

It is also proposed to establish 3 – 5 piezometers only (unless mine-subsidence related effects are detected at water quality site BC1 which do not apply at site

BCC1 – refer **Section A2 above**) in the southern arm of Banksia Creek in and around Swamp 15a.

It is also proposed to establish 3 – 5 piezometers in the subcatchment WC17 of Wongawilli Creek around hanging Swamp 12.

Completion of piezometer installations and map preparation for the suites of Area 3A piezometers was not yet completed at the time of preparation of this report.

It is proposed to progressively install comparable small suites of shallow piezometers in appropriate tributary subcatchments throughout Areas 3B and 3C as the proposed dispositions of the Area 3B and 3C longwalls become reasonably certain.

As noted in **Section 2.5** of this report, downstream Type 1 swamps in Area 3 which are considered possibly susceptible to scour effects enhanced by changes in grade due to mine subsidence were identified by Cardno Forbes Rigby (2007) as Swamps 2, 5, 7, 8 and 15a.

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 it is proposed to install small suites of 3 – 5 piezometers in then prior to the periods when proposed longwalls in Areas 3B and 3C mine beneath them.

Parameters measured in the piezometers would be limited to field measurements of water level, pH, EC and ORP.

Only in the event that the intermediate water quality TARPs of a fall in pH of more than 1.5 pH units and/or a rise in EC of more than 50 µS/cm and/or fall in ORP of more than 150 mV was activated would a set of water samples be taken for detailed laboratory analysis of the parameters listed for surface water sites in Table A3 below.

If geochemical effects are detected by the water quality monitoring program 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, back-tracking of the tributary subcatchments both water quality and hydrologic behaviour would be initiated. It is proposed tributary investigations triggered in this way would follow an integrated staged response plan as follows:

1. Water quality data would be obtained from pools and storm flows within the tributary for assessment against TARPs.
2. If exceedance of the secondary TARP is found to occur then there would be temporary deployment of one of four relocatable Starflow Doppler flow meters held by IC to a gauging site above the confluence of the tributary and creek main channel to obtain quantitative flow data through several storm events for hydrologic assessment as proposed in **Sections 3.1 and 4.2**.
3. In this event the number of shallow piezometers within the tributary subcatchment, would also be significantly increased - possibly up to as many as 20 to gauge changes through time in the extent and/or thickness variation of the hillslope aquifer(s) over the active longwalls and to integrate the hillslope aquifer data with the modelling of the data provided by the Starflow Doppler flow meter.

A6 PROPOSED WATER QUALITY MONITORING PROGRAM

The proposed locations of the water quality monitoring sites and their identifiers are described in **Table A2.** These locations may be identified on the area map in **Figure A1**. An effort has been made to to ensure that flow and quality measuring sites are integrated wherever possible.

TABLE A2: PROPOSED WATER QUALITY MONITORING SITES

Monitoring Location	**Site Identifier - Water Quality/Site Identifier - Flow**	**Easting (MGA)**	**Northing (MGA)**	**Catchment (subcatchment)**	**Site Type**
Upper Wongawilli 1	WWU1	291347	6187987	Wongawilli	Baseline
Upper Wongawilli 4	WWU4/WWU	290803	6189783	Wongawilli	Baseline
Mid-Wongawilli 1	WWM1	291102	6192297	Wongawilli	Longwall 10
Mid-Wongawilli 2	WWM2	290787	6193041	Wongawilli	Longwalls 8, 9 &10
Mid-Wongawilli 3	WWM3	290767	6193885	Wongawilli	Longwalls 6 - 1
Lower Wongawilli	WWL	290977	6197548	Wongawilli	Far field impac (Areas 3A, 3B and 3C)
Upper Donalds Castle	DCU3/DCU	289398	6195573	Donalds Castle	Area 3C
Longer Donalds Castle	DCL3	289539	6200191	Donalds Castle	Far field impac (Area 3C)
Banksia Creek	BCC/BCC1	293356	6192427	Sandy (Banksia)	Longwalls 9 &1
Lower Banksia	B1/BC1	293608	6192516	Sandy (Banksia)	Longwalls 8, 9 &10
Cascade	CC1	293708	6191802	Sandy (Cascade)	Longwall 10
Upper Sandy	SCU1	293664	6191303	Sandy	Baseline
Lower Sandy	SCL	293825	6192650	Sandy	Far field impac (area 3A)

The proposed field and laboratory analytical parameters, monitoring frequencies and sampling trigger states at the proposed Area 3 water sites are outlined in **Table A3**.

