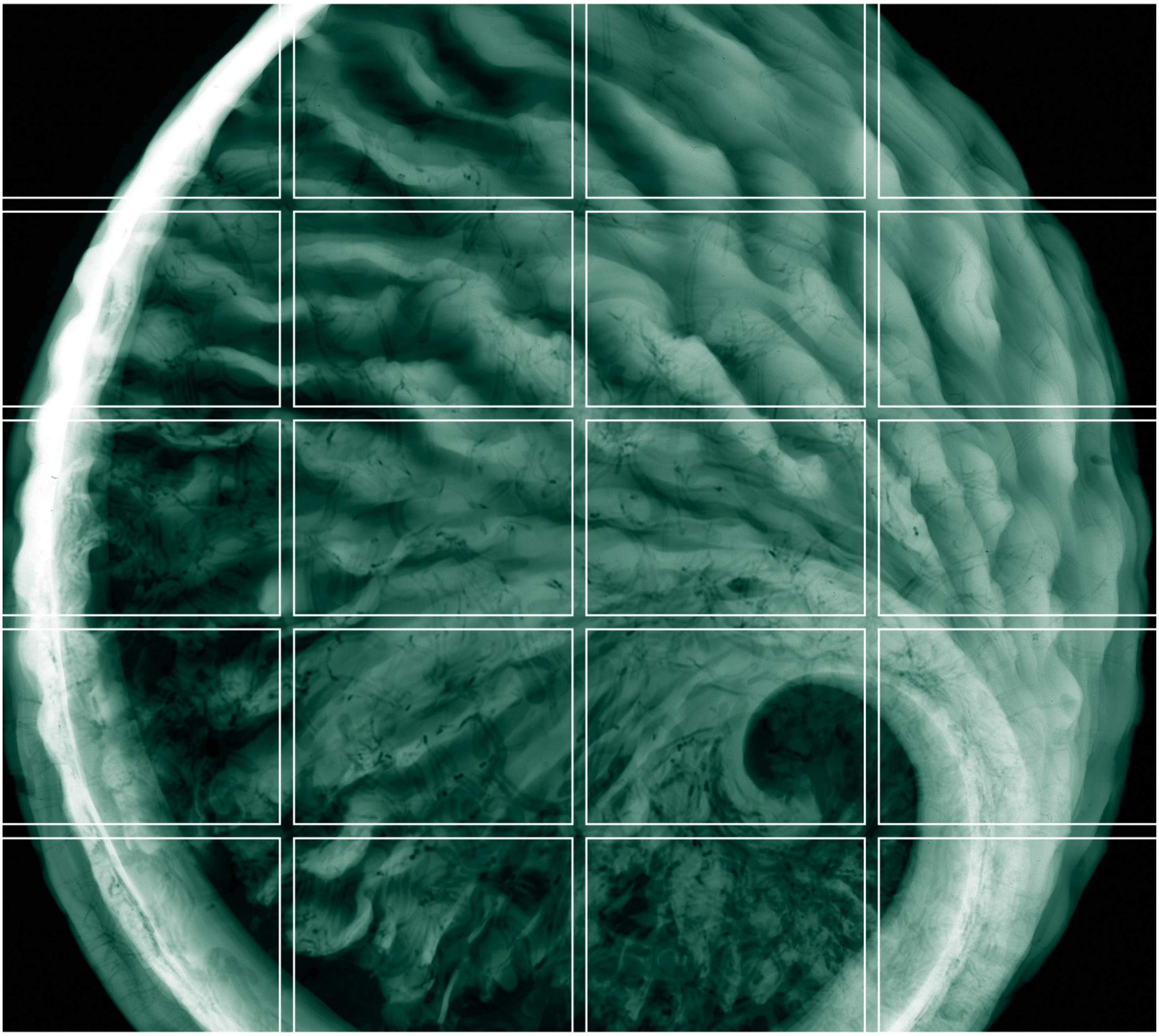

NRE No.1 Colliery Project Application (09_0013)

Environmental Assessment
Volume V— Annexes P to R

Gujarat NRE Coking Coal Pty Ltd

February 2013

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Annex P

Groundwater Assessment

GeoTerra

GUJARAT NRE COKING COAL LTD
NRE No.1 COLLIERY
MAJOR EXPANSION
GROUNDWATER ASSESSMENT
Bellambi, NSW

GUJ1-GWR1C

27 NOVEMBER, 2012

GeoTerra Pty Ltd ABN 82 117 674 941

PO Box 220 Canterbury NSW 2193

Phone: 02 9787 9137 Fax: 02 9787 1874 Mobile: 0417 003 502 Email: geoterra@iinet.net.au

GUJ1-GWR1C (27 NOVEMBER, 2012)

GeoTerra

Gujarat NRE Coking Coal Pty Ltd
PO Box 281
Fairy Meadow NSW 2519

Attention: Chris Harvey

Chris,

RE: NRE No.1 Colliery Groundwater Assessment

Please find enclosed a copy of the above mentioned report.

Yours Faithfully

GeoTerra Pty Ltd

Andrew Dawkins
Managing Geoscientist (MAusIMM CP-Env)

Distribution:	Original	Geoterra Pty Ltd
	1 electronic copy	Gujarat NRE Coking Coal Pty Ltd
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Authorised on behalf of Geoterra Pty Ltd:	
Name:	Andrew Dawkins
Signature:	
Position:	Managing Geoscientist

Date	Rev	Comments
30.11.2010		Draft
31.01.2011	A	Incorporate review comments
26.10.2012	B	Incorporate adequacy review comments
27.11.2012	C	Incorporate review comments

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EXECUTIVE SUMMARY

Gujarat NRE Coking Coal (Gujarat) propose to extract the Wongawilli Seam through longwall mining in two areas at the NRE No.1 colliery. Wonga East is located to the east, whilst Wonga West is situated to the west of Cataract Reservoir, approximately 13km west of Wollongong in NSW.

Previous and Proposed Mining

The Study Area is divided into two major mining domains being the Wonga East and Wonga West areas.

At Wonga East, mining has been undertaken in three different coal seams involving bord and pillar mining and pillar extracton in the Bulli seam; bord and pillar and longwall mining in the Balgownie seam and longwall mining in the Wongawilli seam (WE-A2-LW4).

It is proposed to undertake further longwall mining within the Wongawilli seam.

In the Wonga West area bord and pillar mining, pillar extraction and longwall mining has been undertaken in the Bulli seam and it is proposed to undertake longwall mining in the Wongawilli seam.

The Bulli Seam overlies the Balgownie Seam by approximately 5 - 8m, and in turn, the Balgownie Seam overlies the Wongawilli Seam by approximately 22 - 26m of interburden.

The depth of cover ranges from 237 - 255m in Wonga East Area 1 which has three proposed 105m wide panels and from 267 - 320m in Wonga East Area 2 with eight proposed 150m wide panels which underlie the catchment and channel of Cataract Creek, and to a lesser degree, the headwater catchments of Bellambi Creek and Cataract River, upstream of Cataract Reservoir.

The Wonga West panels are subdivided into Area 3, to the west of Lizard Creek, and Area 4, to the east of Lizard Creek. The five proposed Area 3 panels are also terminated immediately north of Wallandoola Creek.

The Wonga West Area 3 longwalls are proposed to be 374 - 390m wide whilst longwalls 6 and 7 in Wonga West Area 4 are proposed to be 155m wide, with a 457 – 512m depth of cover.

Extraction thickness of the Wongawilli Seam is proposed to range from 2.7 – 3.2m.

Predicted Subsidence

Maximum subsidence in Wonga East is predicted to range up to 1.2m, with up to 2.55m at Wonga West.

The maximum predicted subsidence and uplift of the main channel of Lizard, Wallandoola or Cataract Creek is predicted to be 0.5m and 120mm respectively.

Overburden cracking and bedding delamination associated with the predicted subsidence of up to 1.2m at Wonga East and 2.55m at Wonga West is anticipated to cause depressurisation above the seam in the free draining goafed zone and the vertically hydraulically connected zone, and increased horizontal permeability in the overlying bedding delamination zone, all of which will induce seepage to the workings from beneath the Bald Hill Claystone.

The Bald Hill Claystone is anticipated to retain its semi-confining properties and to maintain hydraulic separation between the Hawkesbury Sandstone and Quaternary alluvial aquifers from the Bulgo Sandstone and deeper systems beneath the Bald Hill Claystone. As a result, free draining connective cracking to the proposed workings at Wonga West is not anticipated.

At Wonga East, the Bald Hill Claystone has been eroded through to the Bulgo Sandstone in the valley of Cataract Creek, and therefore, due to its lower thickness to limited absence downstream of the freeway, and reduced lithostatic loading pressure in the stream reaches where it is partially eroded, the Bald Hill Claystone is anticipated to have a higher hydraulic transmissivity.

Although the Bald Hill Claystone is partially to fully eroded in Cataract Creek, mine pump-out monitoring indicates there is no direct connection from the creek stream flow or catchment recharge to the workings.

Based on the lack of progression of subsidence cracking into the upper section of the Bulgo Sandstone, the subsidence study (Seedsman Geotechnics, 2012A) assessed there should be no anticipated free draining connective cracking from Wonga East or Wonga West to the proposed Wongawill Seam workings.

Groundwater Modelling and Geology

Computer based simulations of the proposed mining have been conducted to assess the groundwater processes that may occur due to extraction of the proposed longwalls. The FEFLOW model is a finite element code that simulates variably saturated flow in the overburden. Model simulation of the proposed workings was used to predict groundwater depressurisation and mine water seepage impacts on the overburden strata and catchments of Lizard, Wallandoola, Cataract and Bellambi Creeks as well as Cataract River and Cataract Reservoir.

Five hydrogeological domains have been identified, including the;

- hydraulically disconnected (perched), ephemeral weathered Hawkesbury Sandstone soil and upland swamps;
- deeper Hawkesbury Sandstone, which is hydraulically separated from the underlying Bulgo Sandstone and deeper lithologies at Wonga West by the Bald Hill Claystone, but is not present in the lower eroded channel of Cataract Creek at Wonga East;
- Narrabeen Group sedimentary lithologies, the lower portions of which have already been locally fractured and depressurised above the existing workings, and are anticipated to be fractured and depressurised over the proposed workings up to the upper Bulgo Sandstone;
- Illawarra Coal Measures, which contains the Bulli, Balgownie and Wongawilli Seam aquifers that have also been fractured and depressurised by the existing workings and will be locally fractured and depressurised by the proposed workings, and the;
- sedimentary sequence underneath the Wongawilli Seam.

Within the basement strata, the Balgownie, Bulli and Wongawilli Seams have limited groundwater storage and transmission potential, whist the interburden sandstones, siltstones, conglomerates and shales / mudstones have very low permeabilities.

The Bald Hill Claystone is interpreted to limit vertical flow between the Hawkesbury Sandstone and Quaternary units from the underlying Bulgo Sandstone and deeper lithologies, except where it has been partially eroded in the valley of Cataract Creek at Wonga East.

Monitoring of regional aquifer pressures in the dual porosity basement strata indicates a topographically driven flow regime which is potentially enhanced in the weathered, shallower strata by flow through more open joints, fractures or bedding planes.

Groundwater flow in the region is essentially horizontal to sub-horizontal due to the prominent, although shallow, bedding plane and the general strata dip to the north-west, although the flow is locally modified by gravity flow to the base of local valleys and Cataract Reservoir.

The FEFLOW model was developed to represent the anticipated strata depressurisation where a freely draining “goaf” zone and an overlying vertically connected fracture zone is anticipated to extend into the mid Bulgo Sandstone. An overlying enhanced porosity and elevated horizontal conductivity “delamination” zone, without vertical free drainage, is anticipated to extend from the ground surface up to 20m below surface.

A constrained vertical groundwater flow zone is anticipated to extend from 20m below surface down to the horizontal delamination zone, which overlies the vertically connected fracture zone that is predicted to propogate up from the extracted workings. This vertically constrained flow zone, which incorporates the Bald Hill Claystone, is anticipated to have an enhanced horizontal flow component due to bedding flexure, but not a vertically connected groundwater flow mechanism, thereby hydraulically seperating the two systems.

The model used both direct field measurements from Gujarat installed bores and piezometers and extrapoltaed values from adjoing studies to calibrate the model to observed water level data and mine inflows.

Within the limitations and constraints of the model, simulations predict the proposed mining could depressurise the overburden up to the upper Bulgo Sandstone, although the Hawkesbury Sandstone, which overlies the Bald Hill Claystone, is predicted to remain hydraulically seperated from the Bulgo Sandstone.

Groundwater modelling predicts there may be up to 12m depressurisation of the Upper Hawkesbury Sandstone (Layer 2) in the Lizard Creek and Wallandoola Creek catchments at the end of Mining Wonga West Area 4.

Depressurisation of the Upper Hawkesbury Sandstone (Layer 2) of up to 4m is predicted at the end of Mining Wonga East Area 2 in the Cataract Creek catchment and V Mains under the Wallandoola Creek catchment due to extraction of the proposed workings.

Mine water seepage into the workings is predicted to rise from the current 1.1ML/day (402ML/year) to 3.1 ML/day (1,131ML/year), Short term increases of 0.1 - 0.5 ML/day may ocurr if any vertically enhanced permeability structures are present, however the inflows should dissipate over a period of weeks to months.

Potential Basement Groundwater Impacts Summary

SHALLOW TO MID HAWKESBURY SANDSTONE (WONGA EAST AREA)
Temporary lowering of the upper Hawkesbury Sandstone phreatic surface by up to 4m at the end of Area 2, with subsequent recovery of the phreatic surface and no observable change in water quality..
SHALLOW TO MID HAWKESBURY SANDSTONE (WONGA WEST AREA)
Temporary lowering of the upper Hawkesbury Sandstone phreatic surface by up to 12m at the end of Area 4, with limited recovery (approximately 2m) of the phreatic surface and no observable change in water quality.
DEEP HAWKESBURY SANDSTONE
Temporary lowering and subsequent recovery of the phreatic surface, with no observable change in water quality
BALD HILL CLAYSTONE (WONGA EAST)
Due to partial erosion into and through the Bald Hill Claystone in the valley of Cataract Creek, the Hawkesbury Sandstone and upper Bulgo Sandstone may not be hydraulically separated within the eroded area however where it is not eroded, the semi confining integrity of the Bald Hill Claystone is anticipated to remain following subsidence.
BALD HILL CLAYSTONE (WONGA WEST)
Due to insufficient deflection of the Bulgo Sandstone, the Bald Hill Claystone is predicted to remain intact and as a result, there will be no predicted free drainage hydraulic interconnection or loss of surface water / Hawkesbury Sandstone groundwater into the lithologies below the Bald Hill Claystone or into the mine workings at Wonga West.
NARRABEEN GROUP AND ILLAWARRA COAL MEASURES
Hydraulic interconnection and depressurisation of the sedimentary overburden under the Bald Hill Claystone, up to the mid / upper Bulgo Sandstone is predicted, which will be tempered by the existing depressurisation from previous mining depressurisation effects.
MINE INFLOWS
Underground mine inflows may potentially rise from current 0.2 ML/day to 1.4 ML/day at the end of mining Wonga East and from the current 0.9 ML/day to 1.7 ML/day at Wonga West (with a total estimated increase across both areas from 402ML/year to 1131ML/year)
Stream Baseflow Changes
(0.02ML/day, 0.0012ML/km^2/day or 0.1%) gain to (0.1Ml/day, 0.0058ML/km^2/day, or 0.6%) reduction in Lizard Creek flow
(0.06 – 0.25ML/day), (0.0018 - 0.0075ML/km^2/day) or (0.2 – 0.8%) reduction in Wallandoola Creek flow.
(0.06 – 0.07ML/day), (0.0115 - 0.0135 ML/km^2/day) or (0.5 – 0.6%) reduction in Cataract Creek flow.
Stream Water Quality
Potential localised iron hydroxide precipitation and acidification of the interstitial water due to oxidation where groundwater is oxygenated, with no overall change in the bulk stream water quality discharging from the predicted 20mm subsidence areas into Cataract Reservoir, at Wonga East, or Cataract River at Wonga West

Upland Swamps

The alluvial / colluvial aquifers in the Study area are limited to upland headwater and valley fill swamps associated with Lizard, Wallandoola, Cataract and Bellambi Creeks and the Cataract River catchments (upstream of Cataract Reservoir). The Wonga West swamps generally comprise moderate to low permeability humic clays, silts and sands up to approximately 2m thick that are rainfall dependent with a highly variable, shallow water table. The Wonga East swamps, on the other hand, are generally shallower, less expansive, with less humic content and drier than the Wonga West ones.

Where paired measurements are available, the swamps have been shown to be hydraulically seperated from the underlying regional Hawkesbury Sandstone aquifer by up to approximately 11m at Wonga West, and by between 1 - 15m at Wonga East, with the lower seperation occurring during extended wet periods when the variable regional groundwater level rises up to near the ground surface.

The effect of subsidence on the upland swamps and weathered basement in Layer 1, which acts as a receptor for rainwater recharge and can contain temporary, perched water, was not directly assessed due to limitations of the model.

Subsidence could affect shallow swamp aquifer water levels due to increased secondary porosity and / or underlying strata fracture permeability through the development of subsidence cracks over the proposed workings. If cracking occurs, the change to swamp water level variability through subsidence depressurisation is not anticipated to be greater than the current varaibility resulting from climatic influences.

Hydraulically connected vertical cracking to the deeper strata is not predicted due to maintenance of the Bald Hill Claystone semi confining layer and the presence of a “constrained” vertical flow zone in the upper Bulgo Sandstone, therefore the swamps and creeks are not predicted to lose water by free drainage into the proposed workings.

Localised, temporary water table elevation changes in swamps may occur in headwater swamps that directly overly the workings due to differential subsidence. However, the perched water table is anticipated to recover as each panel reaches maximum subsidence in the vicinity of a subject swamp, with the effect’s duration being dependent on a swamps permability, storativity, recharge and climatic condition.

As Layer 1 is essentially unsaturated (although can contain small volume, temporary, perched aquifers that are hydraulically seperated from the regional Hawkesbury Sandstone aquifer) there is anticipated to be no observable effect on stream baseflow into the creeks.

All of the swamps at Wonga East are headwater swamps that range from 0.04 – 9.84ha (Biosis, 2012). Of the thirty nine swamps at Wonga East that lie within 600m of the proposed workings and meet the definition of the Coastal Upland Swamp Endangered Ecological Community, fourteen lie within the predicted 20mm subsidence zone. Of those fourteen, seven were assessed to be of “special significance” according to the NSW Office of Environment and Heritage criteria (OEH, 2012), and of those, five are predicted to be potentially subject to subsidence effects (Biosis, 2012), including;

- Crus1 as well as Ccus1, 4, 5 and Ccus10

The swamps at Wonga West contain both valley fill and headwater swamps that range from 0.06 – 129.89ha (Biosis, 2012). Of the forty five swamps at Wonga West that lie within 600m of the proposed workings and meet the definition of the Coastal Upland Swamp Endangered Ecological Community, thirty six lie within the predicted 20mm subsidence zone. Of those thirty six, eight were assessed to be of “special significance” according to the NSW Office of Environment and Heritage criteria (OEH, 2012), and of those, seven are predicted to be potentially subject to subsidence effects (Biosis, 2012), including;

- Lcus1, 6, 8, 27 as well as Wcus4, 7 and Wcus 11

For a detailed description of the field and office investigation, swamp assessment, classification and subsidence impact assessment methodology, the reader is referred to (Biosis, 2012).

Local Streams and Cataract Reservoir

No extraction is proposed under the main channel of Lizard Creek, Wallandoola Creek, Bellambi Creek or Cataract River, with the panel layout being designed to avoid subsidence impacts on the bed of the respective creeks and Cataract Reservoir.

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250mm and the creek experiences greater than negligible impact as defined in the performance criteria for the project.

Cataract Reservoir and all of the creeks (except the headwaters of Cataract Creek) are contained within the Sydney Catchment Authority controlled Metropolitan Special Area.

The local streams are essentially “losing – disconnected” in the upper headwaters, and are interpreted to be “gaining – disconnected” or “gaining- connected” reaches in the incised sections of the catchment.

None of the proposed panels underlie the stored waters (up to the high water mark) of Cataract Reservoir, except for the western end of Longwall 10 in Area 2.

For a detailed discussion, refer to an accompanying study of the surface water system (Geoterra 2012A).

1. INTRODUCTION

Gujarat NRE Coking Coal Ltd (Gujarat) propose to extract coal from the Wongawilli Seam by longwall extraction from eleven panels in the Wonga East and seven panels in the Wonga West extraction areas.

The proposed workings are contained within the NRE No. 1 Colliery Consolidated Coal Lease 745 (CCL745) and Mining Lease 1575 (ML1575) as shown in **Drawing 1**.

The proposed workings are predominantly located within the Sydney Catchment Authority managed, restricted access, Metropolitan Special Area.

The Study area is located approximately 13km northwest of Wollongong and is defined as containing the 20mm predicted subsidence zone (Seedsman 2012A) above the proposed Wongawilli Seam workings as well as a 600m buffer zone from the edge of the proposed workings.

Potential Significant Feature Zones have been defined as 600m wide zones that extend from the edge of the secondary extraction footprint for the assessment of any potentially significant natural features (NSW Planning Assessment Commission, 2009).

In addition, Risk Management Zones have been defined with 400m wide (or 40^o angle of draw from the edge of the proposed underground workings) corridors that extend centrally on the creek centre line for the Cataract River and Wallandoola, Lizard, Cataract and Bellambi Creeks.

Where either of these two zones extend outside the footprint of the 20mm subsidence zone, they have been incorporated in the study area for this assessment.

The two main extraction areas are subdivided into Wonga East (Area 1) and Wonga East (Area 2) as shown in **Drawing 2** as well as Wonga West (Area 3) and Wonga West (Area 4) as shown in **Drawing 3**.

Within the Wonga West area, ephemeral 1st and 2nd order tributary creeks drain into 3rd and 4th order Schedule 2 streams in the Wallandoola and Lizard Creek catchments.

Within Wonga East, 1st and 2nd order tributary creeks drain into the 3rd and subsequently 4th order, Schedule 2 catchment of Cataract Creek (downstream of the freeway) and the 3rd order catchments of Cataract River.

Bellambi Creek is located on the periphery of the study area and will not be undermined by the proposed workings.

The Wonga East catchments drain directly into Cataract reservoir, whilst Lizard Creek and Wallandoola Creek at Wonga West drain into the Cataract River, downstream of the Cataract Dam wall, and subsequently, to Broughtons Pass weir.

Cataract River subsequently drains downstream to the off-take to the Macarthur Water Treatment plant at Broughton’s Pass Weir.

Forty five valley fill and headwater upland swamps are located in and along the tributaries and main streamlines of Wallandoola and Lizard Creeks in the south of the Wonga West Study area (Biosis, 2012), downstream of which the streams become incised into exposed Hawkesbury Sandstone.

Thirty nine headwater swamps are present in the Wonga East study area within the Cataract Creek, Cataract River and Bellambi Creek catchments (Biosis, 2012).

The Study area also contains increasingly incised valleys in the central and northern section of the Wonga West area, and lesser incised, although steeper gradient valleys in Wonga East.

Cataract River is regulated by Cataract Dam, upstream of the Lizard Creek / Wallandoola Creek confluence, as well as by Broughton's Pass Weir, downstream of their confluences with Cataract River.

The proposed Wonga East workings predominantly underlie the Cataract Creek catchment, and to a significantly lesser degree, the Cataract River and Bellambi Creek catchments.

Land use is generally undeveloped bushland, including some limited fire access and power transmission access trails. The Wonga West workings predominantly underlie the Lizard Creek, and a small portion of Wallandoola Creek catchments, and contains mine surface infrastructure and a sealed access road and dirt tracks associated with the Gujarat NRE No. 1 Colliery No. 4 and No. 5 shafts.

This study provides a baseline assessment of the current status of potentially affected groundwater systems within the proposed mining area in accordance with the Department of Planning and Infrastructure (DoPI) Director-Generals Requirements (DGR's).

Office assessments, field monitoring, laboratory analysis and computer modelling studies have been used to prepare a baseline assessment of the shallow and deep groundwater systems, as well as perched upland swamp water levels, water quality and aquifer hydraulic parameters within the Study area.

The study assesses the potential mining impact on the groundwater systems, as well as providing a potential indicative management and monitoring strategy that will be suitable to manage any potential adverse effects that may be caused by subsidence.

Related groundwater features within the Study area include;

- a regional aquifer which has been intersected between 17m to 48m below surface within the Hawkesbury Sandstone. Where paired measurements are available, the regional aquifer has been shown to be hydraulically separated by 11m at Wonga West and from 1-15m at Wonga east by dry to unsaturated, weathered Hawkesbury Sandstone beneath the upland swamps;
- shallow, perched, ephemeral aquifers within the upper (<20m deep) Hawkesbury Sandstone;
- valley infill swamps along the main channel of Wallandoola Creek and Lizard Creek in their southern headwaters, downstream of which the creeks become incised into Hawkesbury Sandstone;
- headwater swamps associated with tributaries of Lizard Creek and Wallandoola Creek in Wonga West;
- headwater swamps within Cataract and Bellambi Creeks as well as the Cataract River catchments in Wonga East;
- shallow (<1.9m deep) perched, ephemeral highly variable water level aquifers within the swamps, and;

- “Losing-disconnected” streams, which predominate in the upper catchments, where stream water permeates into the regional Hawkesbury Sandstone aquifer, and “gaining” streams in incised sections, downstream of the main waterfalls (where present), where groundwater seeps under gravity into the main creek channels.

Previous underground mining in and adjacent to the Study area has been conducted through longwalling the Bulli Seam in the Gujarat lease area to the west, east and beneath Cataract reservoir, as well as in the adjoing southern BHP Billiton’s (BHPB) Cordeaux lease area.

Multi seam mining has been conducted at Wonga East (Area 2) where the Bulli Seam was mined by bord and pillar as well as pillar extraction methods, along with the underlying Balgownie Seam narrow longwalls.

Bord and pillar, as well as pillar extraction of the Bulli Seam has been conducted in Wonga East (Areas 1 and 2), whilst predominantly bord and pillar mining, and to a lesser degree, longwall extraction, has been conducted in the old AIS (subsequently BHPB) Bulli Colliery workings to the north of Wonga East.

The Wongawilli Seam has also recently been mined by Longwall WE-A2-LW4 in the Wongawilli Seam at Wonga East, Area 2.

The proposed mine plan has been specifically designed to not directly undermine the main channels of Lizard Creek and Wallandoola Creek.

Although the main channel of Cataract Creek is proposed to be undermined, narrow longwalls with wide pillars have been used to reduce the total subsidence to less than 0.8m under the creek bed. The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experiences greater than negligible impacts, as defined by the project’s approval conditions performance criteria.

The channel of the Cataract River will not be undermined, although one first order tributary is proposed to be undermined by the western edge of Wonga East Area 2.

The stream assessment for the Study area is discussed seperately in (Geoterra 2012), whilst the swamp assessment is detailed in (Biosis, 2012).

2. SCOPE OF WORK

In accordance with the Director Generals Requirements for Application No. 09_0013, (20/3/2009), the requirements for the groundwater component of the assessment are:

- *a description of the existing environment, using sufficient baseline data;*
- *an assessment of the potential impacts of all stages of the project, including any cumulative impacts, taking into consideration any relevant guidelines, policies, plans and statutory provisions and the findings and recommendations of the recent Southern Coalfield inquiry;*
- *a description of the measures that would be implemented to avoid, minimise, mitigate, rehabilitate/remediate, monitor and/or offset the potential impacts of the project, including detailed contingency plans for managing any potentially significant risks to the environment, and;*
- *a detailed assessment of the potential impacts of the project on the quantity, quality and long-term integrity of the groundwater resources in the project area, paying particular attention to the Upper Nepean River sub-catchment (Metropolitan Special Area)*;

Geoterra were commissioned by Gujarat NRE Coking Coal Ltd to monitor the baseline status and to address any potential groundwater impacts relating to the proposed extraction and associated subsidence of the Wongawilli Seam in the Wonga East and Wonga West areas.

The groundwater investigation was conducted to assess the current and historic;

- standing water levels and / or hydrostatic pressures within formations overlying the existing and proposed workings;
- groundwater quality of the upland swamp, shallow and deeper Hawkesbury Sandstone units;
- hydraulic parameters of the upland swamps, Hawkesbury Sandstone and underlying formations down to the proposed workings, and;
- any observed or inferred groundwater discharge zones into local streams

In addition, the study aims to;

- identify potential groundwater dependent ecosystems;
- collate and review mine water management data;
- collate and review additional data from adjacent mines and government agencies;
- develop a conceptual groundwater model and represent the study area with a numerical FEFLOW groundwater model to assess potential underground mining impacts on the local and regional groundwater system;
- provide a qualitative and quantitative assessment of cumulative impacts from adjacent existing and approved mines;
- assess post mining groundwater impacts in regard to groundwater level recovery;
- develop measures to avoid, mitigate and/or remediate potential impacts on groundwater resources, and;
- indicate groundwater monitoring measures that will measure any impacts on the local and regional groundwater system.

The study provides a baseline, pre-mining assessment of the potentially affected groundwater systems within the proposed mining area and has been conducted to satisfy the Environmental Assessment approvals process as administered by the DoPI.

3. RELEVANT LEGISLATION AND GUIDELINES

The report has been prepared with reference to the following documents;

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC);
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]);
- NSW State Groundwater Quality Protection Policy (DLWC);
- NSW draft State Groundwater Quantity Management Policy (DLWC);
- NSW Groundwater Dependent Ecosystem Policy (DLWC);
- Murray-Darling Basin Commission Groundwater Quality Sampling Guidelines Technical Report No 3 (MDBC);
- Murray-Darling Basin Commission. Groundwater Flow Modelling Guideline (MDBC);
- Water Management Act, 2000
- Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (NSW Office of Water – NOW), and the;
- NSW Aquifer Intereference Policy (NOW).

3.1.1 State Groundwater Policies and Management Plans

The aquifers are covered, as appropriate, by the generic State Groundwater Policy (DLWC, 1997), Groundwater Quality Protection Policy (DLWC, 1998).

The Study area lies within Groundwater Flow System 5 (GFS5) Hawkesbury Sandstone - South-East (Grey and Ross, 2003) which includes the catchment of Cataract Dam. As the area is within the Sydney Catchment Authority controlled Metropolitan Special Area, no groundwater development is permitted as it is a protected area and there are no private bores. GFS5 has a sustainable yield estimate of 58,000 ML/year (Grey and Ross, 2003).

The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources encompasses the Study area, and is contained within the Sydney Basin Nepean Groundwater Source Area. A macro water sharing plan for the Greater Metropolitan Region's surface water resources is also being developed in parallel with the groundwater sharing plan, with technical work on plan development being completed and both plans are expected to be finalised following community consultation (Williams RM, Bailey A, Gill J, 2009).

The water sharing plan annual rainfall recharge in the Sydney Basin Nepean groundwater Source Area is assessed at 224,483ML/year. This volume is subdivided into consumptive pool water and environmental water, with 124,915ML/year of the long term annual average recharge being reserved as environmental water. The remaining volume is classified as a sustainable yield or long term average extraction limit of 99,568ML/year.

The current extraction limits and groundwater entitlement volumes do not include all water taken through aquifer interference activities such as mine voids (remnant or otherwise).

Reservation of environmental water aims to support the long term viability of the aquifers and their dependent ecosystems.

The plan also includes rules aimed at protecting Groundwater Dependent Ecosystems consistent with the Groundwater Dependent Ecosystem Policy (DLWC, 2002). The policy includes wetlands, terrestrial vegetation and caves or karst systems. In the proposed plan, terrestrial ecosystems are protected by a 200m stand off for new bores from any sandstone escarpment where hanging swamps or base flow to rivers is supported by groundwater. It should be noted, however, that no extraction bores are proposed and there are no “hanging” swamps, as opposed to “Upland” swamps in the Study area.

While it does not extend into the Study area, there is currently an embargo on further applications for sub-surface water licences in the Southern Coalfield (ordered under section 113A of the Water Act, 1912), for areas covering the:

- Nepean Sandstone Water Shortage Zone GWMA 607 (gazetted 8 June 2007); and
- NSW Southern Highlands (gazetted 21 May 2004 and 16 December 2005).

3.1.2 Water Management Act, 2000

In regard to swamps, the Act provides for protection of groundwater dependent ecosystems in Sections 3, 5 and 9 and Sections 8(1) and 9 as well as Schedule 4 of the WSP.

Upland Swamps within the study area are not representative of the Temperate Highland Peat Swamps on Sandstone (THPSS) EEC listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The listing advice for the THPSS EEC (TSSC 2005) contains a number of criteria not met by the upland swamps within the study area. It is understood that the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) are currently reviewing the listing of upland swamps, and that the new listing advice is likely to cover swamps on the Woronora plateau, as outlined in (Biosis, 2012).

Notwithstanding, the upland swamps within the Woronara Plateau were considered to be significant by DECCW (subsequently NOW) in the Bulli PAC report.

A full discussion of the WMA, 2000 is contained within an accompanying surface water assessment (Geoterra, 2012)

3.1.3 Water Sharing Plan for the Greater Metropolitan Region Groundwater Water Sources 2011

Under the Rules summary sheet for the Sydney Basin Nepean Groundwater Source (Management Zone 2), those that may be relevant to the proposed mining include:

- A commercial access licence under a controlled allocation order may be made in relation to any unassigned water in this water source

Managing Surface and Groundwater Connectivity

From year 7 of the plan, for areas adjoining unregulated water sources (i.e. rivers and creeks), existing works within 40 metres of the top of the high bank of a river or creek, except existing works for, local water utility, town water supply, food safety or essential dairy care purposes, will have conditions which establish:

- the flow class of the river established under the water sharing plan for the corresponding unregulated water source, or
- in the absence of a flow class, visible flow in the river at the closest point of the water supply works to the river.

These distances and rules may be varied for an applicant if the work is drilled into the underlying parent material and the slotted intervals of the works commences deeper than 30 metres or no minimal impact on base flows in the stream can be demonstrated.

For major utility and local water utility access licences these rules apply to new water supply works from plan commencement.

To minimise interference between neighbouring works

No water supply works (bores) to be granted or amended within the following distances of existing bores:

- 400m from an aquifer access licence bore on another landholding, or
- 100m from a basic landholder rights bore on another landholding, or
- 50m from a property boundary (unless written consent from neighbour), or
- 1,000m from a local or major water utility bore, or
- 200m from a NSW Office of Water monitoring bore (unless written consent from NSW Office of Water).

To protect bores located near contamination

No water supply works (bores) are to be granted or amended within:

- 250m of contamination as identified within the plan, or
- 250m to 500m of contamination as identified within the plan unless no drawdown of water will occur within 250m of the contamination source,
- a distance greater than 500m of contamination as identified within the plan if necessary to protect the water source, the environment or public health and safety.

To protect water quality

To minimise the impact on water quality from saline interception in the shale aquifers overlying Sydney basin sandstone, the bore being used to take groundwater must be constructed with pressure cement to seal off the shale aquifer as specified by the Minister.

To protect bores located near sensitive environmental areas

No water supply works (bores) to be granted or amended within the following distances of high priority Groundwater Dependent Ecosystems (GDEs) (non Karst) as identified within the plan:

- 100m for bores used solely for extracting basic landholder rights, or
- 200m for bores used for all other access licences.

The above distance restrictions for the location of works from high priority GDEs do not apply where the GDE is a high priority endangered ecological vegetation community and the work is constructed and maintained using an impermeable pressure cement plug from the surface of the land to a minimum depth of 30m.

No water supply works (bores) to be granted or amended within the following distances from these identified features:

- 500m of high priority karst environment GDEs, or
- a distance greater than 500m of a high priority karst environment GDE if the Minister is satisfied that the work is likely to cause drawdown at the perimeter of the high priority karst GDE, or
- 40m of a river or stream or lagoon (3rd order or above),
- 40m of a 1st or 2nd order stream, unless drilled into underlying parent material and slotted intervals commence deeper than 30m. (30m may be amended if demonstrate minimal impact on base flows in the stream.), or
- 100m from the top of an escarpment.

To protect groundwater dependent culturally significant sites

No water supply works (bores) to be granted or amended within the following distances of groundwater dependent cultural significant sites as identified within the plan: ,

- 100m for bores used for extracting for BLR, or
- 200m for bores used for all other aquifer access licences

Rules for replacement groundwater works

A replacement groundwater work must be constructed to take water from the same water source as the existing bore and to a depth specified by the Minister.

A replacement work must be located within:

- 20 metres of the existing bore; or
- If the existing bore is located within 40 metres of the high bank of a river the replacement bore must be located within 20 metres of the existing bore but no closer to the high bank of the river or a distance greater if the Minister is satisfied that it will result in no greater impact

Replacement works may be at a greater distance than 20 metres if the Minister is satisfied that doing so will result in no greater impact on the groundwater source and its dependent ecosystem.

The replacement work must not have a greater internal diameter or excavation footprint than the existing work unless it is no longer manufactured. If no longer manufactured the internal diameter of the replacement work must be no greater than 110% of the existing work.

To manage bores located near contaminated sites

The maximum amount of water that can be taken in any one year from an existing work within 500 metres of a contamination source is equal to the sum of the share component of the access licence nominating that work at commencement of the plan.

To manage the use of bores within restricted distances

The maximum amount of water that can be taken in any one year from an existing work within the restricted distances to minimise interference between works, protect sensitive environmental areas and groundwater dependant culturally significant sites is equal to the sum of the share component of the access licence nominating that work at commencement of the plan.

To manage the impacts of extraction

The Minister may impose restrictions on the rate and timing of extraction of water from a water supply work to mitigate the impacts of extraction.

Available Water Determinations (AWDs)

- 100% stock and domestic, local and major utilities and specific purpose access licences
- 1 ML/unit of share aquifer access licences

AWD for aquifer access licences may be reduced in response to a growth in use.

Trading Rules

Into groundwater source - not permitted

Within groundwater source - trading within groundwater source, from Management Zone 2 to Management Zone 1 is prohibited if the trade will increase the total licensed entitlement for the management zone from that at the commencement of the plan. Trading within management zones permitted subject to local impact assessment.

Conversion to another category of access licence

These are not permitted. The plan lists circumstances in which these distance rules may be varied and exemptions from these rules.

3.1.4 NSW Aquifer Interference Policy

The NSW Aquifer Interference policy was released in September 2012.

Under the policy, and the associated WMA 2000, an aquifer is a geological structure or formation that is permeated with water or is capable of being permeated with water, whislt groundwater is all water that occurs beneath the ground surface in the saturated zone. For the purpose of the policy, the terms aquifer and groundwater have the same meaning as groundwater system.

The *Water Management Act 2000* defines an aquifer interference activity as the:

- penetration of an aquifer,
- interference with water in an aquifer,
- obstruction of the flow of water in an aquifer,
- taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations, and the;
- disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

A water license is required under the *Water Management Act 2000,* unless an exemption applies or water is being taken under a basic landholder right, where any act by a person carrying out an aquifer interference activity causes the:

- removal of water from a water source;
- movement of water from one part of an aquifer to another part of an aquifer;
- movement of water from one water source to another water source, such as from an aquifer to an adjacent aquifer, an aquifer to a river/lake, or from a river/lake to an aquifer.

In terms of mining, activities considered as having a minimal impact include:

- sampling and coring using hand held equipment;
- trenching and costeaning;
- access tracks;
- leachate ponds and sumps if constructed, operated and abandoned in accordance with appropriate standards and guidelines as determined by the Minister;
- construction and ongoing use of tailings and ash dams if lined with an impervious layer providing these are carried out in accordance with their planning and other approvals;
- caverns, tunnels, cuttings, trenches and pipelines (intersecting the water table) if a water access license is not required;

In terms of drill holes, the Aquifer Interference Policy, as well as the Water Management (General) Regulation 2011, that was gazetted in September 2011, indicates that a monitoring bore is exempt from requiring an Access Licenses or Approvals if it is;

- required by a development consent under Part 4 or an approval under Part 5.1, of the Environmental Planning and Assessment Act 1979,
- required or undertaken as a result of an environmental assessment under Part 5 of that Act,
- required by a condition of an environment protection license under the Protection of the Environment Operations Act 1997, or where;
- core holes, stratigraphic (chip) holes, geo-environmental and geotechnical bores, works or activities intersecting the water table if they are decommissioned in such a way as to restore aquifer isolation to that which existed prior to the construction of the bore, work or activity and that the decommissioning is conducted within a period of 28 days following completion of the bore, work or activity;

The *Water Management Act 2000* includes the concept of ensuring "no more than minimal harm" for both the granting of water access licenses and the granting of approvals. Water access licenses are not to be granted unless the Minister is satisfied that adequate arrangements are in force to ensure that no more than minimal harm will be done to any water source as a consequence of water being taken under the license.

Where a water access license has been applied for by a method consistent with a controlled allocation process then adequate arrangements are in force to ensure that no more than minimal harm will occur. This is because the controlled allocation process allows for the allocation of a proportion of the unassigned water within the relevant water source using a conservative approach. Furthermore, unassigned water can only occur where total water requirements within a water source are less than the long-term average annual extraction limit specified in the relevant water sharing plan.

Where water is to be taken from a water source that has no unassigned water or insufficient unassigned water to account for any inflows to the activity, either surface or groundwater, then water entitlements will need to be purchased from an existing licensed user.

Any access license dealing requiring the Minister's consent will need to consider the requirements of section 71Y of the *Water Management Act 2000,* including the water management principles that require water sources to be protected and social and economic benefits to be maximised.

Aquifer interference activities may induce flow from adjacent groundwater sources or flow from connected surface water sources to compensate for the water taken from the aquifer in which the activity is occurring or to fill the void created in the aquifer.

Where an aquifer interference activity is taking water from a groundwater source, and this causes movement from an adjacent, overlying or underlying groundwater source, separate aquifer access licenses are required for the groundwater source and for any adjacent, overlying or underlying groundwater sources.

Where an aquifer interference activity causes movement of water from a connected regulated or unregulated river water source into the groundwater source, then an access license in the regulated or unregulated river water source is required to account for the take of water from that water source and another access license in the groundwater source is required for the remainder of the take.

Where an aquifer interference activity is incidentally taking water from a river it must be returned to that river when river flows are at levels below which water users are not permitted to pump.

It is the proponent's responsibility to ensure that the necessary licenses are held with sufficient share component and water allocation to account for all water take, both for the life of the activity and after the activity has ceased.

In determining what licenses are required and which water source(s) the activity will take water from, the following need to be considered;

- prediction of the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity and after closure of the activity. Where required, predictions should be based on modeling conducted in accordance with the Australian Groundwater Modeling Guidelines;
- how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources;
- how any relevant license exemptions might relate to the water to be taken by the activity;
- whether the water is taken at a fixed or varying rate;
- whether sufficient entitlements and allocations are able to be obtained;
- consideration of water sharing plan rules;
- by what mechanism and license category the water will be obtained, consistent with any trading rules specified in either the Minister's access license dealing principles and/or relevant water sharing plans.
- the effect that activation of existing entitlement may have on future available water determinations for the proposed license category and entitlement volume;
- actions required both during operation and post-closure to minimise the risk of inflows to a mine void as a result of flooding. Set-back distances from rivers should be no less than that required to ensure structural integrity of the river bank during flooding events. Levee banks or landforms should also be constructed at the appropriate time to prevent at least a 1 in 100 year flood from entering the site either during or after operation, and;
- a strategy for accounting for any water taken beyond the life of the operation of the project, such as holding the appropriate entitlement or surrendering a component of the entitlement at the end of the project. Where a license or part of a license has been surrendered to the Minister, a security deposit or condition of consent under the EP&A Act may account for or require the upfront payment of fees and

subsequently the license may be retained for the period of ongoing take of water or cancelled.

Where uncertainty in the predicted inflows may have a significant impact on the environment or other authorised water users, the applicant will need to report on:

- potential for causing or enhancing hydraulic connection between aquifers or between groundwater and surface water sources, and quantification of this risk;
- quantification of any other uncertainties in the groundwater or surface water impact modeling conducted for the activity; and
- strategies for monitoring actual and reassessing any predicted take and how changes will be accounted for, including analysis of water market depth and/or in situ mitigation and remediation options

Where there is ongoing take of water, the holder must retain a license until the system returns to equilibrium or surrender it to the Minister. Surrendering entitlements that adequately cover any likely future low available water determination periods is preferable.

The NSW Office of Water will assess the potential impacts of the aquifer interference activity against the minimal impact considerations, as well as any specific rules in a relevant water sharing plan

There are two levels of minimal impact considerations specified in **Table 1**.

Groundwater sources have been divided into "highly productive" and "less productive". Highly productive groundwater is defined as a source that is declared in the Regulations and:

- has total dissolved solids less than 1,500 mg/L, and
- contains water supply works that can yield water at a rate greater than 5 L/sec.

Highly productive groundwater sources are grouped into:

- Alluvial;
- Coastal sands;
- Porous rock;
    - Great Artesian Basin - Eastern Recharge and Southern Recharge;
    - Great Artesian Basin - Surat, Warrego and Central;
- other porous rock, and
- fractured rock

Less productive groundwater sources are grouped as:

- Alluvial;
- Porous rock, and;
- Fractured rock.

Table 1 Minimal Impact Considerations for Aquifer Interference Activities – Highly Productive Fractured Rock Groundwater Sources

Water Table	Water Pressure	Water Quality
Less than or equal to 10% cumulative variation in the water table, allowing for typical post water sharing plan (WSP) variations, 40m from any: High priority groundwater dependent ecosystems, or High priority culturally significant site; listed in the schedule of the relevant WSP. A maximum of 2m decline cumulatively at any water supply work.	A cumulative pressure head decline of not more than 2m decline at any water supply work.	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.
If there is more than 10% cumulative variation in the water table, then appropriate studies will need demonstrate to the ministers satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	If there is more than a 2m pressure head decline, then appropriate studies will need to demonstrate to the ministers satisfaction that the decline will not prevent the long term viability of the water supply works unless make good provisions apply	If the above condition is not met, then appropriate studies will need to demonstrate to the ministers satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.

If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable.

Where an activity's predicted impacts are greater than Level 1, but they exceed it by no more than the accuracy of a robust model, then the project will be considered as having acceptable impacts, with monitoring, as well as potential mitigation or remediation required during operation.

If the predicted impacts exceed Level 1 by more than the accuracy of a robust model, then the assessment will need to involve additional studies, and if the impacts will not prevent the long-term viability of the water dependent asset, then the impacts will be considered acceptable.

A risk management approach to assessing the potential impacts of aquifer interference activities will be adopted, where the level of detail required is proportional to the likelihood of impacts occurring on water sources, users and dependent ecosystems and the potential consequences.

In addition to the volumetric water licensing considerations, a proponent will need to provide;

- baseline groundwater depth, quality and flow;
- a strategy for complying with any water access rules;
- potential water level, quality or pressure impacts on nearby water users, connected ground / surface water sources and groundwater dependent ecosystems;
- the potential for increased saline or contaminated water inflows to aquifers and highly connected river systems;
- the potential to cause or enhance hydraulic connection between aquifers;
- the potential for river bank instability, or high wall instability or failure to occur;
- the method for disposing of extracted water;
- contingency plans or remedial measures if impacts are outside of the licensing and approval requirements.

If a development consent under Part 4, Division 4.1 or Part 5.1 of the EP&A Act has been granted or for any approved mining or CSG production activity that was not subject to the Gateway process, the maximum predicted annual water quantities are to be licensed from the commencement of the activity.

3.2 Southern Coalfields Inquiry, Metropolitan and Bulli Seam Operations Planning Assessment Commission

In addition to the policies and guidelines outlined in Section 2.0, the three following reports have also guided the current assessment;

- NSW Dept of Planning, 2008 Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review;
- NSW Planning Assessment Commission, 2009 The Metropolitan Coal Project Review Report, and;
- NSW Planning Assessment Commission, 2010 Bulli Seam Operations PAC Report

The combined groundwater related issues highlighted in the above Planning Assessment Commission (PAC) reports that are addressed in this study are:

- the use of 3D groundwater numerical modelling that can adequately address high contrasts in hydraulic properties and steep hydraulic gradients in non-steady state flow domains
- aquifer numerical modelling used as a management tool for the ongoing prediction of impacts attributed to longwall extraction
- adequate density and duration of observations with respect to redirected surface flows and regional strata depressurisation, ideally with a minimum two years of baseline environmental data collected at appropriate frequency and scale
- the possibility of a fault or dyke, or other linear features providing a potential leakage conduit from surface to below the Bald Hill Claystone and development of a strategy to characterise the structure and determine the magnitude and extent of the leakage.

The reports indicate that groundwater monitoring regimes and impact assessments should be based on:

- shallow piezometers monitoring groundwater levels within significant upland swamps, drainages or connected alluvium with sufficient distribution to characterise the swamp with a high level of confidence in potentially affected areas. Water level measurements should be automated with daily or more frequent recording;
- sufficient piezometers in swamps and associated regional groundwater systems to verify perching and to monitor the underlying hardrock water table
- groundwater quality classification through regular sampling and analyses that can discriminate mining related impacts and ionic species attributable to new water/rock interactions;
- deep piezometer installations to monitor pore pressures in the natural rock strata with sufficient distribution to describe the distribution of deep aquifer pressures with a high level of confidence using automated daily or more frequent recording;
- strata porosity and permeability measurements used to calculate subsurface flows and presentation of a database to facilitate impact assessment using packer testing, variable head testing, test pumping, core analyses (matrix properties and defects inspections) and geophysical logging where appropriate; and
- a mine water balance (Beca, 2010) to confirm groundwater transmission characteristics of the coal seam, overburden and drainage characteristics of goaves and the overlying failure regimes. Use of a mine water balance can also indicate potentially anomalous mine water seepages that may be initiated by increased connectivity to surface drainage systems or in association with igneous intrusions. The water balance should account for water pumped into and out of the mine, coal moisture, ventilation moisture and any other exports. The capacity of the mine water management system to manage increased contributions from underground operations should also be addressed.
- use of airborne laser survey for detailed topographic mapping, GIS of groundwater systems assessment and management and consideration of data generated by other mine sites
- wireline geophysical logging (natural gamma; density (neutron), resistivity, sonic, acoustic scanner) to improve interpolation of measured permeability and porosity.

4. PREVIOUS GROUNDWATER RELATED STUDIES

Groundwater level and / or hydrostatic water pressure monitoring has been conducted in the Gujarat lease area within the Hawkesbury Sandstone and underlying lithologies over Longwalls adjacent to Cataract Reservoir (Singh, R.N. Jakeman, M. 2001).

Vibrating wire piezometers in open standpipe bores PL1A01 and PL1A02 were used to monitor groundwater levels since December 1992 and August 1993 over Longwalls 501 and 502 respectively, in the NRE1 lease area, and since November 1998 in an open standpipe piezometer PL1A14 over Longwall 514.

Details of the extent of fracturing and depressurisation due to subsidence over Longwalls 501, 502 and 514 are discussed in subsequent sections of this report.

In addition, stream water quality, groundwater seepage and stream flow studies have been conducted since 2001 as outlined in (Geoterra 2012A).

5. PREVIOUS MINING

For full details, refer to (Geoterra 2012A).

6. PROPOSED MINING AND PREDICTED SUBSIDENCE

For details refer to (Geoterra, 2012A).

7. STUDY AREA DESCRIPTION

7.1 Geology

NRE No. 1 Colliery is situated at the southern end of the Permo-Triassic (225-270 My) Sydney Basin within the Illawarra Coal Measures, which contains the Bulli, Balgownie and the Wongawilli seams.

The Study area is predominantly covered by shallow hillslope-based colluvium, with very thin to absent alluvial sedimentary deposits in the valley floors as shown in **Figure 1**.

Outside of the upland swamps, there are no alluvial deposits of any significance within the Gujarat lease except for possibly within, or under, Cataract Reservoir.

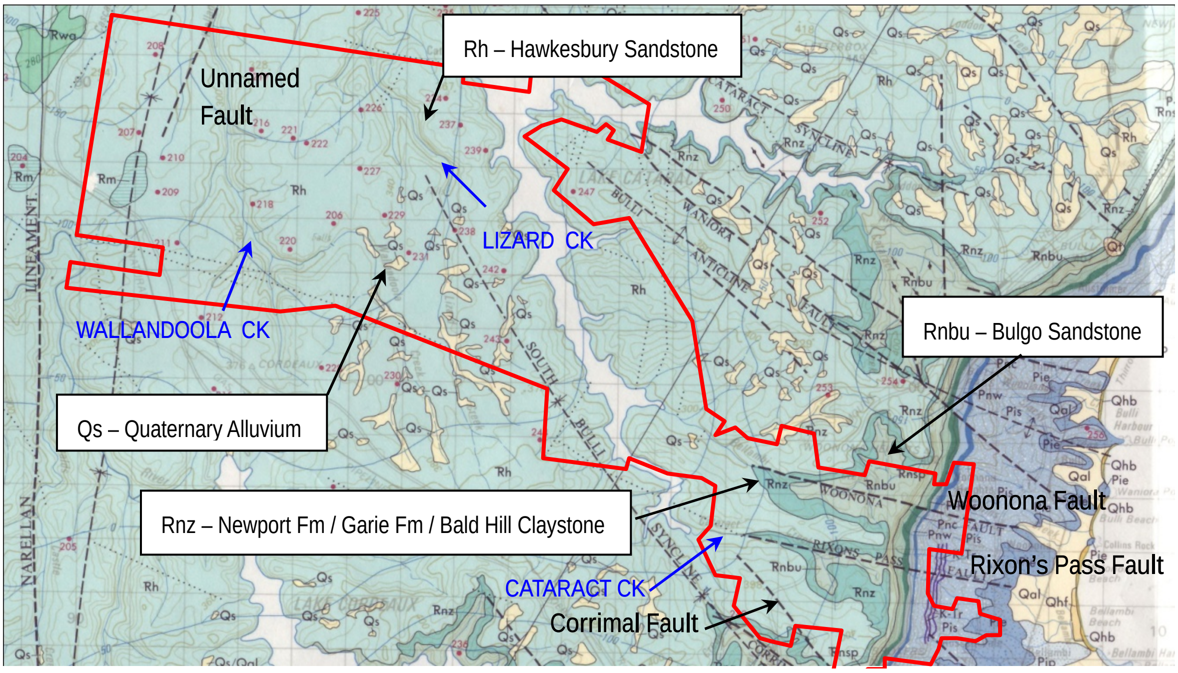


Figure 1 Surficial Geology

Quaternary unconsolidated alluvial and colluvial sediments are also present within both valley fill and headwater upland swamps, and are generally less than 2m thick, comprising humic sands and clayey sands overlying weathered Hawkesbury Sandstone.

The Quaternary sediments in the Wonga East and Wonga West areas are, in turn, sequentially underlain by the:

Wianamatta Group (absent from the study area) – The shale dominated unit has not been directly mapped in the Study area, although its presence as thin, isolated outcrops is possible in the vicinity of Transitional Shale Stringbark Forest (ERM, 2009) vegetation communities.

Hawkesbury Sandstone (absent to 181m thick) – the bedded to massive quartzose sandstone with grey shale lenses up to several metres thick is uppermost in the stratigraphic sequence in the majority of the Study area except where it has been eroded in the headwater valleys of Cataract and Bellambi Creeks in the Wonga East area. Exposed Hawkesbury Sandstone is present across the central and western areas of the lease, with a higher degree of exposure in the downstream reaches of incised creek beds to the north of the Wonga West area in the Lizard Creek and Wallandoola Creek catchments. The Hawkesbury Sandstone also outcrops in the west of the Wonga East area, with the underlying Newport and Garie Formations, Bald Hill Claystone and Bulgo Sandstone being exposed in reaches of Cataract Creek.

Narrabeen Group the Narrabeen Group consists of the following units as described below.

- **Newport and Garie Formations** (4.6 - 36m thick) – The Newport Formation has interbedded grey shales and sandstones which has a variable thickness across the Study area. The Garie Formation is generally around 3m thick and contains cream to brown, massive, characteristically oolitic claystone with a relatively constant thickness across the Study area.

- **Bald Hill Claystone** (17 - 42m thick) - brownish-red marker horizon with a relatively constant thickness over the Study area.
- **Bulgo Sandstone** (113 - 154m thick) - thickly bedded, medium to coarse - grained lithic sandstone with occasional conglomerate and shale.
- **Stanwell Park Claystone** (15 - 26m thick) - greenish-grey mudstone and sandstone, with a general thickening of the claystone to the north west.
- **Scarborough Sandstone** (16 - 31m thick) - thickly bedded sandstone with shale and sandy shale lenses up to several metres thick.
- **Wombarra Claystone** (35 - 61m thick) – has a similar lithology to the Stanwell Park Claystone and generally thickens to the south east.
- **Coal Cliff Sandstone** (8 - 13m thick) - shales and mudstones contiguous with the underlying Bulli seam and varies from a quartzose sandstone in the east to a more shale/mudstone dominated unit in the west.

Illawarra Coal Measures – The Illawarra Coal Measures consist of interbedded shales, mudstones, lithic sandstones and coals, including the Bulli Seam, Loddon Sandstone, Lawrence Sandstone, Eckersley Formation, Wongawilli Coal and Kembla Sandstone. The major coal seams in sequentially lower order are described below.

- **Bulli Seam** (2.0 - 4.7m thick) – Coal from the Bulli Seam has been worked extensively by both longwall as well as bord and pillar methods within and surrounding the Gujarat lease. The Bulli Seam varies from 205 - 290m depth of cover at Wonga East and 425 - 500m at Wonga West, with a seam dip to the north-west of approximately 1 in 30 with modification in the vicinity of the north west / south east trending South Bulli Syncline to the west of Cataract Reservoir, and a north south trending unnamed syncline to the west of Wallandoola Creek. A small scale north south trending syncline is present in the Bulli Seam workings. The Bulli Seam overlies the Balgownie Seam by 5.5 - 13.6m with a median 9.9m separation in the lease area.
- **Loddon Sandstone** (5 - 8m thick) – shale, mudstone, siltstone, sandstone with a sharp conglomeratic base
- **Balgownie Seam** (0.8 - 1.5m thick) – The Balgownie Seam has not been worked extensivley in the southern coalfield, although limited longwall extraction has been conducted in the Wonga east area. The Balgownie Seam overlies the Wongawilli Seam by 10.6-24.7m with a median 18.7m in the lease area.
- **Lawrence Sandstone** (16 - 17m thick) – mudstone, siltstone to sandstone at the base
- **Cape Horn Seam** (0.1 - 0.4m thick) - a thin seam that is not mined commercially
- **Eckersley Formation and Hargraves Coal Member** (6 - 8m thick) – mudstone, claystone, siltstone an shales with the intercalated very thin (0.1 - 0.3m), uncommercial Hargraves Coal Seam
- **Wongawilli Seam** (6.2 - 10.5m thick) – comprised of up to 11 sub seams. It

has predominantly been mined in the southern area of the Southern Coalfields, although has not as yet been mined within or surrounding the Gujarat lease. The Wongawilli Seam varies from 237 - 321m depth of cover at Wonga East and 457 - 512m at Wonga West. In the lease area the Wongawilli Seam underlies the Bulli Seam by 24.1 - 36.4m with a median of 30.4m.

Lithologies underlying the Wongawilli Seam – following units underlie the Wongawilli Seam

- **Kembla Sandstone** (5 - 9m thick) – shale, siltstone and finer to coarse grained sandstone
- **American Creek Coal Member** (0.3 - 3.5m thick) – this seam has not been mined in the Southern Coalfields
- **Allens Creek Formation** (14 - 15m thick) – shale, siltstone and finer to coarse grained sandstone
- **Darkes Forest Sandstone** (5 - 9m thick) – fine to medium grained sandstone
- **Bargo Claystone** (10 - 12m thick) – mudstone, siltstone, shale
- **Tongarra Seam** (1.5 - 2.0m thick) – this seam was mined to a limited extent in the southern part of the Southern Coalfields
- **Wilton Formation** (minimum 4m thick) – claystone, siltstone and shale

7.2 Cataract Creek Geology

Mapping of the lower portion of Cataract Creek was conducted in 1981, with follow up on site assessments by Gujarat staff, Geoterra and Strata Control Technologies in 2012.

The 1981 mapping with overlaid additions is shown in **Figure 2**.

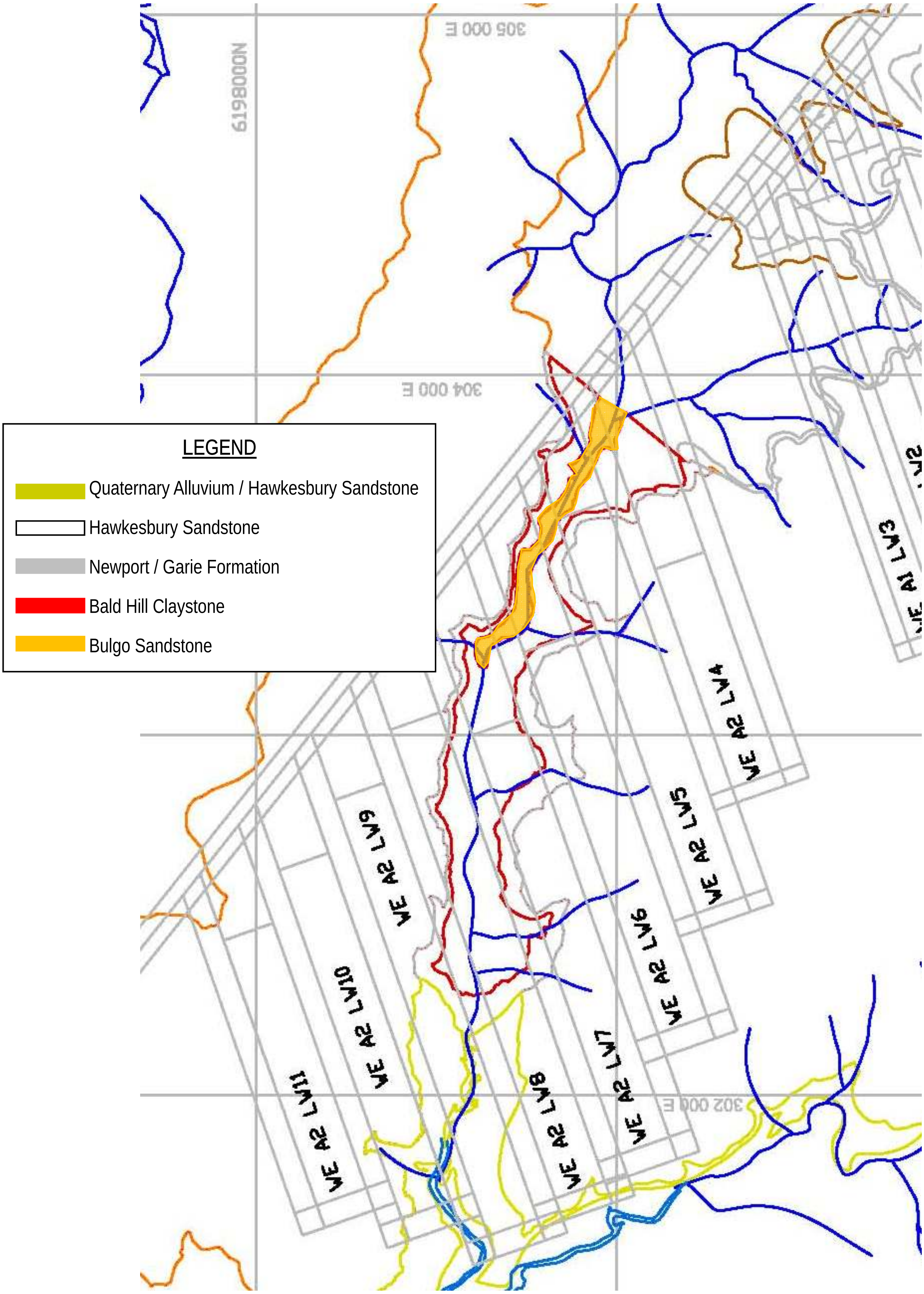


Figure 2 Cataract Creek Outcrop Geology

7.3 Structural Geology

7.3.1 Faults Mapped at Surface

Major faults that are indicated by the 1:100,000 scale mapping (Geological Survey of NSW, 1985) to outcrop at surface in the Study area are shown in **Figure 1.**

It is worth noting that the 1:100,000 geological map is a generalised representation of the surficial geology in the lease area, and that site specific drilling and mapping in the NRE No.1 lease area has established that the map is not wholly accurate. For instance, the exposed Bulgo Sandstone shown in the bed of Cataract Creek is not as extensive as shown in the 1:100,000 mapping.

In addition the location of the faulting is generalised, as discussed in subsequent sections.

7.3.2 Wonga West Underground Mapped Faults

Structures mapped in the Bulli workings to the west of Cataract Reservoir, which may or may not extend up to surface with the same dislocation values and direction, indicate a predominantly south south east / north north west and conjugate north east / south west faulting.

A regional faulted zone to the north of the proposed Wonga West workings is indicated with a throw from 50m to the north and 30m to the northeast of the workings, with the NRE1 area on the downthrown side.

In addition, a faulted zone between the proposed NRE1 Wonga West workings and the decommissioned BHP Cordeaux mine to the south has a throw of 3-5m, with the NRE1 workings located on the downthrown side.

This means that the Wonga West workings are from 30-50m vertically beneath the BHPB lease to the north and from 3-5m beneath the Cordeaux workings.

The fault located to the west of the NRE1 workings is a horizontal strike slip fault with normal movement.

The fault movements and throws indicate the workings to the west of the reservoir are in a downthrown block (horst and graben structure) and are at a lower relative elevation to the BHPBIC lease to the north and south, meaning that groundwater flow in the Bulli / Hargraves and Wongawilli Seam could flow toward the NRE1 lease.

Wonga West Structures mapped in the Bulli workings are shown in **Figure 3**.

There are no known major faults in the overburden above the proposed Wonga West workings.

7.3.3 Wonga West Bulli Seam Igneous Intrusions

An up to approximately 130m wide north east - south west trending dyke / sill with an up to 250m wide cinder zone is located to the south of the proposed Wonga West workings, and is located to the east of the 500 Series Bulli Seam longwalls, which extends under Cataract Reservoir.

A north east - south west trending dyke is also located to the west of the Bulli Seam 300 Series workings.

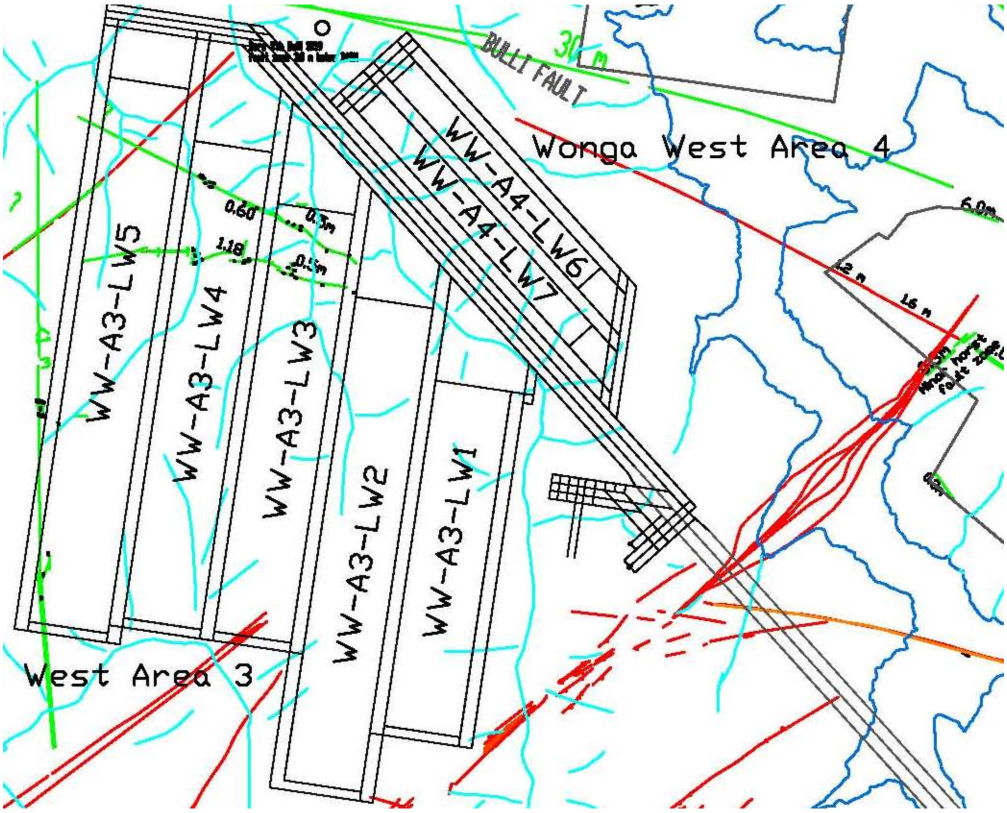


Figure 3 Wonga West Bulli Seam Structures

7.3.4 Wonga East Underground Mapped Faults

There are no known major faults in the overburden above the proposed Wonga East workings, apart from the Corrimal Fault which has only been mapped in the Bulli workings in the western periphery of Wonga East Area 2 as shown in **Figure 4**.

At the Bulli Seam level, the Corrimal Fault has a 1.3 – 3.0m displacement in the vicinity of the proposed workings.

The north-west south-east trending Rixon’s Pass Fault is shown at surface on the 1:100,000 geological map to be sub-parallel to Cataract Creek, however, no trace of it has been identified in the Bulli or Balgownie workings.

A north west / south east trending unnamed splay off the Corrimal Fault is located to the south of Cataract Creek, which crosses under Cataract River, outside of the proposed workings 20mm subsidence zone.

Outside of the historic mine workings, the exact location, throw and inclination of the faulted zones are not known, and their potential position is extrapolated from drilling data and in seam mapping.

7.3.5 Wonga East Bulli Seam Igneous Intrusions

The southern Bulli Seam bord and pillar workings in the Bulli Seam at Wonga East are bound by an east west trending dyke up to approximately 30m wide.

A southeast - northwest trending dyke on the southern boundary of Mining Lease ML1575 was intersected in the Cordeaux Colliery Bulli Seam workings, which are from 20 - 40m south of the NRE No.1 workings.

It should be noted that the majority of dykes identified at the Bulli Seam level have not been mapped at surface, although a dolerite which is highly weatehred to illite and montmorillonite clay, of up to 0.5m wide and with up to 0.8m of displacement, overlies the proposed Wonga East workings as shown in **Figure 4.**

No diatremes have been identified within the proposed subsidence area, however a sill is located to the north of Wonga East Area 2 as shown in **Figure 4**.

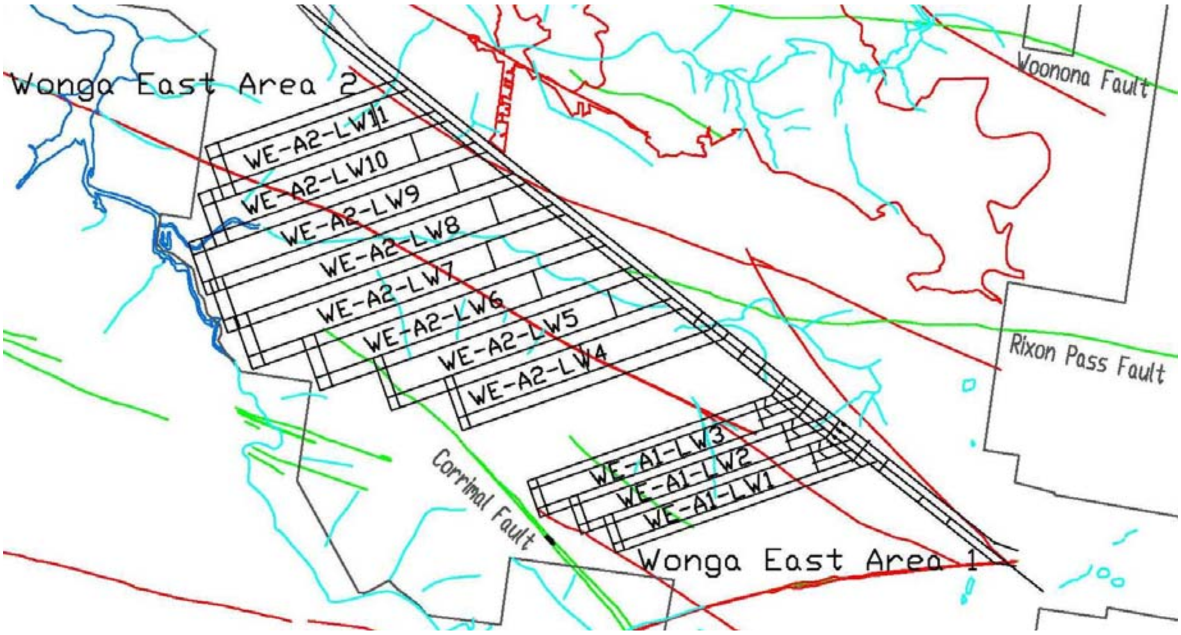


Figure 4 Wonga East Bulli Seam Structures

7.4 Basement Hydrogeology

Four main aquifer systems are present in the Study area, namely:

- unconsolidated, perched ephemeral colluvial aquifers within upland swamps. Excess rainfall produces a highly variable, perched water table within the swamps and outcropping sandstone which is independent of the regional Hawkesbury Sandstone water table. As the swamps are essentially rainfall-fed, their water levels fluctuate with climatic. conditions.
- perched ephemeral aquifers within the dual matrix porosity with tortuous and unpredictable flow paths in limited joint / fracture / bedding plane or dyke related groundwater flow systems of the shallow Hawkesbury Sandstone, which are generally within 20m of the surface,
- dual matrix porosity with tortuous and unpredictable flow paths within limited joint / fracture / bedding plane or dyke related groundwater flow systems within the deeper Hawkesbury Sandstone The shallow groundwater system is separate from the perched groundwater system and defines the regional water table, and;
- a deep groundwater system below the Bald Hill Claystone, which acts as a semi-confining layer between the Hawkesbury Sandstone and the underlying Bulgo

Sandstone and deeper formations in a variable sequence of mudstones, shales and low yielding aquifers in sandstones and coal seams.

Due to the steep topography and limited alluvium within the Cataract Reservoir storage, there is no notable groundwater bearing stream based alluvium in the study area.

7.4.1 Hawkesbury Sandstone

Apart from aquifers in the coal seams, the main aquifer in the Study area is the dual porosity (i.e interstitial pore space along with fractures and joint porosity) Hawkesbury Sandstone which, although having generally low permeability, can provide relatively higher groundwater yields compared to other lithologies in the area.

The Hawkesbury Sandstone outcrops over the majority of the lease area although has been partially eroded in the central valley of Cataract Creek where the upper Bulgo Sandstone is exposed.

Regional water levels within the sandstone result from interaction between rainfall infiltration (recharge) through the shallow weathered zone into the underlying clastic rocks and with topography over geologic time. Rainfall infiltration elevates the water table whilst drainage channels incised through to the water table can provide seepage pathways that constrain groundwater levels to the elevation of stream beds through seepage into “gaining” streams.

Evapo-transpiration losses from deep and shallow rooted vegetation would also reduce the phreatic surface of the water table to varying degrees.

The low groundwater flow rates within the Hawkesbury Sandstone are primarily horizontal with minor vertical leakage due to the dominant horizontal bedding planes and bedding discontinuities interspersed with generally poorly connected vertical joints.

Ephemeral perched water tables within the upper 20m of the Hawkesbury Sandstone that are hydraulically disconnected from the underlying regional aquifer, can occur following extended rainfall recharge periods.

Vertical hydraulic connectivity between the Hawkesbury Sandstone and the Bargo Sandstone is retarded by the Bald Hill Claystone which is a semi-confining layer that extends across the Study area, except where it is eroded away at Wonga East.

In rainfall recharge periods, water levels in shallow aquifers respond by rising, whilst in dry periods, levels are lowered through seepage to the local watercourses. During dry periods the salinity in surface drainages normally rises as the basement baseflow seepage proportionally increases.

Measured standing water levels in the Hawkesbury Sandstone range from to 12m to 39m below surface.

High yields of up to 30L/s have been identified outside of the local area by Sydney Catchment Auhority in the Kangaloon and Leonay-Wallacia areas where the sandstone is distinctly affected by deep regional scale fracturing associated with igneous intrusions or a major regional lineament along the base of the Blue Mountains associated with the Lapstone Monocline (SCA, 2006).

These high yielding sandstones are not located in or near the Study area.

Water quality in the Hawkesbury Sandstone generally has low salinity (81 - 420µS/cm) with relatively acidic pH (3.22-5.45) and can contain high iron levels up to 12.0mg/L in the Study area.

7.4.2 Narrabeen Group

The Narrabeen Group lithologies have significantly lower yielding aquifers compared to the Hawkesbury Sandstone, with very minor productive supplies obtained in the Southern Coalfields due to its generally deeper elevation below surface and its very low permeability. The Bulgo Sandstone can contain salinities of up to 1500mg/L (KBR, 2008) whilst the Scarborough Sandstone (Short et al. 2007) can average around 850µS/cm.

The Narrabeen Group is generally low yielding (<1.0L/sec), with its highest yields obtained from the coarser grained or fractured units.

The Narrabeen Group has generally low permeabilities, where the sandstones can provide porous storage with limited fracture flow and with low transmitivity, whilst mudstones, siltstones and shales effectively impede vertical flow. In some localities, groundwater flow may be enhanced by localised, secondary fracturing where faulting and/or jointing associated with bedding flexure or igneous intrusions can increase the hydraulic conductivity.

Hydraulic connection between the lithologies occurs through fractures and joints. Where vertical connectivity is present more laterally uniform pressure distributions are exhibited. Some local scale faults and dykes are present in the study area as shown in **Figure 1** although they are not anticipated to be large enough to enable loss of stream flow into the workings if dislocated by subsidence.

The Newport and Garie Formations, along with the underlying Bald Hill Claystone and the upper Bulgo Sandstone outcrop within the base of the headwater valleys within the Wonga East area would be directly recharged by stream flow leakage from Cataract Creek and Bellambi Creek.

The base of the Narrabeen Group is marked by the Wombarra Claystone which has very low permeability in its unsibsided state.

7.4.3 Illawarra Coal Measures

Water quality varies regionally both within and between coal seams and interburden in the Illawarra Coal Measures due to the complexity of groundwater flow, with the water being mostly brackish to saline.

The Balgownie, Bulli or Wongawilli Seams do not outcrop within the Study area, although they outcrop along the lower section to the base of the Illawarra Escarpment. They would be recharged by vertical infiltration from overlying lithologies, and there is no direct connection between the seams and the surface creeks.

Since coupled pumping in / out monitoring began in October 2005, groundwater inflows from 0.02 - 0.97ML/day (median 0.59ML/day) have occurred into the NRE No1 workings.

7.5 Registered Piezometers

No groundwater extraction is conducted from private bores or wells in the Study area, with the nearest private registered bore on the Woronora Plateau being a test bore at Appin Colliery, which is located approximately 4.9km to the north of the proposed workings.

At present, one monitoring piezometer PL1A14 (GW102223) is recorded in the NSW Natural Resource Atlas database in the vicinity of the proposed workings.

No regional data within the Study area is available on bore yields.

7.6 Geomorphology

The Study area contains the regulated catchment of Cataract Creek, as well as portions of Cataract River and Bellambi Creek, upstream of Cataract Reservoir at Wonga East, which drain into Cataract Reservoir.

The unregulated Wallandoola Creek and Lizard Creek catchments drain into Cataract River at Wonga West, downstream of the Cataract Dam spillway, which subsequently flows to the regulated section of Cataract River at Broughtons Pass Weir.

The catchments are described in detail in an associated report (Geoterra, 2012) to which the reader is referred for further detailed discussion.

7.7 Stream Flow, Stream Water Quality, Rainfall and Land Use

The Study area stream flow, stream water quality, rainfall and land use is described in detail in an associated report (Geoterra, 2012) to which the reader is referred to for a detailed discussion.

Based on drilling information and site observations, the streams are “disconnected - losing” streams under and in the vicinity of the valley fill and headwater swamps from the south of the lease up to Waterfall L1 in Lizard Creek and Waterfall W1 in Wallandoola Creek, as well as in the first order tributaries of both Lizard and Wallandoola Creeks.

Downstream of the two waterfalls, the streams are interpreted to be “gaining” streams where surface water flows down gradient under gravity to a local stream, and then under gravity along the stream beds to the Cataract River, downstream of Lizard, Wallandoola and Cataract Creeks.

However, due to the lack of drill rig accessibility to install piezometers in the valley floors, it is not possible to directly indicate whether the creeks downstream of the waterfalls are connected or disconnected to the shallow, perched, ephemeral Hawkesbury Sandstone, and thereby to assess or quantify the significance of groundwater flow to baseflow in the creeks.

Surface water drainage from the plateau to the local streams is through ephemeral first and second order gullies. The smaller gullies discharge into the major streams from elevated stream beds after sufficient rain, whilst the majority of rain would infiltrate into the plateau and swamp soils and weathered sandstone.

Recharge to the shallow, and subsequently the deeper regional groundwater system, would occur over an extended delay of months to years. It would occur after the meteoric water has soaked through the plateau’s soil and bedrock, with the majority of water discharging from temporary seeps in the swamps and creek beds along the preferential horizontal flow regime in the Hawkesbury Sandstone.

The predominantly horizontal flow regime and restricted vertical recharge is essentially determined by the;

- horizontally bedded strata with preferential flow along bedded zones with coarser grain size,
- claystone/mudstone banding at the base and tops of sedimentary facies which restrict vertical migration and enhance horizontal flow at the base of the more porous unit,
- fracture zones enhancing horizontal flow through the strata, and;
- bedding planes or unconformities located immediately above finer grained sediments or iron rich zones.

Groundwater seepage to the local streams can occur at isolated iron stained seeps along the creek beds, where low volume and variable duration seeps discharge for a few days to weeks after significant rainfall. The seeps are generally located at the interface between coarser and underlying finer sandstone or shale layers which restrict vertical flow through the bedrock and enhance lateral flow. Most observed seeps in the local streams are anticipated to flow at less than 1L/sec.

The current interaction between surface water, perched and regional groundwater systems is postulated to be that pre-mining conditions prevail such that in wet periods there is a net contribution of groundwater to the surface system, while in dry conditions there is a net loss of surface water, with the resulting surface flow depending on the relative balance between seepage inflow and outflow.

This balance is expected to vary along the length of the streambeds, and to vary between the “losing – disconnected”, “gaining – disconnected” and “gaining – connected’ stream reaches along both Lizard and Wallandoola Creeks, as well as in Cataract Creek.

The surface water and shallow groundwater system is currently hydraulically isolated from the Bulli Seam workings by the approximately 205 - 290m of overburden at Wonga East and 425 – 485m at Wonga West. At present there are two potential aquifer systems subsequent to subsidence over the Bulli, Balgownie and Wongawilli Seam workings, with an upper fractured unit in the Hawkesbury Sandstone to approximately 20m below surface, which migrates into a higher permeability, although not vertically connected section in the lower Hawkesbury Sandstone.

The Hawkesbury Sandstone and Bulgo Sandstone groundwater systems are not hydraulically separated in the valley of Cataract Creek where the Bald Hill Claystone is eroded through to the Bulgo Sandstone in the creek bed downstream of the freeway, and may have locally enhanced permeability due to its lack of lithostatic pressure where it has limited or no overburden.

7.8 Groundwater Dependent Ecosystems

The proposed mining is located within the Sydney Basin Sedimentary Rock Groundwater System as described in the NSW State Groundwater Dependent Ecosystems Policy (SGDEP) (DLWC, 2002) which has its associated dependent ecosystems.

The SGDEP recognises four groundwater dependent ecosystems types in NSW, namely:

- Terrestrial vegetation;
- Base flows in streams;
- Aquifer and cave ecosystems; and
- Wetlands.

Groundwater dependent ecosystems present in the Study area are:

- terrestrial vegetation, in terms of the “valley fill” and “headwater” upland swamps which are susceptible to changes in groundwater seepage inflow rates, the balance between rainfall and evaporation, the effect of bushfies and changes to the erosional regime, and;
- baseflows in streams, which can be affected by changes in groundwater seepage inflow rates to a stream and the balance between rainfall and evaporation.

8. UPLAND SWAMPS

Recent mapping (Biosis, 2012) indicates that thirty-nine (39) upland swamps meet the definition of the Coastal Upland Swamp Endangered Ecological Community within the Wonga East study area, along with forty-five (45) at Wonga West.

The study identified a number of previously unmapped swamps, as well as highlighted the complexity and variability of this vegetation community.

The initial stages of the impact assessment identified that;

- seven swamps in Wonga East, and;
- eight swamps in Wonga West,

are considered to be of 'special significance' using OEH criteria.

Detailed impact assessment, including an initial risk assessment, comparative analysis, groundwater assessment, flow accumulation modelling and analysis of strains and potential for fracturing of bedrock, was undertaken on these 'special significance swamps (Biosis, 2012).

The field mapping, aerial photography and Lidar interpretation indicated that the Wonga West swamps were generally larger and more spatially continuous, whilst the Wonga East swamps were generally drier, shallower and less spatially continuos (Biosis, 2012).

In addition separation and differentiation between valley fill and headwater swamps was conducted on the basis of assessing connected flow regimes, where swamps with both headwater and valley fill components in the same regime were given the same swamp name (Biosis, 2012).

Further detailed information on the swamp structure, component material, ecological diversity and terrestrial flora is provided in (Biosis, 2012)

Swamps in the study area have relatively small upstream catchments, with their saturation relying on rainfall recharge directly into the sandy sediments, seepage out of upslope Hawkesbury Sandstone and the degree of accumulated organic matter.

The storage and water transmission characteristics of the surrounding and underlying Hawkesbury Sandstone is critical in sustaining these environments.

The swamps occur in either headwater tributary valleys that are characteristically derived from colluvial sand erosion from Hawkesbury Sandstone dominated ridgelines or along the riparian zone of the major creeks. They are only located over Hawkesbury Sandstone which provides a low permeability base on which the swamp sediments and organic matter accumulate.

Regional groundwater flow within the Hawkesbury Sandstone is hydraulically beneath, and seperated by approximately 15m from the surficial swamps.

Due to their gentle slope, only the larger swamps can contain small, shallow, poorly defined open channels, which are generally short and located at the downstream reaches, whilst ephemeral patches of saturated sediment can be present in the headwater sections.

The swamps are not located near any cliff scarps, as is the case for “hanging” swamps in the Blue Mountains, and as such there are no “hanging” swamps in the Study area.

The headwater swamps are located within gently sloping, shallow trough shaped gullies and do not extend onto any steep slopes, benches or valley sides, where the plateau is not dissected by the Study area creeks.

The central axes of the swamps are generally saturated after substantial recharge events, though the margins can comparitively dry out after extended dry periods.

The sand and humic material increases the swamp’s water holding capacity and subsequently discharges rainfall infiltration, groundwater seeps and low-flow runoff into the local streams. Rainfall saturates the swamp after storms and with a slow, delayed discharge due to the low slopes when the recharge exceeds evaporation.

Sediments below and laterally lensing into the humic material are variable in nature and can be composed of fine to medium grained sands that can contain clayey bands and comprise a grey to mottled red-orange colour due to insitu weathering.

Both “valley fill” and “headwater” upland swamps are present in the Study area as shown in **Drawings 2** and **3**.

The date and relevant workings that have undermined selected swamps are outlined in **Table 2**, based on measured or back calculated subsidence, strains and tilts.

A detailed discussion of all swamp features is contained in (Biosis, 2012).

Appendix A shows detailed outlines of the NRE1 lease area mapped swamps in Lizard, Wallandoola, Cataract and Bellambi Creeks, as well as the Cataract River catchments (Biosis, 2012).

Table 2 Previous Swamp Undermining Summary

Swamp	Piezo	Workings	Date	Historic Subsidence (m)	Historic Strain (mm/m)	Historic Tilt (mm/m)
Crus1	-	NRE1 bord and pillar	1900's	minor	n/a	n/a
Ccus1	-	NRE1 pillar extraction area	1900's	minor	n/a	n/a
Lcus1	-	Cordeaux longwalls	n/a	n/a	n/a	n/a
Lcus4	-	NRE1 main headings / LW202	1979	0.75 -1.0	n/a	n/a
Lcus1	PL1A	LW202	1979	0.75 - 1.0	n/a	n/a
Lcus6	-	NRE1 main headings	various	0.5	n/a	n/a
Lcus18	-	LW206	1986	0.75 - 1.0	n/a	n/a
Lcus25	P25B, 25D	Main headings / T and W Mains bord / pillar	2008	0.147	1.1	n/a
Lcus28	-	LW305	1985	0.75 - 1.0	<1.5	<4.5
Lcus26	-	none	not mined	none	none	none
Wcus1	PW1	Cordeaux longwalls	n/a	n/a	n/a	n/a
Wcus4	-	LW 208	1988	0.75 - 1.0	n/a	n/a
Wcus4	PW4	LW206 / 207	1985 - 87	0.75 - 1.0	n/a	n/a
Wcus11	PW11	LW206 / 207 / 208	1985 - 89	0.75 - 1.0	n/a	n/a

NOTE: n/a not available

8.1 Valley Fill Swamps

Valley fill swamps occur along the well defined drainage line of Wallandoola and Lizard Creeks, occupying the flatter, undissected upper sections of streams within the main valleys and can form through sediment deposition behind logs at choke points in a stream, or terminate at ‘steps' in the underlying sandstone substrate.

They are generally sustained by surface flow along the streams, along with direct rainfall infiltration and ephemeral shallow groundwater seepage from headwater swamps, and are generally located upstream of “steps” in exposed sandstone areas, with their seepage rate dependent on the prevailing rainfall.

Transitional zones between headwater and valley fill swamps were observed during field mapping, and as a result, differentiation between the two zones in the swamp nomenclature was not used where they are incorporated into the same flow regime (Biosis, 2012).

8.1.1 Wallandoola Creek

Swamp Wcus1 extends up to approximately 120m wide where the creek is present either as an indiscernible channel amongst the swamp in the upper reaches near the southern boundary between the Gujarat and BHPB leases between WC1 and WC3, then migrates into a more distinctive channel with a series of open pools between up and downstream of WC3.

Wcus4, which is located downstream of Wcus1, includes the headwater component, and extends from the confluence of the headwater swamp to the major bend in the creek to the south of the proposed longwalls WW-A3-LW3 and WW-A3-LW4, upstream of WC4.

Downstream of Wcus4, the open exposed sandstone channel becomes more distinctive upstream of the stream monitoring site WC4, with banks of up to approximately 1m high containing riparian grasses, sedge, shrubs and trees.

Wcus1 was not undermined by either the BHP Cordeaux or NRE1 Bulli Seam workings, whilst Wcus4 was undermined by the southern end of LW208 in the NRE1 Bulli Seam workings during 1988, with no observable adverse effects on stream or swamp flow, water quality or ecosystem health.

8.1.2 Lizard Creek

Swamp Lcus1 extends up to approximately 170m wide where the channel is essentially indiscernible with associated, isolated open water pools in the upper reaches of the creek near the southern boundary of the Gujarat and BHPB leases between stream monitoring sites LC1 and LC3

The swamp narrows to approximately 45m wide upstream of LC3, primarily without any discernible channel, then reduces to less than 10m wide at the fire road crossing where the exposed sandstone channel is distinctive, although the banks are less than 0.5m high.

Downstream of LC3, the creek transitions into a constricted channel with a rock bar controlled pool to the west of proposed panel WW-A3-LW1 that extends for approximately 110m downstream of the crossing.

Lcus1 was undermined by the western edge of LW19 and LW20 in the BHP Cordeaux Bulli Seam workings as well as first workings in the southern Gujarat lease area, with no observable adverse effects on stream or swamp flow, water quality or ecosystem health.

Lcus4 is present downstream of the rock pool, and extends for approximately 250m, ending in a 2.5 - 3m deep pool developed upstream of a sandstone rock bar at the confluence of headwater swamp Lcus6.

Lcus4 was undermined predominantly by first workings in the Bulli Seam adjacent to LW202 as well as the eastern margin of LW202 during 1979, with no observable adverse effects on the majority of the swamp, although the northern end has undergone headward erosion of the up to 1.5m deep peaty material within the main channel of the creek.

Downstream of Lcus4, the exposed sandstone channel banks, which are up to 0.5m deep, contain riparian grass, sedge, shrubs and trees along the stream banks.

8.1.3 Cataract Creek

There are no valley fill swamps at Wonga East.

8.2 Headwater Swamps

Headwater swamps are present within first order tributaries of the southern Wonga West and Wonga East areas in elevated ground with relatively flat to gentle slopes, upstream of the Hawkesbury Sandstone incised stream sections.

They are predominantly rain recharged features where total rainfall and shallow sandstone groundwater seepage into the swamps exceed evaporation. Their standing water levels fluctuate in response to rainfall recharge, or lack of recharge where an excess of rainfall produces a raised, perched, shallow water table that is hydraulically separated from the regional underlying Hawkesbury Sandstone water table.

Following rain, overland runoff infiltrates through the swamp sediments, whilst the dense vegetation and the low gradient restricts the formation of open channels.

In some headwater swamps, groundwater seepage can occur along outcropping sandstone along the edge or downstream portions of a swamp.

8.2.1 Wallandoola Creek

Swamp Wcus4 is located downstream of stream monitoring site WC3 to the south west of Fire Road 8 over the southern end of the proposed panel WW-A3-LW2, in the headwaters of a south westerly draining 1st order tributary of Wallandoola Creek.

Wcus11 lies to the south west of Fire Road 8 over the southern to middle section of the proposed panel WW-A3-LW2 in a south westerly draining tributary that flows into Wallandoola Creek between sites WC3 and WC4.

Wcus4 was undermined by the Bulli Seam LW206 and LW207 between 1985 and 1987 with no observable adverse effects on stream or swamp flow, water quality or ecosystem health.

Wcus11 was undermined by the Bulli seam longwalls 206, 207 and 208 between 1985 and 1989, with no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

8.2.2 Lizard Creek

Lizard Creek swamp Lcus1 straddles the east and western banks of Lizard Creek, upstream of stream monitoring site LC3 on the Fire Road 8 culvert crossing.

Lcus1 was undermined by Bulli Seam workings LW202 in 1979 with no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

Lcus6 lies within a westerly draining gully downstream of the Fire Road 8 crossing. It was not undermined by any longwalls, but overlies the main headings adjacent to LW202, and has not had any observable adverse effects on stream / swamp flow, water quality or ecosystem health.

Lcus1 and Lcus6 do not overlie the proposed Area 3 panels, and apart from the northern extremity of Lcus6, lie outside the proposed Wonga West Area 3, 20mm subsidence zone.

Lcus18 is located to the north of Fire Road 8 and overlies the middle section of the proposed Wonga West Area 3 LW2 in the headwaters of a northerly draining 1st order tributary of Lizard Creek. The tributary flows into Lizard Creek downstream of stream monitoring site LC6.

Lcus18 was undermined by the Bulli Seam workings LW206 in 1986 with no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

Lcus25 is a long, narrow headwater swamp that straddles Fire Road 8 in Area 3. It overlies panel WW-A3-LW5 and partially overlies the proposed WW-A3-LW4 in a northerly draining tributary that flows into Lizard Creek at stream monitoring site LCT2.

Lcus25 was not undermined by any Bulli Seam longwall panels, but was subsequently undermined by secondary bord and pillar extraction in T and W Mains since February 2008, with no observable adverse effects on stream / swamp flow, water quality or ecosystem health. The maximum measured subsidence over T and W Mains has been 147mm, with 1.09mm/m maximum strain (Ecoengineers, 2009).

Lcus26 is included in this study as it lies within the 600m distance from the proposed secondary workings. It has never been undermined, and is rarely observed to have stream flow discharge at the stream monitoring site LCT2 except for short periods (days) after significant rainfall.

Lcus27 does not overlie any proposed panels and is located approximately 125m west of the proposed Wonga West Area 4 LW6, and is downstream of Lcus26.

Lcus28 does not overlie any proposed longwalls, and is located approximately 125m north of the proposed Wonga West Area 4 LW6, east of Fire Road 8H. It is located in the headwaters of a north westerly draining tributary that flows into Lizard Creek downstream of stream monitoring site LC7.

Lcus28 was undermined by the Bulli Seam workings LW304 in 1985 with no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

8.2.3 Cataract Creek

Cataract Creek swamps Ccus1 and Ccus2 are located over Wonga East Area 1, to the east of Mount Ousley Road. Ccus1 overlies the proposed panel WE-A1-LW3, whilst Ccus2 overlies the proposed WE-A1-LW1.

Both swamps were undermined by Bulli Seam first workings in the early 1900's and subsequently by Bulli seam pillar extraction and the Balgownie longwalls with no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

Swamps Ccus3, 4, 5 and 6 are located over the proposed longwalls WE-A2-LWs 4 to 8 and drain to the north via 1st and 2nd order gullies into Cataract Creek. All four swamps were undermined by Bulli Seam first workings in the early 1900's and subsequently by Bulli seam pillar extraction and the Balgownie longwalls. Ccus6 was also recently undermined by the Wongawilli Seam longwall WE-A2-LW4.

None of the four undermined swamps have had observable adverse effects on stream / swamp flow, water quality or ecosystem health.

Swamps Ccus10, 11 and 12 are located over the proposed longwalls WE-A2-LWs 9 to 11 and drain to the south via 1st and 2nd order gullies into Cataract Creek. All three swamps were undermined by Bulli Seam first workings, but not by Bulli seam pillar extraction or the Balgownie longwalls, with no observable adverse impacts from subsidence (Biosis, 2012).

8.2.4 Cataract River

Cataract River swamp Crus1 is located to the west of Wonga East Area 2, and partially overlies the proposed longwall WE-A2-LW6. It is located in the headwaters of a north easterly draining tributary of Cataract River.

Swamp Crus1 was undermined by Bulli Seam first workings, but not by Bulli pillar extraction or the Balgownie longwalls, and has had no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

Swamps Crus2 and 3 do not overlie any proposed Wongawilli Seam workings.

8.2.5 Bellambi Creek

Bellambi Creek swamps Bcus4 and Bcus11 are located in the north of Wonga East Area 2, and overly the proposed longwalls WE-A2-LW10 and 11.

They are located in the headwaters of north easterly draining tributaries of Bellambi Creek.

Both swamps were undermined by Bulli Seam first workings, but not by Bulli pillar extraction or the Balgownie longwalls, and have had no observable adverse effects on stream / swamp flow, water quality or ecosystem health.

9. PREVIOUS GROUNDWATER SYSTEM SUBSIDENCE EFFECTS

9.1 Adjacent Historical and Current Mines

9.1.1 Coal Measures Depressurisation

Each of the existing or decommissioned adjacent underground mines have the potential to interact with the groundwater pressure regime within and adjacent to the proposed NRE No.1 Wongawilli Seam workings.

Excavation of the adjacent underground mines has resulted in localised depressurisation of the Bulli Seam and overburden, which has altered regional groundwater flow toward each of the workings.

Combined pressure losses from the decommissioned, existing and proposed BHP Billiton Illawarra Coal (BHPBIC) operations (Appin, Westcliff and Northcliff) and Peabody's Metropolitan Colliery to the north of Cataract River were predicted in the revised groundwater model (Heritage Computing 2010A) to have the following potential drawdowns in the Gujarat lease after 31 years of operation:

- negligible drawdown in the mid Hawkesbury Sandstone;
- 1 - 3m in the lower Hawkesbury Sandstone;
- 5 - 20m in the upper Bulgo; and
- 10m in the Bulli Seam.

The ultimate shape of the depressurised surface will be governed by the prevailing hydraulic properties of the coal measures, connectivity of strata through jointing and fracturing and the cumulative impacts of the regional mines.

It is not known whether the Bulli Seam Operation groundwater model has taken into account an east-west trending fault zone that lies approximately 500m north of Longwall WW-A3-LW5 and 200m north of Longwall WW-A4-LW6 which has a 50m uplift to the north.

The increased or decreased permeability changes along the fault trace together with the lithological displacement may effectively compartmentalise the Gujarat lease area from the BHPBIC workings, thereby reducing the cumulative depressurisation effect on the Gujarat lease.