TABLE A3: PROPOSED FIELD AND LABORATORY WATER QUALITY PARAMETERS AND MONITORING FREQUENCY

Site Identifier	Analytes	Sampling Frequency	Trigger
WWU1	Field pH, EC, DO. All lab. analytes except algae	Monthly	Presence of water in pool
WWU4/WWU	Field pH, EC, ORP, DO. All lab. analytes except algae	Monthly	Active flow
WWM1	Field pH, EC, ORP, DO, All lab. analytes except algae	Monthly	Active flow
WWM2	Field pH, EC, ORP, DO, All lab. analytes except algae	Monthly	Active flow
WWM3	Field pH, EC, ORP, DO, All lab. analytes except algae	Monthly	Active flow
WWL	Field pH, EC, ORP, DO, All lab analytes incl. algae	Monthly	Active flow
DCU3/DCU	Field pH, EC, ORP, DO, All lab. analytes except algae	Monthly	Presence of water at weir
DCL3	Field pH, EC, ORP, DO, All lab analytes incl. algae	Monthly	Active flow
BCC/BCC1	Field pH, EC, ORP, DO, All lab analytes except algae	Monthly	Presence of water at weir
B1/BC1	Field pH, EC, ORP, DO, All lab analytes incl. algae	Monthly	Presence of water at weir
CC1	Field pH EC, ORP, DO, All lab analytes incl. algae	Monthly	Presence of water at weir
SCU1	Field pH, EC, DO, All lab analytes incl. algae	Monthly	Presence of water at weir
SCL1	Field pH, EC, DO, All lab analytes incl. algae	Monthly	Presence of water in pool

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); Dept. of Environment and Conservation (NSW) (2004)

A7 REPORTING

Findings from each year of hydrologic and water quality monitoring will be reported in the Annual Environmental Management Report (AEMR).

A8 MANAGEMENT AND MITIGATION MEASURES

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 3 catchments then it is possible that some management and mitigation measures may be required.

In the first instance, management measures may simply 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 the Sydney Catchment Authority (SCA) owns an area, above ground management and mitigation works are subject to approval under Part 5 of the *Environmental Planning and Assessment Act 1979*, with the SCA being the determining authority. Such works will also be subject to the requirements of the *Sydney Water Catchment Management Act 1998* and *Regulation 2000*.

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 undertake works must be sought from the SCA to access the lands and also to undertake the proposed work. For any works on SCA land there is a requirement for compliance with the Sydney Catchment Authority 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 heavy 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 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).

Therefore, a logical contingency measure that could be considered would be to 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, <u>especially</u> if such pools were located say within 250 m of Lake Cordeaux. Noting that:

1. the estimated <u>maximum</u> daily rate of acid generation in any discrete sub-bed flow diversion zone is 100 mole H_2SO_4/day which is equivalent to 100 mole $CaCO_3$/day to completely neutralize it; and
2. prior 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 <u>not sustained</u> for any more than a few months,

this load of acidity is only equivalent to 10 kg $CaCO_3$/day or (say) one tonne for a three month period. *This could not lead to any exceedance of the hardness and alkalinity limits for Bulk Raw Water supply and hence would not adversely affect waters in Lake Cordeaux or Cordeaux River.*

Emplacement of limestone at any such location would provide a continual reactive surface for:

1. the neutralisation of excessive acidity;
2. encourage the localized 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 6.5 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 Cordeaux or Cordeaux River.

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 easily be moved upslope closer to the spring source.

This would simply involve the deposition of heavy 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 effect 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 neutralization 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.

It is emphasized that such mitigation measures are proposed only on the basis of existing best practice elsewhere.

However, subject to agreement by SCA, DECC etc we suggest it 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 Water Monitoring and Management Plan identified such mitigation measures were merited.

APPENDIX B
ROLE OF HILLSLOPE AQUIFERS IN AREA 3 HYDROLOGY

B1 HYDROLOGIC MODELLING EVIDENCE FOR HILLSLOPE AQUIFERS

As noted in **Section 2.6.3** the proportion of effective precipitation entering the groundwater systems of both Native Dog and greater Donald's Castle Creek catchments (1-α) as determined by modeling was high (ranging from 80 – 98.5%).

This implies that the outflow from the main groundwater system derives from precipitation which fell on, and hence recharged, the major part of the catchment i.e. the plateaus and hill slopes.

The proportion of recharge (i.e. precipitation minus ET) entering this groundwater system was also found in our preliminary hydrologic assessment to invariably contribute >75% of total recharge.

By definition, this implied that the area recharging the aquifer is not small and typically located beneath at least 75% of the catchment i.e. the slopes, swamps and upland plateaus.

Our preliminary hydrologic studies therefore showed that most of the recharge entering aquifers of each catchment (and hence most, if not all, of the catchment storage) would occur largely at elevation above the creek (while still being hydrogeologically connected to the creek bed).

As noted in **Section 3.1 of this report, in our preliminary hydrologic assessment of the Native Dog and greater Donald's Castel Creek catchments** it was found that both the Native Dog and greater Donald's Castle Creek catchment groundwater systems could be satisfactorily fitted by the RUNOFF 2000 model with a reservoir coefficient (Jb) of the groundwater system with an equation of the form $Jb = A/Qb^{0.67\text{--}1.00}$.

This constrains the effective drainage distance (L) to being either constant or varying inversely average head above the drainage base, and 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

There appeared to be no mathematical hydrologic indications that there was a major groundwater system associated exclusively with fractured bedrock or the bottoms of the valleys as this would require Jb to lie in the range of a constant through to no more than $Jb = A/Qb^{0.5}$ (Van de Griend et al. 2002).

In the particular cases of both Native Dog and Greater Donald's Castle Creek catchments, it was therefore inferred that prolonged through flow within hillslopes was driving the delayed flow component. This phenomenon has been often observed and studied elsewhere (e.g. Harr, 1977; Sklash et al., 1986).

This conclusion is also consistent with extensive field observations of these catchments made over the last 5 – 6 years (IC, 2004) which has shown that the geomorphology of these catchments is generally characterized by upland plateaus and a series of 'benches' comprised of catenary hill slopes and/or swamps enclosed within roughly crescent-shaped cliff lines.

B2 PARAMETRIC CHARACTERISTICS OF AN IDEALIZED HILLSLOPE AQUIFER

Mathematically, the above observations 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 idealised 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 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.

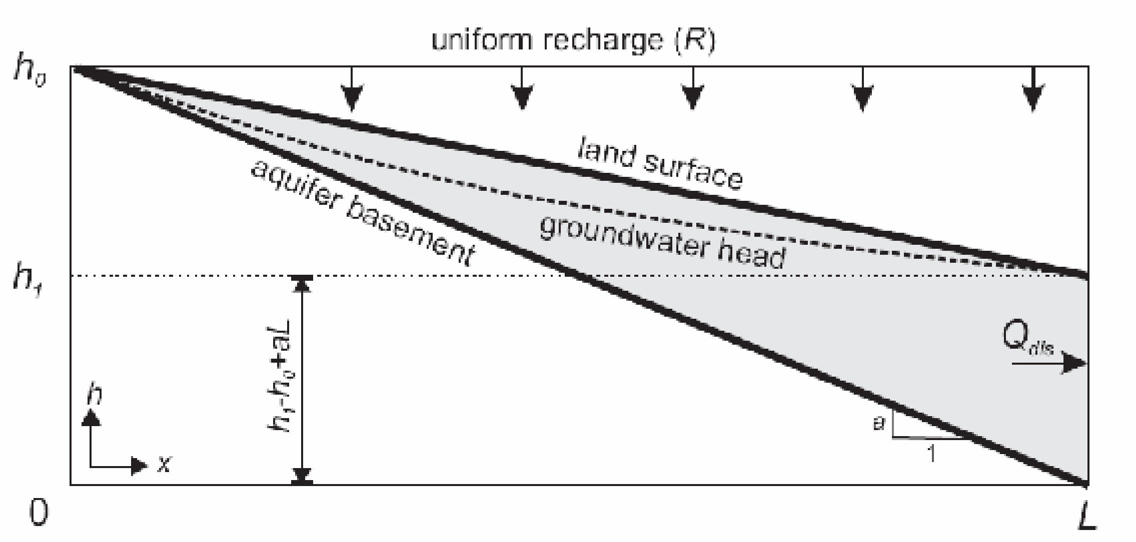
This hillslope aquifer system was considered to be essentially two-dimensional, with no plan convergence/divergence. The system was considered to essentially have a uniform basement slope (a) over an aquifer length (L) with an aquifer thickness of zero at the upper end, increasing monitonically to a 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 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 B1, reproduced from Walker et al (2005), provides an idealized picture of a hill slope aquifer.