No hydraulic parameters for the fault are known.

After 31 years of mining, regional groundwater levels over the BHPBIC workings were modelled to recover at a rate depending on the remaining water held in storage in the coal measures, the hydraulic properties of subsided overburden, rainfall recharge and any seepage discharges to local streams (Heritage Computing, 2010).

9.1.2 Loss of Stream Flow

Due to the highly localised effects of subsidence on streams overlying subsided workings, there is anticipated to be no transmitted effects on streams within the NRE No.1 lease from the adjacent BHPBIC workings as they are either down gradient of the Gujarat lease, or are in a completely separate watershed on the northern side of the Cataract River.

9.1.3 Loss of Bore Yield

No private bores or wells are registered with the NSW Office of Water (NOW) within the Study area.

9.1.4 Changes in Groundwater Quality

No measureable change in groundwater quality has been reported, or is anticipated, within the Study area as a result of mining within the adjoining existing, decommissioned or proposed underground workings.

The previous operators of NRE No.1 colliery, as well as the decommissioned BHP Cordeaux Colliery to the south and the BHP Bulli bord and pillar mine to the east have undermined the catchments of Lizard, Wallandoola, Cataract and Bellambi Creeks, as well as the Cataract River (upstream of Cataract reservoir) in the study area.

Up to 1.3m of subsidence was generated by extraction of the Bulli Seam in the 200, 300, 500 series longwalls to the west of and beneath Cataract Reservoir (Seedsman Geotechnics, 2012A) in the Wonga West Area.

Bord and pillar extraction of the Bulli Seam along with longwalls in the Balgownie Seam was conducted to the east of Cataract Reservoir at Wonga East as shown in **Drawing 4**.

No subsidence was measured in the 200 series longwalls, which consisted of 190m wide panels and 35m wide chain pillars, however the same layout to the north in the 300 series panels, recorded 0.9m of subsidence. Longwall mining generated a maximum vertical subsidence of 1.1m for 155m wide longwalls with 30m wide pillars, whilst the 205m wide panels in Cordeaux Colliery with 30m wide chain pillars generated up to 1.3m of subsidence (Seedsman Geotechnics, 2012A).

No publicly available pre and post mining surveys of groundwater levels or groundwater quality are known to be available over the BHPB Cordeaux or Bulli mine workings.

9.2 BHP Bulli Colliery Short Walls

Three 80 - 86m wide short walls (1SW, 2SW, 3SW) with 67m wide pillars were mined in the Bulli Seam adjacent to and under Cataract Reservoir in the Bulli Colliery between 1983 and 1986 for a 230 - 340m depth of cover and 1.9 - 2.6m seam thickness.

A major NE-SW dyke zone with 2 x 5m wide doleritic dykes cutting across the workings corresponded to a pronounced surface lineament, however no evidence of the dyke was seen at surface. The dykes typically had minimal associated seepage into the workings.

During mining the workings were typically “dry” (Holla, L. Barclay, E. 2000).

Monitoring of two piezometer arrays installed to the base of the Bulgo Sandstone and the Bulli Seam near the workings indicated that the vertical permeabilities were generally very low (Bulgo Sandstone horizontal hydraulic conductivity of 7.5×10^{-8} – 1.2×10^{-9}) and that the extraction did not have a significant effect on the vertical permeability of the overburden with the maximum subsidence of 127mm and strains being less than 2.25mm/m.

An upper perched aquifer zone in the Hawkesbury Sandstone showed no response to subsidence, whilst the Bald Hill Claystone and upper Bulgo Sandstone showed a slow response to panel extraction, whilst the lower Bulgo Sandstone showed a pronounced response (Reid, P. 1991).

9.3 Depressurisation and Fracturing over the NRE1 Lease 500 Series Longwalls

As discussed below, observations from vibrating wire piezometer arrays over the 500 series Bulli Seam panels as well as the Bulli short-wall workings indicated:

- up to 15m of drawdown was observed in the Hawkesbury Sandstone, followed by a 4 month recovery; and
- up to 31m drawdown was observed in the lower to mid Bulgo Sandstone, followed by a 4 month period to where the water level recovered to approximately 24m below its original level.

Studies over Longwall panels 501 and 502 (Singh R. N. and Jakeman, M. 2001) in 1992 and 1993 indicated that for the 115m wide longwalls with 65m wide pillars and 400 – 440m depth of cover, seepage from the walls or overlying goaf was too small to measure.

It should be noted that the eastern portion of the panels underly Cataract Reservoir and that the Bellambi West Colliery at the time was referred to as a “dry” pit.

A 338m deep multi level vibrating wire piezometer was installed in PL1A01 with intakes in the:

- Hawkesbury Sandstone at 110mbgl;
- Bulgo Sandstone at 174mbgl, 228mbgl and 274mbgl; and
- Scarborough Sandstone at 328mbgl.

In addition, three experimental open standpipe piezometers were installed in P502 with multiple intakes in the different bores at 90mbgl in the Hawkesbury Sandstone as well as 167mbgl and 21mbgl in the Bulgo Sandstone.

Just after undermining, the Scarborough Sandstone in P501 indicated a 30m rise in head which was attributed to compression of the strata ahead of the longwall face.

Following passage of the longwall, the P501 piezometers indicated propagation of fractures up to 85m above the seam floor. The middle Bulgo Sandstone water pressure dropped by 11m when undermined, indicating a smaller pressure reduction up to 185m above the seam floor due to horizontal bedding plane separation.

The deeper P502 piezometers did not show any clear link with the mining operations whereas the upper Bulgo Sandstone piezometer at 240m above the seam floor did not record any measureable pressure changes.

A combined study over Longwall 514 at Bellambi West in 1998 using micro seismic monitoring (CSIRO, 2000) and an open standpipe piezometer indicated that the majority of fracturing was concentrated in the Coalcliff and Scarborough Sandstones, to approximately 100m above the Bulli Seam.

Vibrating wire piezometer monitoring between longwalls 501 and 502 indicates that the hydraulic integrity of the Bulli Seam and the Hawkesbury Sandstone was not adversely affected (Seedsman, R,W. & Kerr, G, 2001).

Regular monitoring of P501 and P502 began in December 1992 and August 1993 respectively, whilst P514 began in November 1998. The piezometer locations are shown in **Drawing 3** and the water levels are plotted in **Figures 5** to **7**.

P501 and P502 are located over Panels 501 and 502 respectively, whilst P514 is located over Panel 514. All three piezometers are adjacent to Cataract Reservoir.

Groundwater head pressures in Piezometer 501 (P1 and P2), which were installed 85m above the Bulli Seam at 325m below surface, gradually reduced from 284m of head in December 1992 then went down to approximately 161m in September 1993. Just prior to the piezometer being undermined, the head pressure rose by approximately 26m in both P1 and P2, and then, when the panel undermined the piezometer, intakes P1 and P2 failed and did not record any further data.

The initial rise in pressure before each piezometer is undermined is due to overburden compression that occurs ahead of the advancing longwall. The overburden initially deforms in compression just before subsidence fracturing occurs, which then causes a sudden drop in groundwater pressure heads as the system re-equilibrates to the secondary porosity generated by the fracturing. The effect of rising pressure heads is generally more prevalent at the start of a longwall panel and reduces as the panel advances.

Intake P5, which is installed at 226m below surface in the Bulgo Sandstone, initially had its head pressure fall as the intake equalised with the hydrostatic and lithostatic pressures in the overburden from around 185m down to approximately 177m. After that, pressures varied from approximately 173m to 177m, and then, as the panel approached the piezometer, the pressure gradually fell to around 174m. When the piezometer was undermined, P5 directly fell by around 15m to around 160m, and settled until continued mining of the panel generated a pressure reduction to approximately 148m in September 1996.

Since September 1996, the pressure has remained relatively static around 153 to 155m in early to mid 2007, then rose to around 157m in September 2008, presumably in response to rainfall recharge and infiltration into the cracked overburden following the break in the drought.

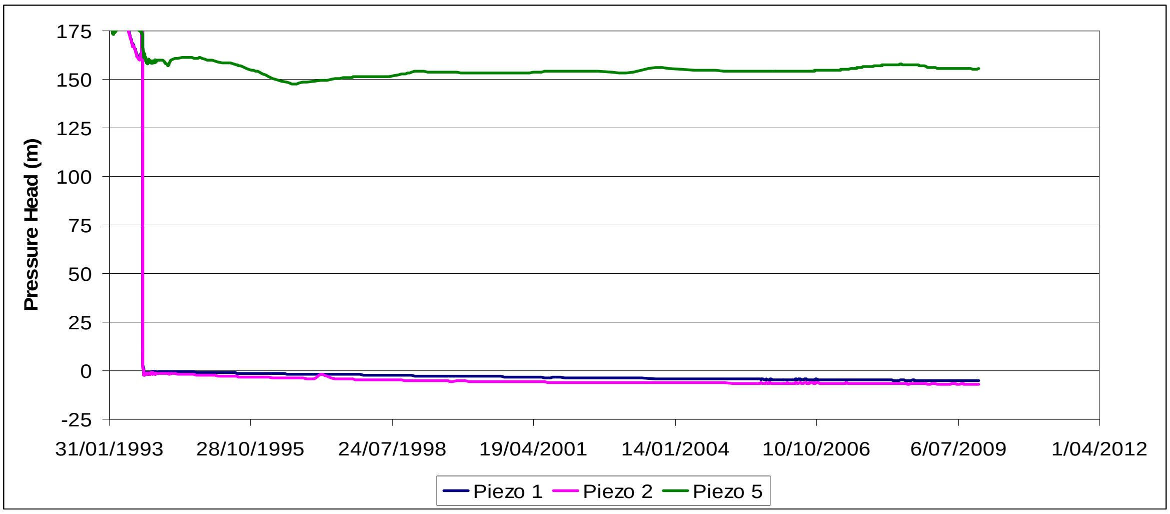


Figure 5 Longwall 501 Water Pressures

Within piezometer PL1A02, head pressures at intake P11, which was installed within the Hawkesbury Sandstone at 90m below surface, have remained essentially static, ranging between approximately 186m and 194m below surface, with a rise in pressures following the start of the rainy period around April 2007.

Intakes P12 and P13 were installed 240m above the base of the Bulli Seam in the Bulgo Sandstone. When the piezometers were undermined, both piezometers fell by around 18m to 20m around March 1994, to approximately 106m to 108m. P13 then recovered up to around October 1996 to approximately 138m. Piezometer P12 stopped functioning after it was undermined.

Since October 1996, P13 wavered around 130m to 135m, until responding to the rainy period around April / May 2007.

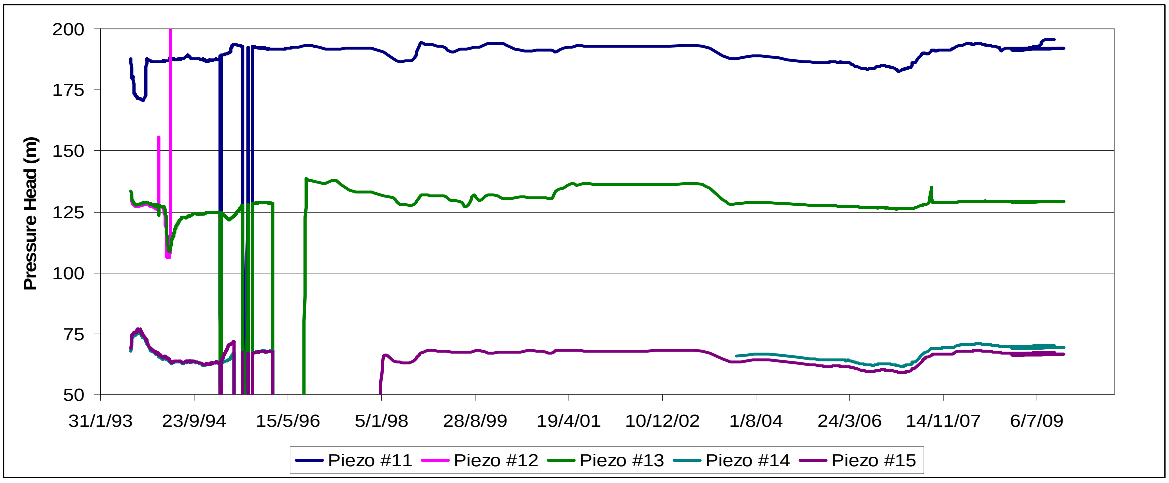


Figure 6 Longwall 502 Water Pressures

Intakes P14 and P15 were installed at 100m below surface in the Hawkesbury Sandstone. When the piezometers were undermined, both piezometers fell by around 10m between October 1993 and April 1994 to approximately 63m, then P15 recovered up until around October 1996 to approximately 71m, whilst P14 recovered to around 67m. Piezometer P14 then stopped functioning between August 1995 and February 2004.

Both P14 and P15 responded with falling pressures during the drought then rising pressures after the rainy period began in April 2007.

Monitoring over the 110m wide Panels 501 to 509, indicated a maximum subsidence of 202mm, with maximum tensile / compressive strain of 0.8mm/m and 0.4mm/m.

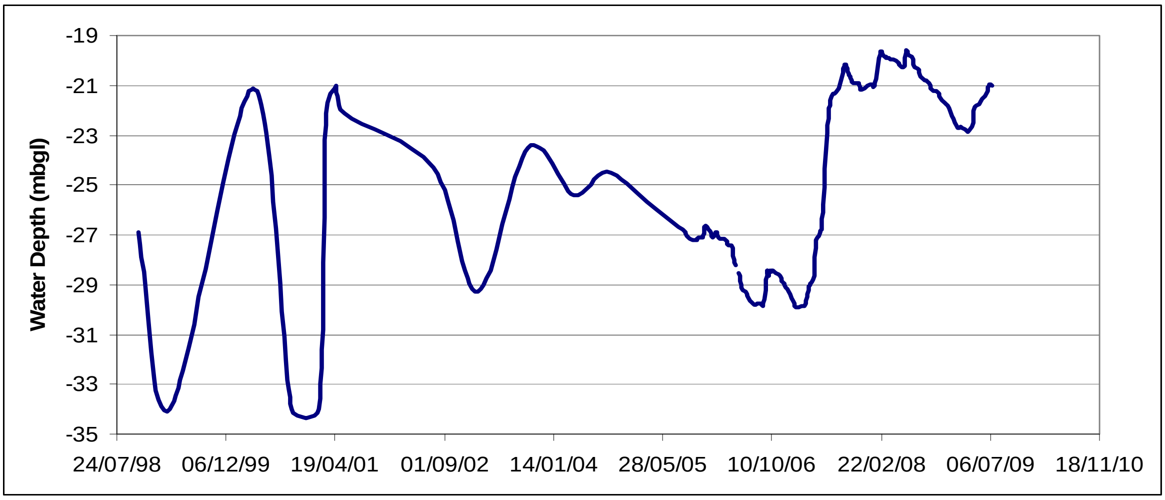


Figure 7 **Piezometer 514 Groundwater Levels**

Groundwater pressure monitoring indicated that over Panels 501 and 502, vertical interconnected fracturing extended for less than 153m above the Bulli Seam, with a low permeability connection from the lower Bulgo Sandstone to the Bulli Seam goaf. It was interpreted that linked vertical fracturing was unlikely to have extended up into the mid Bulgo Sandstone, however it was potentially affected by horizontal bed separation (Seedsman Geotechnics, 1998).

The open standpipe piezometer P514 (GW102223) was installed to 191m below surface with a (sealed?) intake between 160-188mbgl in November 1998 within the lower Hawkesbury Sandstone and the Newport Formation over the 150m wide, 310-380m deep Panel 514.

Since installation, P514 had a wavering water level between approximately 19m and 34m below surface, then essentially fell from 21 -30m below surface between April 2001 and March 2007 due to the drought.

The standing water level then rose following the start of the rainy period around April 2007 by approximately 10m from 30m to 20m below surface.

The piezometer became blocked between July and August 2009 and was no longer able to be used for equipment access to the water table.

9.4 Wonga East Longwall WE-A2-LW4

One vibrating wire piezometer array (GW1) and one open standpipe piezometer (GW1A) were installed adjacent to WE-A2-LW4 and WE-A2-LW5 in late August 2012. GW1 is located 190m, whilst GW1A is located 280m east of longwall WE-A2-LW4.

The bores are in an area where the Bulli seam has previously been mined by bord and pillar, as well as Bulli seam pillar and Balgownie seam longwall extraction.

GW1 was drilled to 170.1mbgl into the Scarborough Sandstone, whist GW1A was drilled to 27m into the Bulgo Sandstone, with numerous fractures observed in GW1.

Neither bore intersected the Hawkesbury Sandstone or Bald Hill Claystone in their upper strata.

Eight vibrating wire piezometers were installed in GW1 as shown in **Figure 8,** along with the stratigraphy, hydrostatic pressure from 24mbgl (the standing water level) and pore pressure profile.

The results indicate there is a restriction to downward flow in the upper Bulgo Sandstone.

Below the third VWP (45mbgl), the pressure gradient diverges from hydrostatic, which is consistent with low level downward flow. At approximately 140mbgl a reduction in pore pressure was observed with increasing depth consistent with the top of a more hydraulically connected fracture network above the Balgownie Seam longwall goaf.

A hydrostatic pressure gradient represents the rate of increase in water pressure that would be expected in a connected body of water where there is no vertical flow. A pore pressure gradient that is reduced below hydrostatic indicates downward flow, with the rate being dependent on the hydraulic conductivity of the strata.

The pressure profile indicates that the vertical flow rate is likely to be relatively insignificant in comparison with rainfall recharge, but the magnitude of downward flow indicated by this profile depends on the hydraulic conductivity of the overburden strata.

Packer testing in GW1 indicates the Bulgo Sandstone has gradually reducing permeability with depth, whilst the Stanwell Park Claystone has lower permeability than the overlying Bulgo Sandstone or the underlying Scarborough Sandstone (SCT Operations, 2012) as shown in **Figure 8**.

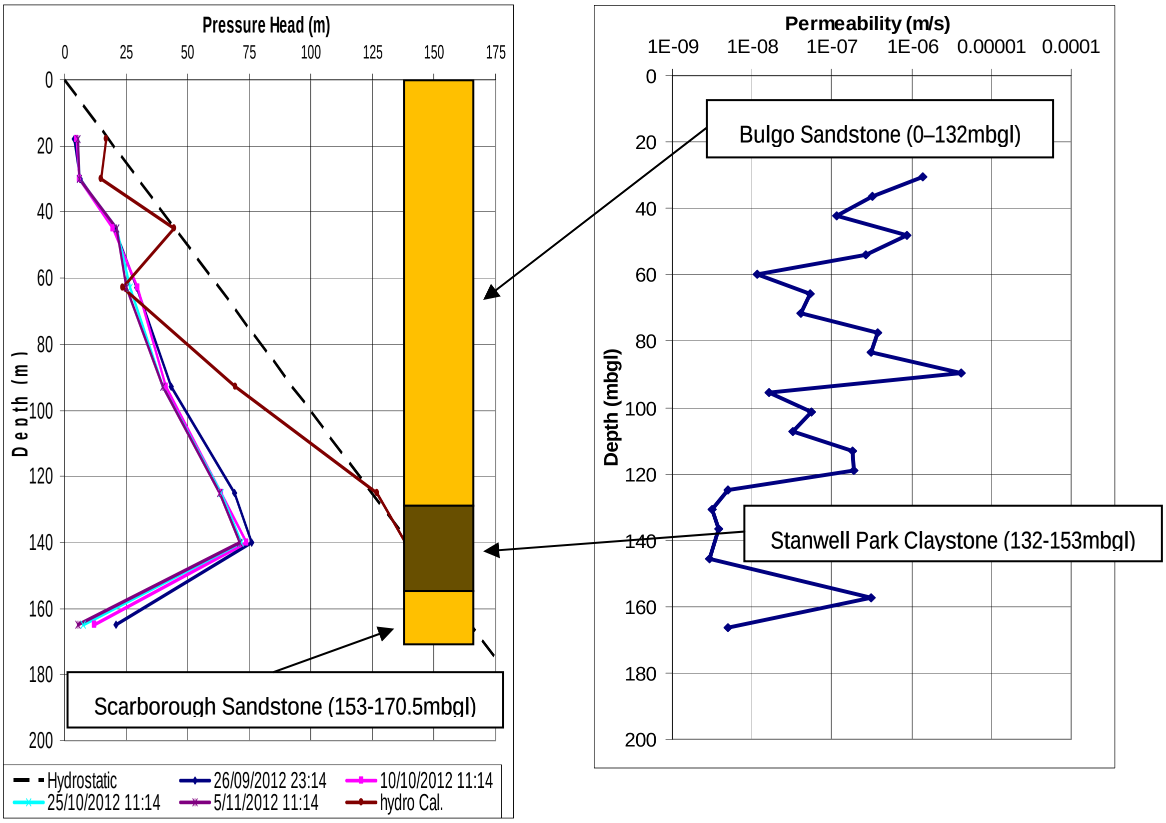


Figure 8 GW1 Pressure Head and Packer Test Data

The groundwater head pressure vs time plot for GW1 is shown in **Figure 9**.

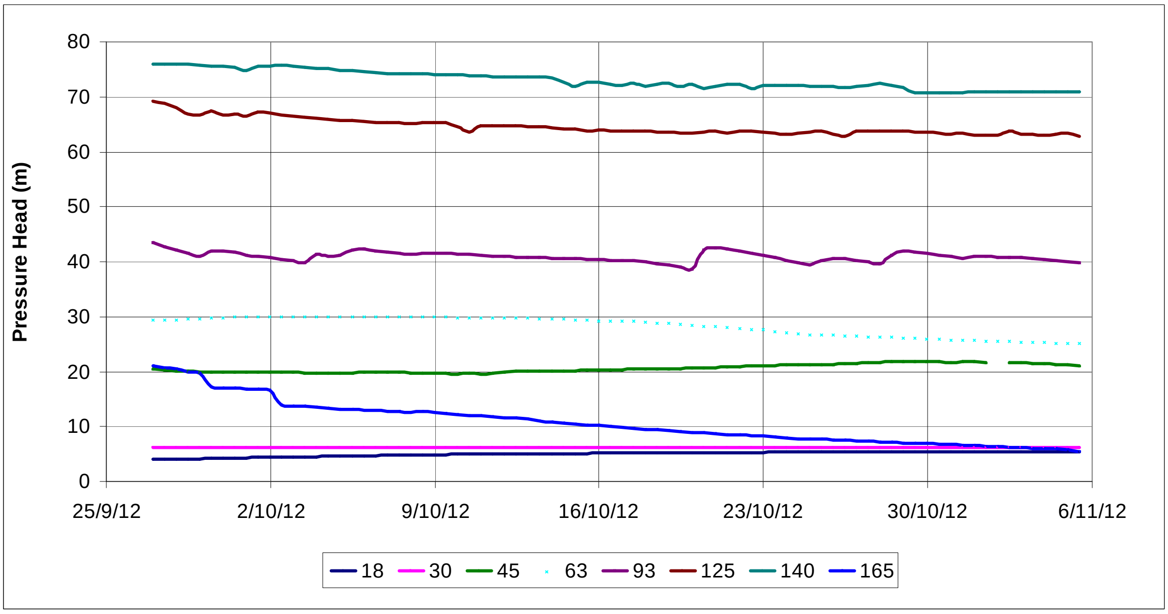


Figure 9 GW1 Pressure Head vs Time

The phreatic surface groundwater surface through NRE-A, GW1 and GW1A to Cataract Creek indicates the groundwater essentially follows the ground surface, and that the creek has a "losing" relationship to the regional groundwater.

It should also be noted that the <1.0m wide, highly weathered dyke which is located between GW1 and WE-A2-LW4 does not appear to be acting as a groundwater flow barrier.

9.5 NRE1 Lease Area Swamps

No adverse effects have been observed on the shallow, ephemeral, perched, colluvial groundwater systems or groundwater seepage to streams within (or from) any headwater upland swamps within the NRE No.1 lease area due to subsidence over the Bulli, Balgownie or Wongawilli Seam workings.

It is also noteworthy that the Southern Coalfield Inquiry Panel was also not made aware of any significant impacts on headwater swamps that could be directly attributed to subsidence.

Most known impacted swamps are valley infill swamps. However, at all sites inspected by the Metropolitan PAC Panel, there had been a range of other environmental factors in play including evidence or pre existing scour pools, previous initiation of erosion, concurrent drought, and subsequent heavy rainfall and / or severe bushfires. The sequence of events was not clear in relation to the swamp impacts (drying, erosion, and scouring, water table drop, burning, vegetation succession etc.).

The PAC Panel therefore could not be certain that subsidence either initiated or contributed to the damage at these swamps (NSW Department of Planning, 2008).

10. HYDROGEOLOGICAL INVESTIGATIONS

10.1 Swamp Piezometers

Up to 18 shallow piezometers have been installed at NRE1 as shown in **Table 3.**

Table 3 Wonga West Upland Swamp Piezometers

Bore	Swamp	Installed	E	N	Total Depth (mbgl)	Intake Screen (m)	Intake Lithology
				WONGA WEST			
PL1A	Lcus1	July 09	296860	6202190	1.22	0.72 – 1.22	humic sandy clay / wthrd sast
PL1B	Lcus1	July 09	296820	6202160	1.47	0.97 – 1.47	humic sandy clay / wthrd sast
PL18	Lcus18	Mar 12	296060	6203735	1.7	1.2 – 1.7	humic sandy clay / wthrd sast
PL25A	Lcus25	July 06	294810	6204140	1.8	1.3 – 1.8	humic sandy clay / wthrd sast
PL25B	Lcus25	Oct 09	294795	6204130	1.9	1.4 – 1.9	humic sandy clay / wthrd sast
PL25C	Lcus25	July 06	295805	6204435	0.75	0.35 – 0.75	humic sandy clay / wthrd sast
PL25D	Lcus25	Oct 09	295815	6204440	1.55	1.05 – 1.55	humic sandy clay / wthrd sast
PW1	Wcus1	July 09	295855	6201545	1.5	1.0 – 1.5	humic sandy clay / wthrd sast
PW4	Wcus4	July 09	296015	6202445	1.85	1.35 – 1.85	humic sandy clay / wthrd sast
PW11	Wcus11	July 09	295960	6202990	1.65	1.15 – 1.65	humic sandy clay / wthrd sast
				WONGA EAST			
PCc2	**Ccus2**	May 12	303745	6196095	1.60	1.1 – 1.6	humic sandy clay / wthrd sast
	Ccus2#	May 12	303735	6196100	-	Dry at 0.75	weathered sandstone
	Ccus2#	May 12	303730	6196080	-	Dry at 0.75	weathered sandstone
PCc3	**Ccus3**	Mar 12	302820	6196810	1.2	0.7 – 1.2	sandy clay / wthrd sast
PCc4	**Ccus4**	Mar 12	302615	6196925	0.9	0.4 – 0.9	sandy clay / wthrd sast
PCc5A	**Ccus5**	May 12	302110	6197135	1.24	0.7 – 1.2	humic sandy clay / wthrd sast
	Ccus5#	May 12	302135	6197155	-	Dry at 0.3	weathered sandstone
	Ccus5#	May 12	302135	6197160	-	Dry at 0.5	weathered sandstone
	Ccus5#	May 12	302105	6197130	-	Dry at 1.6	weathered sandstone
PCc5B	**Ccus5**	May 12	302245	6197250	1.31	0.8 – 1.3	humic sandy clay / wthrd sast
PCc6	**Ccus6**	Mar 12	303165	6196790	1.2	0.7 – 1.2	weathered sast
PCr1	**Crus1**	Mar 12	302290	6196625	0.55	0.3 – 0.55	humic sandy clay / wthrd sast
PB4	**Bcus4**	May 12	302485	6198060	0.6	0.25 – 0.6	humic sandy clay / wthrd sast
SP1	**No swamp**	Mar 12	303245	6196955	0.60	0.1 – 0.6	sandy clay / wthrd sast
SP2	**No swamp**	Mar 12	302830	6196905	1.05	0.55 – 1.05	sandy clay / wthrd sast

NOTE: AMG co-ords based on GPS readings # shading indicates a dry hole with no piezometer

In addition, 2 shallow soil piezometers (SP1 and SP2) have been installed down slope of two swamps, and 5 drill holes were not completed with piezometer intakes as the holes were dry, or did not encounter swamp materials within a designated swamp domain at Wonga East.

Drill hole depth and piezometer construction details are shown in **Figures 10** and **11**.

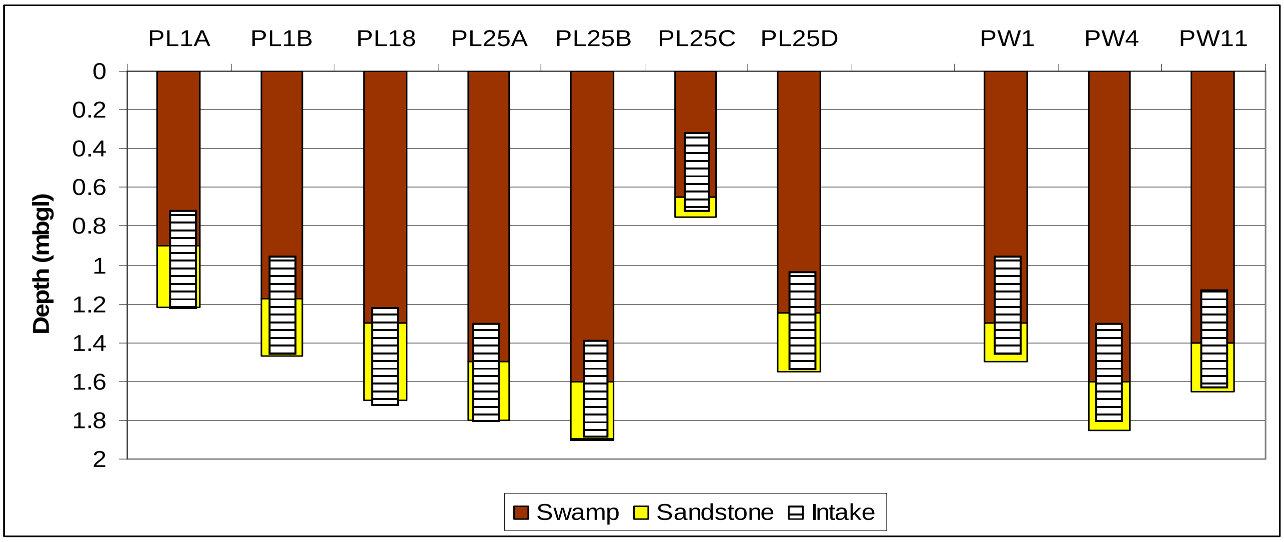


Figure 10 Wonga West Swamp Piezometers

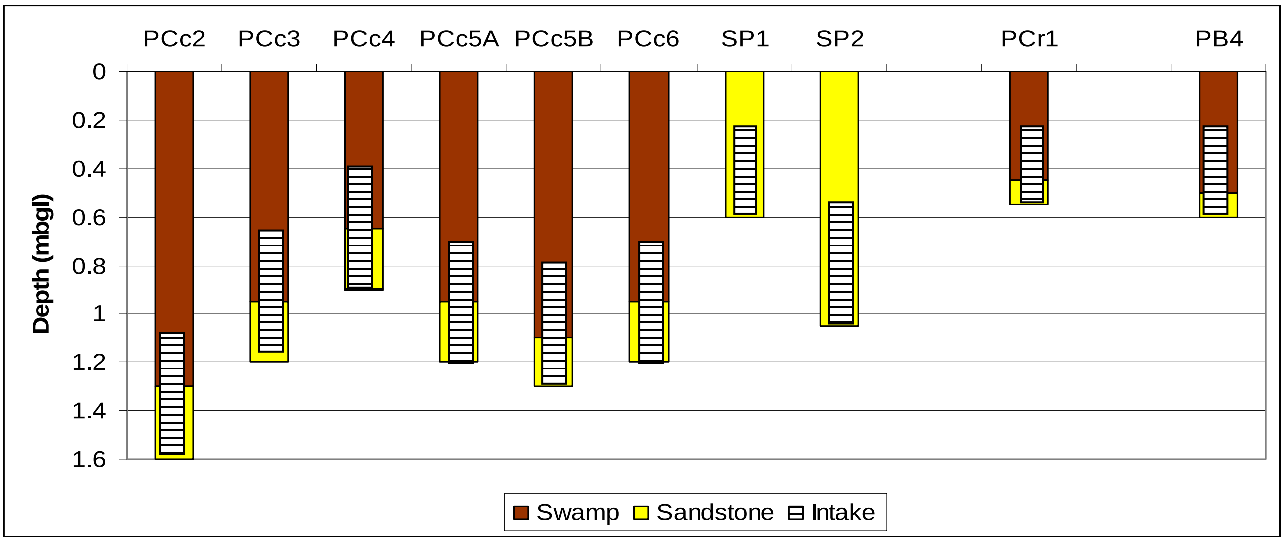


Figure 11 Wonga East Swamp Piezometers

10.2 Basement Piezometers

Drilling, piezometer installation, low flow pump out tests, falling head tests, packer tests and installation of open standpipe and vibrating wire piezometers, as well as groundwater level and water chemistry monitoring were conducted within the Study area between 1992 and the present.

The majority of drilling and monitoring conducted after July 2009 was used to provide input data for the development of a “FEFLOW” model and assessment of the hydrogeological characteristics of the:

- upland swamps;
- Hawkesbury Sandstone,
- Narrabeen Group lithologies, and
- Illawarra Coal Measures.

To date, groundwater investigation in the Study area has involved the installation of;

- 8 open standpipe, and;
- 7 vibrating wire array piezometers,

as shown in **Drawings 2** and **3**, with drilling extending to 325m below surface.

Drilling was contained within the NRE1 lease area, although the groundwater model domain includes the adjacent BHPB and Peabody lease areas and current / decommissioned / proposed workings as well as peripheral areas within the major watersheds outside of the lease.

Relevant open standpipe piezometers details are shown in **Table 4**, whilst geological logs and piezometer construction details are shown in **Appendix B**.

According to the Water Management (General) Regulation 2011, which was gazetted on 30 June 2011, piezometers installed as part of an environmental assessment do not require an access license. Piezometers installed prior to that date were licensed by Gujarat. All relevant approvals from the Sydney Catchment Authority were obtained prior to drilling.

Table 4 **Hawkesbury Sandstone Open Standpipe Piezometer Hydraulic Parameters and Standing Water Levels**

Bore	Installation Date	E	N	Mining Domain	Total Depth (m)	Screen Interval (mbgl)	Hydraulic Conductivity (m/day)	Screened Interval Transmissivity (m^2/day)	Standing Water Level (mbgl)
NRE A	21/11/09	303692	6196033	Wonga East	47	24 - 47	0.011	0.276	19.21 – 22.37
NRE C	3/12/09	303233	6198797	Wonga East	24	18 – 24	0.017	0.121	12.82 – 14.31
NRE D	6/11/09	301870	6198509	Wonga East	52	40 - 52	0.038	0.495	27.21 – 30.73
NRE E	23/10/09	296727	6202286	Wonga West	29	17 - 29	2.07	26.91	11.57 – 11.91
NRE G	20/10/09	296949	6205678	Wonga West	53	36 - 53	0.043	0.775	29.63 – 30.51
NE3	5/12/09	294803	6201954	Wonga West	60	48 - 60	0.004	0.052	39.22 – 39.34
P514	1/11/98	297917	6204280	Wonga West	191	160 - 188	Not tested	Not tested	20.0 – 34.0
GW1A	22/8/12	303742	6196983	Wonga East	27	21 - 27	Not tested	Not tested	24.0

It should be noted that where vibrating wire piezometers were installed, as shown in **Table 5**, the bores were sealed to surface with cement / bentonite and no NOW licences were required.

Table 5 **Vibrating Wire Piezometer Bores**

Piezometer	E	N	Total Depth (mbgl)	Intakes (mbgl)
NRE A VWP	303680	6196034	153	45(mid HS) 60(low HS) 75(up BS) 140(mid BS)
NRE B	303939	6197567	170	27.5(low HS) 43(up BS) 63(mid BS) 168(SPCS)
NRE D VWP	301875	6198493	176	33(mid HS) 60(low HS) 73(BHCS) 135(mid BS)
NE3	294794	6201945	281	100(mid HS) 130(low HS) 155(NP) 255(low BS)
PL1A01	298771	6201855	335	110(HS) 174(up BS) 226(mid BS) 274(low BS) 325 (SS)
PL1A02	298598	6202049	167	90(low HS) 167(up BS) 218(mid BS)
GW1	303693	6196913	107.1	18 (BS) 30 (BS) 45 (BS) 63 (BS) 93 (BS) 125 (BS) 140 (SPCS) 165 (SS)

NOTE: HS - Hawkesbury Sandstone NP - Newport Formation BHCS - Bald Hill Claystone BS - Bulgo Sandstone SPCS - Stanwell Park Claystone SS - Scarborough Sandstone

10.2.1 Basement Hydraulic Properties

Low flow (<0.16L/sec) pump out tests of less than 45 minutes duration were conducted in all open standpipe piezometers seated in the upper to middle Hawkesbury Sandstone as shown in **Table 6** and **Appendix C**.

The hydraulic conductivity of the shallow (<50m) unconfined to semi-confined Hawkesbury Sandstone was analysed using the Jacob Straight Line Method (Jacob, 1950). Although the piezometers were installed in the upper portion of the aquifer and did not fully penetrate the Hawkesbury Sandstone, the hydraulic conductivity was assessed by comparing the transmissivity to the intake interval.

The average hydraulic conductivity for the upper Hawkesbury Sandstone pump out tests (excluding NRE-E) is 0.023m/day. The elevated conductivity in NRE E of 2.07m/day could result from subsidence cracking of the surficial sandstone over the western chain pillar between Longwall 202 and the S3 pillar extraction area.

Packer tests over 5.5m intervals were conducted in 6 bores to 281m below surface (SCT Operations, 2009).

As shown in **Table 6**, the average packer test hydraulic conductivity of the Hawkesbury Sandstone varies from 0.0131m/day in the upper section to 0.0003m/day in the mid section and 0.0008m/day in the lower horizon. The Bald Hill Claystone averages 0.0298m/day whilst the upper Bulgo Sandstone averages 0.0066m/day and the mid Bulgo Sandstone averages 0.0004m/day.

Table 6 NRE No.1 Packer Tests

Borehole	From (m)	To (m)	Interval (m)	K (m/s)	K (m/day)	Median K (m/day)
HAWKESBURY SANDSTONE UPPER						
NRE-A	35	41.5	6.5	1.1E-07	9.5E-03	**1.31E-02**
NRE-A	41	47.5	6.5	1.4E-08	1.21E-03	
NRE-A	48	60	12	1.6E-07	1.382 E-02	
NRE-A	42	60	18	3.1E-09	2.7E-05	
NRE-D	41	47.5	6.5	2.1E-08	1.81E-03	
NRE-D	47	53	6	1.5E-07	1.296E-02	
NRE-D	24.1	30.6	6.5	9.1E-09	7.9E-05	
NRE-D	30.1	36.6	6.5	0.0E+00	-	
NRE-D	36.1	42.6	6.5	2.6E-08	2.25E-03	
NRE-E	19	25.5	6.5	6.8E-07	5.875E-02	
NRE-E	25	30	5	>1e-6	-	
NRE-G	42	48.5	6.5	6.2E-07	5.357E-02	
NE3	48.7	55.2	6.5	1.8E-08	1.56E-03	
NE3	54.7	61.2	6.5	9.6E-09	8.3E-04	
HAWKESBURY SANDSTONE MID						
NE3	102.7	109.2	6.5	4.8E-09	0.00041	**0.0003**
NE3	108.7	115.2	6.5	2.3E-09	0.00020	
HAWKESBURY SANDSTONE LOWER						
NE3	126.7	133.2	6.5	4.5E-09	0.00039	
NE3	132.7	139.2	6.5	1.9E-08	0.00164	
NRE-D	54.1	60.6	6.5	5.2E-09	0.00045	**0.0008**
NEWPORT FORMATION						
NRE-D	66.1	72.6	6.5	>1e-6		**>1e-6**
BALD HILL CLAYSTONE						
NRE-A	53	59.5	6.5	1.0E-09	0.00009	**0.0298**
NRE-A	59	65.5	6.5	5.4E-07	0.04666	
NRE-B	35.7	42.2	6.5	6.1E-10	0.00005	
NRE-B	41.7	48.2	6.5	1.8E-07	0.01555	
NRE-D	78.1	84.6	6.5	1.5E-06	0.12960	
NRE-D	84.1	90.6	6.5	1.9E-07	0.01642	
NE3	180.7	187.2	6.5	5.0E-09	0.00043	
BULGO SANDSTONE UPPER						
NRE-A	71.8	78.3	6.5	4.5E-09	0.00039	**0.0066**
NRE-A	77.8	84.3	6.5	2.4E-10	0.00002	
NRE-B	59.7	66.2	6.5	2.7E-10	0.00002	
NRE-B	65.7	72.2	6.5	3.0E-08	0.00259	
NRE-D	102.1	108.6	6.5	4.7E-07	0.04061	
NRE-D	108.1	114.6	6.5	0.0E+00		
NE3	210.7	217.2	6.5	4.4E-09	0.00038	
NE3	216.7	223.2	6.5	2.8E-08	0.00242	
BULGO SANDSTONE MID						
NRE-A	128.8	135.3	6.5	0.0E+00		**0.0004**
NRE-A	134.8	141.3	6.5	3.6E-10	0.00003	
NRE-B	113.7	120.2	6.5	8.6E-10	0.00007	
NRE-B	119.7	126.2	6.5	5.3E-10	0.00005	
NRE-D	150.1	156.6	6.5	0.0E+00		
NRE-D	156.1	162.6	6.5	0.0E+00		
NE3	246.7	253.2	6.5	1.4E-09	0.00012	
NE3	252.7	259.2	6.5	2.2E-08	0.00190	

Based on a combination of on-site tests as well as assessment of regional studies (Heritage Computing, 2010) hydraulic conductivities in the BHP Billiton Bulli Seam proposed workings region vary from 0.026m/day to 1E-06m/day, whilst the western region around Tahmoor (Geoterra, 2009) ranges from 9.26E-06m/day to 1.55E-09m/day. The Dendrobium workings range from 8.64E-1m/day to 8.64E-5m/day (GHD, 2007) as shown in **Figure 12**.

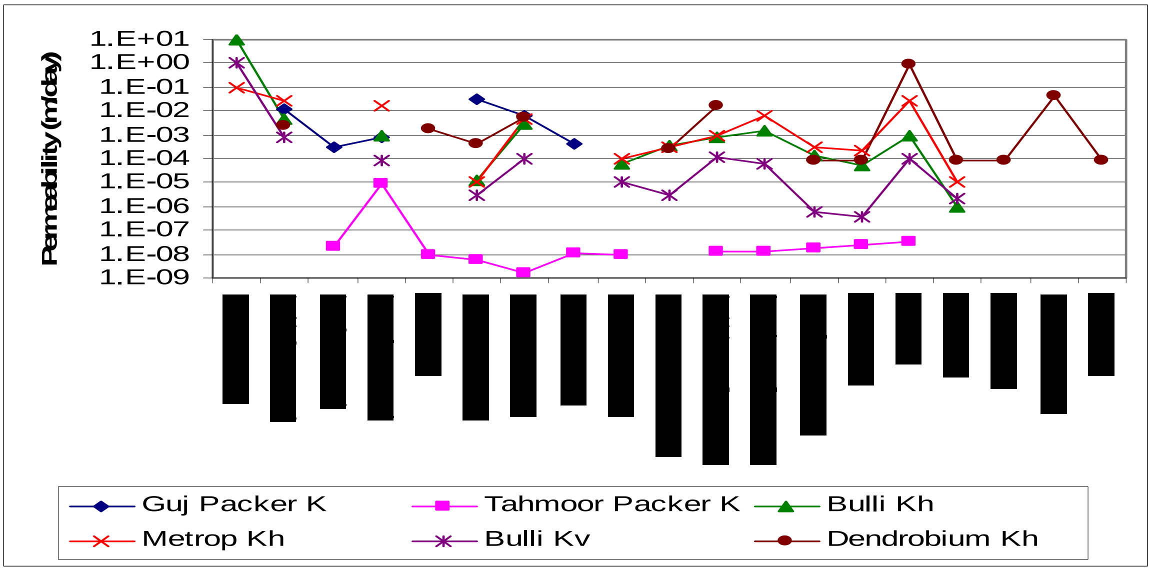


Figure 12 Regional Hydraulic Conductivities Vs Depth

10.3 Swamp Groundwater Levels

The upland swamps are perched systems that are hydraulically separated from the deeper, regional groundwater table in the Hawkesbury Sandstone. They can, however, be connected to shallower, ephemeral seepage from the upper Hawkesbury Sandstone where bedding discontinuities or low permeabilities enhance horizontal flow into a swamp after high rainfall periods.

Depending on the relative height of the ephemeral, perched and regional water tables, groundwater seepage can supplement swamp moisture or, alternatively, unsaturated swamp moisture can seep into the underlying shallow ephemeral sandstone aquifer.

In turn, the shallow bedrock aquifers are also usually ephemeral, and are hydraulically disconnected from the deeper, regional aquifers within the Hawkesbury Sandstone.

The water table within the swamps is dependent on surface inflow recharge after rain and can be supported by ephemeral seepage of near surface groundwater from the Hawkesbury Sandstone.

Water storage is usually limited within the clay rich sandy sediments, although this can allow relatively small inflows to support a highly variable ephemeral water table in the more organic layers.

Recharge into the Hawkesbury Sandstone shallow aquifer that seeps into a swamp is generally moderated by connate water stored in a swamp, which is also recharged by rainfall. Water can enter a swamp from ephemeral seeps located at the upper and lower section of any topographic or basement steps that may be present.

Episodes of inundation and surface run off within a swamp are directly related to the extent and duration of storm events, with the short term, post storm drainage occurring within indistinct channels or flow paths in the swamp.

Groundwater seepage into a swamp is usually transmitted within the more sandy or peaty layers and can “daylight” where the water table extends to surface. Water accumulation within a swamp is a balance between:

- surface inflow;
- horizontal seepage and downstream flow;
- swamp storage capacity;
- vertical seepage rates into the lower weathered rock strata; and
- evaporative processes.

10.3.1 Wonga West

Groundwater levels within the Wonga West perched valley fill and headwater swamps have been monitored since July 2006 (at PL25A and PL25B), along with more recent installations since July 2009 as shown in **Figure 13.**

Essentially all the headwater and valley fill swamps at Wonga West have been undermined and subsided by Bulli longwall workings, apart from the valley fill section of Wcus1 that overlies the unmined barrier between NRE1 and Cordeaux collieries.

Swamp water levels are variable, and can range from fully saturated to dry in the headwater swamps, whilst the valley fill swamp in Wallandoola Creek (PW1) has been saturated (although with variable levels) since monitoring began.

The headwater swamp water levels rise and fall in direct response to the changing patterns of rainfall and dry periods at similar rates whereas the valley fill swamp in Wallandoola Creek at P6 has a moderated response to rainfall as it is in direct connection to stream seepage through the Wallandoola Creek valley.

Recharge generally occurs rapidly in “steps” after rainfall, and to date, albeit with intermittent recharge events, Swamps PW11 and PW4 have taken up to 4 months to dry out.

This “desiccation” time would shorten for more extended dry periods when the swamp is not intermittently “topped up” and would vary depending on the season in which the drying event occurred.

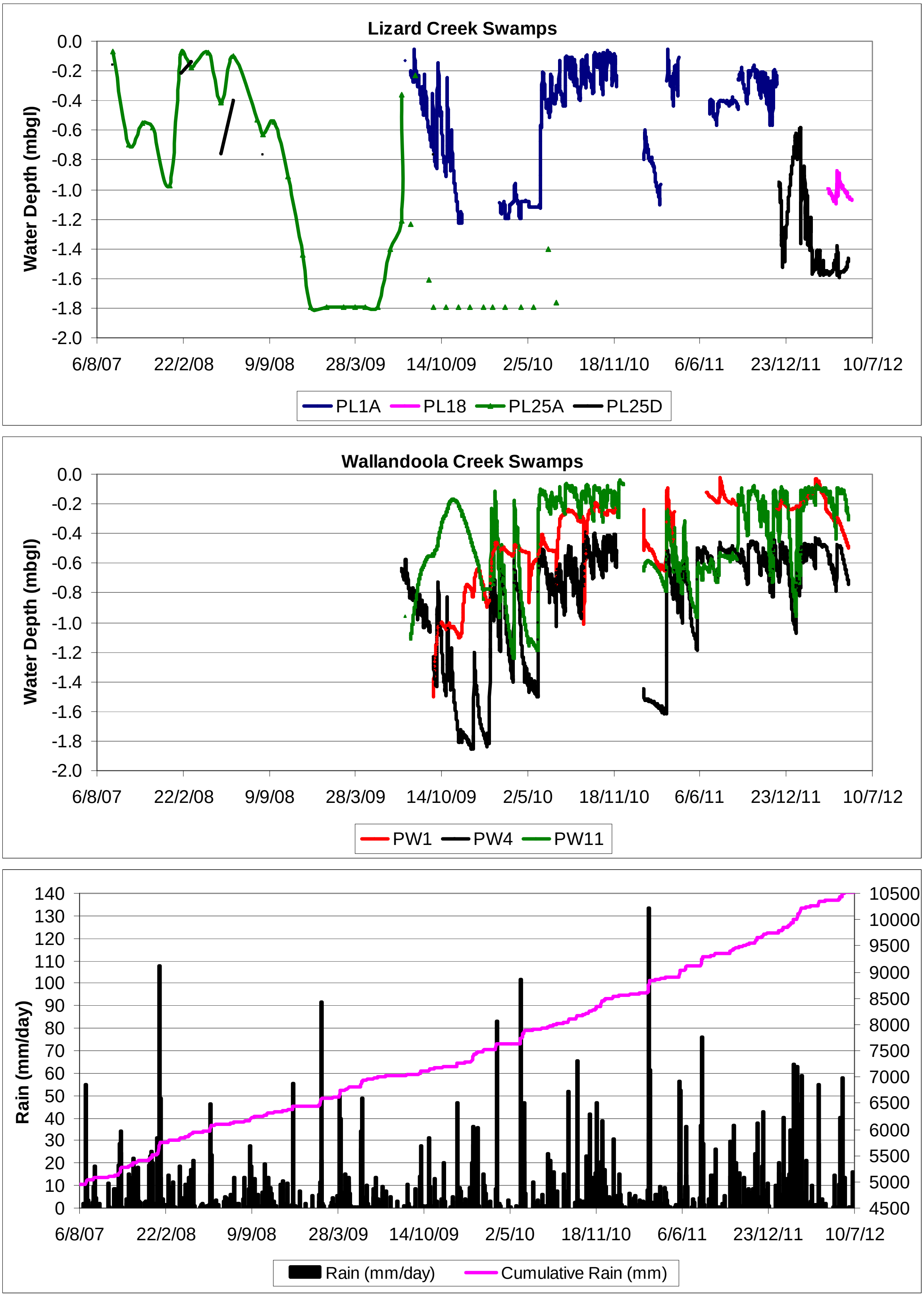


Figure 13 Wonga West Swamp Standing Water Levels and Rainfall

10.3.2 Wonga East

Groundwater levels within the Wonga East headwater swamps have been monitored since February 2012 as shown in **Figure 14.**

All the headwater swamps at Wonga East have been undermined and subsided by Bulli bord and pillar, Bulli pillar, Balgownie longwall, and more recently, the Wongawilli seam longwall WE-A2-LW4.

The Wonga East swamps are markedly different to Wonga West in that they are generally smaller, shallower, have significantly less humic material and have more interspersed sandstone outcrops within their outlines.

The swamp water levels are variable, and can range from fully saturated to dry, whilst some of the swamsp have been essentially dry since piezometers were installed in them (PCc3, PCc6, PB4), or have short “wet” periods (PCc2, PCr1).

The headwater swamp water levels rise and fall in direct response to the changing patterns of rainfall and, in addition, the Wonga East swamps are more reliant on surface water runoff recharge compared to the Wonga West swamps.

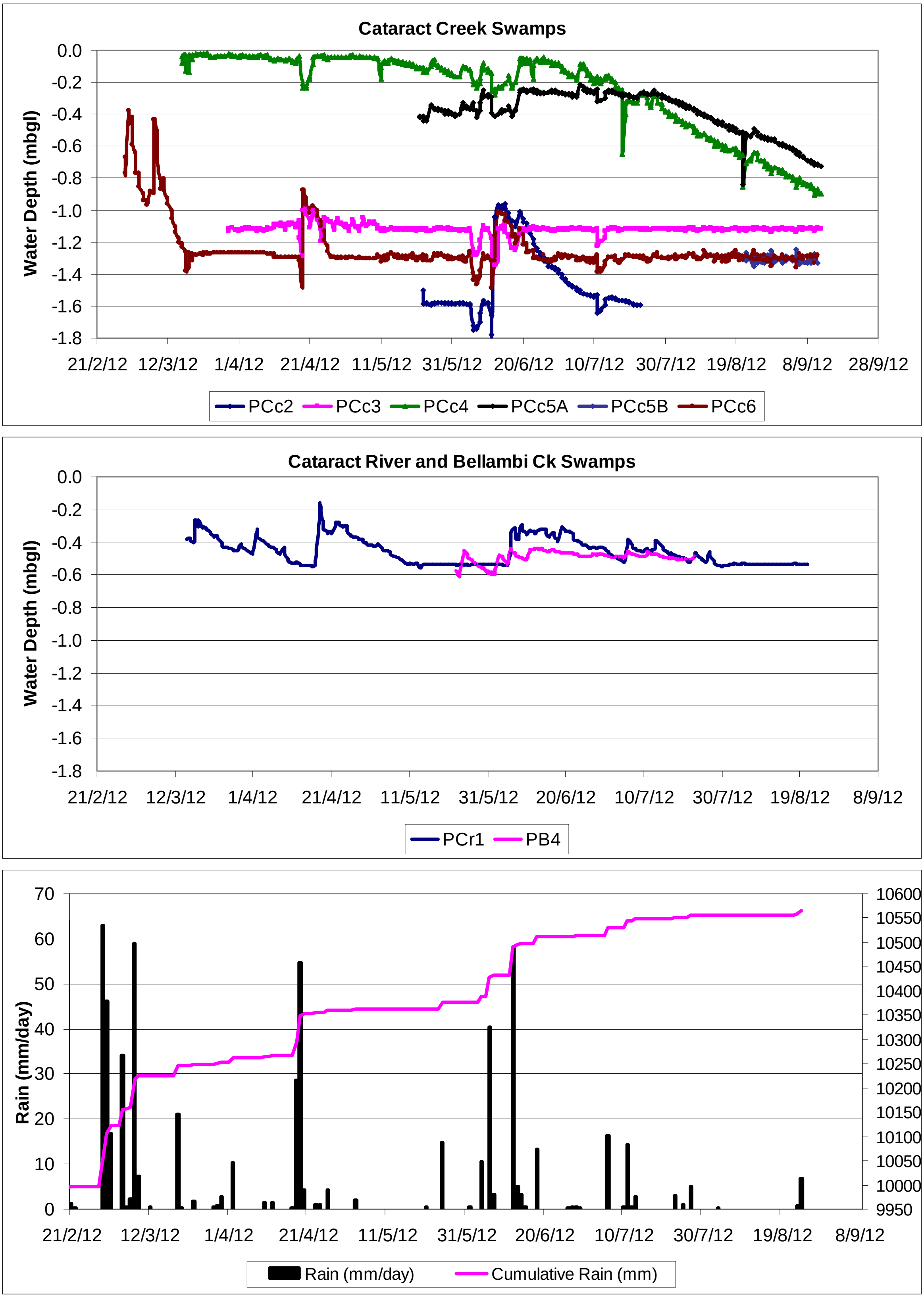


Figure 14 Wonga West Swamp Standing Water Levels and Rainfall

10.3.3 Wonga West Paired Swamp and Basement Piezometers

Paired swamp and Hawkesbury Sandstone monitoring at PL1A and NRE-E shown in **Figure 15** indicates that the two systems are hydraulically separated by approximately 10.5m.

Recharge following rain events through the semi-pervious sandstone to the regional aquifer is apparent, with the swamp and the regional sandstone aquifer having similar responses to rainfall recharge.

Due to limited data in the area near the two piezometers (which has previously been subsided by the Bulli longwalls) the proportional contribution of the Lcus1 (PL1A) swamp, as a proportion of the overall (non swamp) recharge and its contribution to the Lizard Creek stream flow is not able to be quantified.

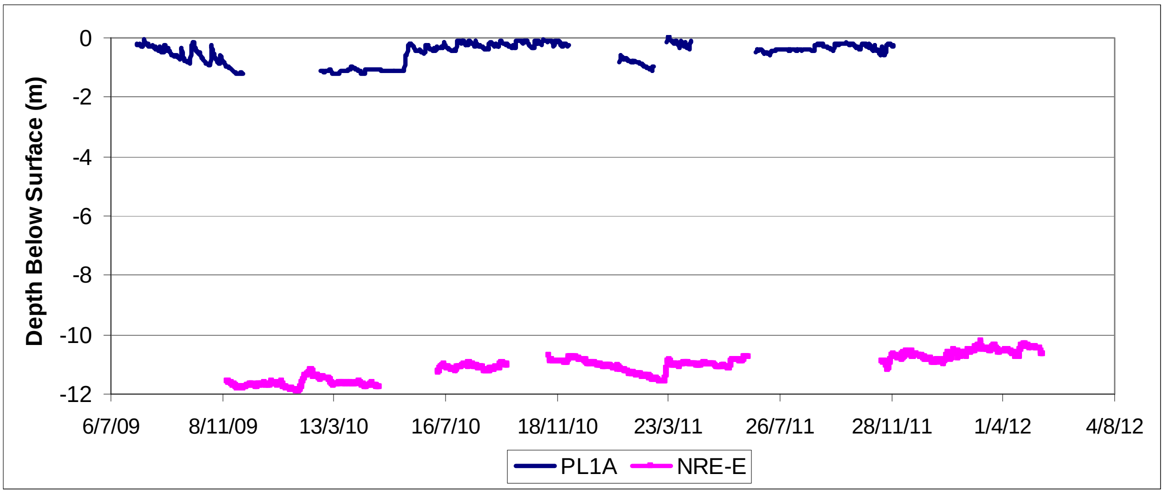


Figure 15 Wonga West Upland Swamp and Hawkesbury Sandstone Water Levels

10.3.4 Wonga East Paired Swamp and Basement Piezometers

Paired swamp and Hawkesbury Sandstone monitoring at PCc2 and NRE-A shown in **Figure 16** indicate the two systems have variable hydraulic separation, ranging from 1 – 15m.

Recharge following rain events through the semi-pervious sandstone to the regional aquifer is apparent, with the swamp and the regional sandstone aquifer having similar temporal responses to rainfall recharge.

Comparison of the water levels in GW1 and PCc6 in swamp Ccus6 indicate a current 12.8m hydraulic separation, however ongoing data is required to assess the comparative variability in their respective water levels.

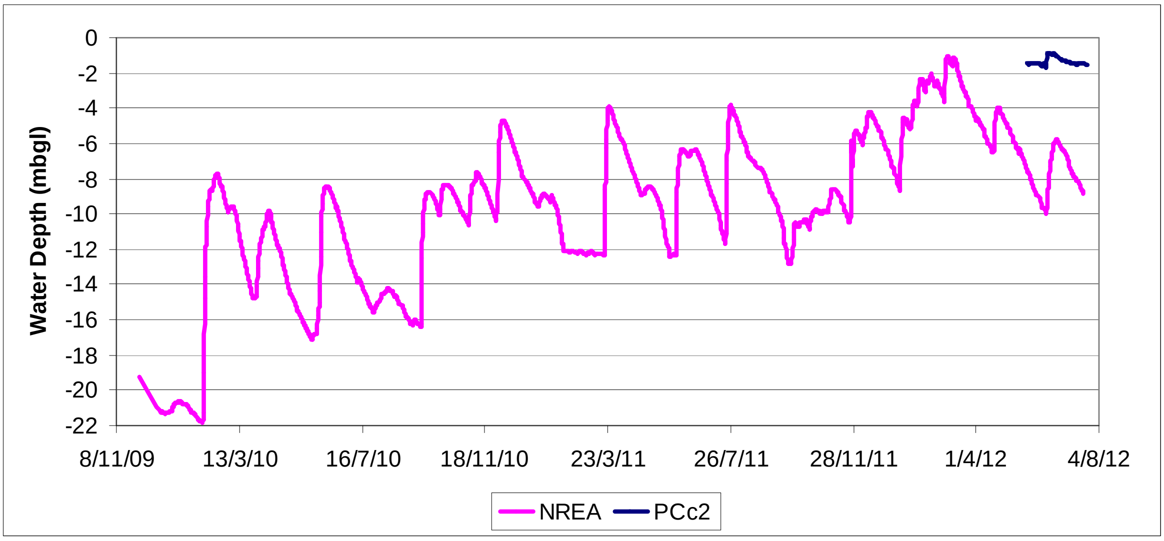


Figure 16 Wonga East Upland Swamp and Hawkesbury Sandstone Water Levels

10.4 Hawkesbury Sandstone Open Standpipe Water levels

Water levels from open standpipe piezometers installed in the upper Hawkesbury Sandstone are shown in **Figure 17** from locations shown in **Drawing 1**.

The Wonga East piezometers are generally more responsive to rainfall than at Wonga West (except for NE3) as shown in **Table 7**.

Table 7 Hawkesbury Sandstone Water Level Variability

Piezometer	Drilling First Water Intercept (mbgl)	Water Level Range (mbgl)	Water Level Variability (m)
Wonga East			
NRE A	24.0	1.36 – 22.18	20.8
NRE C	18.0	6.68 – 13.06	6.4
NRE D	40.0	1.99 – 29.76	27.8
GW1A	24.0	n/a	n/a
Wonga West			
NRE E	17.0	10.53 – 11.55	1.0
NRE G	36.0	27.12 – 30.51	3.4
NRE3	48.0	6.97 – 39.50	32.5

Note that the high water level variability in NRE3 is unusual, and is suspected to be due to incomplete sealing of the surface casing annulus, which allows overland surface water runoff to enter the casing and “artificially” raise the standing water level in the piezometer.

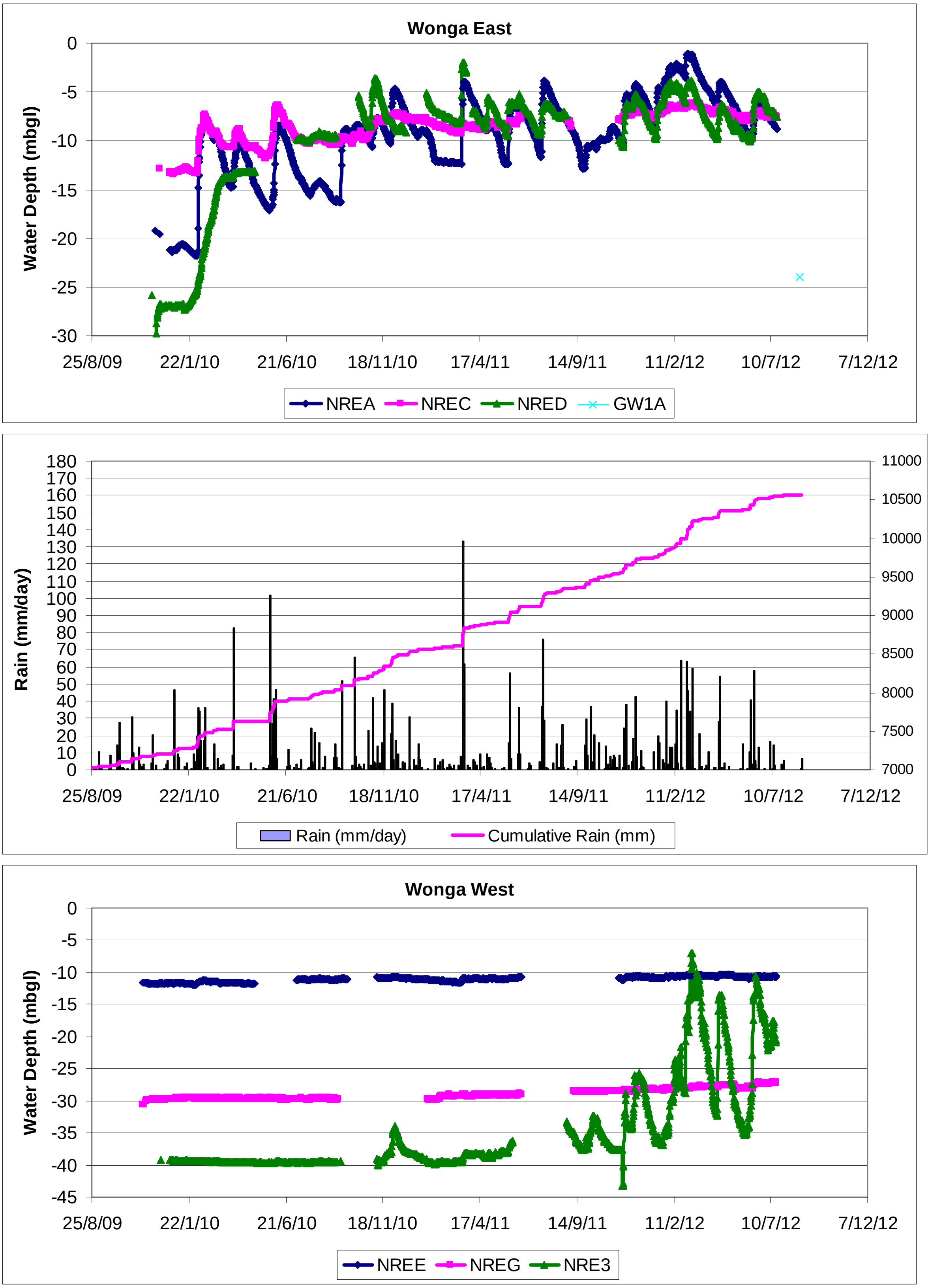


Figure 17 **Hawkesbury Sandstone Water Levels and Rainfall**

10.4.1 Multi Level Piezometers

Multi level piezometers have been installed at selected depths between the Upper Hawkesbury Sandstone and the Stanwell Park Claystone since July 2009 in four bores at Wonga East and one (excluding P501, 502 and 514) at Wonga West as summarised in **Table 8**.

The Wonga West array in NRE-3 augments data collected since 1992 from multi level piezometers over Longwalls 501, 502 and 514.

In December 2009 the pressure head in NRE-A rose between the lower Hawkesbury Sandstone and the Bald Hill Claystone indicating a potential groundwater flow up into the Hawkesbury Sandstone, then sequentially reduced below the Bald Hill Claystone indicating a downward flow gradient.

A similar situation is observed between the Newport Formation and the Bald Hill Claystone in NRE-D, where groundwater pressure gradients indicate a potential flow from the Bald Hill Claystone to the Newport Formation, and a downward flow gradient from the Bald Hill Claystone to underlying lithologies.

NRE-B and NRE-3 show a downward flow gradient through the stratigraphic profile.

A contour plot of the regional upper Hawkesbury Sandstone piezometric surface based on data from the open standpipe and upper vibrating wire piezometer intakes as well as assumed water levels in the base of valleys and along Cataract Reservoir is shown in **Drawing 8**.

The plot indicates a general flow at Wonga East from the escarpment to the Cataract Reservoir, whilst at Wonga West the regional groundwater flow is essentially to the Cataract River in the north and to Cataract Reservoir in the east.

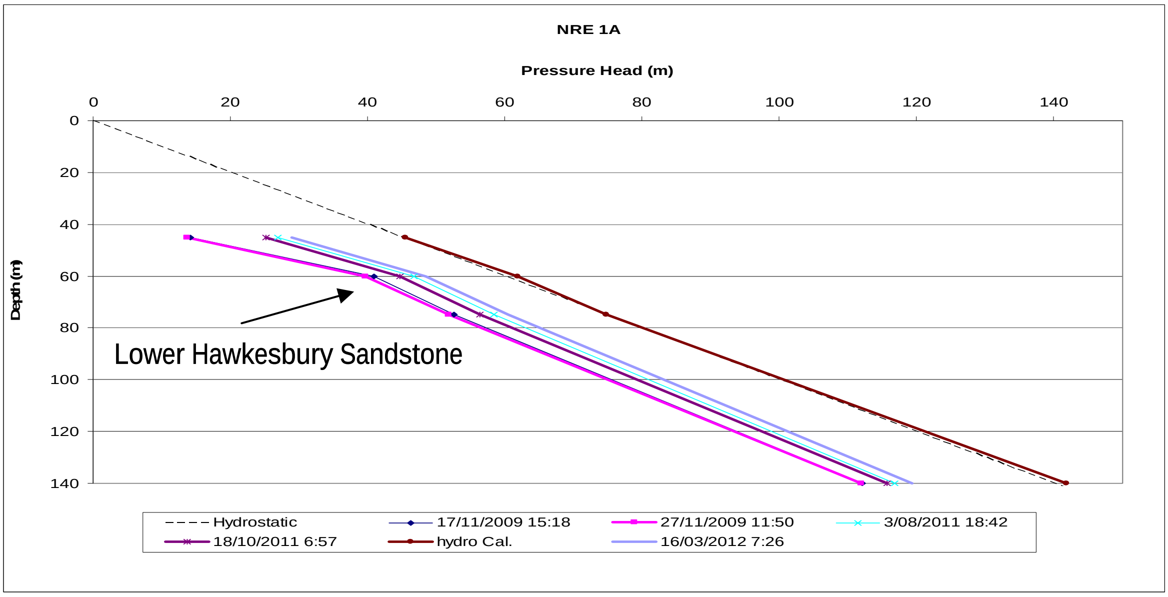
Table 8 Vibrating Wire Piezometers

Piezometer Intake Depth (mbgl)	Formation	Piezometer Intake Depth (mbgl)	Formation
NRE-A	**(Wonga East)**	**NRE-B**	**(Wonga East)**
45	Mid Hawkesbury Sandstone	**27.5**	Lower Hawkesbury Sandstone
60	Lower Hawkesbury Sandstone	**43**	Upper Bulgo Sandstone
75	Upper Bulgo Sandstone	**63**	Mid Bulgo Sandstone
140	Mid Bulgo Sandstone	**168**	Stanwell Park Claystone
NRE-D	**(Wonga East)**	**NRE-3**	**(Wonga West)**
33	Mid Hawkesbury Sandstone	**100**	Mid Hawkesbury Sandstone
60	Lower Hawkesbury Sandstone	**130**	Lower Hawkesbury Sandstone
73	Bald Hill Claystone	**155**	Newport Formation
135	Mid Bulgo Sandstone	**255**	Lower Bulgo Sandstone
GW1 (Wonga East)			
18	Upper Bulgo Sandstone	**93**	Mid Bulgo Sandstone
30	Upper Bulgo Sandstone	**125**	Lower Bulgo Sandstone
45	Upper Bulgo Sandstone	**140**	Stanwell Park Claystone
63	Mid Bulgo Sandstone	**165**	Scarborough Sandstone

NOTES: mbgl metres below ground level

No breaching of the Bald Hill Claystone is evident in the pressure head versus depth plot at NRE-A as shown in **Figure 18**.

The head pressure versus depth and the water level plots in **Figure 18** indicate that within the NRE-A array, which is installed over the southern edge of the Balgownie longwalls and Bulli Seam pillar extraction area, the 45mbgl intake water level trace in the mid Hawkesbury Sandstone has a reduced head pressure in comparison to the lower Hawkesbury Sandstone (60mbgl) and upper Bulgo Sandstone (75mbgl) intakes, although the 45, 60 and 75mgbl all trend in a similar manner in response to rainfall recharge. The mid Bulgo Sandstone intake at 140mbgl, beneath the Bald Hill Claystone, has a dampened response to rainfall recharge.



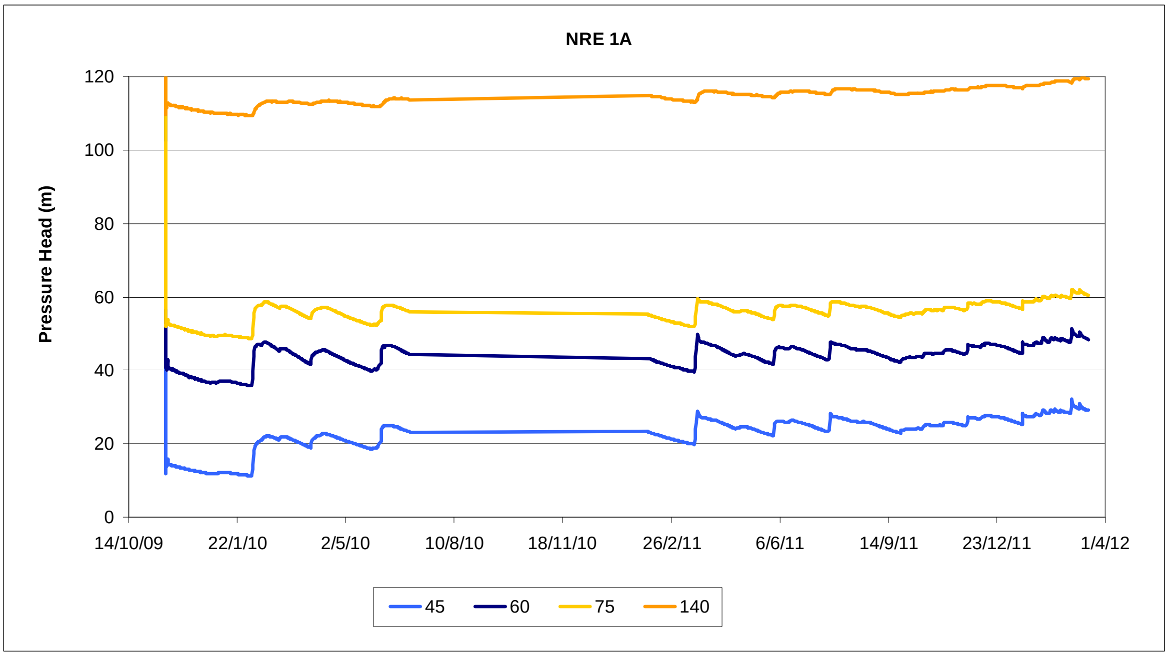


Figure 18 Wonga East NRE-A VWP Pressure Head Levels

No breaching of the Bald Hill Claystone is evident in **Figure 19**, however depressurisation between the upper and Mid Bulgo Sandstone is apparent in the pressure head versus depth plot.

Figure 19 indicates that at NRE-B, which is over unmined ground, the 27.5mbgl intake (lower Hawkesbury Sandstone), as well as the 43mbgl intake (Bulgo Sandstone), have relatively stable pressures.

The 63mbgl (mid Bulgo Sandstone) and 168mbgl (Stanwell Park Claystone) have relatively stable to gradually declining water pressures.

None of the plots have enhanced responses to rainfall recharge.

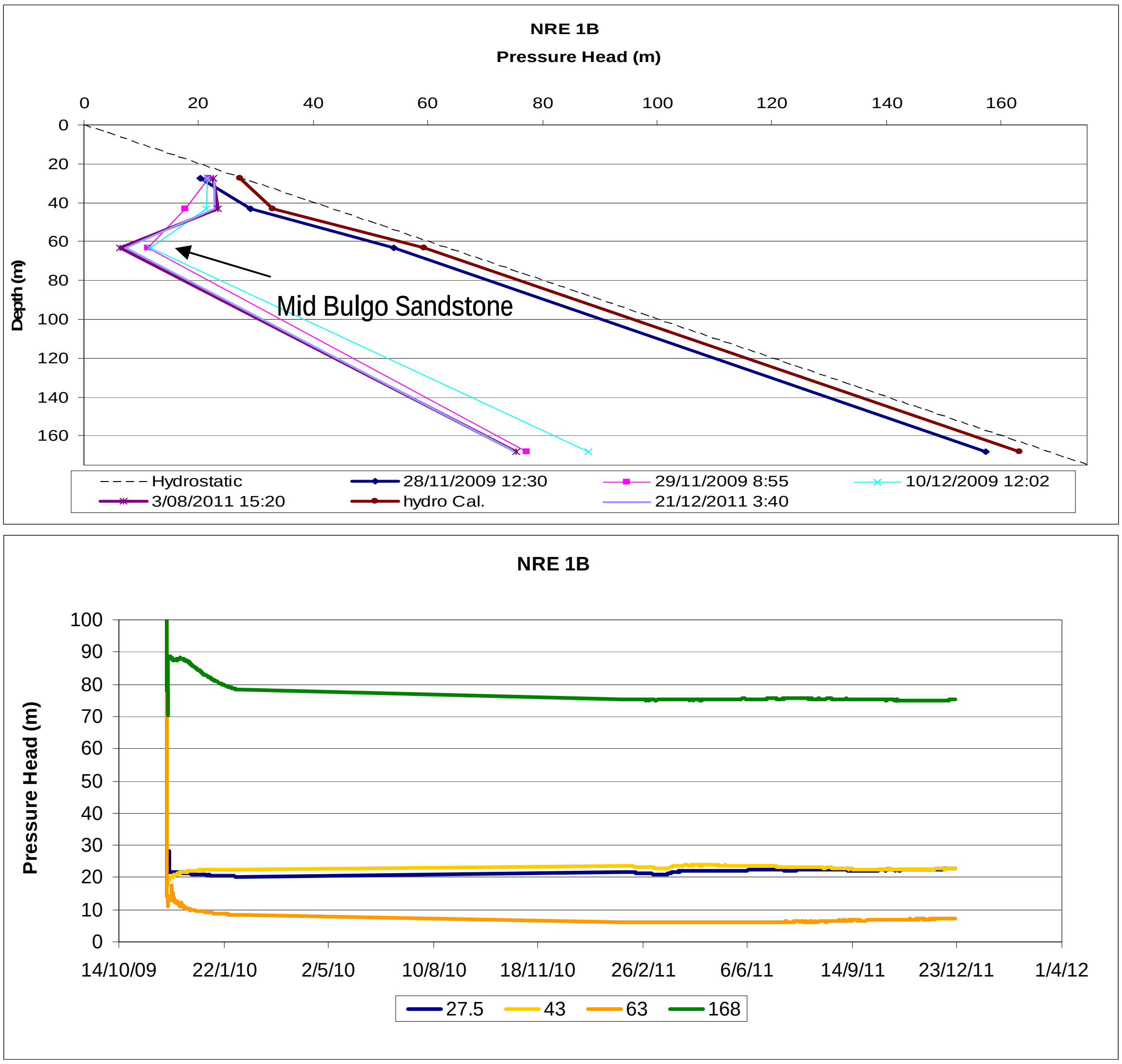
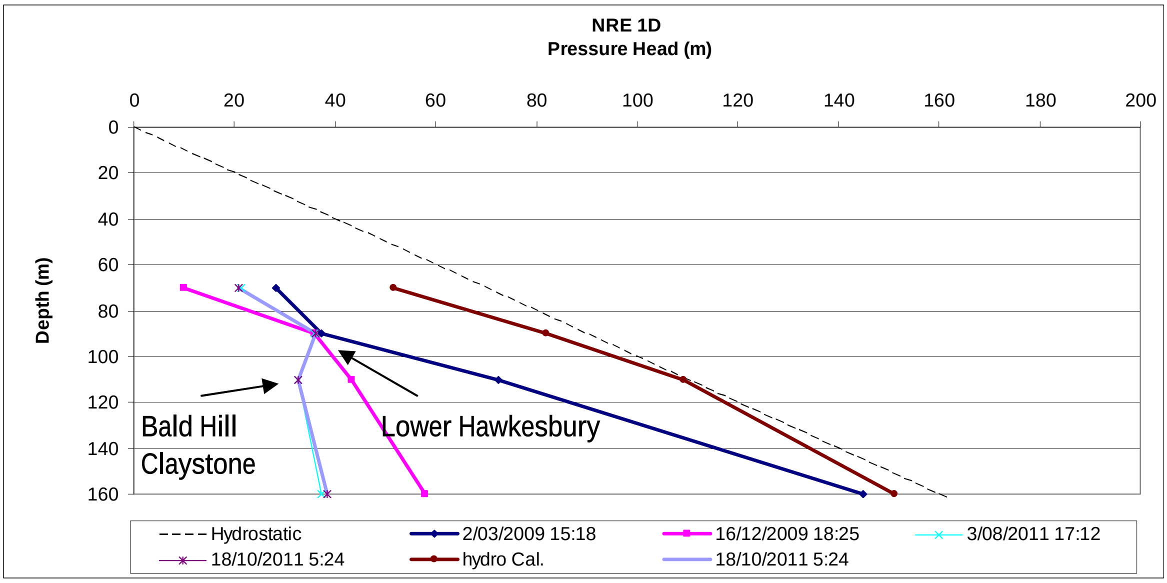


Figure 19 **Wonga East NRE-1B VWP Pressure Head**

Breaching of the Bald Hill Claystone and depressurisation of the Mid Bargo Sandstone is evident in the pressure head versus depth plot, as shown in **Figure 20**.

Figure 20 indicates that NRE-D, which is located over bord and pillar workings in the Bulli Seam, indicate that the intakes at 70mbgl (mid Hawkesbury Sandstone), 110mbgl (Bald Hill Claystone) and 160mbgl (mid Bulgo Sandstone) all have rising pressures, which is most evident in the mid Hawkesbury Sandstone.

The 90mbgl intake in the Lower Hawkesbury Sandstone has a relatively flat trend, whilst the mid Hawkesbury Sandstone exhibits and enhanced response to rainfall recharge.



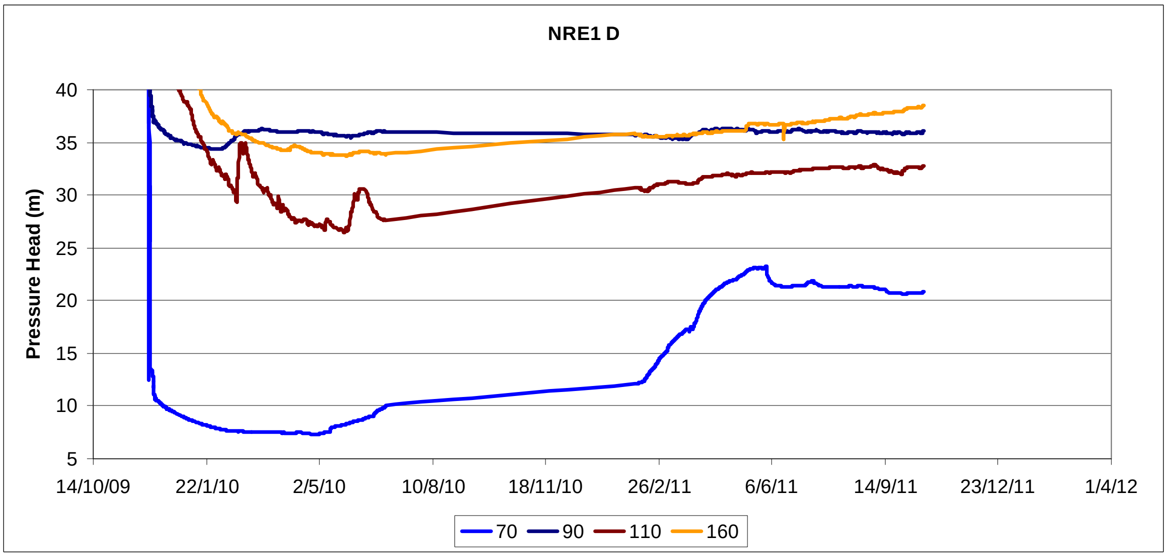
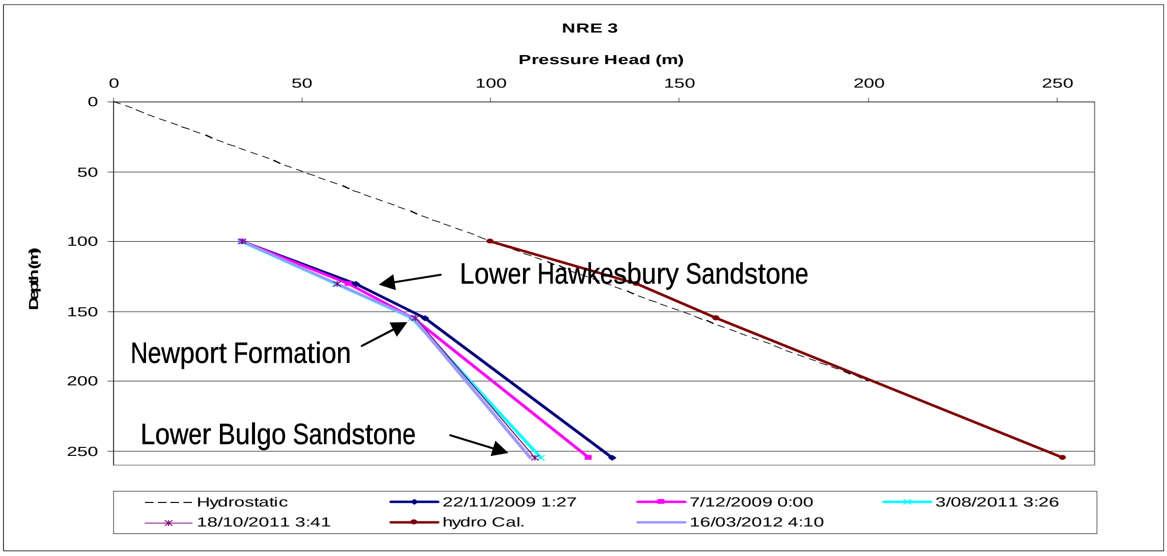


Figure 20 Wonga East VWP Pressure Head

Minor depressurisation between the Newport Formation and the Lower Bargo Sandstone is evident in **Figure 21.**

Figure 21 indicates that NRE-3, which is located at Wonga West near the southern lease boundary, has limited response to rain events.

Relatively stable pressures are noted in the mid and lower Hawkesbury Sandstone (100 and 130mbgl) and in the Newport Formation (155mbgl), whilst the lower Bulgo Sandstone (255mbgl) is gradually depressurising.



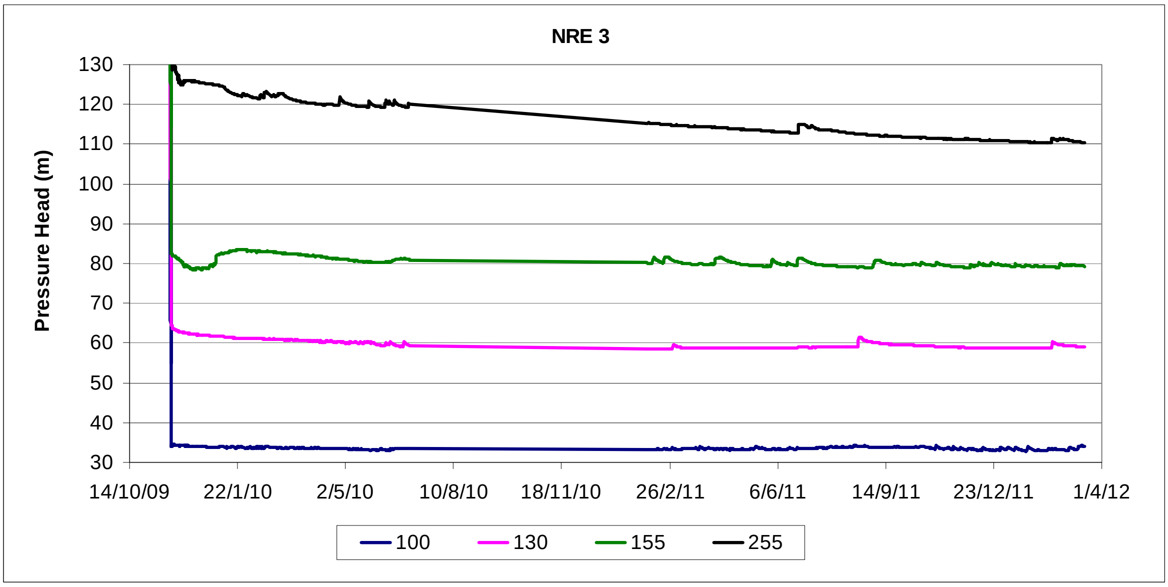


Figure 21 **Wonga West NRE-3 VWP Pressure Head**

10.5 Mine Water Pumping

It is not a straight forward exercise to directly compare rainfall infiltration in the catchment to water discharged out of the NRE1 workings, or internally flowing within sub-sections of the mine as there is a combination of water extracted from the mine, followed by storage in holding ponds at surface and recycling back into the workings, numerous times over, before the water is discharged from the mine at Russel Vale.

The mine currently has an application for a Water Access Licence for 365ML/year that was sent to NOW on 22 January, 2009 for its current operations. The licence aplication has not yet been approved, however, it may need to be modified to account for the predicted 1,131ML/year of inflow during extraction of the Wongawilli Seam workings.

10.5.1 200 and 300 Series Longwalls West of Cataract Reservoir

It is assessed there is no free drainage through the Bald Hill Claystone at Wonga West, as the existing workings are currently depressurised and essentially dry, although ponded water is present in a syncline in the central, southern section of the 200 series longwalls near as well as within the BHP Cordeaux workings (S Wilson, pers comm.).

Monitoring of mine water pump-out from workings to the west of Cataract Reservoir, along with observations from underground supervisors (S Wilson, pers comm.) indicate there is no short term increase in mine water make from the current workings following significant rain in the Lizard and Wallandoola Creek catchments.

Monitoring of water level trends in piezometers over the 200 and 300 series longwalls indicates the upper Hawkesbury Sandstone does not have an enhanced response to rainfall recharge.

10.5.2 Current Workings East of Cataract Reservoir

It is assessed there is no free drainage into the existing workings to the east of Cataract Reservoir as they are currently depressurised and essentially dry (S Wilson, pers comm.) apart from a few small ponding areas at the down dip end of the old workings where the dewatering pump is not able to extract the water, until it “spills” into a downgradient section of the workings.

Monitoring of water pump-out from the eastern workings, along with observations from underground supervisors (S Wilson, pers comm.) indicate there is no observed associated short term increase in mine water make from the current eastern workings or after extraction of the Wongawilli Seam longwall WE-A2-LW4, following significant rain in the Cataract Creek, Cataract River or Bellambi Creek catchments as shown in **Figure 22**.

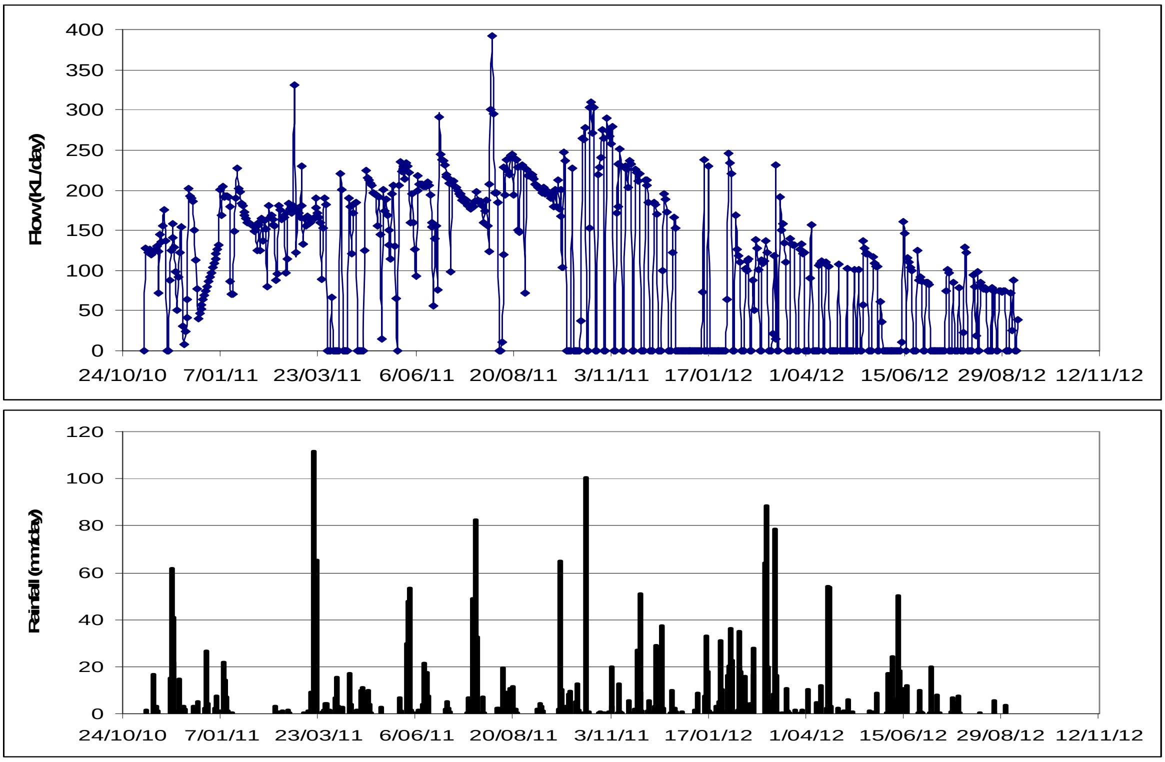


Figure 22 Wonga East (27 Cut through) Groundwater Extraction and Rainfall

Based on mine pumping discharge records available since November 2010, the average daily groundwater inflow extracted via the 27 cut through bore is approximately 0.158ML/day (median 0.165ML/day) from the NRE No.1 workings.

Monitoring of water level trends in piezometers over the eastern workings does, however, indicate the upper Hawkesbury Sandstone has an enhanced response to rainfall recharge.

10.6 Groundwater Chemistry

Groundwater samples have been collected, stored and despatched in accordance with AS/NZS 5667 (Standards Australia, 1998) whilst field water quality parameters are measured in the field using Hanna probes and meters which are freshly calibrated with two point pH buffers and EC standards bracketing the expected range, with results corrected to 25^{0}C.

Sampling of field water is conducted using appropriate decontaminated sample bottles supplied with appropriate additives and labelling as prescribed by NATA protocols.

All plastic ware is decontaminated by storing in dilute acetic acid, with the equipment being thoroughly washed with distilled water prior to use. Field filtration is conducted with 0.45 micron filters.

The method of sampling, including the use of blanks and replicates, and analysis methods employed are in accordance with guidelines for sampling and analysis of water and pollutants i.e. (ANZECC, 2000b and DEC NSW, 2004). In all cases, analysis methods employed are those providing adequate limits of resolution as listed in DEC NSW, 2004.

10.6.1 Lizard Creek Swamps

The Lizard Creek swamps at Wonga West have electrical conductivities ranging from 64 – 305µS/cm, with the salinity varying in relationship to rainfall recharge that occurs prior to sampling, along with the degree of brackish seepage from the weathered Hawkesbury Sandstone.

The pH ranges from 3.6 – 7.5 as shown in **Figure 23**.

Monitoring indicates the swamp salinity is generally within the acceptable range for potable water, however is outside the ANZECC 2000 South Eastern Australia Upland Stream criteria for pH and can be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines, as shown in **Appendix D,** for;

- filtered copper, lead, zinc, nickel, and occasionally aluminium (where its pH exceeds 6.5, which it rarely occurs), as well as;
- total nitrogen, and total phosphorous.

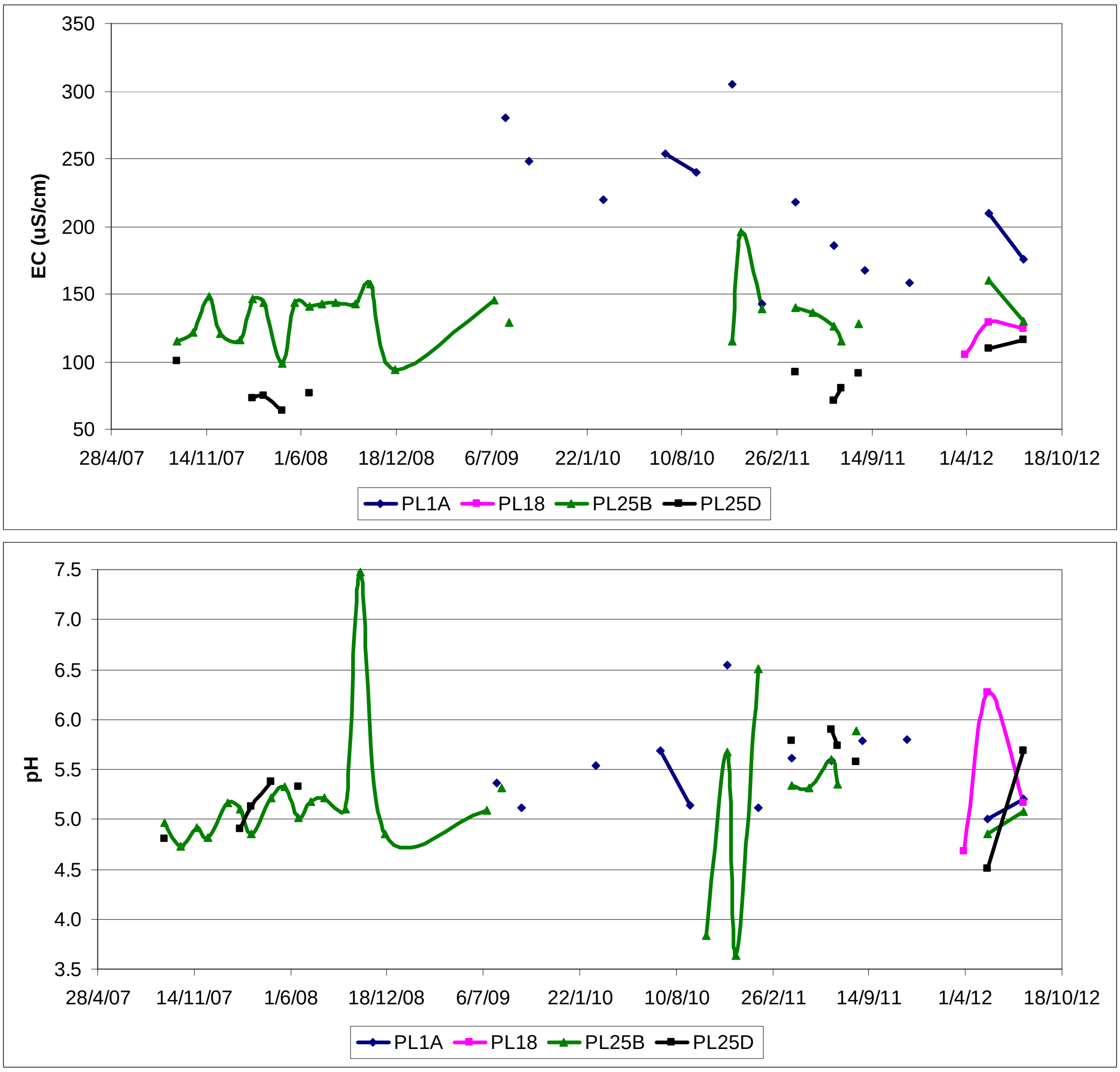


Figure 23 **Lizard Creek Swamps Field Water Quality**

10.6.2 Wallandoola Creek Swamps

The Wallandoola Creek swamps at Wonga West have electrical conductivities ranging from 86 – 1,120µS/cm, with the salinity varying in relationship to rainfall recharge that occurs prior to sampling, along with the degree of brackish seepage from the weathered Hawkesbury Sandstone.

The pH ranges from 5.1 – 7.4 as shown in **Figure 24**.

Monitoring indicates the swamp salinity is generally within the acceptable range for potable water, except generally in PW11, however it can be outside the ANZECC 2000 South Eastern Australia Upland Stream criteria for pH and can be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines, as shown in **Appendix D,** for;

- filtered copper, lead, zinc, nickel, and occasionally aluminium (where its pH exceeds 6.5, which it rarely occurs), as well as;

- total nitrogen, and total phosphorous.