FIGURE B1: 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) as follows:

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

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

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 idealised 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.

Walker et al's 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).

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:

$Q = RL – (R-R_0)L\exp(t/t_s)$

Where R = recharge over the period of interest

R_0 = recharge at time t = 0

L = length of the aquifer (see **Figure 2.1**2 above)

t_s= the groundwater system time-scale of response which is equivalent to the RUNOFF2005 model groundwater reservoir coefficient Jb.

Walker et al. (2000) found the relationship between aquifer saturated volume and 1/G appears to be linear for each value of B.

To explore this relationship further, they 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 idealised 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); and
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 timescale of response t_s (= Jb) is proportional to aquifer specific yield (S), also known as effective porosity, aquifer flow length (L), aquifer bulk mean hydraulic conductivity (K) and slope of the aquifer basement (a) (**Figure A1**) 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-dimensionalisation carried out by Walker et al. (2000) is that it separates the scaling arguments from the geometric effects.

This allows the 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 is an illustration of 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 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 many complications relating to geometry (i.e. landscape topography) which will distort this time-scale, but for a given overall shape and properties, these scaling relationships will be preserved.

The idealised groundwater analogue described by Walker et al. 2005 thus captures the important scalar parameters of real, sloping hillslope aquifer systems. This provides a basis for beginning to analyze gross groundwater responses to changes in landscape behaviour such as those which may be induced by longwall mining.

B3 HYDROGEOMORPHIC IMPLICATIONS OF HILLSLOPE AQUIFERS

Consequently, we closely examined the Native Dog Creek and greater Donald's Castle Creek catchments in terms of typical representative hillslope aquifer cross sections and these are shown in **Figure B2**. Some 10 triangular hillslope sections were generated for each catchment.

FIGURE B2: MEASURED HILLSLOPE AQUIFER SECTIONS NATIVE DOG AND DONALD'S CASTLE CREEKS

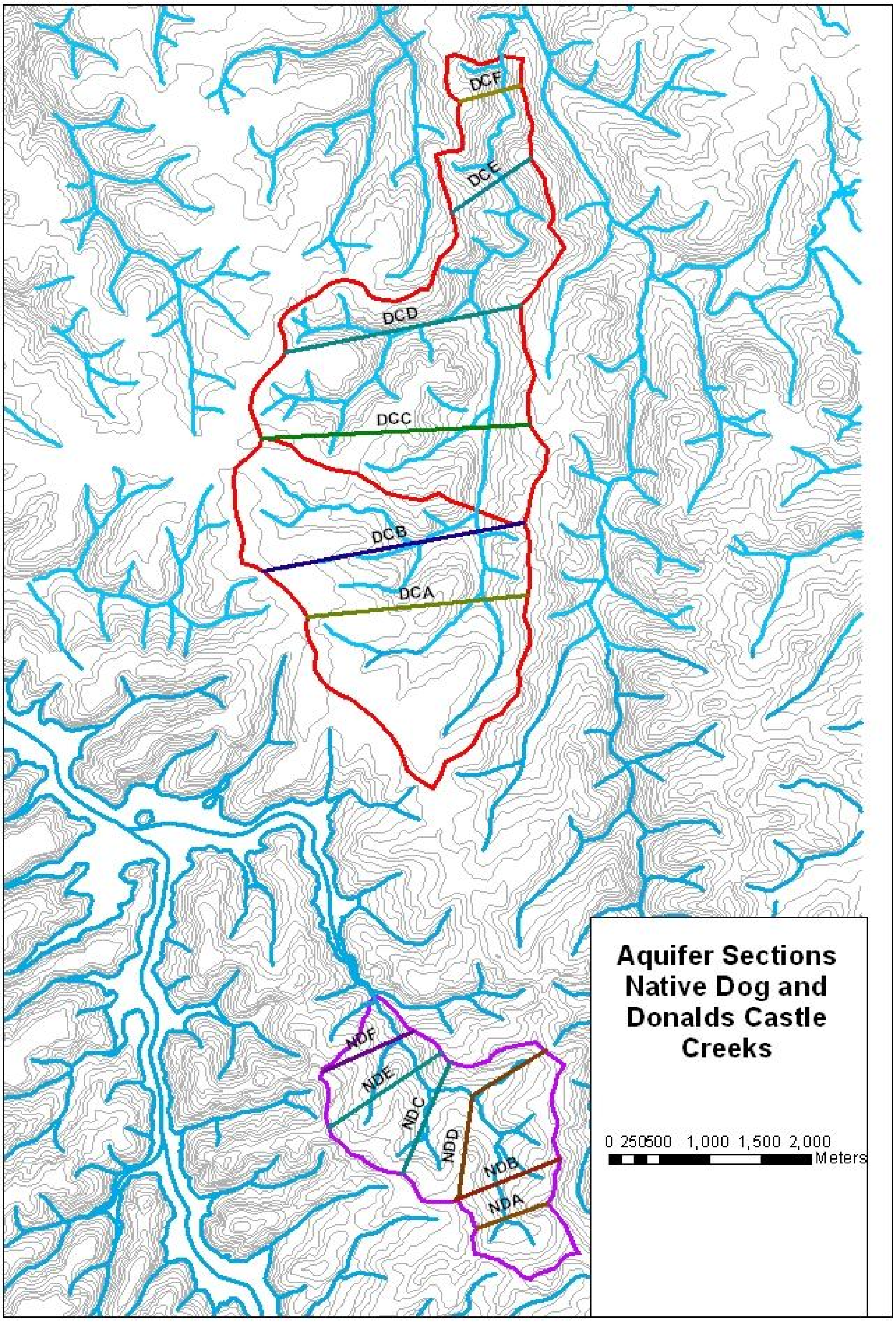


Table B1 below sets out the basic scalar characteristics (absolute L, relative levels of h_0, and h_1, from which may be computed aquifer basement slope 'a' for any creek bedrock aquifer thickness, d) of 12 representative sections (6 western and 6 eastern) within these two catchments.

TABLE B1: REPRESENTATIVE HILLSLOPE AQUIFER SECTIONS IN NATIVE DOG AND DONALD'S CASTLE CREEK CATCHMENTS

Native Dog Creek Catchment						
Western Side				**Eastern Side**		
Section	**L (m)**	**h_o RL (m AHD**	**h_1RL (m AHD)**	**L (m)**	**h_1 RL (m AHD)**	**h_o RL (m AHD)**
NDA	304	460	410	444	410	463
NDB	420	440	398	679	398	460
NDC	951	430	363	291	363	415
NDD	1085	440	372	866	372	432
NDE	1055	440	353	304	353	410
NDF	832	440	340	155	340	380
Greater Donald's Castle Creek Catchment						
Western Side				**Eastern Side**		
Section	**L (m)**	**h_o RL (m AHD)**	**h_1RL (m AHD)**	**L (m)**	**h_1 RL (m AHD)**	**h_o RL (m AHD)**
DCA	1761	413	340	431	340	394
DCB	2185	413	328	448	328	381
DCC	2246	412	315	410	315	375
DCD	2001	402	300	379	300	362
DCE	608	370	269	353	269	350
DCF	458	355	259	209	259	292

Table A2 sets out the results of an Excel spreadsheet we established to determine the effects of actual aquifer length (L), basement slope (a), aquifer thickness at the creek (h_1), aquifer specific yield (S) and mean bulk hydraulic conductivity on the typical timescales of response (Jb) that might be expected from local hillslope aquifers with these cross sections.