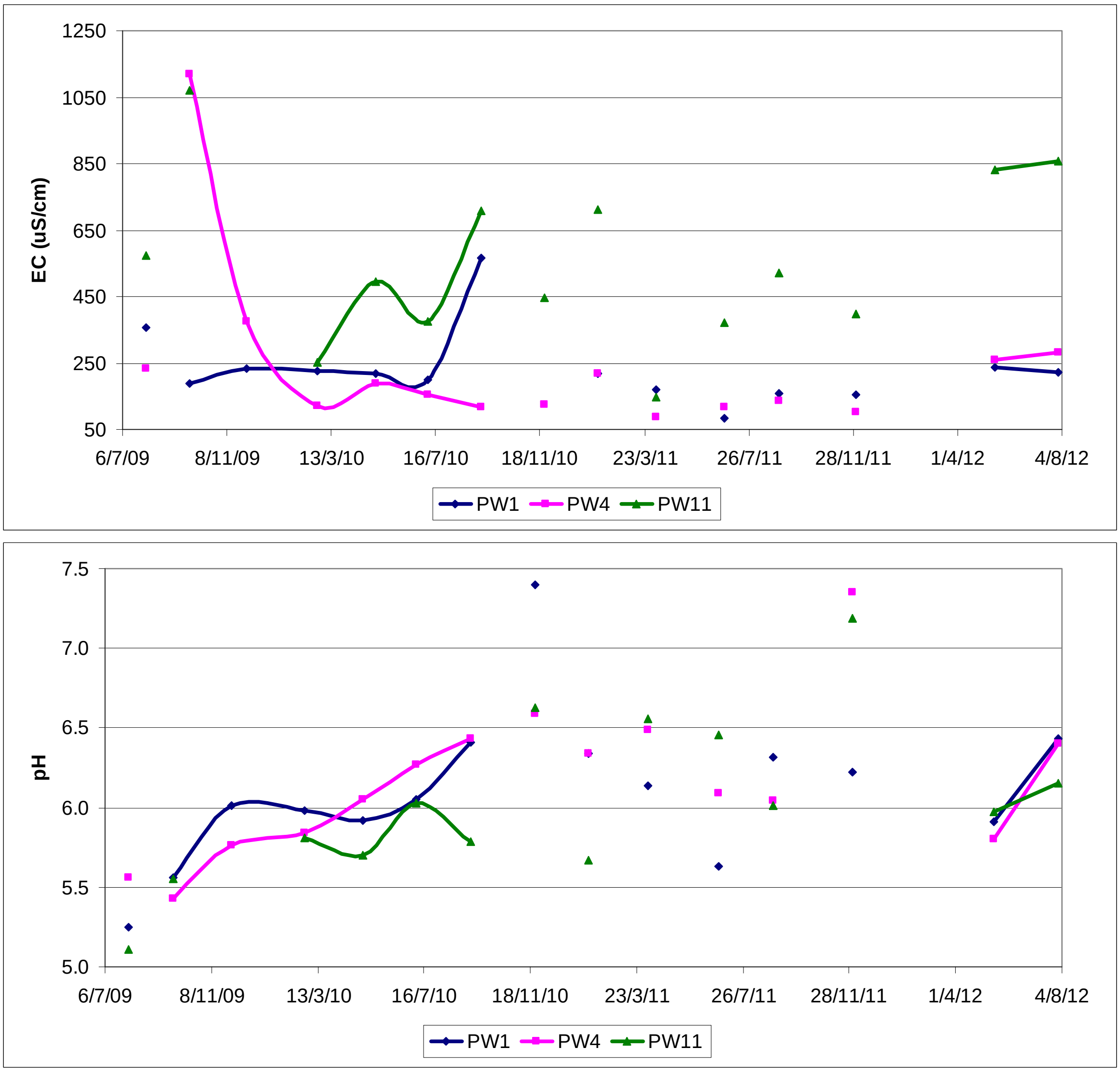


Figure 24 **Wallandoola Creek Swamps Field Water Quality**

10.6.3 Wonga East Swamps

The Cataract Creek, Bellambi Creek and Cataract River swamps at Wonga East have electrical conductivities ranging from 70 – 170µS/cm, with the salinity varying in relationship to rainfall recharge that occurs prior to sampling, along with the degree of brackish seepage from the weathered Hawkesbury Sandstone.

The pH ranges from 3.8 – 7.3 as shown in **Figure 25**.

Monitoring indicates the swamp salinity is within the acceptable range for potable water, however it is generally outside the ANZECC 2000 South Eastern Australia Upland Stream criteria for pH and can be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines, as shown in **Appendix D,** for;

- filtered copper, lead, zinc, nickel, and occasionally aluminium (where its pH exceeds 6.5, which it rarely occurs), as well as;
- total nitrogen, and total phosphorous.

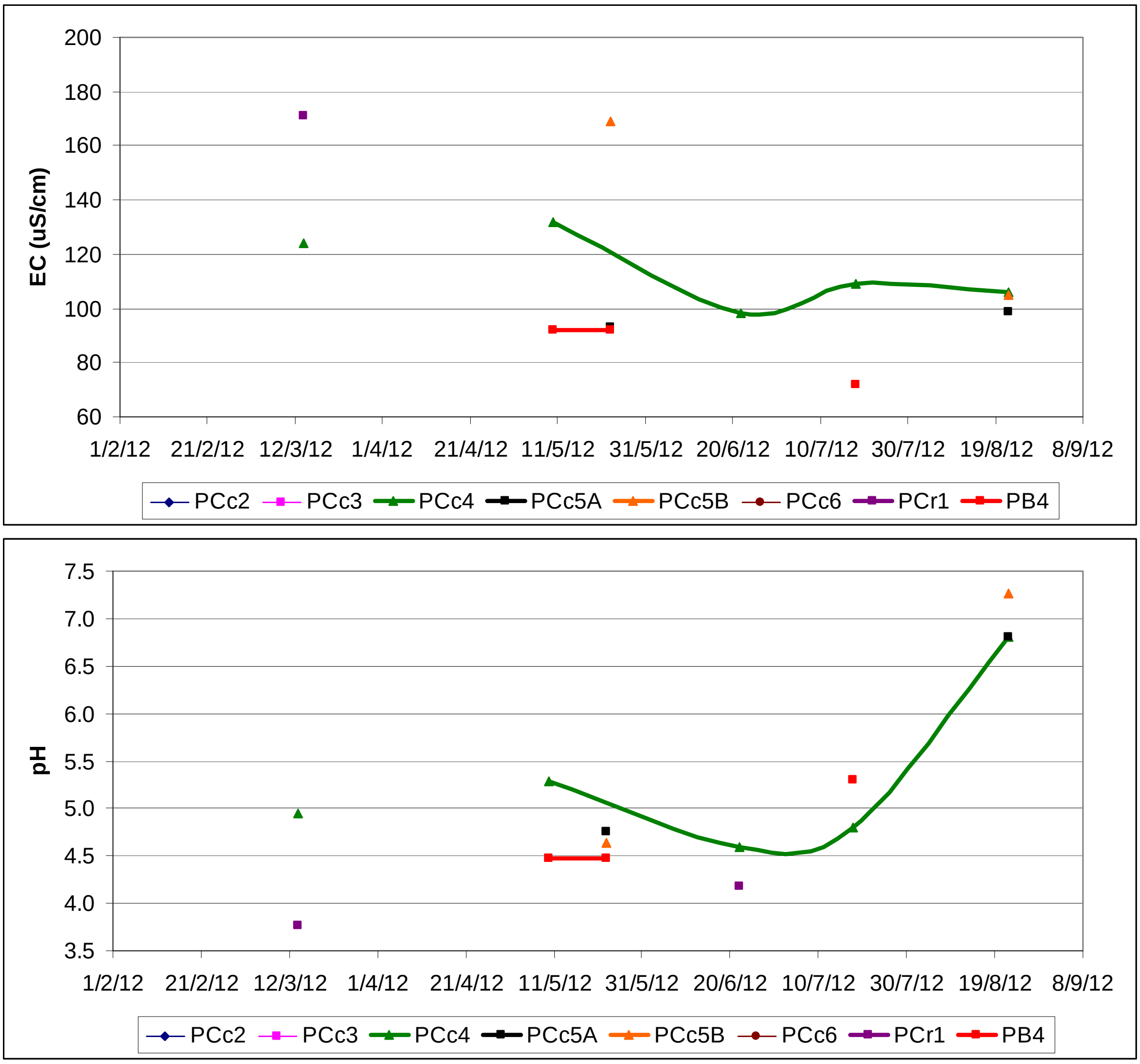


Figure 25 Wonga East Swamps Field Water Quality

10.6.4 Wonga West Basement

Groundwater within the Hawkesbury Sandstone at Wonga West ranges from 81 - 420µS/cm with a pH from 4.1 – 6.7 as shown in **Figure 26**.

The moderate pH acidification and low salinity indicate meteoric rainfall recharge into the Hawkesbury Sandstone, with the salinity and pH range being typical of similar lithologies in the Southern Coalfields.

On the basis that the shallow groundwater discharges through seeps into the local streams, monitoring indicates the groundwater salinity is generally within the acceptable range for potable water, however it is predominantly outside the ANZECC 2000 South Eastern Australia Upland Stream criteria for pH and can be above the ANZECC 2000 95%

Species Protection Level for Freshwater Aquatic Ecosystem Guidelines for:

- filtered copper, lead, zinc and aluminium (where the pH exceeds 6.5, which rarely occurs), as well as;
- total nitrogen and total phosphorous.

Figure 26 **Wonga West Hawkesbury Sandstone Salinity and pH**

10.6.5 Wonga East Basement

Groundwater within the Hawkesbury Sandstone at Wonga East ranges from 76 - 776µS/cm with a pH from 3.2 – 6.8 as shown in **Figure 27**.

The moderate pH acidification and low salinity indicate meteoric rainfall recharge into the Hawkesbury Sandstone, with the salinity and pH range being typical of similar lithologies in the Southern Coalfields.

On the basis that the shallow groundwater discharges through seeps into the local streams, monitoring indicates the groundwater salinity is generally within the acceptable range for potable water, however it is predominantly outside the ANZECC 2000 South

Eastern Australia Upland Stream criteria for pH and can be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines for:

- filtered copper, lead, zinc and aluminium (where the pH exceeds 6.5, which rarely occurs), as well as;
- total nitrogen and total phosphorous.

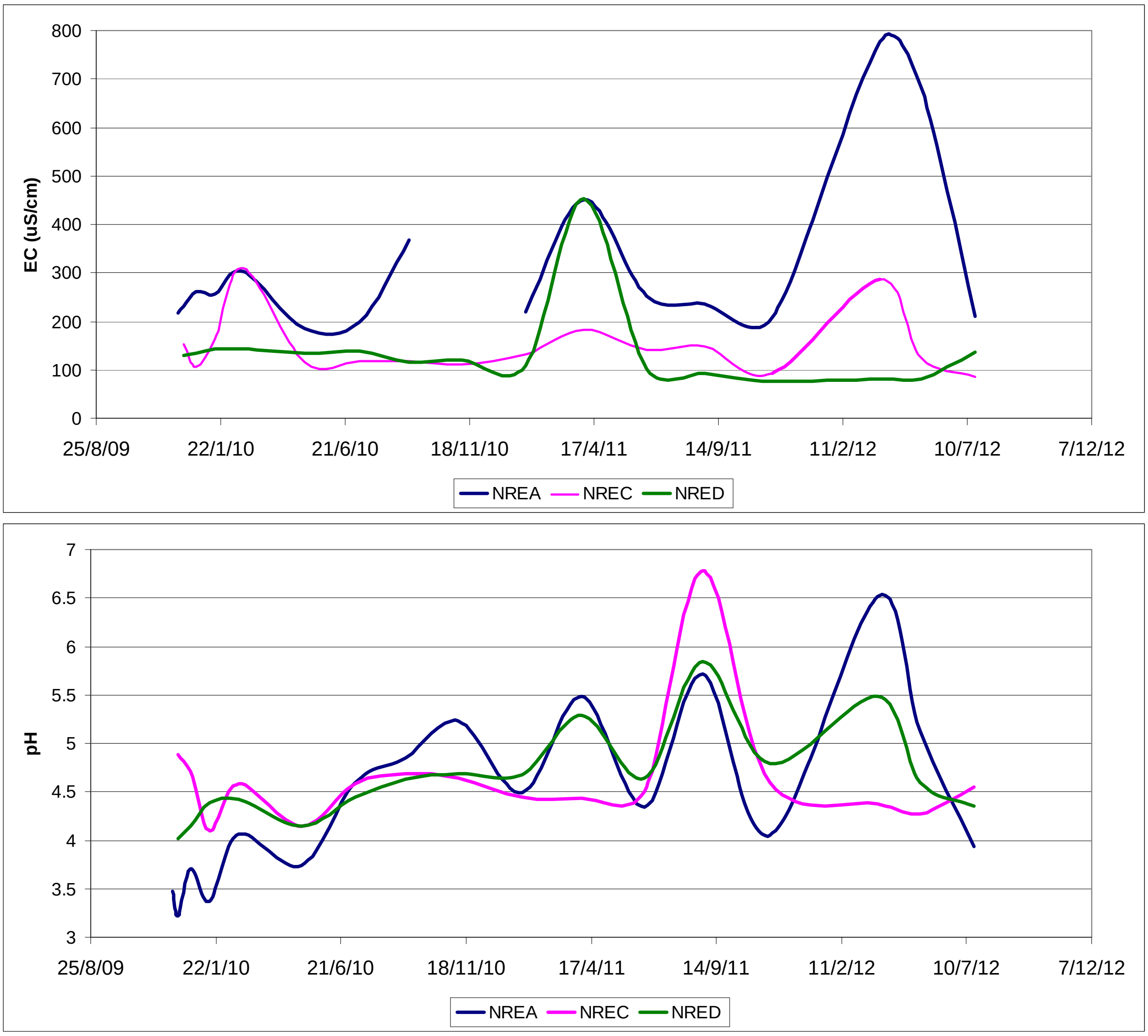


Figure 27 Wonga East Hawkesbury Sandstone Salinity and pH

11. SWAMP SIGNIFICANCE ASSESSMENT

A detailed swamp significance assessment was conducted by (Biosis, 2012) and the reader is referred to this reference for full details.

In summary, the study assessed that thirty-nine (39) upland swamps meet the definition of the Coastal Upland Swamp Endangered Ecological Community within the Wonga East study area and forty-five (45) are located within Wonga West.

The study initially determined that;

- seven (7) swamps in Wonga East, and;
- eight (8) in Wonga West

are considered to be of 'special significance' using OEH criteria.

A subsequent risk assessment, comparative analysis, groundwater assessment, flow accumulation modelling, analysis of strains and assessment of the potential for fracturing of bedrock was undertaken on these 'special significance swamps' as discussed in (Biosis, 2012).

11.1 Bulli PAC Swamp Subsidence Criteria

The Bulli PAC recommended that the threshold for investigation values shown in **Table 9** should be applied to swamps that may be at risk of negative environmental consequences.

It is worth noting, however, that the threshold levels outlined below were obtained primarily from subsided (incised) stream beds and that very little cause / effect monitoring data due to subsidence is available for swamps in the Southern Coalfield.

The Bulli PAC noted that these levels do not conclude that a swamp will be impacted or suffer adverse consequences.

It should be noted that the 200mm valley closure criteria is deemed to be an *"unsatisfactory interim measure"* on page 93 and 94 of the Bulli PAC. It has been omitted from **Table 9** as the total compressive strain of 2mm/m is preferred by the PAC.

Table 9 Bulli PAC Swamp Impact Assessment Thresholds

Parameter	Investigation Criteria
Systematic Tensile Strain	0.5mm/m
Systematic Compressive Strain	2mm/m
Depth of Cover	<1.5 x panel width
Tilt (Transient or Final)	4mm/m
Closure Strain	7.0mm/m

12. GROUNDWATER MODELLING

Assessment of the current and potential mining related impacts due to extraction of the proposed Wongawilli Seam longwalls on the NRE No.1 groundwater systems involved conceptualisation of the local groundwater flow processes, measurement of hydraulic parameters in the field, simulation using computer based mathematical modeling with FEFLOW, imposition of changes brought about by the proposed extraction and assessment of the resulting impacts.

The FEFLOW model structure, modelling approach and simulations generated by Golder Associates Pty Ltd in association with Geoterra Pty Ltd are detailed in **Appendix E**, with the potential groundwater impacts summarised in subsequent sections.

The model provides an assessment of the existing groundwater system status and predicts the potential effects from extraction of the proposed Wongawilli longwalls.

Due to the pre-existing depressurisation from the existing workings in the NRE No.1, as well as the adjoining Cordeaux and Bulli mines, and to minimise the use of assumed water level and hydraulic parameters outside of the study area, the model was set up to represent the current and proposed longwalls at selected time intervals within the model domain. The intervals correlated to the:

- current period;
- end of extracting V-Mains as well as Wonga East Areas 1 and 2;
- end of extraction in Wonga West Areas 3 and 4; and
- 10 years after mining has finished in Wonga West Area 4.

Some uncertainty is present due to the lack of direct field measurement of post subsidence hydraulic conductivities applied to represent sedimentary formations above the existing workings. In addition, assumptions were incorporated regarding the interactive effect of adjoining mines and workings within the overall Study area.

The spatial relationship of the proposed and existing workings within the model domain are shown in **Appendix E**.

It should be noted that the modelling requires simplification of the groundwater system in regard to lithological thicknesses, their hydraulic properties and applied stresses including previous subsidence, rainfall infiltration, creek leakage and underground seepage.

It is also challenging, within the model limitations, to represent steep hydraulic gradients above the mine workings and the potential for zero pore pressure horizons.

12.1 Conceptual Hydrogeological Model

A conceptual model was developed to enable set up of the FEFLOW model using the “standard” Southern Coalfield sequence of Hawkesbury Sandstone at surface, with the Narrabeen Group and Illawarra Coal Measures underlying the Hawkesbury Sandstone.

Lithological layer depths and thicknesses were based on in situ piezometer and coal exploration drilling results within the Gujarat lease area.

Five conceptual groundwater sub-domains are present:

1. a hydraulically disconnected (perched), ephemeral weathered Hawkesbury Sandstone soil / upland swamp profile which provides the majority of baseflow to the local streams and overlies the entire Study area;
2. the deeper Hawkesbury Sandstone, which is hydraulically separated from the overlying Quaternary sediments and weathered sandstone perched aquifers as well as from the underlying Bulgo Sandstone at Wonga West, although not at Wonga East, both before and after subsidence;
3. the Narrabeen Group sedimentary lithologies which have already been locally fractured and depressurised above the existing workings up to the mid to lower Bulgo Sandstone, and are anticipated to be fractured and partially depressurised over the proposed Wongawilli Seam longwall workings up to the mid to upper Bulgo Sandstone;
4. the Illawarra Coal Measures, containing the Bulli, Balgownie and Wongawilli Seam aquifers, which have also been fractured and depressurised by the existing workings and will be locally fractured and depressurised by the proposed workings; and
5. the sedimentary sequence underneath the Wongawilli Seam.

The model was set up with 22 layers to represent both the existing lithological and Bulli / Balgownie Seam subsidence affected areas, and to account for the anticipated change in hydraulic properties following extraction of the Wongawilli workings as discussed in **Appendix E**.

The existing NRE No.1 workings within the model were assumed to be partially flooded in the central southern section of the longwalls to the west of Cataract Reservoir, in the Cordeaux workings, as well as in the Bulli bord and pillar workings.

Where the workings were dry they were modelled with seepage boundaries with head levels set to the elevation of the mine floor to simulate atmospheric pressure. The adjoining Cordeaux and Bulli workings were assumed to be separated from NRE No.1 by at least a 40m wide intact coal barrier.

The Cataract Dam reservoir was represented with a constant head boundary.

Recharge was set at 2% of rainfall in the central, western and eastern recharge zones, with 4% over the multi-seam mined, Bald Hill Claystone eroded sections at Wonga East.

Groundwater pressures or standing water level data from piezometers within the Study area were used, whilst water levels over the Cordeaux and Bulli workings were approximated, as no direct data was available.

Direct measurements of hydraulic parameters from bores within the Gujarat lease were used, and where data was unavailable, approximated parameters were sourced from studies over the BHPB workings to the north (Heritage Computing, 2010).

Underground dewatering was represented by inclusion of the proposed mine voids in the Wongawilli Seam as well as incorporating the associated changes in overburden hydraulic parameters in the overlying sedimentary units due to subsidence.

The post Wongawilli Seam extraction subsidence parameter distribution was based on a conceptual understanding of longwall mine subsidence geomechanics and fracture development as detailed in **Appendix E**.

12.2 Height of Fracturing

The Bald Hill Claystone is interpreted to maintain its semi confining status following subsidence based on the field geotechnical and hydrogeological studies outlined in previous sections, as well as the multi-seam extraction subsidence study (Seedsman Geotechnics, 2012). The subsidence study assessed that the Bulgo Sandstone will not sufficiently deflect to generate free draining connective fracturing through the Bald Hill Claystone to the ground surface.

Previous studies and references on the height of fracturing in NSW and Qld are based on single seam extraction workings, and have not been extrapolated to the proposed multi seam operation at NRE No.1 (Fortser, 1992; Gale, 2008).

The Bald Hill Claystone is not anticipated to act as a semi confining layer between the Hawkesbury Sandstone and Bulgo Sandstone aquifers where it is partially eroded in the mid valley of Cataract Creek, to the east of Cataract Reservoir over the proposed Wonga East workings.

Based on in-situ monitoring, the hydraulic characteristics of strata overlying the existing Bulli and Balgownie Seam longwalls have been altered due to subsidence that may have generated vertical connective fracturing up to the lower Bulgo Sandstone.

Horizontal bedding separation, without vertical free drainage, is modelled above that height to the surface, with the upper 20m also containing increased vertical permeability.

Based on mine pump out monitoring versus rainfall observations, free drainage through vertically connected fracturing to surface streams and the overall catchment is not apparent over the existing workings to the east, to the west or under Cataract reservoir.

In the model, it was assumed that the hydraulic conductivity after extraction of the proposed longwalls could enable free drainage within the goaf, with vertical connective fracturing to the mid / Upper Bulgo Sandstone.

Plastic deformation with bed delamination, without vertical hydraulic connectivity, was interpreted to be present from the mid / upper Bulgo to 20m below surface, whilst enhanced horizontal / vertical fracturing over the Wongawilli Seam longwalls from 20m below surface to the surface was assumed, compared to pre-extraction / subsidence conditions.

No hydraulic conductivity change was assumed in the thin Quaternary alluvial / colluvial soil profile.

12.3 Model Calibration

Due to the complex interactive depressurisation effects of the existing subsidence and adjacent workings on groundwater levels and the predominantly “dry” nature of the NRE No.1 workings, model calibration focussed on matching observed and modelled groundwater levels as discussed in **Appendix E**.

12.4 Sensitivity Analysis

A sensitivity analysis was conducted using increased permeabilities over the existing and proposed Wonga East workings, with possible connective cracking as outlined in **Appendix E**.

In the sensitivity analysis, drawdowns over Wonga East were predicted to be approximately 20m in the upper Hawkesbury Sandstone (Layer 2) with higher stream flow losses in Cataract Creek (up to 0.4ML/day) and higher inflows to the workings (up to 1.4ML/day).

12.5 Effect of Structures

Due to the limitations and constraints inherent with modeling and uncertainty in the location, stratigraphic persistence and hydraulic properties of geological structures in the Study area were not included in the simulation.

13. POTENTIAL SUBSIDENCE EFFECTS, IMPACTS AND CONSEQUENCES

13.1 Stream Bed Alluvium and Plateau Colluvium

There are no anticipated subsidence effects on stream bed alluvium or plateau colluvium as there is no significant accumulation of Quaternary sediments within the studied catchments, outside of the upland swamps, which can reach up to 2.0 m deep.

Where the swamps are absent in the lower catchment, the stream beds are dominated by either exposed sandstone or boulder reaches without significant alluvial deposits.

13.2 Upland Swamps

Due to limitations of the FEFLOW code and the regional scale model set up, the effect of subsidence on the predominantly unsaturated layer in the upland swamps was not conducted in the simulation.

Subsidence could, however, affect swamps directly overlying the proposed longwalls due to either transient and/or spatial changes in porosity and permeability of a swamp or its underlying weathered sandstone substrate through generation of cracks or differential displacement of the perched aquifer.

If a swamp overlies an extracted panel, it may undergo temporary extensional “face line” cracking (perpendicular to the long axis of the panel) as a panel advances, followed by re-compression as the maximum subsidence occurs at any one location.

In addition, where a swamp overlies a longwall, it may also undergo both longer term extensional “rib line” cracking (parallel to the long axis of the panel) along the outer edge and compression within the central portion of a panel’s subsidence trough.

The more susceptible portions of a swamp to increased secondary porosity and / or permeability changes are where it undergoes “rib line” cracking.

Any adverse effects, if they occur, would be related to the extent and degree of cracking that occurs in the underlying weathered sandstone, as cracking is unlikely to manifest in a swamp due to its saturated, clayey, humic, plastic nature.

It should be noted that headwater swamps have undergone up to 1.0m of subsidence, up to 1.5mm/m of strain and up to 4.5mm/m of tilt due to undermining by the Bulli 200 and 300 series longwalls at Wonga West, along with the Bulli bord and pillar, Bulli seam pillar extraction and Balgownie longwall extraction at Wonga East, with no apparent adverse effects on their water holding capacity or ecology.

The swamps were predominantly undermined between 1979 and 1989.

The detailed assessment (Biosis, 2012) identified that for the designated "special significance" swamps, there is a;

negligible likelihood of negative environmental consequences for eight (8) swamps:

- Crus2, Crus3, Lcus1, Lcus6, Lcus26, Lcus27, Wcus1 and Wcus4-vfs

low likelihood of negative environmental consequences for five (5) swamps:

- Ccus4, Ccus10, Crus1, Lcus8 and Wcus11

moderate likelihood of negative environmental consequences for two (2) swamps:

- Wcus4-hws and Wcus7, and;

significant likelihood of negative environmental consequences for two (2) swamps:

- Ccus1 and Ccus5.

Locations of these swamps are shown in **Drawings 2 and 3** and discussed in **Appendix A**.

The changes in storativity and permeability are estimated to have no observable impact above the water level variability due to climatic influences.

Connective cracking to deeper strata is not predicted and as such, it is not anticipated that the swamps could freely drain into the deeper sandstone strata.

Based on observation of previously undermined swamps at NRE No.1 that have undergone similar strains to those predicted due to undermining by the previous Bulli and Balgownie workings, no observable adverse consequences are anticipated on the water holding capacity, water quality or ecosystem health of the majority of swamps, except possibly Ccus1 and Ccus5.

All other designated "special significance" swamps are not anticipated to undergo sufficient compressional or extensional strains to generate cracks in the underlying or adjacent sandstone, and therefore are not anticipated to undergo any adverse effects or consequences from the proposed mining.

It should be noted that, in general, the Wonga East swamps are shallower, less spatially continuous and drier than the Wonga wWest swamps.

Where a swamp straddles a chain pillar or is on the edge of the subsidence bowl, it could experience temporary, localised, re-distribution of perched water levels through differential subsidence of the ground.

Tilting of a swamp could also potentially re-distribute surface runoff, which may lead to potential scouring or erosion if the vegetation does not provide sufficient resistance.

Excessive tilt could also generate a re-distribution of water flow and storage, thereby causing changes to the saturation characteristics which may alter the vegetation associations within a swamp.

Negative environmental consequences may be caused by erosion and drying out of the swamp via channel erosion, by redistribution of water, or by water diversion through connected pathways exposed by buckling or shearing of the underlying sandstone. The swamps, however, contain sediment and organic material that could either seal or reduce water loss into the underlying fracture network.

While all these impacts are possible, no adverse ecological effects on the swamps have been observed with the extensive, up to triple seam, mining that has occurred due to previous mining subsidence (Biosis 2012).

13.2.1 Seepage Baseflow from Swamps to Streams

Upland swamp water is stored within the shallow, perched, ephemeral groundwater system, whilst regional water is contained within the deeper Hawkesbury Sandstone aquifers.

Lowering of the shallow, perched water table may occur within Wallandoola Creek valley fill swamp Wcus7 after extraction of longwalls WW-A3-LW3 and WW-A3-LW4 through development of new cracks in the underlying low permeability weathered sandstone, which could enable partial drainage of swamp water into the sandstone.

Empirical observation and field mapping (Biosis, 2012) indicates that past undermining of swamps in the Gujarat lease area has not generated adverse ecological effects on swamps. It is therefore anticipated that observable reduction of swamp discharge to the study area catchments will not occur following subsidence across the subject catchment areas, although generation of potentially enhanced leakage from the base of the swamps may occur.

Seepage from the swamp is currently highly ephemeral, with the volume and duration of baseflow being directly related to the degree of rainfall recharge and stream flow in the catchment.

It is not anticipated that the ephemeral water levels or baseflow seepage will be significantly adversely affected in the other headwater and valley fill swamps in the study area following the proposed mining as outlined in (Biosis, 2012).

13.2.2 Swamp Erosion

Changes in flow regimes within swamps can result in changed flow paths or runoff characteristics within a swamp, with the potential for development of nick points, scouring and erosion.

Valley infill swamps are considered more susceptible to scouring and erosion due to increased flow rates through these swamps (Biosis, 2012).

Headwater swamps are less susceptible to erosion and scouring as:

- lower flow rates within headwater swamps result from more dispersed sheet flow across the swamp;
- they have less reliance on perched ephemeral groundwater systems compared with valley infill swamps, and;
- they are less susceptible to non-conventional subsidence effects, such as valley

closure, buckling and shearing.

Dewatering and drying of swamps due to subsidence fracturing of the bedrock may increase the erosion potential of swamps. Drying, in conjunction with fire and substantial rainfall, can increase the susceptibility of swamps, particularly valley fill swamps, to erosion. However, it is often the case that no single factor can be directly implicated in enhanced erosion of upland swamps (Biosis, 2012).

The only swamp in the NRE1 lease area that has undergone notable erosion is the valley fill swamp Lcus4.

Although erosion of swamps is possible where elevated tilts occur due to subsidence, it is only generally valley fill swamps which have been directly undermined that are susceptible to erosion and scouring.

As no valley fill swamps are proposed to be directly undermined, then it is not anticipated that swamp erosion and / or scouring is a high risk impact due to the proposed mining.

Although swamp Wcus7 is not proposed to be directly undermined, it is sufficiently close to longwalls WW-A3-LW3 and WW-A3-LW4 that it is at risk of undergoing some degree of erosion or bed scouring.

Further detailed discussion of swamp erosion and scouring is contained in (Biosis, 2012).

13.3 Basement Groundwater Levels

Cross sections of the modelled depressurisation after mining in Wonga East Area 2 and V Mains, followed by the end of mining at Wonga East Area 4 are shown in **Figures 28** and **29**, and are discussed in the following sections.

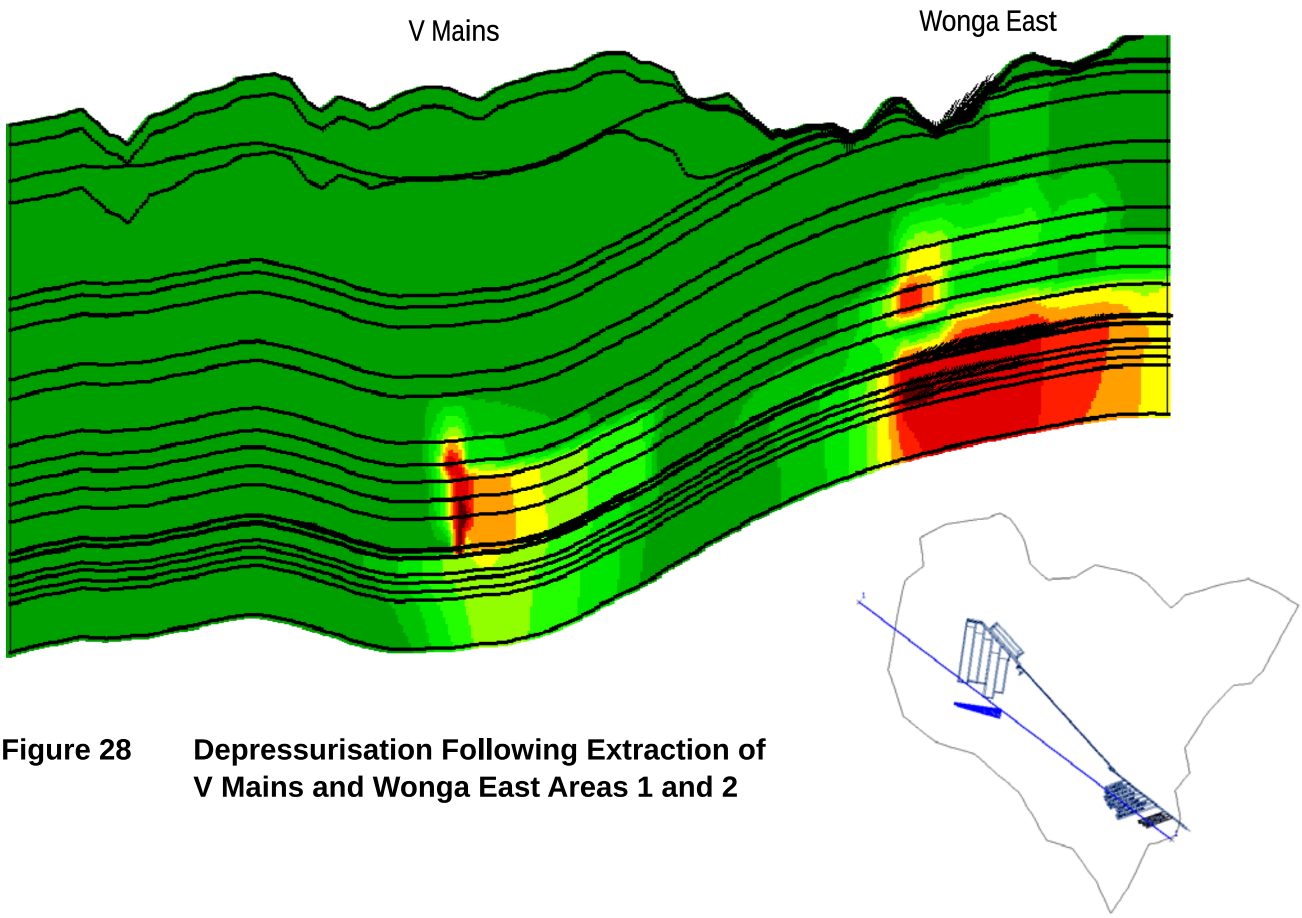


Figure 28 **Depressurisation Following Extraction of V Mains and Wonga East Areas 1 and 2**

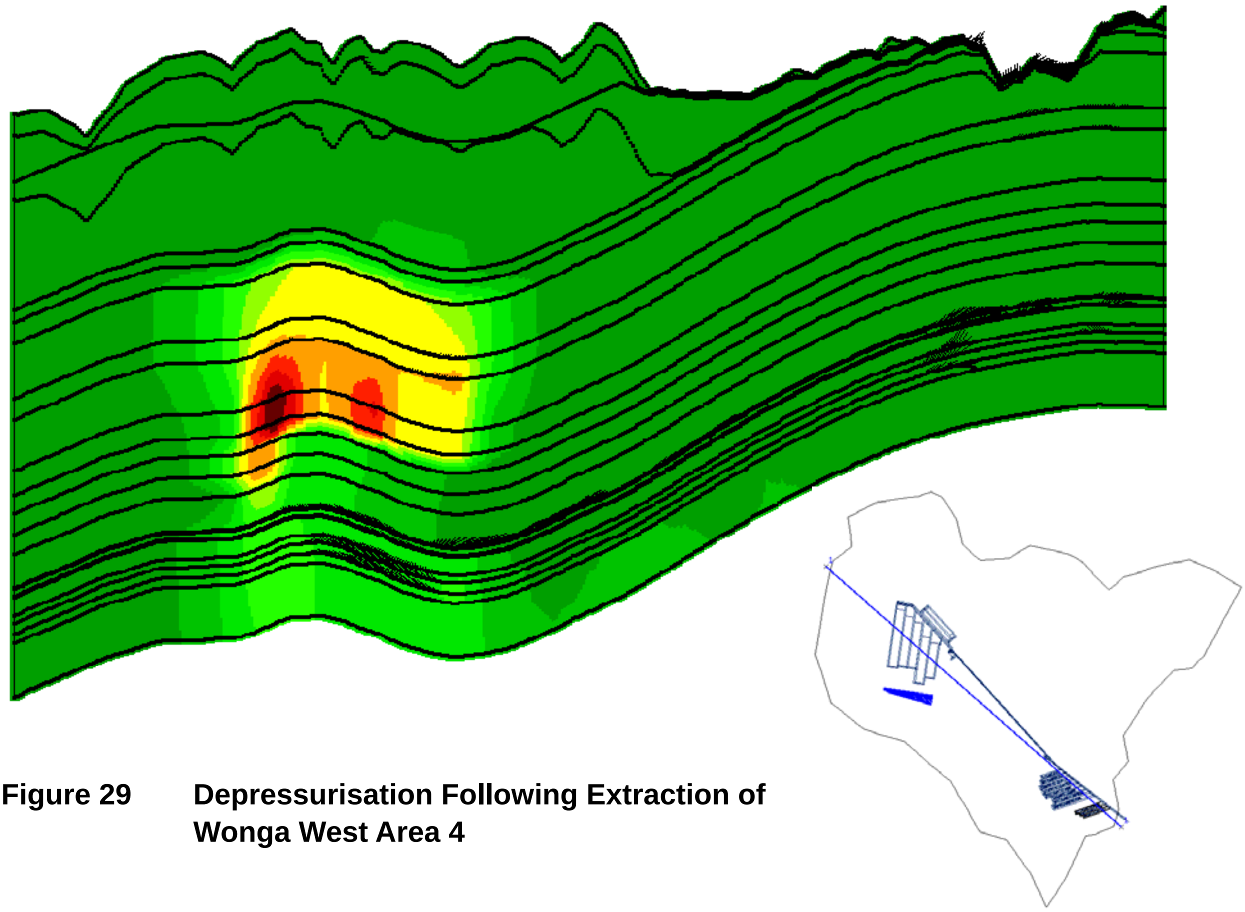


Figure 29 Depressurisation Following Extraction of Wonga West Area 4

13.3.1 Shallow, Perched, Ephemeral, Hawkesbury Sandstone

Perched, ephemeral, shallow groundwater within the upper Hawkesbury Sandstone (Layer 1) could undergo a water level reduction over the proposed workings following subsidence.

However, as the “ephemeral” shallow Hawkesbury Sandstone aquifers dissipate after extended dry periods, the effect on the mostly unsaturated, disconnected, perched aquifers with limited extent was not modelled.

Subsidence of Layer 1 is not anticipated to have a significant overall effect on stream baseflow or stream water quality where the temporary aquifers seep into local catchments. However, temporary, localised effects may be observed.

13.3.2 Upper Hawkesbury Sandstone

The upper Hawkesbury Sandstone aquifer extends across the study area, with drilling and piezometer data indicating water levels ranging from 10 – 40m in Wonga West and 1.1 – 26.7m below surface in Wonga East.

It should be noted that the monitored water level is affected by semi-confined head pressures, whereas the first drilling water intercept, which indicates the upper bound of the aquifer, varied from 18 – 40m at Wonga West and 17 – 48m below surface in Wonga East.

Once the piezometer is completed, subsequent water level measurements indicate a combination of head pressure in the aquifer, variability of recharge or other factors.

Based on past experience in the Southern Coalfields, the upper regional Hawkesbury Sandstone water levels can rise by up to 2m ahead of a piezometer being undermined, then reduce by up to 15m after development of cracking and additional secondary void space (porosity) in the aquifer.

The reduced water level is generally regained over a few months, depending on rainfall recharge in the catchment and the post subsidence seepage rate, if it occurs, to local streams. Complete re-establishment of the pre-mining water level generally, although may not fully, occur.

Modelling of Layer 2 (Hawkesbury Sandstone Upper 2) after the end of mining in Wonga East Areas 2 and V Mains indicates up to 4m of drawdown over Wonga East in **Figure 30** and up to 12m at Wonga West when mining is completed in Area 4 as shown in **Figure 31**.

Following mining, as has been observed in the piezometers to the east of the reservoir, the upper sandstone water levels exhibit a heightened response to recharge, or lack of recharge due to the higher porosity, as well as interconnected permeability of the aquifer.

As shown in **Figure 32**, 10 years after mining has been completed in Area 4, up to 12m of water level recovery is predicted, although localised ongoing depressurisation of up to 10m may be present under the upper Wallandoola and Lizard Creek catchments.

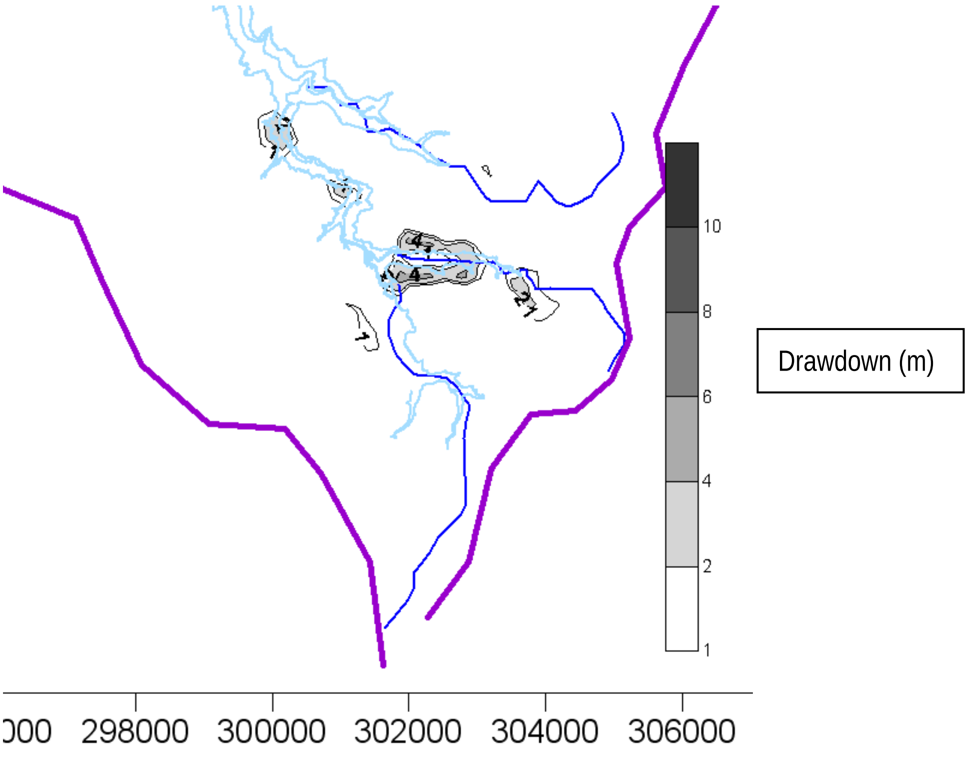


Figure 30 Upper Hawkesbury Sandstone (Layer 2) Drawdown After Mining Wonga East Areas 1 and 2 and V Mains

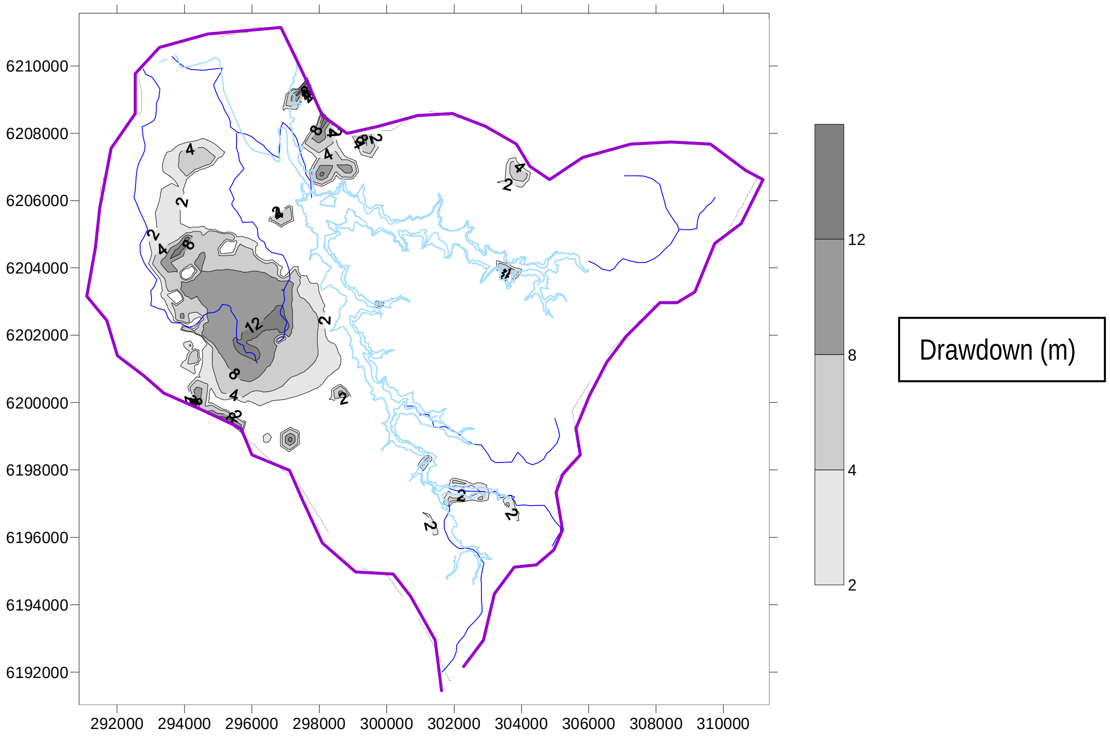


Figure 31 Upper Hawkesbury Sandstone (Layer 2) Drawdown After Mining Wonga West Areas 3 and 4

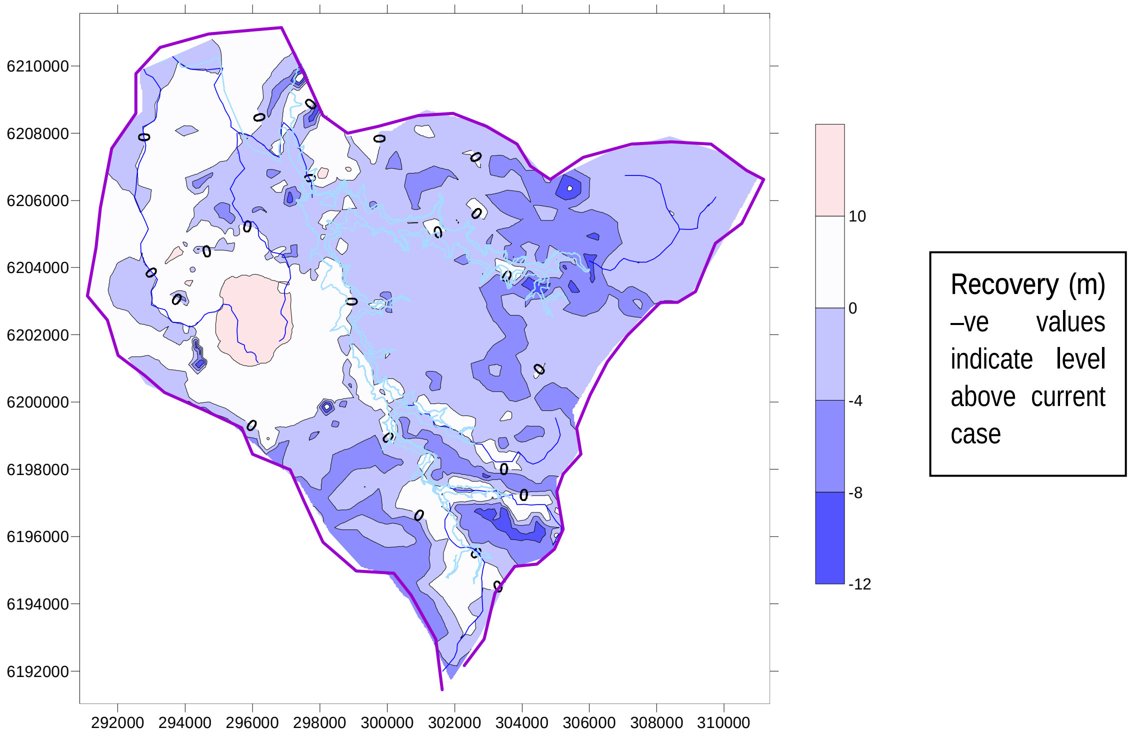


Figure 32 Upper Hawkesbury Sandstone (Layer 2) Recovery 10 Years After Mining Area 4

13.3.3 Lower Hawkesbury Sandstone

Modelling of Layer 4 (Hawkesbury Sandstone Lower 2) after the end of mining at Wonga East Area 2 indicates up to 4m of drawdown as shown in **Figure 33.**

After mining Wonga West Area 4, up to 4m of drawdown is predicted over Wonga East and up to 12m over Wonga West when mining is completed at Wonga West as shown in **Figure 34**.

Figure 35 indicates that 10 years after Area 4 is completed, up to 20m of water level recovery is predicted at Wonga East, although localised depressurisation of up to 6m may be present under the plateau between the headwaters of Lizard and Wallandoola Creeks.

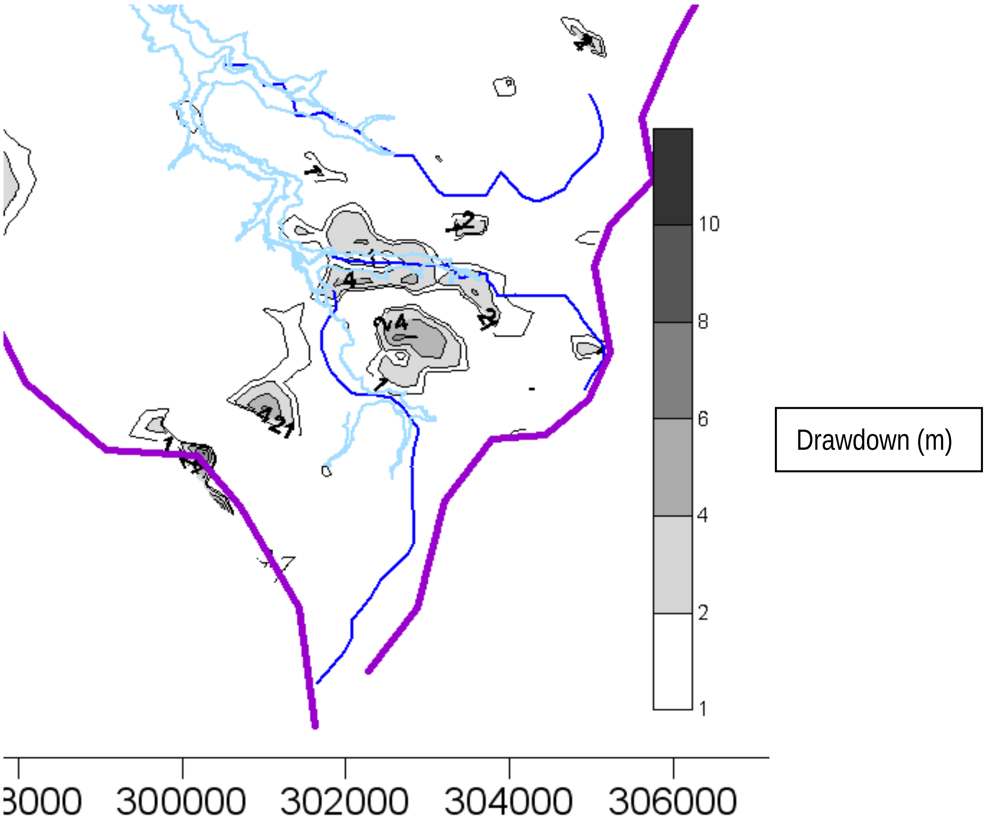


Figure 33 **Lower Hawkesbury Sandstone (Layer 4) Drawdown After Mining Wonga East Areas 1, 2 and V Mains**

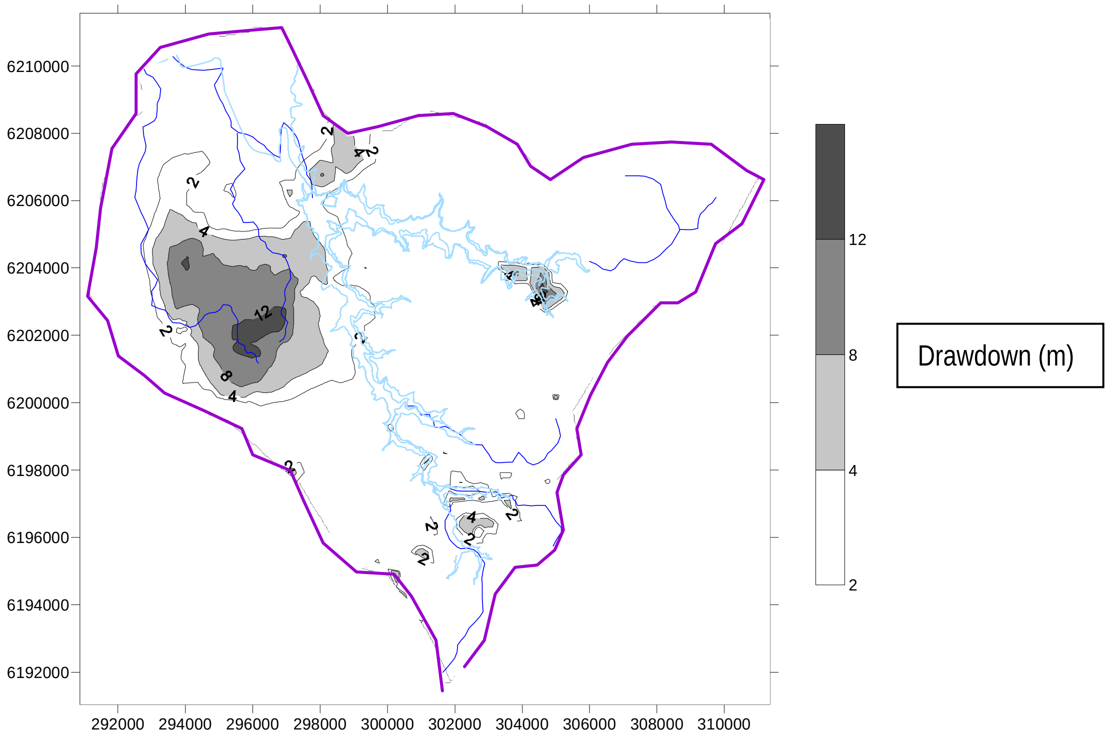


Figure 34 Lower Hawkesbury Sandstone (Layer 4) Drawdown After Mining Wonga West Area 4

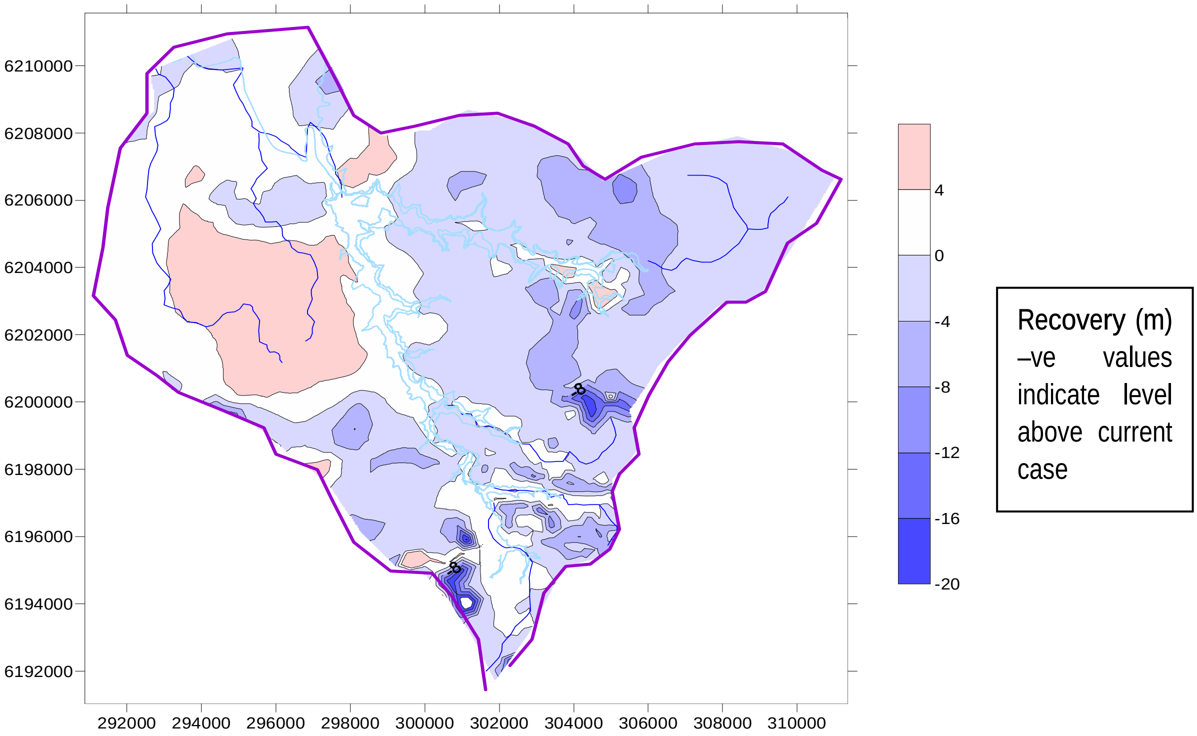


Figure 35 Lower Hawkesbury Sandstone (Layer 4) Recovery 10 Years After Mining Area 4

13.3.4 Upper Bulgo Sandstone

Based on geotechnical predictions (Seedsman Geotechnics, 2012) that predict maintenance of its semi confining properties following subsidence, the Bald Hill Claystone is not modelled to enable free drainage depressurisation from the Hawkesbury Sandstone through to the underlying Bulgo Sandstone.

Modelling of Layer 7 (Bulgo Sandstone Upper 1) after the end of mining Wonga East Area 2 indicates up to 8m of drawdown over Wonga East and V Mains as shown in **Figure 36.**

At the completion of Wonga West Area 4, up to 5m drawdown is predicted over Wonga East and up to 100m over Wonga West as shown in **Figure 37**.

Figure 38 indicates that 10 years after mining has been completed in Area 4, groundwater levels recover by up to 30m at Wonga East, and remain depressurised by up to 110m over Wonga West.

The degree of drawdown increases with increasing depth towards the workings in the upper, mid to lower Bulgo Sandstone in association with an upward migration of zero pore pressures over subsided Wongawilli longwalls.

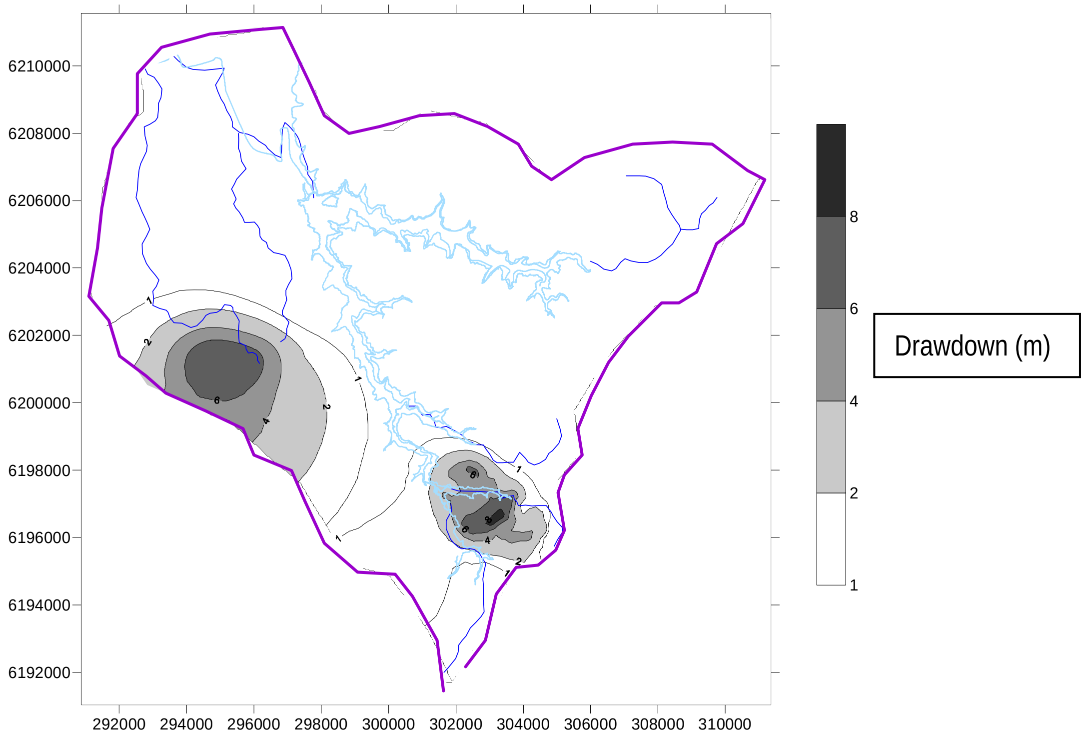


Figure 36 Upper Bulgo Sandstone Drawdown After Mining Wonga East Areas 1, 2 and V Mains

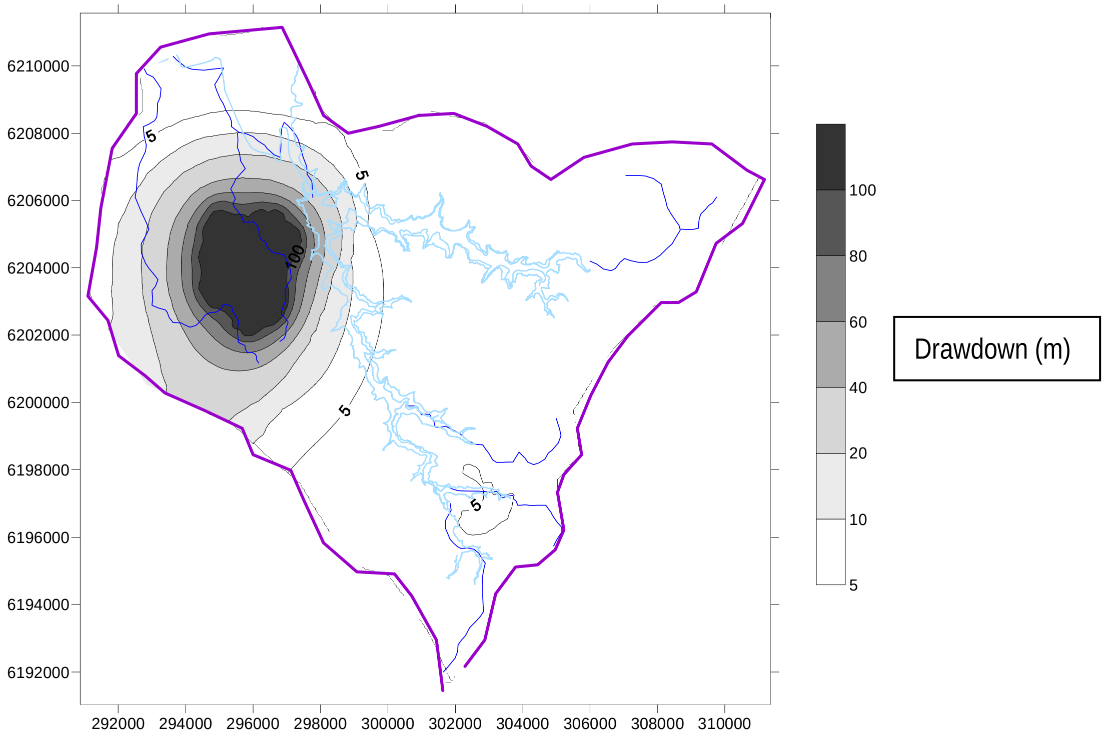


Figure 37 Upper Bulgo Sandstone Drawdown After Mining Wonga West Area 4

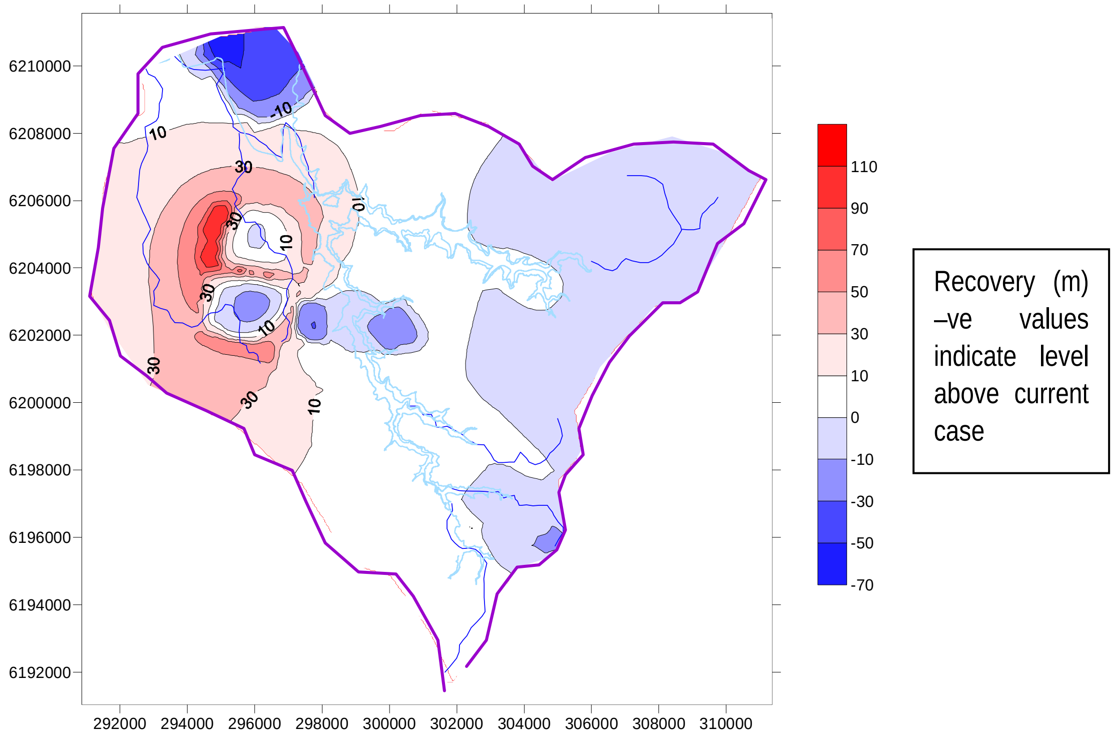


Figure 38 Upper Bulgo Sandstone Recovery 10 Years After Mining Area 4

13.3.5 Scarborough Sandstone

Modelling of Layer 12 (Scarborough Sandstone) after the end of mining Wonga East Area 2 and V Mains indicates up to 40m of drawdown at Wonga East and 110m over V Mains as shown in **Figure 39.**

Drawdowns of up to 20m over Wonga East and 140m over Wonga West are predicted when mining is completed at Wonga West Area 4 as shown in **Figure 40**.

Figure 41 indicates that 10 years after mining has been completed in Area 4, water levels are predicted to recover by up to 60m over Wonga East and by up to 120m over Wonga West.

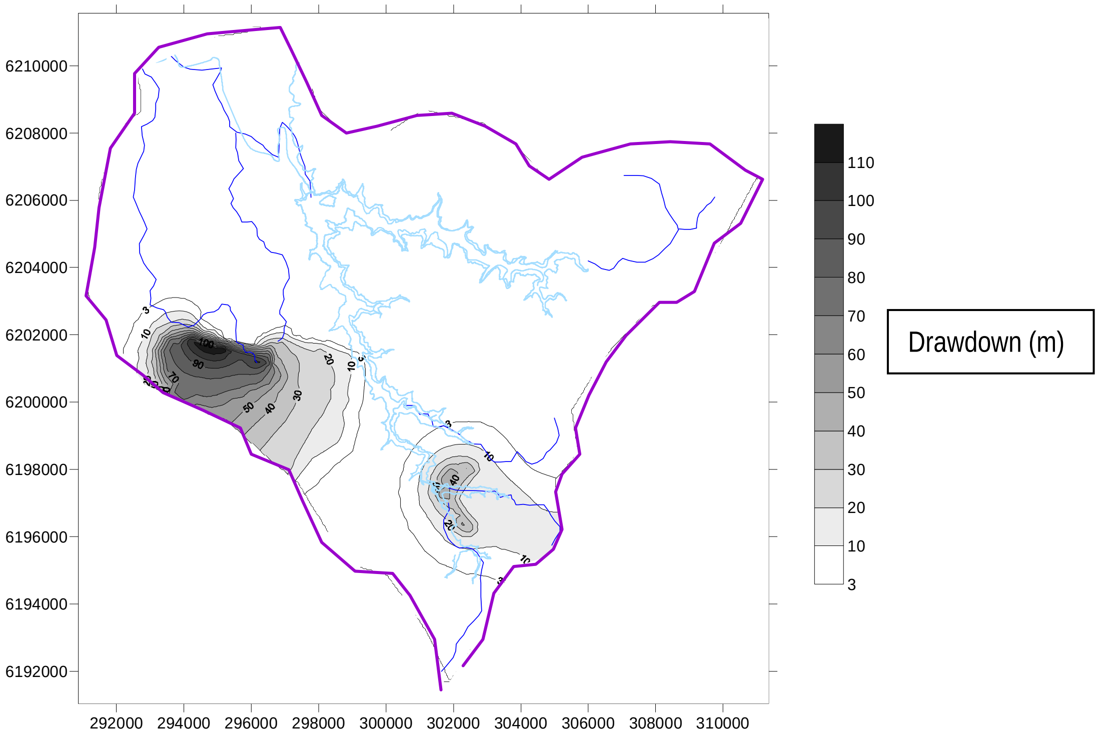


Figure 39 Scarborough Sandstone Drawdown After Mining Wonga East Area 2 and V Mains

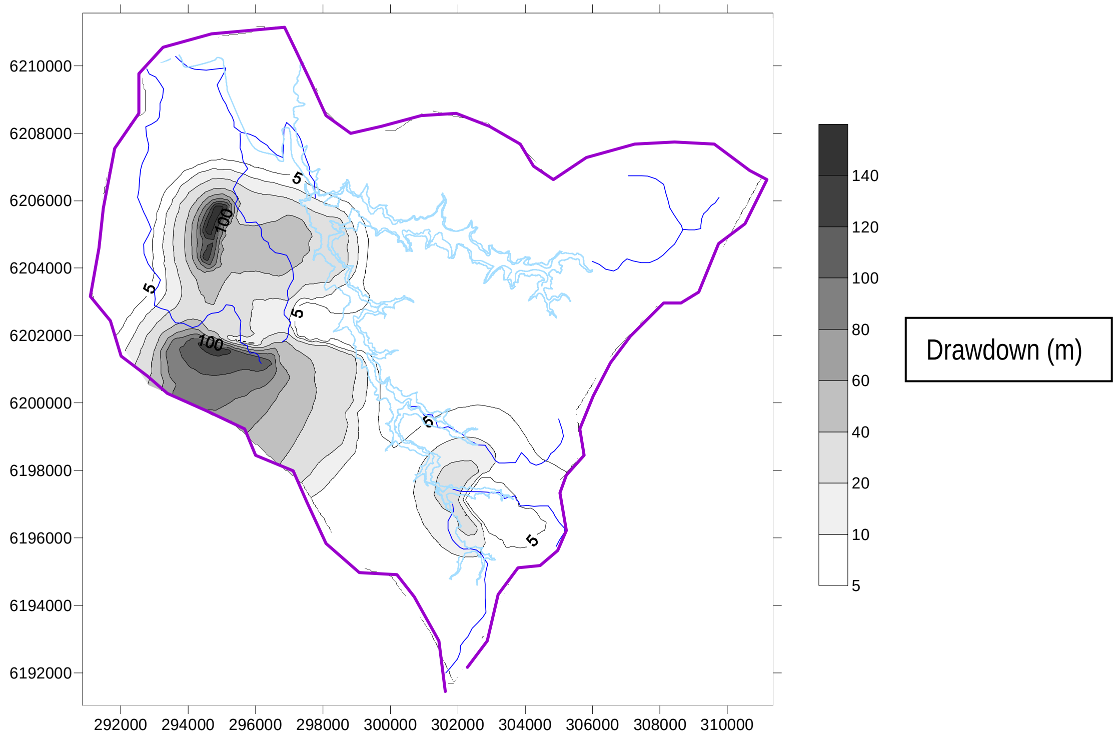


Figure 40 Scarborough Sandstone Drawdown After Mining Wonga West Area 4

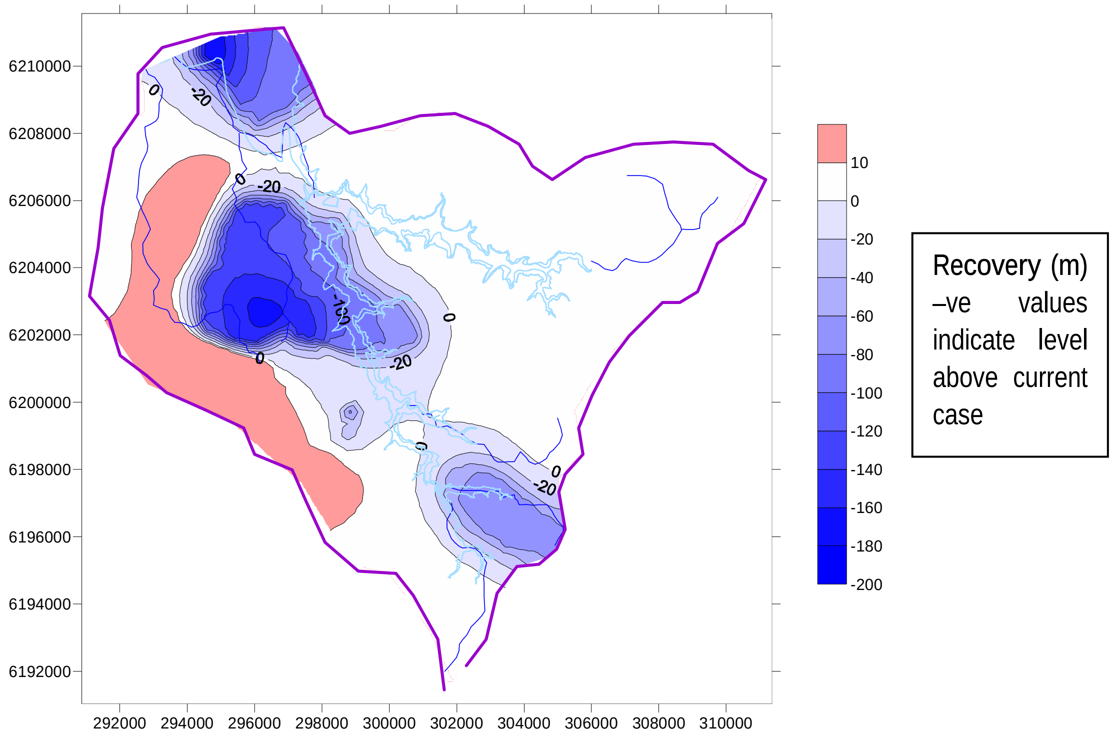


Figure 41 Scarborough Sandstone Recovery 10 Years After Mining Area 4

13.3.6 Bulli Seam

As shown in **Appendix E**, drawdown in the Bulli Seam at the end of mining Wonga East Area 2 and V Mains reaches up to 40m over Wonga East and up to 130m over V Mains.

At the completion of Area 4, Wonga East is predicted to be depressurised by approximately 10m, and Wonga West by up to 120m.

Ten years after mining is completed in Area 4, the Bulli Seam is modelled to recover by up to 110m above the present day levels at Wonga East and up to 190m over Wonga West.

13.3.7 Wongawilli Seam

Drawdown in the Wongawilli Seam at the end of mining Wonga East Area 2 and V Mains is modelled to reach up to 50m over Wonga East and up to 60m over Wonga West / V Mains as shown in **Appendix E**.

Figure 42 indicates that at the end of mining Wonga West Area 4, depressurisation is modelled to reach up to 40m over Wonga West and up to 90m over the Wonga East and main drive workings.

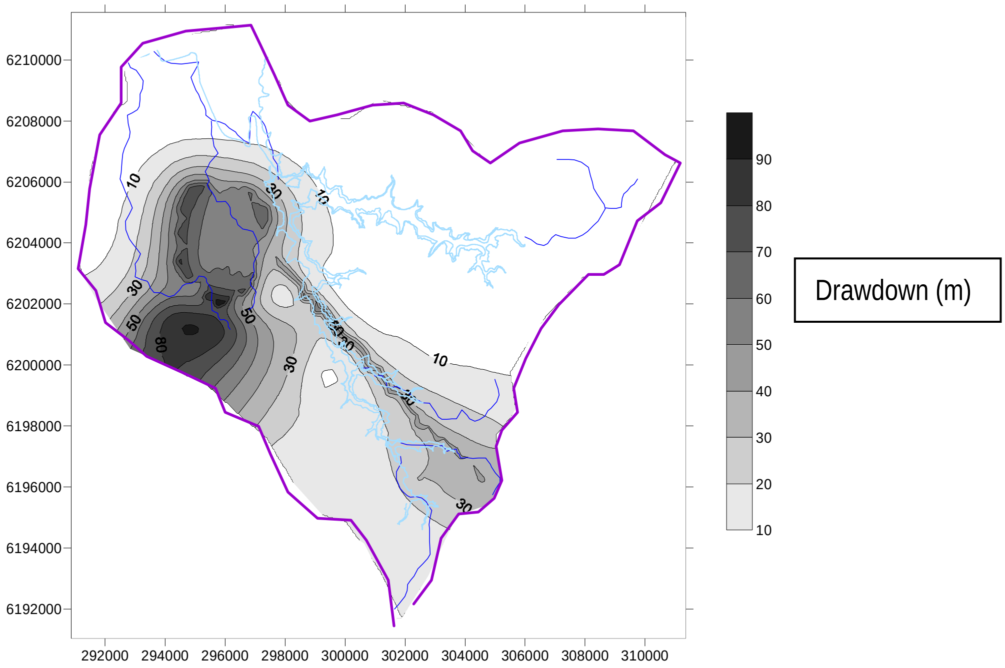


Figure 42 **Wongawilli Seam Drawdown After Mining Area 4**

Ten years after mining is completed, the Wongawilli Seam is modelled to recover by up to 160m above the present day levels at Wonga West and up to 100m over Wonga East as shown in **Figure 43** and **Appendix E**.

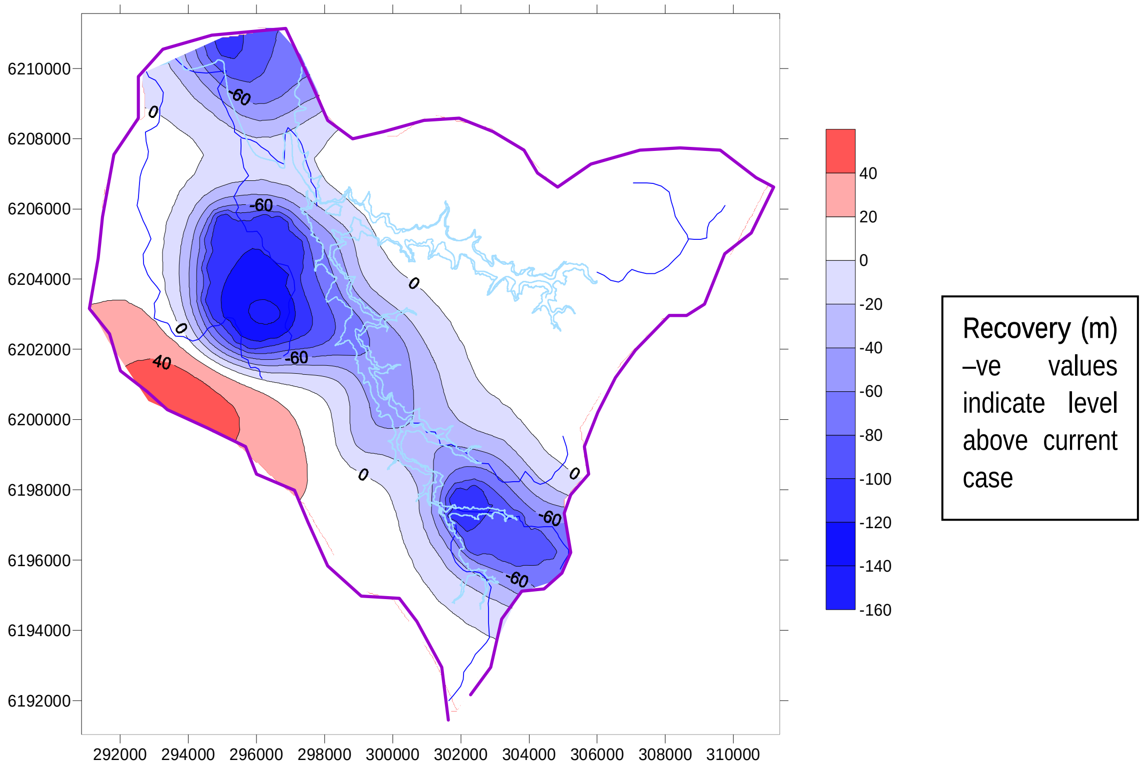


Figure 43 Wongawilli Seam Recovery 10 Years After Area 4

13.4 Stream Flow and Groundwater Connectivity

A number of mechanisms can potentially occur within shallow groundwater systems associated with streams as follows:

- direct flow of surface water into mining induced fracture systems and vertical drainage into the shallow basement groundwater system;
- flow of surface water from the “gaining – connected” or “gaining – disconnected” streams into the shallow groundwater system migrating along the local hydraulic gradient and re-emerging further down gradient in the catchment, with no hydraulic connection to the workings where the Bald Hill Claystone does not undergo subsidence related connective fracturing;
- reversal of water transfer from the shallow groundwater system to the “losing – disconnected” streams during periods of high recharge; or
- flow of stream water into the shallow groundwater system migrating along the hydraulic gradient to emerge further downstream within other groundwater catchment regimes.

Tracer tests using fluorescent dyes, or salts or other ecologically suitable markers can be used to assess the potential connection and through flow paths between stream and shallow groundwater systems. Although they have not been used in the Gujarat lease area to date, they could be used if required.

13.4.1 Cataract Creek

The geotechnical subsidence assessment conducted for this project proposal (Seedsman Geotechnics, 2012) concluded the multi-seam mined Bulli and Balgownie Seam workings at Wonga East have collapsed the majority, if not all, of the overburden sequence, and it was assessed there is no spanning capacity left in the Bulgo Sandstone directly above the proposed Wongawilli Seam longwalls.

Observations over longwall WE-A2-LW4, which was mined in the Wongawilli Seam, indicates that due to the previously fractured nature of the overburden above the Bulli and Balgownie Seam workings the subsidence “bowl” did not effectively extend outside of the longwall footprint (SCT Operations, 2012) and (Seedsman Geotechnics, 2012A).

In the multi-seam mined area, even though horizontal bedding subsidence displacement may have extended up into the upper Bulgo Sandstone, this does not mean a direct, free vertical drainage hydraulic connection is present from the surface to the workings.

Monitoring of mine water pump-out from workings to the east of Cataract Reservoir, along with prolonged observations from underground supervisors (S Wilson, Gujarat NRE, pers comm.) indicate there is no observed associated short term increase in mine water make from the current workings following significant rain in the Cataract Creek, Bellambi Creek or Cataract River (upstream of the reservoir) catchments over the Bulli, Balgownie and Wongawilli Seam workings.

Monitoring of water level trends in piezometer NRE-A over the multi-seam mined area indicates the upper Hawkesbury Sandstone down to the Upper Bulgo Sandstone lithologies have an enhanced response to rainfall recharge. However, no adverse effect on stream flow has been observed as the headwater tributaries and main channel of Cataract Creek have had continuous flow throughout the monitoring period.

The bord and pillar mined areas represented by the open standpipe and vibrating wire piezometers at NRE-B, C and D have a limited to minor response to rainfall recharge.

Where only Bulli seam first workings have been extracted, the proposed narrow longwalls and wide pillars are not predicted to destabilise the Bulli seam pillars sufficiently to cause fracturing or displacement that will extend into the upper Bulgo Sandstone (Seedsman Geotechnics, 2012).

This means there will be no predicted free drainage connection from surface to seam in these areas.

Beneath the plateau over the multi-seam mined Bulli and Balgownie workings between Cataract Creek and Bellambi Creek, extraction of the proposed longwalls is modelled to generate up to 4m of depressurisation in the upper Hawkesbury Sandstone at the end of mining Wonga East Area 2.

The modelled, localised reduction is anticipated to reduce the regional phreatic surface gradient from the plateau to the creek, as well as toward Cataract reservoir, thereby potentially reducing baseline seepage flow volumes to the creek and dam.

It is also possible that, if they exist, the location of seepage outflow points may be relocated up to 4m lower down in the catchment.

Based on the groundwater contours shown in **Drawing 8**, the modelled reduction in the upper Hawkesbury Sandstone phreatic surface over the proposed workings represents a change in gradient of flow toward Cataract reservoir from 0.021 to 0.019.

On the basis that there is no direct free drainage flow path to the workings, which is supported by water pumping monitoring in the current workings, the water level decline will be temporary, as the water table is anticipated to recover from 4 – 12m once the mining at Wonga East has been completed and dewatering in the area is restricted to keeping the main access drive dry.

Stream flow modelling indicates the average daily flow from Cataract Creek to Cataract reservoir is 11.73ML/day (WRM Water & Environment, 2012).

Modelled groundwater flow diagrams indicating the current, post Stage 1 (Area 2 and V Mains) as well as the post Stage 2 (Area 4) in the upper Hawkesbury Sandstone are shown in **Figure 44**.

The groundwater modelling predicts a 0.06ML/day loss of stream flow in the Cataract Creek catchment at the end of mining Area 2 and 0.07ML/day at the end of Area 4 as shown in **Table 10**.

The modelled changes are therefore relatively minor (0.5 – 0.6%) compared to the average flow in the creek to the Cataract Reservoir.

Table 10 Modelled Cataract Creek Stream Flow Changes

	Creek Catchment Area (km2)	Creek Flow Loss (ML/day)	Creek Flow Gain (ML/day)	Net Result (ML/day)	Change due to Proposed Mining Compared to Current Stage (ML/day)
Current	5.2	- 0.03	+ 0.36	0.33 (gaining)	-
End of Mining Area 2	5.2	- 0.04	+ 0.31	0.27(gaining)	0.06 (0.0115 ML/km^2/day) or 0.5% loss
End of Mining Area 4	5.2	- 0.04	+ 0.30	0.26 (gaining)	0.07 (0.0135 ML/km^2/day) or 0.6% loss

13.4.2 Cataract Creek, Cataract River (Upstream of Cataract Reservoir) and Bellambi Creek

Although groundwater level reductions are predicted over the Wonga East workings, the majority of the changes are contained within the Cataract Creek catchment, and as such, there is anticipated to be no observable change in stream flow or groundwater seepage in the Cataract River (upstream of Cataract Reservoir) and Bellambi Creek catchments due to the very low proportion of the two catchments that may be partially depressurised.

Modelled groundwater flow diagrams indicating the current, post Stage 1 (Area 2 and V Mains) as well as the post Stage 2 (Area 4) in the upper Hawkesbury Sandstone are shown in **Figure 44**.

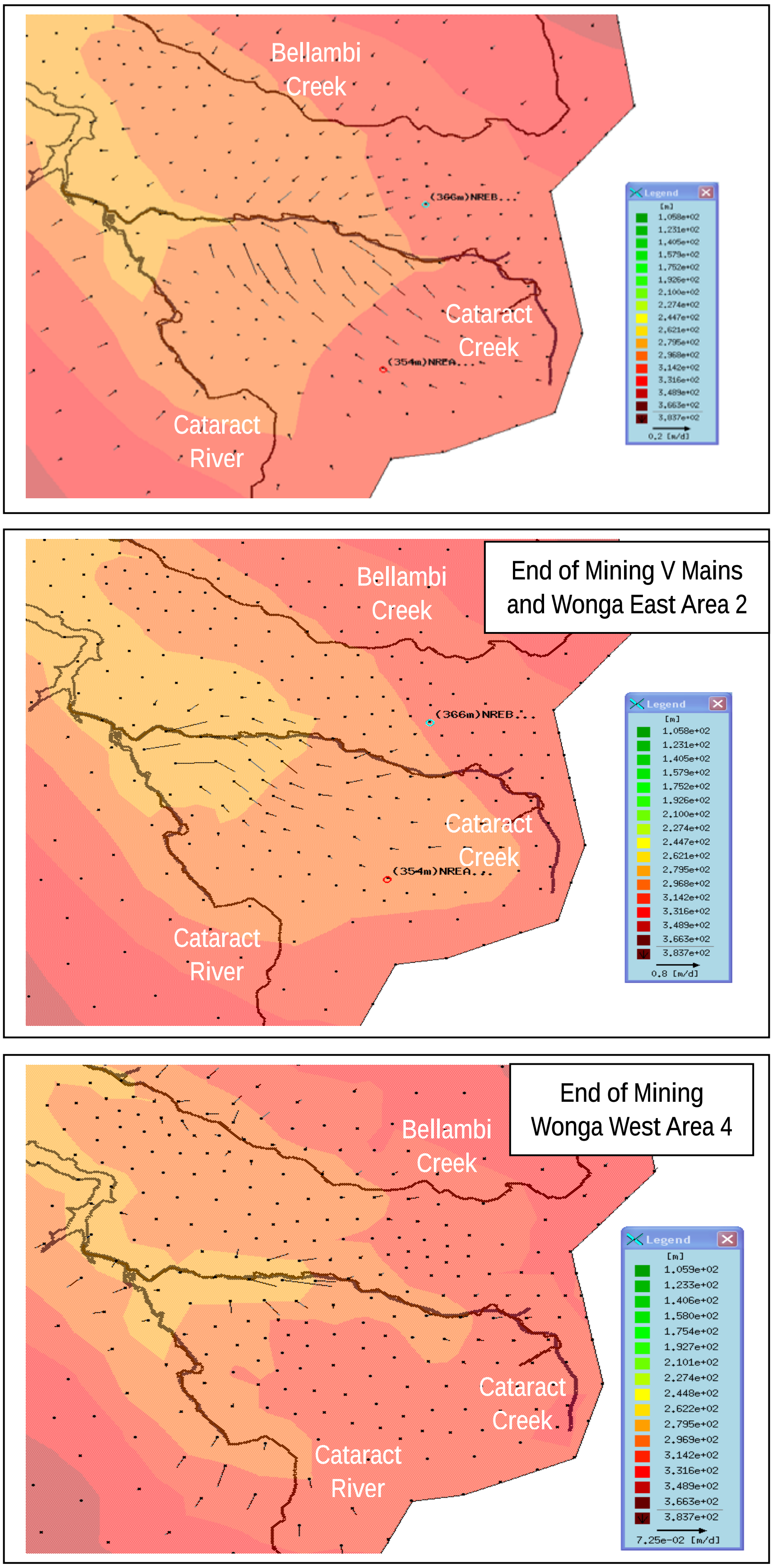


Figure 44 Wonga East Upper Hawkesbury Sandstone Groundwater Flow

13.4.3 Lizard and Wallandoola Creeks

The subsidence assessment (Seedsman Geotechnics, 2012) concluded that where the 200 and 300 series Bulli seam longwalls have been extracted, mining of the proposed Wongawilli Seam longwalls is predicted to generate constrained deflection, without deformation failure of the Bulgo Sandstone.

On this basis, vertical hydraulic fracture connection from the Bulgo Sandstone to the Hawkesbury Sandstone, through the Bald Hill Claystone is not predicted to be enhanced.

The mid to upper Bulgo Sandstone to lower Hawkesbury Sandstone is interpreted to remain as a vertical flow constrained zone following extraction of the Wongawilli Seam without enhanced vertical drainage.

This means that free draining hydraulic connection between the surface water system to the mine workings is not anticipated.

Extraction of the proposed longwalls is modelled to generate up to 12m of depressurisation in the upper Hawkesbury Sandstone (in Layer 2) in the upper headwaters of the Lizard and Wallandoola Creek catchments at the end of mining Area 4.

The modelled, localised reduction in the headwaters is not anticipated to reduce the overall phreatic surface gradient toward Cataract River (downstream of the reservoir), although there may be some lowering of seepage outflow elevation by up to 12m from the upper Hawkesbury Sandstone in the “gaining” reaches of the creeks downstream of the major waterfalls L1 and W1.

No effect on seepage point location or flows are anticipated in the “losing” reaches, upstream of the waterfalls, as the streams and regional groundwater are currently disconnected, and there is no currently observed regional groundwater seepage into the creeks in these reaches.

Stream flow modelling indicates the average daily flow from Lizard Creek and Wallandoola Creek to the Cataract River is 17.0ML/day and 33.0ML/day respectively (WRM Water & Environment, 2012).

Modelled groundwater flow diagrams indicating the current, Stage 1 and Stage 2 sequences in the upper Hawkesbury Sandstone (Layer 2) are shown in **Figure 45**.

The groundwater modelling predicts a 0.02ML/day gain of stream flow in the Lizard Creek catchment at the end of mining Area 2, followed by a 0.10ML/day loss at the end of Area 4 as shown in **Table 11**. The modelled changes are therefore relatively minor (0.12% gain to a 0.6% loss) compared to the average flow from Lizard Creek into Cataract River.

The groundwater modelling also predicts a 0.06ML/day loss of stream flow in the Wallandoola Creek catchment at the end of mining Area 2, followed by a 0.25ML/day loss at the end of Area 4. The modelled changes are therefore relatively minor (0.18% to 0.76% loss) compared to the average flow from Wallandoola Creek into Cataract River.

Table 11 Modelled Lizard And Wallandoola Creek Stream Flow Changes

	Creek Catchment Area (km^2)	Creek Flow Loss (ML/day)	Creek Flow Gain (ML/day)	Net Result (ML/day)	Change due to Proposed Mining Compared to Current Stage (ML/day)
Lizard Creek					
Current	17.1	- 0.50	+ 0.31	-0.19 (losing)	-
End of Mining Area 2	17.1	- 0.49	+ 0.32	-0.17(losing)	0.02 (0.0012 ML/km^2/day) or 0.1% gain
End of Mining Area 4	17.1	- 0.52	+ 0.23	-0.29 (losing)	0.10 (0.0058 ML/km^2/day) or 0.6% loss
Wallandoola Creek					
Current	33.2	- 0.70	+ 0.90	+ 0.20 (gaining)	-
End of Mining Area 2	33.2	- 0.76	+ 0.90	+ 0.14 (gaining)	0.06 (0.0018 ML/km^2/day) or 0.2% loss
End of Mining Area 4	33.2	- 0.70	+ 0.65	- 0.05 (losing)	0.25 (0.0075 ML/km^2/day) or 0.8% loss

Modelled groundwater flow diagrams indicating the current, post Stage 1 (Area 2 and V Mains) as well as the post Stage 2 (Area 4) in the upper Hawkesbury Sandstone at Wonga West are shown in **Figure 45**.

At Wonga West, no surface to seam free drainage is predicted, even though the overburden hydraulic connection may be enhanced by the predicted subsidence within the shallow (0 - 20m below surface) to mid (20 - 50m below surface) Hawkesbury Sandstone aquifers as well as within the enhanced vertical drainage zone between the goaf and the mid Bulgo Sandstone.

It is not anticipated there will be any observable effects on Lizard Creek or Wallandoola Creek stream flow due to the limited depressurisation predicted by the groundwater model in the upper Hawkesbury Sandstone, except possibly after extreme, extended dry periods.

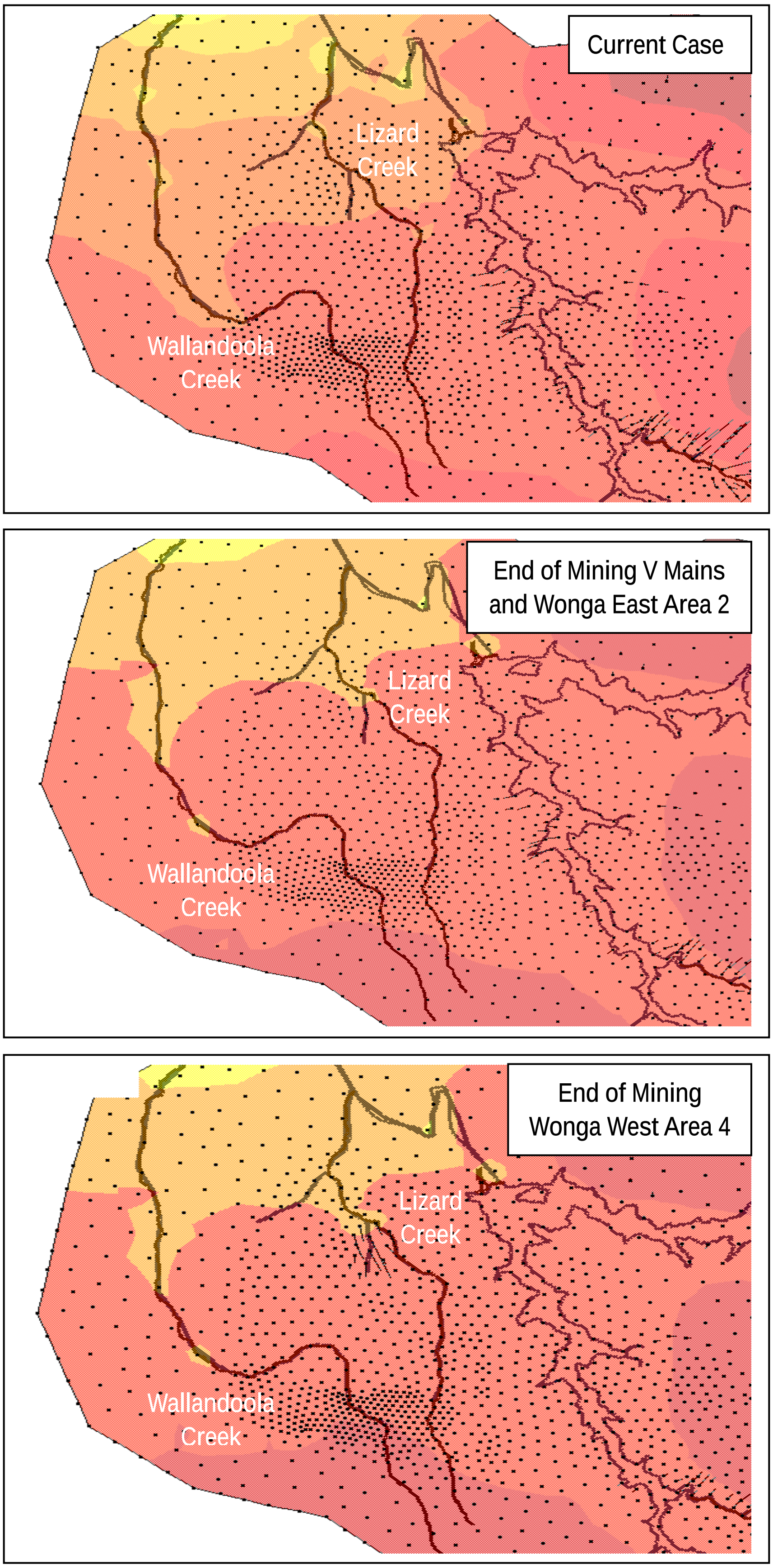


Figure 45 Wonga West Upper Hawkesbury Sandstone Groundwater Flow

13.5 Cataract Reservoir Inflow

Due to the proposed workings setback from the Cataract reservoir, no adverse stored water quantity or quality impacts are predicted to occur on or in Cataract reservoir based on the factors discussed in previous sections.

The groundwater model indicates a potential sub-surface transfer of stream flow to the underlying groundwater system of;

- 0.07ML/day for Cataract Creek;
- 0.03ML/day for Bellambi Creek;
- 0.25ML/day for Wallandoola Creek, and;
- 0.10ML/day for Lizard Creek

A potential annual transfer at the end of mining in Wonga East and Wonga West from stream flow to underflow, or throughflow, after 164.3ML/year, is predicted by the groundwater model. It is anticipated, however, that the water will flow via subsurface fractures and discharge down gradient into the lower section of the streams, and / or into Cataract Reservoir. As such, the change is anticipated to be a sub surface diversion, not an overall loss, to the surface water balance.