In computing a typical G for each cross section the estimated annualized rate of groundwater recharge of Native Dog Creek catchment over the 48 day gauging/modelling period in April/May 2003 was used (refer Section 2.6).

This is: Peff(1-α) = 15.67 mm x 0.963 = 14.60 mm/48 days = 111 mm/y. The estimated annualized rate of recharge of greater Donald's Castle Creek catchment over the similar 59 day gauging/modelling period was Peff(1-α) = 76.49 mm x 0.985 = 75.34 mm/59 days = 466 mm/y.

A specific yield (S) for the aquifer of 0.05 (5%) was assumed. This is considered a reasonable value for an aquifer dominated by weathered sandstone (Domenico and Schwarcz, 1998).

Parameters varied in the spreadsheet (h_1 and K) are highlighted in **bold**.

TABLE B2: ESTIMATES OF NATIVE DOG CREEK AND DONALD'S CASTLE CREEK IDEALISED HILLSLOPE AQUIFER SECTIONS SCALAR PARAMETERS INCLUDING RESERVOIR COEFFICIENT (Jb) FOR A RANGE OF HYDRAULIC CONDUCTIVITIES (K) AND AQUIFER THICKNESSES (h_1) AT THE CREEK

Native Dog Creek Catchment											
Western Side											
Section	**h_0 (m)**	**h_1 (m)**	**K (m/y)**	**RL (m^2/y)**	**B**	**G**	**a**	**L/a**	**D^***	**~E^***	**Jb (y)**
NDA	60	**10**	**15**	34	5.0	0.731	0.197	1540	0.083	0.417	2.6
NDB	52	**10**	**15**	47	4.2	0.322	0.124	3392	0.096	0.404	5.7
NDC	77	**10**	**15**	106	6.7	0.100	0.081	11745	0.065	0.435	19.6
NDD	78	**10**	**15**	120	6.8	0.078	0.072	15093	0.064	0.436	25.2
NDE	97	**10**	**15**	117	8.7	0.106	0.092	11474	0.052	0.448	19.1
NDF	110	**10**	**15**	92	10.0	0.195	0.132	6293	0.045	0.455	10.5
Eastern Side											
NDA	63	**10**	**15**	49	5.3	0.363	0.142	3129	0.079	0.421	5.2
NDB	72	**10**	**15**	75	6.2	0.182	0.106	6403	0.069	0.431	10.7
NDC	62	**10**	**15**	32	5.2	0.830	0.213	1366	0.081	0.419	2.3
NDD	70	**10**	**15**	96	6.0	0.108	0.081	10714	0.071	0.429	17.9
NDE	67	**10**	**15**	34	5.7	0.833	0.220	1379	0.075	0.425	2.3
NDF	50	**10**	**15**	17	4.0	2.250	0.323	481	0.100	0.400	0.8
Greater Donald's Castle Creek Catchment											
Western Side											
Section	**h_0 (m)**	**h_1 (m)**	**K (m/y)**	**RL (m^2/y)**	**B**	**G**	**a**	**L/a**	**D^***	**~E^***	**Jb (y)**
DCA	83	**10**	**15**	821	7.3	0.008	0.047	37363	0.060	0.440	62.3
DCB	95	**10**	**15**	1018	8.5	0.006	0.043	50255	0.053	0.447	83.8
DCE	107	**10**	**15**	1047	9.7	0.006	0.048	47145	0.047	0.453	78.6
DCD	112	**10**	**15**	932	10.2	0.008	0.056	35750	0.045	0.455	59.6
DCE	111	**10**	**15**	283	10.1	0.088	0.183	3330	0.045	0.455	5.6
DCF	106	**10**	**15**	213	9.6	0.147	0.231	1979	0.047	0.453	3.3
Eastern Side											
DCA	64	**10**	**15**	201	5.4	0.094	0.148	2903	0.078	0.422	4.8
DCB	63	**10**	**15**	209	5.3	0.085	0.141	3186	0.079	0.421	5.3
DCE	70	**10**	**15**	191	6.0	0.115	0.171	2401	0.071	0.429	4.0
DCD	72	**10**	**15**	177	6.2	0.139	0.190	1995	0.069	0.431	3.3
DCE	91	**10**	**15**	164	8.1	0.209	0.258	1369	0.055	0.445	2.3
DCF	43	**10**	**15**	97	3.3	0.243	0.206	1016	0.116	0.384	1.7
Greater Donald's Castle Creek Catchment											
Western Side											
Section	**h_0 (m)**	**h_1 (m)**	**K (m/y)**	**RL (m^2/y)**	**B**	**G**	**a**	**L/a**	**D^***	**~E^***	**Jb (y)**
DCA	83	**2**	**10**	821	36.5	0.001	0.043	41348	0.013	0.487	103.4
DCB	95	**2**	**10**	1018	42.5	0.001	0.040	54876	0.011	0.489	137.2
DCE	107	**2**	**10**	1047	48.5	0.001	0.044	50955	0.010	0.490	127.4
DCD	112	**2**	**10**	932	51.0	0.001	0.052	38500	0.010	0.490	96.3
DCE	111	**2**	**10**	283	50.5	0.012	0.169	3589	0.010	0.490	9.0
DCF	106	**2**	**10**	213	48.0	0.020	0.214	2140	0.010	0.490	5.4
Eastern Side											
DCA	63	**2**	**10**	201	27.0	0.012	0.130	3317	0.018	0.482	8.3
DCB	63	**2**	**10**	209	26.5	0.011	0.123	3649	0.018	0.482	9.1
DCE	70	**2**	**10**	191	30.0	0.015	0.151	2711	0.016	0.484	6.8
DCD	72	**2**	**10**	177	31.0	0.019	0.169	2244	0.016	0.484	5.6
DCE	91	**2**	**10**	164	40.5	0.028	0.235	1501	0.012	0.488	3.8
DCF	43	**2**	**10**	97	16.5	0.032	0.167	1248	0.029	0.471	3.1
Greater Donald's Castle Creek Catchment											
Western Side											
Section	**h_0 (m)**	**h_1 (m)**	**K (m/y)**	**RL (m^2/y)**	**B**	**G**	**a**	**L/a**	**D^***	**~E^***	**Jb (y)**
DCA	83	**10**	**2**	821	7.3	0.001	0.047	37363	0.060	0.440	467
DCB	95	**10**	**2**	1018	8.5	0.001	0.043	50255	0.053	0.447	628
DCE	107	**10**	**2**	1047	9.7	0.001	0.048	47145	0.047	0.453	589
DCD	112	**10**	**2**	932	10.2	0.001	0.056	35750	0.045	0.455	447
DCE	111	**10**	**2**	283	10.1	0.012	0.183	3330	0.045	0.455	41.6
DCF	106	**10**	**2**	213	9.6	0.020	0.231	1979	0.047	0.453	24.7
Eastern Side											
DCA	63	**10**	**2**	201	5.4	0.012	0.148	2903	0.078	0.422	36.3
DCB	63	**10**	**2**	209	5.3	0.011	0.141	3186	0.079	0.421	39.8
DCE	70	**10**	**2**	191	6.0	0.015	0.171	2401	0.071	0.429	30.0
DCD	72	**10**	**2**	177	6.2	0.019	0.190	1995	0.069	0.431	24.9
DCE	91	**10**	**2**	164	8.1	0.028	0.258	1369	0.055	0.445	17.1
DCF	43	**10**	**2**	97	3.3	0.032	0.206	1016	0.116	0.384	12.7

It is noted that the non-dimensional parameter G is relatively small for the western portion sections (DCA through DCD) of greater Donald's Castle Creek catchment, being invariably <0.01.