Cataract Reservoir has a full operating storage of 97,190ML. The lowest level of the storage that NRE is aware of is 27,620ML or 29.3% capacity on 20 July 2006.

If the low level figure is used, the sub-surface transfer of 164.3ML per year at the end of all proposed mining is less than 0.6% of the low level, or 0.17% of its full storage capacity..

13.6 Subsidence Interaction with Faults and Dykes

The Corrimal Fault is mapped to cross over the proposed Wonga East workings in longwalls WE-A2-LW6 to WE-A2-W9, however it is not anticipated to generate a hydraulic connection to the surface water system or Cataract Reservoir through extraction of WE-A2-LW6. The fault has been identified as a “hinge fault” with a varying throw of approximately 25m in the east, reducing to 1.8m at Maingate 5, and predicted to reduce to no displacement around longwalls WE-A2-LW7 and LW8.

In addition, a thin (<1m wide) highly weathered dyke is located over the Wonga East workings, however, due to its highly weathered clay state and associated low intrinsic permeability, undermining this structure is not anticipated to enhance its permeability or potential hydraulic connection to the surface water systems or to Cataract Reservoir.

If inflow monitoring in the mine, and observation of the piezometers installed over the Wonga East domain, indicate that there may be a potential for increased permeability along the Corrimal Fault due to mining induced changes, then the mining of subsequent panels can be adjusted through adaptive management of the mine workings. To date, mining in the Bulli seam on both sides of the Corrimal Fault (both first and second workings), has not resulted in observable increased flows to the mine workings.

The main structures adjacent to, but not overlying the Wonga West workings are the essentially east – west trending Bulli Fault, which is located to the north of the proposed workings, and the south-west north-east trending dyke that is located to south west of the proposed workings.

None of the known intrusive or fault structures overlying the proposed Wongawilli West workings are anticipated to be of sufficient scale or regional extent, after subsidence, to generate a direct hydraulic connection to the overlying surface water systems or Cataract Reservoir.

Based on past mining experience, the faults in the Bulli / Balgownie workings are essentially dry and are not anticipated to provide enhanced permeability fluid pathways in the proposed mining area.

No water inrush has been reportedly associated with faults or dykes in the Bulli or Balgownie workings (S Wilson, pers comm).

13.7 Groundwater Inflow to the Workings

The predicted average daily modelled inflow to the proposed NRE No.1 workings for each stage is shown in **Table 13**.

Table 12 Predicted Mine Inflows at the End of Mining

Stage	Current Inflow (ML/day)	Predicted Wongawilli Workings Inflow (ML/day)	Predicted Wongawilli Seam Inflow (ML/year)
Wonga East	0.2	1.4	511
Wonga West	0.9	1.7	621
TOTAL	**1.1**	**3.1**	**1131**

The modelled seepage rates into the workings may be enhanced if unidentified fracture related storages are intercepted, which may lead to short term increases of potentially up to 0.1 - 0.5ML/day which should dissipate over a period of weeks to months.

13.8 Groundwater Quality

Previous observations at NRE No.1 indicates that groundwater quality within the regional groundwater system has not been adversely affected, however there may be some localised increased iron hydroxide precipitation and limited lowering of pH if the groundwater is exposed to “fresh” surfaces in the strata through dissolution of unweathered iron sulfide or carbonate minerals.

The degree of iron hydroxide and pH change is difficult to predict, and can range from no observable effect to a distinct discolouration of the formation water. The discolouration does not pose a health hazard, however it can cause iron hydroxide precipitation at seepage points in local streams which can also be associated with algal matting and / or lowering of dissolved oxygen levels in the creek at the seepage point.

It should be noted that many Hawkesbury Sandstone aquifers in the Southern Coalfield already have significant iron hydroxide levels, and that ferruginous seeps can also be observed in previously un-subsided catchment areas.

As a result of the proposed workings, pH acidification of up to 1 order of magnitude may occur, however the change may be reduced if the aquifer has sufficient bicarbonate levels.

Outside of isolated iron hydroxide seepages, no adverse groundwater quality is anticipated to discharge from the proposed Wongawilli Seam workings subsidence areas.

13.9 Loss of Bore Yield

There will be no loss of bore yield as there are no private bores or wells registered by the NSW Department of Climate Change and Water – Office of Water (NOW) in the study area.

14. RISK ASSESSMENT

14.1 Pillar Run

A risk assessment was conducted for the potential pillar run issue in the Wonga East area (KNJ Consultants, 2012) and subsequently after WE-A2-LW4 was extracted as detailed below with regard to the selected natural features.

Stored waters of Cataract Dam - Hazard does not exist

Any potential pillar run would be terminated by a combination of the Corrimal Colliery barrier pillar and a barrier within the Bulli Seam workings extending from N6,196,700, E302,000 through to the Bulli Seam mains at N6,197,500.

The existence of the barrier is supported by the mine plan and subsidence data from the extraction of the Balgownie Seam longwalls. The observed subsidence above the previous Balgownie Seam longwalls was in accordance with expected behaviour of strata in this coalfield. In addition, the mine plan shows substantial pillars in the Bulli Seam in the vicinity of the stored waters of the Cataract Dam.

Cataract River - Hazard does not exist

The Cataract River is located to the south & east of the Corrimal Colliery barrier pillar, which would terminate any pillar run in the Bulli Seam that may be initiated from the Wonga East area.

Cataract Creek - Possible Low Risk

Without pillar run, it is anticipated that the bed of Cataract Creek could experience maximum vertical subsidence of up to 0.8m and strain levels of up to 9.5mm/m (Seedsman Geotechnics, 2012) with the current mine plan.

Possible worst case subsidence could occur over 7 days between the Bulli Seam Mains & the barrier pillar extending from N6,196,700, E302,000 through to the Bulli Seam Mains at N6,197500, for a creek length of approximately 400m.

The maximum reasonable consequence of the worst case scenario was possible ferruginous upwellings and fracturing of rock beneath the sandy creek bed with no substantial loss of water to the mine workings.

Upland Swamps – Possible Low Risk

Swamps associated with Cataract and Bellambi Creeks Cataract River could have a worse possible case of up to 1.2m subsidence over 7 days.

The maximum reasonable environmental consequence could be possible drying or water level reduction in the area of the swamp and fracturing of rock beneath the swamp with no substantial loss of water to the mine workings.

14.1.1 Non Conventional Subsidence, Far Field Impacts and Risk of Re-activation of Fracturing From Previous Mining

There are some examples of unusual subsidence related to geological structures, mainly dykes, but these are relatively rare. In general, faults and dykes do not significantly change surface subsidence behavior.

Previous mining on two levels has been conducted adjacent to or under the dykes and faults at Wonga East, with no evidence in the measured subsidence profiles of these features having any influence on surface subsidence behavior.

The main influence of these structures appears to have been at seam level where it has been difficult to mine through the dyke in the Balgownie Seam longwalls.

No strong evidence is available to indicate that structures may become reactivated as hydraulic pathways, or that they are either more or less hydraulically conductive than the surrounding strata or that they provide a connection between the surface and underground (SCT Operations, 2012).

Significant disturbance to the overburden strata through vertical subsidence is likely to be substantially avoided if surface features are not directly mined under because most of the vertical stretching that contributes to increased hydraulic conductivity is located directly over each longwall panel.

There is still potential for some disturbance and associated increase in the hydraulic conductivity as a result of secondary effects such as valley closure or where aquifers or stratigraphic with higher natural hydraulic conductivity, but these effects tend to be greater directly above each panel.

The valley closure impacts tend to be specific to topographic low points and are not necessary associated with increased vertical hydraulic conductivity to the mining horizon, although the impacts may be significant within the context of the river channel or valley infill swamp.

Subsurface mining disturbance to stratigraphic units that have naturally higher hydraulic conductivity may result in a pathway of increased hydraulic conductivity between groundwater stored in these units and the mining horizon. There is potential for the associated drawdown to extend well outside the footprint of individual longwall panels, particularly when horizontal movements that occur toward each longwall goaf result in a net volume increase of the aquifer.

However, the further away a longwall panel is from a given surface feature, the less likelihood there is for significant impact.

Far-field horizontal movements, valley closure movements, and lateral drawdown within the deep groundwater system are recognised to have potential to extend beyond, the limits of vertical subsidence, however these effects do not generally have a significant impact on mine inflows or surface water systems not overlying the subsidence zone (SCT Operations, 2012).

15. CUMULATIVE GROUNDWATER RELATED IMPACTS

15.1 Upland Swamps

The cumulative impact of previous subsidence effects on the adjoining, upstream swamp systems in the Cordeaux mine lease area cannot be definitively assessed as the pre-mining status of the associated Lizard Creek and Wallandoola Creek stream and swamp systems have not, to our knowledge, been monitored.

Current pool height and water quality monitoring data collected for this study indicates the Cordeaux swamps maintain seepage flow in to the Gujarat lease area, whilst ferruginous seepage is present in the streams, however, due to the lack of pre-mining data, no comment can be made as to whether the seepage is mining induced or not.

No other adjoining previous mining operations provide a cumulative impact on swamps in the Study area.

No swamps are present downstream of the Gujarat lease area.

15.2 Basement Groundwater

The cumulative impact of the existing and proposed NRE No. 1 workings along with the surrounding mines has been assessed in the existing and predictive model runs by including the effects of:

- subsidence and associated fracture propagation and hydraulic permeability distribution over non-mining areas, as well as over bord and pillar / pillar extraction or longwalls of variable widths on the regional groundwater pressure distribution;
- known or estimated degree of flooding in the adjoining workings;
- separation distance of adjoining workings (i.e. the Appin / Westcliff / Northcliff / Metropolitan / Tahmoor mining areas were interpreted to be sufficiently distant from the existing and proposed NRE1 workings to be discounted as discussed in **Appendix D**).

16. MONITORING, CONTINGENCY MEASURES & REPORTING

16.1 Swamp Monitoring

The existing suite of shallow piezometers installed within the NRE1 upland swamps should be monitored to gauge any changes in standing water levels and swamp groundwater quality over an active mining area and for all key water quality parameters on a regular basis for the duration and an appropriate time following mining.

It should be noted that no vehicular access is available within the upland swamps, and installation of any further piezometers will require entry on foot.

Prior to mining under or adjacent to a swamp, a Swamp Risk Management Plan (SRMP) should be developed which demonstrates that the predicted subsidence should ensure the size and functioning of the swamp, including potential changes in species composition or distribution within the swamp will not be adversely affected. It should ensure that water will not drain from the swamp due to subsidence or be re-distributed to an extent where such potential adverse changes could occur.

A monitoring program should be designed and implemented to:

- assess the swamp hydrology;
- provide advance warning of potential exceedances of subsidence predictions;
- detection of exceedances and adverse impacts on the swamp and underlying strata hydrology; and
- characterise the relationship between swamp/s and their role in recharging the regional groundwater systems.

16.1.1 Swamp Standing Water Levels

Standing water levels will be measured automatically, twice daily by pressure transducers and regularly by manual dip meter.

Should the standing water level or groundwater quality be unacceptably affected due to subsidence, the Colliery will investigate methods to ameliorate the situation until the water level or water quality recovers.

16.1.2 Swamp Groundwater Quality

At least one appropriately purged and collected, stored and transported groundwater sample should be collected from each swamp piezometer pre and post undermining to enable ongoing assessment of any subsidence related changes in groundwater quality. Samples should be analysed for the following:

- Field pH, electrical conductivity, temperature;
- total dissolved solids;
- Na / Ca / Na / K / SO4 / Mg / Cl / F;
- total alkalinity;
- total / filterable Fe, Mn, Al;
- filterable Ni, As, Li, Ba, Sr, Cu, Pb, Zn; and
- total nitrogen and total phosphorous

Observations should be made on the quantum of iron hydroxide precipitating from the pumped water before and after undermining.

16.2 Basement Groundwater Monitoring

16.2.1 Groundwater Levels

Piezometers to be included in the monitoring suite are shown in **Table 14**.

The suite is divided into standpipe and vibrating wire piezometers, with water level transducers and vibrating wire piezometers used to monitor standing water levels or pressure heads twice daily to assess variations in the colluvial and basement formations.

Table 13 Groundwater Level Monitoring Suite

	Piezometer Type
Basement	
NREA, C, D, E, G, NRE3, GW1A	Open Standpipe
NREA, B, D, NRE3, GW1	VWP
Colluvium	
SP1, SP2	Open Standpipe
Swamps	
PL1A, B PL18, PL25A, B, C, D	Lizard Creek catchment open standpipe
PW1, 4, 11	Wallandoola Creek catchment open standpipe
PCc2, 3, 4, 5A, 5B, 6	Cataract Creek catchment open standpipe
PCr1	Cataract River catchment open standpipe
PB4	Bellambi Creek catchment open standpipe

NOTE: VWP = vibrating wire piezometer

Inclusion of additional groundwater monitoring locations and depths will be incorporated, if required, following discussions with the SCA and NOW.

Monitoring will also involve bi-monthly manual standing water level measurement in all open standpipe piezometers, at which time the loggers will be downloaded and re-initiated as shown in **Table 15**.

Table 14 Standing Water Level Monitoring Method and Frequency

Monitoring Site	Sampling Method	Frequency / Download	Units
NREA, C, D, E, G, NRE3, GW1A	Water level logger / dip meter	twice daily / bi-monthly	mbgl
NREA, B, D, NRE3, GW1A	Vibrating wire piezometer	twice daily / quarterly	m head pressure
SP1, SP2	Water level logger / dip meter	twice daily / bi-monthly	mbgl
PL1A, B PL18, PL25A, B, C, D	Water level logger / dip meter	twice daily / bi-monthly	mbgl
PW1, 4, 11	Water level logger / dip meter	twice daily / bi-monthly	mbgl
PCc2, 3, 4, 5A, 5B, 6	Water level logger / dip meter	twice daily / bi-monthly	mbgl
PCr1	Water level logger / dip meter	twice daily / bi-monthly	mbgl
PB4	Water level logger / dip meter	twice daily / bi-monthly	mbgl

NOTE: mbgl = meters below ground level

16.2.2 Groundwater Quality

Tables 16 and **17** present the parameters to be measured, frequency of monitoring and sampling method for groundwater quality monitoring, with monitoring to continue for 12 months after mining has ceased.

Table 15 Groundwater Quality Monitoring Parameters

ANALYTES	Units	FREQUENCY
EC, pH	µS/cm, pH units	Bi - monthly
(EC, pH) + TDS, Na, K, Ca, Mg, F, Cl, SO4, HCO3, NO3, Total N, Total P, hardness, Cu, Pb, Zn, Ni, Fe, Mn, As, Se, Cd (metals filtered)	mg/L	Start / finish of panel for piezometers adjacent to a panel, or in an active mining area, otherwise 1 sample per year

The frequency of monitoring will be reassessed after mining is complete as it may be possible, depending on results, to lengthen the intervals. The frequency of monitoring and the parameters to be monitored may be varied by NOW once the variability of the groundwater quality is established.

Table 16 Groundwater Quality Monitoring Method and Frequency

Monitoring Site	Sampling Method	Frequency
Open Standpipe Piezometers	Pumped field meter readings	Bi-monthly
Open Standpipe Piezometers	Pumped sample for laboratory analysis	Start / finish of each panel for piezometers adjacent to a panel or in an active mining area, otherwise 1 sample per year

Groundwater samples should be collected at the start and finish of each panel from piezometers either adjacent to an active panel, or within an active mining area and analysed at a NATA registered laboratory for major ions and selected metals. Piezometers not within an active mining area should be sampled and analysed once per year.

It is anticipated that the groundwater program should be maintained in its current status, with possible modification of the program at the end of each panel after a review of all monitoring data has been conducted.

Additional piezometers may be added to the existing suite if required.

The groundwater monitoring program is anticipated to be extended beyond the active mining period in order to assess the potential long term change in groundwater level recovery and quality changes for 12 months after completion of mining.

16.3 Surface Water and Groundwater Connectivity

The potential for surface water and groundwater system hydraulic connectivity should be assessed through monitoring of stream flows in and near actively mined areas (as outlined in Geoterra 2012) as well as through monitoring and interpretation of the basement groundwater open standpipe and vibrating wire piezometers water levels / pressures and mine inflow changes.

16.4 Mine Water Pumping

The volume of water pumped into and out of the NRE No. 1 workings should be monitored daily to enable the differential groundwater seepage into the workings to be assessed.

16.5 Ground Survey

The ground surface over the proposed underground workings should be surveyed in accordance with DII subsidence monitoring requirements.

16.6 Rainfall

Daily rainfall data should be obtained from a local weather station for the duration of mining in the NRE No.1 catchment area.

16.7 Ongoing Monitoring

All results should be reviewed after each panel is completed and an updated monitoring and remediation program should be developed, if required, in association with NOW and DII.

16.8 Quality Assurance and Control

QA/QC should be attained by calibrating all measuring equipment, ensuring that sampling equipment is suitable for the intended purpose, using NATA registered laboratories for chemical analyses and ensuring that site inspections and reporting follow procedures outlined in the ANZECC 2000 Guidelines for Water Quality Monitoring and Reporting.

16.9 Impact Assessment Criteria

16.9.1 Groundwater Levels

Impact assessment criteria investigation trigger levels should be initially set where a groundwater level reduction exceeds more than 10% of the saturated aquifer thickness over a 12 month period, compared to the minimum height within the last 12 months of data, excluding any short term recharge peaks. Should the trigger be exceeded, the actual rate of change of water levels should be investigated to determine whether the change is solely subsidence induced or due to a range of other potential factors.

If a significant increase in the rate of water level decline is noted, based on interpretation by a qualified hydrogeologist, then an assessment should be conducted to determine the cause of the change (such as variation in climate or effects from adjacent mining operations) and to consider potential contingency measures that may be adopted.

16.9.2 Groundwater Quality

Groundwater quality impact assessment criteria are sourced from the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC, 2000) for Aquatic Ecosystems as shown in **Table 18.**

Table 17 Groundwater Quality Impact Assessment Criteria

Indicator	Irrigation Criteria
pH	<6.5 or >7.5 or >10% variation over 4 months compared to previous 12 months data
Conductivity	>10% variation over 4 months compared to previous 12 months data
TDS	>350mg/L or >10% variation compared to previous 12 months data
Total Nitrogen	>250µg/L or >10% variation compared to previous 12 months data
Total Phosphorous	>20µg/L or >10% variation compared to previous 12 months data

A trigger to assess the cause and effects of adverse groundwater quality changes should be implemented when there is a prolonged and extended non-conformance of the outlined criteria at a particular piezometer. If a field parameter (pH, conductivity) is outside the designated criteria for at least six months in a sequence, or alternatively, exceeds its previous range of results by greater than a 10% variation for at least 4 months, then the cause should be investigated, and a remediation strategy should be proposed, if warranted.

The criteria and triggers should be reviewed after each 12 month block of data is interpreted and may be modified as appropriate, depending on the results.

If the impacts on the groundwater system resulting from future underground operations are demonstrated to be greater than anticipated, the proponent should:

- assess the significance of these impacts;
- investigate measures to minimise these impacts; and
- describe what measures would be implemented to reduce, minimise, mitigate or remediate these impacts in the future to the satisfaction of the Director-General, NOW and the Sydney Catchment Authority.

16.10 Contingency Procedures

Contingency procedures should be developed as required, with the measures to be developed being dependent on the issue that requires addressing.

The procedures should be used to manage any impacts identified by monitoring that demonstrate the groundwater management strategies may not have adequately predicted or managed the groundwater system's anticipated response to mining.

Activation of contingency procedures should be linked to the assessment of monitoring results, including water quality, aquifer hydrostatic pressure levels and the rate of water level changes.

Performance indicators should be identified prior to extraction of the proposed underground workings and a statistical assessment should be undertaken to detect when, or if, a significant change has occurred in the groundwater system which should benchmark the natural variation in groundwater quality and standing water levels.

A monitoring and management strategy along with an outline of a Trigger Action Response Plan (TARP) should be prepared to provide guidance on the procedures and actions required in regard to the surface water and groundwater systems in the proposed mining area.

16.11 Piezometer Maintenance and Installation

The current network should be maintained by protecting the wellhead from damage by animals and scrub fires by maintaining their steel sealed wellheads.

If required, the piezometers may be cleaned out by air sparging if they become clogged.

In the event that any new piezometers are required, they should be installed by suitably licensed drillers after obtaining the relevant bore licence from the SCA and NOW.

16.12 Reporting

Following completion of extraction of each panel, a report should be prepared for all prior panels that summarises all relevant monitoring to date. The report should outline any changes in the groundwater system over the relevant mining area.

The report should contain an interpretation of the data along with:

- a basic statistical analysis (mean, range, variable, standard deviation) of the results for the parameters measured;
- an interpretation of water quality and standing water level changes supported with graphs or contour plots; and
- an interpretation and review of the results in relation to the impact assessment criteria.

Relevant monitoring and management activities for each year should also be reported in the AEMR.

16.13 Adaptive Management

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek, through adaptive management measures relating to operation of the mine workings if subsidence and ground movements exceed 250mm and the creek is predicted to experience greater than negligible impact as defined by the project approval performance criteria.

An adaptive management plan should be developed to use the monitoring program to detect the need for adjustment to the mining operation so that the subsidence predictions are not exceeded and subsidence impacts creating a risk of negative environmental consequences do not occur.

The adaptive management procedures should be implemented to provide a systematic process for continually detecting impacts, validating predictions and improving mining operations to prevent further adverse impacts on the swamp and basement groundwater systems overlying the proposed mining domains.

Monitoring, evaluation, and reporting on management performance and ecological impact should be integrated into the site's core management systems to progress the technical understanding and predictive capability of subsidence effects, impacts and consequences on the sites surface water systems.

An evidence-based approach should be used to validate the extent to which outcomes are being achieved, with the monitoring results being related to, and demonstrating how management strategies have been achieved or where improvements can be made.

As longwalls WE-A2-LW4 to LW7 in Area 2 are planned to be mined first, and as they do not overlie the main channel or significant tributaries of Cataract Creek, they would provide a "baseline" monitoring opportunity to assess the effect of subsidence on fracture propogation and development through the overburden, height of fracturing, development of cracking at surface, changes to an upland swamp perched water system (Crus1) as well as flow and water quality in Cataract Creek and any changes in mine inflows.

Data gained from monitoring a suite of extensiometers, vibrating wire piezometer arrays and open standpipe piezometers as well as geochemical monitoring of groundwater and surface water and stream flow regimes over the panels would then be able to be used to update the curent geotechnical, hydrogeological and hydrological assessments for the proposed mining and to incorporate, if required, adaptive management measures for future panels.

Additional groundwater related monitoring that could be used to enhance the adaptive management process may include conducting:

- continuation of the existing mine water pump monitoring and updating the mine water balance;
- additional drilling, with a range of vibrating wire piezometers and core testing to establish the mechanical and hydraulic properties of the overburden in proximity to water dependent systems in the catchments (including swamps);
- installation of additional deep vibrating wire piezometers and extensiometers to assess/quantify the impacts of fracturing within the subsidence zone;
- installation of paired shallow piezometers (where appropriate) targeting swamps and the underlying shallow Hawkesbury Sandstone aquifer to assess their hydraulic connection and climatic implications;
- sediment profiling in swamps to characterise type, thickness and sensitivity to differential subsidence; and
- update the numerical modelling when sufficient additional data becomes available to enhance the prediction of subsidence zone fracture distributions, connectivity and groundwater transmissivity capacities.

17. POTENTIAL REHABILITATION MEASURES

While the nature and extent of possible subsidence impacts are considered to be manageable, the range of possible remediation or rehabilitation measures is discussed below.

17.1 Streams

For discussion of potential stream related rehabilitation measures, refer to (Geoterra, 2012).

17.2 Upland Swamps

Potential remediation measures for impacts on upland swamps could include:

- *installation of coir log dam erosion control structures at knick points in a swamp;*

Tilting of the swamp can re-direct runoff leading to scour and erosion or alter water distribution in a swamp. However, no swamps in the Study area have been assessed with a moderate or higher risk of drainage line alignment change in terms of their erosion and scour potential.

Coir logs can be installed at knick points for construction of small dams, and have been used successfully in swamp rehabilitation in the Blue and Snowy Mountains (BHP Billiton Illawarra Coal, 2009).

A trench is initially cut into the swamp so the first coir logs sits on the substrate or at ground level and is held by wooden stakes and bound with wire. The dam slows the flow and enables siltation behind the log with coir log dams constructed at intervals down the erosion channel. For increased flow filtering, the coir logs can be wrapped in jute fibre matting.

The main objective of siting erosion control structures is to maintain the saturated water level in the soil profile by reversing the hydraulic head to enable water to permeate back into the swamp (BHP Billiton Illawarra Coal, 2009).

The coir log dams can also capture sediment to restore an incised channel to the level of the surrounding intact soil layer and provide a barrier to headward erosion.

- *use of water spreading techniques, involving long lengths of coir logs and hessian `sausages' linked together across a swamp contour such that water flow builds up behind them and seeps through the water spreaders to maintain swamp moisture;*

Maintenance of swamp moisture can be enhanced by installing coir logs and hessian `sausages' linked across a swamp contour to build up water flow and enhance seepage through the spreaders which can be positioned in shallow trenches.

Erosion control and water spreading involves soft-engineering materials that would contribute to and function as part of the swamp system but would degrade and be integrated into the swamp (BHP Billiton Illawarra Coal, 2009).

- *sealing of surface cracks through the use of grouting products*

Where bedrock controlled features within or on the margins of a swamp are impacted from subsidence and there is limited ability for fractures to infill naturally, surface cracks can be sealed with grout, such as small quantities of cement with various additives mixed on-site and placed by hand with bunds used to contain local spillage.

- *injection grouting.*

Grouts and filler materials can be injected to fill voids in fractured strata via hand held drilling equipment to achieve a low permeability layer 1 - 2 m thick below the depth of a controlling rock bar.

Where colluvial soils overlie the sandstone, a grout may be injected through rods to seal voids in or under the soil or peat material.

Implementation of any management measures should be considered with regard to the specific circumstances of the subsidence impact, such as the location, nature and extent of the impact and the assessment of the potential environmental consequences of the remediation technique used.

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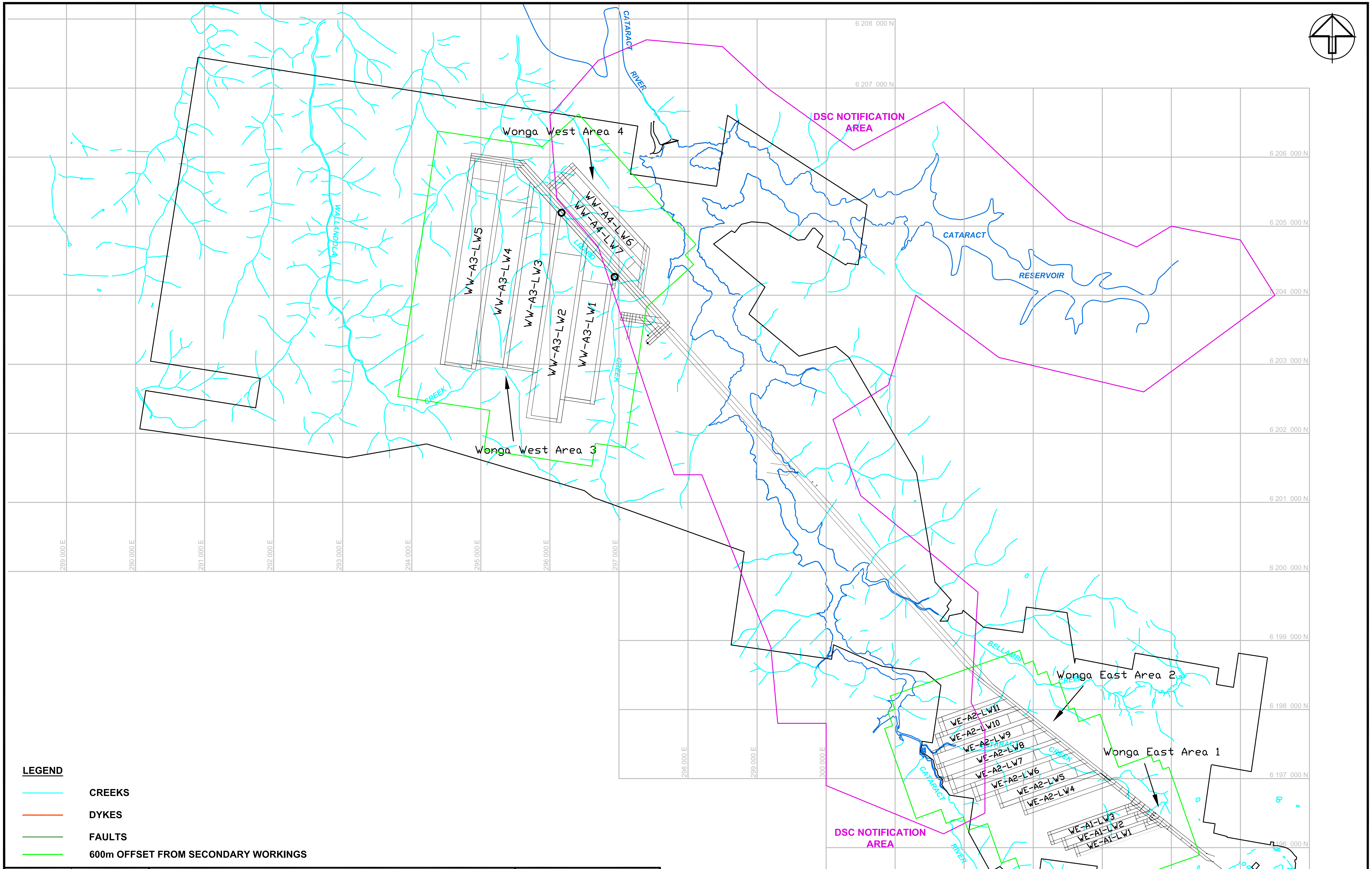

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DRAWN:	A. DAWKINS
DATE:	26 Oct 2012
SCALE:	1:5 000

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NRE No.1 COLLIERY

PROPOSED WONGAWILLI SEAM WORKINGS

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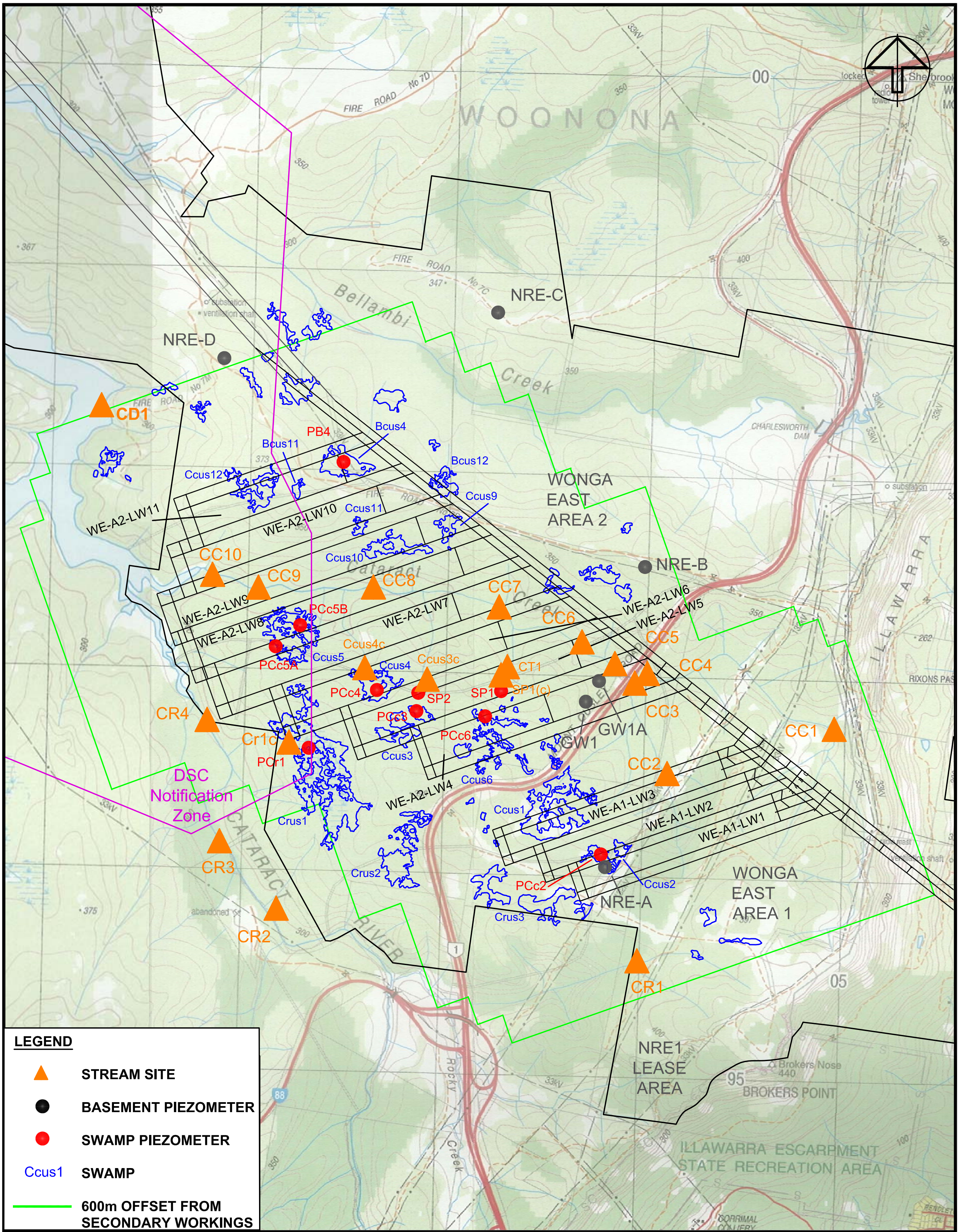
DRAWING 1



LEGEND

▲ **STREAM SITE**

● **BASEMENT PIEZOMETER**

● **SWAMP PIEZOMETER**

Ccus1 **SWAMP**

🟩 **600m OFFSET FROM SECONDARY WORKINGS**

PROJECT:	GUJ1-S-R1
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DATE:	19 Nov 2010
SCALE:	1:250

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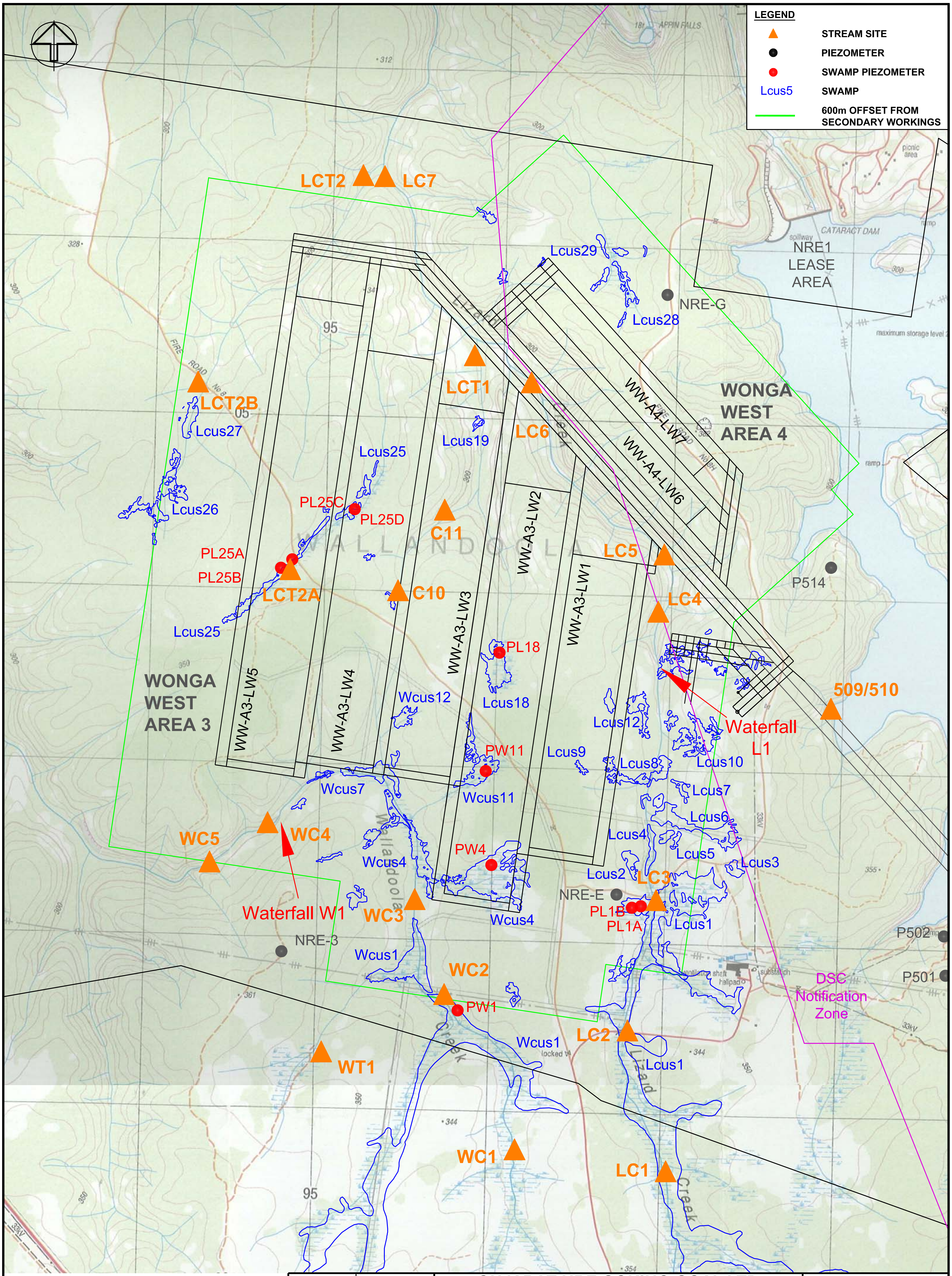
NRE No. 1 COLLIERY

Proposed Wonga East Workings and Monitoring Locations

GeoTerra

DRAWING 2



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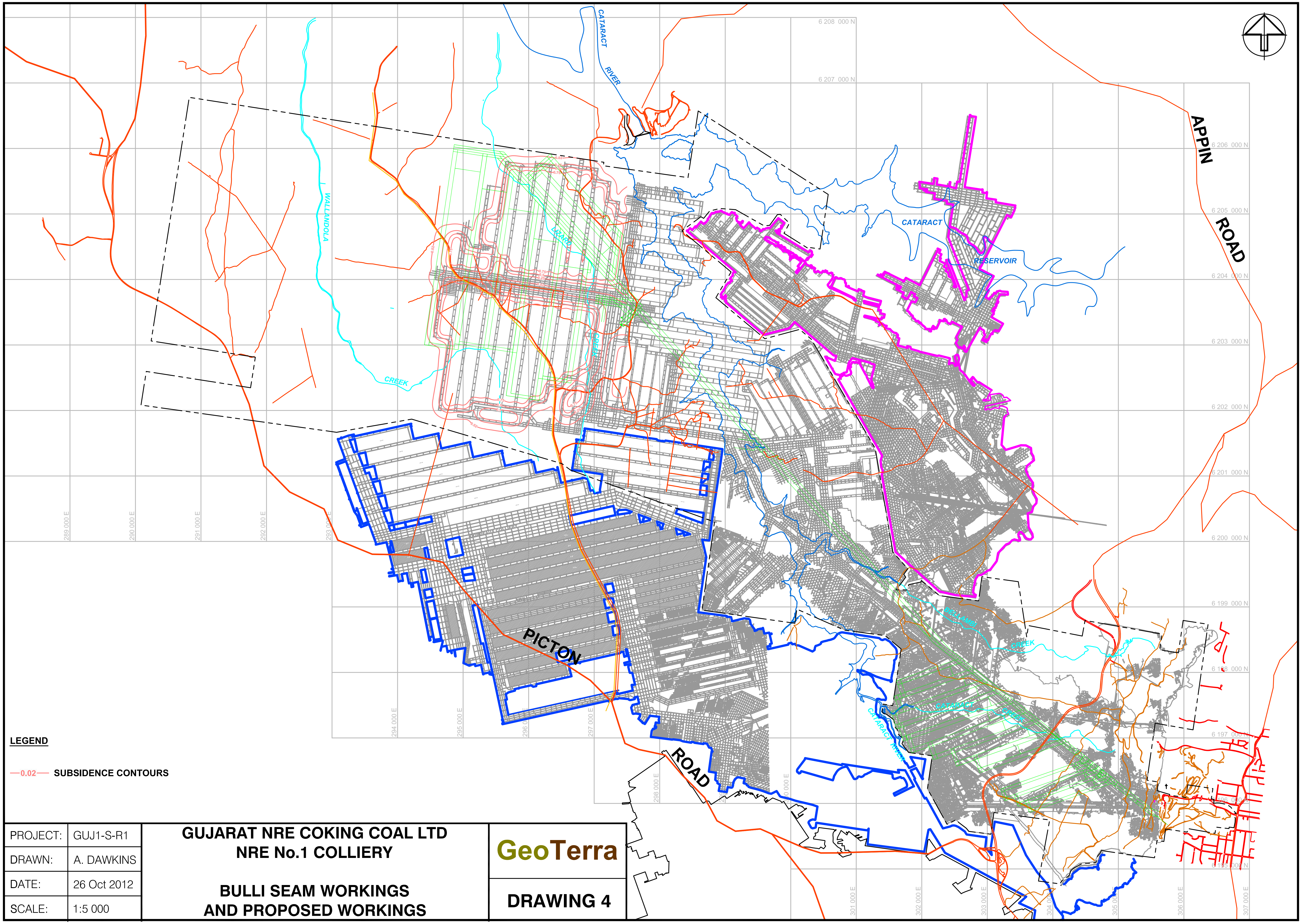
Proposed Wonga West Workings and Monitoring Locations

GeoTerra

DRAWING 3



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—0.02— SUBSIDENCE CONTOURS

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BULLI SEAM WORKINGS
AND PROPOSED WORKINGS

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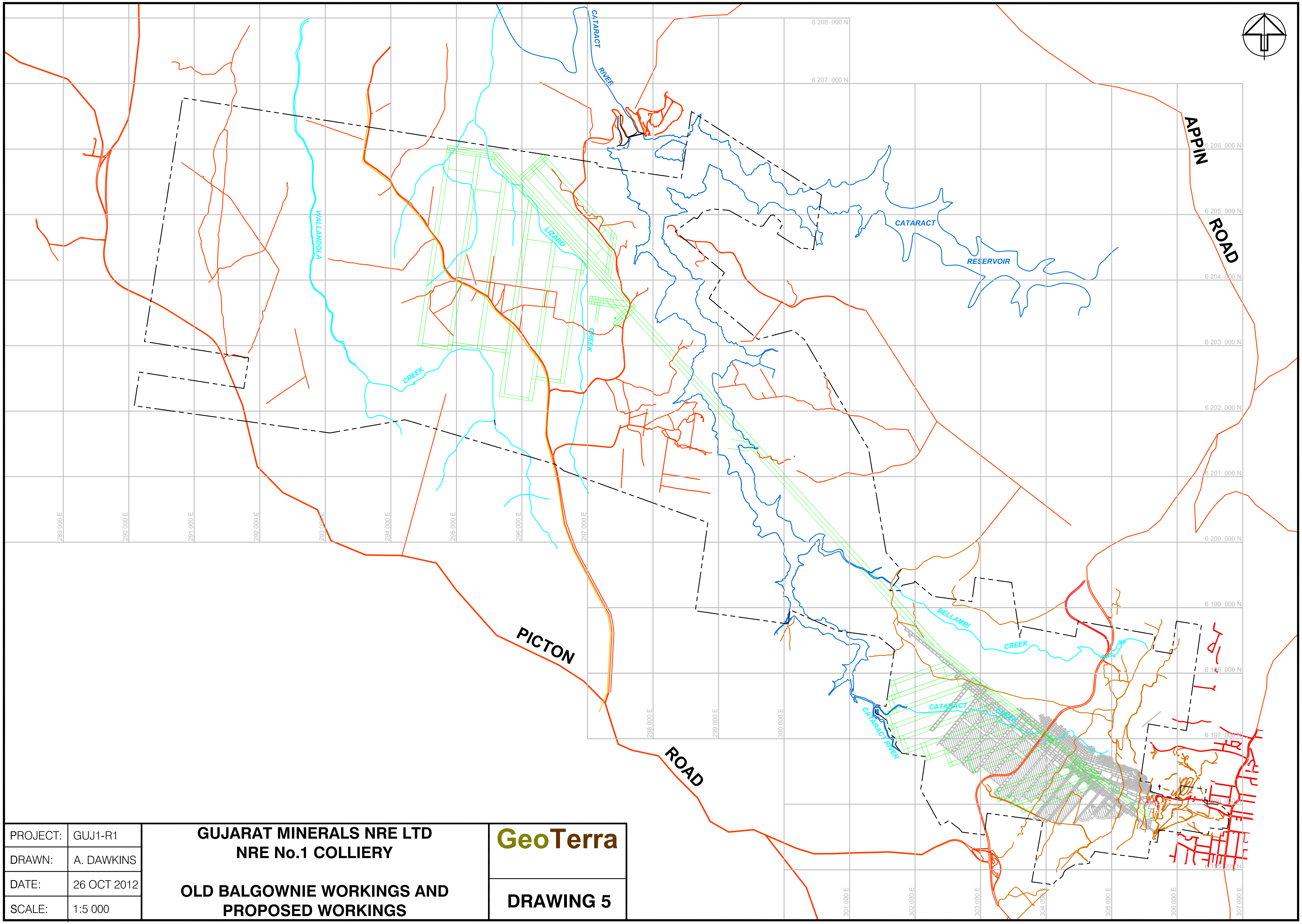
DRAWING 4



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OLD BALGOWNIE WORKINGS AND
PROPOSED WORKINGS

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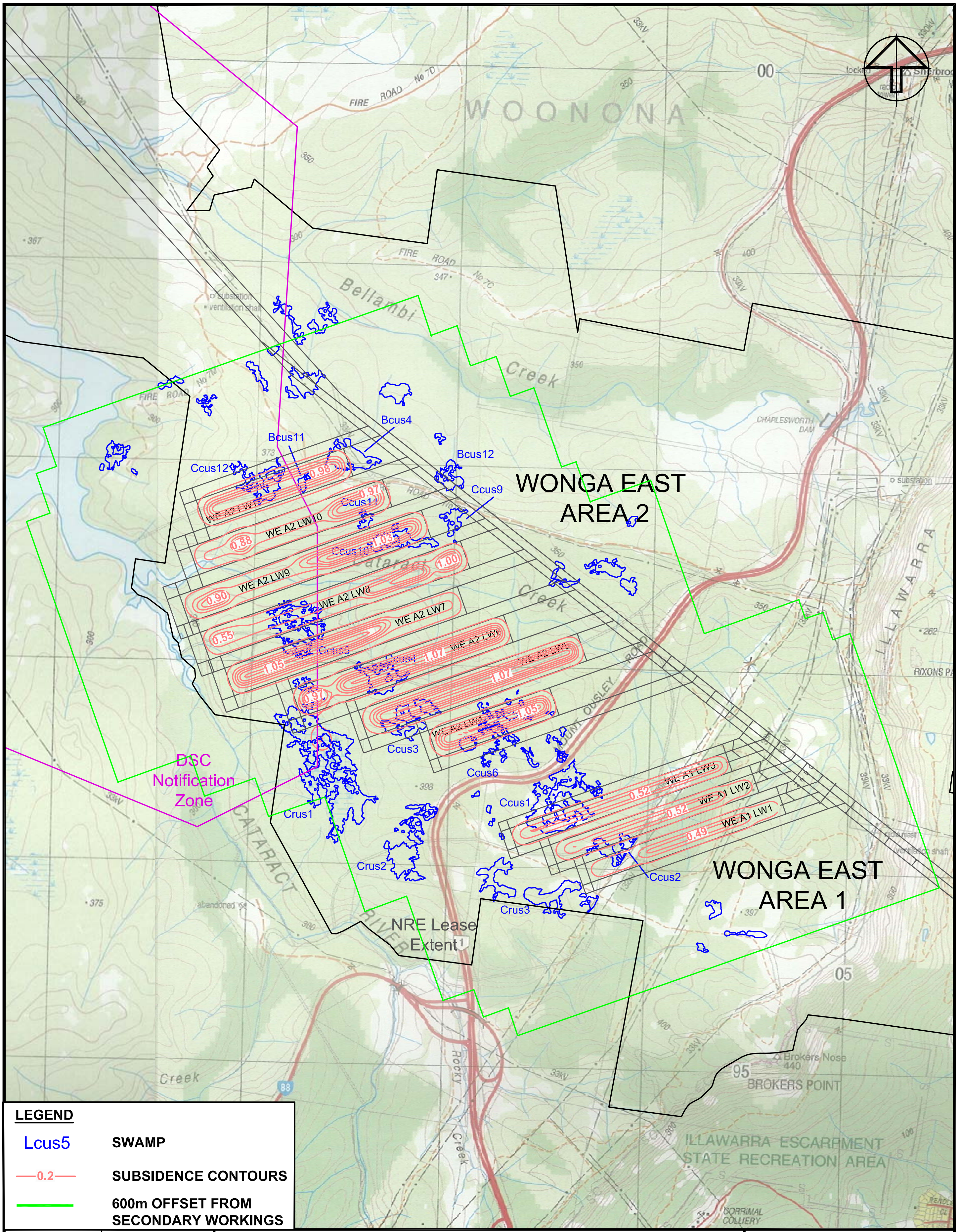
DRAWING 5



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Proposed Wonga East Workings and Subsidence Contours

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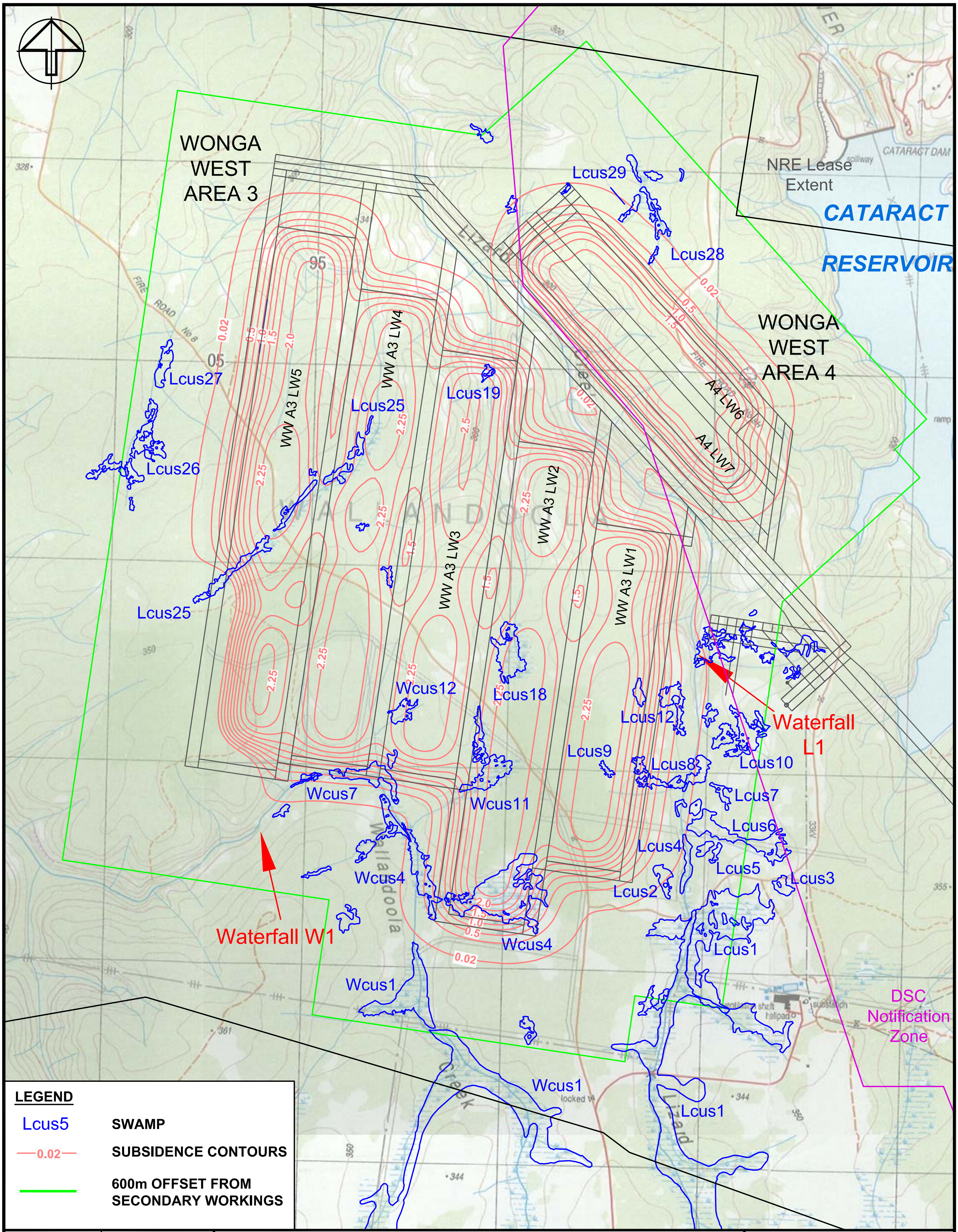
DRAWING 6



PROJECT: GUJ1-R1

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DATE: 26 OCT 2012

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Proposed Wonga West Workings and Subsidence Contours

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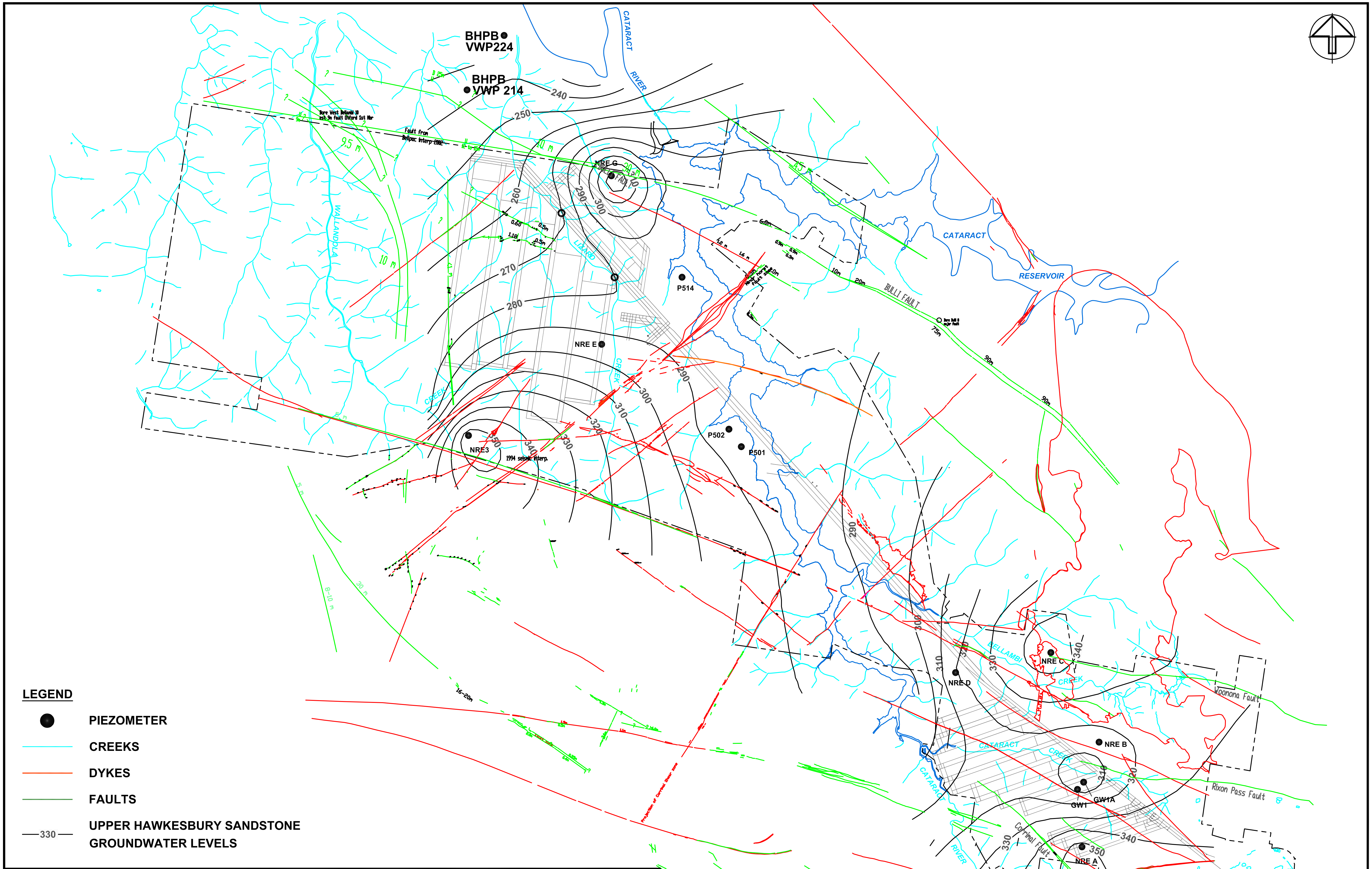
DRAWING 7



LEGEND

● PIEZOMETER

CREEKS

DYKES

FAULTS

—330— UPPER HAWKESBURY SANDSTONE GROUNDWATER LEVELS

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Proposed Workings
and Standing Water Levels

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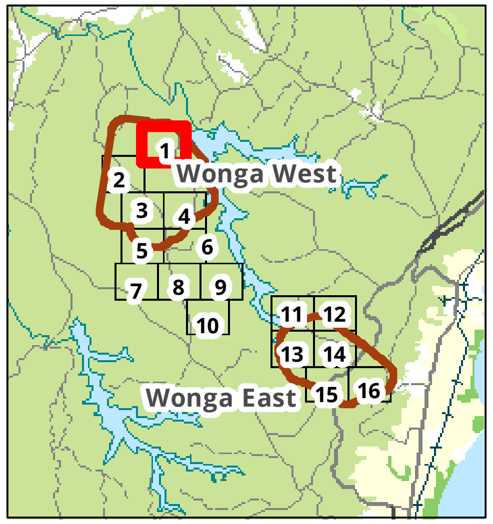
DRAWING 8

APPENDIX A

DETAILED SWAMP MAPPING
(Biosis, 2012)

Map 1: Wonga East & West Swamp Mapping



Legend

—	Longwalls
▭	Swamp Boundary

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

N

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Date: 25 September 2012,
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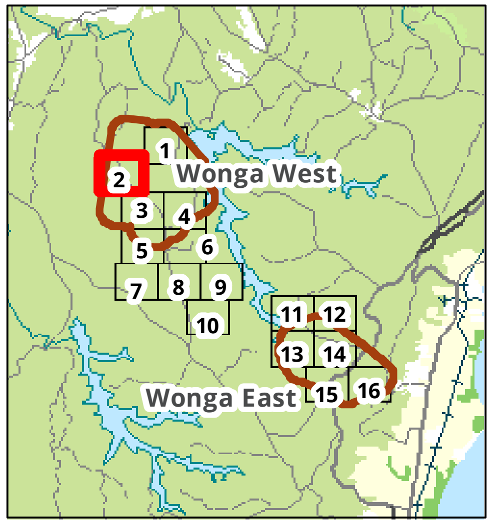

Legend

Longwalls

Swamp Boundary

Map 2: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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Date: 25 September 2012,
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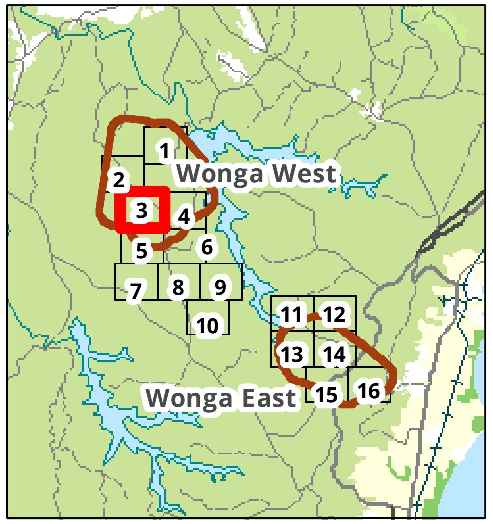
Acknowledgements: Imagery (c) Nearmap 2012



Legend

- Longwalls
- Swamp Boundary

Map 3: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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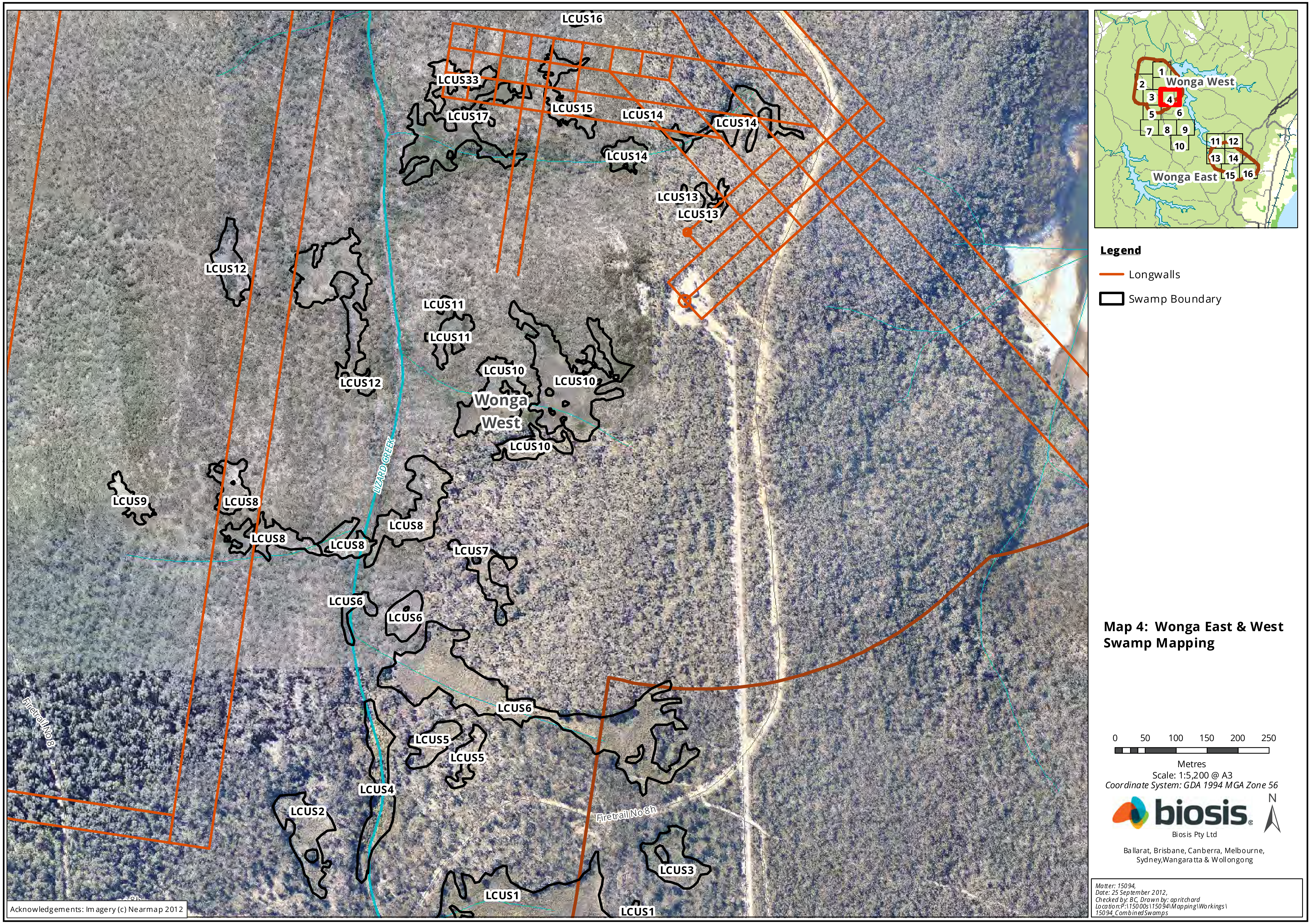

Acknowledgements: Imagery (c) Nearmap 2012

Map 4: Wonga East & West Swamp Mapping

Scale: 1:5,200 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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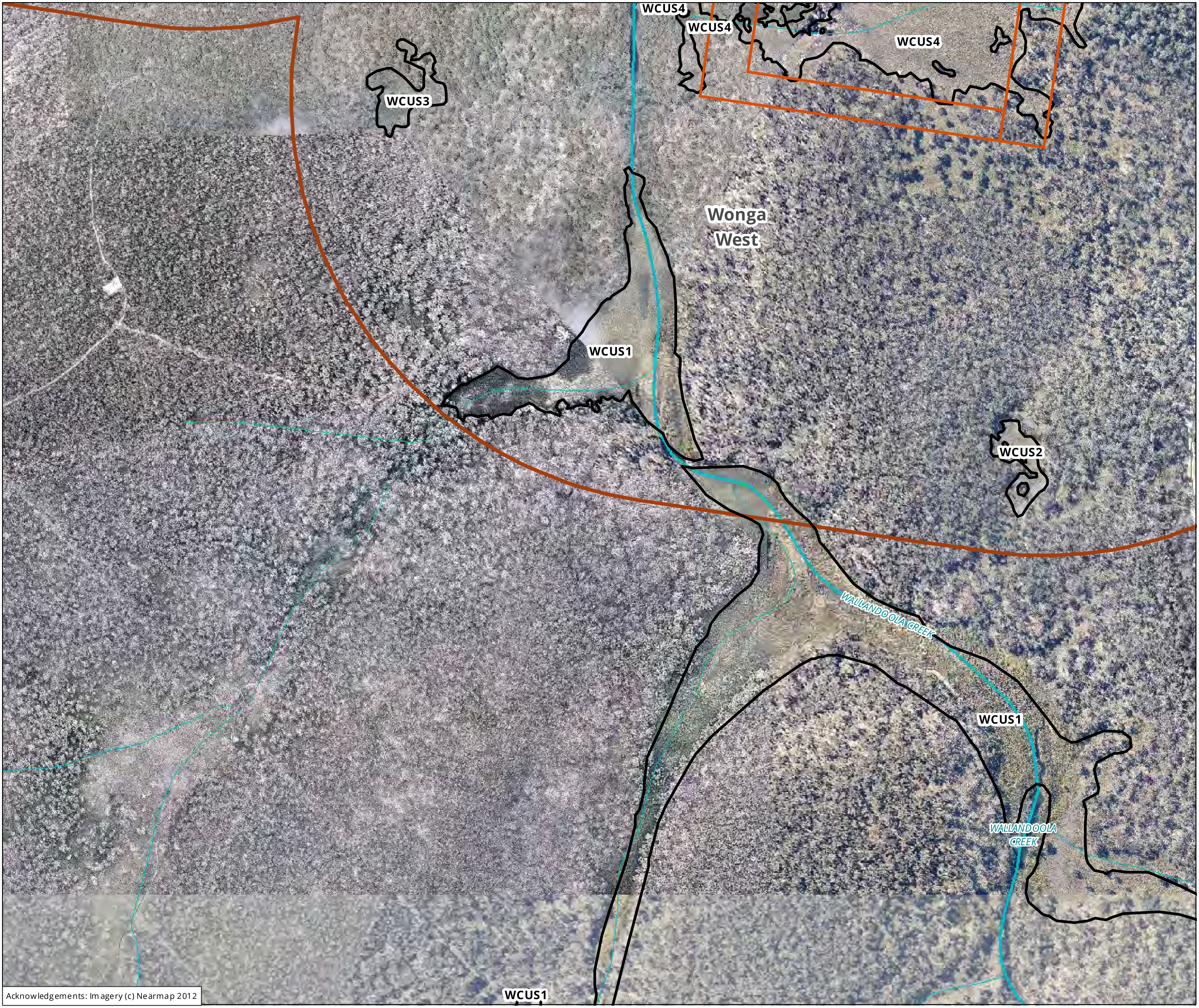

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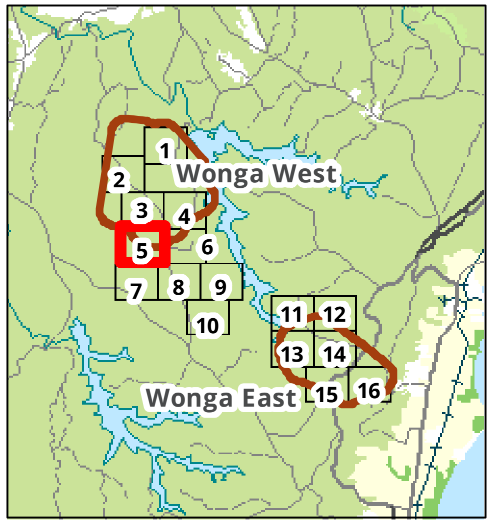

Legend

- Longwalls
- ☐ Swamp Boundary

Map 5: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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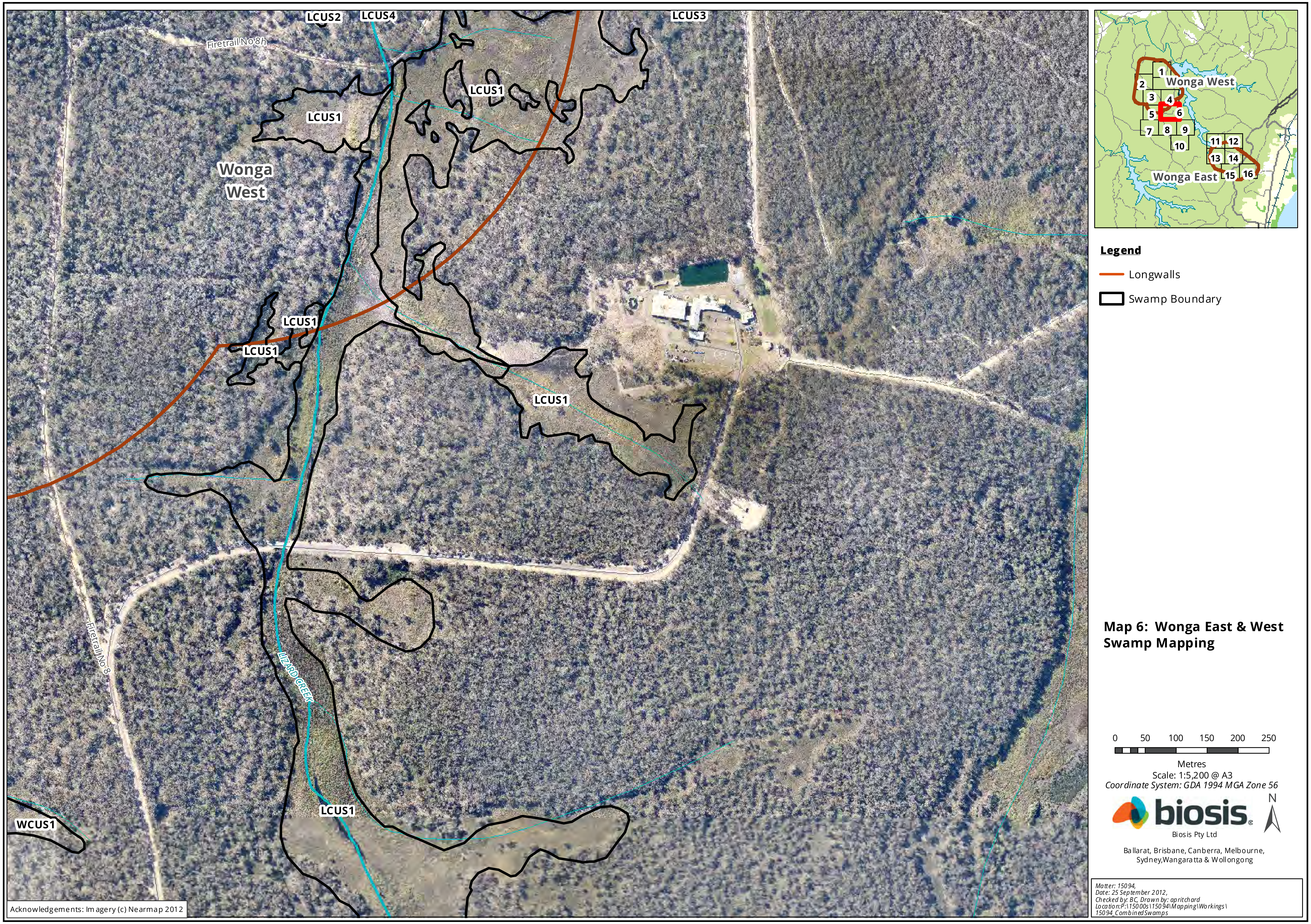

Map 6: Wonga East & West Swamp Mapping

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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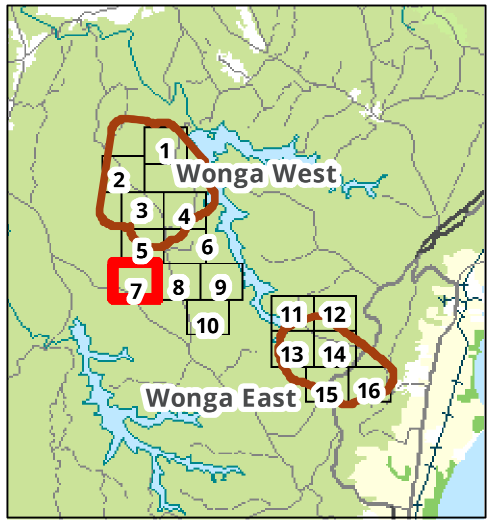
Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

Acknowledgements: Imagery (c) Nearmap 2012

Acknowledgements: Imagery (c) Nearmap 2012



Legend

— Longwalls

▭ Swamp Boundary

Map 7: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres
Scale: 1:5,200 @ A3
Coordinate System: GDA 1994 MGA Zone 56

N

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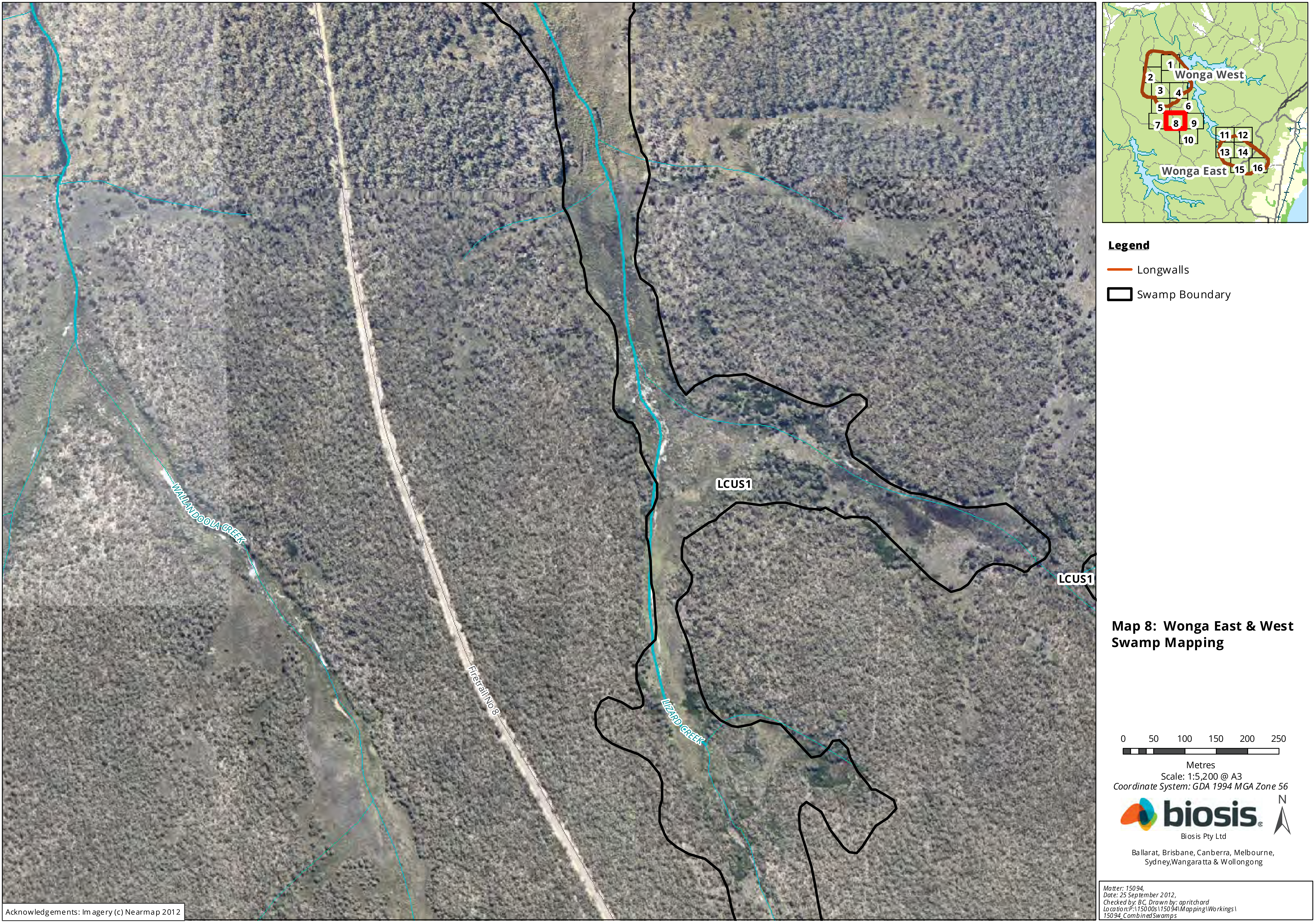
Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps



Legend

- Longwalls
- Swamp Boundary

Map 8: Wonga East & West Swamp Mapping

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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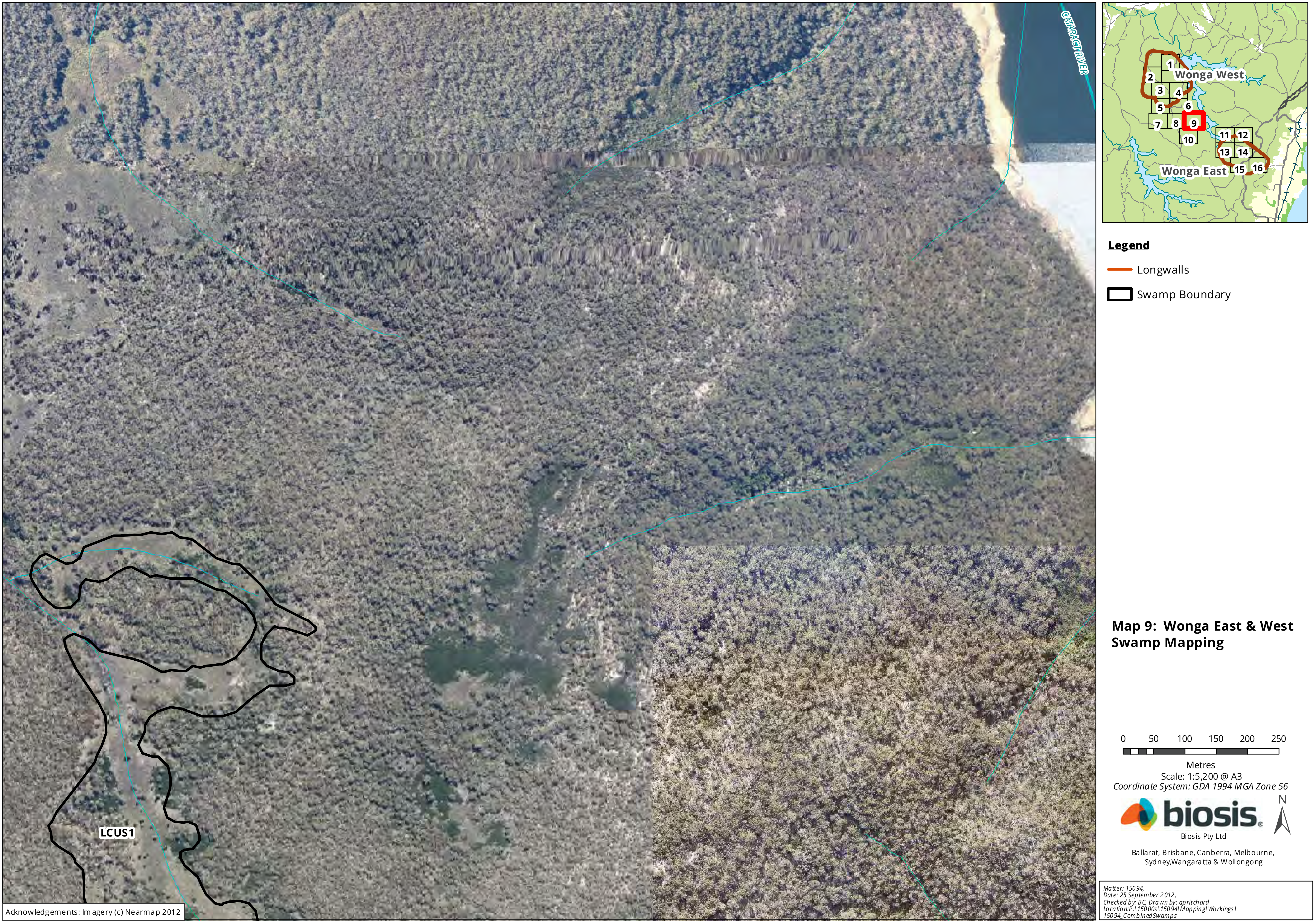
Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

Acknowledgements: Imagery (c) Nearmap 2012



Legend

— Longwalls

▭ Swamp Boundary

Map 9: Wonga East & West Swamp Mapping

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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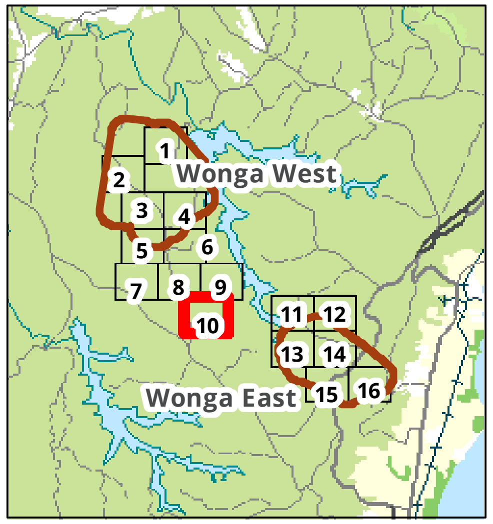
Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

Acknowledgements: Imagery (c) Nearmap 2012

Acknowledgements: Imagery (c) Nearmap 2012



Legend

Longwalls

Swamp Boundary

Map 10: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

N

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Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

Acknowledgements: Imagery (c) Nearmap 2012

Legend

Longwalls

Swamp Boundary

Map 11: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

N

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Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
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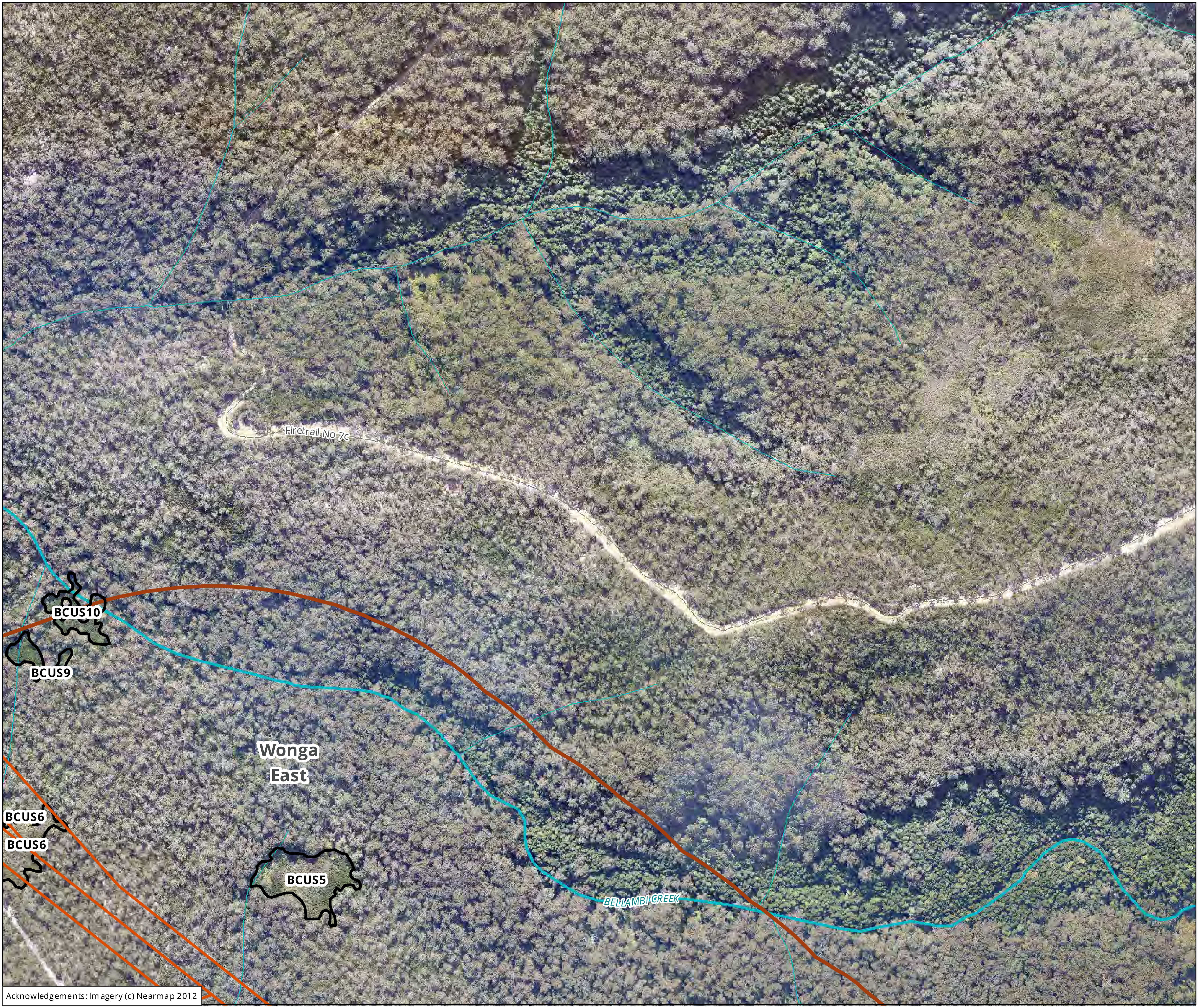

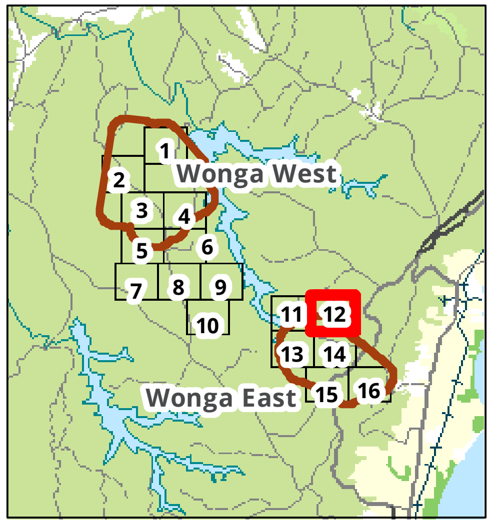

Legend

Longwalls

▭ Swamp Boundary

Map 12: Wonga East & West Swamp Mapping

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
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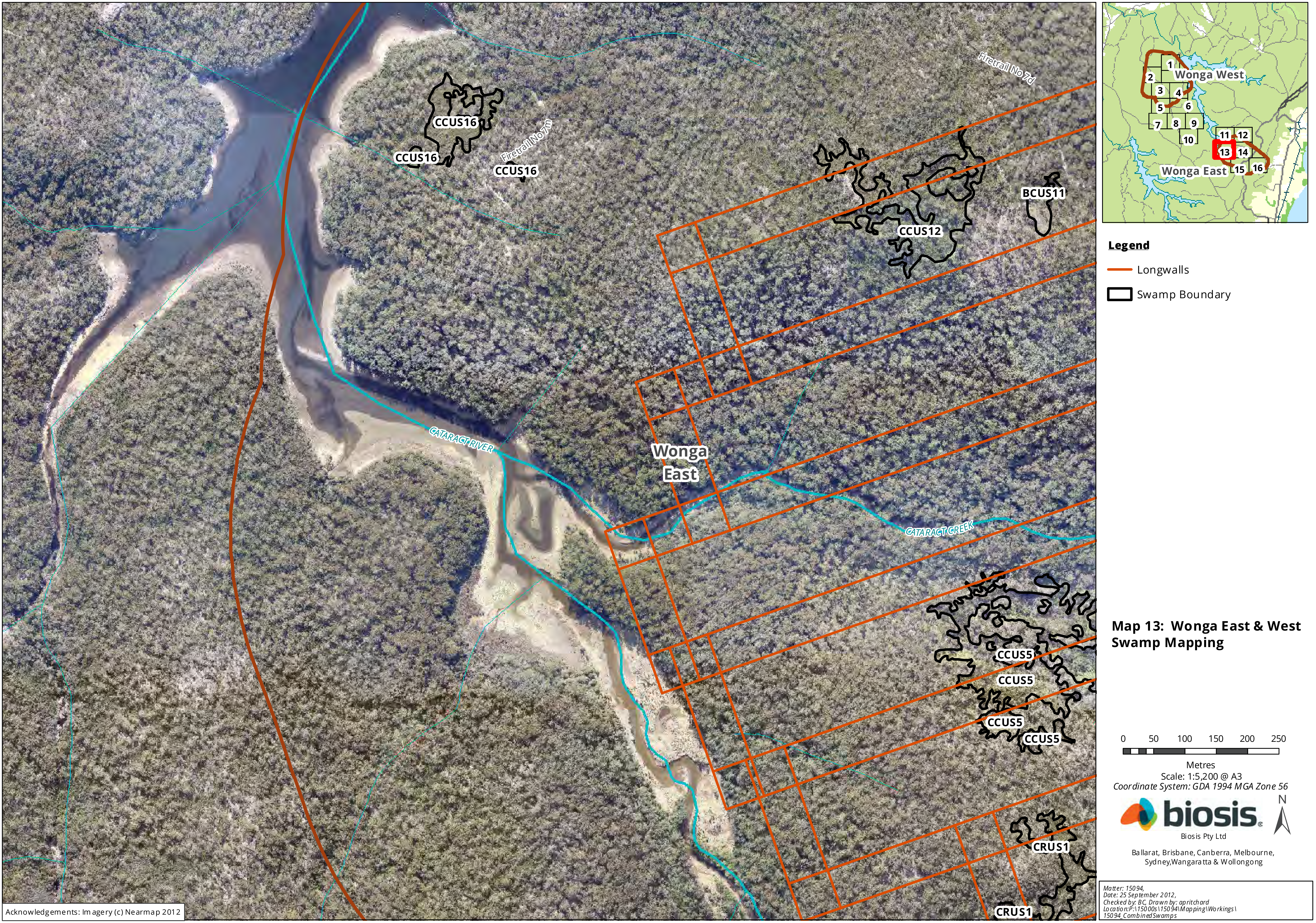

Acknowledgements: Imagery (c) Nearmap 2012

Legend

- Longwalls
- ▭ Swamp Boundary

Map 13: Wonga East & West Swamp Mapping

0 50 100 150 200 250
Metres
Scale: 1:5,200 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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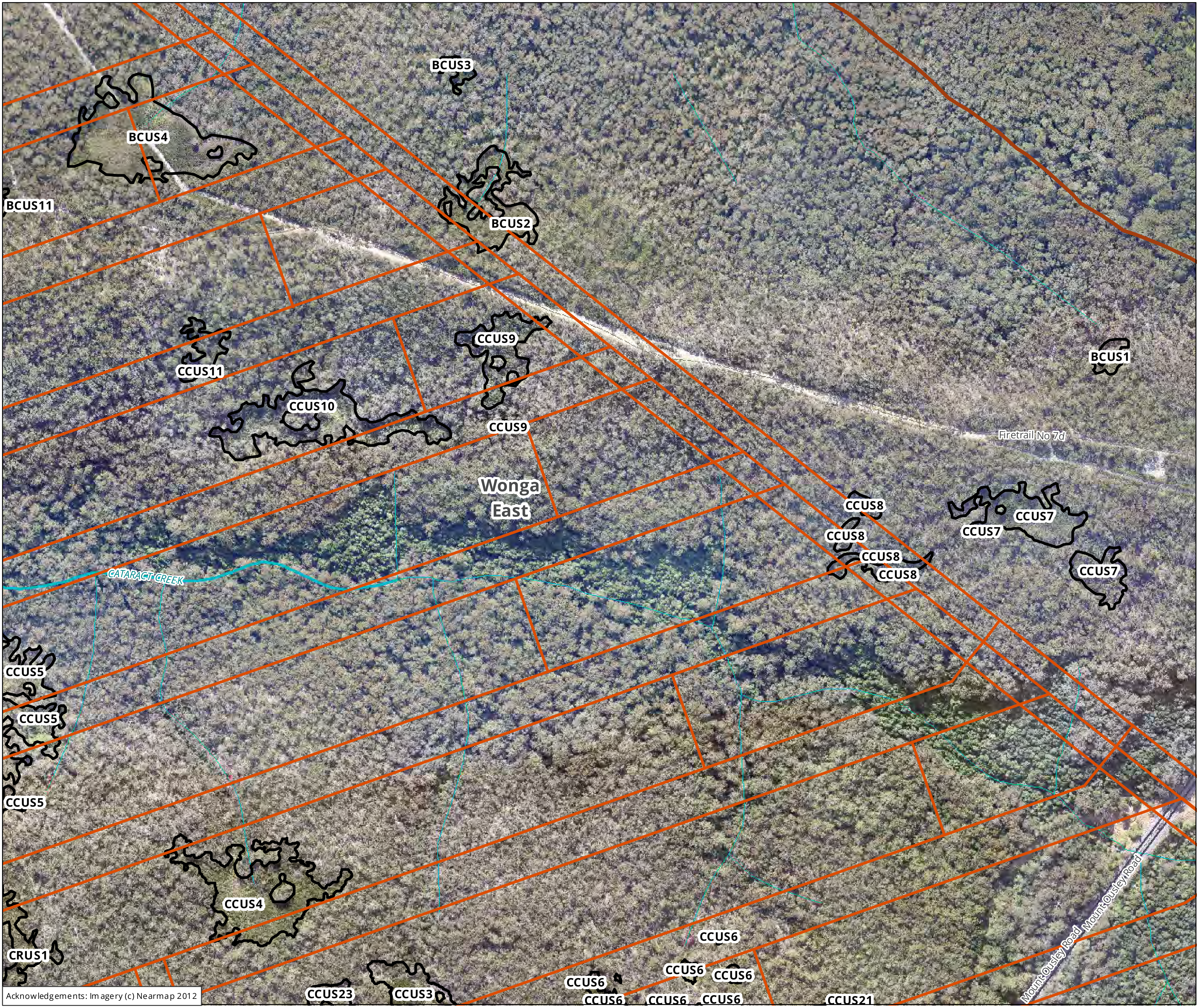
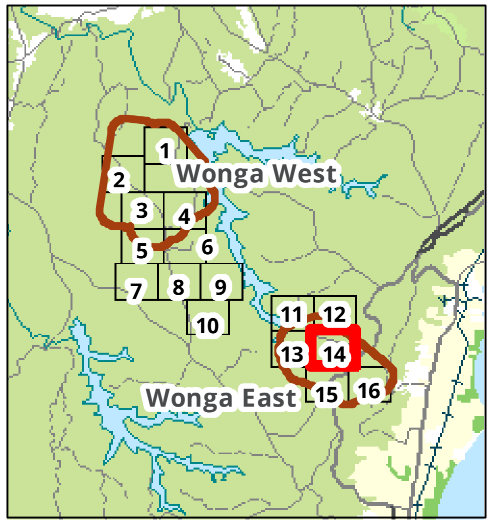
Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings
15094_CombinedSwamps

Map 14: Wonga East & West Swamp Mapping



Acknowledgements: Imagery (c) Nearmap 2012



Legend

- Longwalls
- Swamp Boundary

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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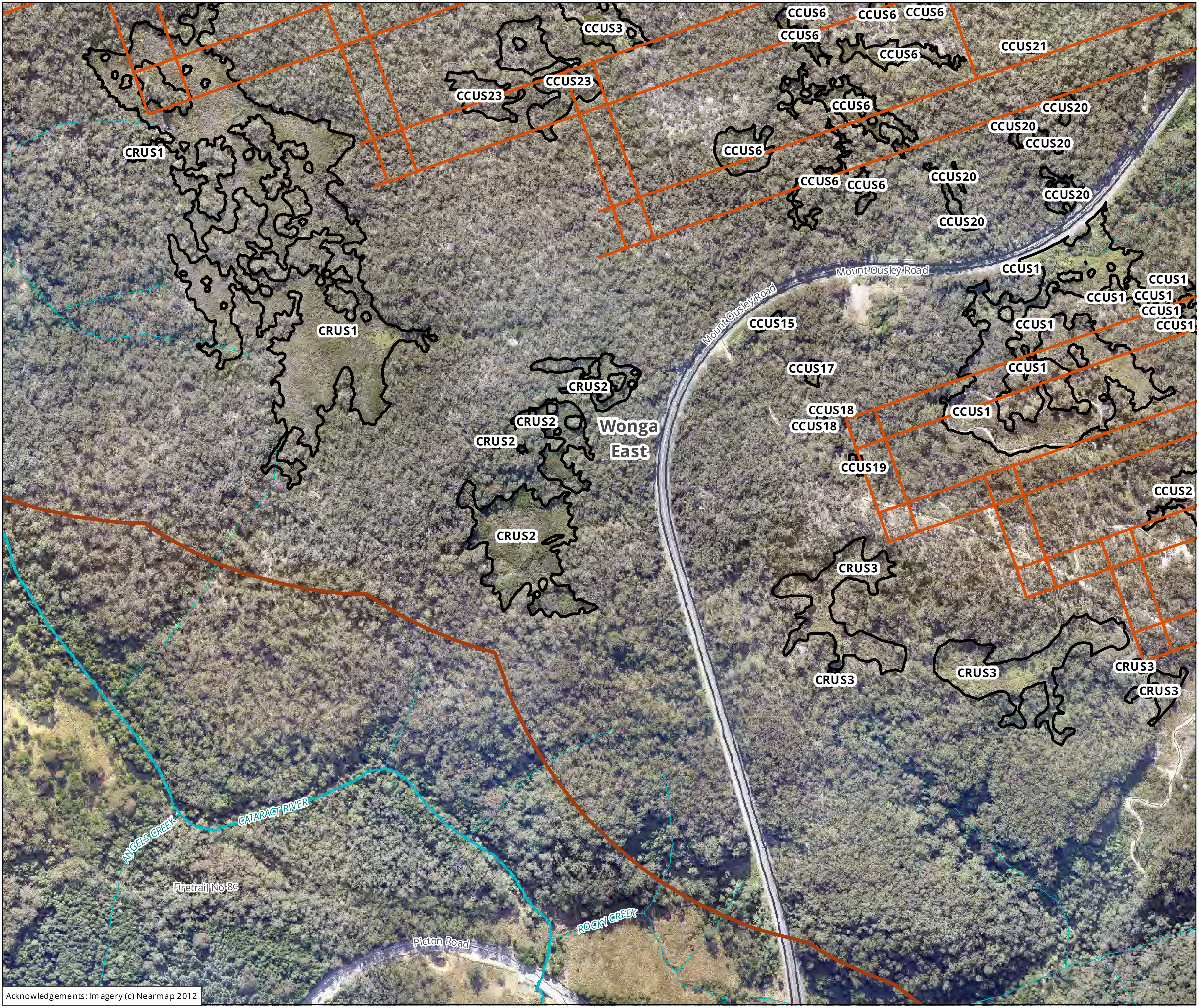
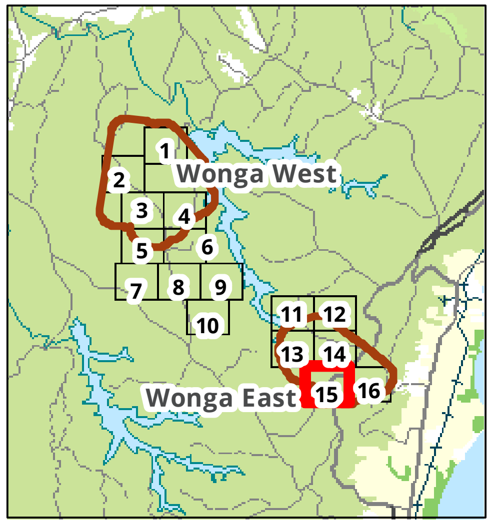
Sydney,Wangaratta & Wollongong

Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

Map 15: Wonga East & West Swamp Mapping



Acknowledgements: Imagery (c) Nearmap 2012



Legend

Longwalls

▭ Swamp Boundary

0 50 100 150 200 250

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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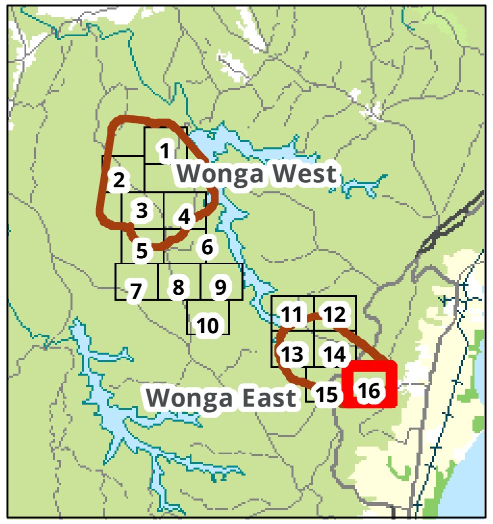
Sydney,Wangaratta & Wollongong

Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

Acknowledgements: Imagery (c) Nearmap 2012



Legend

Longwalls

▭ Swamp Boundary

Map 16: Wonga East & West Swamp Mapping

Metres

Scale: 1:5,200 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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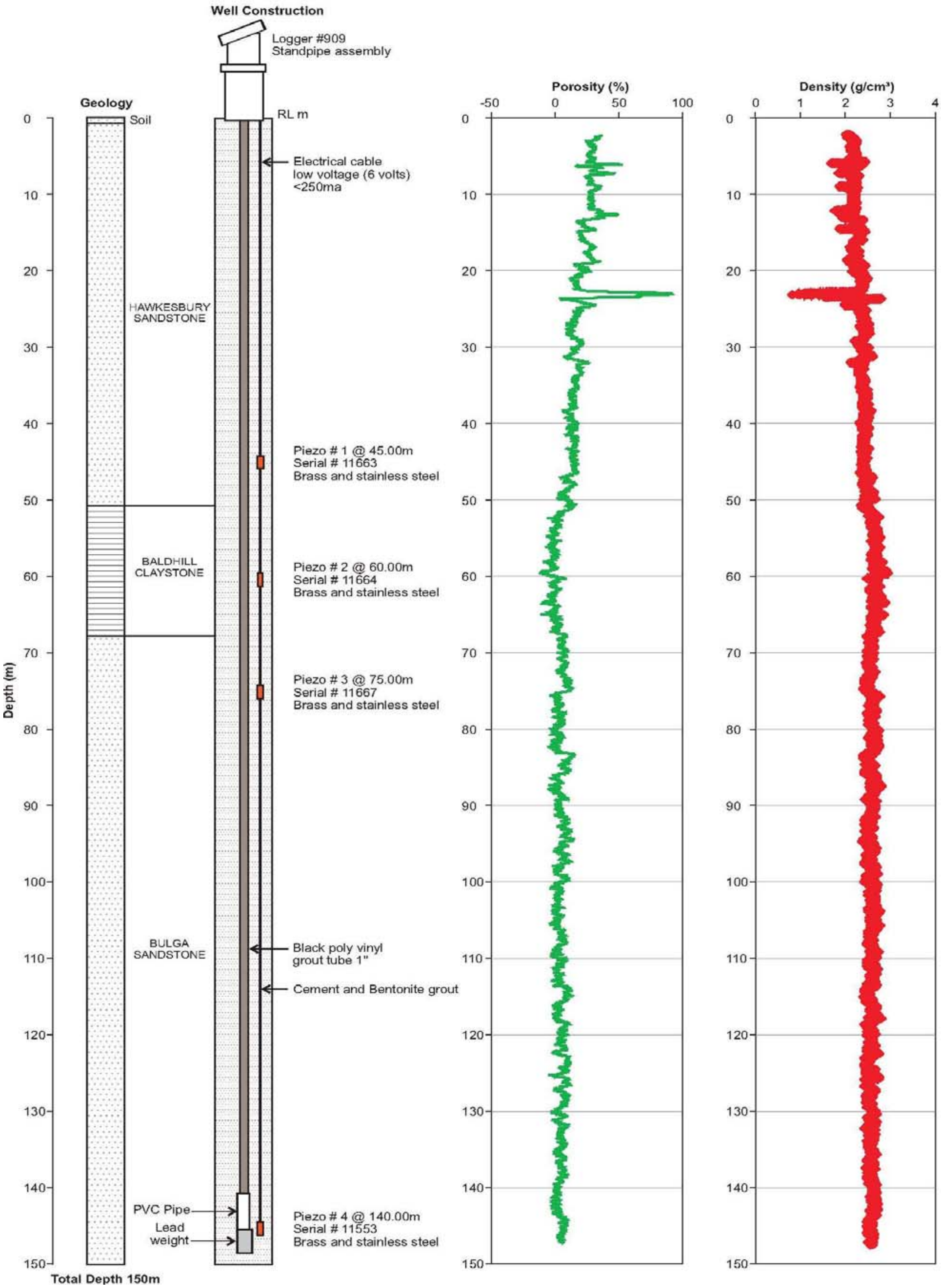
Matter: 15094,
Date: 25 September 2012,
Checked by: BC, Drawn by: apritchard
Location:P:\15000s\15094\Mapping\Workings\15094_CombinedSwamps

APPENDIX B

PIEZOMETER CONSTRUCTION DETAILS



VW PIEZOMETER INSTALLATION – NRE-1A

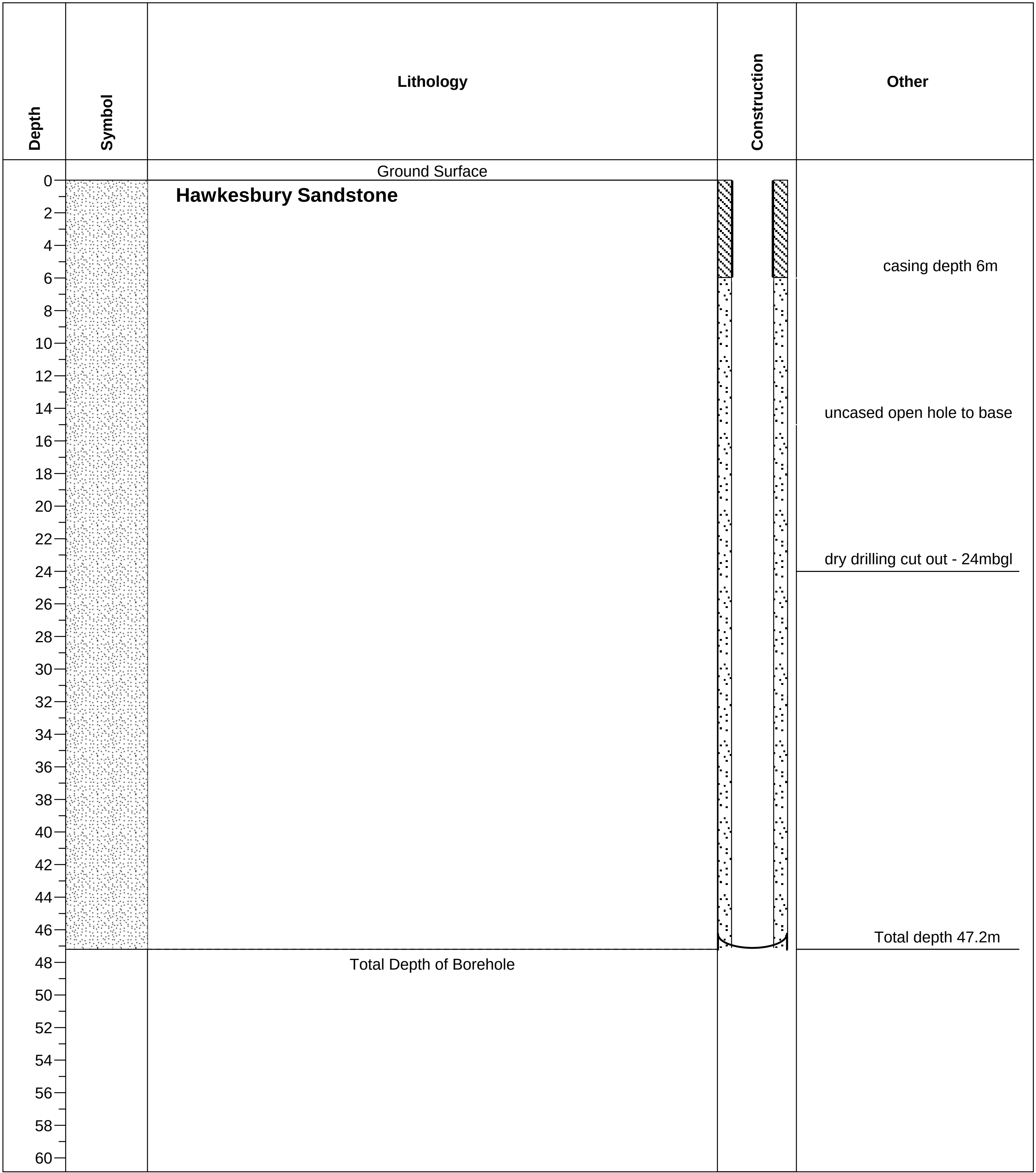
Bore / Piezo: NRE A **Page 1 of 1**

Project: Wongawilli

Location: NRE 1

Coordinates: E 303692 **N 6196033** **Project Number: GUJ1**

Datum: **Elevation: 376.18m** **Logged By: H Chandra**



Driller: Rob Budd

Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 21/11/09

Drilling Finish: 21/11/09

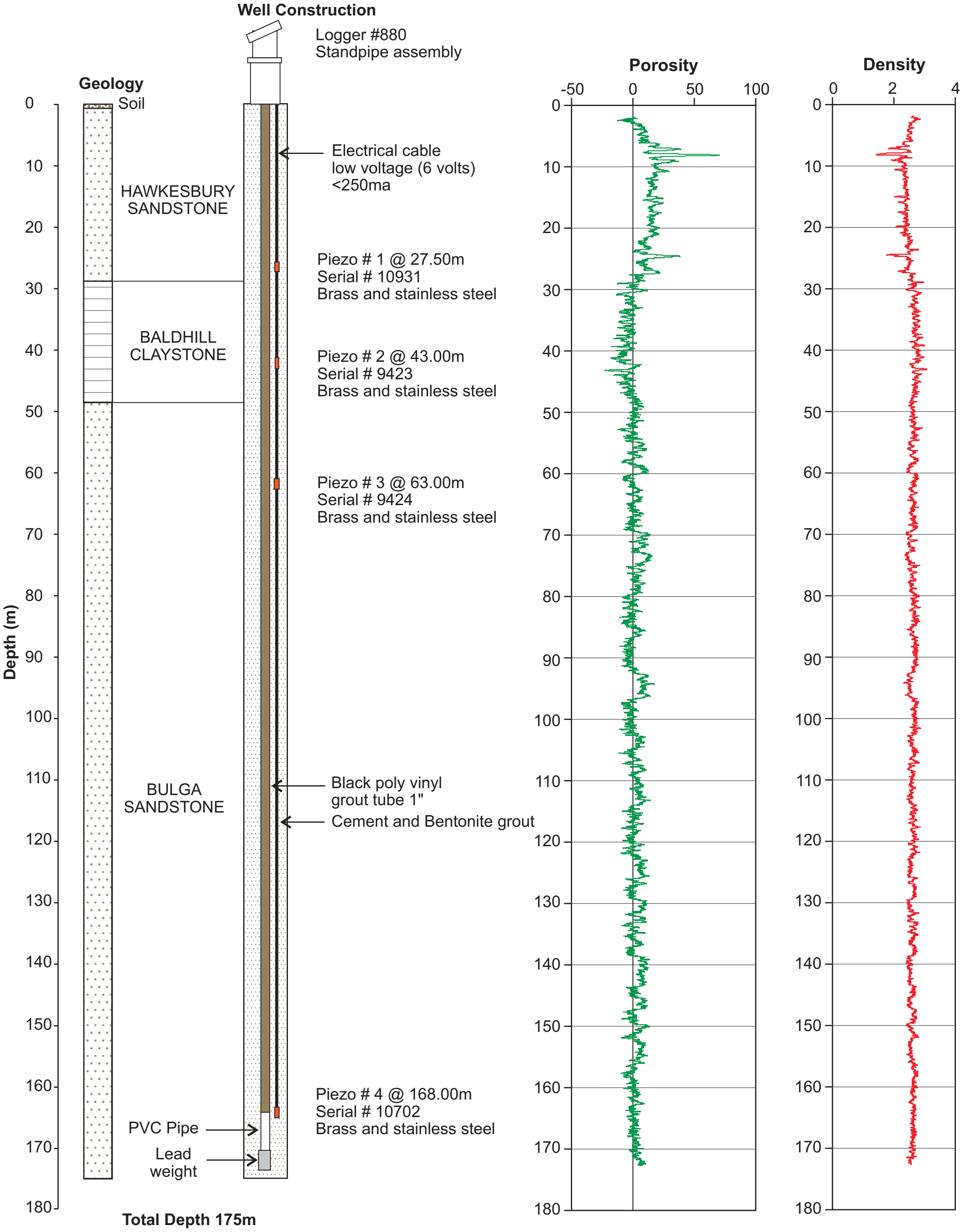


Figure 3: VW Piezo Installation - NRE NE-1B

GeoTerra

Bore / Piezo: NRE C

Page 1 of 1

Project: Wongawilli

Location: NRE 1

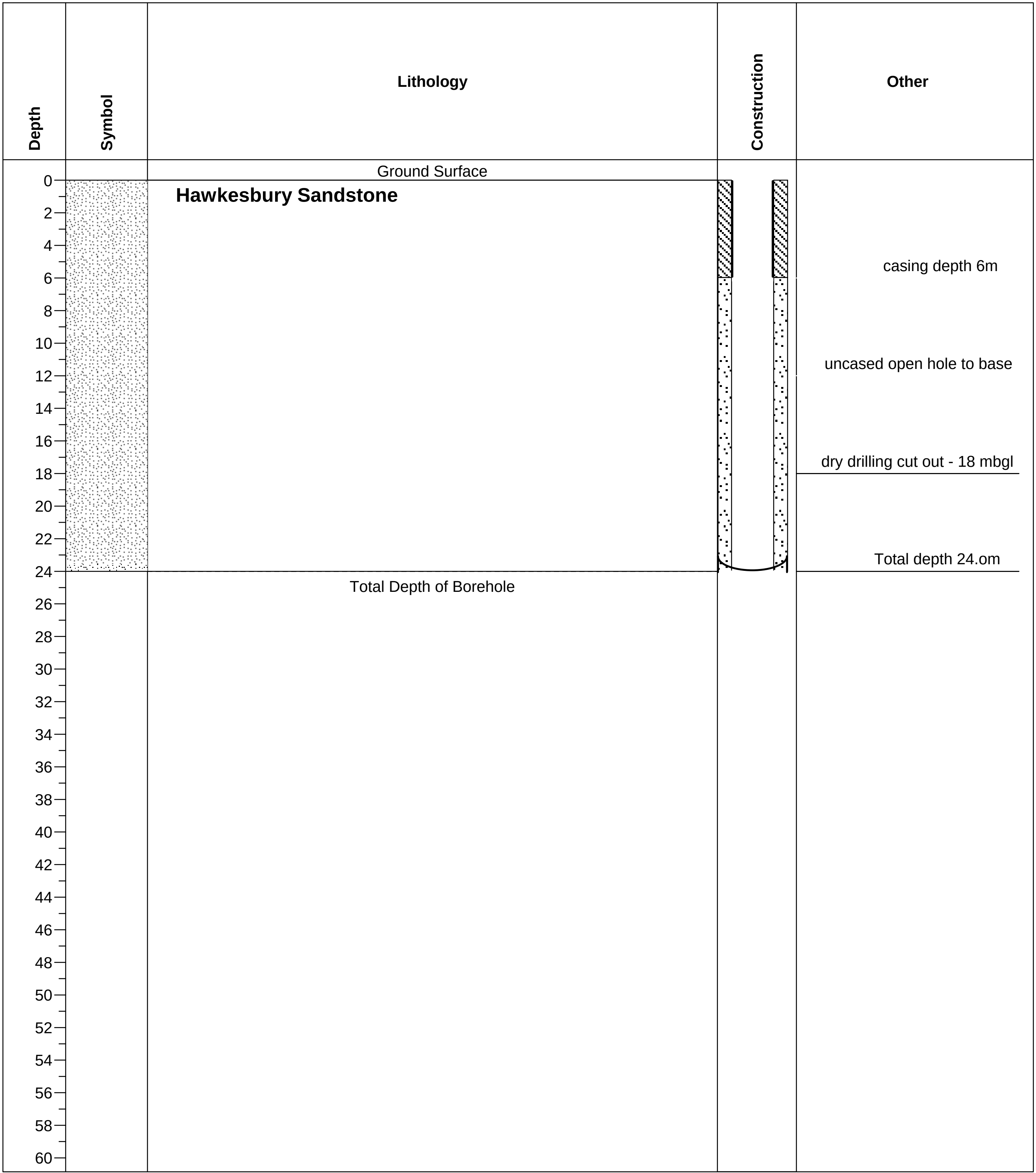
Coordinates: E 303233 N 6198797

Project Number: GUJ1

Datum:

Elevation: 362.72

Logged By: H Chandra



Driller: Rob Budd

Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 3/12/09

Drilling Finish: 3/12/09

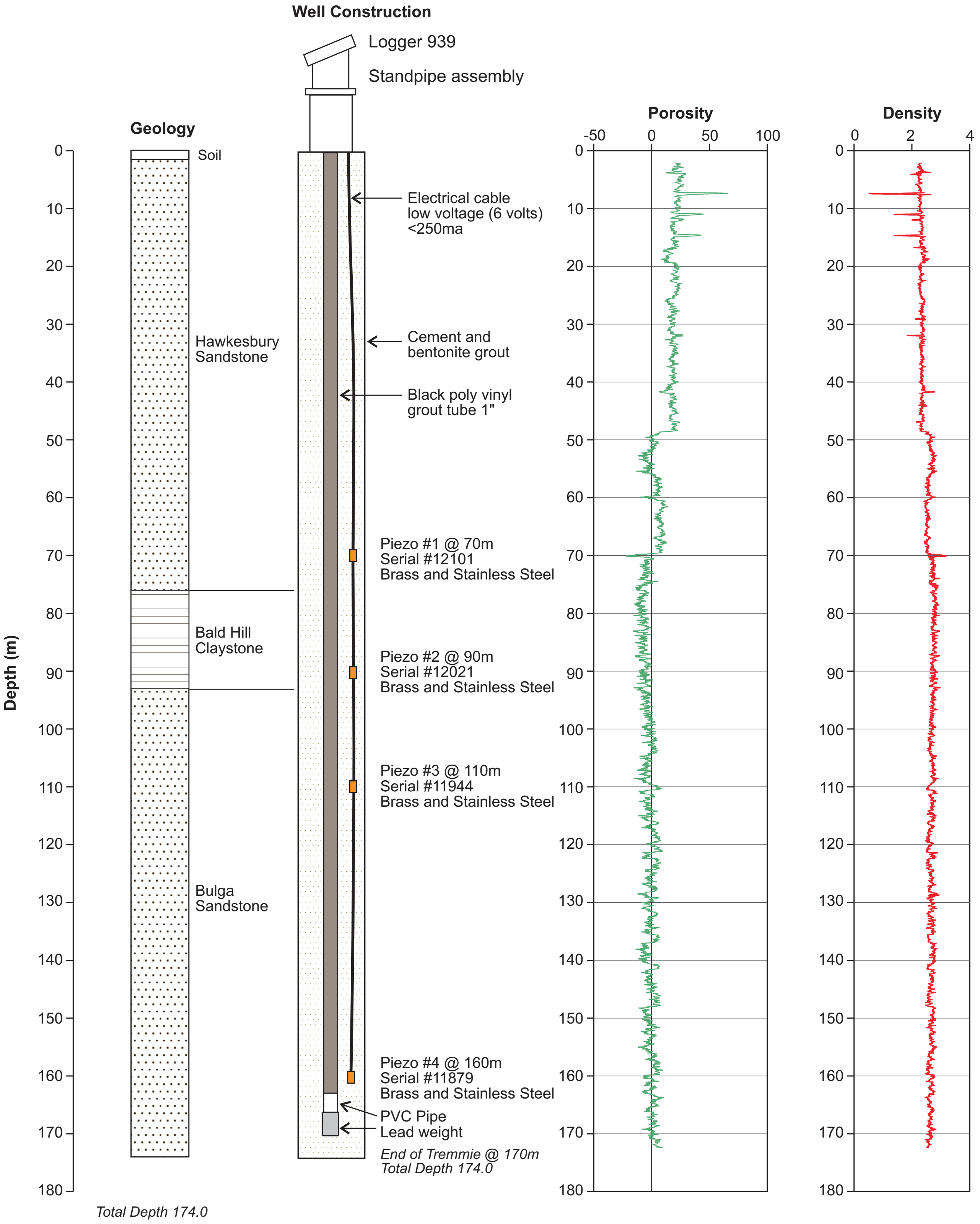


Figure 3: VW Piezo installation - NRE 1D.

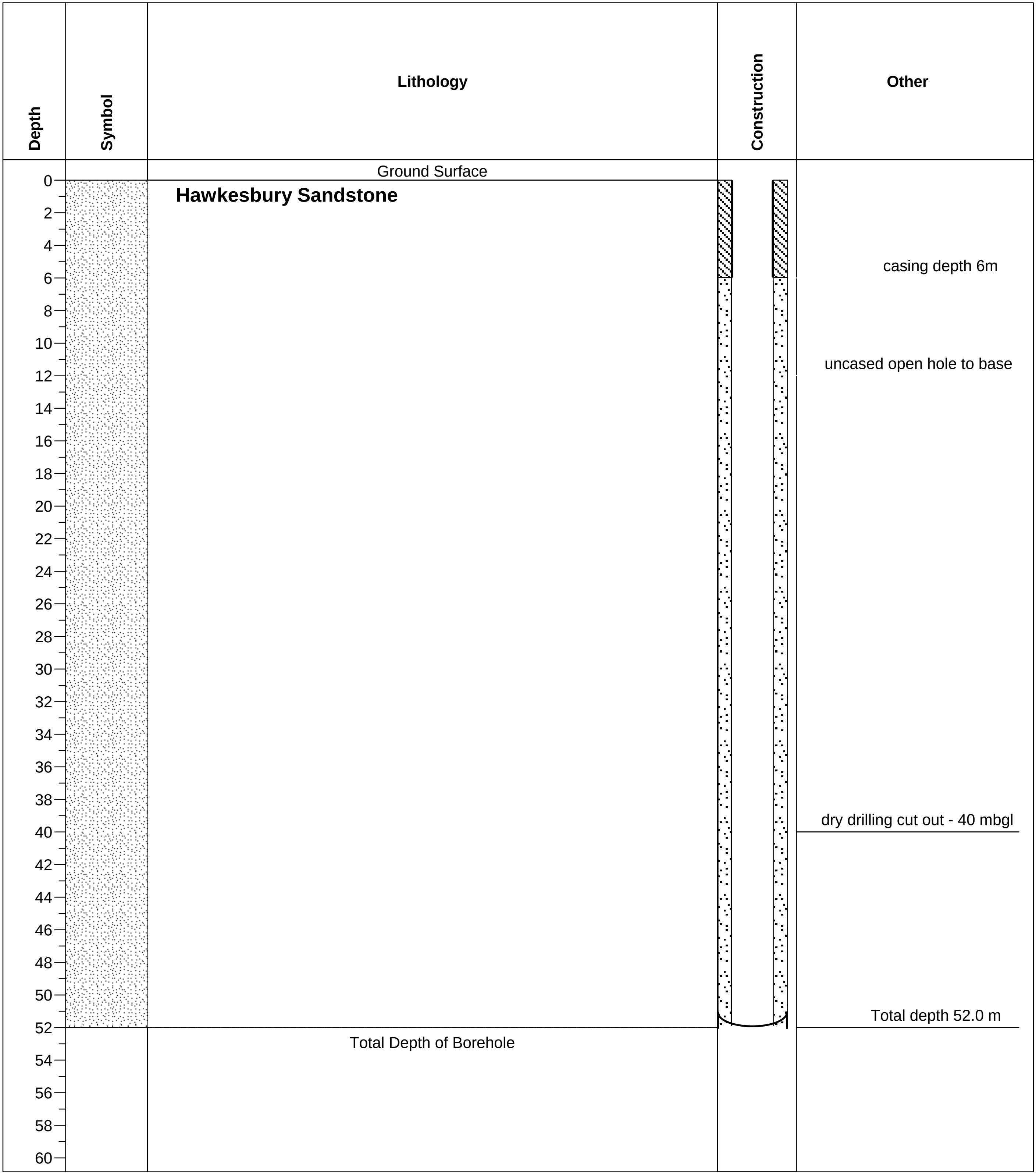
Bore / Piezo: NRE D **Page 1 of 1**

Project: Wongawilli

Location: NRE 1

Coordinates: E 301870 **N 6198509** **Project Number: GUJ1**

Datum: **Elevation: 348.83** **Logged By: H Chandra**



Ground Surface

Hawkesbury Sandstone

Total Depth of Borehole

casing depth 6m

uncased open hole to base

dry drilling cut out - 40 mbgl

Total depth 52.0 m

Driller: Rob Budd

Drilling Method: open hole hammer

Drilling Equipment: open hole hammer

Drilling Start: 6/11/09

Drilling Finish: 6/11/09

Bore / Piezo: NRE E

Page 1 of 1

Project: Wongawilli

Location: NRE 1

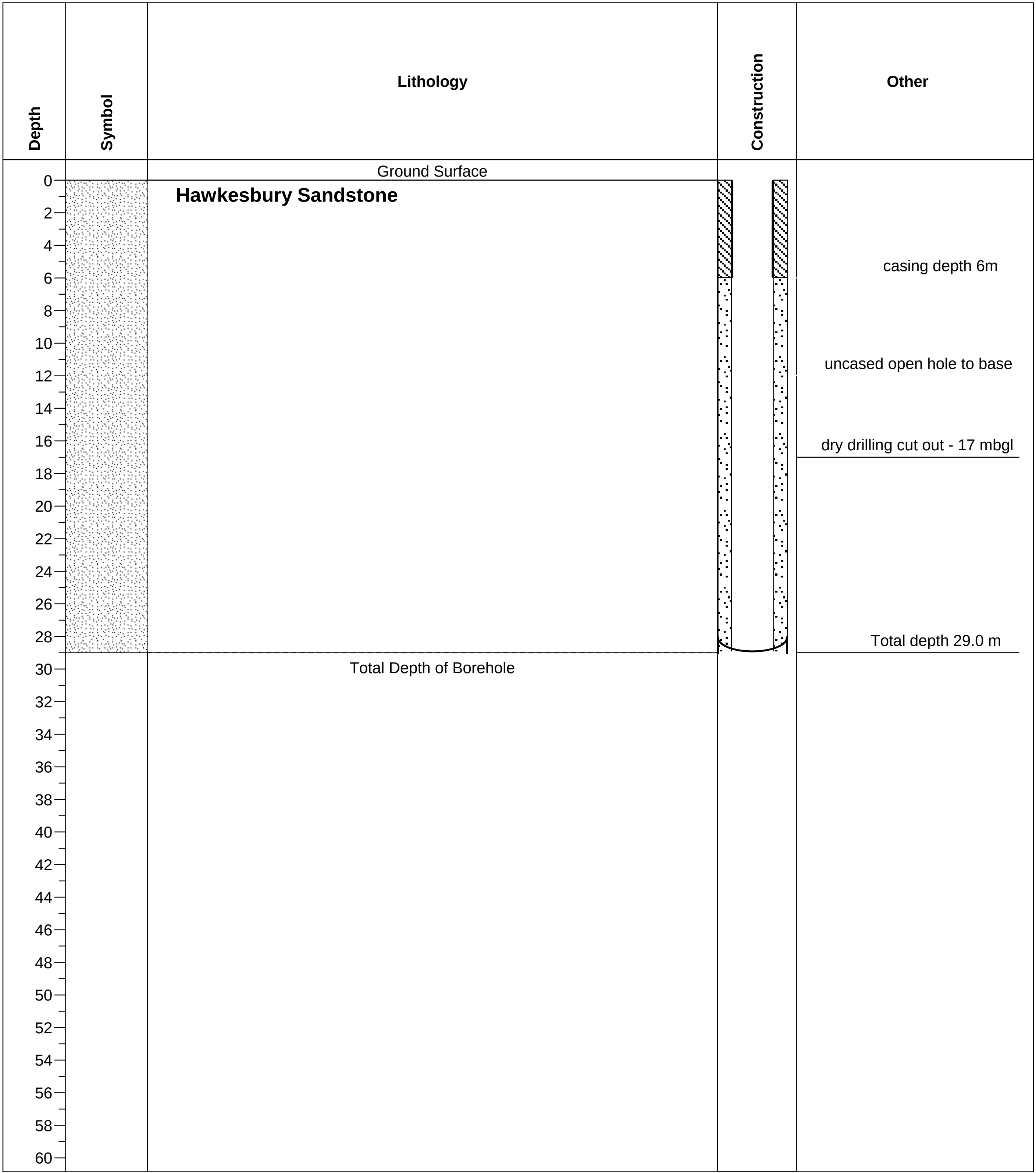
Coordinates: E 296727 N 6202286

Project Number: GUJ1

Datum:

Elevation: 329.24

Logged By: H Chandra



Driller: Rob Budd

Drilling Method: open hole hammer

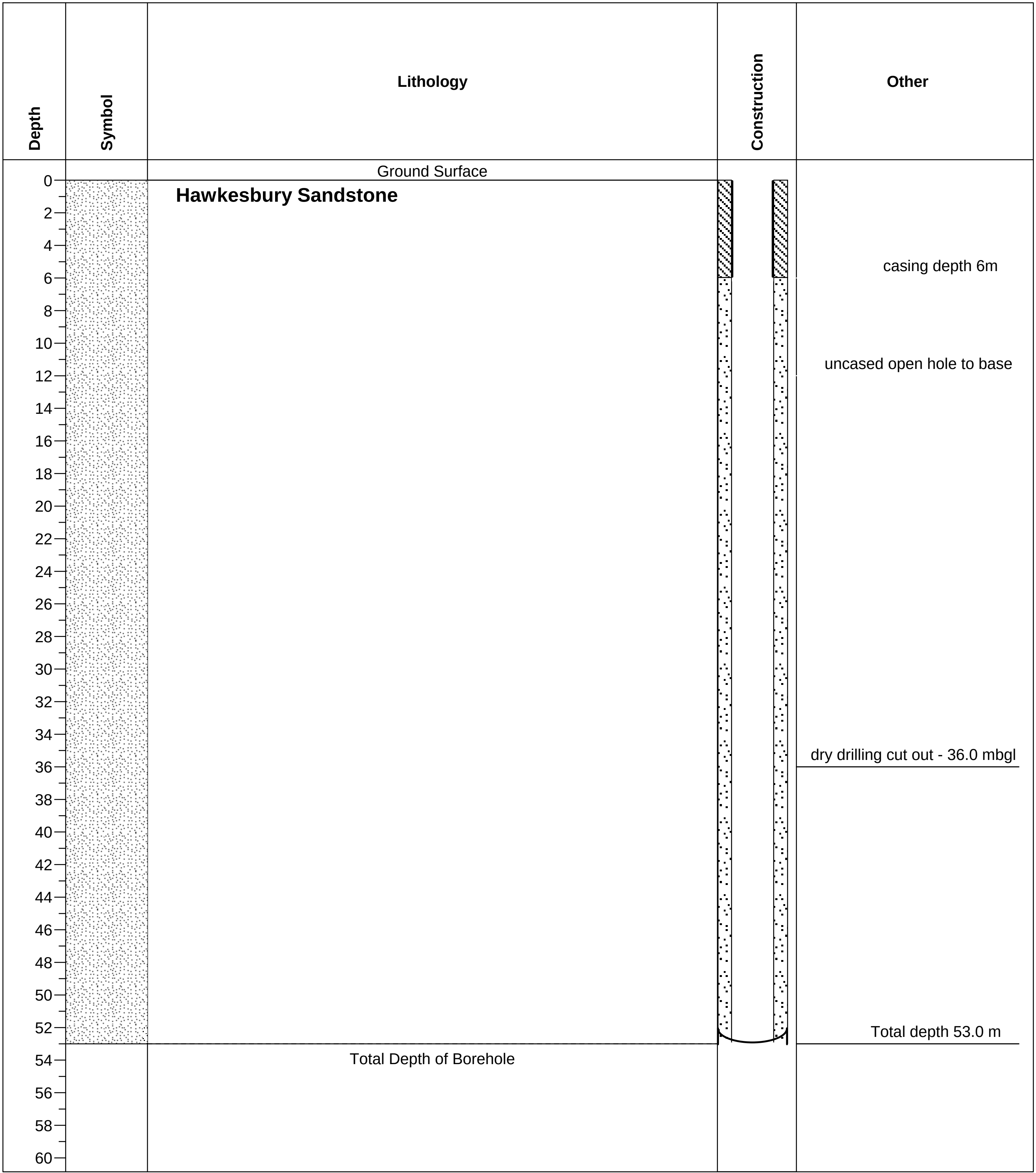
Drilling Equipment: open hole hammer

Drilling Start: 6/11/09

Drilling Finish: 6/11/09

GeoTerra

Bore / Piezo: NRE G **Page 1 of 1**
Project: Wongawilli
Location: NRE 1
Coordinates: E 296949 **N 6205678** **Project Number: GUJ1**
Datum: **Elevation: 363.03** **Logged By: H Chandra**



Driller: Rob Budd
Drilling Method: open hole hammer
Drilling Equipment: open hole hammer
Drilling Start: 20/10/09
Drilling Finish: 20/10/09

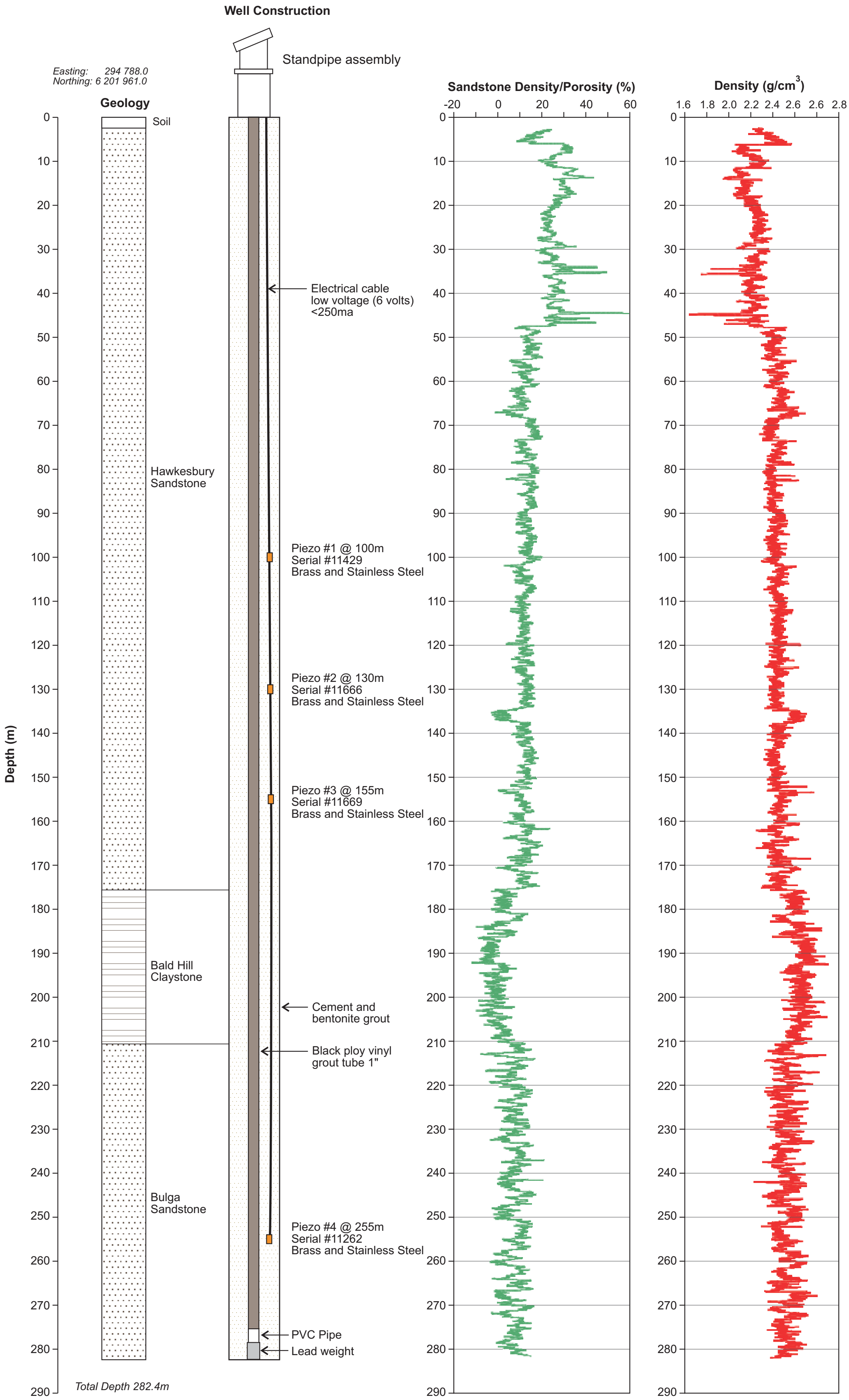


Figure 3: VW Piezo installation - NRE NE-3.

Bore / Piezo: NE 3

Page 1 of 1

Project: Wongawilli

Location: NRE 1

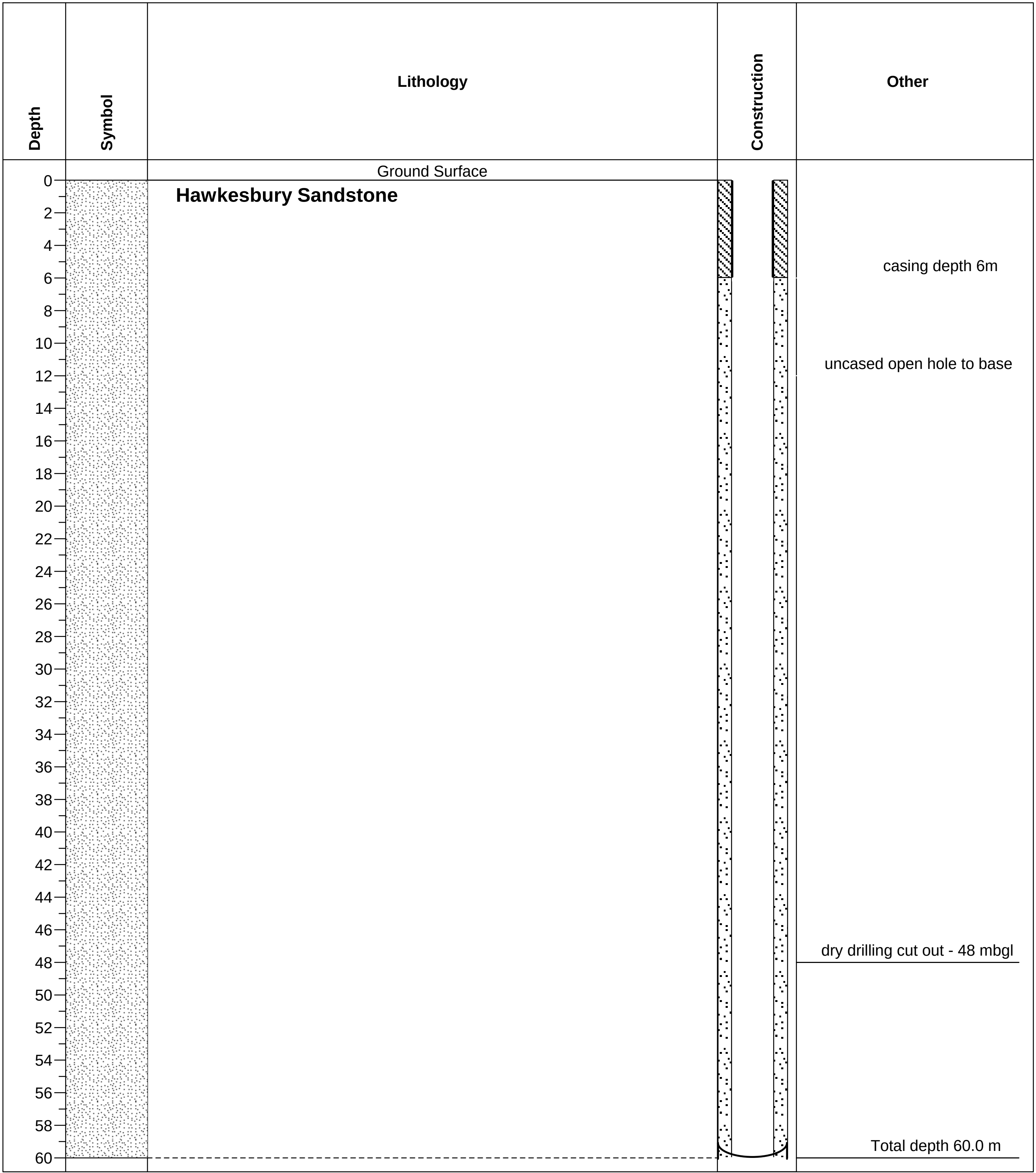
Coordinates: E 294803 N 6201954

Project Number: GUJ1

Datum:

Elevation: 359.27

Logged By: H Chandra



Driller: Rob Budd

Drilling Method: open hole hammer

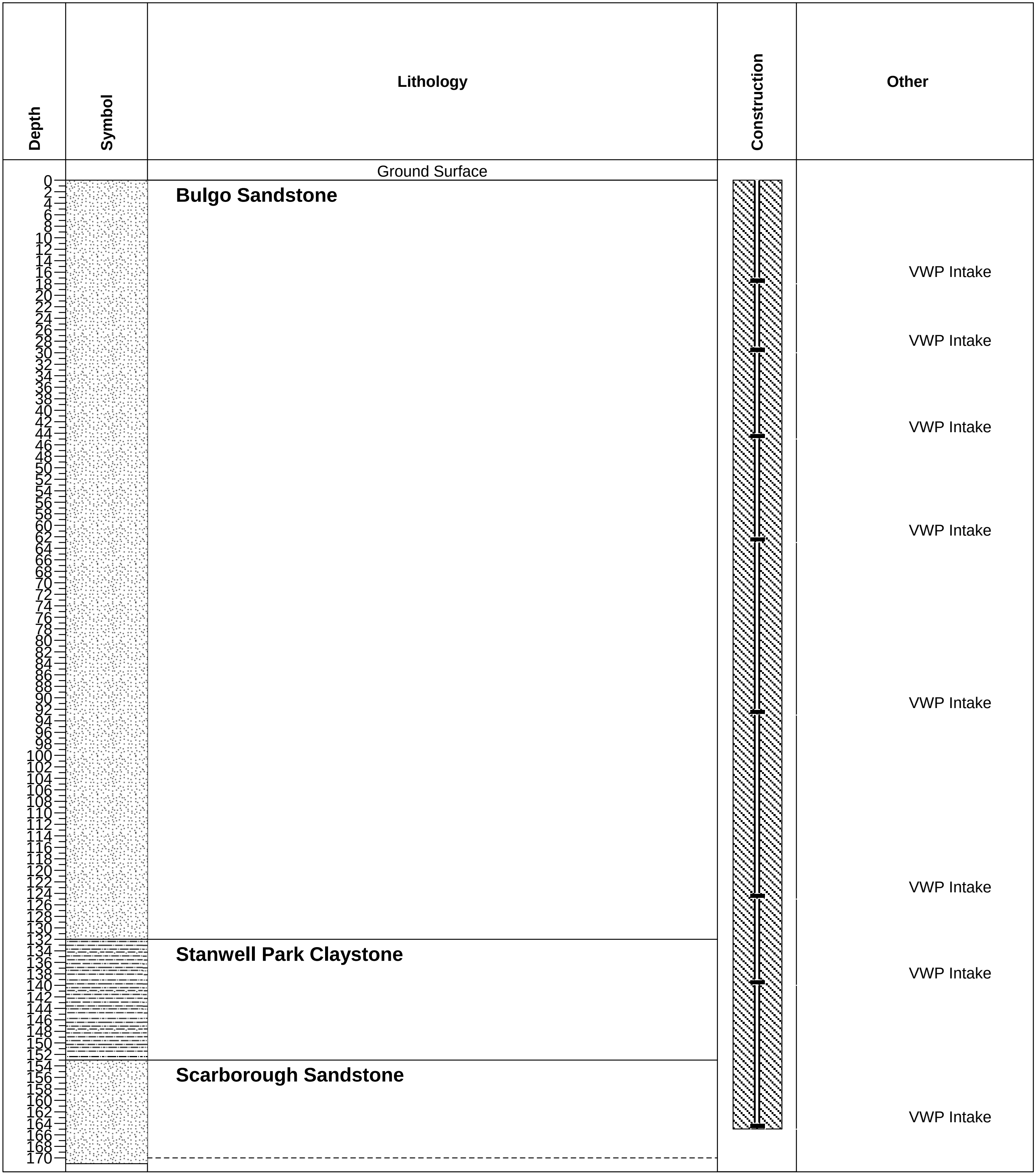
Drilling Equipment: open hole hammer

Drilling Start: 5/12/09

Drilling Finish: 5/12/09

GeoTerra

Bore / Piezo: GW1 **Page 1 of 1**
Project: Wongawilli Seam Major Expansion
Location:
Coordinates: E 3030693 N 6196913
Project Number: NRE1
Datum: **Elevation:** 318.2
Logged By: R Cartwright



Driller: Roger Ritchie
Drilling Method: open hole hammer
Drilling Equipment:
Drilling Start: 23 August 2012
Drilling Finish: 23 August 2012

Bore / Piezo: GW1A **Page 1 of 1**

Project: Wongawilli Seam Major Expansion

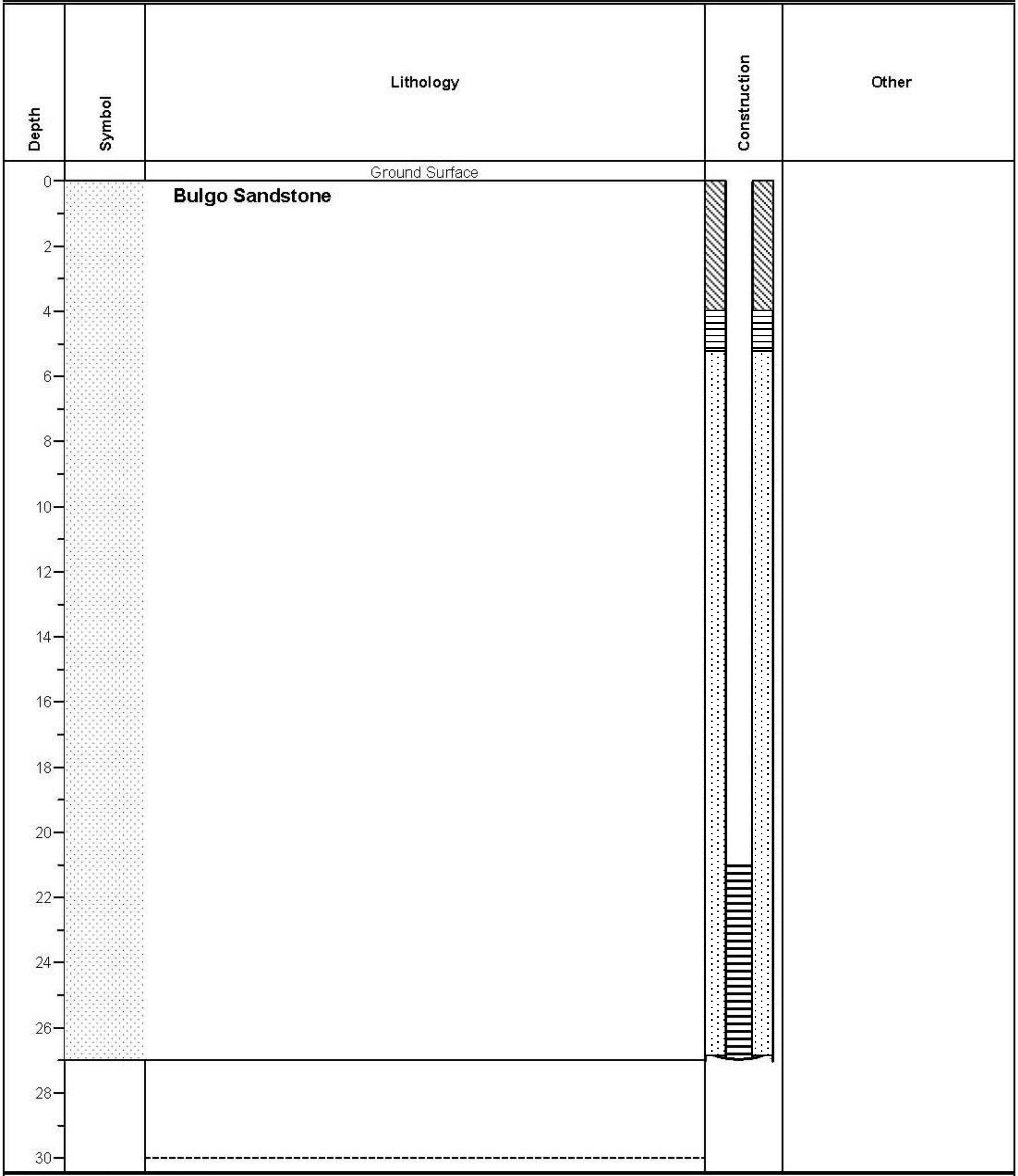
Location:

Coordinates: E 303742 **N 6196983**

Project Number: NRE1

Datum: **Elevation: 311.7**

Logged By: R Cartwright



Driller: Roger Ritchie

Drilling Method: open hole hammer

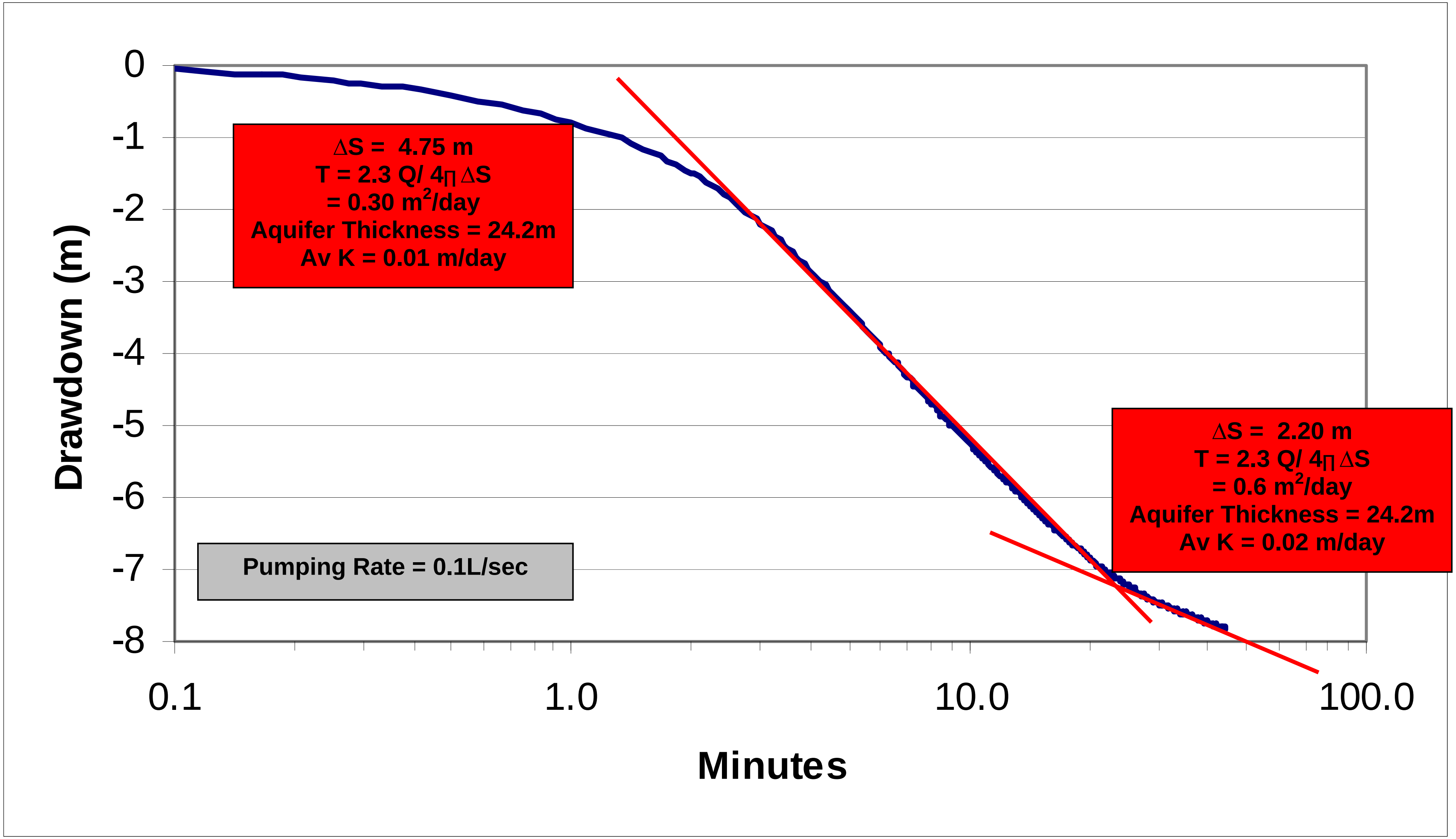
Drilling Equipment:

Drilling Start: 22 August 2012

Drilling Finish: 22 August 2012

APPENDIX C

HYDRAULIC PARAMETER INVESTIGATIONS

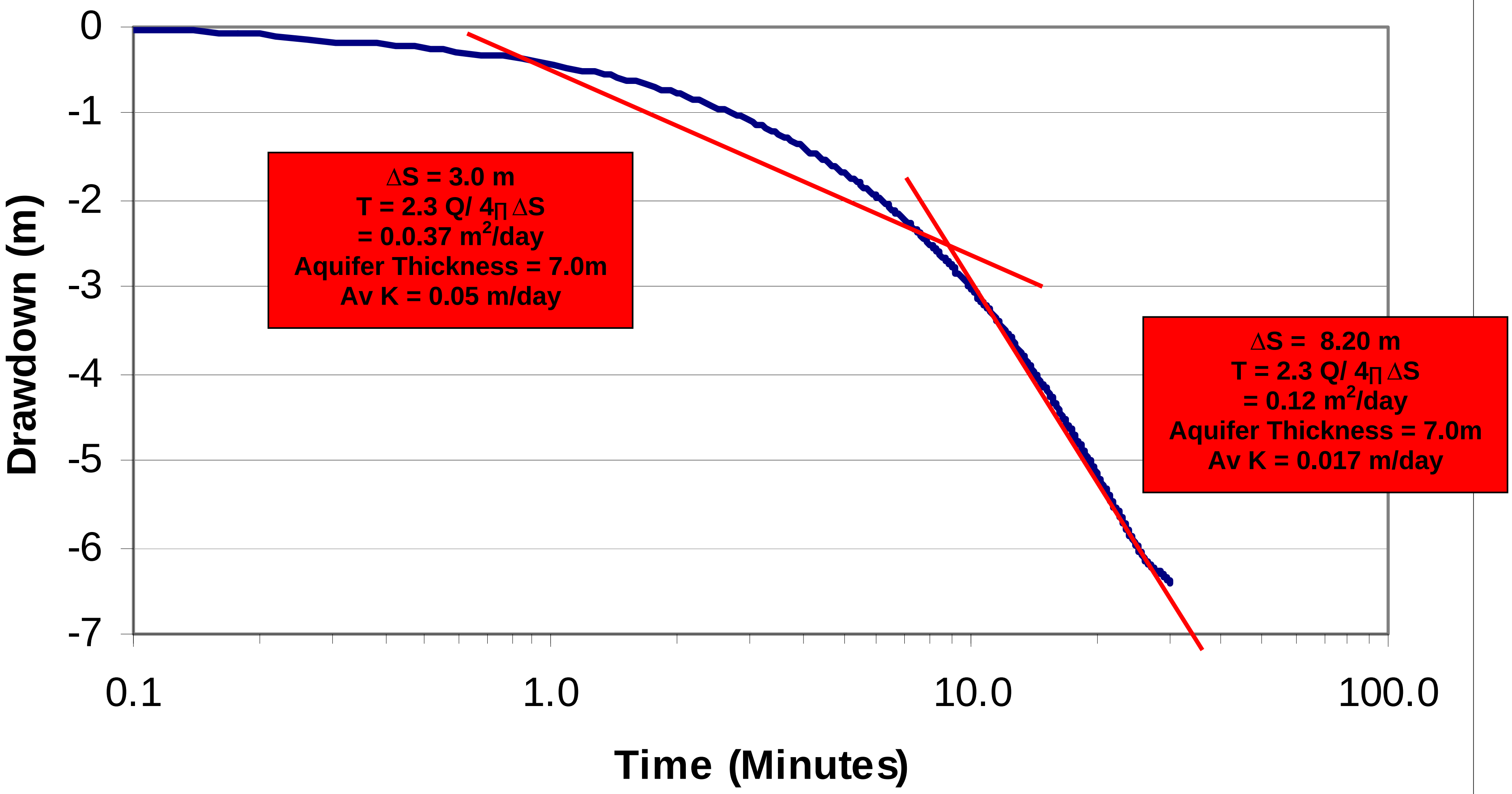


ΔS = 4.75 m
T = 2.3 Q/ 4∏ ΔS
= 0.30 m^2/day
Aquifer Thickness = 24.2m
Av K = 0.01 m/day

ΔS = 2.20 m
T = 2.3 Q/ 4∏ ΔS
= 0.6 m^2/day
Aquifer Thickness = 24.2m
Av K = 0.02 m/day

Pumping Rate = 0.1L/sec

Project	GUJ1	GUJARAT COKING COAL LTD	GeoTerra
Drawn	A Dawkins		
Date	17.01.2011	Constant Rate Pumping Test	NRE A
Scale	NTS		

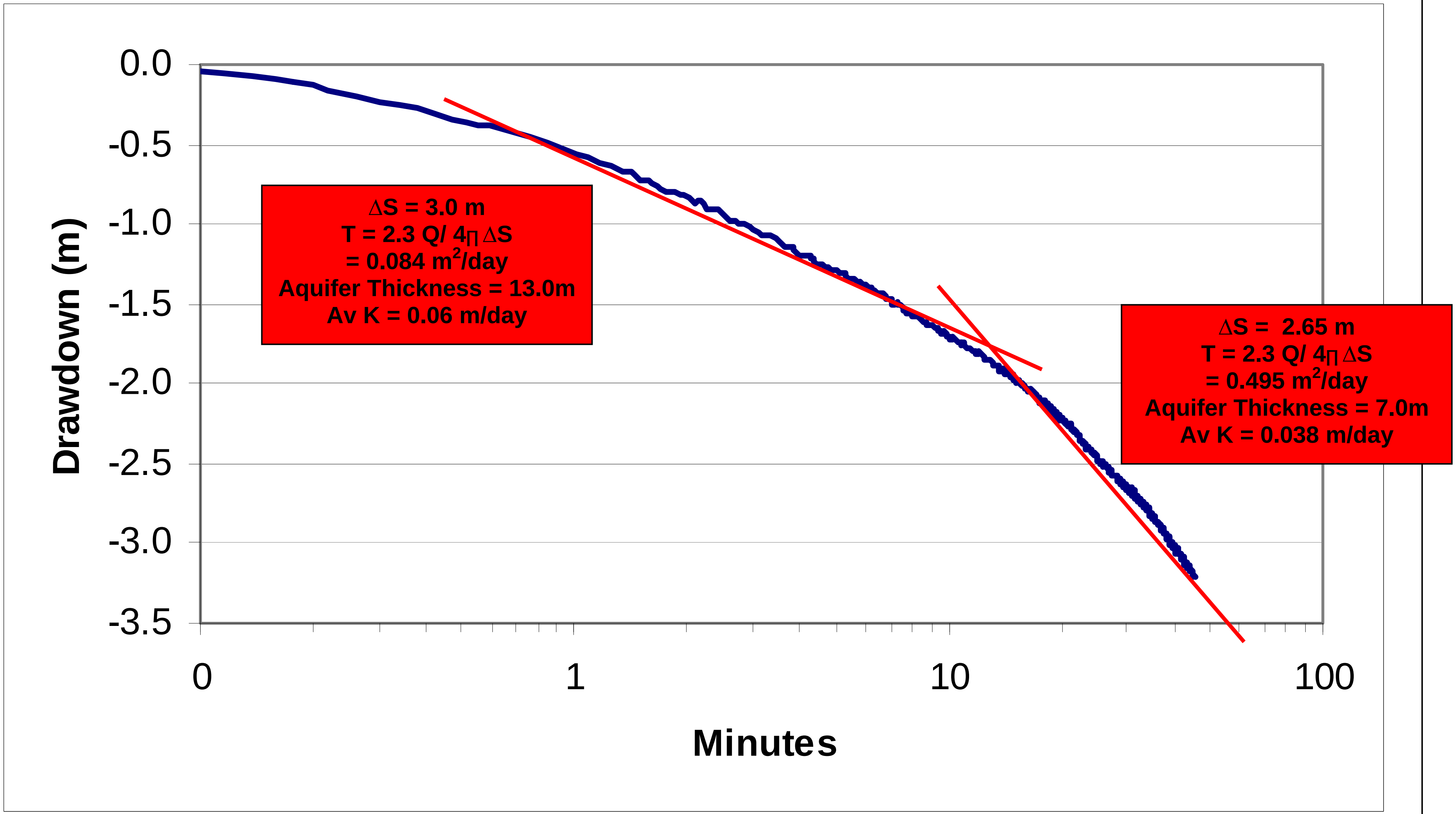


ΔS = 3.0 m
T = 2.3 Q/ 4∏ ΔS
= 0.0.37 m^2/day
Aquifer Thickness = 7.0m
Av K = 0.05 m/day

ΔS = 8.20 m
T = 2.3 Q/ 4∏ ΔS
= 0.12 m^2/day
Aquifer Thickness = 7.0m
Av K = 0.017 m/day

Pumping Rate = 0.07L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	**GeoTerra**
Drawn	**A Dawkins**		
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NRE C**
Scale	**NTS**		

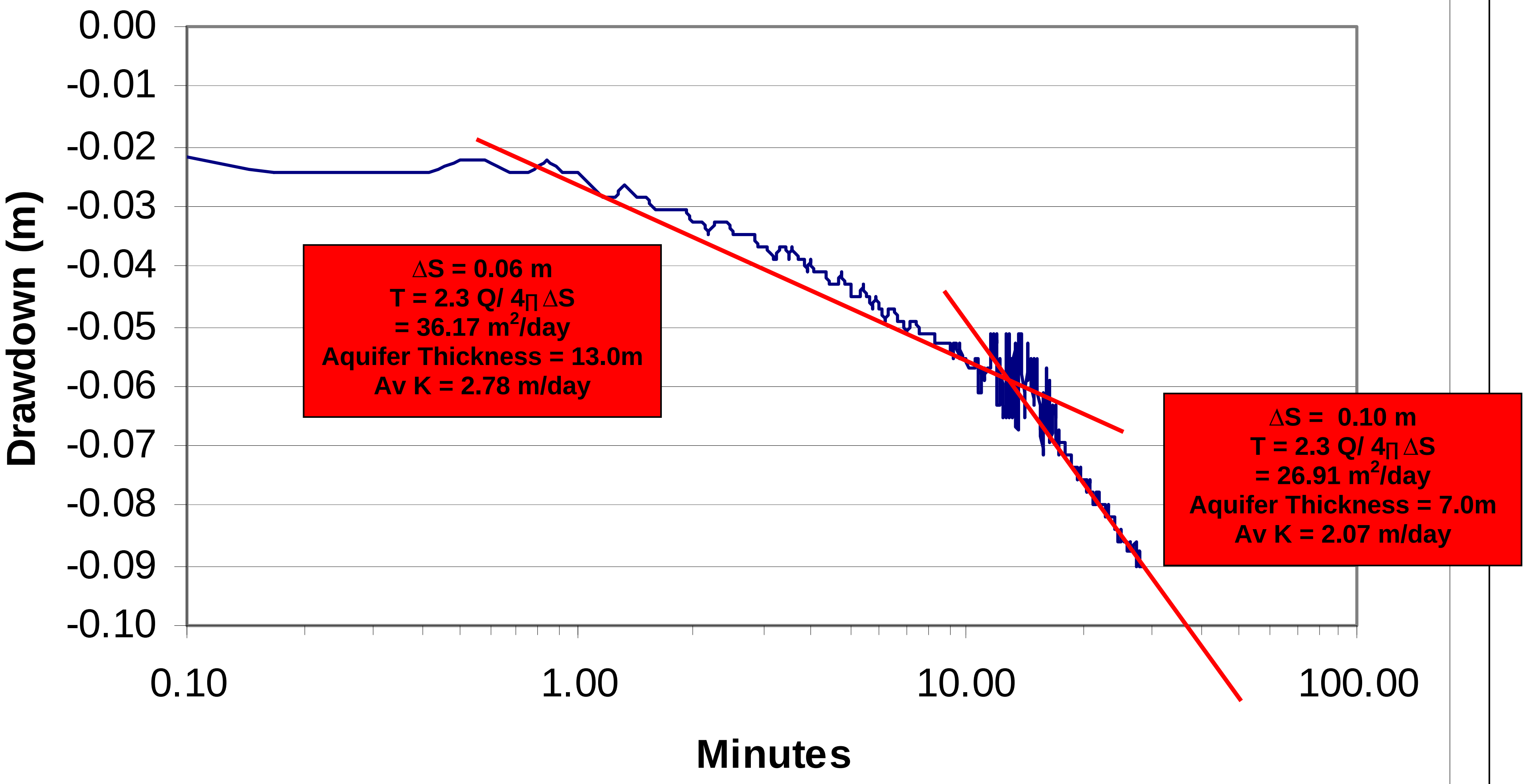


$\Delta S = 3.0$ m
$T = 2.3\ Q/\ 4\pi\ \Delta S$
$= 0.084\ m^2/day$
Aquifer Thickness = 13.0m
Av K = 0.06 m/day

$\Delta S = 2.65$ m
$T = 2.3\ Q/\ 4\pi\ \Delta S$
$= 0.495\ m^2/day$
Aquifer Thickness = 7.0m
Av K = 0.038 m/day

Pumping Rate = 0.09L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	**GeoTerra**
Drawn	**A Dawkins**		
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NRE D**
Scale	**NTS**		

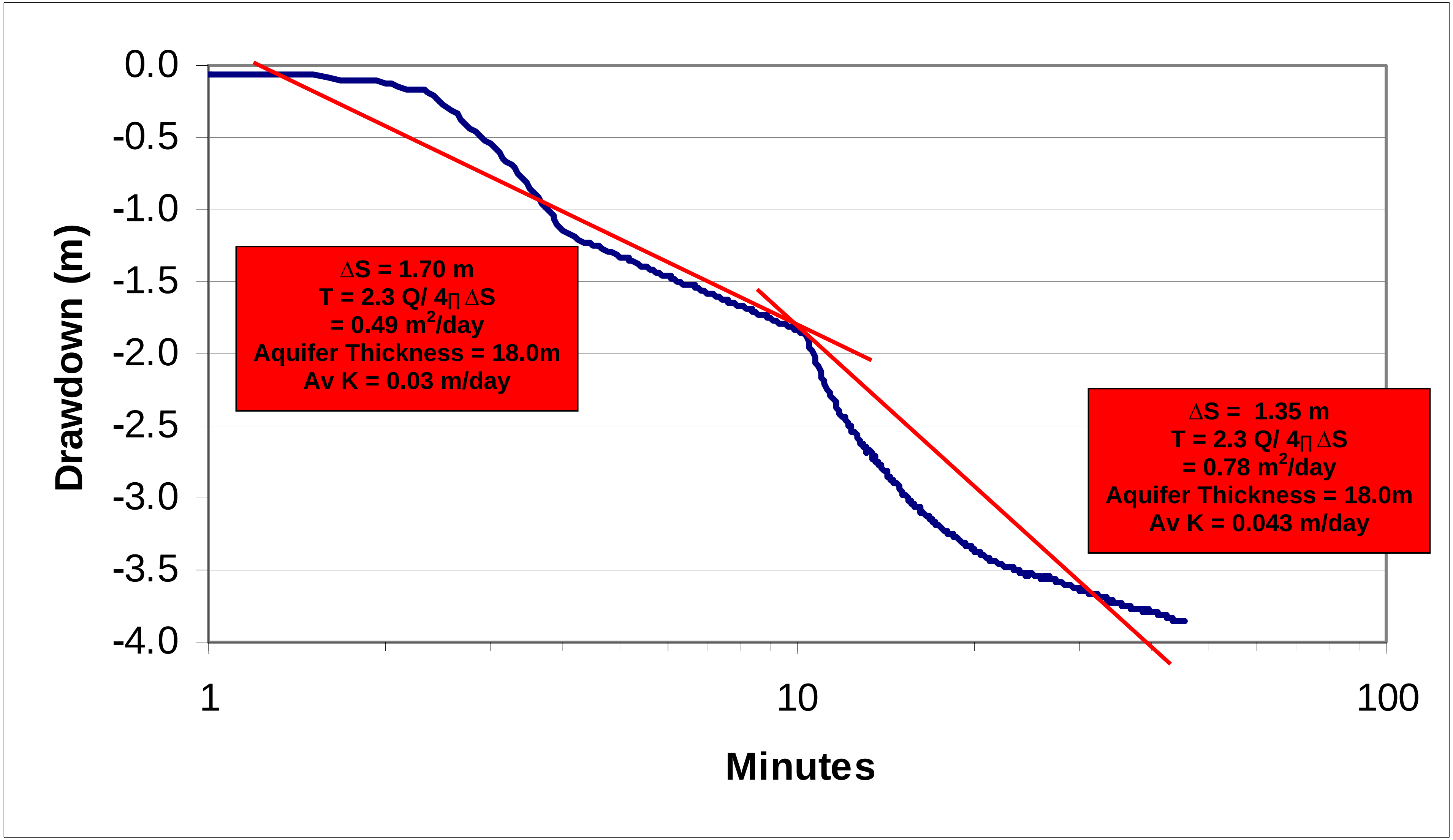


ΔS = 0.06 m
T = 2.3 Q/ 4∏ ΔS
= 36.17 m^2/day
Aquifer Thickness = 13.0m
Av K = 2.78 m/day

ΔS = 0.10 m
T = 2.3 Q/ 4∏ ΔS
= 26.91 m^2/day
Aquifer Thickness = 7.0m
Av K = 2.07 m/day

Pumping Rate = 0.13L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD** **Constant Rate Pumping Test**	**GeoTerra** **NRE E**
Drawn	**A Dawkins**		
Date	**17.01.2011**		
Scale	**NTS**		

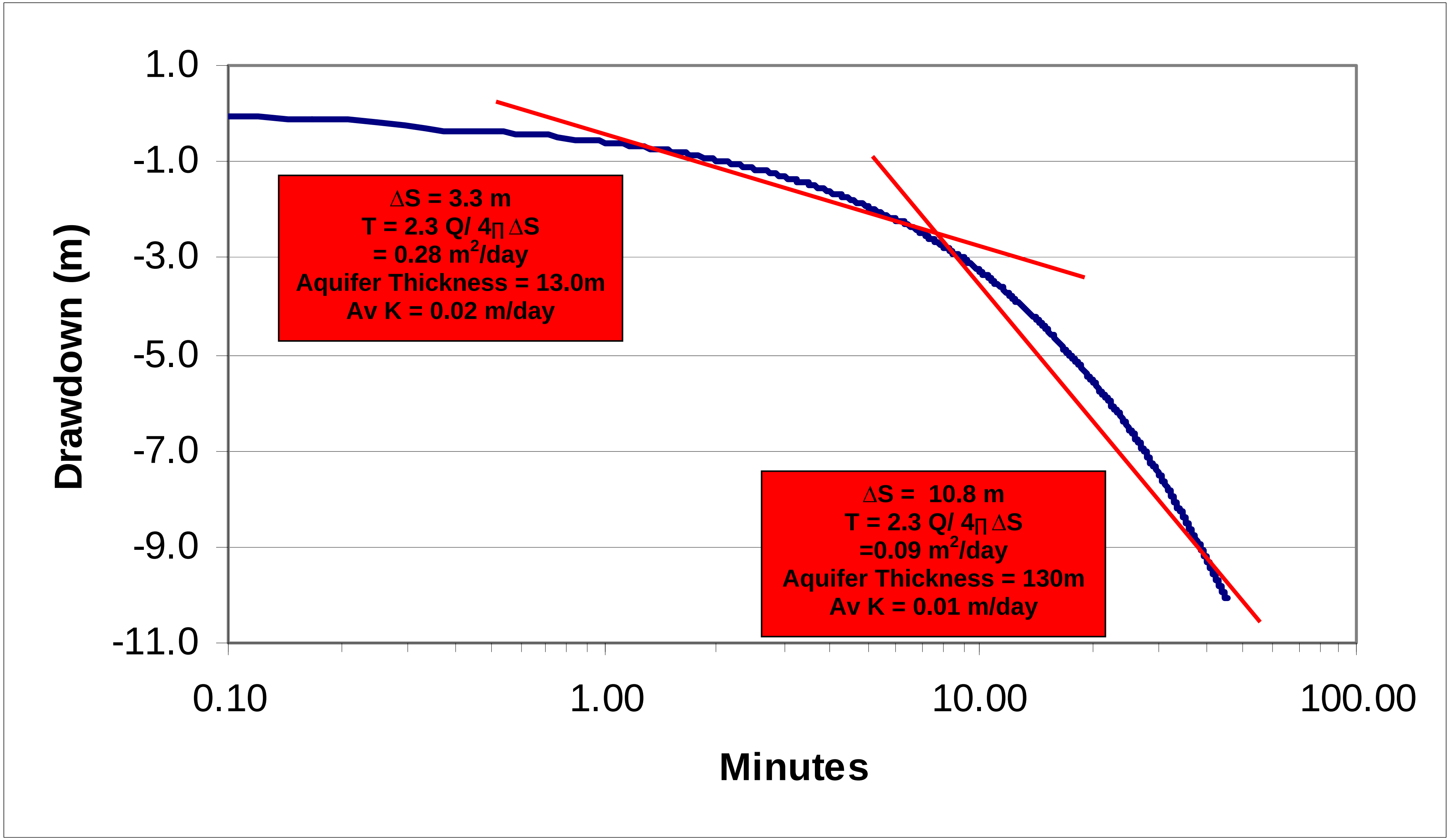


ΔS = 1.70 m
T = 2.3 Q/ 4π ΔS
= 0.49 m^2/day
Aquifer Thickness = 18.0m
Av K = 0.03 m/day

ΔS = 1.35 m
T = 2.3 Q/ 4π ΔS
= 0.78 m^2/day
Aquifer Thickness = 18.0m
Av K = 0.043 m/day

Pumping Rate = 0.05L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	**GeoTerra**
Drawn	**A Dawkins**		
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NRE G**
Scale	**NTS**		



Pumping Rate = 0.06L/sec

Project	**GUJ1**	**GUJARAT COKING COAL LTD**	**GeoTerra**
Drawn	**A Dawkins**		
Date	**17.01.2011**	**Constant Rate Pumping Test**	**NE3**
Scale	**NTS**		

APPENDIX D

FEFLOW GROUNDWATER MODELLING

20 November, 2012

GUJARAT NRE COKING COAL LTD

NRE No.1 Colliery: Wonga East and Wonga West Groundwater Modelling

Submitted to:
Andrew Dawkins
Geoterra Pty Ltd
77 Abergeldie Street
Dulwich Hill NSW 2203

REPORT

Report Number. 107636001-003-Rev4

Distribution:

Danyil Skora
Gujarat NRE Coking Coal LTD

A world of capabilities delivered locally

Golder Associates

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

Gujarat NRE Coking Coal Ltd (Gujarat) operates the NRE No.1 Colliery which is located approximately 13 km northwest of Wollongong. Mining operations include continued underground mining with a proposed expansion of eleven longwall panels in the Wonga East area and seven longwall panels in the Wonga West area. The proposed expansion extends the existing underground operation by the extraction of coal from the Wongawilli Seam as well as limited first workings within the Balgownie and Bulli seams.

The proposed workings are located beneath the Sydney Catchment Authority managed, restricted access, Metropolitan Special Area. Golder Associates (Golder) has been engaged to develop a numerical model to assist in the assessment of the groundwater-surface water bodies that may already have been affected by mining to date and to predict possible effects associated with the proposed works. The modelling was conducted to assess the relative changes in the groundwater regime and recharge to surface water bodies due to the proposed mining.

The area of interest for this study comprises two locations within the model domain – Wonga East, located near the Illawarra Escarpment and Wonga West, situated to the West of Cataract Dam. The majority of existing mine workings in the area are located within the Bulli seam covering the entire area from, and including, Wonga East to Wonga West. The historical extraction methods comprise bord and pillar excavations and longwall panels. The vast majority of the existing workings are single seam operations except for one area in the Wonga East region with multi-seam extraction, where the Balgownie Seam underlying the Bulli Seam was exploited (Balgownie Workings) which led to increased subsidence effects. One longwall (LW4) has been extracted in the Wongawilli seam at Wonga East

The proposed workings are pre-dominantly located within the Wongawilli Seam and underlie existing Bulli Seam workings. Multi-seam extraction of the nature proposed is relatively new to the Southern Coalfield and there is a degree of uncertainty in the prediction of resulting subsidence.

The possible extent of subsidence induced fracturing and associated change in physical characteristics affecting water flow behaviour (for example, hydraulic conductivities) as a result of the proposed workings have been assessed in geotechnical studies undertaken by others. We have relied on these assessments in our modelling.

2.0 STUDY AREA

The study area, located inland of Wollongong, NSW, is situated within the restricted entry water catchment areas surrounding Cataract Dam. It comprises large areas of previous underground mining, with smaller areas in which mining is proposed to be continued or to start. The proposed workings are located in two areas – Wonga East near the Illawarra Escarpment, and Wonga West near Cataract Dam (Figure 1).

2.1 Topography and Drainage

The study area is dominated by plateau and valley topography characteristic of the Sydney Basin. Drainage of the plateaus is generally via deeply incised drainage lines into the Cataract Dam (Figure 2). The creeks are ephemeral in the upper reaches but are flowing throughout the year at lower elevations. The area is heavily wooded and elevations range from approximately 285 – 415 m Australian Height Datum (AHD).

Valley infill and headwater swamps are present within the study area, and are primarily located at the headwaters of the streams, before the streams become increasingly more incised.

2.2 Rainfall and Recharge

Rainfall, evaporation and runoff data was extracted from a draft report by WRM (2012) on surface water modelling. The mean annual rainfall isohyets produced by WRM were based on 1969–1990 rainfall data from the Bureau of Meteorology. A simplified spatial distribution schematic of rainfall is presented in Figure 3.

Rainfall data in the study area show a noticeable decrease in rainfall from around 1,750 mm/year in the East to around 1,000 mm/year in the West. Mean annual pan evaporation at Cataract Dam is approximately 1,420 mm/year.

Data for two long term streamflow stations, one in the northern catchment at Loddon River, and one in the southern catchment at Bellambi Creek, were evaluated by WRM[1]. They concluded that “while baseflow is a notable feature in the stream flows, it contributes a relatively small portion of total streamflow volume” and “At both catchments, over 90% of the total streamflow volume comes from the largest 40% of daily flows. “

However, during some periods flows were observed to be different in the two catchment areas, possibly due to spatially variable rainfall. “The Loddon River catchment exhibits a significantly higher runoff to rainfall ratio”. It is noted, however, that available data is limited, and that some water can be expected to flow as subsurface flow within the rocky and fractured stream-beds, and so will not be registered at the gauging stations.

Recharge for the numerical model was approximated using this information.

2.3 Surface Water Features

The study area is located within the Metropolitan Special Area (managed by the Sydney Catchment Authority) and contains Cataract Dam which is used to supply drinking water to Sydney and Wollongong.

The Wonga West area contains both valley infill and headwater upland swamps along the Wallandoola and Lizard Creek streamlines. The Wonga East area contains one headwater swamp (Geoterra, 2012).

Ephemeral 1st and 2nd order tributary creeks present within the Wonga West area drain into 3rd order streams in the Wallandoola and Lizard Creek catchments. In the Wonga East area, 1st and 2nd order tributary creeks drain into the 3rd and 4th order Cataract Creek catchment.

Cataract Creek drains directly into Cataract Reservoir at Wonga East. Lizard Creek and Wallandoola Creek flow from the south-east to the Cataract River over the proposed Wonga West workings. Inspections of Cataract Creek, Lizard Creek and Wallandoola Creek have indentified potential mining impacts (cracking of bars, localised loss of surface water flows) in Lizard and Wallandoola Creeks, however no flow of water into the mine has been related to loss of flow from any of the creeks (Seedsman, 2012).

2.4 Land Use

In Wonga East the proposed workings underlie the Cataract Creek catchment and channels in essentially undeveloped bushland apart from limited fire access and power transmission access trails. The Wonga East area is fully contained within the SCA surface water catchment area that drains directly into Cataract Dam.

The Wonga West area is essentially undeveloped bushland with mine surface infrastructure and access road associated with the Gujarat NRE No. 1, No. 4 and No. 5 shafts.

2.5 Existing Mine Workings and Current Case Status

Mining in the area has been undertaken since the early 20th century. Early mines were developed as bord and pillar workings within the Bulli Seam – see Figure 4 for the regional extent of such mines around the study area. Due to the relatively narrow workings, large areas retain a measure of support within the bord and pillar workings which generally only lead to very limited subsidence / fracturing above the workings. Pillar extraction has also been conducted.

Besides the (historic) bord and pillar workings, there are also several longwall developments in the study area (Figure 5). The majority of the longwalls were developed within the Bulli Seam. Their panel widths range up to 190 m wide near or under the water storage dams (Geoterra, 2012).

Where wider panel longwall mining was undertaken, subsidence was assessed to exist above them up into the lower and mid Bulgo Sandstone. Over time, conceptual models have been developed outlining the vertical extent and nature of subsidence.

As a result of subsidence and the induced fracturing and delamination in the study area, hydraulic parameters can be expected to have been changed, and the current day groundwater/surface water system can be expected to reflect these 'disturbed' conditions.

Refer to Section 4.0, for details regarding the observed and inferred effects of subsidence on subsurface strata and related changes in hydraulic parameters.

2.6 Related Mine Studies in the Surrounding Area

Several comparable studies have been undertaken for mines in the wider area (for example, The Metropolitan Coal Project Review Report (NSW Planning Commission, 2008), Metropolitan Coal Project Groundwater Assessment (Heritage Computing, 2008), Bulli Seam Operations Groundwater Assessment (Heritage Computing, 2010). These reports have been assessed and parameters published in these studies were used to establish initial hydraulic properties used in this study.

3.0 GEOLOGICAL SETTING

The geology of the study area is presented in detail in (Geoterra, 2012). A summary is presented below.

The study area is located in the Southern Coalfield which is situated in the Southern Sydney Basin. The Illawarra Coal Measures, which are targeted for extraction are overlain by sedimentary sequences of the Narrabeen and Hawkesbury Groups. These sequences are characterised by an inter-layering of sandstone, shale, conglomerate and claystone units (Figure 6).

In more detail it is noteworthy that the Wonga West area differs from the Wonga East area. The strata dips down towards the west in a S-shaped fashion, within increasing overburden thicknesses. Wonga East is located just west of the Illawarra Escarpment, and is characterised by less overburden over the coal strata with a depth of cover ranging from 235 – 325 m.Overburden above the proposed working in Wonga West is reaching between 460 – 520 m (Figure 7 and Figure 8).

Wonga East is also characterised by deeply incised valleys which expose strata down to the Bald Hill Claystone and upper Bulgo Sandstone in Cataract Creek.

The Study Area is predominantly covered by shallow colluvium, with thin to absent alluvial sedimentary deposits on the valley floors. Quaternary unconsolidated alluvial sediments are also present within both valley fill and headwater upland swamp areas, and are generally less than 2 m thick. These deposits comprise humic clayey sands overlying weathered Hawkesbury Sandstone. The Quaternary sediments in the Wonga East and Wonga West areas are, in turn, sequentially underlain by the:

- Hawkesbury Sandstone (absent to 181 m thick) - eroded in the headwater valleys of Cataract and Bellambi Creeks in the Wonga East area, with outcrops in the west of the Wonga East area;
- Narrabeen Group, consisting of the following units
  - Newport and Garie Formations (4.6-36 m thick)
  - Bald Hill Claystone (17-42 m thick)
  - Bulgo Sandstone (113-154 m thick);
  - Stanwell Park Claystone (15-26 m thick)
  - Scarborough Sandstone (16-31 m thick);
  - Wombarra Claystone (35-61 m thick)
  - Coal Cliff Sandstone (8-13 m thick);
- Illawarra Coal Measures. The major coal seams in sequentially lower order are:

- Bulli Seam (2.0-4.7 m thick) – worked extensively by longwall and bord and pillar methods, varies from 205-290 m depth of cover at Wonga East and 425-500 m at Wonga West;
- Loddon Sandstone (5-8 m thick);
- Balgownie Seam (0.8-1.5 m thick) – limited longwall extraction has been conducted in Wonga East;
- Lawrence Sandstone (16-17 m thick);
- Cape Horn Seam (0.1-0.4 m thick);
- Eckersley Formation and Hargraves Coal Member (6-8 m thick);
- Wongawilli Seam (6.2-10.5 m thick) – predominantly mined in the southern area of the Southern Coalfields, yet to be been mined within the Gujarat lease. The Wongawilli Seam varies from 237-321 m depth of cover at Wonga East and 457-512 m at Wonga West.
- Kembla Sandstone (5.0-9.0 m thick);
- American Creek Coal Member (0.3-3.5 m thick);
- Allens Creek Formation (14-15 m thick);
- Darkes Forest Sandstone (5.0-9.0 m thick);
- Bargo Claystone (10-12 m thick);
- Tongarra Seam (1.5-2.0 m thick);
- Wilton Formation (minimum 4 m thick).

The general layer thicknesses are summarised in Table 1.

Table 1: Geological Model Layer Thickness

Name	Thickness (m)	Layer
Hawkesbury Sandstone (Upper 1)	20.0	1
Hawkesbury Sandstone (Upper 2)	17.0	2
Hawkesbury Sandstone (Lower 1)	43.0	3
Hawkesbury Sandstone (Lower 2)	77.0	4
Newport and Gary Formation	12.2	5
Bald Hill Claystone	20.1	6
Bulgo Sandstone (Upper 1)	51.0	7
Bulgo Sandstone (Upper 2)	20.0	8
Bulgo Sandstone (Lower 1)	48.0	9
Bulgo Sandstone (Lower 2)	23.0	10
Stanwell Park Claystone	17.1	11
Scarborough Sandstone	19.5	12
Coalcliff Sandstone / Wombarra Claystone (Upper)	49.0	13
Coalcliff Sandstone / Wombarra Claystone (Lower)	27.7	14
Bulli Coal Seam	2.3	15
Loddon Sandstone	9.5	16
Balgownie Coal Seam	1.2	17
Lawrence Sandstone	17.0	18
Eckersley Formation	7.6	19
Wongawilli Coal Seam	9.7	20
Kembla Sandstone	9.0	21
Generalised Sedimentary Unit	50.0	22

Some igneous intrusive activity and faulting is known to have occurred in the study area. A large doleritic intrusion is known to exist at depth at the central eastern edge of the study area. However, the exact nature and extent of the intrusion is not known. Several dykes are also known to be present in the area.

Faulting is also recorded in the area with faults trending mainly E - W and NW – SE. Throws of up to 90 m have been recorded, but details about their vertical extent and associated hydraulic properties are not available.

4.0 SUBSIDENCE AND GROUNDWATER CHARACTERISATION IN MODEL

4.1 Subsidence

4.1.1 Existing Workings

Subsidence effects are expected to modify the hydraulic conductivity values for the overburden above existing workings. For the purposes of modelling, the effects of fracturing and subsidence above workings have been applied in the model by modifying hydraulic conductivity values above the existing workings as follows shown in Table 5, Table 6 and Table 7.

The extent of fracture development and hydraulic conductivity increase above the existing workings is primarily dependent on the degree of extraction and resultant goaf and subsidence development above the workings. As can be noted from Table 7, the least development of horizontal and vertical fracturing is present over the bord and pillar workings, followed by the less than 155 m wide longwalls, then the less than 186 m wide longwalls and up to 490 m wide pillar extraction areas in the Bulli Coal Seam.

Additional overburden fracture propagation and increased hydraulic conductivity is developed where both the Bulli and Balgownie Coal Seam workings have been extracted.

As shown in Table 7, extraction of the proposed Wongawilli Coal Seam longwalls will subsequently increase the height of fracturing and permeabilities above the existing and proposed workings in direct relationship to the degree of subsidence, which principally relates to the width of extraction and the size and scale of the existing Bulli and, where present, Balgownie workings.

4.1.2 Proposed Workings

There are three types of proposed workings – narrow / short longwall extraction mining of the Wongawilli Seam in Wonga East area, wider / longer longwall extraction of the Wongawilli Seam in Wonga West area and narrow first workings and pillar extraction works in the Bulli Seam in the V-Mains area (Figure 9 and Figure 10).

Areas1 and 2 in Wonga East are scheduled for extraction within the Wongawilli Seam in longwall panel sets of three and seven. Areas 3 and 4 in Wonga West are proposed longwall extraction areas in the Wongawilli Seam, largely underlying the existing longwall panels in the Bulli seam. ‘V-Mains’ is a small triangular area marked for extraction in the Bulli seam to the south of the existing Wonga West 300 series workings.

The proposed workings would normally have subsidence similar to that observed in the existing workings if they were the only workings in the area, however, the majority of these workings will undermine existing workings and are hence predicted to have a different subsidence pattern. In the Wonga East area, the proposed extraction will interact with the existing area of subsidence to increase subsidence and the degree of fracturing of the strata overlying the Wongawlli Seam. The proposed workings are predicted to lead to surface subsidence of up to 1.2 m at Wonga East and 2.55 m at Wonga West (Seedsman, 2012). Maximum subsidence or pillar collapse is expected where the proposed workings are located beneath the existing Balgownie workings. The areas of the proposed workings that are not located below the existing Balgownie workings are expected to subside to an extent similar to that above the small longwalls of the 500 series in Wonga West.

Given the limited data with respect to hydrogeological parameters in existing zones of subsidence and the uncertainty in the prediction of multi-seam subsidence (Seedsman, 2012), there is uncertainty in assigning the vertical extent of fracture zones, and fracture intensity, for the proposed workings. Based on the information provided to us, the following assumptions have been made regarding hydraulic conductivity above the proposed workings:

- Bald Hill Claystone and the Newport Formation (immediately above the Bald Hill Claystone) were considered to be unaffected except for a localised area over the Balgownie longwalls and Wongawilli Seam longwall WE-A2-LW4 in Wonga East.
- As shown in Table 7, extraction of the proposed Wongawilli Coal Seam longwalls will subsequently increase the height of fracturing and permeabilities above the existing and proposed workings in direct relationship to the degree of subsidence, which principally relates to the width of extraction and the size and scale of the existing Bulli and, where present, Balgownie workings.
- For V-Mains in the Bulli Coal Seam, conductivities were increased up to the Stanwell Park Claystone with a slightly higher horizontal conductivity in the Lower Bulgo Sandstone to represent delamination.

4.2 Groundwater

To establish current conditions as well as monitor potential effects of proposed mining, twenty swamp piezometers, eight open standpipe and seven vibrating wire array piezometers (VWPs) were installed during the hydrogeological investigation program, the details of which are presented in Geoterra (2012). Drilling extended to 325 m below surface. Low flow pumping tests were conducted in all open standpipe piezometers seated in the upper to middle Hawkesbury Sandstone. In addition, packer tests over 5.5 m intervals were conducted in six bores to 281 m below surface (SCT Operations, 2009).

The results of testing indicated generally slightly higher hydraulic conductivity values in the East, and lower ones in the West. Conductivity values are similar to those reported for other mines in the wider area (BHPIC, 2010; Heritage Computing, 2010) and also represent increasing permeabilities with increasing depth of cover for the same lithology.

Based on a combination of on-site tests as well as regional studies (Heritage Computing, 2010) hydraulic conductivities in the eastern section of the Southern Coalfields vary from 0.03 m/s to 1E-06 m/s, whilst the western region around Tahmoor (Geoterra, 2012), which has a generally greater depth of cover, ranges from 9.3E-06 m/s to 1.6E-09 m/s.

The available groundwater data is sourced from locations shown in Table 2 (data supplied by GeoTerra) and Figure 11.

Table 2: NRE1 Groundwater Monitoring Bores and Groundwater Levels

BORE	Easting	Northing	Date	SWL (mbgl)	Ground Elevation (mAHD)	VWP Intake (mbgl)	Lithol*	Head (m)	Water Level (mAHD)
NREA	303692	6196033	15/01/2010	21.78	376.18		up HS		354.40
NRE A VWP	303680	6196034							
Piezo #1			21/12/2009		376.23	45	low HS	12.13	343.4
Piezo #2			21/12/2009		376.23	60	BHCS	37.02	353.2
Piezo #3			21/12/2009		376.23	75	up BS	49.72	350.9
Piezo #4			21/12/2009		376.23	140	mid BS	110.45	346.7
NRE B VWP	303939	6197567							
Piezo #1			21/12/2009		372.69	27.5	HS	21.11	366.3
Piezo #2			21/12/2009		372.69	43	up BS	21.93	351.6
Piezo #3			21/12/2009		372.69	63	mid BS	9.96	319.6
Piezo #4			21/12/2009		372.69	168	SPCS	86.25	290.9
NREC	303233	6198797	15/01/2010	13.95	362.72		mid HS		348.77
NRED	301870	6198509	15/01/2010	28.29	348.83		mid HS		320.54
NRE D VWP	301875	6198493							
Piezo #1			21/12/2009		348	70	NP	9.57	287.6
Piezo #2			21/12/2009		348	90	BHCS	35.46	293.5
Piezo #3			21/12/2009		348	110	up BS	42.00	280.0
Piezo #4			21/12/2009		348	160	low BS	54.17	242.2
NREE	296727	6202286	15/01/2010	11.91	329.24		up HS		317.33
NRE F	NOT	DRILLED	_	_	_				_
NREG	296949	6205678	15/01/2010	29.64	363.03		up HS		333.39
NE3	294803	6201954	15/01/2010	39.34	359.27		up HS		319.93
GW1A	303733	6196982	20/08/2012	24.00	329		up HS		305.00

BORE	Easting	Northing	Date	SWL (mbgl)	Ground Elevation (mAHD)	VWP Intake (mbgl)	Lithol*	Head (m)	Water Level (mAHD)
GW1	303697	6196905	1/09/2012		333	18	up BS	4	319.0
						30	up BS	6	309.0
						45	BS	20	308.0
						63	mid BS	29	299.0
						93	mid BS	43	283.0
						125	low BS	69	277.0
						140	SPCS	76	269.0
						165	ScS	21	189.0
NE3 VWP	294794	6201945							
Piezo #1			21/12/2009		360.23	100.0	mid HS	33.94	294.2
Piezo #2			21/12/2009		360.23	130.0	low HS	61.95	292.2
Piezo #3			21/12/2009		360.23	155.0	NP	78.96	284.2
Piezo #4			21/12/2009		360.23	255.0	mid BS	125.34	230.6
501 VWP	298771	6201856							
Piezo #1			30/11/2009		326.18	325	ScS	-5.20	-4.0
Piezo #2			30/11/2009		326.18	325	ScS	-6.90	-5.7
Piezo #5			30/11/2009		326.18	226	mid BS	15.43	115.6
502 VWP	298598	6202049							
Piezo #11			30/11/2009		319.32	222	mid BS	189.24	286.6
Piezo #12					319.32	167	up BS	0.00	0
Piezo #13			30/11/2009		319.32	167	up BS	128.90	281.2
Piezo #14			30/11/2009		319.32	100	low HS	67.98	287.3

BORE	Easting	Northing	Date	SWL (mbgl)	Ground Elevation (mAHD)	VWP Intake (mbgl)	Lithol*	Head (m)	Water Level (mAHD)
Piezo #15			30/11/2009		319.32	100	low HS	65.19	284.5
514	297917	6204280	14/07/2009	20.99	308.23		mid BS		287.24
BHP DDH120 (VWP214)	294825	6206962	1/12/2009		302.6	424.52	Bulli		206.10
BHP DDH124 (VWP224)	295215	6207858	1/12/2009		299.7	455.67	Bulli		213.72

*HS=Hawkesbury Sandstone, BHCS=Bald Hill Claystone, BS=Bulgo Sandstone, SPCS=Stanwell Park Claystone, NP=Newport, ScS=Scarborough Sandstone, Bulli=Bulli Coal Seam

5.0 CONCEPTUAL HYDROGEOLOGICAL MODEL

The study area is part of the Southern Coalfields which are contained within the southern region of the Sydney Basin. The basin is dominated by interlayered sandstone and siltstone/shale sequences containing coal layers at depth.

In the Wollongong area the landscape is dominated by a North-South trending escarpment where the Upper Narrabeen and overlying units outcrop. The sedimentary units are generally shallow dipping towards the west to north-west. To the west of the escarpment the landscape is dominated by deeply incised plateaus, with dammed lakes in the valleys of the lower reaches of Cataract Creek and Cataract River.

Intrusive bodies ranging from kilometre-wide in diameter intrusions to sills and dykes. Faults of variable length and extent of throw are also known to be present in the area, however detailed in-situ information regarding the faults hydraulic properties are not available.

Coal mining has taken place in the area, especially in the Bulli seam, since the early 20th century. Originally the workings were undertaken as bord and pillar excavations as well as limited pillar extraction and later longwall mining was introduced. The former will have led to depressurisation within the coal seam without any significant subsidence and depressurisation of the overburden above the bord and pillar workings. Longwall mining in contrast will have led to depressurisation not only in the mined coal seam but also subsidence and depressurisation above the workings, with the extent and height of the depressurisation relating to the extent and interconnection of subsidence over the longwalls.

Within the study area, there are differences between the Wonga West and Wonga East areas in terms of the geology and also in terms of the historical mining activity. In the Wonga West area, overburden is considerable thicker. Existing monitoring data suggests that in the Wonga West area, the Bald Hill Claystone (which overlies the major, spanning, Bulgo Sandstone) has restricted depressurisation of the overlying Hawkesbury Sandstone and the associated potential effects on the overlying streams and water supply dams.

In the Wonga East area overburden is less, the escarpment is closer and the old bord and pillar workings have been partially undermined by longwalls in the Balgownie seam and LW4 in the Wongawilli seam, all of which has led to more subsidence /stress-relaxation throughout the shallow units and up to surface, particularly in the area of the Balgownie longwalls. Furthermore, erosion in the deep valleys has exposed the upper Narabeen Group, locally eroding through the Bald Hill Claystone to the Bulgo Sandstone.