Therefore the more likely it is that in this portion of the catchment, the aquifer has significant resistance to recharge due to poor transmission and hence the groundwater surface will often intersect the land surface directly, leading to discharge onto the land surface. This in turn will return groundwater to the direct runoff/quickflow system. This will especially be the case where the travel path is short and there is limited opportunity for that water to re-enter the hillslope aquifer due to its saturation.

If there were groundwater returned to the surface for this reason it would be expected to:

- appear within local hanging swamps; and
- appear in the draining tributary creek,

as a late contributor to the direct runoff/quickflow system and flow at a relatively constant rate for a period following a significant storm event.

Notwithstanding the adopted approximation for the geometric factor E* identified by Walker et al. (2000), the spreadsheet outcomes presented in **Table A2** above provide clear scalar explanations for the following observations:

1. The hillslope aquifer time of response or reservoir coefficients Jb of both catchments are measured in timescales of years because the average bulk hydraulic conductivity of the hillslope aquifer is fairly low and most likely in the range of 3 – 30 m/y i.e. ~10^{-7} – 10^{-6} m/sec, with our best estimate being about 15 m/y i.e. 5 x 10^{-7} m/s. This suggests that most of the flow is occurring in sandy clays and/or fractured sandstone.
2. The greater Donald's Castle Creek catchment is predicted to exhibit a generally higher range of times of response or reservoir coefficients for the direct runoff/quickflow and groundwater systems (Jd and Jb) essentially because it is a much larger catchment in which the hillslope aquifers are dominated by a substantial western upland area (refer sections DCA through DCD) that have a much larger length (L) to slope (a) ratio, a higher RL factor and hence a very low G factor i.e. these sections are those which have the greatest potential recharge rate but the lowest transmission rate and hence the highest potential spillage (overflow) rate. This provides the most likely explanation for why the substantial 89.0 mm storm event between 9 and 12 March 2003 was not preceded by a recognisable baseflow. Rather, it was followed by a recession curve that included a distinct 'plateau' phase of near constant direct runoff/quickflow that lasted almost one month until about 7 April 2003. This probably resulted from a period of continuous 'daylighting' of groundwaters from the extensive thin, saturated hillslope aquifer in the western headwaters of the Creek.

B4 CONCLUSIONS

It may be concluded from inspection of Table B2 above that Table B2 above that as it's catchment contains a substantial western portion with a much higher hydraulic resistance to recharge, greater Donald's Castle Creek is geomorphically and hydrogeologically insufficiently alike Native Dog Creek catchment to be suitable as a reference catchment for detecting gross changes in catchment hydrology possibly induced by longwall mining-based effects.

We conclude from this finding that any choice of a not mined under <u>control catchment</u> for comparative hydrologic assessment purposes must have scalar attributes (i.e. areas, slopes, slope lengths) which are not too different from the target mined-under catchment.

It may also be concluded from inspection of Table B2 above that hillslope aquifer reservoir coefficients (Jb) or times of response are likely to range from the order of a few years to periods in excess of 50 years.

It is noted in connection with this last conclusion that there is already a significant body of evidence that baseflows from local catchments in Dendrobium Area 3 may well have on occasion water ages in excess of 50 years.

Average Tritium (^{3}H) concentration measurements made in Lakes Cordeaux and Avon by Ecoengineers for IC in recent years (averaging 2.00±0.12 and 2.09±0.25 TU/L respectively) show that these water bodies contain a significant proportion of water with much lower tritium levels than can be found in modern rainfall at Mt. Keira or further inland at Mittagong (more variable but averaging 3.4±1.6 and 2.7±1.2 TU/L respectively).

Therefore these lakes must contain a significant fraction of 'non-modern' 'old' water pre-dating the modern atomic bomb era which commenced around 1958. Such waters can only have been delayed in their travel times to these lakes by slow passage through near surface hillslope aquifers.