Limited information is available with respect to the state of flooding of the existing workings. The model assumes NRE 1 workings (existing and proposed) and Appin workings (to the north of Wonga West) to be dry, with the old Cordeaux workings to the West of the NRE1 workings, and old Bulli workings to the East, to be partially flooded.

Rainfall is variable across the area, and is highest in the East and diminishing towards the West (Figure 3). Recharge is a function of rainfall as well as run-off behaviour, which can vary between adjacent valleys. Recharge is expected to be higher over the fully collapsed Bulli / Balgownie seam in the Wonga East area compared to the deeper / less subsided Wonga West Bulli seam workings.

Headwater and valley fill swamps are present in parts of the study area and their water levels are perched (Geoterra, 2012) and therefore separated from the deeper regional groundwater level located in the Hawkesbury Sandstone.

6.0 GROUNDWATER MODEL SETUP

6.1 Software

Modelling was undertaken using FEFLOW, a finite element groundwater modelling package developed by WASY Institute for Water Resources Planning and Systems Research in Berlin, Germany. FEFLOW has become an industry standard in the context of finite element models for groundwater flow and mass and contaminant transport simulations. The finite element code allows areas that involve complex structural geometry to be represented reasonably accurately, without a loss of computational efficiency.

FEFLOW offers the following advantages:

- The capability to simulate groundwater flow in conditions dominated by irregular geological structure;
- An enhanced capability to represent three-dimensional geometry accurately.

6.2 Model structure

6.2.1 Extent

The extent of the model follows the catchment boundaries and is shown in Figure 13.

6.2.2 Layers

Model construction was based on supplied topography and Bulli and Wongawilli Coal Seam elevation data, This was combined with the stratigraphic data in Table 1 and was simplified to allow for model construction on the given scale. Some geological units were subdivided to accommodate the required parameter changes in connection with subsidence occurring over existing and proposed mine workings. The model consists of 22 layers and 23 slices (boundaries between layers), which allows a detailed representation of stratigraphy and subsidence effects on the overburden. The stratigraphy – layer relationships are listed in Table 3. Layer elevation variations are shown in two cross-sections in Figure 7 and Figure 8.

The incised valleys at Wonga East into which six model layers are known to daylight required extreme thinning of the upper layers and localised assignment of higher hydraulic conductivities in those areas to allow for sufficient recharge through the Bald Hill Claystone and the exposed Bulgo Sandstone.

Table 3: Model Layers

Slice ID	Layer ID	Name	Elevation Notes	Thickness	Slice height above/ below Bulli Floor (m)
1		Topography			
	1	Hawksbury Sandstone (Upper)		20 m	
2		Bottom of Upsidence Cracking	20 mbgl*	*37 m average*	399.2
	2	Hawksbury Sandstone (Upper)		17 m	
3		Hawksbury Sandstone (Central)			382.2
	3	Hawksbury Sandstone (Lower)		43 m	
4		Bottom of Upsidence Delamination	80 mbgl	*120 m average*	339.2
	4	Hawksbury Sandstone (Lower)		77 m	
5		Hawksbury Sandstone (Bottom)			262.2
	5	Newport and Gary Formation		12.2 m average	
6		Newport and Gary Formation (Bottom)			250
	6	Bald Hill Claystone		20.1 m average	
7		Bulgo Sandstone (Top)			229.9
	7	Bulgo Sandstone (Upper)		51 m	
8		Extension of upper delamination in multiseam extraction		*71 m average*	178.9
	8	Bulgo Sandstone (Upper)		20 m	
9		Bulgo Sandstone (Central)	to 159 m above Bulli Top		158.9
	9	Bulgo Sandstone (Lower)		48 m	
10		Extension of Upper Cracking Boundary	to 111 m above Bulli Top	*71 m average*	110.9
	10	Bulgo Sandstone (Lower)		23 m thick	
11		Bulgo Sandstone (Bottom)			87.9
	11	Stanwell Park Claystone		17.1 m average	
12		Scarborough Sandstone (Top)			70.8
	12	Scarborough Sandstone		19.5 m average	

Slice ID	Layer ID	Name	Elevation Notes	Thickness	Slice height above/ below Bulli Floor (m)
13		Coalcliff Sandstone (Top)	51 m above Bulli Top		51.3
	13	Coalcliff Sandstone / Wombarra Claystone		49 m average	
14		30 m heavy-cracking zone above Bulli Seam	30 m above Bulli Top		30
	14	Coalcliff Sandstone / Wombarra Claystone		27.7 m	
15		Bulli Coal Seam Roof			2.3
	15	Bulli Coal Seam		2.3 m average	
16		Bulli Coal Seam Floor	Data source: Gujarat		0
	16	Loddon Sandstone		9.5 m average	
17		Balgownie Coal Seam Roof			-9.5
	17	Balgownie Coal Seam		1.2 m average	
18		Balgownie Seam Floor			-10.7
	18	Lawrence Sandstone		17.0 m average	
19		Lawrence Sandstone (Bottom)			-27.7
	19	Eckersley Formation		7.6 m average	
20		Wongawilli Coal Seam Roof			-35.3
	20	Wongawilli Coal Seam		9.7 m average	
21		Wongawilli Coal Seam Floor			-45
	21	Kembla Sandstone including coal		9 m	
22		Bottom of Kembla Sandstone			-54
	22	Generalised Sedimentary Unit		50 m	

6.2.3 Existing mines

The existing mines were classified into three groups for the purpose of assigning the degree and extent of subsidence-induced fracturing and associated increase of hydraulic conductivity.

Bord and Pillar workings were considered to have negligible subsidence effects and only little fracturing was imposed on the layer directly above, plus delamination above the fracturing.

The small longwalls with wide pillars mined under, or in the immediate vicinity of, the Cataract Reservoir were considered to have caused limited subsidence and/or disruption to overlying strata. In these areas, subsidence effects were considered to extend to a height of approximately 100 m above the workings. The extensive longwalls, especially in Wonga West, were considered to have caused some surface subsidence and more extensive fracturing and delamination in the overburden materials to a height of approximately 150 m above the workings.

In the Wonga East area where the Balgownie longwalls have undermined the earlier Bulli seam workings it was necessary to simplify the complex situation to a possible ‘average’ equivalent. The main concern was the potential ‘partial’ collapse of the spanning Bulgo Sandstone. Seedsman (Addendum, 2012) discussed three main scenarios (see Seedsman, 2012). For the modelling, an increase in fracturing / hydraulic conductivity of half an order of magnitude compared to the prevailing conditions was assigned as a worst case scenario to the Bulgo Sandstone in the overburden above the Balgownie longwalls (Seedsman, 2012).

All seam extractions were modelled as having been mined or fully collapsed over their entire thickness.

Note that barriers were modelled to extend around the existing NRE1 workings, hydraulically separating these from neighbouring mines. Due to the uncertainly in the width and nature of these barriers, i.e. whether they are only remnant rock / coal, or whether they are at least in part cemented structures, a conservative approach was adopted modelling these barriers as ‘natural material’. The thickness of those barriers, where recorded, were in the order of 40 m. In the model the thickness is variable, based on elements size, and on the order of approximately 30 -100 m.

6.2.4 Faults and Intrusive bodies

Several faults and intrusive bodies, ranging from several-kilometre-wide doleritic intrusions to dykes are present in the study area (Figure 12). Some of these have been mapped, but hydrogeological parameters are not known about these features. The inclusion of these types of features would require knowledge as to the nature of their influence on groundwater flow – that is, whether the faults in question tends to act as conduits facilitating groundwater flow or as “low hydraulic conductivity walls” retarding groundwater flow. Initial attempts to include these features devolved into a circular loop of calibrating hydrogeological parameters to unknown feature properties. Given the uncertainty in connection with these features and the already high complexity of the model these features were not subsequently included into the model.

A large doleritic body is present at the eastern edge of the model, east of former BHP workings. Only limited information is available regarding this intrusion, which indicates a large variability in properties. Given the already large variability of hydraulic conductivity in the area near the escarpment with its incised valleys, this body was not further considered, as it was assessed to not have a quantifiable influence on the model results.

Several dykes are known to be present in the area, with two being prominent: a large SW-NE trending dyke with weathered periphery was shown on maps to be located amongst the old BHP workings to the NE of the Gujarat mines. It was not considered in the modelling as it is outside the area of subsidence. The other dyke was reported to be located between the proposed V-Main workings and the old BHP Cordeaux workings to the South. This was only modelled as a clearly defined separation between the workings, no changes in hydraulic conductivity was applied.

Several small and two ‘large’ faults were identified on maps. One is located to the west and north of the Wonga East area, with reported throws of between 20 and 90 m. Where high throws were reported old bord and pillar workings are shown to have stayed clear of the area, but workings were progressed towards the fault once throws of less than 20 m were recorded. It was considered unlikely that the fault is a high hydraulic conductivity feature, as workings would likely not have been extended in close proximity to the fault, if there was an inflow issue.

Another large fault has been recorded immediately north of existing Wonga West workings in the Bulli seam. Again little is known about its hydrogeological features, but the throw is recorded to be in the order of 90 m, with upthrow to the north. No increase of inflows into the existing workings has been reported, indicating that the feature possibly does not have high hydraulic conductivity. However, off-set of layers with thicknesses on a meter to tens of meter scale can be expected to have some influence on the groundwater regime to the north of the Wonga West workings, as the off-set clearly disrupts the continuity of the coal seams, which are considered to be the main high hydraulic conductivity layers. It is not known whether the fault extends to surface. However, given the complexity of this issue, the offset was not considered in the Feflow model, and observation points north of this fault were not used in the calibration of the model.

6.3 Boundary conditions

Transfer boundaries with high conductivity transfer rates (equivalent to gravelly material) were used to represent creeks.

Cataract Reservoir was represented using constant head boundaries.

Part of the existing Bulli seam and the proposed mine workings in the Wongawilli and Bulli seam within the NRE1 lease and within the existing BHP Appin workings at the northern boundary of the model domain were presumed to be dry / pumped out at present, and those areas were represented using seepage boundary conditions. All other workings such as the old Cordeaux and Bulli workings were assumed to be flooded.

Recharge was applied as 2% of rainfall in each of the three recharge zones (eastern, central and western areas), leading to a slight decrease in recharge from East to West, with the exception of the area above the fully collapsed Bulli / Balgownie seam in Wonga East where recharge was set to a higher value of 4% of rainfall.

6.4 Observation / Calibration Points

The existing VWPs (Table 2) were used as calibration points for the model. Geological borehole logs (for the deep VWPs) were available.

Furthermore it should be noted that in FEFLOW observation points are placed onto slices and not within layers. This can introduce some error, especially where slices are boundaries between materials with large differences in hydraulic conductivity.

Due to the already large complexity of the model, no additional slices were introduced to ‘fine-tune’ calibration where this issue was thought to possibly have a noticeable effect.

6.5 Parameters

Hydraulic parameters adopted for the modelling were based on packer testing (GeoTerra, 2012) and results of extensive groundwater model calibration and sensitivity analyses carried out for the Metropolitan Mine (Heritage Computing, 2010) and BHPB Bulli Seam Environmental Assessments.

Fracturing and subsidence effects were generalised with fracturing and delamination zones above the proposed and existing workings applied in the groundwater model as specified in Section 4.1. The spatial extent of the subsidence zones above the proposed workings are illustrated in Figure 14.

Hydraulic conductivities used in the model for undisturbed areas are summarised in Table 5. The hydraulic conductivities applied in the model to represent the subsidence effects of the existing and proposed mining are summarised in Table 6 and Table 7 respectively. The cell colours illustrate the change in hydraulic conductivity (see Table 4 for colour code).

Figure 15 through to Figure 18 show the conductivity zones for each layer of the model.

Table 4: Colour Code to Tables 6 and 7

Cell Colour	Order of Magnitude Increase in Hydraulic Conductivity
⬜	0
🟦	<0.5
🟦	0.5
🟦	1.0
🟦	1.5
🟦	2.0
🟦	>2.0

Table 5: Original Unsubsided Overburden

Layer	Formation	Top of Model Layer Height above/below top of Bulli Seam	Western Area		Central Area		Eastern Area		East Area Incised Valley		Storativity
			Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	
1	Hawkesbury Sandstone Upper	417	1.50E-06	1.50E-07	7.50E-06	7.50E-07	1.50E-05	1.50E-06	absent	absent	0.01
2	Hawkesbury Sandstone Upper	397	1.50E-06	1.50E-07	7.50E-06	7.50E-07	1.50E-05	1.50E-06	absent	absent	0.01
3	Hawkesbury Sandstone Lower	380	8.10E-09	9.38E-10	4.05E-08	4.69E-09	8.10E-08	9.38E-09	7.64E-07	1.09E-08	0.01
4	Hawkesbury Sandstone Lower	338	8.10E-09	9.38E-10	4.05E-08	4.69E-09	8.10E-08	9.38E-09	7.64E-07	1.09E-08	0.01
5	Newport Formation	260	1.04E-09	1.04E-10	5.20E-09	5.20E-10	1.04E-08	1.04E-09	7.64E-07	1.09E-08	0.01
6	Bald Hill Claystone	248	1.16E-10	3.59E-11	5.80E-10	1.80E-10	1.16E-09	3.59E-10	7.64E-07	1.09E-08	0.01
7	Bulgo Sandstone Upper	228	7.64E-08	1.09E-09	3.82E-07	5.45E-09	7.64E-07	1.09E-08	7.64E-07	1.09E-08	0.01
8	Bulgo Sandstone Upper	177	7.64E-08	1.09E-09	3.82E-07	5.45E-09	7.64E-07	1.09E-08	not	affected	0.01
9	Bulgo Sandstone Lower	157	8.10E-10	1.16E-10	8.10E-10	1.16E-10	8.10E-10	1.16E-10	not	affected	0.01
10	Bulgo Sandstone Lower	108	8.10E-10	1.16E-10	8.10E-10	1.16E-10	8.10E-10	1.16E-10	not	affected	0.01
11	Stanwell Park Claystone	86	4.28E-10	4.28E-12	4.28E-10	4.28E-12	4.28E-10	4.28E-12	not	affected	0.01
12	Scarborough Sandstone	68	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.01
13	Coalcliff Sandstone	49	6.37E-10	4.05E-12	6.37E-10	4.05E-12	6.37E-10	4.05E-12	not	affected	0.01
14	Coalcliff Sandstone	28	6.37E-10	4.05E-12	6.37E-10	4.05E-12	6.37E-10	4.05E-12	not	affected	0.01
15	Bulli Seam	0	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.03
16	Loddon Sandstone	-2.5	2.00E-10	2.31E-11	2.00E-10	2.31E-11	2.00E-10	2.31E-11	not	affected	0.01
17	Balgownie Seam	-12	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.01
18	Lawrence Sandsone	-14	7.64E-08	1.09E-09	7.64E-08	1.09E-09	7.64E-08	1.09E-09	not	affected	0.01
19	Eckersly Formation	-30	9.77E-09	1.04E-10	9.77E-09	1.04E-10	9.77E-09	1.04E-10	not	affected	0.01
20	Wongawiili Seam	-38	1.16E-08	1.16E-09	1.16E-08	1.16E-09	1.16E-08	1.16E-09	not	affected	0.03
21	Kembla sandstone	-47	7.64E-09	2.31E-10	7.64E-09	2.31E-10	7.64E-09	2.31E-10	not	affected	0.01

Kh : Horizontal Conductivity, Kv : Vertical Conductivity

Table 6: Subsided Bulli and Balgownie Workings

Layer	Formation	Top of Model Layer Height above/below top of Bulli Seam	Balgownie Longwall		Western Longwalls[1]		Central and Eastern Narrow Longwalls[2]		Bord & Pillar Workings		Storativity
			Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	
1	Hawkesbury Sandstone Upper	417	1.05E-04	1.05E-05	1.05E-05	1.05E-06	1.05E-04	1.05E-05	original (W)	original (W)	0.03
2	Hawkesbury Sandstone Upper	397	1.05E-04	7.50E-06	1.05E-05	7.50E-07	7.50E-05	7.50E-06	original (W)	original (W)	0.02
3	Hawkesbury Sandstone Lower	380	5.67E-07	original (E)	5.67E-08	original (W)	4.05E-07	original (E/C)	original (W)	original (W)	0.02
4	Hawkesbury Sandstone Lower	338	4.05E-07	original (E)	4.05E-08	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.02
5	Newport Formation	260	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
6	Bald Hill Claystone	248	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
7	Bulgo Sandstone Upper	228	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
8	Bulgo Sandstone Upper	177	3.82E-06	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
9	Bulgo Sandstone Lower	157	5.67E-09	5.80E-10	4.05E-09	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.02
10	Bulgo Sandstone Lower	108	8.10E-09	8.12E-10	2.30E-09	5.80E-10	4.05E-09	original (E/C)	original (W)	original (W)	0.02
11	Stanwell Park Claystone	86	4.28E-09	4.28E-11	3.00E-09	3.00E-11	3.00E-09	2.14E-11	original (W)	original (W)	0.02
12	Scarborough Sandstone	68	5.80E-07	5.80E-08	1.16E-07	5.79E-09	7.00E-08	5.80E-09	original (W)	original (W)	0.02
13	Coalcliff Sandstone	49	3.19E-08	2.03E-10	1.00E-08	1.00E-08	6.00E-09	3.00E-09	3.19E-09	2.03E-11	0.03
14	Coalcliff Sandstone	28	6.37E-08	4.05E-10	4.00E-08	4.00E-08	9.00E-09	9.00E-09	6.00E-09	6.00E-11	0.03
15	Bulli Seam	0	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	0.03[#]
16	Loddon Sandstone	-2.5	1.16E-07	8.10E-08	9.00E-10	original (W)	7.00E-10	original (E/C)	original (W)	original (W)	0.01
17	Balgownie Seam	-12	1.16E-05	1.16E-05	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
18	Lawrence Sandsone	-14	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
19	Eckersly Formation	-30	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01
20	Wongawiili Seam	-38	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.03[#]
21	Kembla sandstone	-47	original (E)	original (E)	original (W)	original (W)	original (E/C)	original (E/C)	original (W)	original (W)	0.01

[1] width and length range: 190x760 m to 190x1,450 m

[2] width and length range: 145x670 m to 145x1,010 m

[#] 0.9 for mined areas

Kh : Horizontal Conductivity, Kv : Vertical Conductivity

(E)-East (W)-West (C)-Central

Table 7: Subsided Proposed Wongawilli Seam Workings

Layer	Formation	Top of Model Layer Height above/below top of Bulli Seam	Proposed Wonga East - over Balgownie[3]		Proposed Wonga West[3]		V- Main		Storativity
			Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	
1	Hawkesbury Sandstone Upper	417	1.05E-03	1.05E-04	1.05E-04	1.05E-05	1.50E-05	1.50E-06	0.03
2	Hawkesbury Sandstone Upper	397	1.05E-03	3.75E-05	1.05E-04	3.75E-06	1.50E-05	7.50E-07	0.02
3	Hawkesbury Sandstone Lower	380	3.97E-06	original (E)	2.84E-07	original (W)	5.67E-08	original (W)	0.02
4	Hawkesbury Sandstone Lower	338	2.03E-06	original (E)	2.03E-07	original (W)	4.05E-08	original (W)	0.02
5	Newport Formation	260	original (E)	original (E)	original (W)	original (W)	original (W)	original (W)	0.01
6	Bald Hill Claystone	248	original (E)	original (E)	original (W)	original (W)	original (W)	original (W)	0.01
7	Bulgo Sandstone Upper	228	3.82E-07	original (E)	original (W)	original (W)	original (W)	original (W)	0.01
8	Bulgo Sandstone Upper	177	2.67E-05	5.45E-09	3.82E-07	original (W)	original (W)	original (W)	0.02
9	Bulgo Sandstone Lower	157	5.67E-08	4.06E-09	4.00E-09	5.80E-10	original (W)	original (W)	0.02
10	Bulgo Sandstone Lower	108	8.10E-08	8.12E-09	1.20E-08	3.40E-09	4.05E-09	original (W)	0.02
11	Stanwell Park Claystone	86	4.28E-08	4.28E-10	2.10E-08	2.10E-10	2.14E-09	2.14E-11	0.02
12	Scarborough Sandstone	68	5.80E-06	5.80E-07	1.20E-06	5.80E-08	1.16E-07	1.16E-08	0.03
13	Coalcliff Sandstone	49	1.59E-07	1.01E-09	1.00E-07	1.00E-07	3.19E-08	2.03E-10	0.03
14	Coalcliff Sandstone	28	3.19E-07	2.03E-09	4.00E-07	4.00E-07	6.37E-08	4.05E-10	0.03
15	Bulli Seam	0	1.16E-05	1.16E-05	1.20E-05	1.20E-05	1.16E-05	1.16E-05	0.03[#]
16	Loddon Sandstone	-2.5	1.16E-07	8.10E-08	1.02E-08	1.20E-09	2.00E-09	original (W)	0.03
17	Balgownie Seam	-12	1.16E-05	1.16E-05	5.80E-07	5.80E-08	original (W)	original (W)	0.03
18	Lawrence Sandsone	-14	5.80E-07	5.80E-08	3.80E-06	5.40E-08	original (W)	original (W)	0.03
19	Eckersly Formation	-30	3.82E-06	5.45E-08	4.90E-07	5.20E-09	original (W)	original (W)	0.03
20	Wongawiili Seam	-38	1.16E-05	1.16E-05	1.20E-05	1.20E-05	original (W)	original (W)	0.03[#]
21	Kembla sandstone	-47	7.64E-08	original (E)	7.60E-08	original (W)	original (W)	original (W)	0.01

[3] hydraulic conductivities superimposed on existing disturbed material longwall size up to 390x2,500 m [#]0.9 for mined areas

Kh : Horizontal Conductivity, Kv : Vertical Conductivity

(E)-East (W)-West (C)-Central

7.0 MODEL RESULTS

7.1 Overview

The purpose of this modelling study was to assess the influence that the proposed extraction of Wonga East, Wonga West and VMains may have on current conditions, in addition to the effects of the existing workings.

Accordingly one of the main aims of the study has been to assess whether the Bald Hill Claystone is sufficient to limit the effects of depressurisation on Cataract Dam in the Wonga West area. Because of the limited extent of available data and the uncertainties regarding subsidence over multi-seam coal extractions, it is only possible to provide predicted values for changes in groundwater levels and groundwater inflows to/outflows from surface water bodies.

A quasi-steady state model was developed to reflect the current case (existing workings). Calibration of the model was performed using measured water levels presented in Table 2 with resultant heads shown in Figure 19.

Three transient models were then run for the following cases:

1) **Stage 1** - The 6.5 years from current case to end of mining of Wonga East (Areas 1 and 2) and V Mains (all three areas modelled simultaneously);

2) **Stage 2** - The resultant heads from Stage 1 were then used as initial conditions for the second scenario which represented the subsequent 8 years to end of mining for Wonga West (Areas 3 and 4, both areas modelled simultaneously).

3) **Recovery** - The resultant heads from Stage 2 were then used as initial conditions for a 10-year recovery model with no pumping from the NRE1 (or Appin) workings.

7.2 Calibration for Current Case

Calibration results (modelled head versus measured heads) are shown in Figure 20. The largest discrepancies between the modelled and actual hydraulic heads are associated with the following factors:

- the limitations of the model in terms of representing the complex subsidence pattern associated with the existing Balgownie longwalls in Wonga East, and the uncertainty in variability of subsidence effects above the longwalls of variable size in Wonga West;
- the requirement within FEFLOW to place observation points on layer boundaries rather than within layers, and the decision (based on modelling efficiency) not to discretise lower hydraulic conductivity units into sub-layers; and
- areas of the model where numerous zones of different hydraulic conductivities border each other, and for which the exact locations of boundaries in relation to monitoring bores/piezometers are not known accurately.

7.3 Estimated Depressurisation Resulting from Proposed Workings

Depressurisation resulting from the proposed workings has been evaluated at four elevations: Upper Hawkesbury Sandstone, Lower Hawkesbury Sandstone, Upper Bulgo Sandstone and Wongawilli Coal Seam. The estimated depressurisation at the corresponding model surfaces for end-of-mining is discussed in the following sections.

7.3.1 Stage 1 Mining in Area 1, Area 2 and VMains

Stage 1 development was modelled as the simultaneous introduction of all proposed Wonga East and the V Mains workings in Wonga West area for 6.5 years.

Contours of drawdown (relative to current steady-state conditions) are shown in Figure 21 to Figure 27. Drawdown at the end-of-mining of Stage 1 is shown for the Upper Hawkesbury Sandstone (Figure 21), Lower Hawkesbury Sandstone (Figure 22), Upper Bulgo Sandstone (Figure 23), Lower Bulgo Sandstone

(Figure 24), Scarborough Sandstone (Figure 25), Bulli Coal Seam (Figure 26) and Wongawilli Coal Seam (Figure 27).

Drawdown in relation to the introduction of the VMain workings extends mainly in a southerly direction, due to the already existing depressurisation in and above the existing Wonga West workings immediately to the North.

Drawdown at the end of mining, in the Upper and Lower Hawkesbury at Wonga East is less than 5 m. The Upper Bulgo Sandstone has a drawdown of 6 m in Wonga West over VMains and 8 m in Wonga East. The Lower Bulgo Sandstone has a drawdown of 50 m in Wonga West over VMains and 30 m in Wonga East. Drawdown in the Scarborough Sandstone is 110 m over VMains in Wonga West and less than 50 m in Wonga East. The Bulli Coal Seam experiences 130 m of drawdown in Wonga West and 50 m drawdown in Wonga East, whilst the Wongawilli Coal Seam experiences 60 m drawdown in Wonga West and 50 m drawdown in Wonga East.

Figure 28 shows a drawdown cross-section passing through the proposed workings in VMains and Wonga East at the end-of-mining of Stage 1. The depressurisation zone surrounding the proposed workings is restricted to below the Upper Bulgo Sandstone except in Wonga East where the fracturing of the spanning Bulgo Sandstone, and the partial erosion of the Bald Hill Claystone has lead to a more permeable connection between the workings and the surface.

7.3.2 Stage 2 Mining in Area 3 and Area 4

Stage 2 development was modelled as the simultaneous introduction of the two stages of proposed development in the Wonga West area, and over an additional 8 years. Mining was considered to be completed in Wonga East with only the access drift between Wonga West and East being kept dry.

Contours of drawdown (relative to current steady-state conditions) are shown in Figure 29 to Figure 35. Drawdown at the end-of-mining of Stage 2 is shown for the Upper Hawkesbury Sandstone (Figure 29), Lower Hawkesbury Sandstone (Figure 30), Upper Bulgo Sandstone (Figure 31), Lower Bulgo Sandstone (Figure 32), Scarborough Sandstone (Figure 33), Bulli Coal Seam (Figure 34) and Wongawilli Coal Seam (Figure 35).

Drawdown of less than 12 m occurs in the Upper and Lower Hawkesbury Sandstone in Wonga West. Drawdown in the Upper Bulgo Sandstone, below the Bald Hill Claystone, is up to 100 m in Wonga West but has decreased to 5 m in Wonga East, where mining has ceased and the recovery starts to occur. Similarly, drawdown in the Lower Bulgo Sandstone is 180 m in Wonga West but only 10 m in Wonga East.

The Scarborough Sandstone has drawdown of 140 m over the Wonga West Wongawilli workings, 100 m over VMains and 20 m in Wonga East.

Drawdown in the Bulli Coal Seam is shown to be up to 120 m in the west and up to approximately 20 m in the east.

Drawdown in the Wongawilli Coal Seam, which contains the majority of the proposed workings in Wonga West and East, is up to 90 m in the west and up to approximately 40 m in the east along the access rift. Note that the access rift between the Wonga West and East workings was modelled by applying seepage boundaries to the nodes, but no subsidence was modelled to occur above the first workings.

Figure 36 shows a drawdown cross-section passing through the proposed workings in Wonga West at the end-of-mining of Stage 2. There is a slight extension of the depressurisation zone into the Lower Hawkesbury but it is mainly restricted by the Bald Hill Claystone.

7.3.3 Ten-Year Recovery

After Stage 2, boundary conditions representing removal of water from all mines in the model domain (including the Appin workings to the north of Wonga West) were removed from the model which was then run for a further 10 years. Figure 37 to Figure 43 show changes in water levels from current case (initial conditions) to ten years after mining has ceased (levels above current case are shown as negative values).

Model results for the Upper and Lower Hawkesbury show full recovery in Wonga East and recovery commencing in Wonga West. Total heads in the Upper and Lower Bulgo Sandstone were modelled to be still below current levels in the Wonga West area during the 10-year recovery period, while all other areas show rises in head levels between the current day situation and after 10 years of recovery.

The Bulli and Wongawilli Coal Seams show significant recovery after 10 years, in both the Wonga West and the Wonga East areas.

7.3.4 Effects on surface water features

The model has been used to interpret potential changes to stream flow, however the resolution of the model in terms of actual flow volume is limited, i.e., streams are modelled as transfer boundary conditions allowing for the potential recharge or discharge of water into and out of the model domain. Creeks are modelled as being always flowing. Based on modelling results, the potential effects of the proposed mine workings on Cataract reservoir are considered to be negligible. Modelled effects on the creeks manifested as a reduction in discharge to the creek (recharge from the creek into the model remained unchanged). Quantities shown in Table 8 represent a total reduction along the full length of the creek.

Table 8: Effects on Creeks

Creek	Modelled Reduction in Discharge to Creek (ML/d)
Cataract	0.07
Bellambi	0.03
Wallandoola	0.25
Lizard	0.10

Geoterra (2012) and other studies carried out for swamps indicate that they have perched water tables which are separated from the deeper regional water table by 10 – 20 m. These perched water table systems have not been specifically represented in the regional model.

In the Wonga West area, the model indicates possible 12 m drawdown in the Hawkesbury Sandstone at the end of mining. In the Wonga East area, Cataract Creek and Cataract River cross the area that has already been impacted by subsidence. At Wonga East, the model predicts drawdown of up to 8 m in the Upper Bulgo Sandstone, and 5 m in the overlying Hawkesbury Sandstone.

In the area of Bellambi Creek and the Cataract River upstream of Cataract Reservoir, the model indicates negligible drawdown in the Hawkesbury Sandstone and Bulgo Sandstone. This is further illustrated by the modelled groundwater flow directions in the Upper and Lower Hawkesbury Sandstones, shown in Figure 44 to Figure 55 for all four creeks for current case, Stage 1 and Stage 2 (note that the scale of the velocity vectors varies between the figures).

7.4 Mine Inflow Rates

Model-generated flow rates into the proposed Wongawilli Seam workings at the end of mining are presented in Table 9.

Table 9: Model-Generated Inflow Rates (ML/d)

	Current Bulli Seam Workings	End of Mining Wongawilli Seam Workings
Wonga East	0.2	1.4
Wonga West	0.9	1.7

The modelled current groundwater inflows to the existing workings are relatively close to the monitored 0.6 ML/day of water pumped out of the workings, which with 0.11 ML/day of extracted moisture in air and 0.1 ML/day of moisture in extracted coal, represents approximately an average of 0.81 ML/day of groundwater make to the workings.

7.5 Sensitivity Analysis

An additional scenario is presented here to further explore sensitivity to parameters and possible variations in the hydrogeological model.

Scenario 2 was modelled as a case that had increased subsidence over the proposed workings in Wonga East and decreased subsidence above the Bald Hill Claystone in Wonga West. The parameter set is shown in Table 10.

Table 10: Scenario 2 - Changed Parameters (compared to Scenario 1)

Layer	Formation	Proposed Wonga East - over Balgownie		Proposed Wonga West		V- Main	
		Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)	Kh (m/s)	Kv (m/s)
1	Hawkesbury Sandstone Upper	3.0E-03	2.5E-05	original (W)	original (W)	original (W)	original (W)
2	Hawkesbury Sandstone Upper	3.0E-03	2.5E-05	original (W)	original (W)	original (W)	original (W)
3	Hawkesbury Sandstone Lower	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
4	Hawkesbury Sandstone Lower	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
5	Newport Formation	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
6	Bald Hill Claystone	1.9E-05	2.7E-07	original (W)	original (W)	original (W)	original (W)
7	Bulgo Sandstone Upper	3.8E-05	5.4E-07	3.8E-07	original (W)	original (W)	original (W)
8	Bulgo Sandstone Upper	3.8E-05	5.4E-07	3.8E-07	5.4E-09	original (W)	original (W)
9	Bulgo Sandstone Lower	8.1E-08	1.2E-08	4.0E-09	5.8E-10	original (W)	original (W)
10	Bulgo Sandstone Lower	8.1E-08	1.2E-08	1.2E-08	3.4E-09	4.0E-09	original (W)
11	Stanwell Park Claystone	2.1E-07	2.1E-09	2.1E-08	2.1E-10	2.1E-09	2.1E-11
12	Scarborugh Sandstone	5.8E-06	5.8E-07	1.2E-06	5.8E-08	1.2E-07	1.2E-08
13	Coalcliff Sandstone	3.2E-07	2.0E-09	1.0E-07	1.0E-07	3.2E-08	2.0E-10
14	Coalcliff Sandstone	3.2E-07	2.0E-09	4.0E-07	4.0E-07	6.4E-08	4.0E-10
15	Bulli Seam	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05
16	Loddon Sandstone	1.2E-07	8.1E-08	1.02E-08	1.2E-09	2.0E-09	original (W)
17	Balgownie Seam	1.2E-05	1.2E-05	5.8E-07	5.8E-08	original (W)	original (W)
18	Lawrence Sandsone	5.8E-07	5.8E-08	3.8E-06	5.4E-08	original (W)	original (W)
19	Eckersly Formation	3.8E-06	5.4E-08	4.9E-07	5.2E-09	original (W)	original (W)
20	Wongawiili Seam	1.2E-05	1.2E-05	1.2E-05	1.2E-05	original (W)	original (W)
21	Kembla sandstone	7.6E-08	original (W)	7.6E-08	original (W)	original (W)	original (W)

Stage 1 drawdown in Wonga West increased to 20 m in the Upper Hawkesbury Sandstone (Figure 56). This induced a larger reduction in discharge to Cataract Creek (to 0.4 ML/d) and, to a lesser extent, Bellambi Creek (to 0.2 ML/d). Modelled inflows to the proposed Wonga East Wongawilli workings were 1.4 ML/d.

Drawdowns in the Upper and Lower Hawkesbury Sandstones were negligible in Wonga West with negligible effects on Wallandoola and Lizard Creeks. There was less drawdown in the Upper Bulgo Sandstone (Figure 57), whilst drawdown in Scarborough Sandstone, Bulli and Wongawilli Coal Seams drawdown remained relatively unchanged. Modelled inflows to the proposed Wonga West Wongawilli workings were 1.7 ML/d.

7.6 Results Summary

The modelling undertaken gives indicative results with respect to effects of proposed mine workings on existing ground and surface waters in the study area. The main results of modelling are as follow:

- In the Wonga West area, based on the geotechnical assessment and the derived hydraulic parameters, the proposed longwalls will significantly depressurise the strata below the Bald Hill Claystone. Geotechnical studies indicate that the current hydraulic conductivity of this unit is unlikely to be unaffected by subsidence as a result of the proposed workings.

  With the unfractured Bald Hill Claystone intact, the model indicated that near-surface depressurisation and effects on the Cataract reservoir are estimated to be negligible.

- In the Wonga East area, the geotechnical studies indicate that the Bulgo Sandstone (the main spanning unit in the area) has been at least partially subsided and fractured as a result of existing workings. As a result, the proposed workings, which will increase the subsidence / fracturing, indicate depressurisation of the order of 10 – 20 m near-surface.

It should be noted that because of the lack of available data, model results should be regarded as predictive only. Note also that the results, especially the extent of the magnitude of depressurisation outside the immediate vicinity of the proposed workings, are sensitive to the current state of existing workings, such as whether they are hydraulically separated from each other, and whether they are dry or flooded (those assumptions were outlined previously).

8.0 RECOMMENDATIONS

The following recommendations are made:

- Additional data would be required if further modelling is required to more accurately assess the likely impacts of the proposed workings. Additional data would include (but would not be limited to) a detailed assessment of the current status of all existing workings with regards to flooded / naturally dry / pumped dry, as the extent of flooding /pumping has been shown to have noticeable effect on the extent of depressurisation in areas throughout the extensively mined catchment.

- Continued monitoring of the areas should be carried out around and between the Wonga West and Wonga East proposed workings and the water supply dams, with respect to water levels in the dams as well as potential mine inflows.

9.0 LIMITATIONS

Model performance is dictated by data availability. The limited piezometric data and borehole geological information available for this modelling study has resulted in simplifications and assumptions to be made regarding model structure and parameters. For example, some parameter values have been taken from published literature and some geology formations have been simplified which limits the capabilities of the model.

All existing workings were assumed to be flooded, except for locations in the existing NRE1 workings which were considered to be pumped and the BHP Appin workings north of Wonga West.

The Bald Hill Claystone, where currently considered intact, was assumed to remain unaffected by subsidence above the proposed (Wonga West) workings. As a result, the model indicates negligible drawdown in overlying strata, and we have therefore concluded that there is likely to be negligible impact on surface water flows in this area. However, we note that if subsidence develops in this area and causes changes in the hydraulic conductivity of more brittle strata overlying the Bald Hill Claystone, this may cause changes to near surface recharge and discharge patterns. Specific details of likely changes in hydraulic conductivity and a more localised model would be required to assess these possible impacts.

The effects of fracturing were represented by changes in hydraulic conductivity. For each layer, those changes were applied uniformly through the extent of the fracturing zone (i.e., individual fractures have not been modelled). Those parameter changes, and the extent of fracturing zones have been applied using general rules (outlined in Section 4.2) and will not necessarily capture the full extent of localised drawdown due to localised fracture flow.

Due to some limitations in the ability of the software to resolve thin layers for the full extent of the cross-sections, several individual lithologies have been incorporated into fewer (and thicker) layers with conductivities gauged to be representative of the combined components.

The parameters and changes thereof used in this study largely depended on available published data from other studies undertaken in the wider vicinity of the study area and from geotechnical studies undertaken for proposed workings. It should be noted that the geotechnical studies clearly state that multiseam (longwall) mining is a relatively new concept in Australia. Accordingly not much experience or precedence is present. Hence there is a larger than normal degree of uncertainty in connection with the prediction of subsidence above such workings. All hydraulic parameters chosen are naturally affected by the geotechnical uncertainty plus a further uncertainty in correlating changes in hydraulic parameters with the predicted subsidence effects. Only thorough monitoring of the groundwater levels can determine the validity of the parameters chosen in this study.

10.0 REFERENCES

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Report Signature Page

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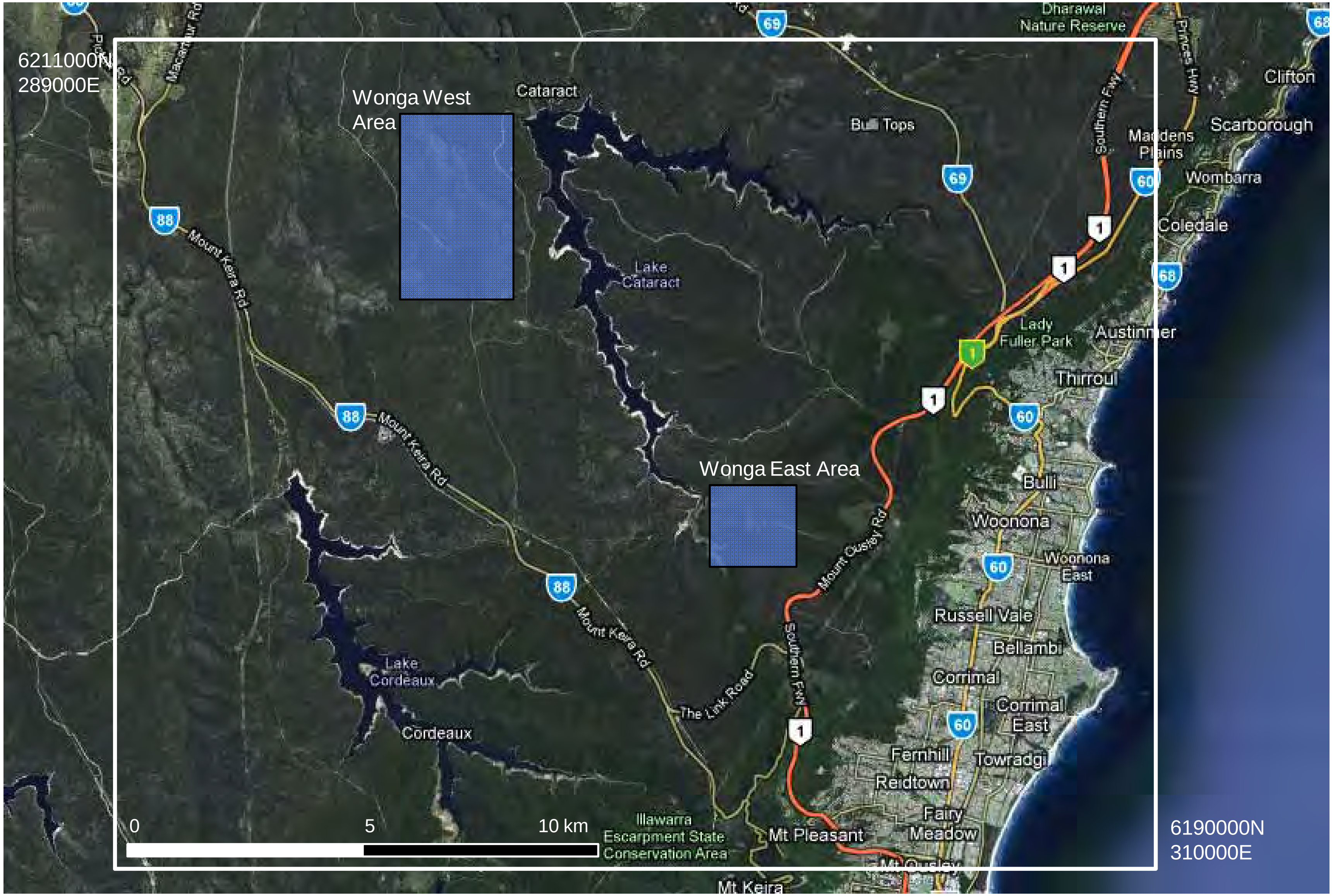
FIGURES



🟦 Study Areas

CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

TITLE **Location of Study Area**

CHECKED

DATE

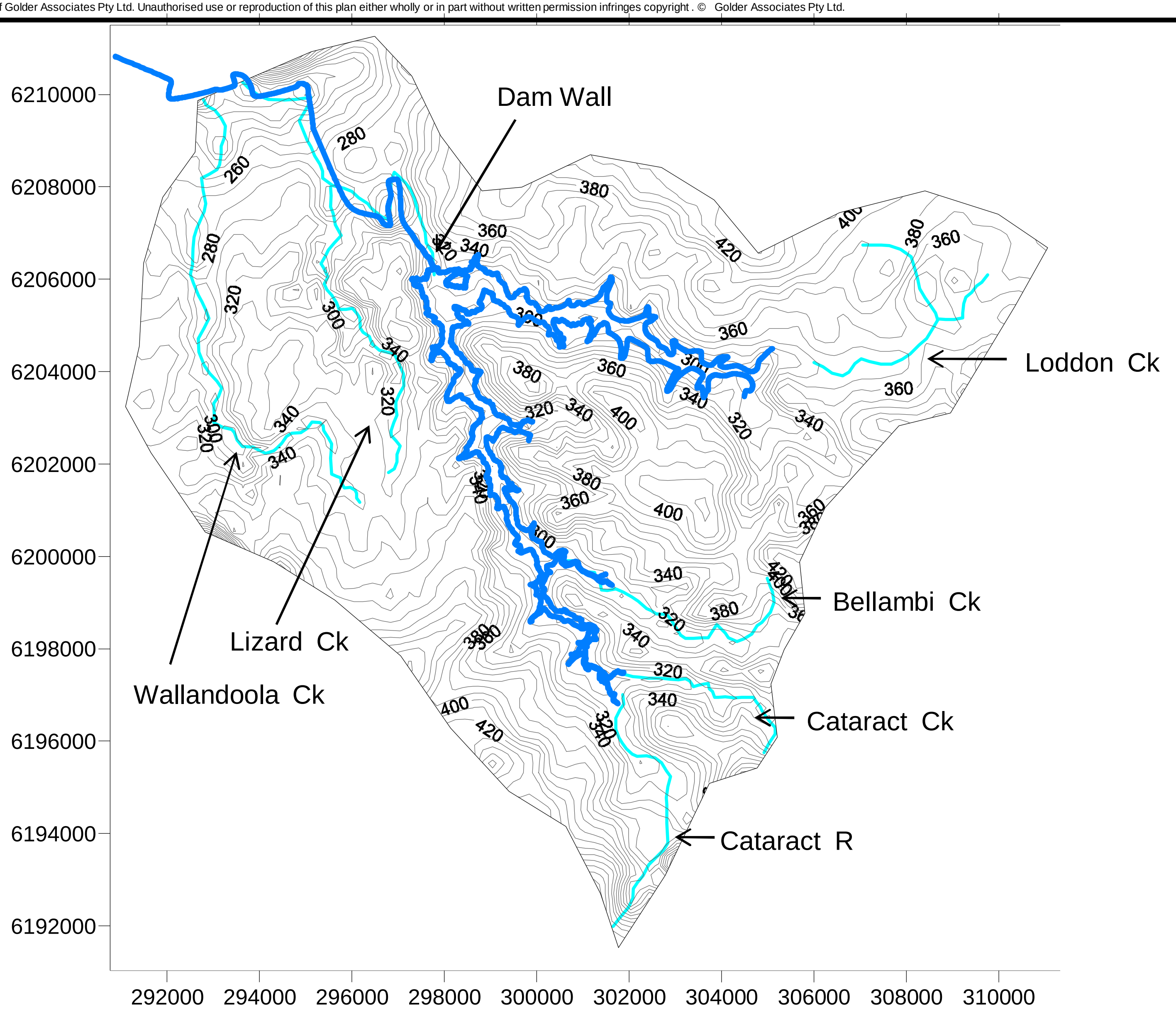
SCALE As shown

PROJECT No 107636001

FIGURE No 1

REV No

A4



▬ **Cataract Reservoir**

▬ **Creeks**

—320— **Elevation (mAHD)**

Golder Associates

CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE **Topography and Main Water Bodies**

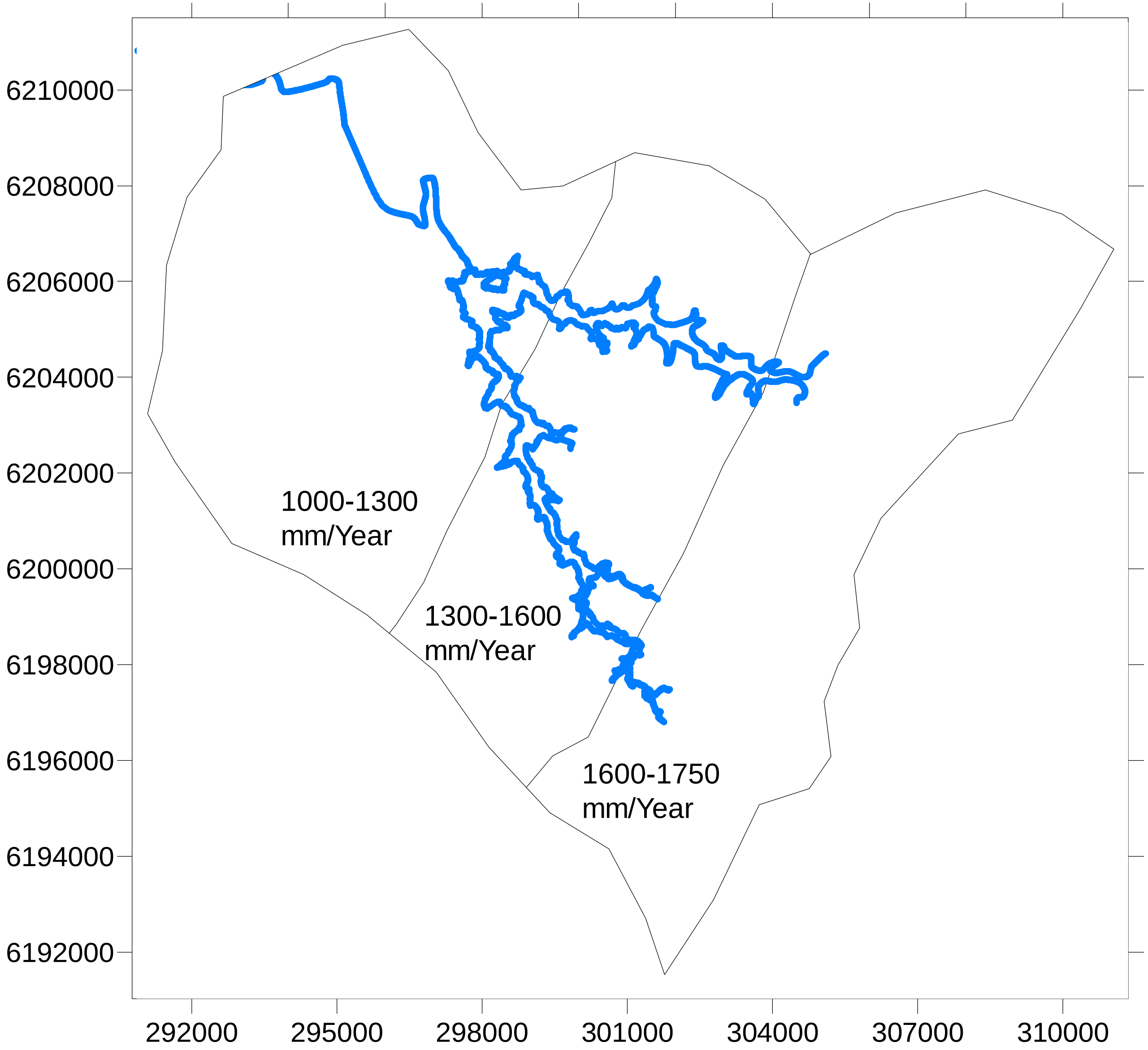
SCALE As shown

PROJECT No 107636001

FIGURE No 2

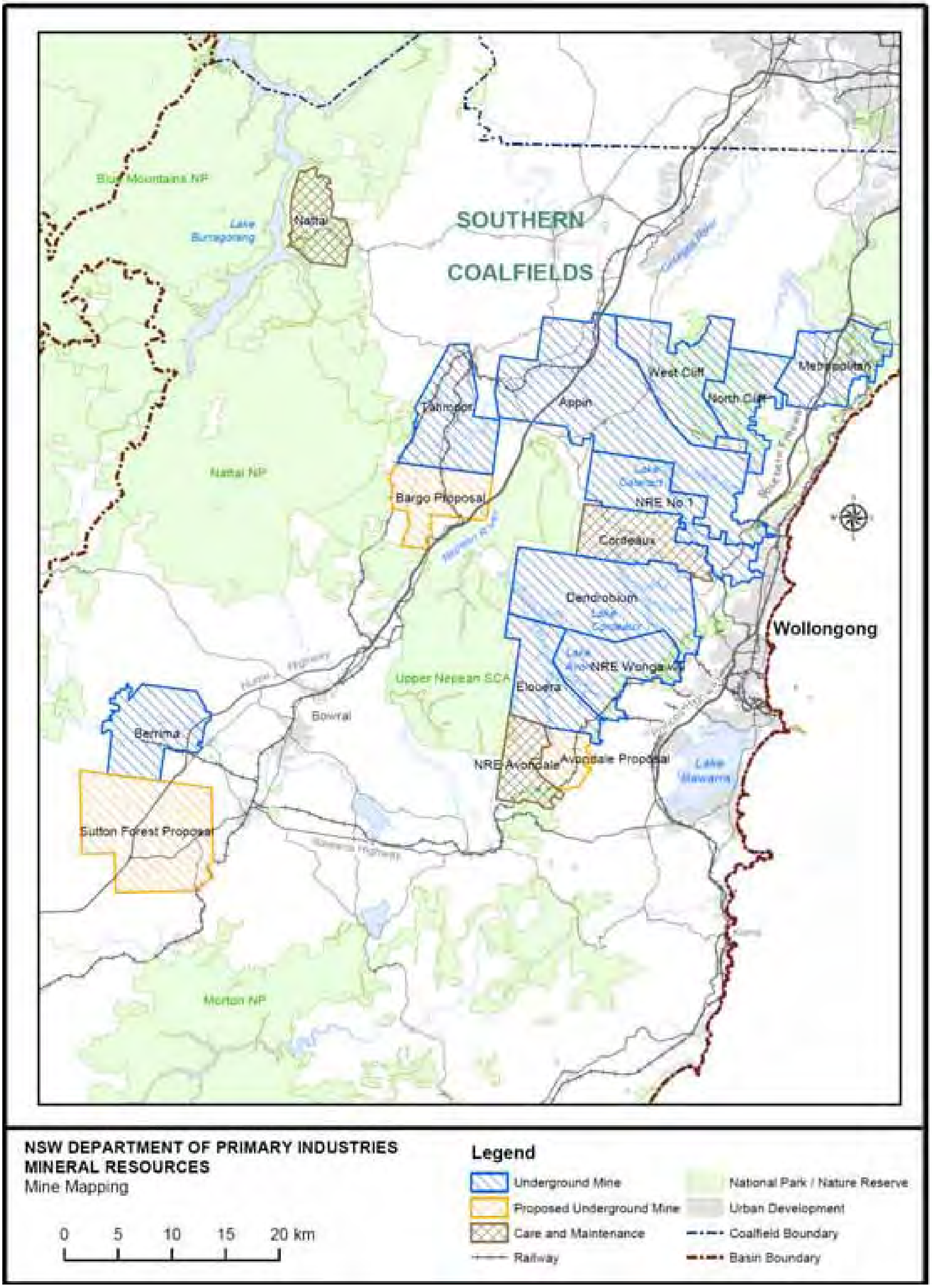
REV No

A4



🟦 **Cataract Reservoir**

CLIENT	Gujarat
PROJECT	Groundwater Modelling
DRAWN	SWW
DATE	Nov 2011
CHECKED	
DATE	
TITLE	**Mean Annual Rainfall Zones (summarised from WRM, 2010)**
SCALE	As shown
PROJECT No	107636001
FIGURE No	3
REV No	
	A4



CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	Current and Proposed Coal Mining Areas in the Southern Coalfield (NSW Govt , 2008)
CHECKED	DATE		
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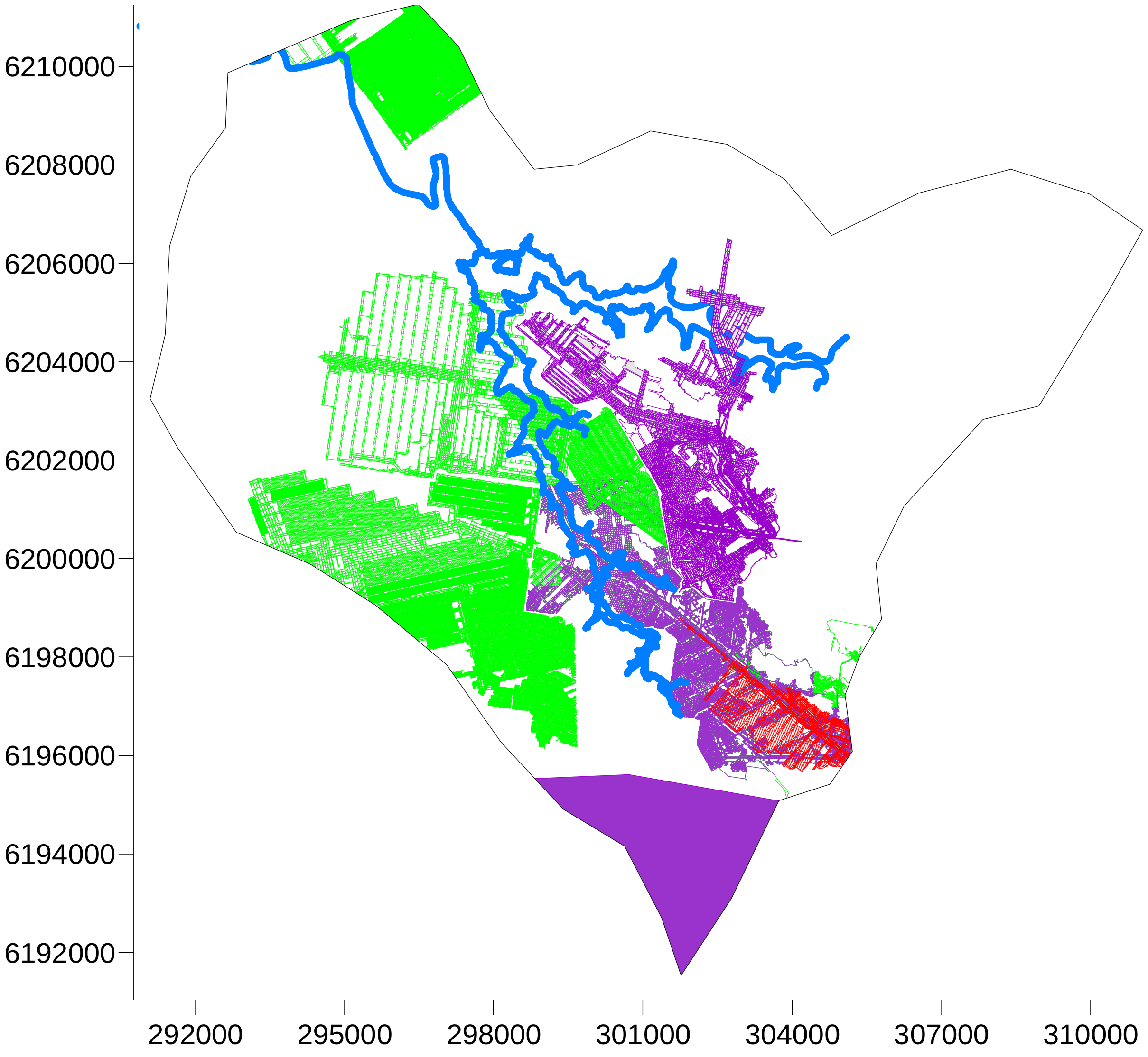

🟦 **Cataract Reservoir**

🟩 **Bulli Longwall**

🟪 **Bulli Bord and Pillar**

🟥 **Balgownie Longwall**

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CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE
Existing Workings by Seam and Type

SCALE
As shown

PROJECT No 107636001

FIGURE No 5

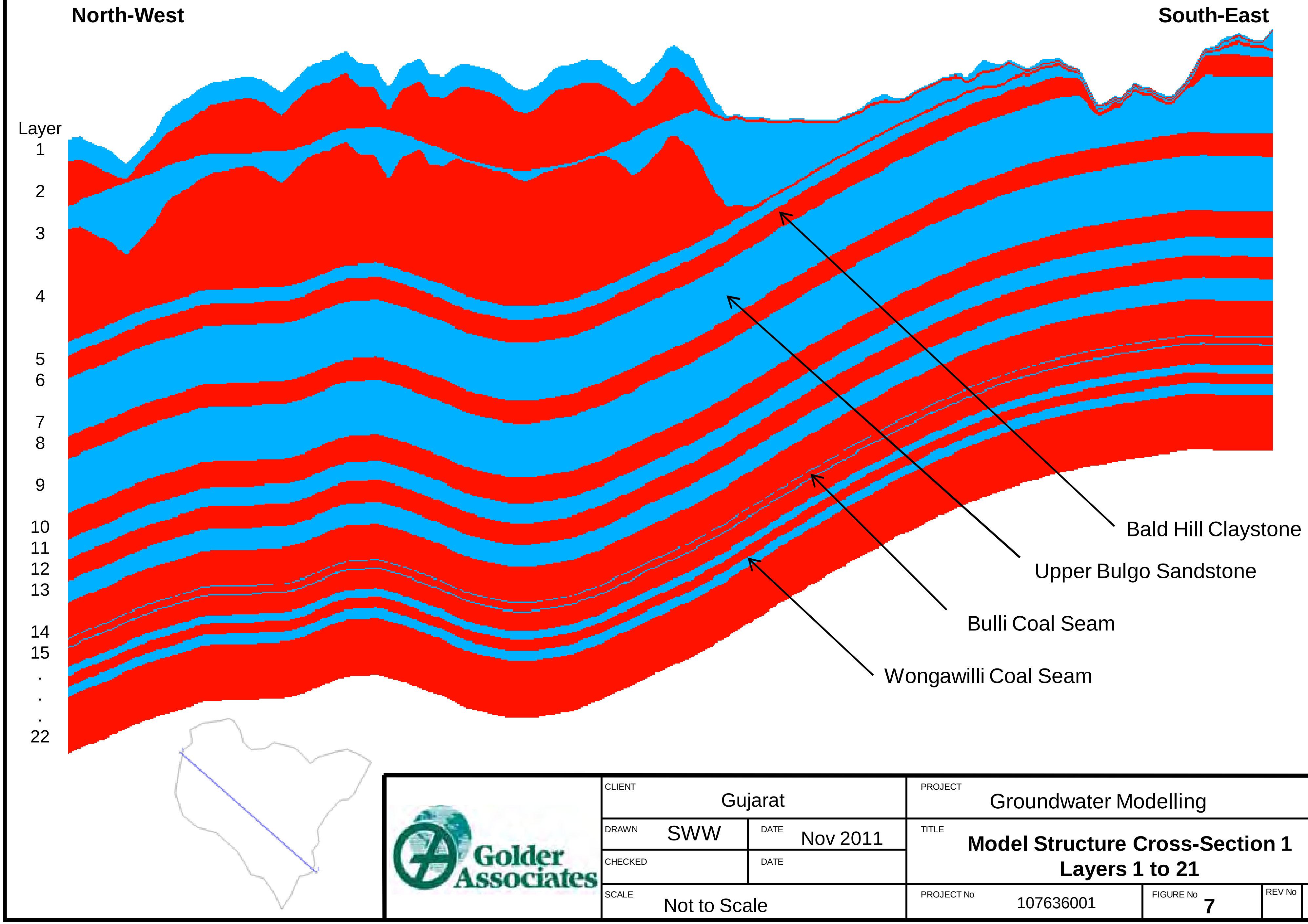
REV No

A4

GROUP	STRATIGRAPHIC UNIT[1]	GRAPHIC	INDICATIVE DEPTH[2] (m)	GEOLOGICAL DESCRIPTION[3]
WIANAMATTA GROUP	BRINGELLY SHALE (AQUITARD)	▤	60	Shale, carbonaceous claystone, claystone, laminite, fine to medium grained lithic sandstone, rare coal and tuff.
	MINCHINBURY SANDSTONE	🟨	70	Fine to medium grained lithic sandstone.
	ASHFIELD SHALE (AQUITARD)	▤	110	Dark grey to black claystone-siltstone and fine sandstone-siltstone laminite.
	MITTAGONG FORMATION	🟥	120	Interbedded shale, laminite and medium grained quartz sandstone
	HAWKESBURY SANDSTONE (AQUIFER)	🟦	300	Medium to very coarse grained quartz sandstone, very minor laminated mudstone, shale, claystone and siltstone lenses.
NARRABEEN GROUP	NEWPORT FORMATION	🟥	320	Interbedded shale, laminite and quartz to quartz-lithic sandstone.
	GARIE FORMATION	🟥	340	Clay-pellet sandstone.
	BALD HILL CLAYSTONE (AQUITARD)	▤	360	Dominantly red-brown claystone and red shale with fine to medium grained sandstone.
	BULGO SANDSTONE (AQUIFER)	🟦	610	Fine to medium grained quartz-lithic sandstone with lenticular shale interbeds.
	STANWELL PARK CLAYSTONE	▤	640	Red, green and grey shale and quartz-lithic sandstone.
	SCARBOROUGH SANDSTONE	🟨	660	Quartz-lithic sandstone, pebbly in parts.
	WOMBARRA CLAYSTONE	▤	670	Grey shale and minor quartz-lithic sandstone.
	COAL CLIFF SANDSTONE	🟨		Fine to medium grained quartz-lithic sandstone.
ILLAWARRA COAL MEASURES	BULLI COAL	⬛	690	Interbedded quartz-lithic sandstone, grey siltstone and claystone, carbonaceous claystone, clay, laminite and coal.
	LODDON SANDSTONE	🟨		
	BALGOWNIE COAL MEMBER	⬛		
	LAWRENCE SANDSTONE	🟨		
	ECKERSLEY FORMATION	🟥		
	WONGAWILLI COAL	⬛	750	
	KEMBLA SANDSTONE	🟨	760	
	ALLANS CREEK FORMATION	🟥	770	
	DARKES FOREST SANDSTONE	🟨	790	
	BARGO CLAYSTONE	▤	820	
	TONGARRA COAL	⬛	850	

Source: The Design of a Hydrological and Hydrogeological Monitoring Program to Assess the Impact of Longwall Mining in SCA Catchments

Golder Associates	CLIENT Gujarat		PROJECT Groundwater Modelling			
	DRAWN SWW	DATE Nov 2011	TITLE Simplified stratigraphy of the Southern Sydney Basin (NSW DIPNR)			
	CHECKED	DATE				
	SCALE Not to Scale		PROJECT No 107636001	FIGURE No 6	REV No T	A4



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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

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TITLE **Model Structure Cross-Section 1**
Layers 1 to 21

SCALE Not to Scale

PROJECT No 107636001

FIGURE No 7

REV No

A4

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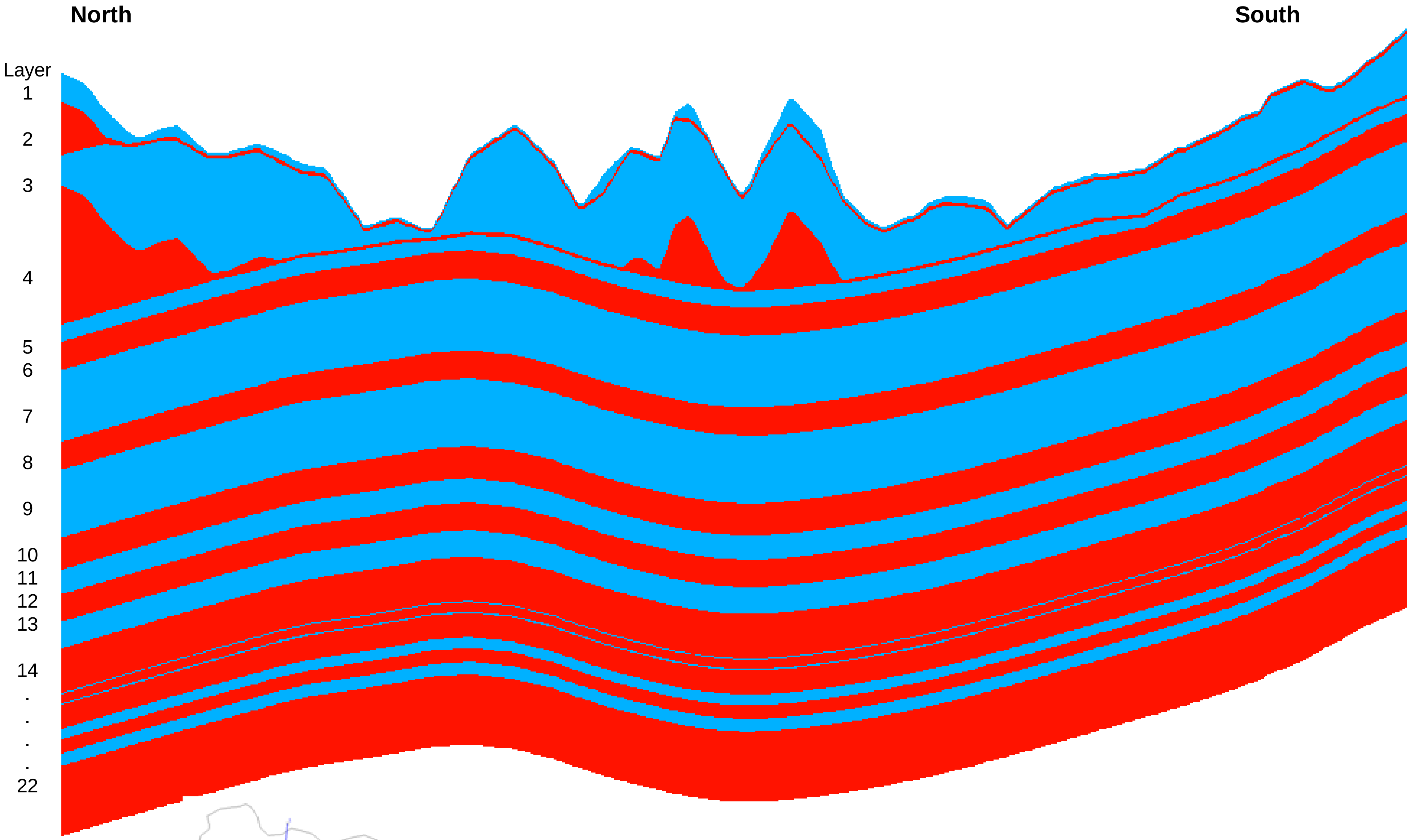

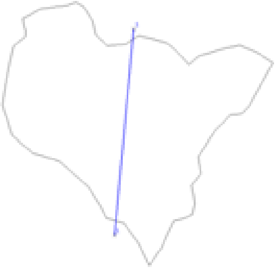

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Model Structure Cross-Section 2 Layers 1 to 21**	
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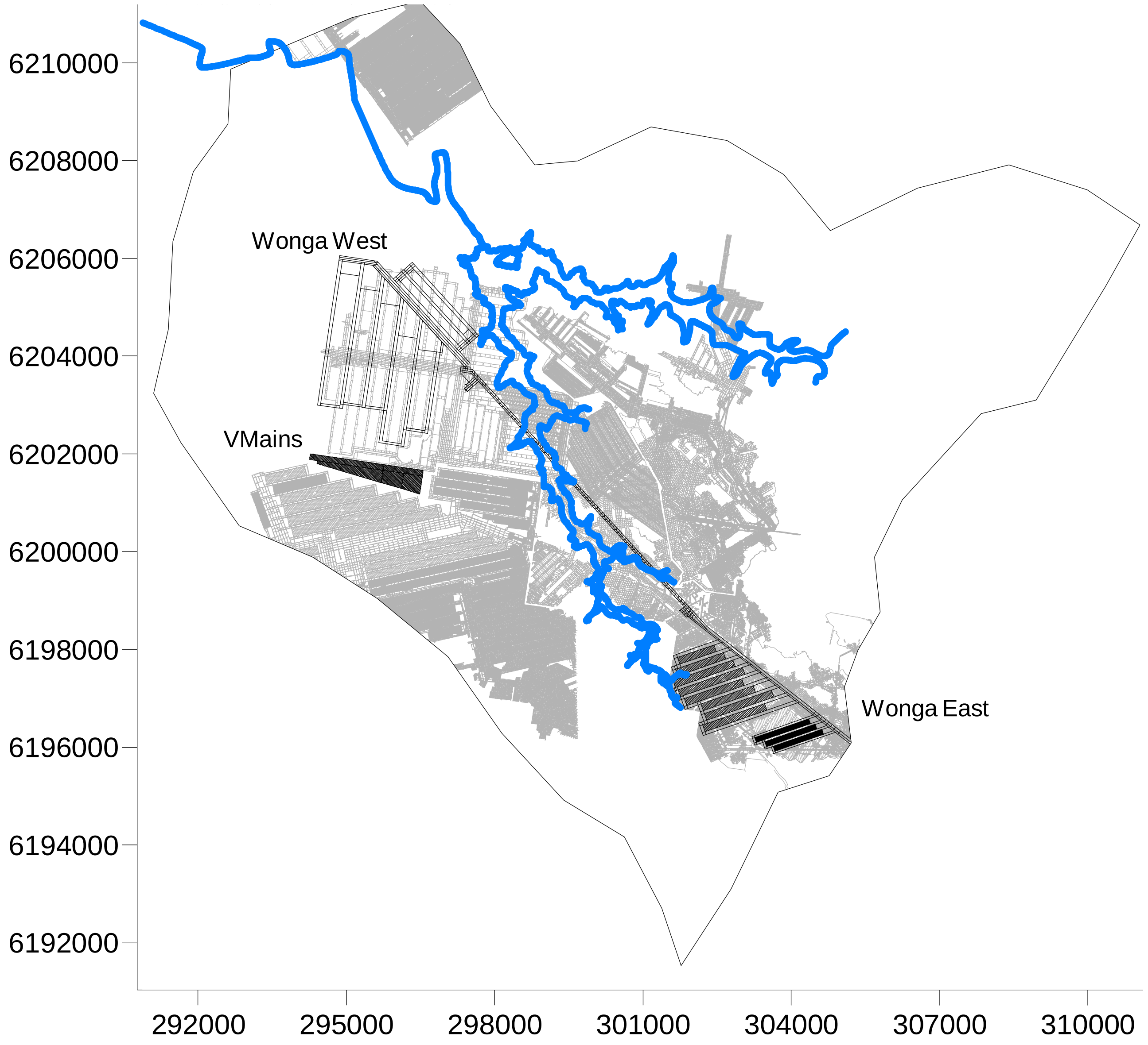
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 8
		REV No	**A4**



▬ **Cataract Reservoir**

▨ **Existing Workings**

■ **Proposed Workings**

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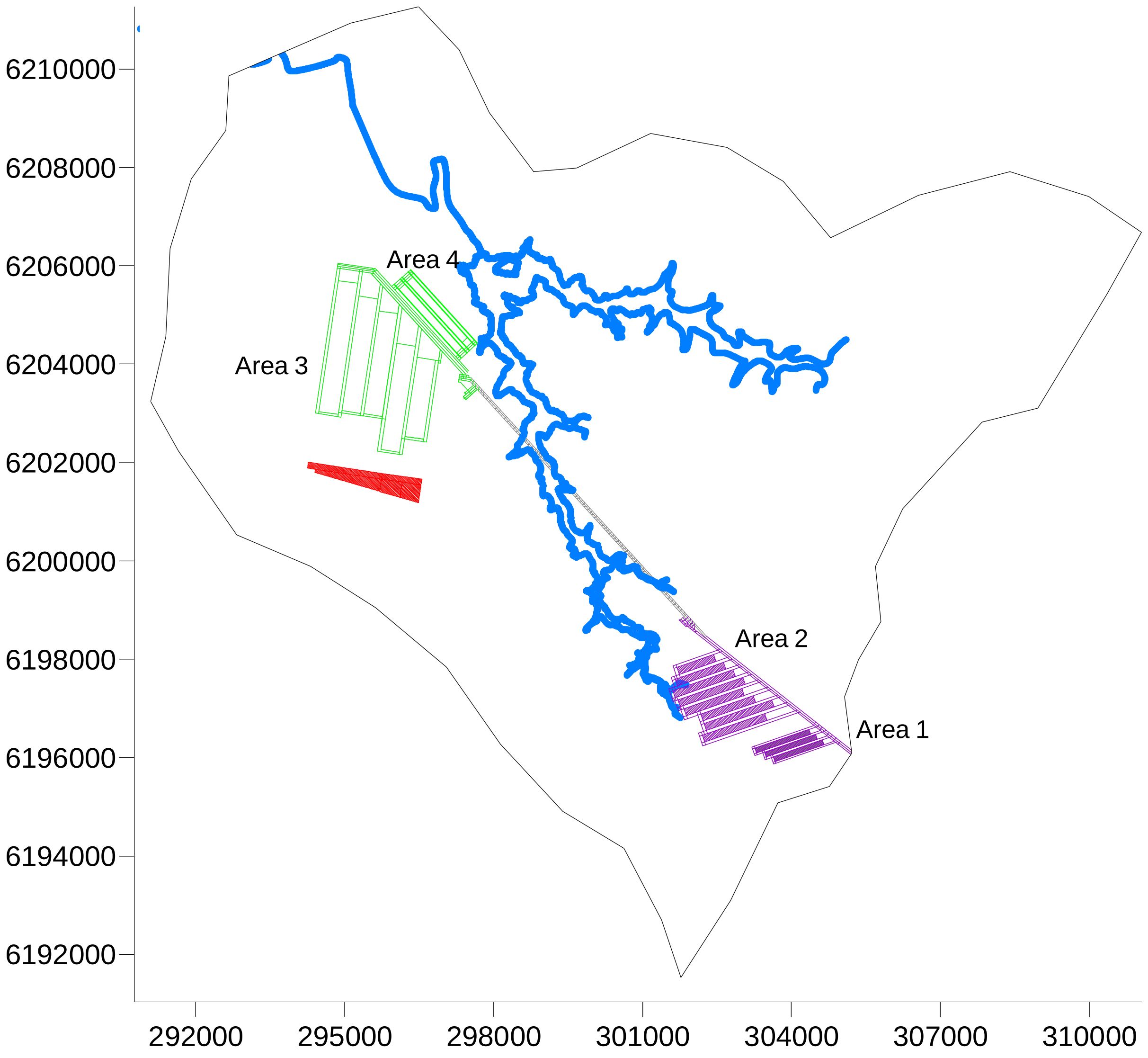
CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Proposed and Existing Workings**	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 9 · REV No · A4



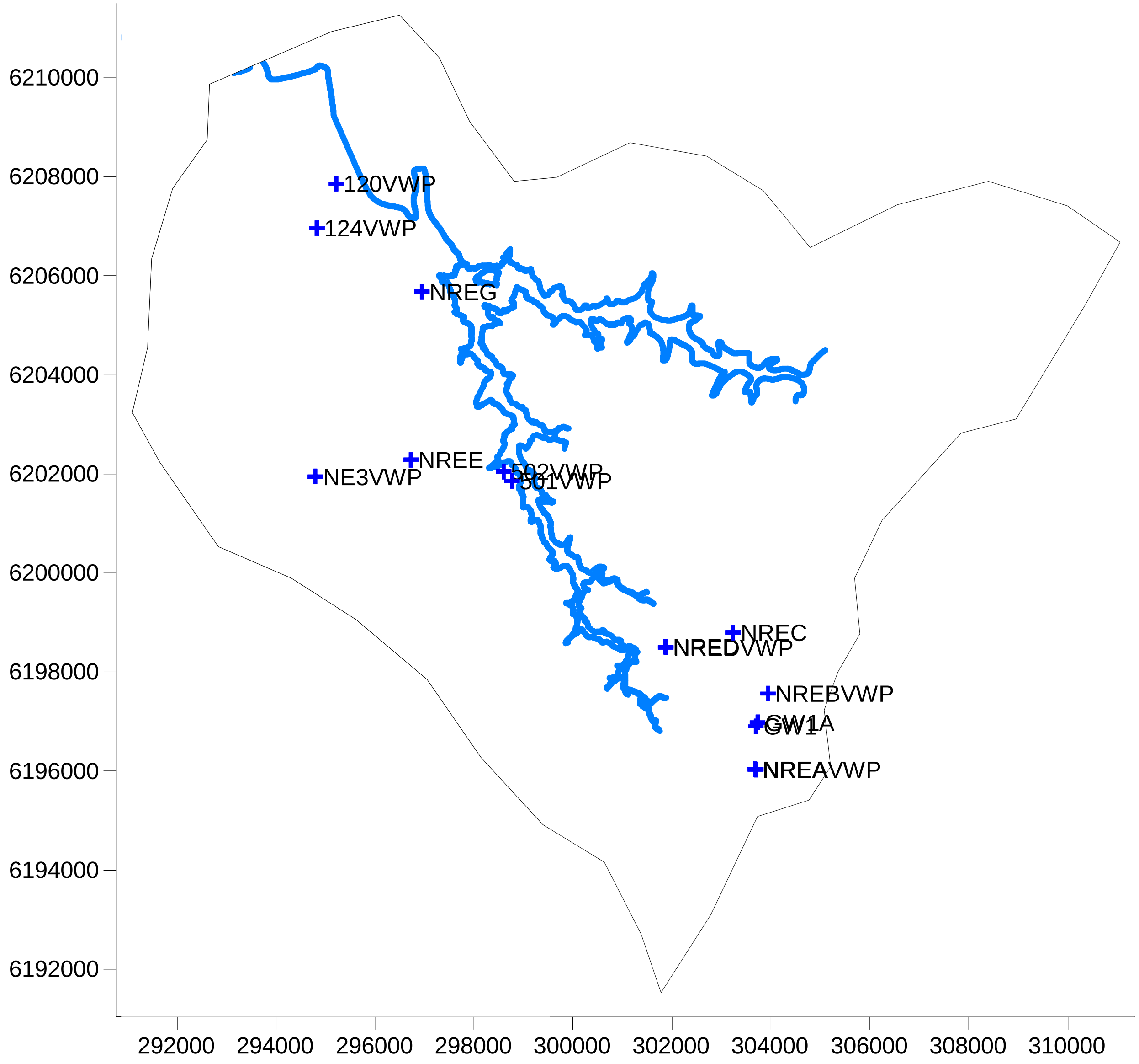
🟦 **Cataract Reservoir**

🟩 **Wonga West Longwall**

🟪 **Wonga East Longwall**

🟥 **VMains Pillar Extraction**

CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN	SWW	DATE	Nov 2011
CHECKED		DATE	
TITLE	**Proposed Workings by Type**		
SCALE	As shown	PROJECT No	107636001
FIGURE No	**10**	REV No	**A4**



▬ **Cataract Reservoir**

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Monitoring Bores**	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 11 / REV No / A4

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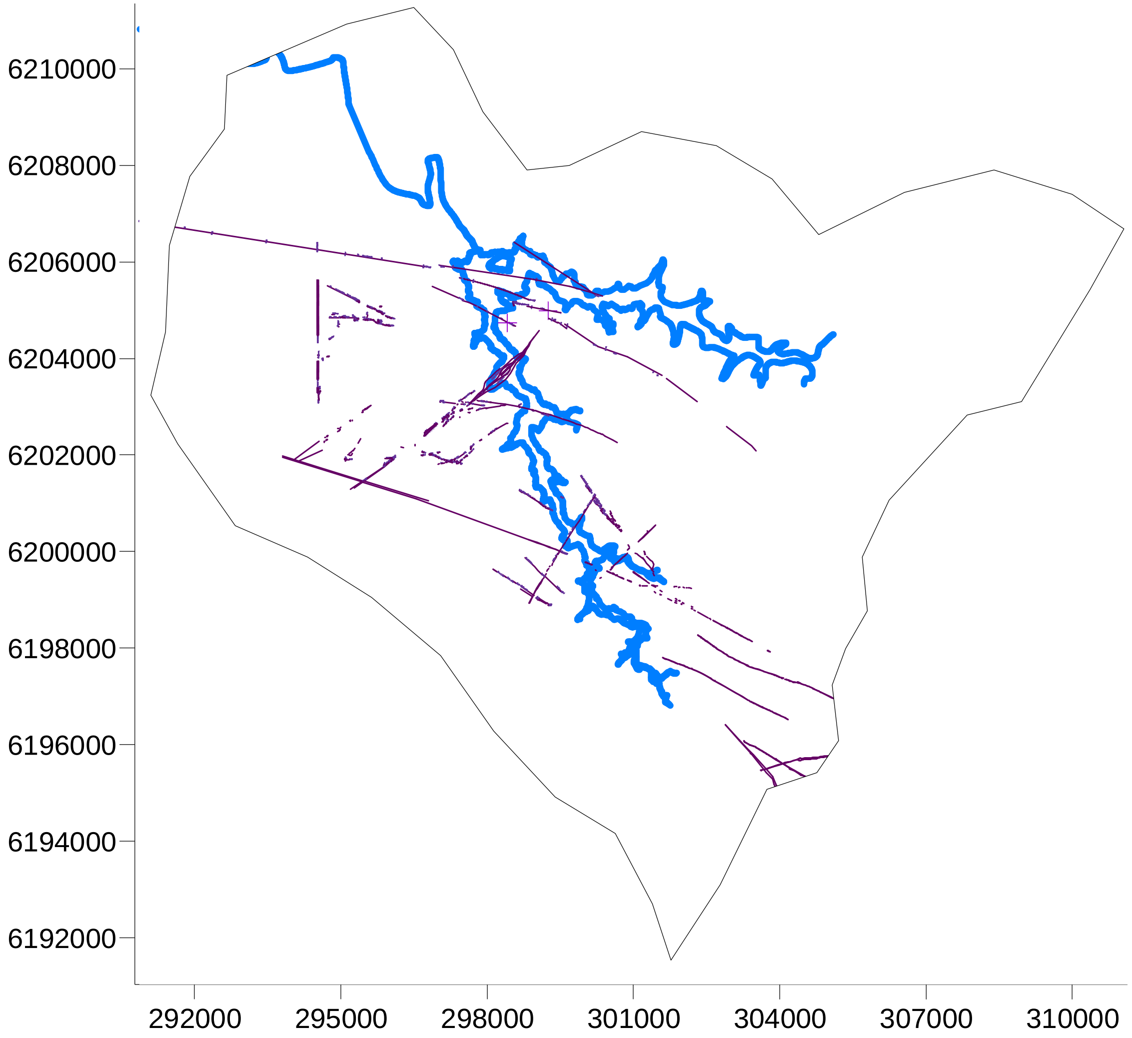
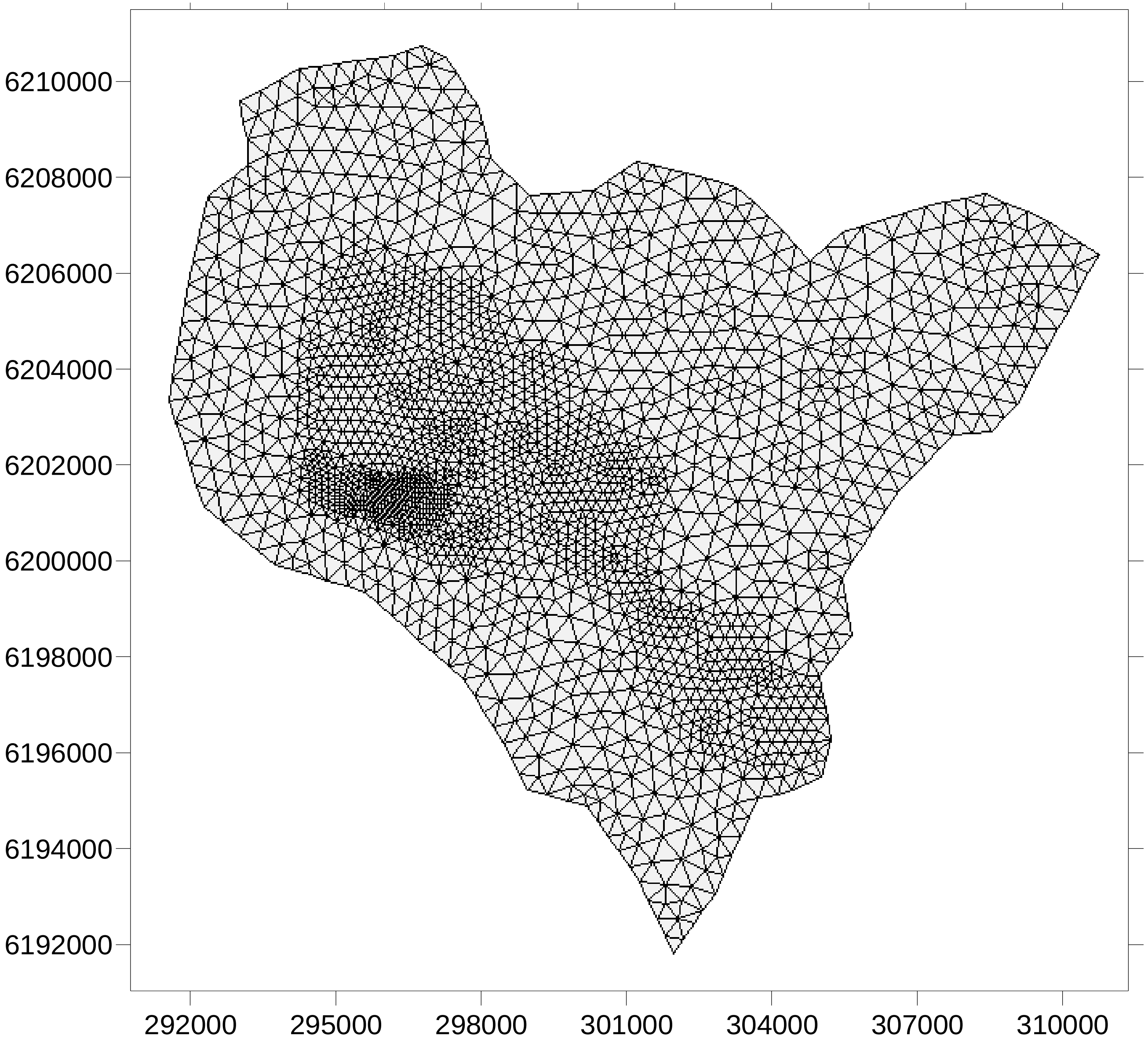
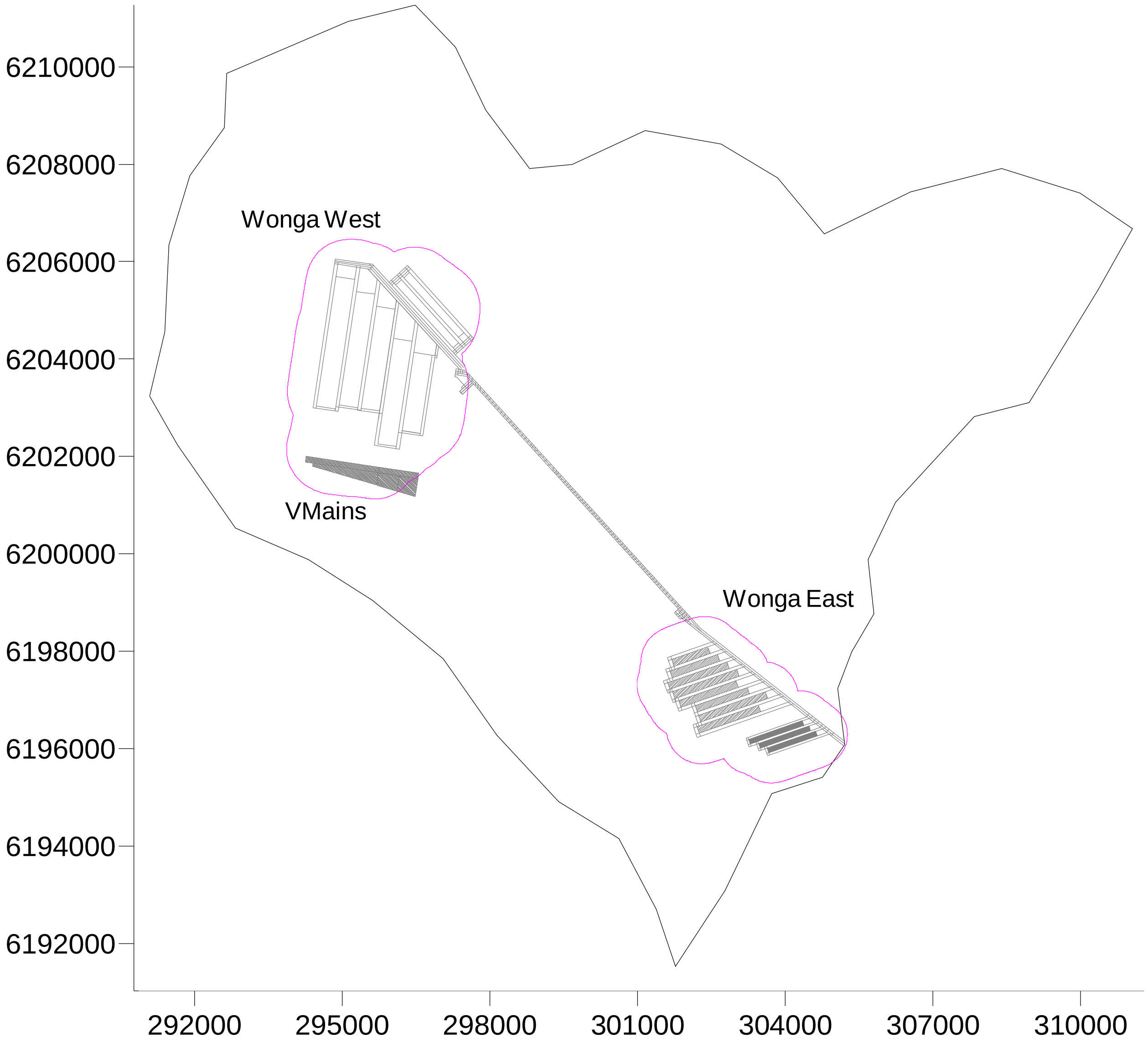


🟦	**Cataract Reservoir**
🟪	**Fault/Dyke**

Golder Associates	CLIENT Gujarat	PROJECT Groundwater Modelling	
	DRAWN SWW / DATE Nov 2011	TITLE **Locations of Faults and Dykes**	
	CHECKED / DATE		
	SCALE As shown	PROJECT No 107636001	FIGURE No 12 / REV No / **A4**



CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE **Model Mesh and Extent**		
CHECKED	DATE			
SCALE As shown		PROJECT No 107636001	FIGURE No 13	REV No	A4



— **Subsidence Zone**

▬ **Proposed Workings**

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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

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DATE

TITLE **Extent of 20mm subsidence over longwall extractions (Seedsman, 2010)**

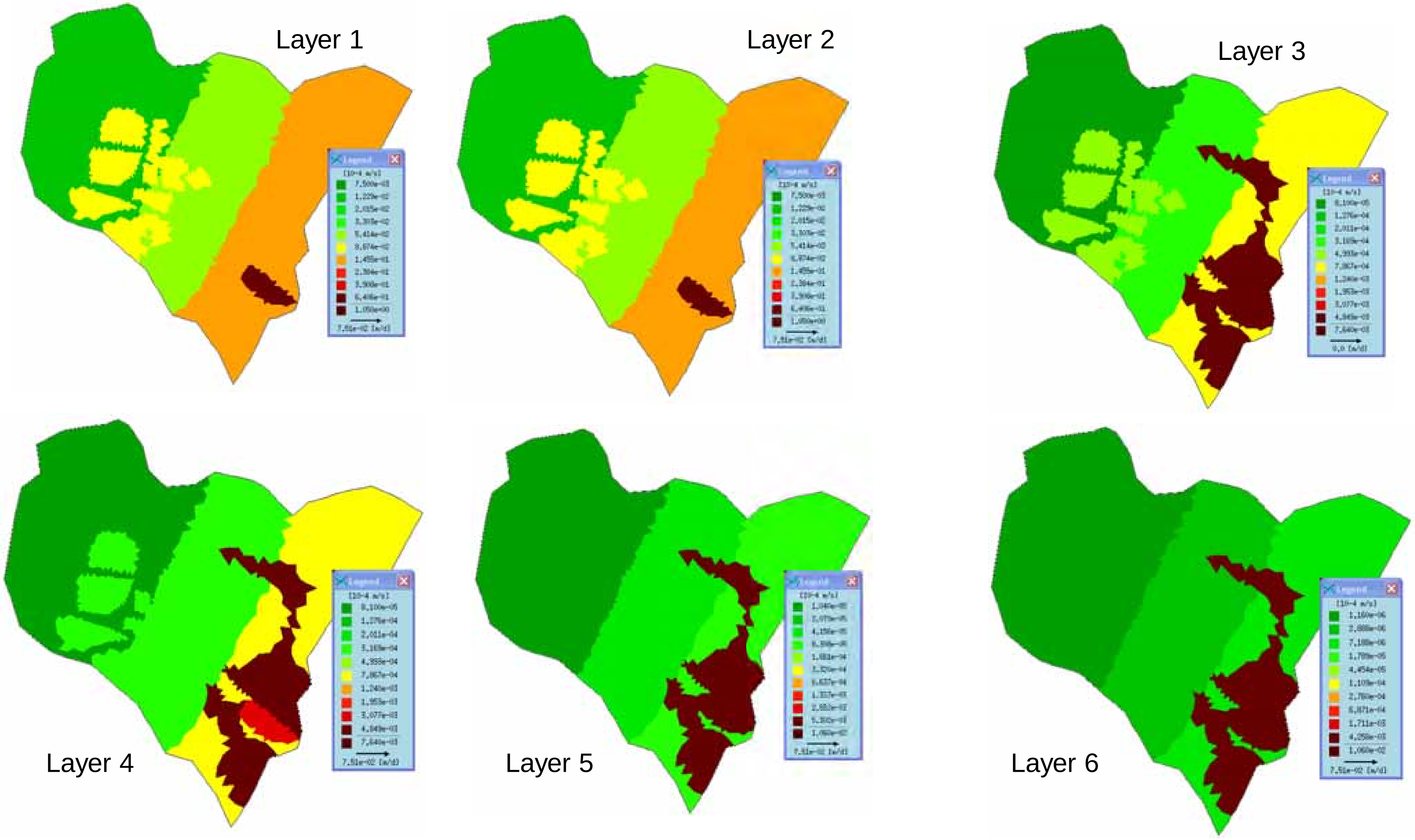
SCALE

PROJECT No 107636001

FIGURE No **14**

REV No

A4



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Groundwater Modelling

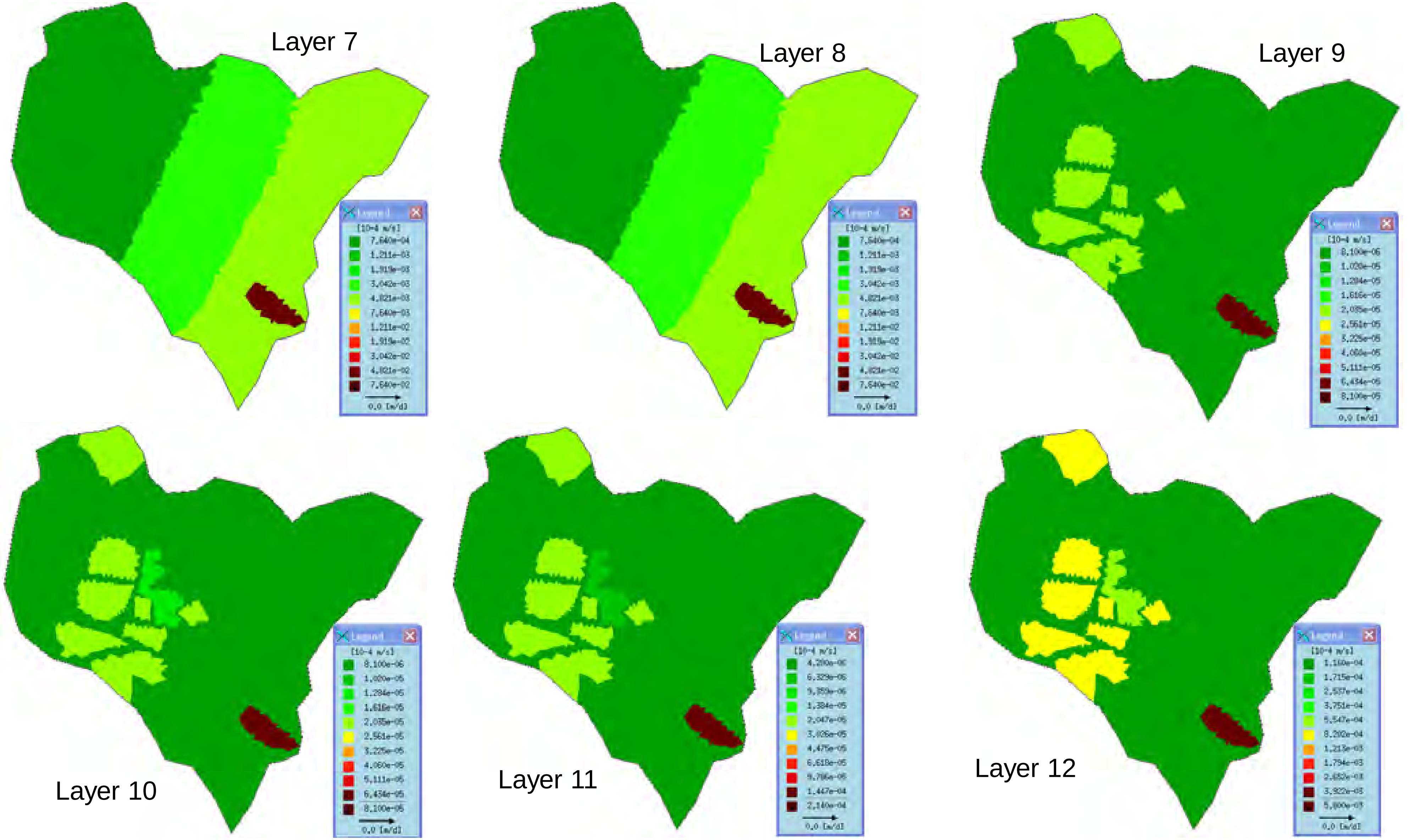
DRAWN SWW
DATE Nov 2011

TITLE
Model Structure Layers 1 to 6

CHECKED
DATE

SCALE
Not to Scale

PROJECT No 107636001
FIGURE No 15
REV No
A4



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Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW
DATE Nov 2011

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DATE

TITLE
Model Structure Layers 7 to 12

SCALE
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PROJECT No 107636001
FIGURE No **16**
REV No
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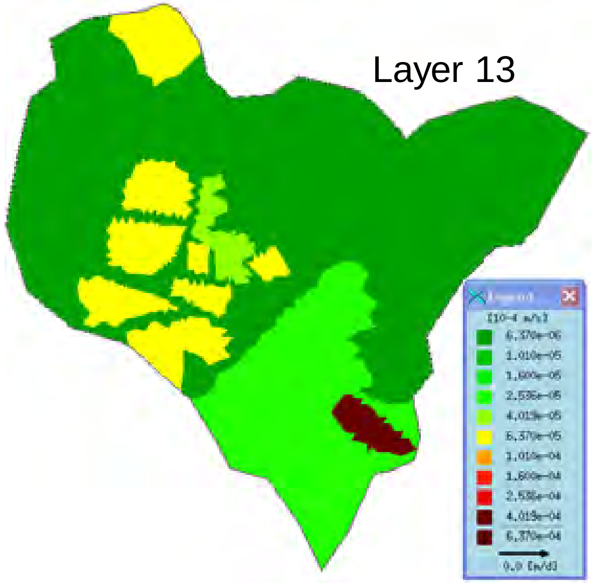
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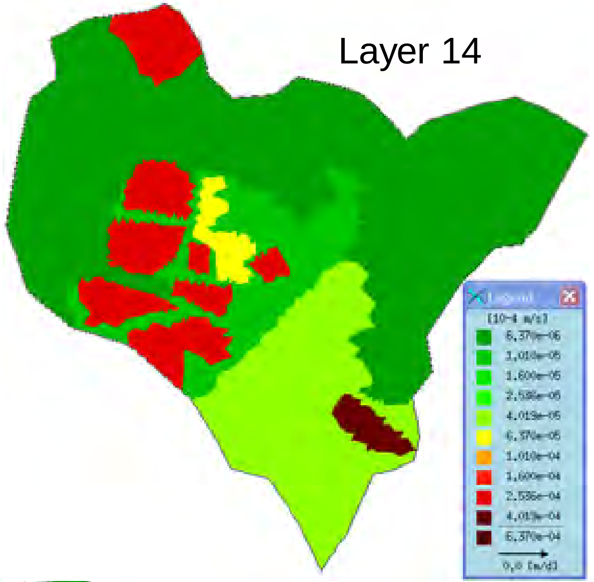
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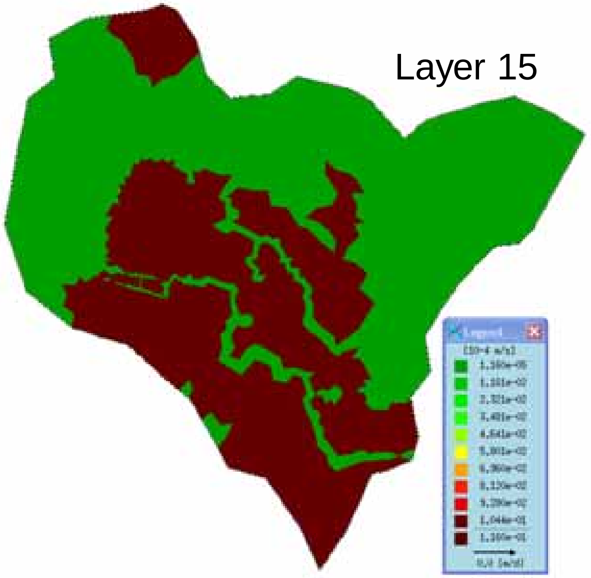
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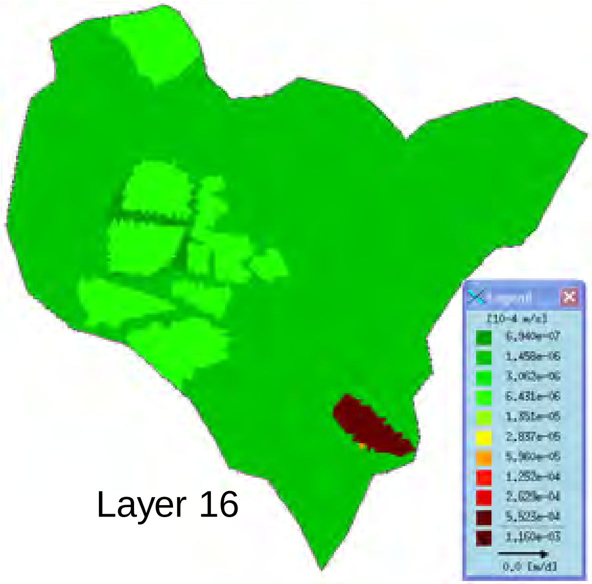
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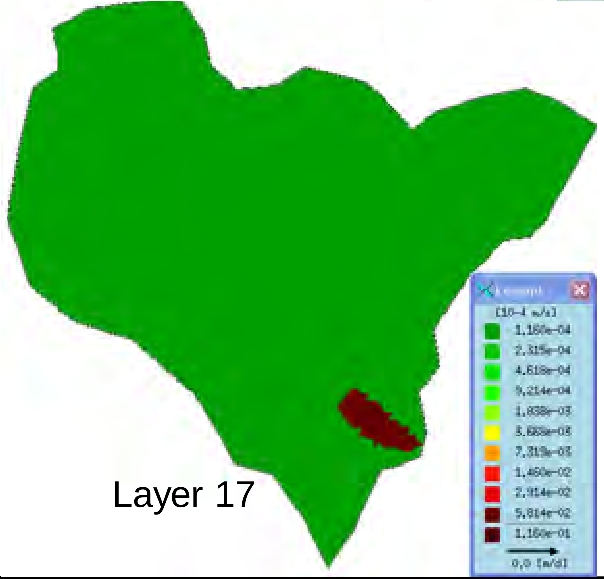
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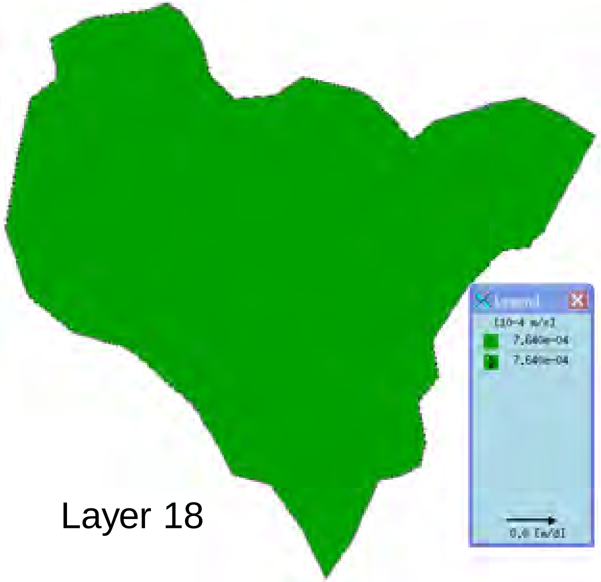
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CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE **Model Structure Layers 13 to 18**

SCALE Not to Scale

PROJECT No 107636001

FIGURE No **17**

REV No

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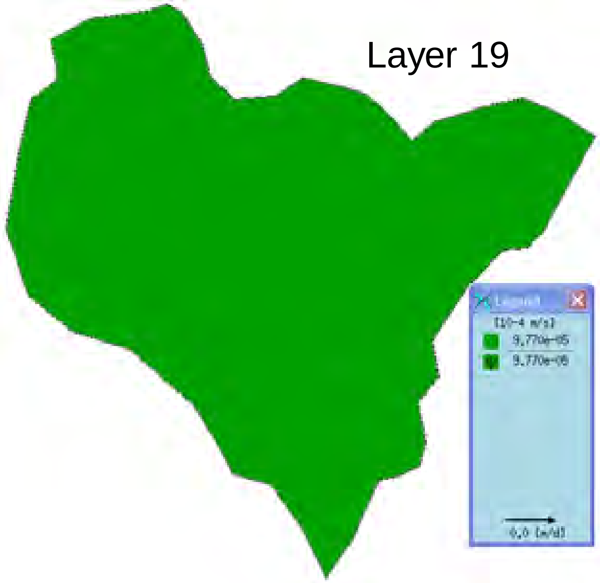
Layer 19



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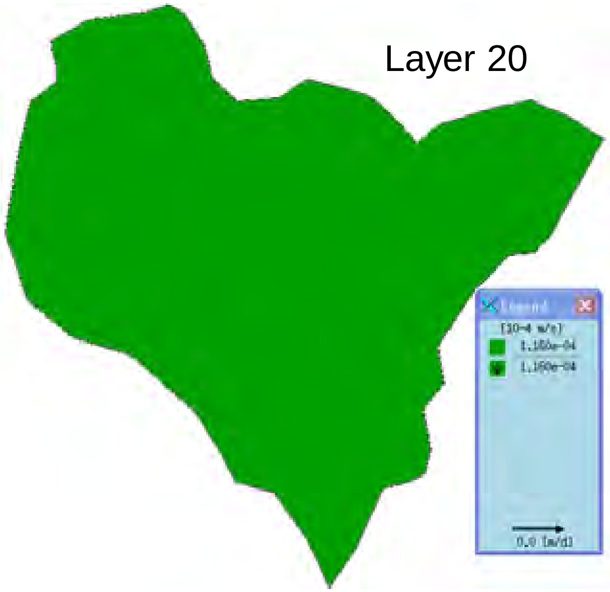

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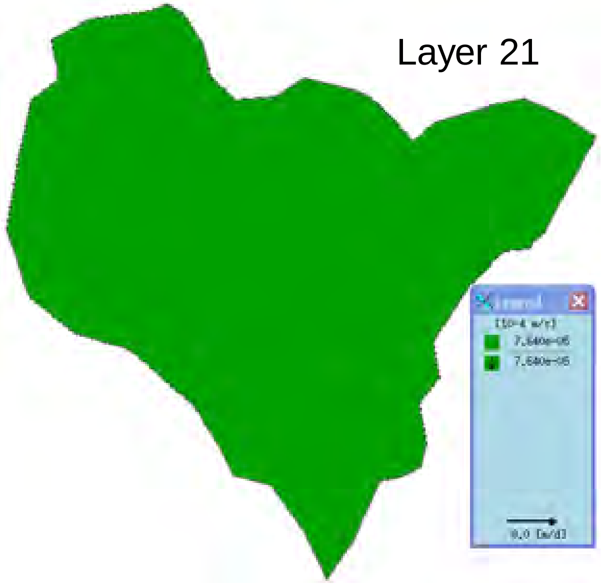
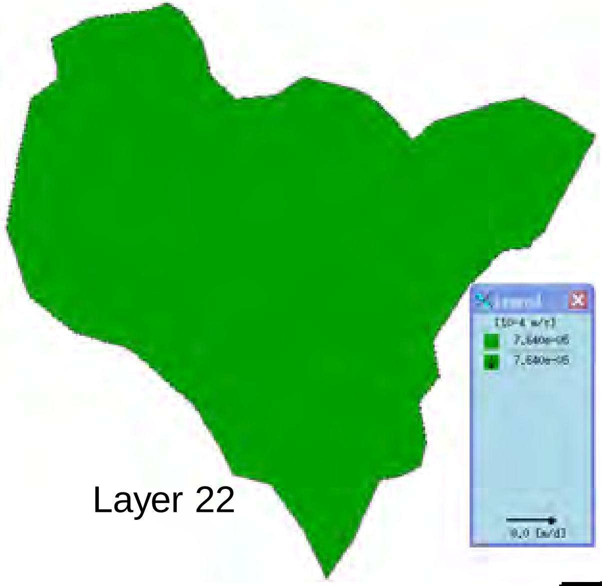
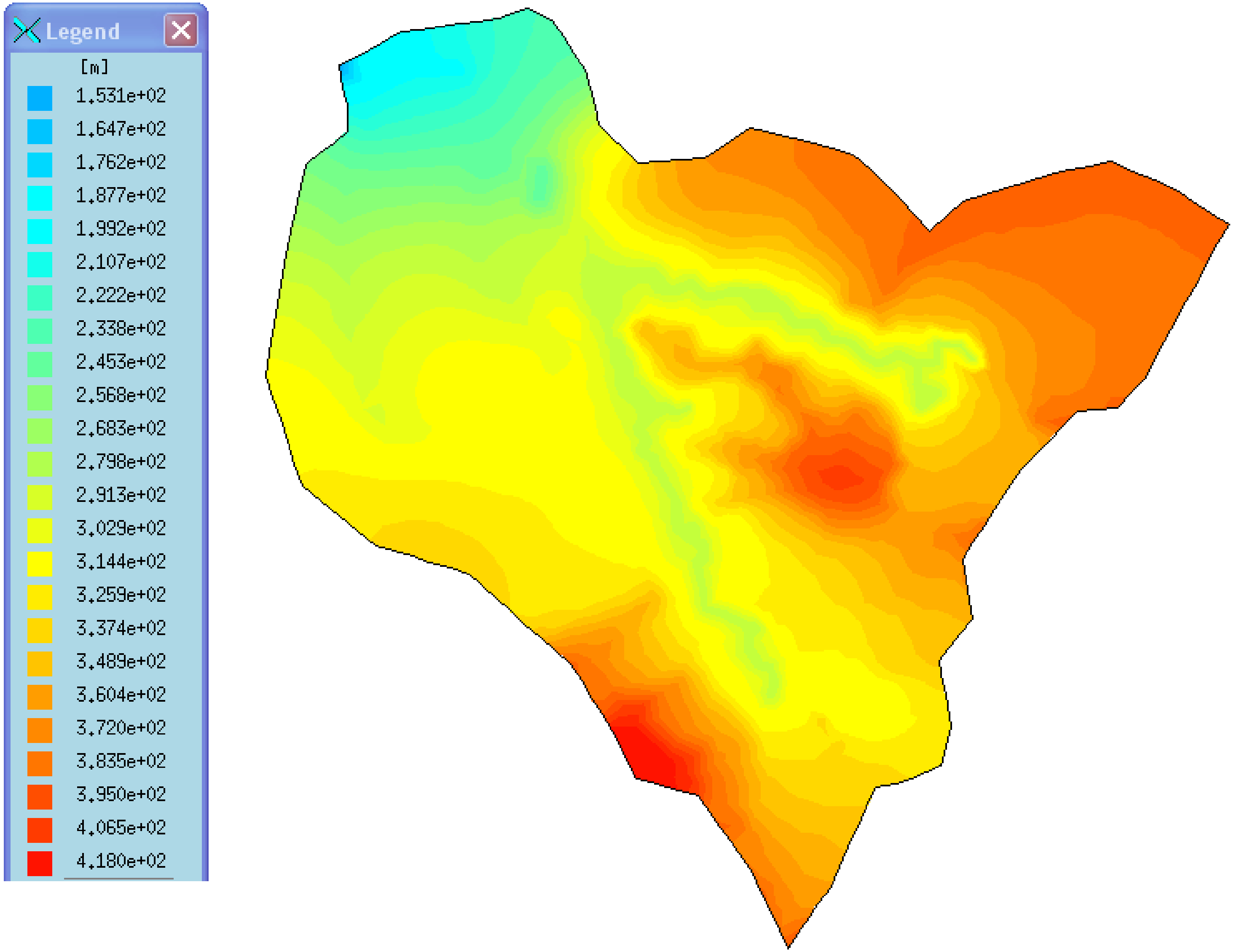


Layer 22



Golder Associates

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE **Model Structure Layers 19 to 22**	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No **18** REV No **A4**



CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE **Initial Groundwater Heads (mAHD)**

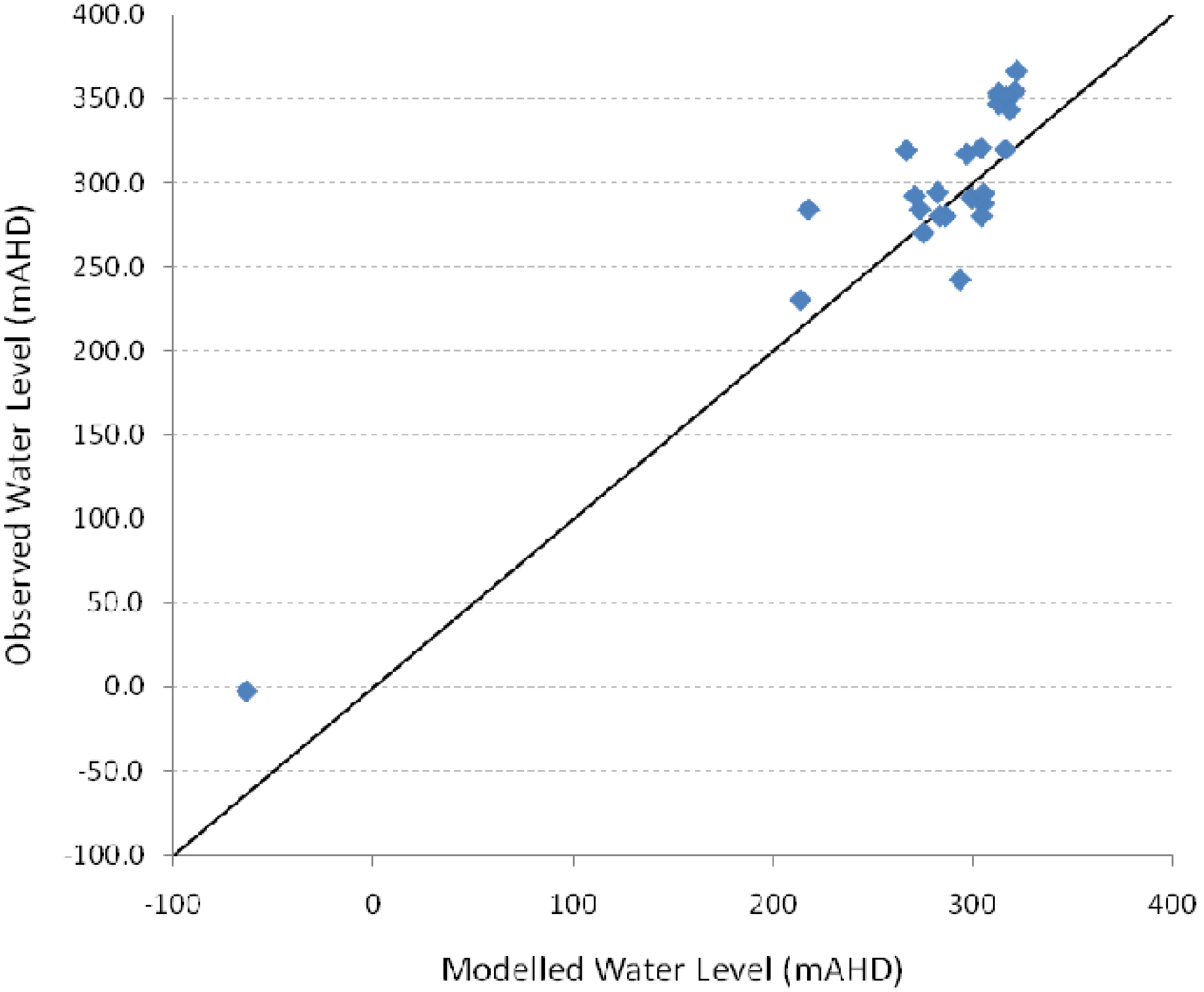
SCALE Not to Scale

PROJECT No 107636001

FIGURE No **19**

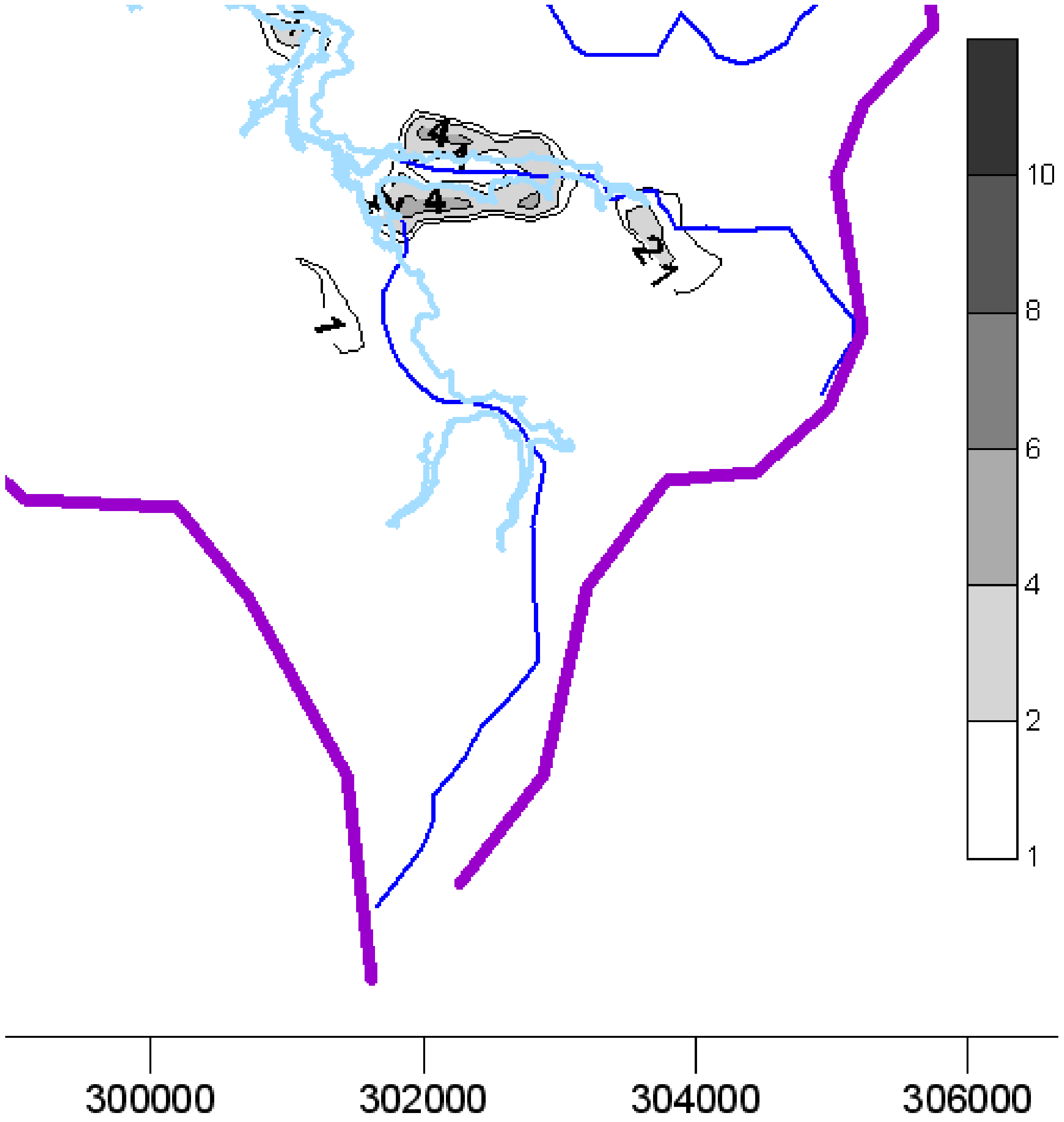
REV No

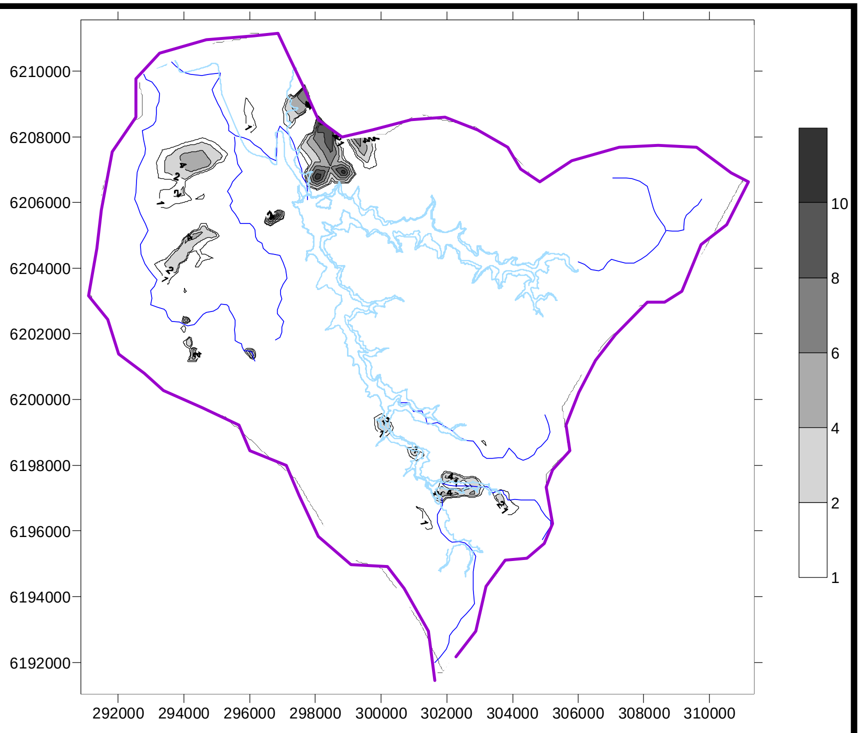
A4



CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE **Calibration Results**		
CHECKED	DATE			
SCALE Not to Scale		PROJECT No 107636001	FIGURE No **20**	REV No	**A4**

Golder Associates





Golder Associates

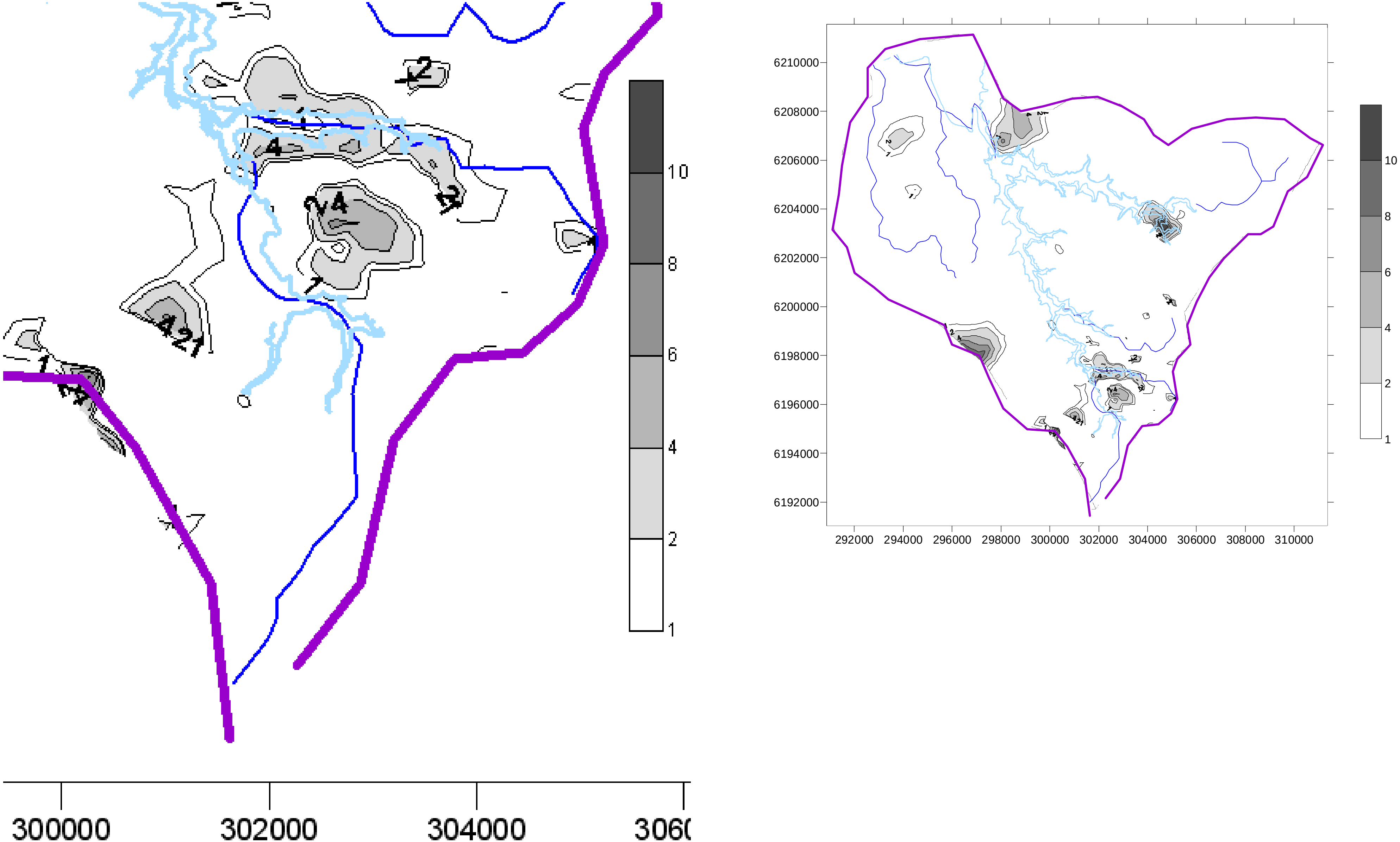
CLIENT
Gujarat

DRAWN SWW
DATE Nov 2011
CHECKED
DATE
SCALE As shown

PROJECT
Groundwater Modelling

TITLE
End Of Stage 1 Drawdown (m)
in Upper Hawkesbury Sandstone

PROJECT No 107636001
FIGURE No 21
REV No
A4



Golder Associates

CLIENT Gujarat

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

SCALE As shown

PROJECT Groundwater Modelling

TITLE End Of Stage 1 Drawdown (m)
In Lower Hawkesbury Sandstone

PROJECT No 107636001

FIGURE No 22

REV No

A4

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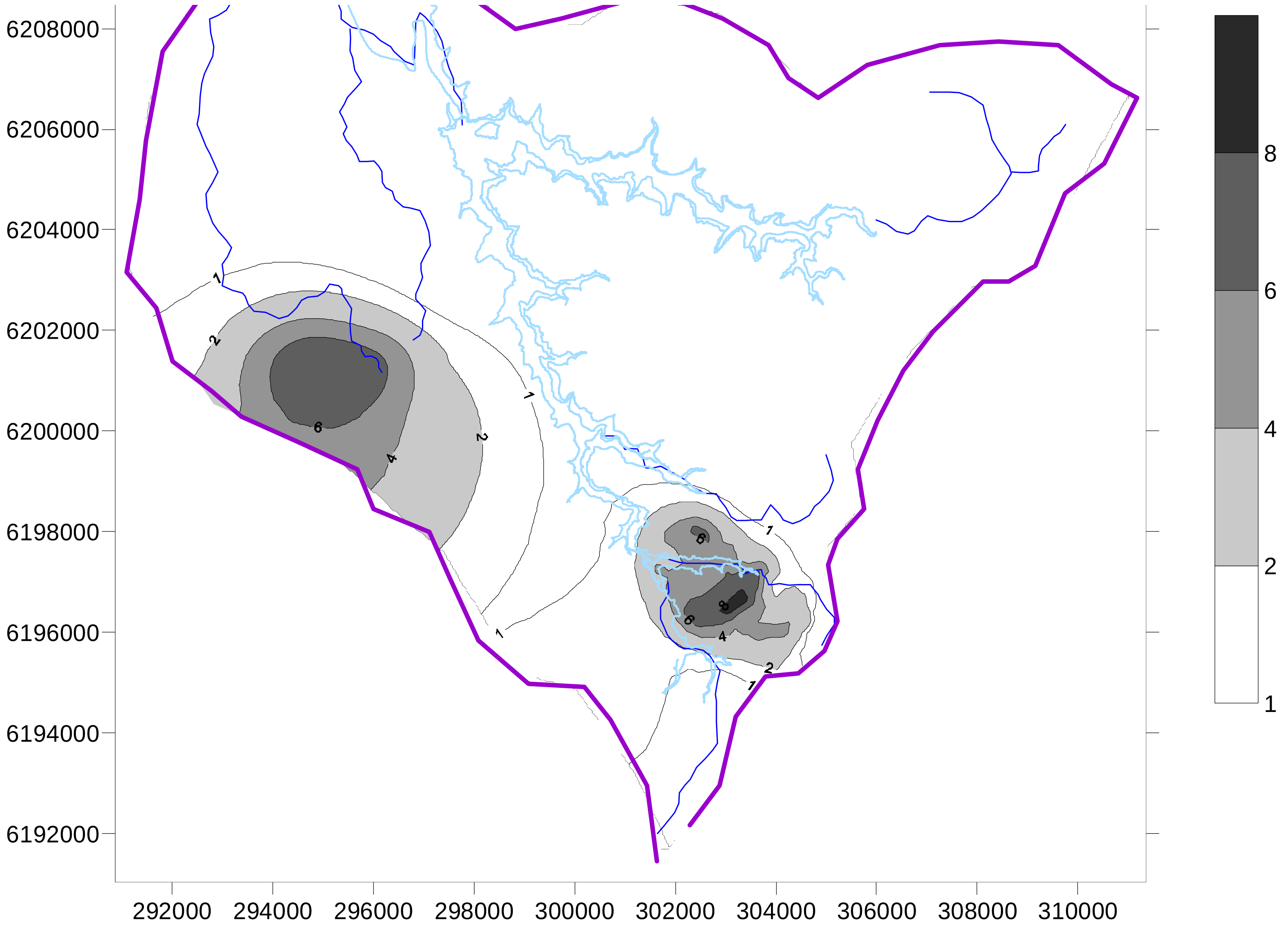
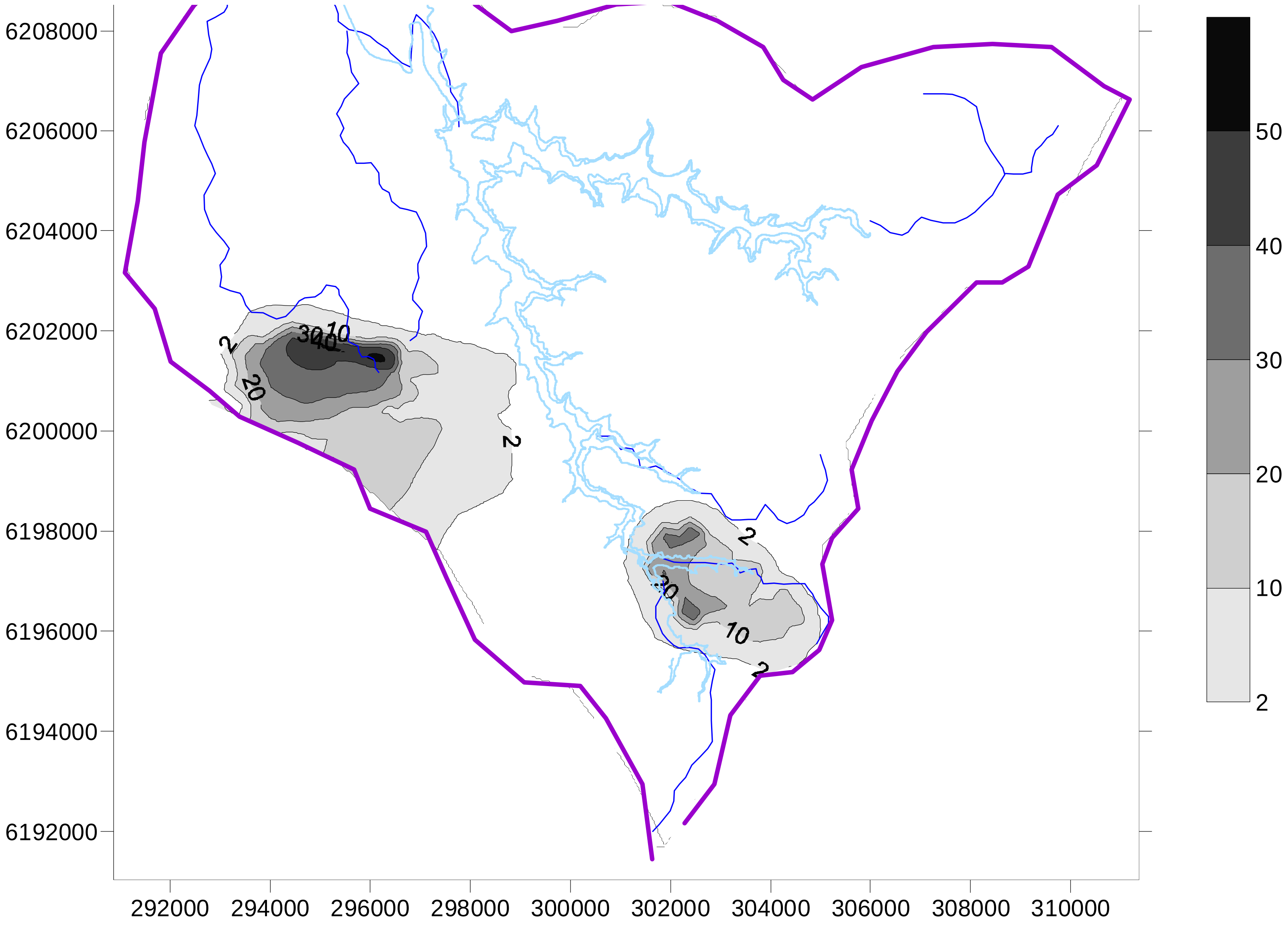
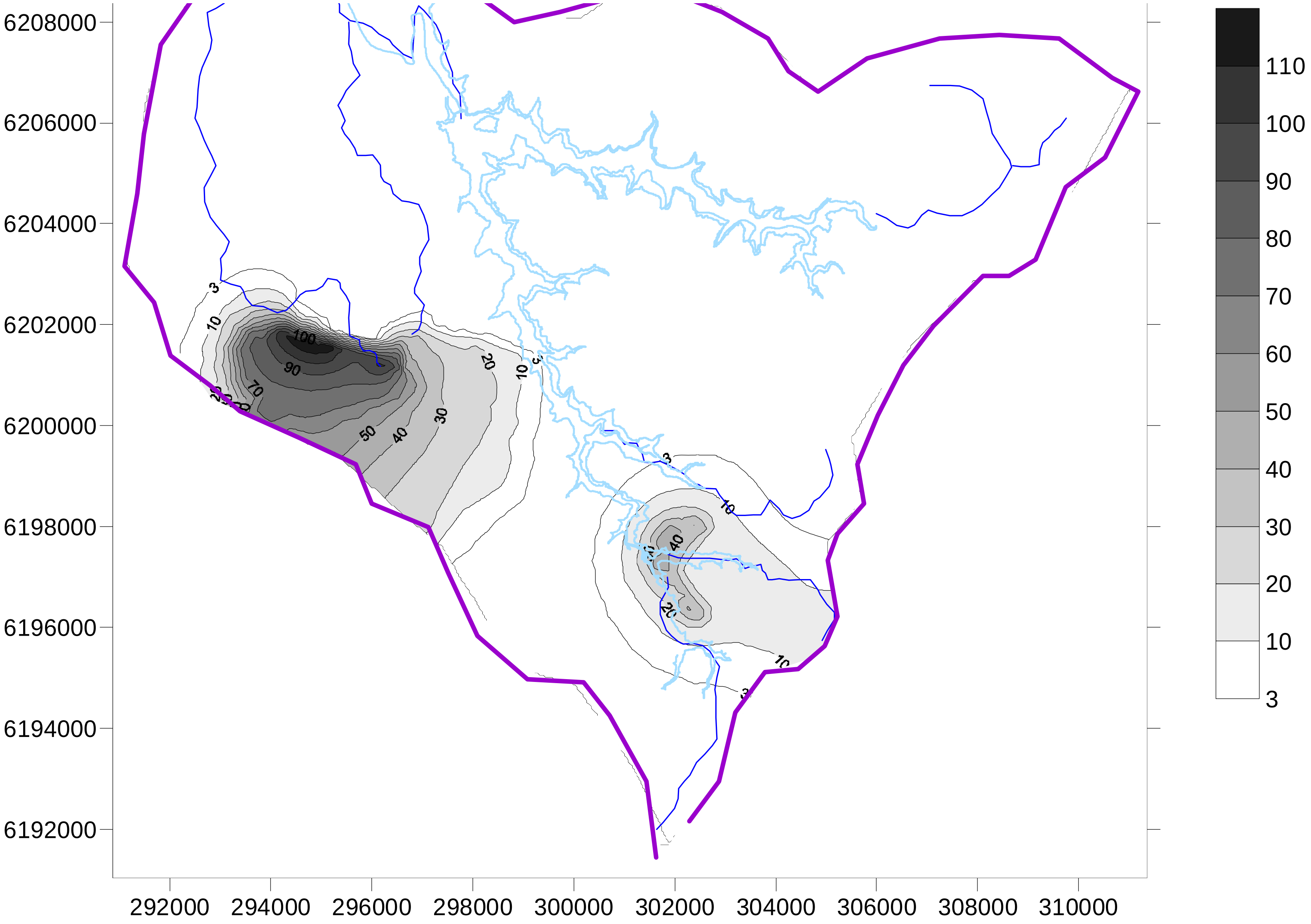


CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 1 Drawdown (m) in Upper Bulgo Sandstone		
CHECKED	DATE			
SCALE As shown		PROJECT No 107636001	FIGURE No 23	REV No A4



CLIENT Gujarat			PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011		TITLE End Of Stage 1 Drawdown (m) in Lower Bulgo Sandstone		
CHECKED	DATE				
SCALE As shown			PROJECT No 107636001	FIGURE No 24	REV No

A4



Golder Associates

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 1 Drawdown (m) In Scarborough Sandstone	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 25 · REV No · A4

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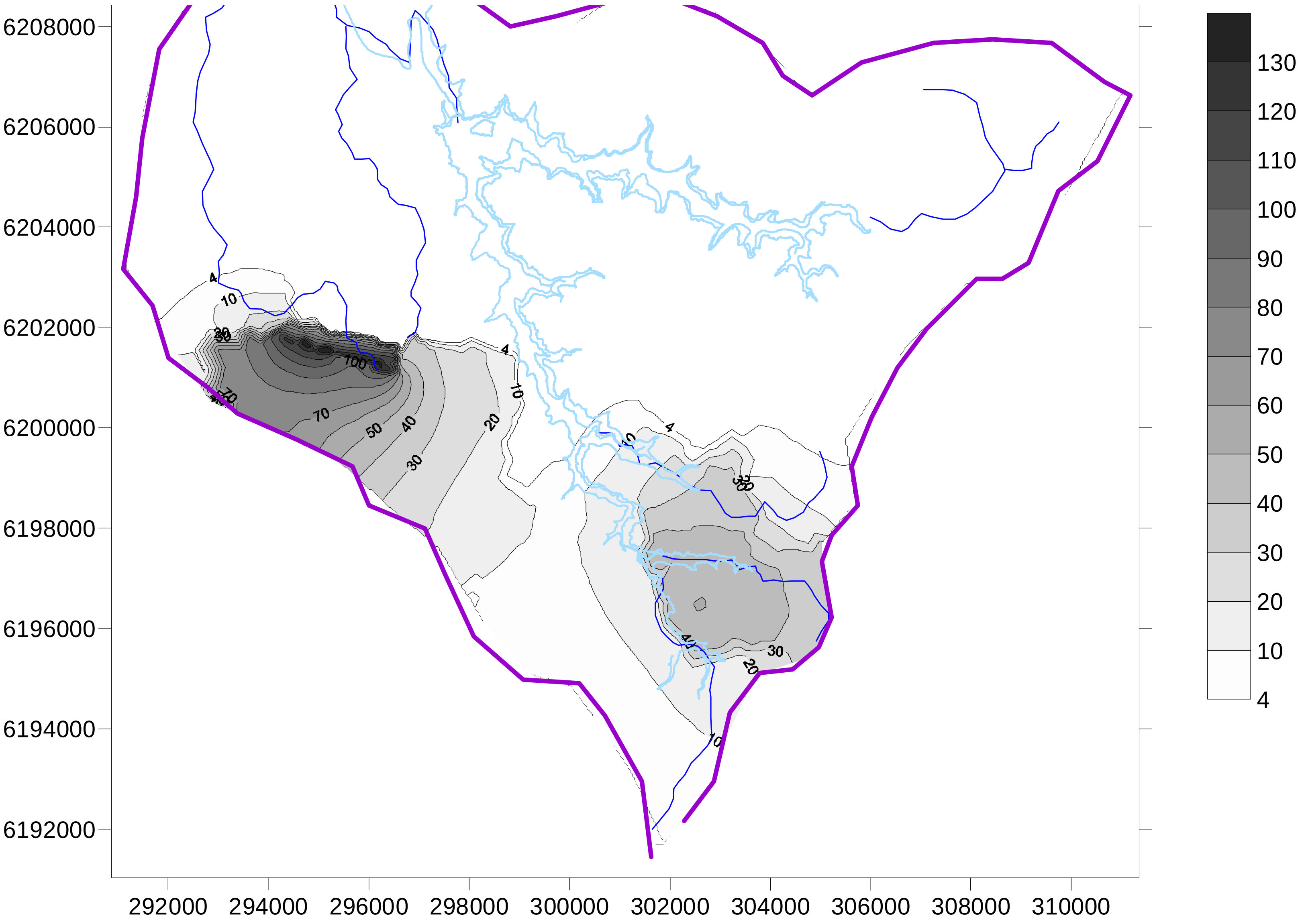


CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW
DATE Nov 2011

CHECKED
DATE

TITLE
End Of Stage 1 Drawdown (m)
In Bulli Coal Seam

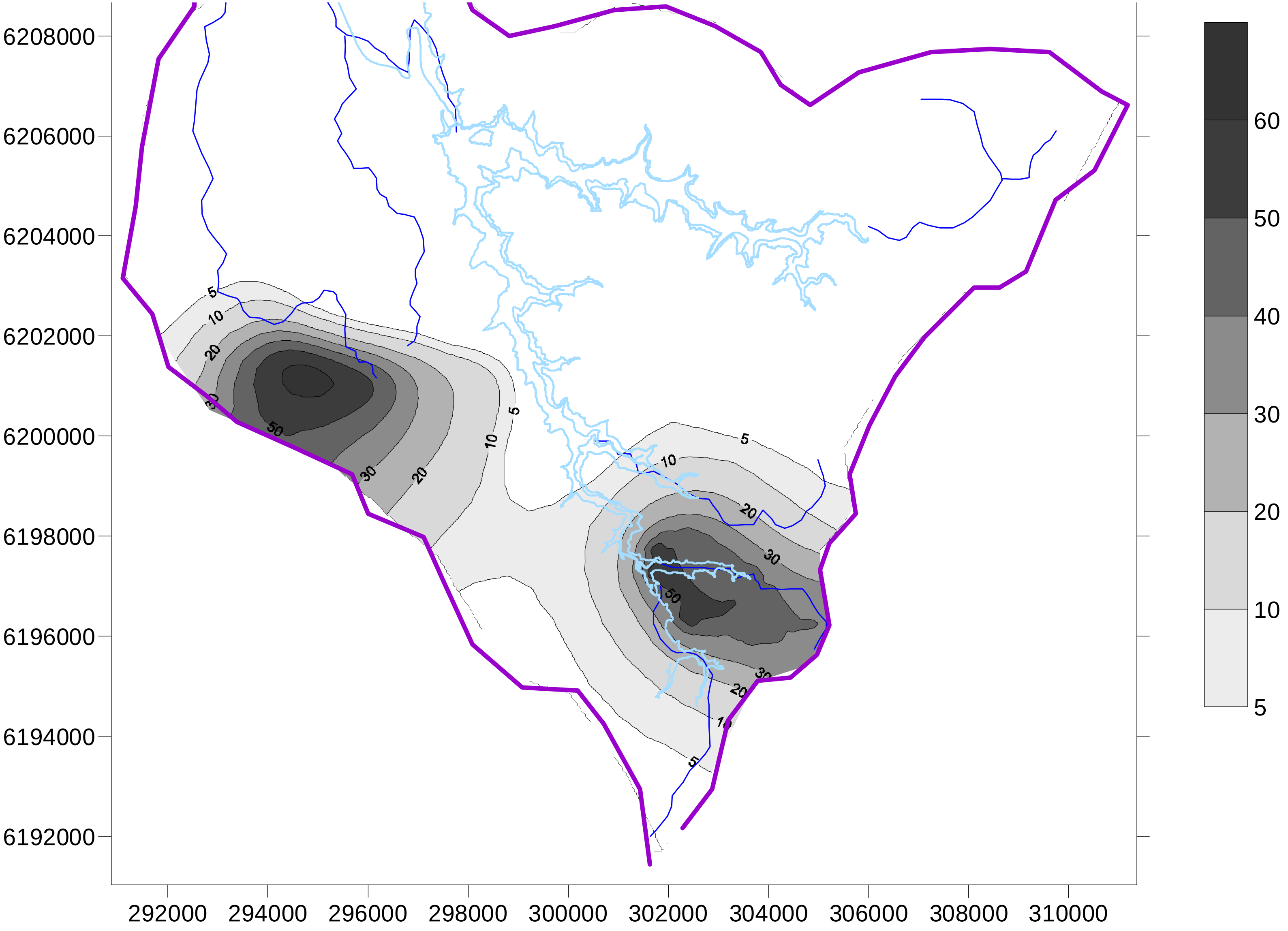
SCALE
As shown

PROJECT No
107636001

FIGURE No
26

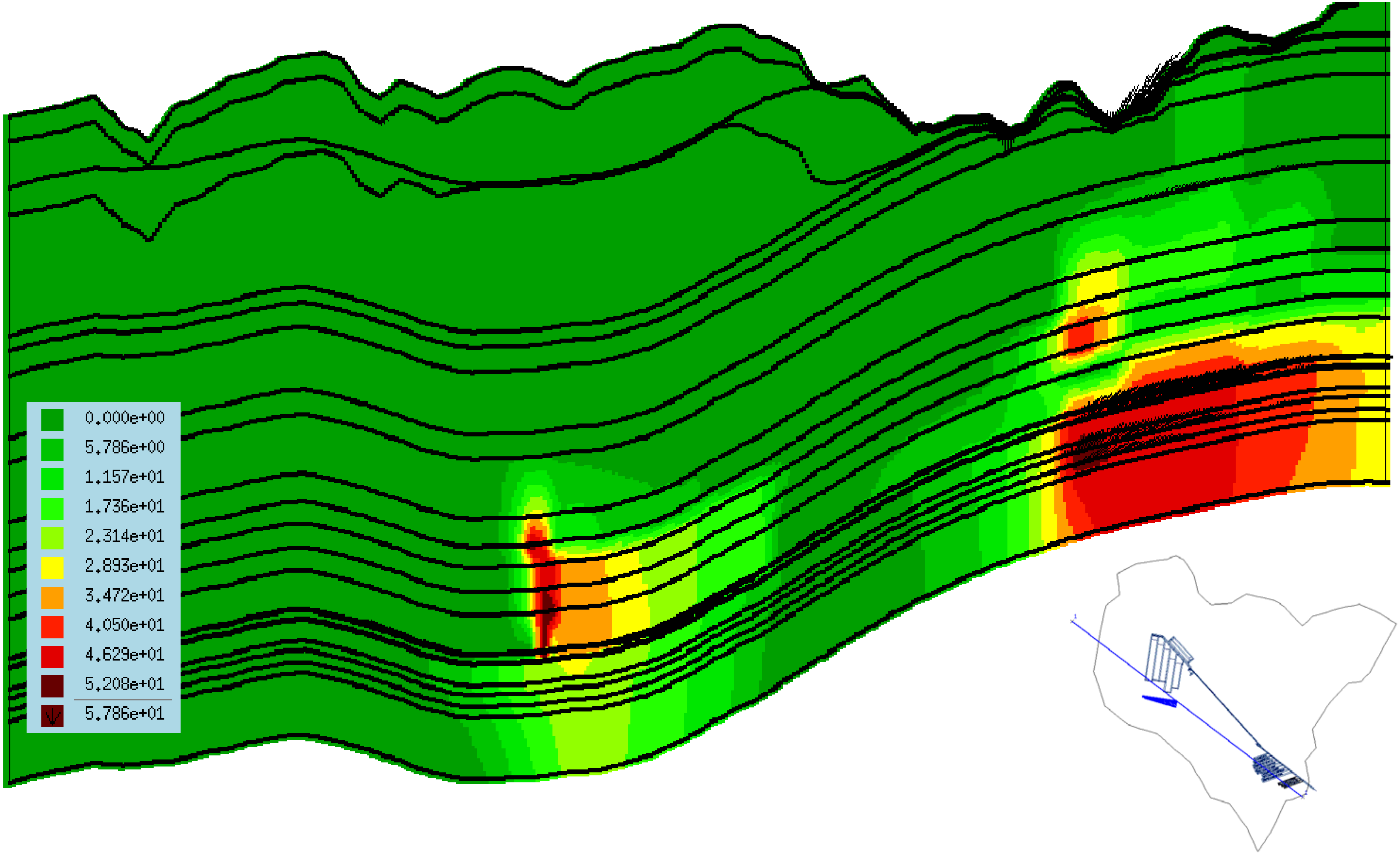
REV No

A4

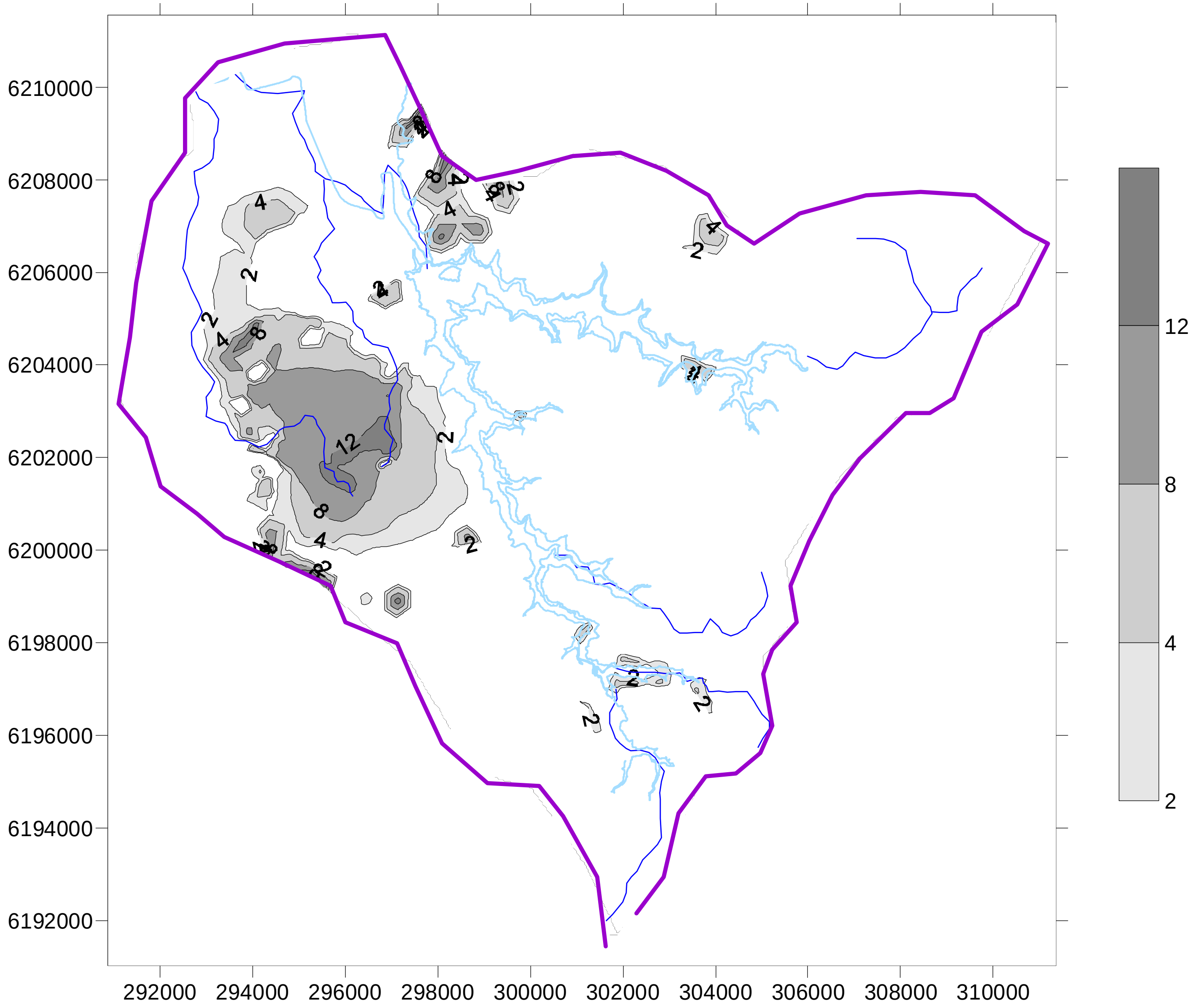


CLIENT Gujarat		PROJECT Groundwater Modelling			
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 1 Drawdown (m) In Wongawilli Coal Seam			
CHECKED	DATE				
SCALE As shown		PROJECT No 107636001	FIGURE No 27	REV No	A4

Golder Associates

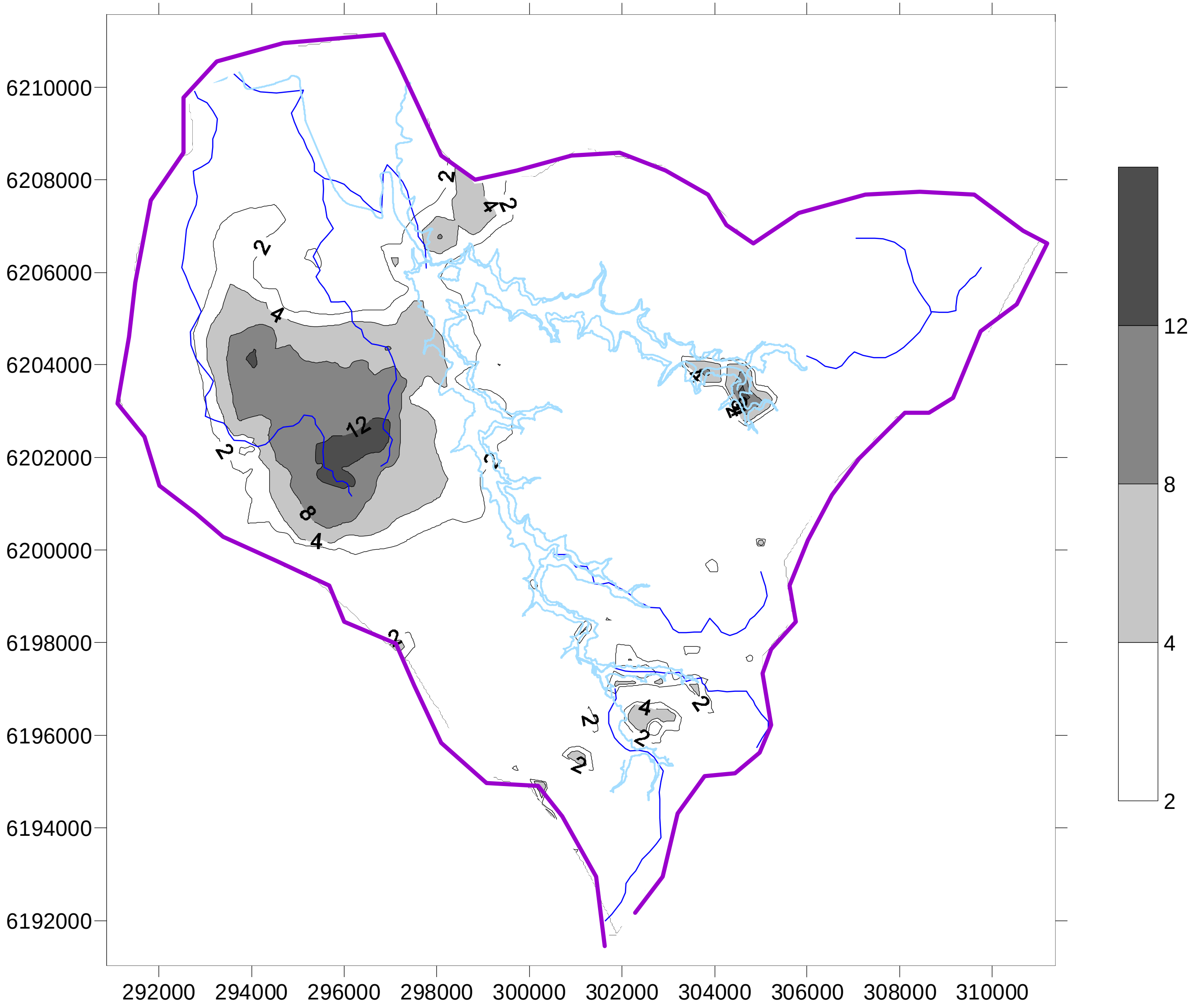


CLIENT	Gujarat	
PROJECT	Groundwater Modelling	
DRAWN	SWW	
DATE	Nov 2011	
CHECKED		
DATE		
TITLE	Stage 1 Drawdown (m) Cross-Section	
SCALE	Not To Scale	
PROJECT No	107636001	
FIGURE No	28	
REV No		
	A4	

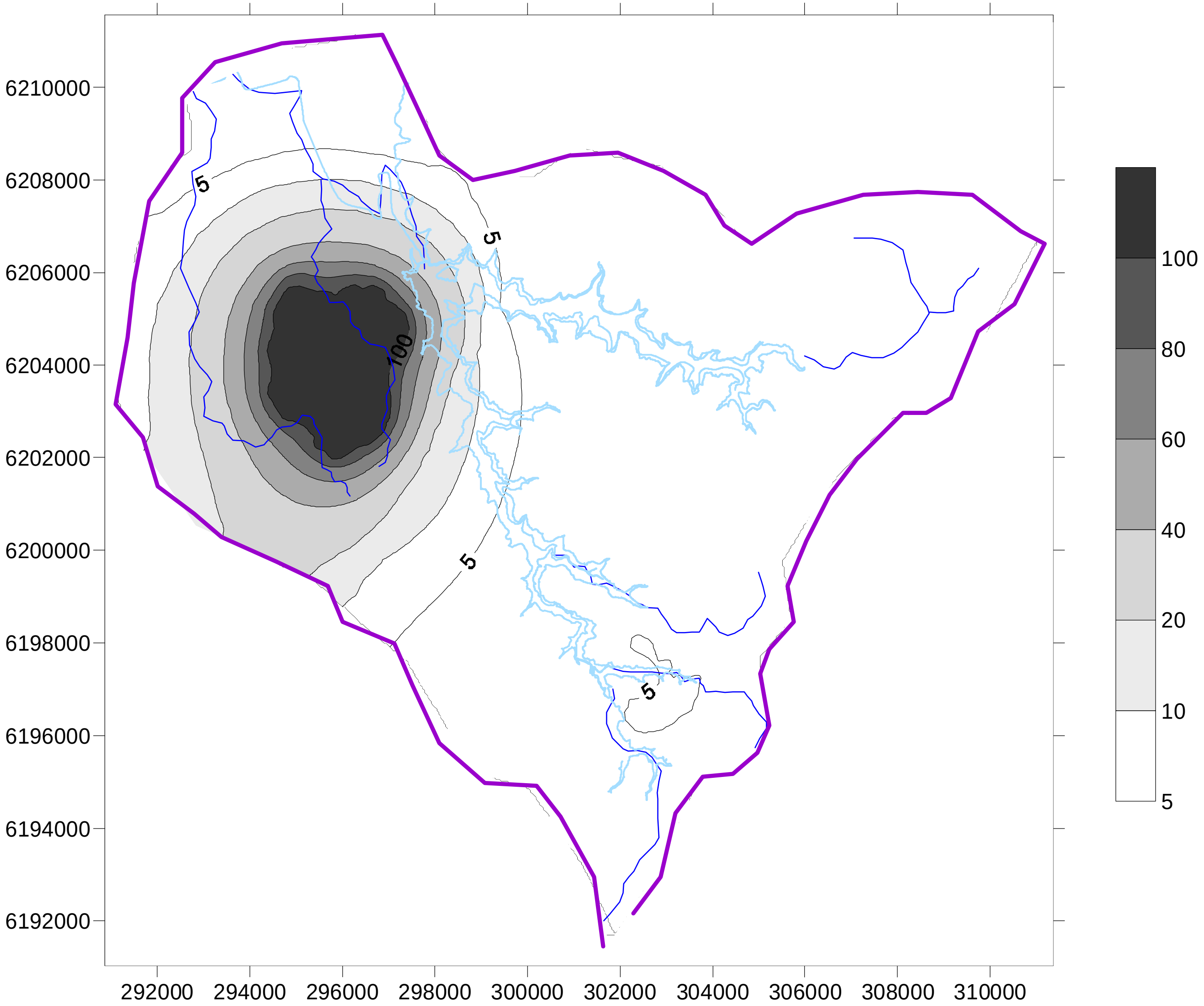


CLIENT		PROJECT		
Gujarat		Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE		
CHECKED	DATE	End Of Stage 2 Drawdown (m) in Upper Hawkesbury Sandstone		
SCALE As shown		PROJECT No 107636001	FIGURE No 29	REV No

A4

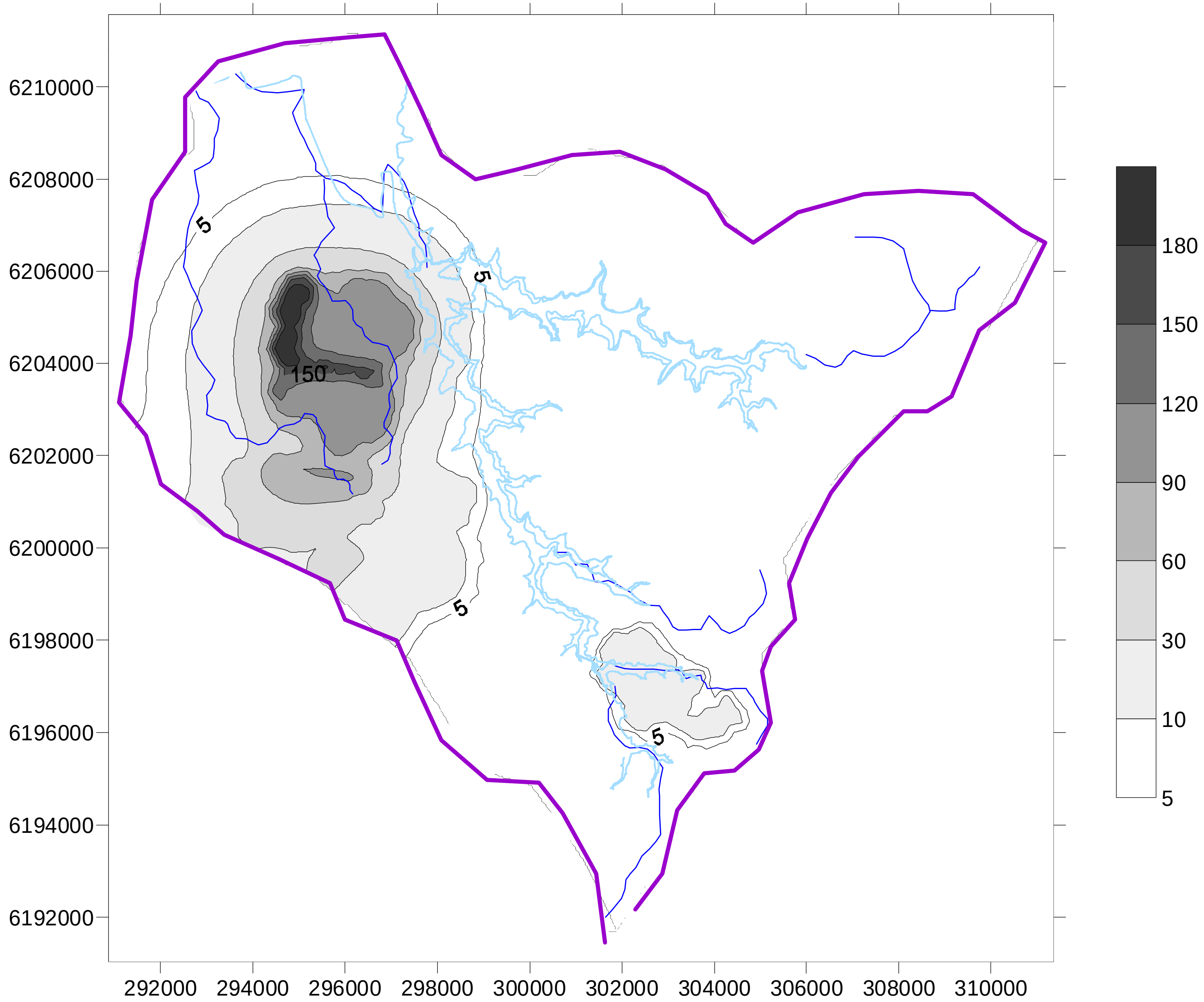


CLIENT Gujarat	PROJECT Groundwater Modelling
DRAWN SWW / DATE Nov 2011	TITLE
CHECKED / DATE	End Of Stage 2 Drawdown (m) In Lower Hawkesbury Sandstone
SCALE As shown	PROJECT No 107636001 / FIGURE No 30 / REV No / A4



CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	End Of Stage 2 Drawdown (m) in Upper Bulgo Sandstone
CHECKED	DATE		
SCALE	As shown	PROJECT No 107636001	FIGURE No 31 / REV No / A4

Golder Associates



CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 2 Drawdown (m) In Lower Bulgo Sandstone		
CHECKED	DATE			
SCALE As shown		PROJECT No 107636001	FIGURE No 32	REV No

A4

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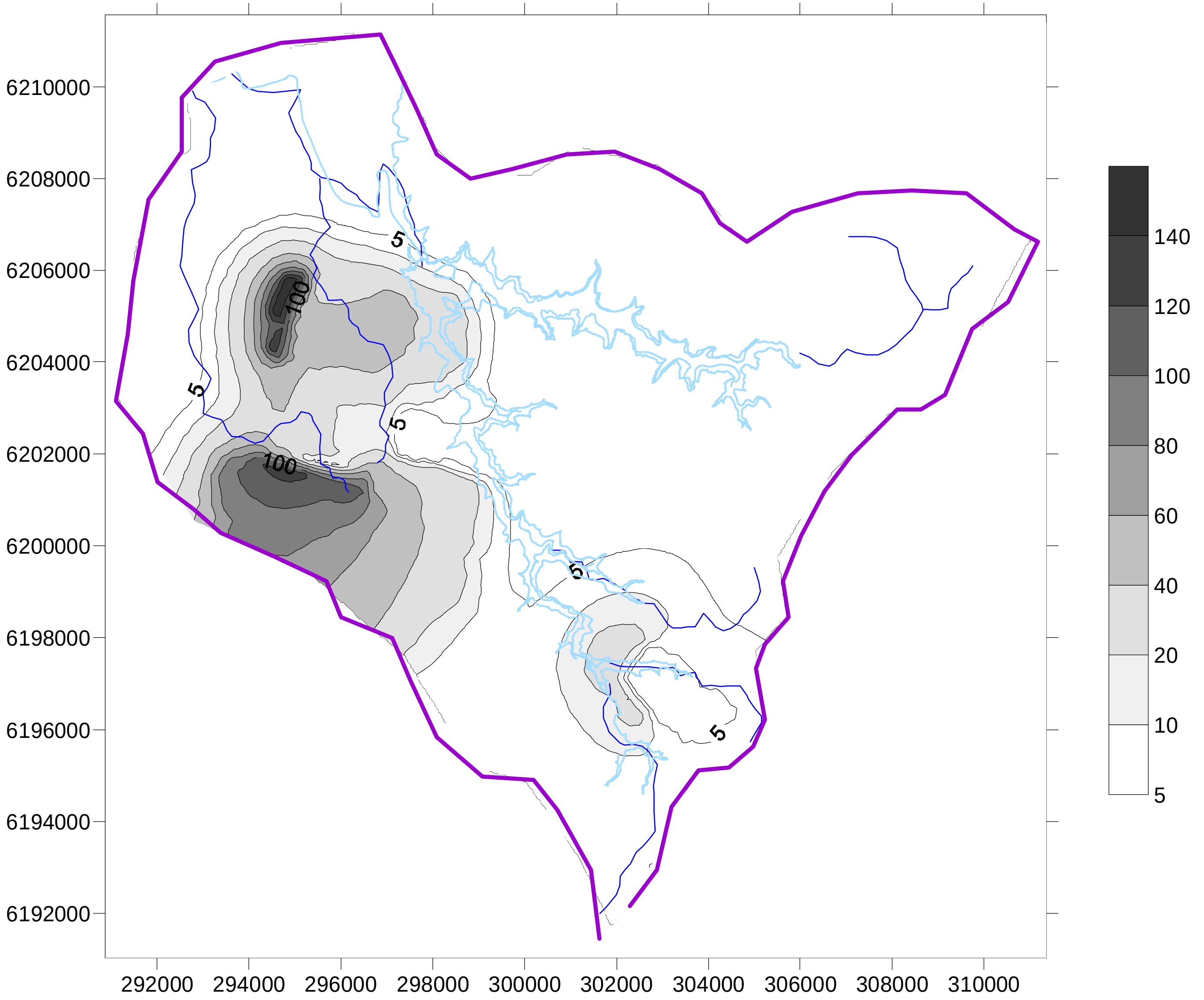
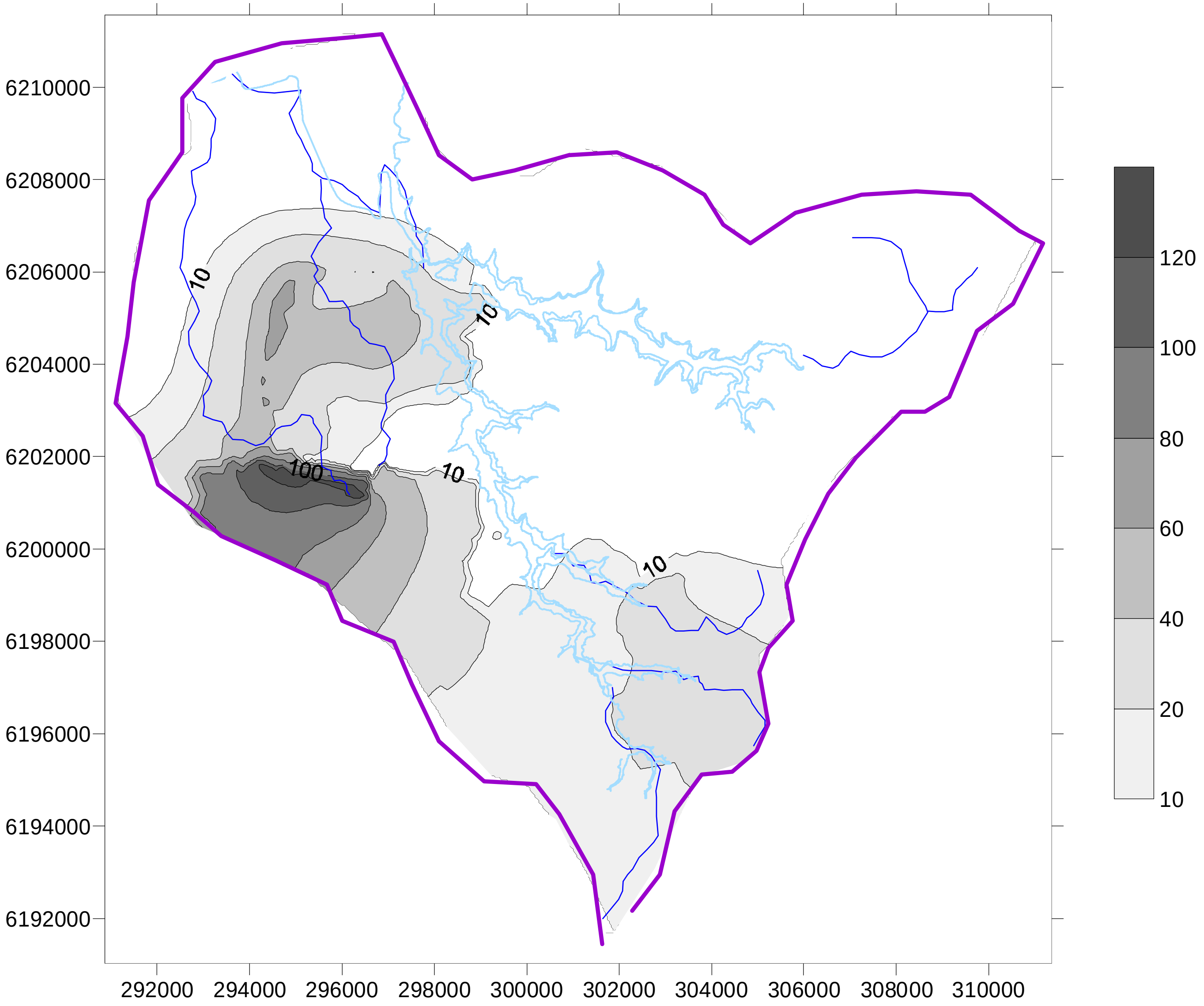
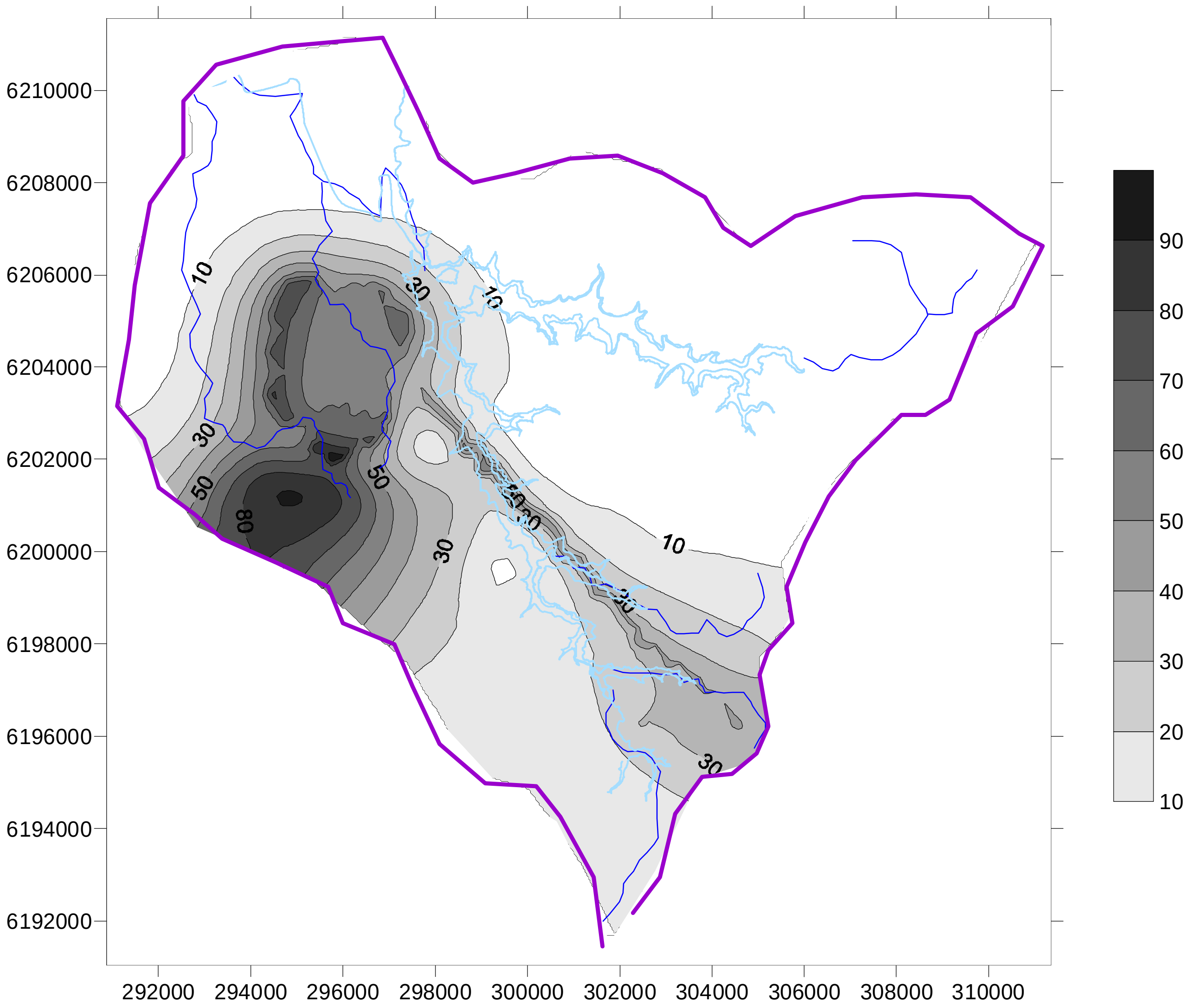


Golder Associates	CLIENT Gujarat			PROJECT Groundwater Modelling		
	DRAWN SWW	DATE Nov 2011		TITLE End Of Stage 2 Drawdown (m) In Scarborough Sandstone		
	CHECKED	DATE				
	SCALE As shown			PROJECT No 107636001	FIGURE No 33	REV No	A4



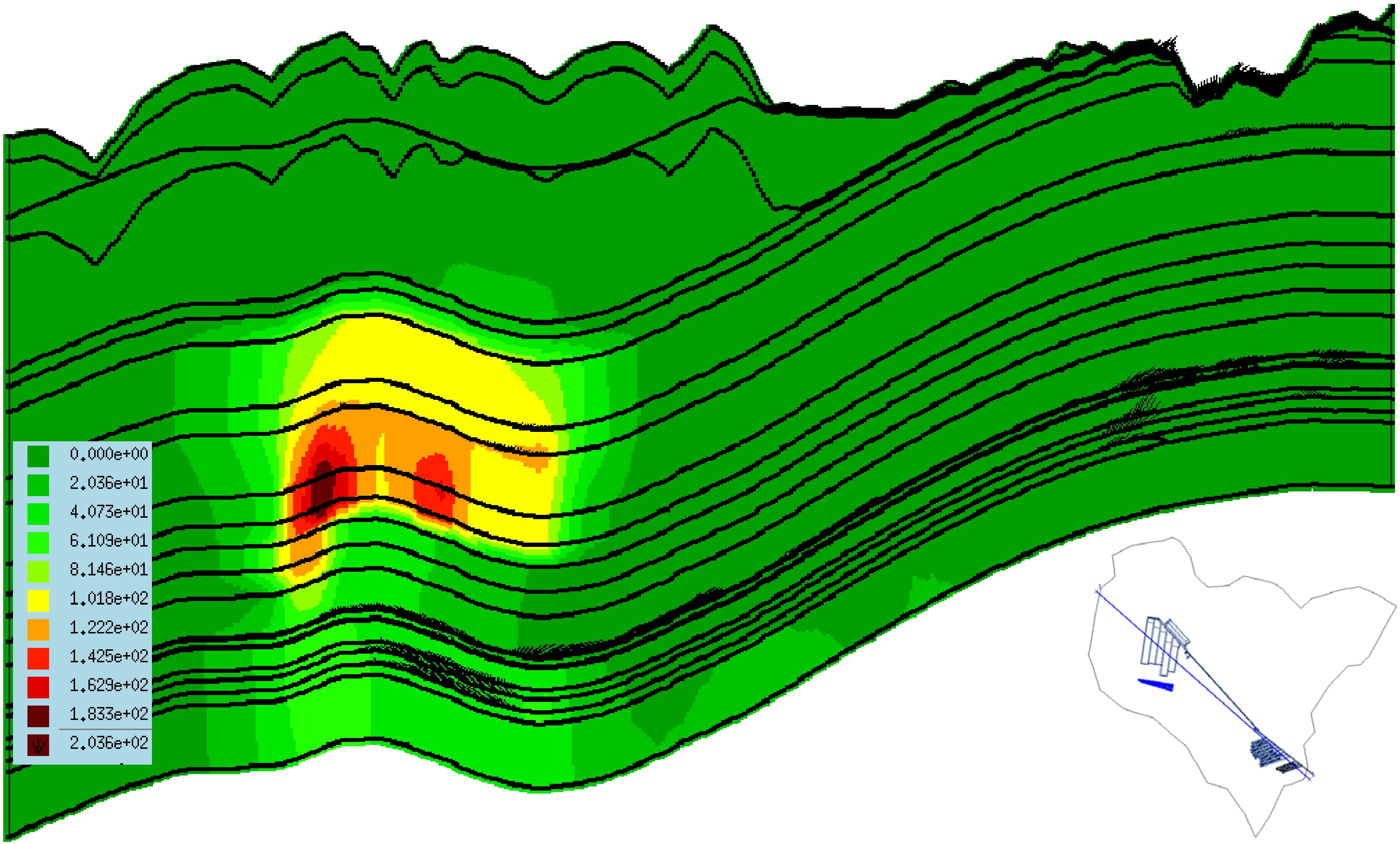
Golder Associates

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE End Of Stage 2 Drawdown (m) In Bulli Coal Seam	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 34
REV No	A4		



CLIENT Gujarat			PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011		TITLE End Of Stage 2 Drawdown (m) In Wongawilli Coal Seam		
CHECKED	DATE				
SCALE As shown			PROJECT No 107636001	FIGURE No 35	REV No	A4

Golder Associates



Golder Associates

CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW

DATE Nov 2011

TITLE
Stage 2 Drawdown (m)
Cross-Section 2

CHECKED

DATE

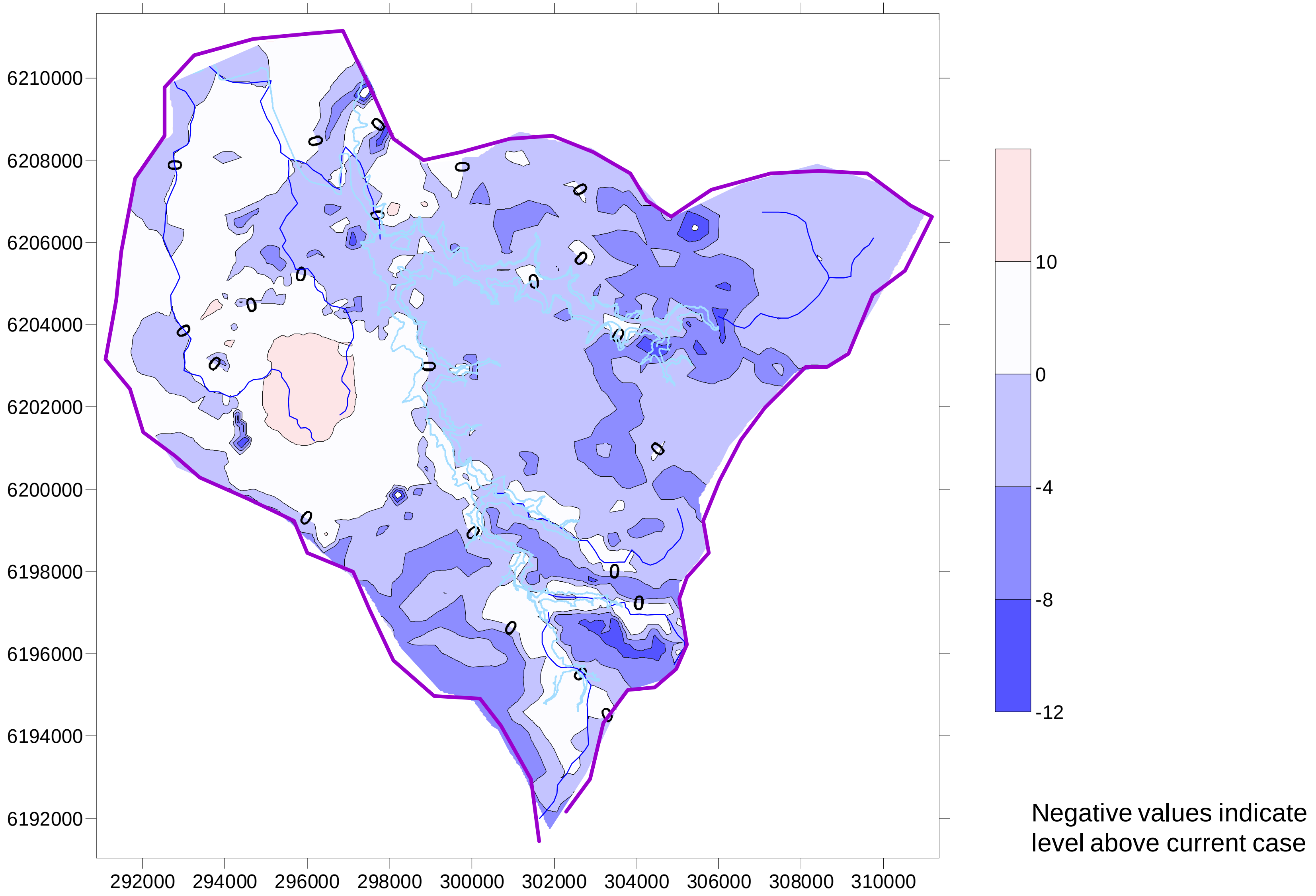
SCALE Not to Scale

PROJECT No 107636001

FIGURE No 36

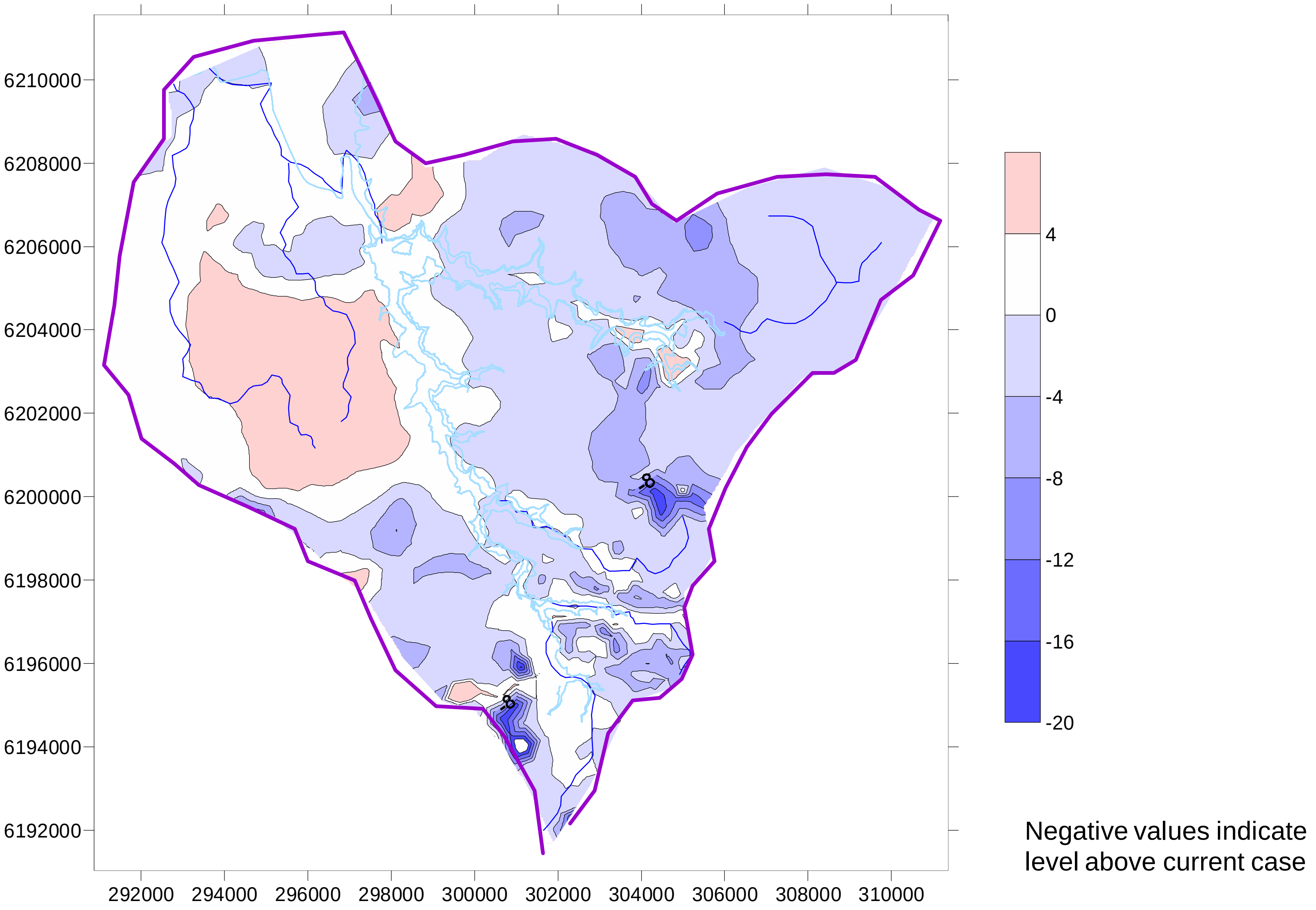
REV No

A4



Negative values indicate level above current case

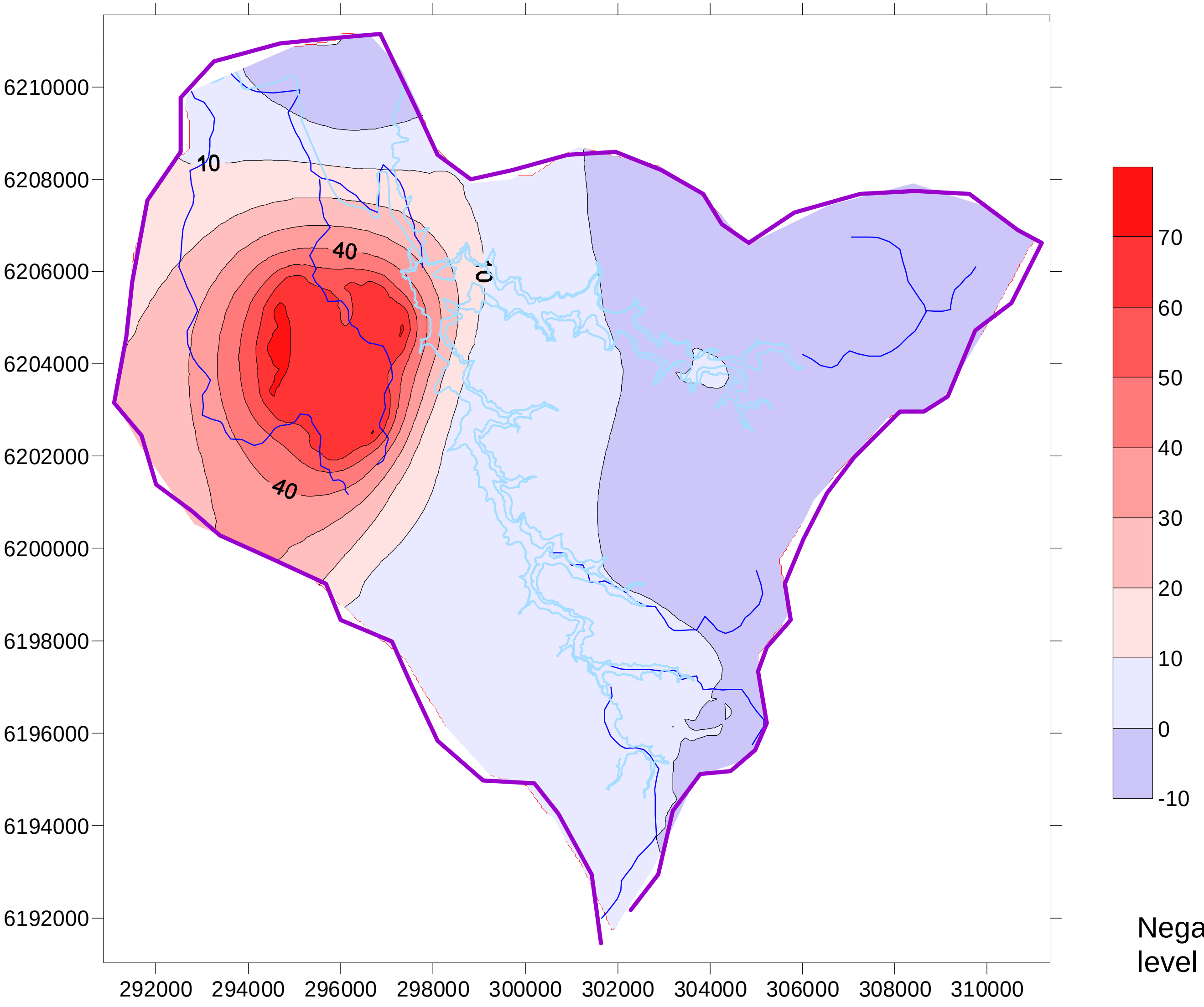
CLIENT		PROJECT			
Gujarat		Groundwater Modelling			
DRAWN SWW	DATE Nov 2011	TITLE Change in Water Levels From Current to 10-Years Post-Mining in Upper Hawkesbury Sandstone (m)			
CHECKED	DATE				
SCALE As shown		PROJECT No 107636001	FIGURE No 37	REV No	A4



Negative values indicate level above current case

CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	Change in Water Levels From Current to 10-Years Post-Mining in Lower Hawkesbury Sandstone (m)
CHECKED	DATE		
SCALE	As shown	PROJECT No 107636001	FIGURE No 38 · REV No · A4

Golder Associates



Negative values indicate level above current case

Golder Associates

CLIENT Gujarat

PROJECT Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE Change in Water Levels From Current to 10-Years Post-Mining in Upper Bulgo Sandstone (m)

SCALE As shown

PROJECT No 107636001

FIGURE No 39

REV No

A4

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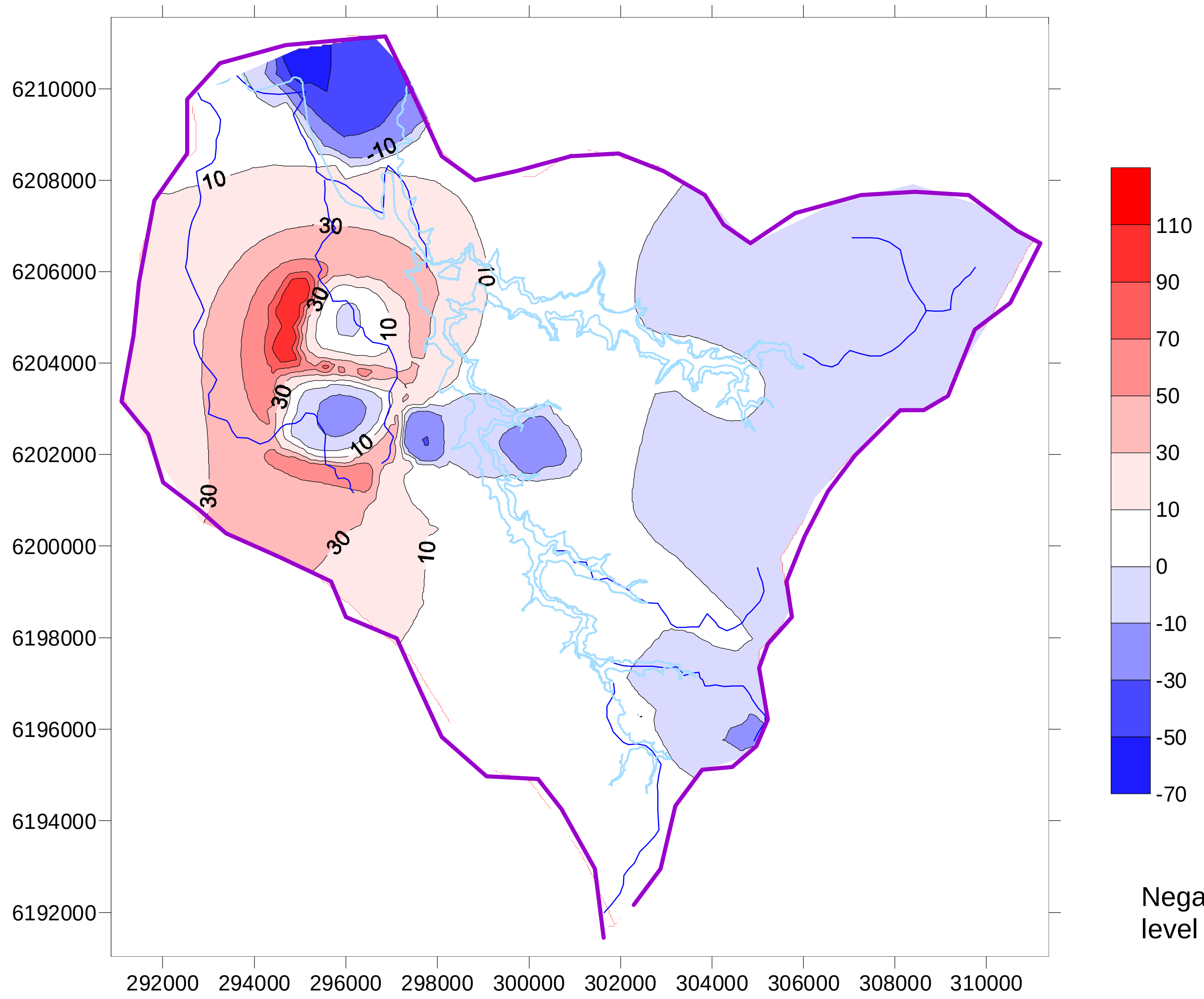
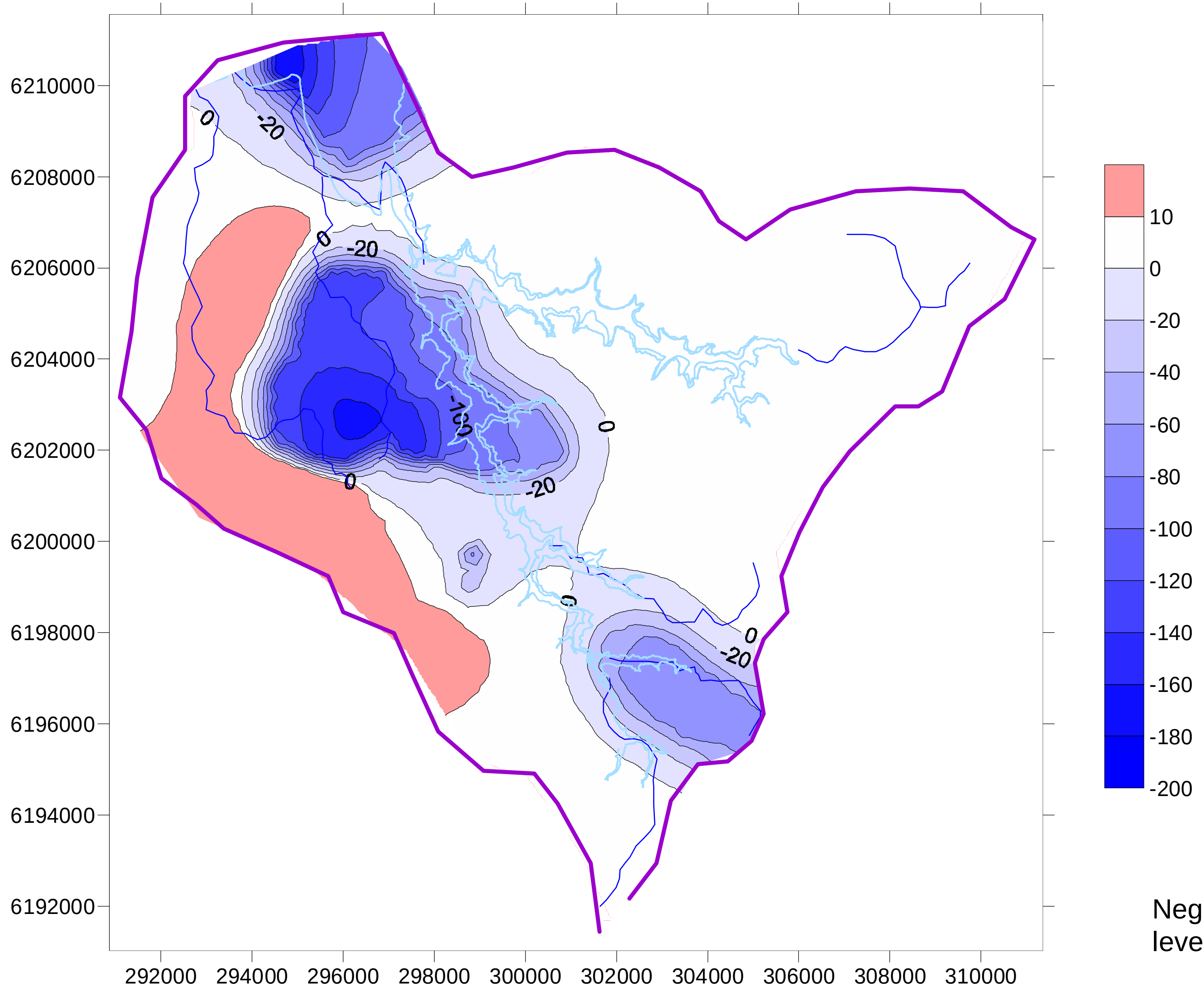


Negative values indicate
level above current case

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE Change in Water Levels From Current to 10-Years Post-Mining in Lower Bulgo Sandstone (m)	
CHECKED	DATE		
SCALE As shown		PROJECT No 107636001	FIGURE No 40 · REV No · A4



Negative values indicate level above current case

CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW

DATE Nov 2011

CHECKED

DATE

TITLE
Change in Water Levels From Current to 10-Years
Post-Mining in Scarborough Sandstone (m)

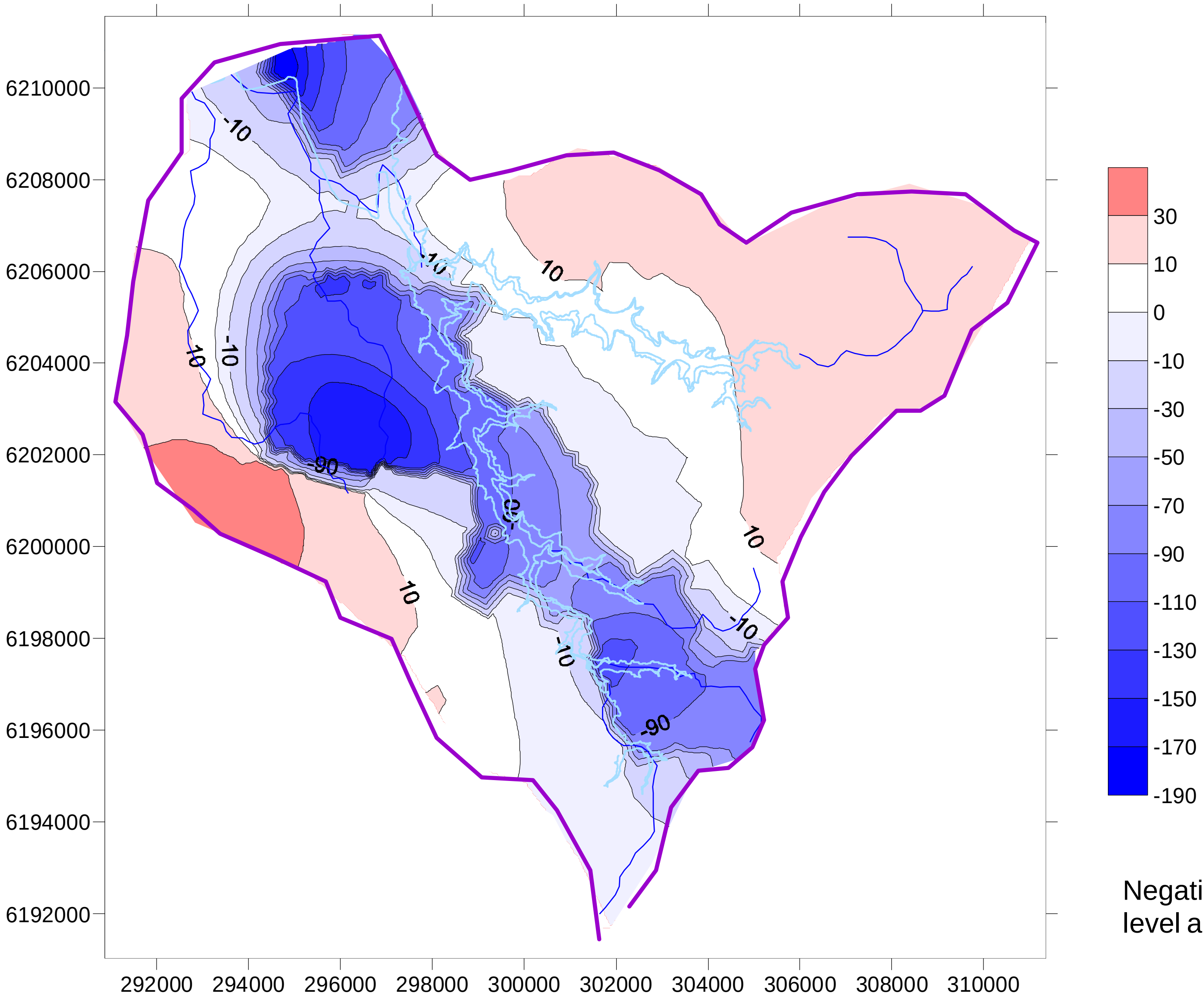
SCALE As shown

PROJECT No 107636001

FIGURE No 41

REV No

A4



Negative values indicate level above current case

CLIENT Gujarat			PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011		TITLE Change in Water Levels From Current to 10-Years Post-Mining in Bulli Coal Seam (m)		
CHECKED	DATE				
SCALE As shown			PROJECT No 107636001	FIGURE No 42	REV No	A4

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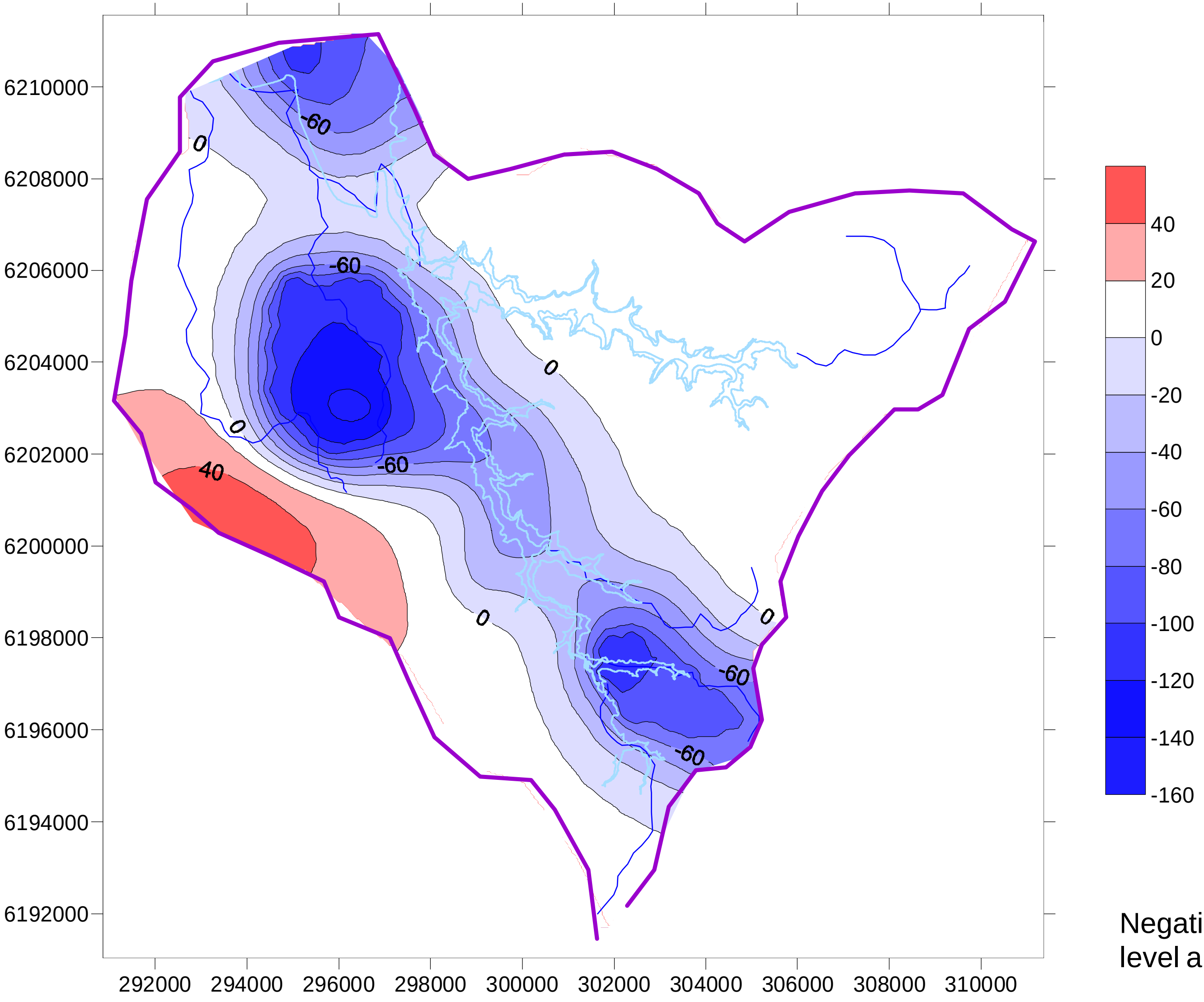

Negative values indicate level above current case

CLIENT
Gujarat

PROJECT
Groundwater Modelling

DRAWN SWW
DATE Nov 2011

CHECKED
DATE

TITLE
Change in Water Levels From Current to 10-Years Post-Mining in Wongawilli Coal Seam (m)

SCALE
As shown

PROJECT No 107636001

FIGURE No 43

REV No

A4

Golder Associates

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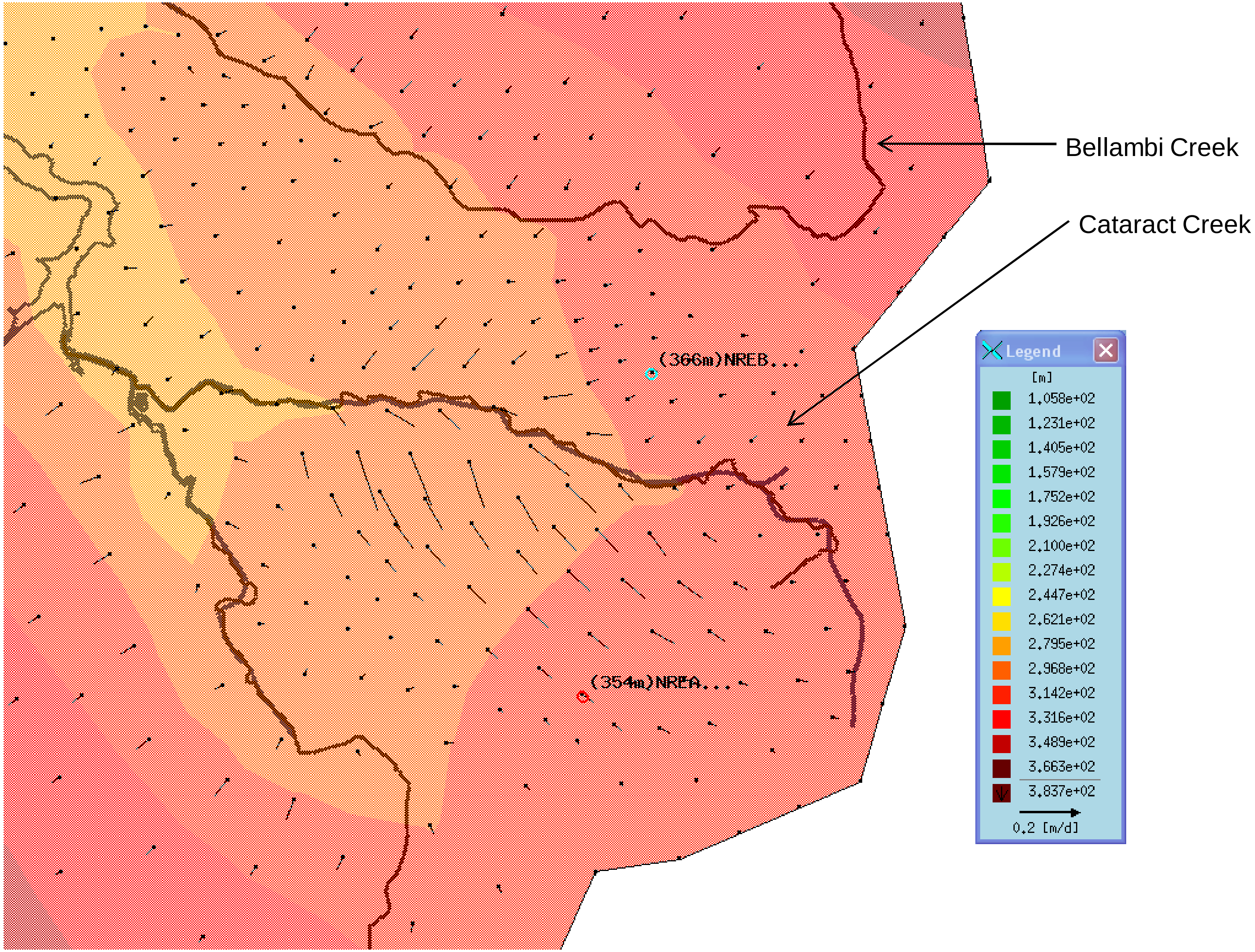
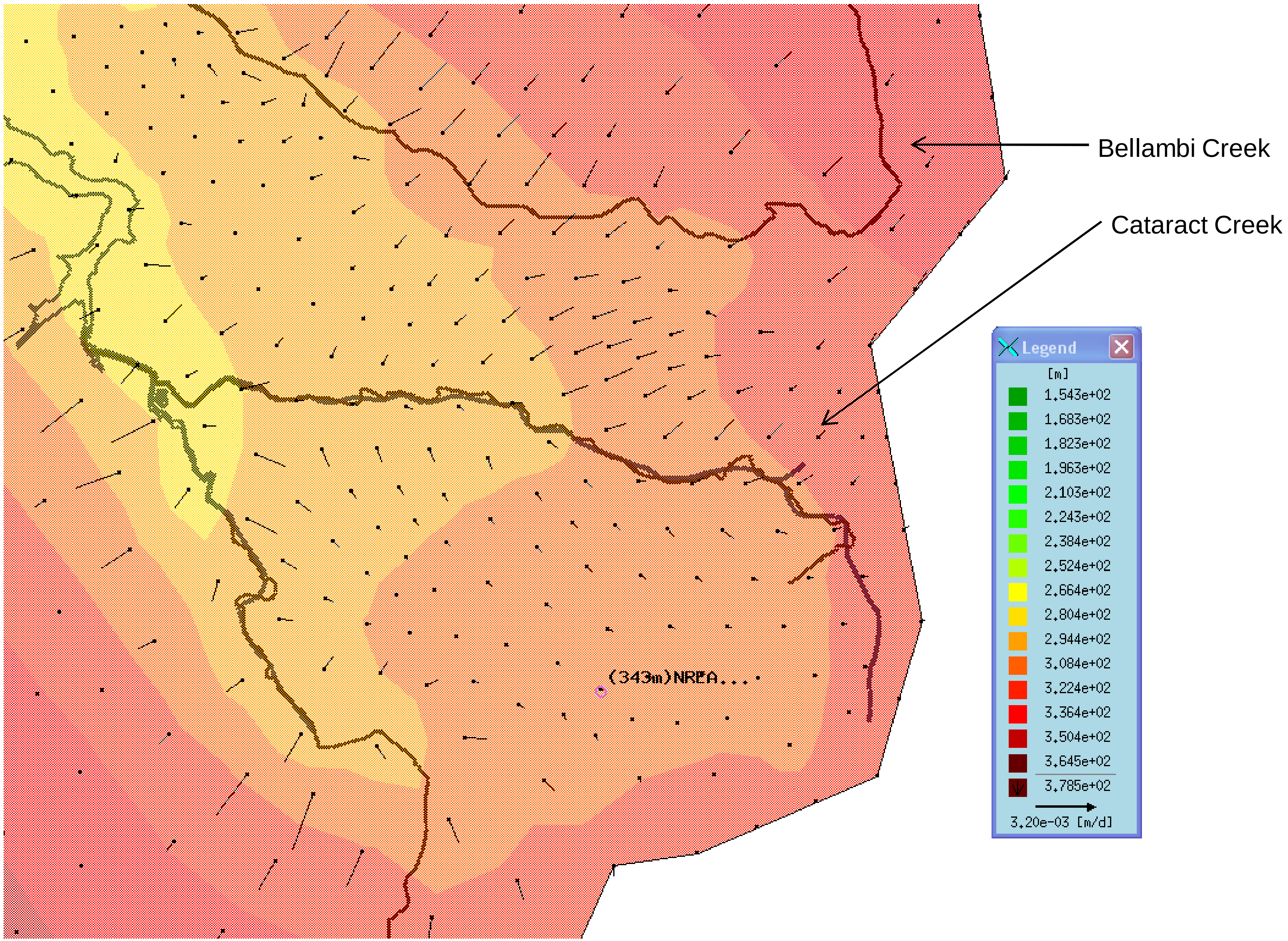
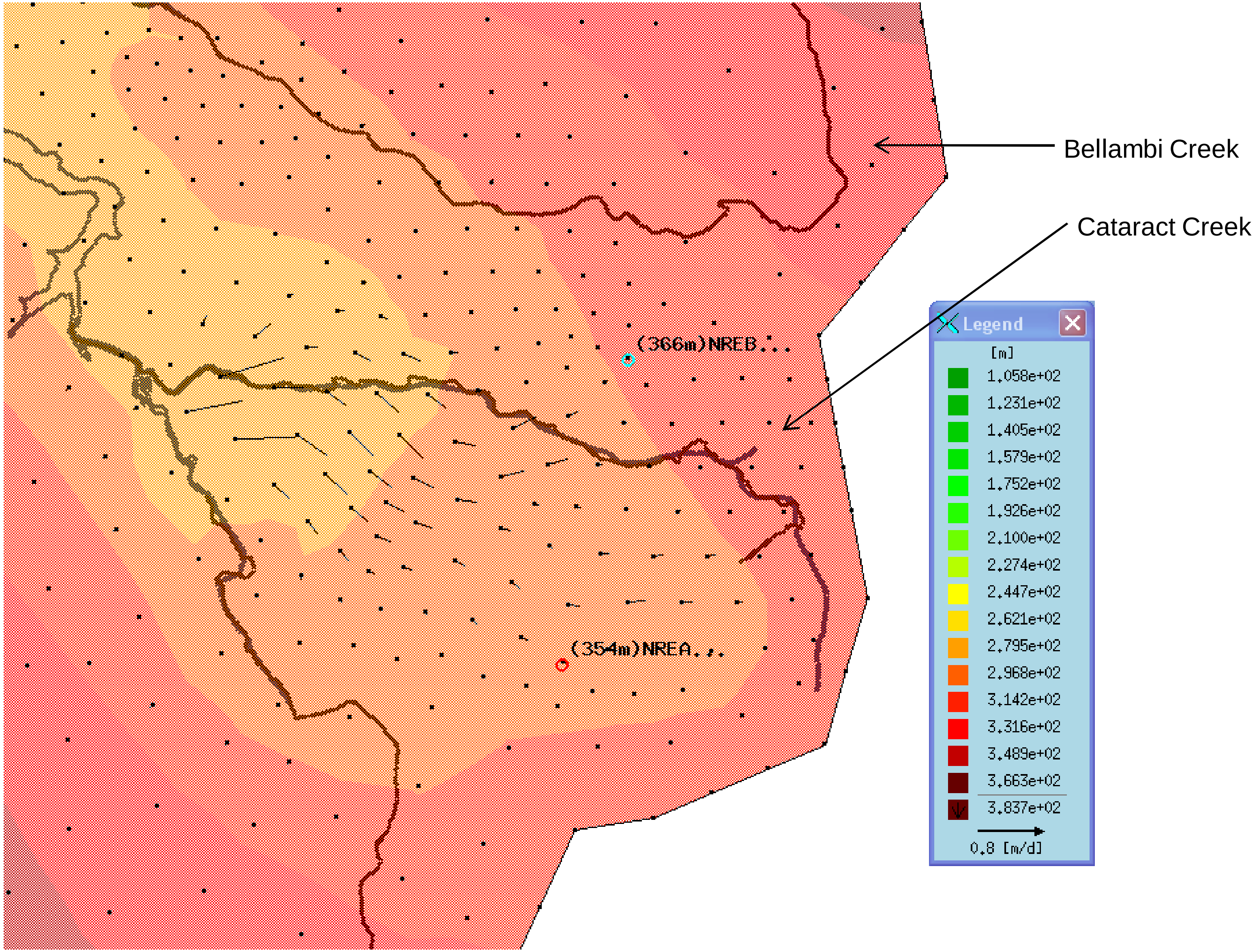


CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	Current Case – Flow Direction Wonga East Upper Hawkesbury
CHECKED	DATE		
SCALE	Not to Scale	PROJECT No 107636001	FIGURE No 44 · REV No · A4



Golder Associates	CLIENT Gujarat	PROJECT Groundwater Modelling	
	DRAWN SWW	DATE Nov 2011	TITLE Current Case – Flow Direction Wonga East Lower Hawkesbury
	CHECKED	DATE	
	SCALE Not to Scale	PROJECT No 107636001	FIGURE No 45 · REV No · A4



CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE Stage 1 – Flow Direction Wonga East Upper Hawkesbury	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 46 / REV No / A4

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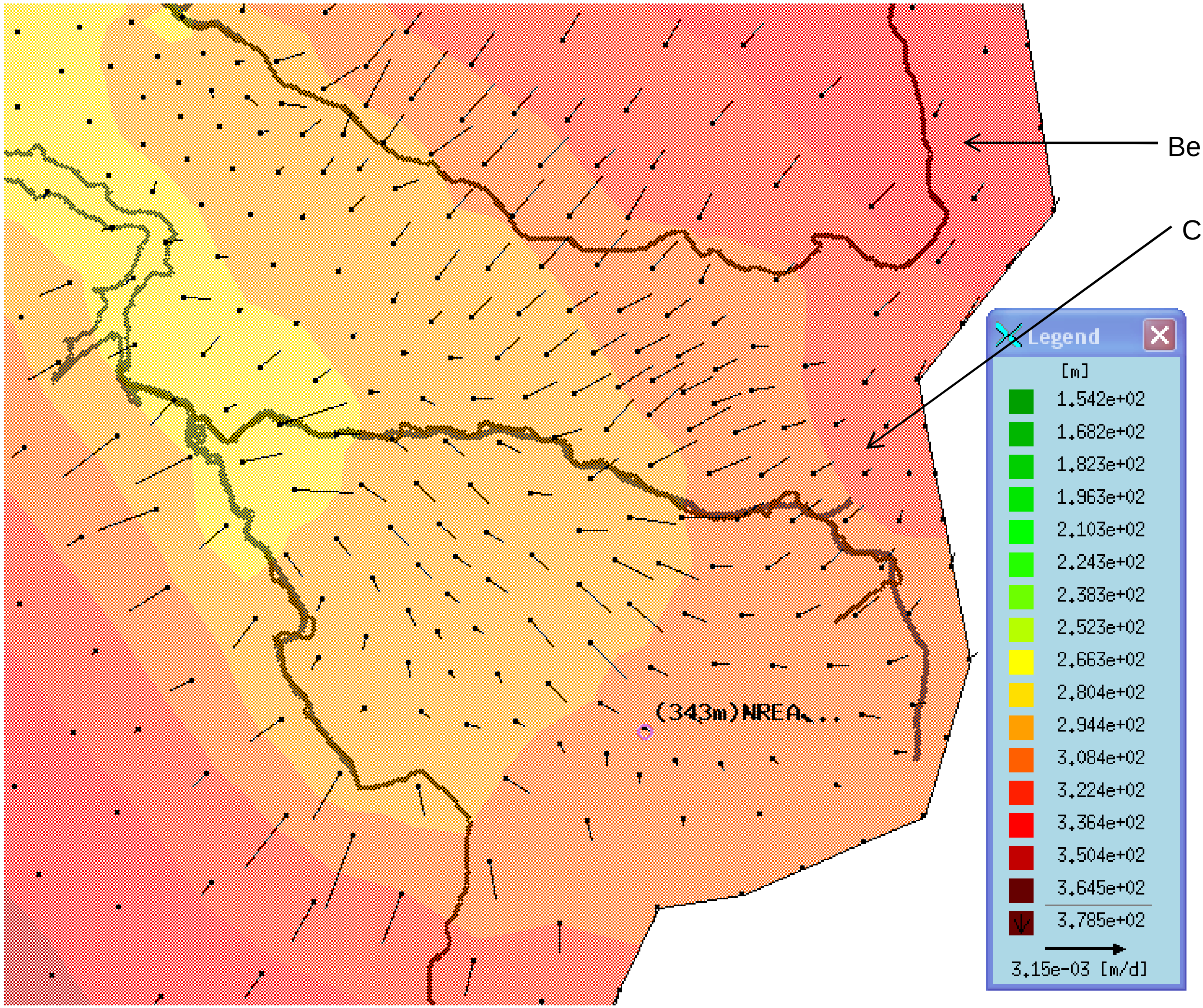
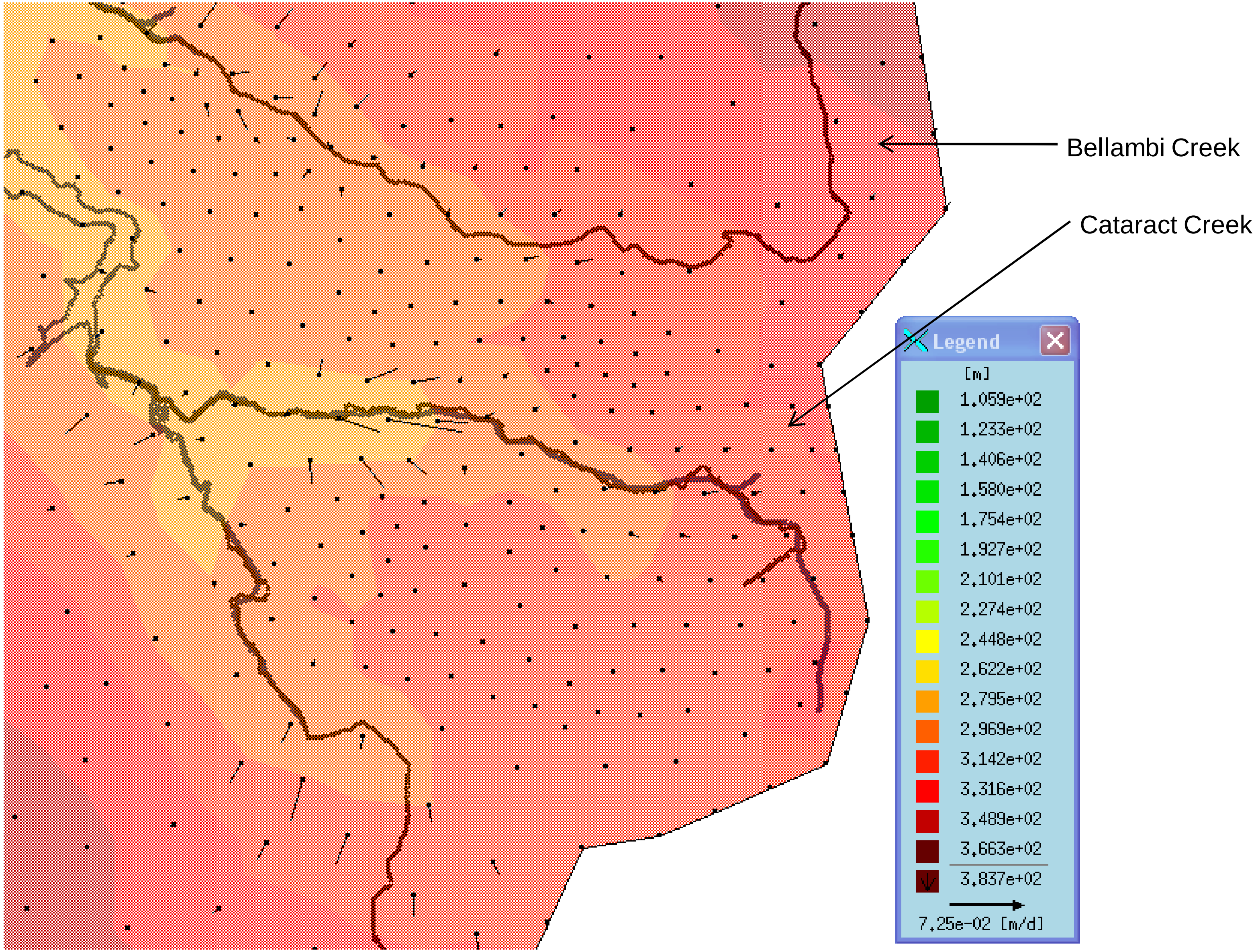


Bellambi Creek

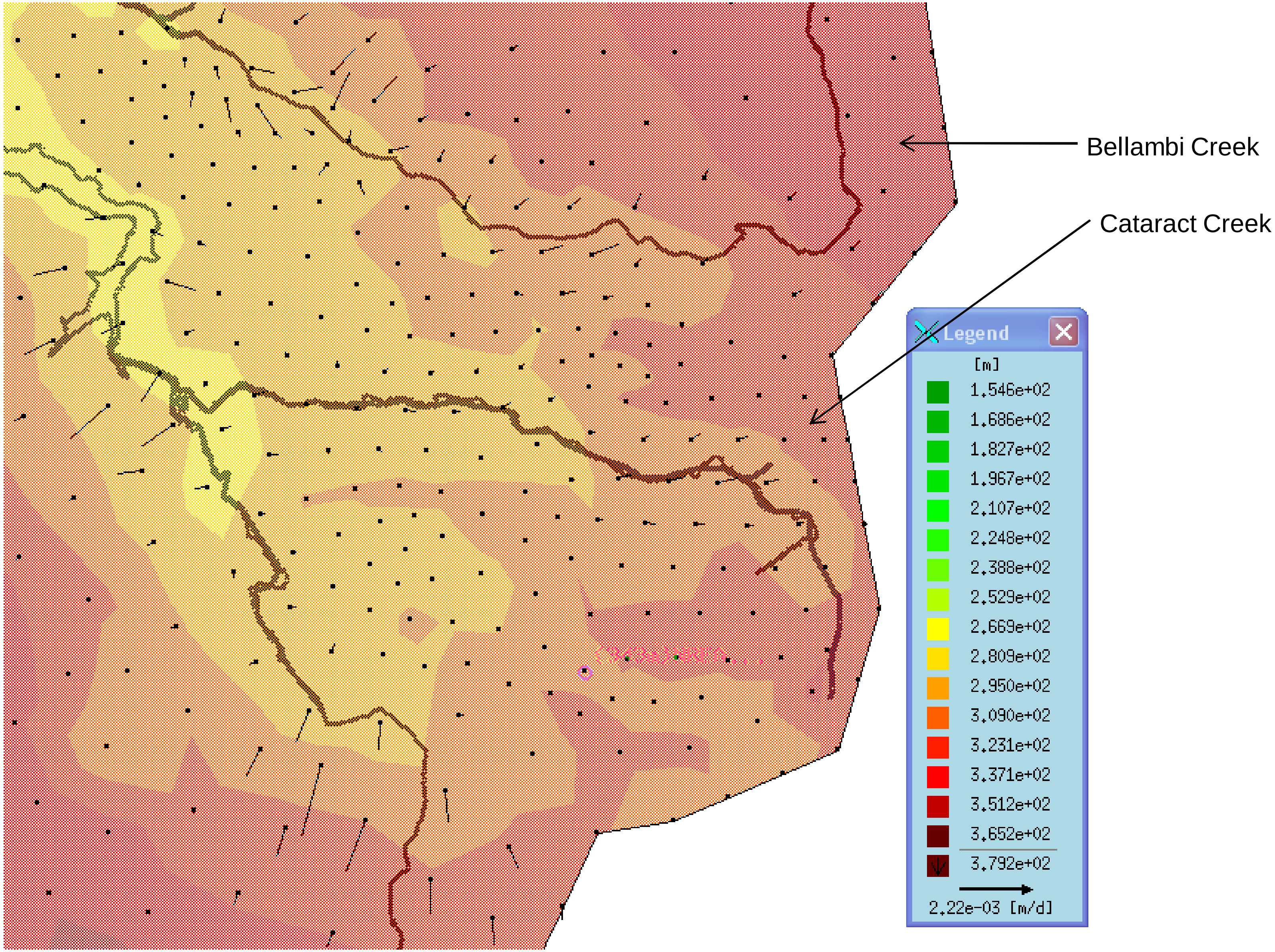
Cataract Creek

CLIENT	Gujarat
DRAWN	SWW
DATE	Nov 2011
CHECKED	
DATE	
SCALE	Not to Scale
PROJECT	Groundwater Modelling
TITLE	Stage 1 – Flow Direction Wonga East Lower Hawkesbury
PROJECT No	107636001
FIGURE No	47
REV No	
	A4



Golder Associates

CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE Stage 2 – Flow Direction Wonga East Upper Hawkesbury	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 48 · REV No · A4



CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	Stage 2 – Flow Direction Wonga East Lower Hawkesbury
CHECKED	DATE		
SCALE	Not to Scale	PROJECT No 107636001	FIGURE No 49 · REV No · A4

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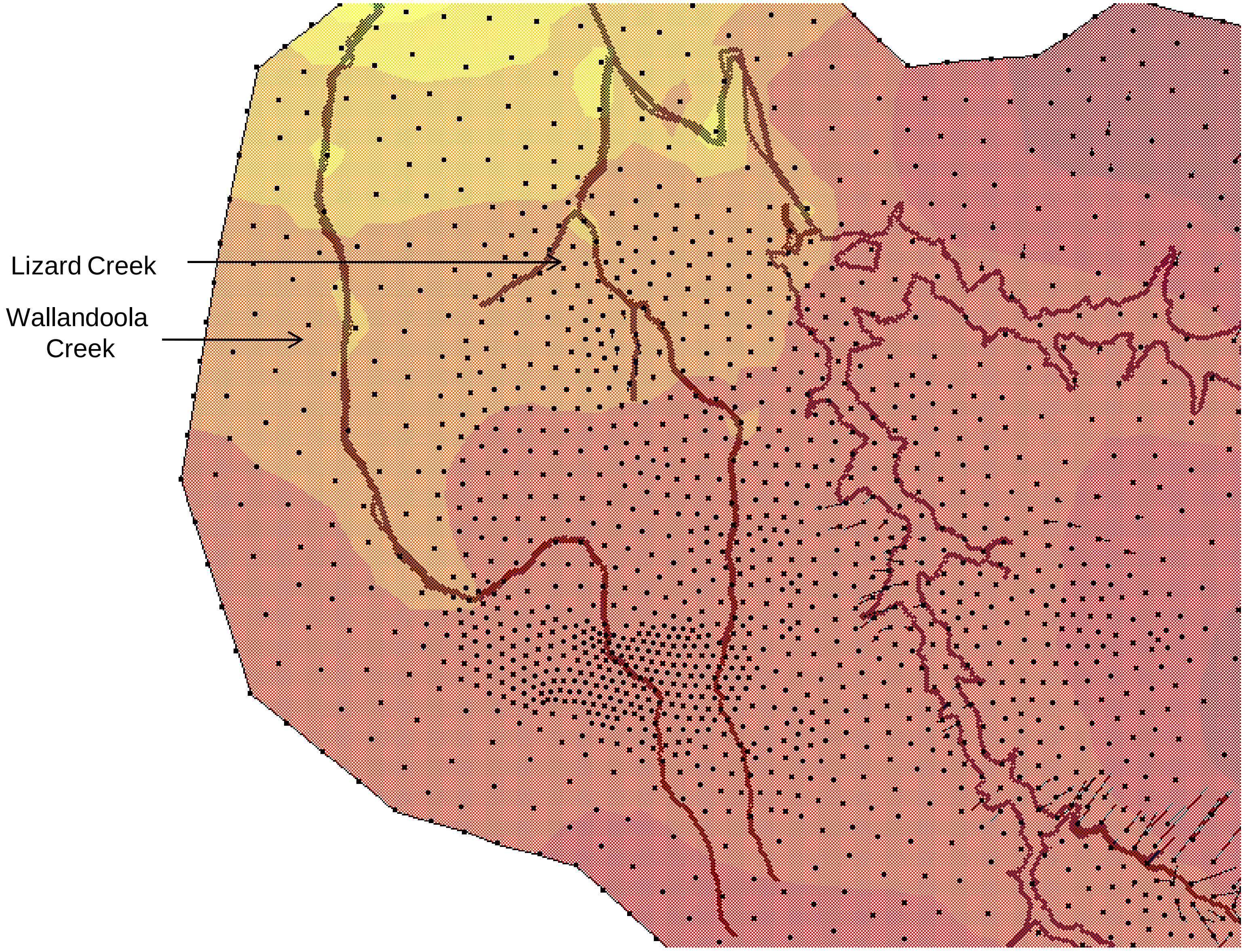
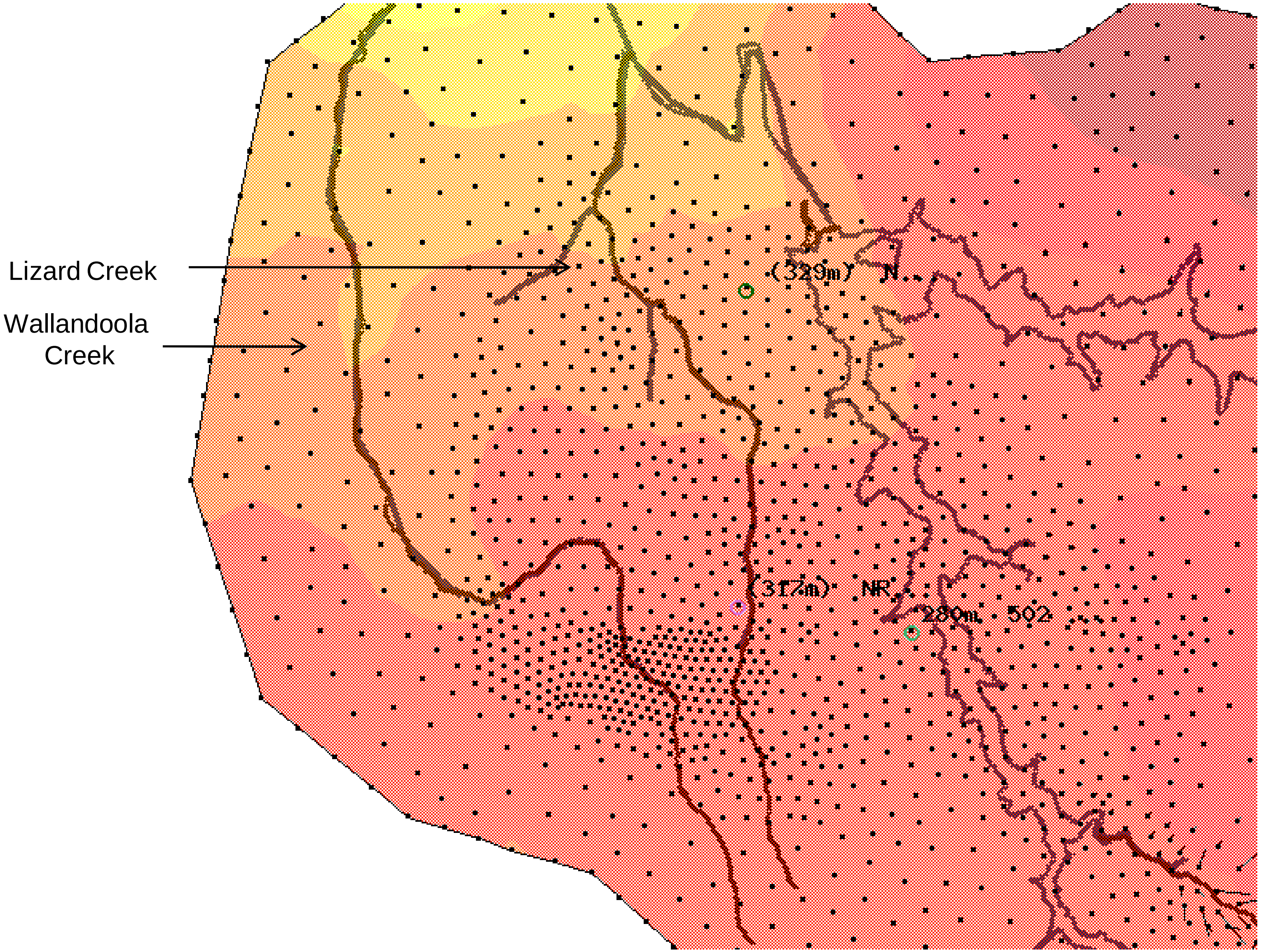
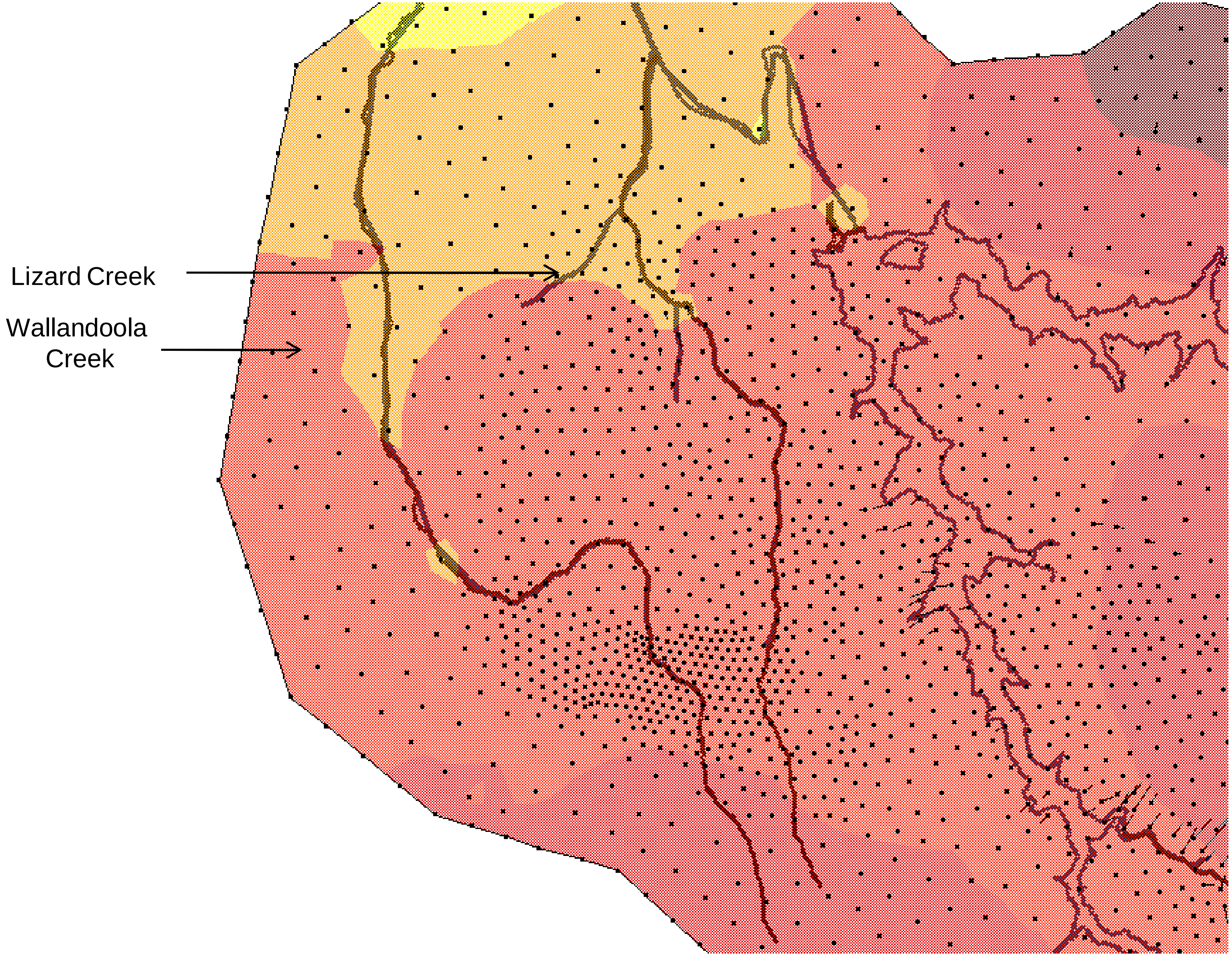


Golder Associates

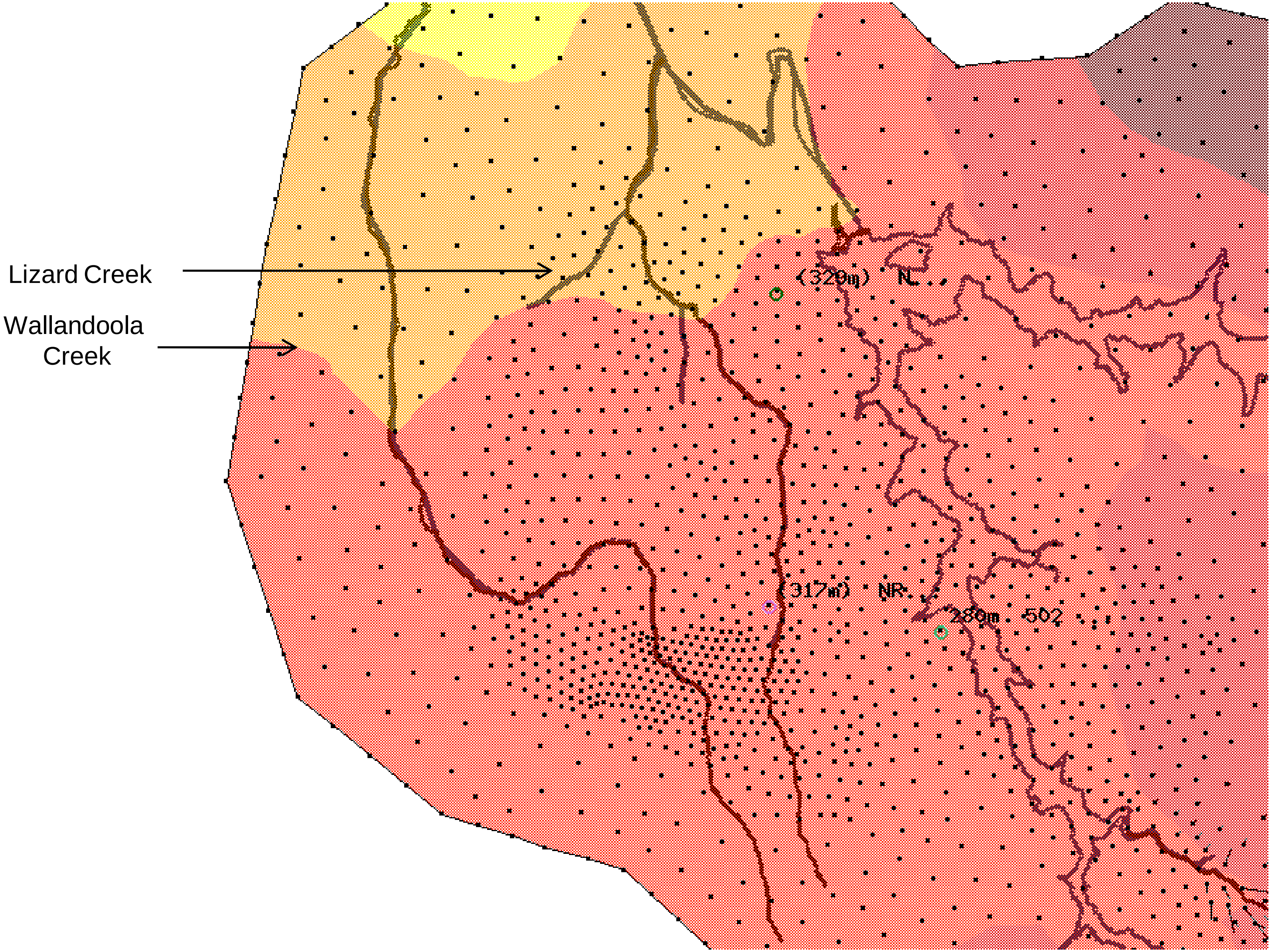
CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	Current Case – Flow Direction Wonga West Upper Hawkesbury
CHECKED	DATE		
SCALE	Not to Scale	PROJECT No 107636001	FIGURE No 50 · REV No · A4



CLIENT	Gujarat		PROJECT	Groundwater Modelling	
DRAWN	SWW	DATE Nov 2011	TITLE	Current Case – Flow Direction Wonga West Lower Hawkesbury	
CHECKED		DATE			
SCALE	Not to Scale		PROJECT No 107636001	FIGURE No 51	REV No	A4



CLIENT	Gujarat		PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011		TITLE	Stage 1 – Flow Direction Wonga West Upper Hawkesbury
CHECKED	DATE			
SCALE	Not to Scale		PROJECT No 107636001	FIGURE No 52 · REV No · A4



CLIENT Gujarat		PROJECT Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE Stage 1 – Flow Direction Wonga West Lower Hawkesbury
CHECKED	DATE	
SCALE Not to Scale		PROJECT No 107636001 | FIGURE No 53 | REV No | A4

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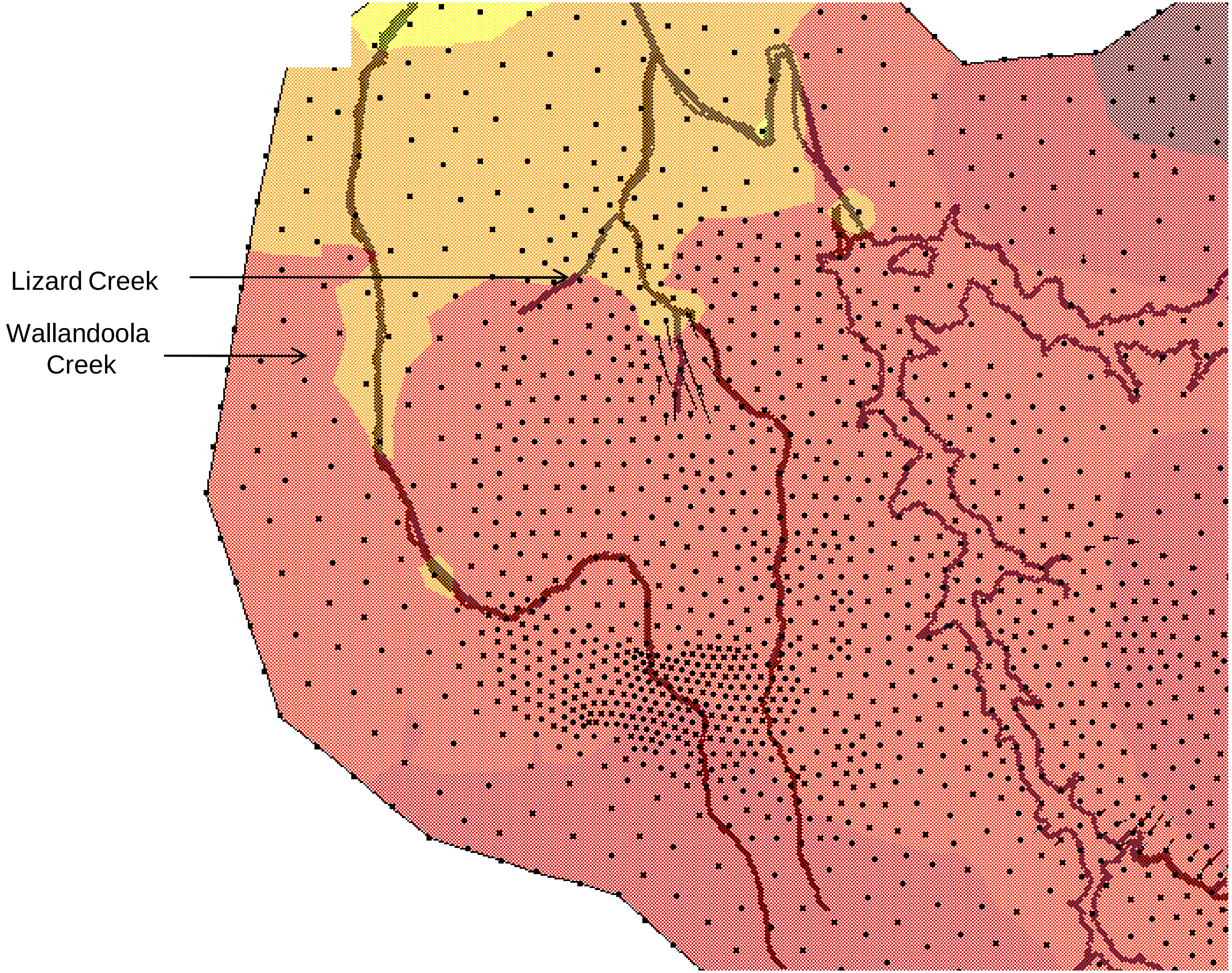

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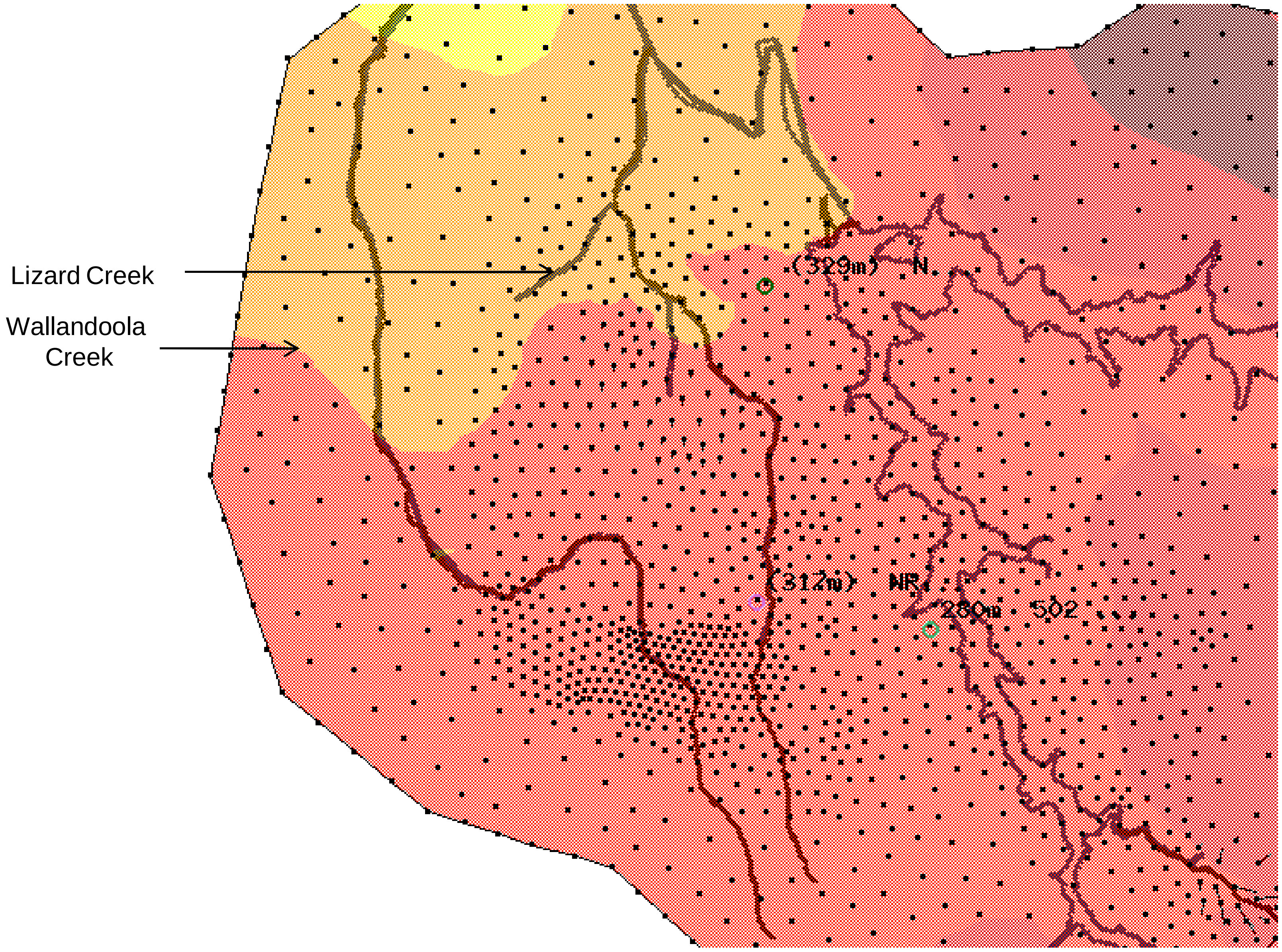
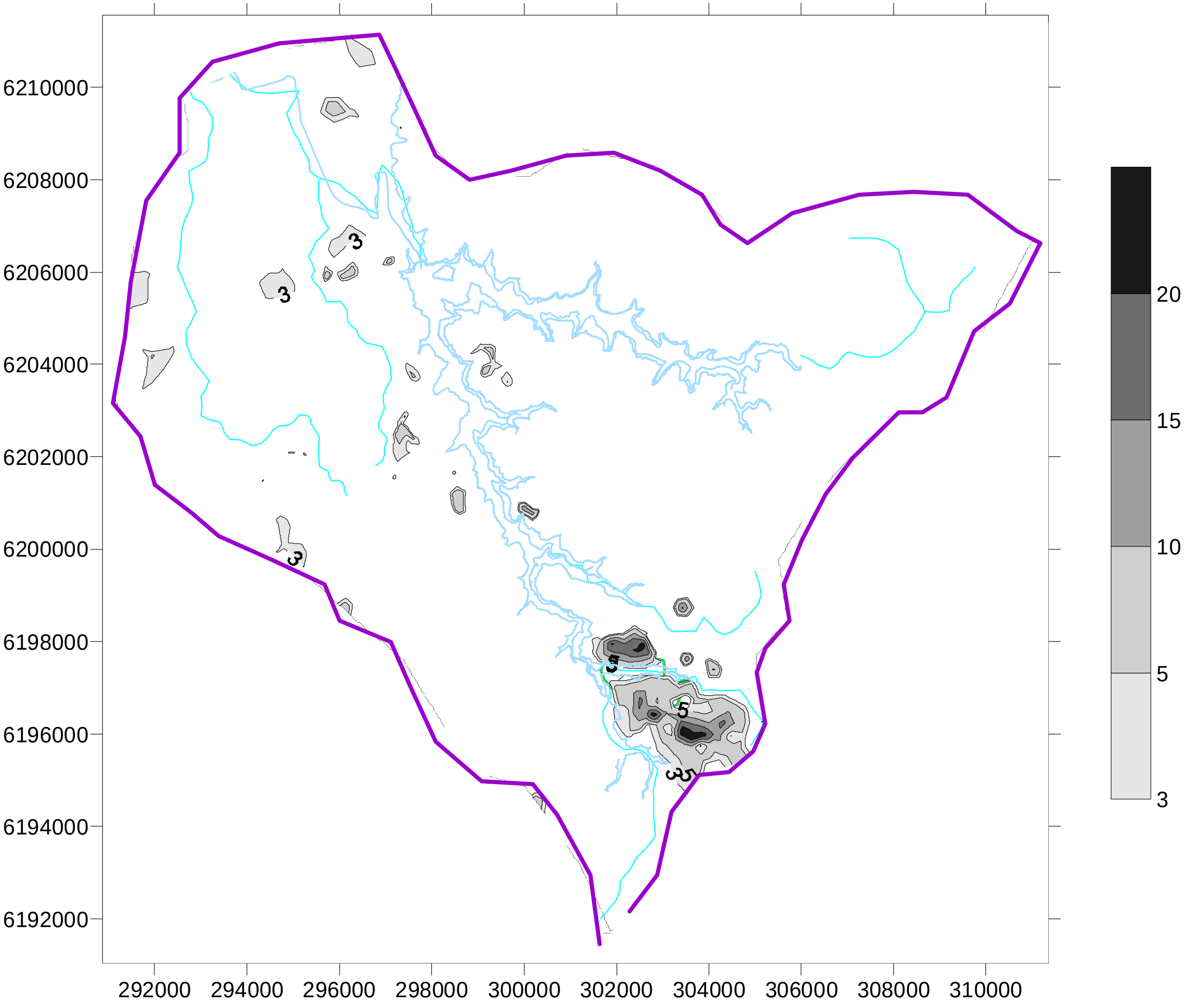
CLIENT	Gujarat	PROJECT	Groundwater Modelling
DRAWN SWW	DATE Nov 2011	TITLE	Stage 2 – Flow Direction Wonga West Upper Hawkesbury
CHECKED	DATE		
SCALE	Not to Scale	PROJECT No 107636001	FIGURE No 54 · REV No · A4

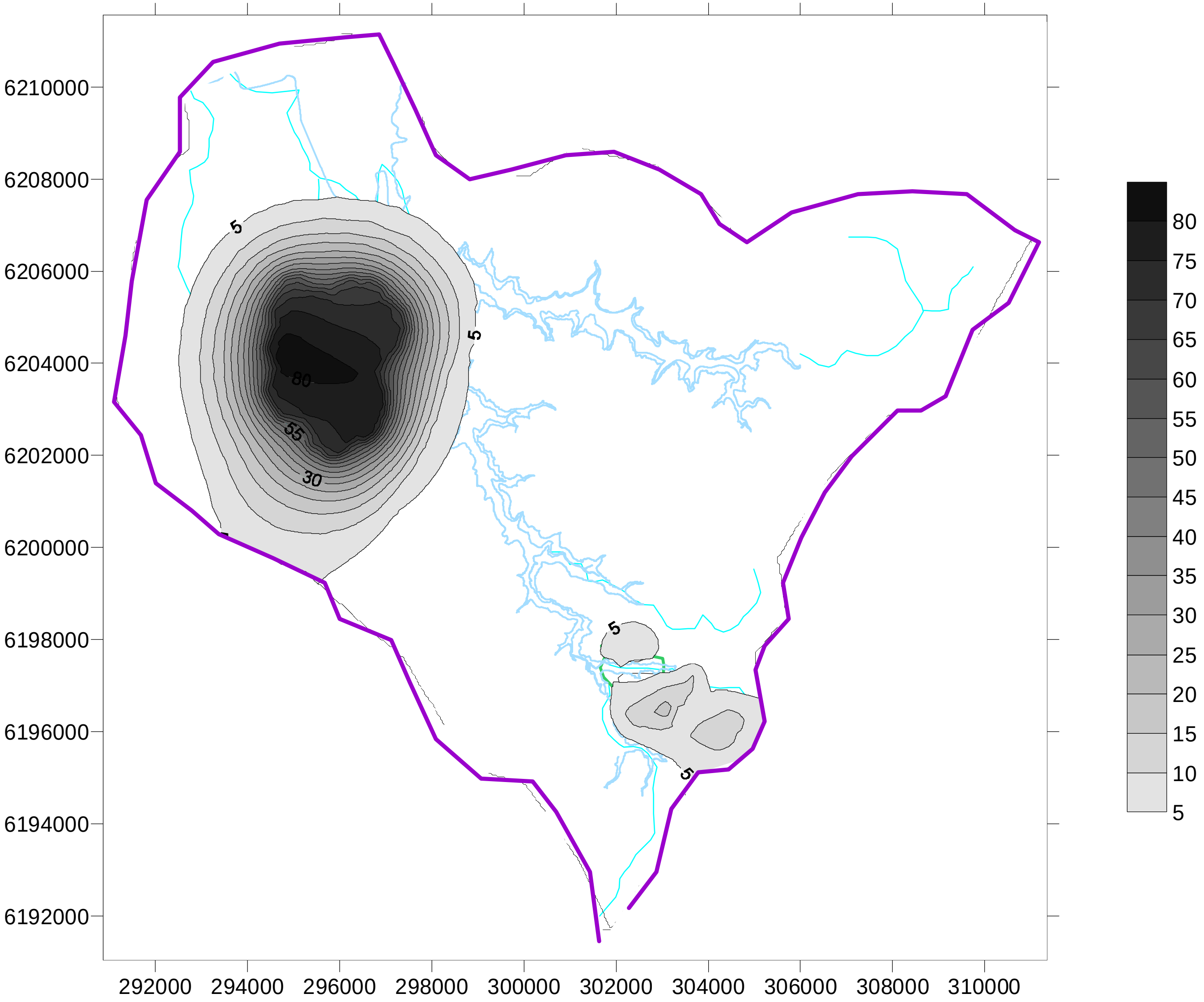


CLIENT Gujarat		PROJECT Groundwater Modelling	
DRAWN SWW	DATE Nov 2011	TITLE Stage 2 – Flow Direction Wonga West Lower Hawkesbury	
CHECKED	DATE		
SCALE Not to Scale		PROJECT No 107636001	FIGURE No 55 · REV No · A4

Golder Associates



CLIENT Gujarat		PROJECT Groundwater Modelling		
DRAWN SWW	DATE Nov 2011	TITLE Sensitivity Case – Stage 1 Drawdown (m) in Upper Hawkesbury Sandstone		
CHECKED	DATE			
SCALE As shown		PROJECT No 107636001	FIGURE No 56	REV No	A4



CLIENT	Gujarat			PROJECT	Groundwater Modelling
DRAWN	SWW	DATE	Nov 2011	TITLE	Sensitivity Case – Stage 2 Drawdown (m) in Upper Bulgo Sandstone
CHECKED		DATE			
SCALE	As shown			PROJECT No 107636001	FIGURE No 57 / REV No / A4

APPENDIX A

Limitations

LIMITATIONS

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Annex Q

Upland Swamp Assessment

NRE No. 1 Colliery Major Expansion
Upland Swamp Assessment

Prepared for Gujarat NRE Coking Coal Limited

27 November 2012

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The following Biosis staff were involved in this project:

- Ben Coddington, Ed Cooper, Jodie Cooper for assistance in the field

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Summary

Biosis Pty Ltd was commissioned by Gujarat NRE Coking Coal Ltd to undertake a detailed assessment of upland swamps. This detailed assessment will be used as part of the Environmental Assessment (EA) being undertaken by ERM for NRE's No. 1 Major Expansion Project.

The study area is located on the Woronora plateau, approximately 8 km north of Wollongong and approximately 70 km south of the Sydney CBD.

Upland swamps were mapped using a combination of LiDAR data, to define areas requiring further investigation, ground truthing of these areas in the field to define swamp boundaries and map swamp sub-communities and use of a Geographic Information System (GIS) to spatially represent data.

Following identification of upland swamps within the study area, an impact assessment was undertaken. The impact assessment was undertaken in two stages. The first stage involved the undertaking of an impact assessment according to the Draft *Upland Swamp Environmental Impact Assessment Guidelines* (OEH 2012). The second stage involved an assessment of the potential for upland swamps of 'special significance' to be impacted based on a variety of features, including an initial risk assessment according to OEH (2012), comparative analysis of upland swamps that have previously been undermined, changes to flow accumulation and potential for fracturing of bedrock and desiccation.

This project identified a total of thirty-nine (39) upland swamps meeting the definition of the Coastal Upland Swamp Endangered Ecological Community within the Wonga East study area and forty-five (45) upland swamps within the Wonga West study area. This assessment method identified a number of previously unmapped swamps within the study area, as well as highlighted the complexity and variability of this vegetation community.

The initial stages of the impact assessment identified that seven (7) upland swamps in Wonga East and eight (8) upland swamps in Wonga West are considered to be of 'special significance' using OEH criteria. Detailed impact assessment, including an initial risk assessment, comparative analysis, groundwater assessment, flow accumulation modelling and analysis of strains and potential for fracturing of bedrock, was undertaken on these 'special significance swamps'.

This detailed impact assessment identified that:

- There is a negligible likelihood of negative environmental consequences for seven (7) upland swamps within the study area, including CRUS2, CRUS3, LCUS1, LCUS6, LCUS27, WCUS1 and WCUS4-vfs. NRE can proceed to mining and monitoring in these areas.
- There is a low likelihood of negative environmental consequences for five (5) upland swamps within the study area, including CCUS4, CCUS10, CRUS1, LCUS8 and WCUS11. NRE may wish to consider changes to longwall layout to reduce impacts to these swamps.
- There is a moderate likelihood of negative environmental consequences for two (2) upland swamps within the study area, including WCUS4-hws and WCUS7. NRE should consider implementation of suitable impact avoidance, minimisation and mitigation measures to reduce impacts to these swamps.
- There is a significant likelihood of negative environmental consequences for two (2) upland swamps within the study area, including CCUS1 and CCUS5. NRE should consider implementation of suitable impact avoidance, minimisation and mitigation measures to reduce impacts to these swamps.

A number of recommendations to avoid or minimise impacts to upland swamps considered to 'special significance' are provided in the conclusions. NRE need to consider changes to the mine layout and / or suitable impact avoidance and mitigation measures to reduce the impacts on these swamps, including:

- adjust the layout in respect of Area 1 LW3 to avoid impacts to CCUS1.
- adjust the layout in respect of Area 2 LW7 and LW8. If this is not feasible, detailed monitoring of CCUS5 should be undertaken during the extraction of Longwalls 7 and 8. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
- adjust the layout in respect of Area 3 LW2 to minimise impacts on the headwaters of WCUS4.
- adjust the layout in respect of Area 3 LW3 and LW4 to reduce predicted strains to WCUS7 and Wallandoola Creek.

Provided the recommendations outlined in this report are implemented negative environmental outcomes for upland swamps of 'special significance' can be avoided.

1. Introduction

1.1 Project background

Biosis Pty Ltd (Biosis) was commissioned by Gujarat NRE Coking Coal Limited (NRE) to undertake a detailed assessment of upland swamps. This detailed assessment will support the Environmental Assessment (EA) being undertaken by ERM for NRE's No. 1 Major Expansion Project.

NRE is currently seeking approval for expansion of operations at the NRE No. 1 Mine, including longwall mining of two areas known as Wonga East and Wonga West (see Section 1.4). The Wonga East and Wonga West areas are located on the Woronora plateau, a deeply dissected plateau gradually declining from south to northwest (NPWS 2003). Upland swamps are a significant natural feature of the Woronora plateau.

1.1.1 Previous Assessments of Upland Swamps

A number of ecological assessments have been undertaken for the Major Expansion Project (ERM 2011, 2012). These assessments have previously identified upland swamps within the study area, based on vegetation mapping by NPWS (2003), ground-truthing and assessment of groundwater levels.

Initially, some areas mapped by NPWS (2003) as upland swamps were excluded based on low or negligible groundwater levels, a lack of humic layer, no free moisture and very shallow sandstone (ERM 2012). However review of the Final Determination for Coastal Upland Swamp Endangered Ecological Community (EEC) by the NSW Scientific Committee (2012) has highlighted that these areas are likely to be consistent with the EEC, and these areas were included as a part of the Preliminary Works Part 3A Modification for Area 2 LW4 and 5 (Cardno 2012). This iterative process has resulted in some upland swamps being included in previous work, then removed, and then included again.

Due to potential discrepancies between the description of Coastal Upland Swamp in the Final Determination (NSW Scientific Committee 2012), various literature and geomorphological processes, it was identified that a consistent approach to identification and impact assessment was required.

The approach of this assessment is to identify all areas of the Coastal Upland Swamp EEC (NSW Scientific Committee 2012) within the study area. All areas meeting the definition of the Coastal Upland Swamp EEC (upland swamp) were included for further analysis.

To allow for comparison to previous mapping of upland swamps, Table 1 reconciles current naming and previous naming.

Table 1: Current naming of upland swamps compared to previous naming

Swamp Name - Current	Swamp Name - Previous
BCUS1	-
BCUS10	-
BCUS11	-
BCUS2	-
BCUS3	-
BCUS4	-
BCUS5	-

Swamp Name - Current	Swamp Name - Previous
BCUS6	-
BCUS7	-
BCUS8	-
BCUS9	-
CCUS1	CChs1
CCUS10	-
CCUS11	-
CCUS12	-
CCUS13	-
CCUS14	-
CCUS15	-
CCUS16	-
CCUS17	-
CCUS18	-
CCUS19	-
CCUS2	CChs2
CCUS20	-
CCUS21	-
CCUS22	-
CCUS23	-
CCUS3	CChs3
CCUS4	CChs4
CCUS5	-
CCUS6	-
CCUS7	-
CCUS8	-
CCUS9	-
CRUS1	CRhs1
CRUS2	CRhs2
CRUS3	CRhs3
CRUS4	-
CRUS5	-
LCUS1	LCvfs1

Swamp Name - Current	Swamp Name - Previous
LCUS10	-
LCUS11	-
LCUS12	-
LCUS13	-
LCUS14	-
LCUS15	-
LCUS16	-
LCUS17	-
LCUS18	LChs3
LCUS19	-
LCUS2	-
LCUS20	-
LCUS21	-
LCUS22	-
LCUS23	-
LCUS24	-
LCUS25	LChs4
LCUS26	LChs6
LCUS27	LChs6
LCUS28	LChs5
LCUS29	LChs5
LCUS3	-
LCUS30	-
LCUS31	-
LCUS32	LChs5
LCUS33	-
LCUS4	LCvfs2
LCUS5	-
LCUS6	LChs2
LCUS7	-
LCUS8	-
LCUS9	-
WCUS1	WCvfs1

Swamp Name - Current	Swamp Name - Previous
WCUS10	-
WCUS11	WChs2
WCUS12	-
WCUS2	-
WCUS3	-
WCUS4	WChs1 / WCvfs1
WCUS5	-
WCUS6	-
WCUS7	WCvfs2
WCUS8	-
WCUS9	-

1.2 Upland Swamps

1.2.1 Formation

On the floors of low gradient / low flow valleys or in seepage zones along benched slopes, upland swamps form due to the obstruction of drainage and subsequent trapping of sediment. Upland swamps are formed by a positive feedback mechanism, where sediment is accumulated in valley floors though some type of initial blockage (e.g. rock benches, obstruction by large logs etc.). This results in impeded drainage, waterlogging of the soil, increased soil moisture, killing of trees due to waterlogging and an increase in dense hydrophilic vegetation. This process reduces the transpiration capacity of the vegetation, which allows the water table to rise more frequently than if trees were present, reinforcing the process (Young 1982, Keith *et al.* 2006, Tompkins & Humphrey 2006, NSW Scientific Committee 2012).

1.2.2 Hydrology, Soils and Vegetation

Soils and vegetation communities within upland swamps are strongly associated with the distribution of water (both surface water flows and groundwater) within upland swamps (Keith *et al.* 2006, Tompkins & Humphrey 2006, NSW Scientific Committee 2012).

In areas of frequent waterlogging / high groundwater levels and / or permanent moisture, soils contain a high organic content, are generally deeper and tend to support areas of Tea-tree Thicket dominated by Tea-tree *Leptospermum* spp., *Melaleuca squarrosa* and *Acacia rubida*, with an understorey of Coral Fern *Gleichenia* spp.. In areas of intermittent waterlogging and / or moisture, soils consist of a mix of organic material and mineral sands, and tend to support Cyperoid heath, dominated by dense stands of large sedges from the Cyperaceae family including *Gymnoschoenus sphaerocephalus*, *Lepidosperma limicola*, *Chorizandra sphaerocephala* and *Baumea rubiginosa*. In the driest parts of upland swamps, soils can vary in depth and composition, with driest areas supporting mineral sands of a few centimetres in depth. These areas intergrade with deeper, wetter soils mentioned above. These drier areas support a mix of Restioid Heath, Sedgeland and Banksia Thicket. Sedgeland, located in areas subject to periodic waterlogging and seepage, is comprised of a low dense cover of sedges such as *Leptocarpus tenax, Schoenus brevifolius* and *S. paludosus* with some small shrubs such as *Baeckea imbricata, Sprengelia incarnata* and *Actinotus minor*. Restioid Heath, located on swamp margins and upper slopes where the water table rarely reaches the surface, is comprised of a low shrub layer of *Banksia oblogifolia*, *Banskia robur*, *Epacris obtusifolia* and a dense ground cover of species such as *Empodisma minus, Lepyrodia scariosa, Leptocarpus tenax* and *Schoenus brevifolius*. Banksia Thicket, located on swamp margins and upper slopes where the water table rarely reaches the surface, forms a dense heath, often on the margins of upland swamps or in smaller swamps located along benched terraces (N. Garvey pers. obs.).

As demonstrated above, hydrology plays a key role in the formation and maintenance of upland swamps, and changes in hydrology play a significant role in determining the spatial variation in vegetation sub-communities within upland swamps. Some upland swamps are reliant on the perched ephemeral water table to maintain moisture dependent vegetation communities, which in turn assists in the development of a deep layer of organic material, which in turn traps more moisture. However, other swamps are reliant on rainfall and surface water flows, and perched ephemeral water tables may be absent or may dry out during periods of low rainfall. These differences in reliance on groundwater versus rainfall lead to differences in susceptibility to impacts.

1.2.3 Legislative Status

Upland swamps within the study area are currently listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act) as the Coastal Upland Swamp in the Sydney Basin Bioregion EEC.

Upland Swamps within the study area are not representative of the Temperate Highland Peat Swamps on Sandstone (THPSS) EEC listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The listing advice for the THPSS EEC (TSSC 2005) contains a number of criteria not met by the upland swamps within the study area, as outlined in Table 2.

Table 2: Criteria for THPSS and Comparison with Upland Swamps within the Study Area

THPSS Criteria	Upland Swamps within the Study Area
Altitudinal range of 600 – 1100 m ASL.	Altitudinal range of 350 m – 300 m ASL.
Distributional components, as defined in Table 2 of DSEWPaC (2012) and mapped by DEH (2005).	No Woronora swamps are listed as components of the THPSS. No Woronora swamps are mapped within the geographic boundaries of the EEC.
Soils are generally black to grey coloured acid, peaty soils, with a moderate to high organic matter content.	Only some swamps generate peat. Associated with waterlogged swamps.

On the basis of the criteria assessed in Table 1 upland swamps within the study area are not representative of the THPSS EEC. We understand that the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) are currently reviewing the listing of upland swamps, and that the new listing advice is likely to cover swamps on the Woronora plateau.

1.2.4 Potential Impacts

Subsidence associated with longwall mining has potential to result in changes to hydrological processes within upland swamps. There are two broad mechanisms by which subsidence can result in impacts to upland swamps, as summarised in Table 3 below.

Table 3: Mechanisms for and Impacts to Upland Swamp Resulting from Subsidence

Broad mechanism	Potential Impacts
Fracturing of bedrock as a result of tensile and	Lowering of the water table below a swamp, leading

Broad mechanism	Potential Impacts
compressive strains, resulting in increased transportation of water through this fracture network.	to dewatering and drying of the swamp and lower levels of soil moisture. This can in turn, result in changes to vegetation composition within swamps.
Changes in gradients within a swamp, as a result of tilts associated with subsidence, leading to potential for redistribution of water within a swamp.	Changes to the gradients within a swamp can lead to increased accumulation of water in some areas and reduced accumulation in other areas. This, in turn, can result in changes to vegetation composition within swamps.
	Changes in flow regimes within swamps result in the re-concentration of flows within a swamp, potential for development of nick points and potential for scouring and erosion.

Vegetation sub-communities within upland swamps that are reliant on certain hydrological regimes differ in their susceptibility to impact. Vegetation sub-communities reliant on permanent water are most likely to be reliant on shallow groundwater flows or accumulation of surface water against flow impeders such as rockbars, accumulation of logs or other obstructions. These sub-communities, including Tea-tree Thicket (MU43) and Cyperoid Heath MU44c), are particularly susceptible to impacts resulting from fracturing of the bedrock and a decrease in soil moisture (Keith *et al.* 2006). Changes in gradient within a swamp, resulting in increased water accumulation are likely to favour transition from drier sub-communities, such as Banksia Thicket (MU42), Sedgeland (MU44a) and Restioid Heath (MU44b), to wetter sub-communities such as Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43; Keith *et al.* 2006). Changes in gradient resulting in more rapid transportation of water and less pooling are likely to favour transition from wetter sub-communities to drier ones (Keith et al. 2006).

Valley infill swamps are considered more susceptible to scouring and erosion due to increased flow rates through these swamps (Earth Tech 2003, PAC 2010, OEH 2012). Headwater swamps are likely to be less susceptible to impact for a variety of reasons, including:

- lower flow rates within the swamp, resulting from more dispersed sheet flow of water across the swamp;
- less reliance on perched ephemeral groundwater systems when compared with valley infill swamps; and,
- less susceptibility to non-conventional subsidence effects, such as valley closure, buckling and shearing.

Scour pools within a swamp are a good indicator of susceptibility to erosion (Tomkins & Humphrey 2006).

For these reasons, impacts to upland swamps resulting from subsidence associated with longwall mining are considered a 'major concern' (PAC 2010).

1.3 Scope of assessment

NRE has engaged Biosis to undertake a detailed and comprehensive assessment of upland swamps within their Wonga East and Wonga West study areas, to allow a detailed and comprehensive impact assessment to be undertaken.

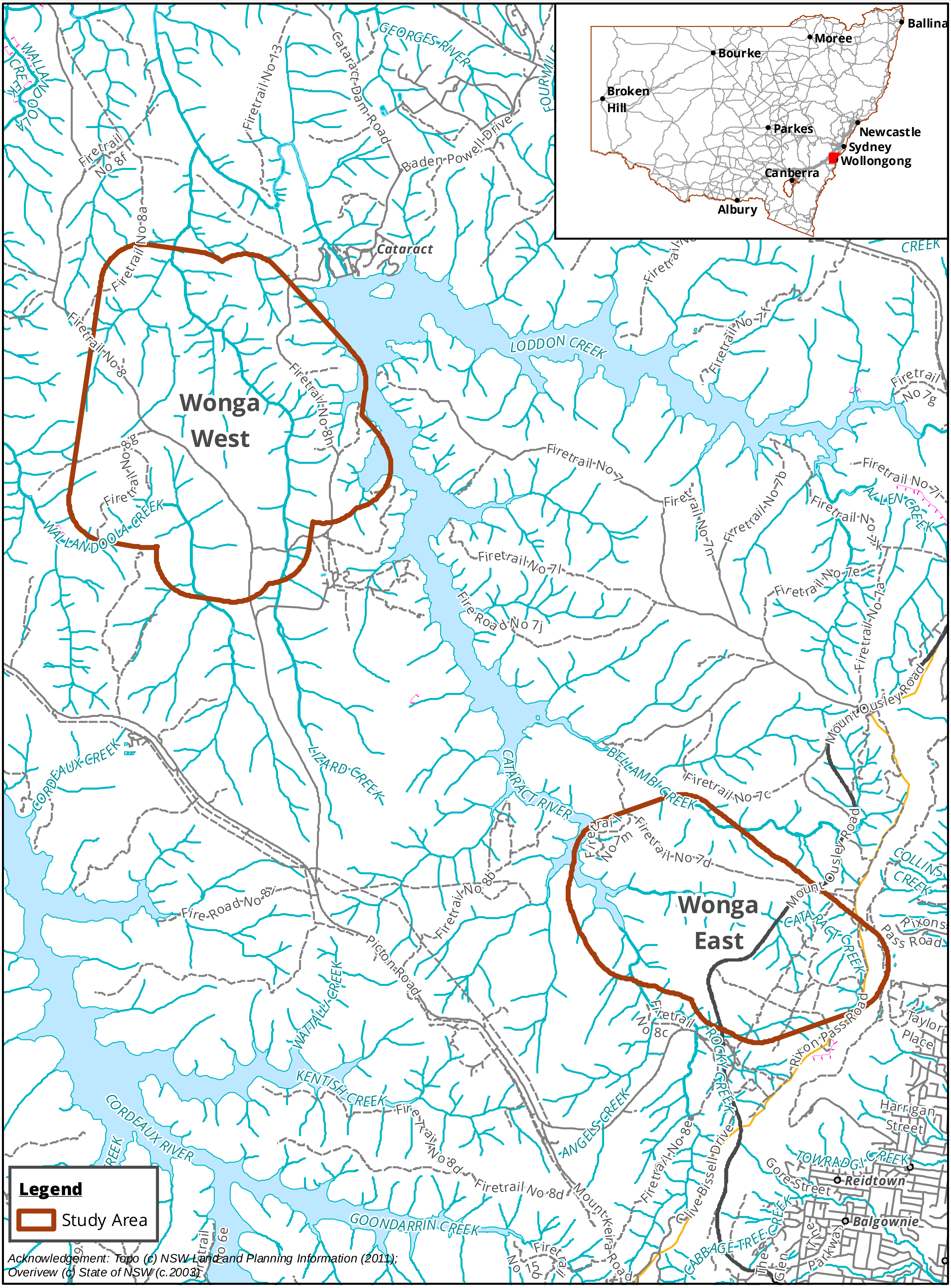
The objectives of this assessment are to:

- Accurately map the boundaries of upland swamps within the Wonga East and Wonga West areas.
- Undertake detailed mapping of vegetation sub-communities within upland swamps.
- Undertake an impact assessment to determine those significant upland swamps considered at significant risk from subsidence associated with longwall mining of Wonga East and Wonga West.

1.4 Location of the study area

The study area is located on the Woronora plateau, approximately 8 km north of Wollongong and approximately 70 km south of the Sydney CBD (Figure 1).

The NRE No1 Major Expansion Project includes longwall mining of the Wongawilli seam in two areas referred to as Wonga East and Wonga West (Figure 2). The study area is defined as an area incorporating a 600 m buffer from the edge of secondary extraction.



Acknowledgement: Topo (c) NSW Land and Planning Information (2011);
Overivew (c) State of NSW (c.2003)

Figure 1: Location of the study area, in a regional context

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Scale 1:70,000 @ A4, GDA 1994 MGA Zone 56

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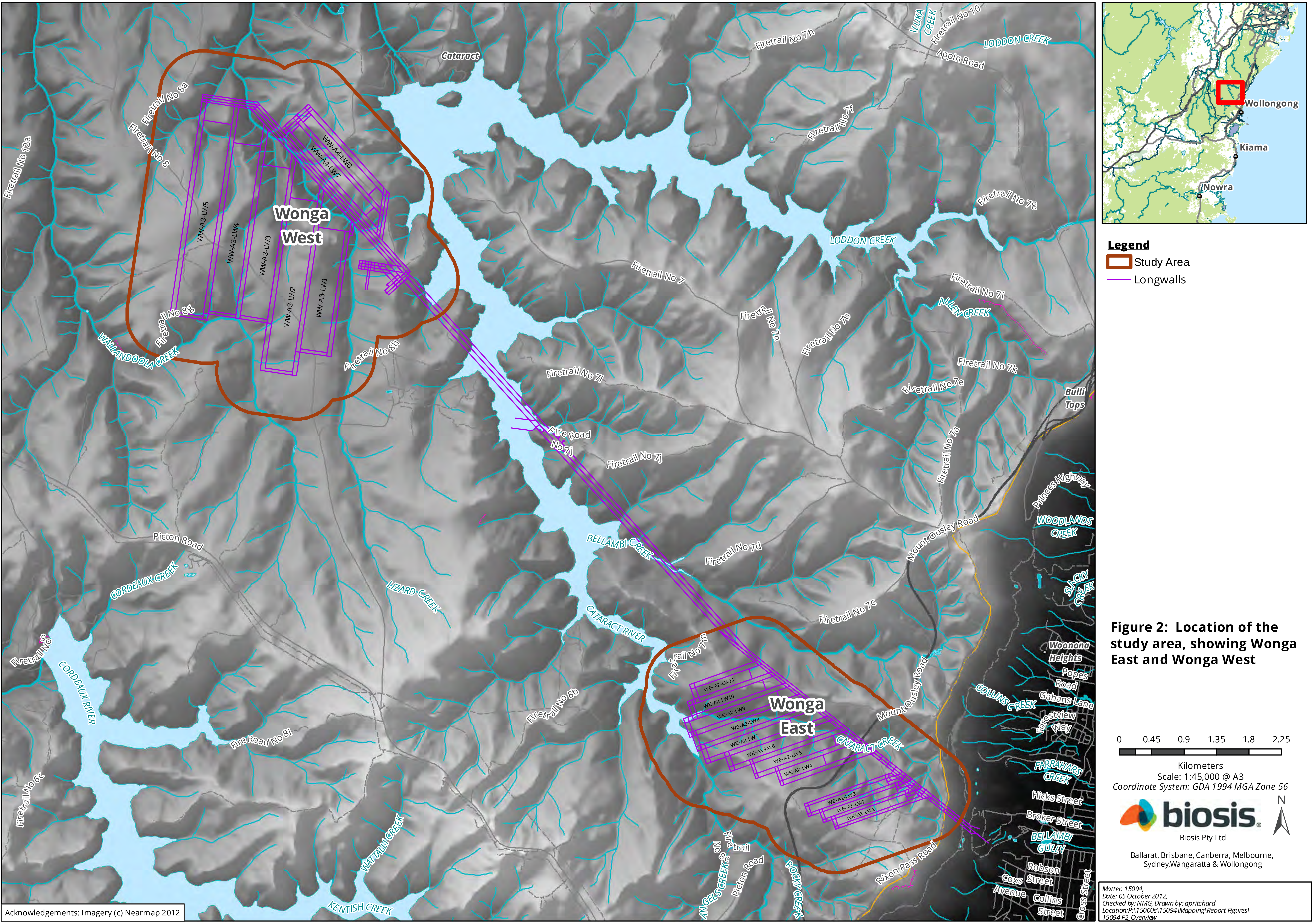

Acknowledgements: Imagery (c) Nearmap 2012

Legend

▭ Study Area

— Longwalls

Figure 2: Location of the study area, showing Wonga East and Wonga West

Kilometers

Scale: 1:45,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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15094 F2_Overview

2. Methods

2.1 Detailed Mapping of Upland Swamps

Upland swamps were mapped using a combination of Light Detection and Ranging (LiDAR) data, to define areas requiring further investigation, ground truthing of these areas in the field to define swamp boundaries and map swamp sub-communities and use of a Geographic Information System (GIS) to spatially represent data. This methodology is outlined further below.

2.1.1 Mapping of 'Potential Wetlands'

LiDAR data was obtained by AAM Group (previously AAM Hatch) using Airborne Laser Scanning (ALS) from a fixed wing aircraft on 20 October 2009.

Initial areas of 'Potential Wetland' were determined in an automated process using a series of GIS analysis tools in ArcGIS, which were combined into a single ArcGIS Model Builder geoprocessing model.

A CSV file, containing the raw LiDAR non-ground returns, was converted into a point feature class with one point for every captured non-ground return. The points were converted to a raster using the 'Topo to Raster' geoprocessing tool within ArcGIS Spatial Analyst to convert the points to a continuous raster surface. The matching CSV file, containing the raw LiDAR ground points, was converted to point data. The points were converted to a raster DEM using the same tool and parameters as the non-ground. A Canopy Height Model (CHM) was developed by subtracting the values of the ground raster from the non-ground raster. This CHM was then run through the 'Focal Statistics' tool in ArcGIS to produce a focal range raster. The output raster created by this tool represents the rate of change in the height of vegetation within a 1m^2 neighbourhood. It was taken that a high rate of change within this relatively small area would be likely to signify the boundary of a swamp.

The range values were then reclassified into categories in order to create hard breaklines between what was possibly swamp and what was likely taller, fringing vegetation. After discussion with experts on upland swamps within Biosis and some testing and evaluation of data in areas of known swamp it was decided that a rate of change greater than 2 m within a 1 m neighbourhood appeared to give the best indication of a potential swamp boundary. Although there may be instances where different vegetation communities within a swamp create a change greater than 2 m height within 1 m of travel, this option gave the closest representation of the boundary of the previously mapped control swamps whilst filtering out 'background noise' in the data.

The range raster by itself showed many areas where the rate of change was less than 2 m within a 1 m neighbourhood outside swamp areas due to thick canopy coverage of mature trees of similar height. To remove these areas the range raster it was run through the Conditional (Con) geoprocessing tool within ArcGIS to only retain areas of the range raster where the total vegetation height was less than 6 m. This was considered representative of swamps where vegetation rarely exceeds 6 m in height. The con raster was then converted to polygons representing a first cut of potential swamp land.

Following the automated process of LiDAR data into potential wetland polygons, further manual 'cleaning' of the polygons was required to further filter out false positives. The polygons were dissolved so any with overlapping or coincident boundaries were treated as a single swamp. After comparison with the known swamp control dataset, it was decided that only polygons over 1000 m^2 should be kept in order to filter out further 'background noise'. Any obvious false positives, including areas such as clearings, rods and waterbodies, were manually removed from the dataset using aerial imagery interpretation.

The polygons were then loaded on GIS capable field computers for field staff to locate and ground-truth.

2.1.2 Detailed Ground Truthing and Mapping of Vegetation Sub-communities

Following automated mapping of 'Potential Wetlands' these areas were ground-truthed to determine whether areas mapped were representative of upland swamps. A team of botanists experienced with the identification of upland swamps on the Woronora plateau visited all potential upland swamps.

Some areas mapped as 'Potential Wetland' consisted of rocky outcropping, mallee, dry heath vegetation or sparse canopy. These areas were excluded from further analysis.

Areas of upland swamp were assessed in detail. Boundaries of all swamps were mapped accurately using a combination of LiDAR data, ground-truthing using a handheld GPS and aerial photo interpretation (API). Where boundaries obtained during the automated processing of LiDAR data did not accurately reflect swamp boundaries these boundaries were revised using API and marked on printed field maps.

Vegetation sub-communities present within swamps were mapped using a combination of ground-truthing using a handheld GPS and API. Sub-communities were mapped according to community profiles contained within *The Native Vegetation of the Woronora, O'Hares and Sydney Metropolitan Catchments* (NPWS 2003), and included those communities considered part of the Coastal Upland Swamp EEC (NSW Scientific Committee 2012), including:

- MU 42 Upland Swamps: Banksia Thicket;
- MU43 Upland Swamps: Tea-tree Thicket;
- MU44 Upland Swamps: Sedgeland Heath Complex;
    - MU44(a) Sedgeland;
    - MU44(b) Restioid Heath;
    - MU44(c) Cyperoid Heath.

The NSW Scientific Committee Final Determination for Coastal Upland Swamp EEC (NSW Scientific Committee 2012) was also used as a key reference when classifying upland swamps.

Photos were taken of each swamp and photo points were recorded using a hand held GPS.

Following field assessment the results of detailed ground-truthing were digitised in a GIS. Boundaries of upland swamps and of sub-communities within swamps were refined, in collaboration with GIS staff using API. Where swamp boundaries continue beyond the Study Area polygons have been created based on a combination of aerial photo interpretation and NPWS (2003) vegetation mapping.

2.1.3 Classification and Naming of Upland Swamps

Upland swamps were classified into headwater swamps or valley infill swamps. Headwater swamps form in the headwater tributaries with gentle gradients less than 10 degrees, where plateau incision is weak. Valley infill swamps are formed in the incised valleys of second or third order streams and tend to elongate along the valley (Tompkins & Humphrey 2006, DoP 2008).

However, these traditional concepts for differentiation of upland swamps were difficult to implement as a part of this study, particularly for upland swamps in Wonga West where a number of what appeared to be narrow valley infill swamps were located on first order streams in low gradient areas, while complex mosaics of headwater and valley infill swamps occurred in other areas. In addition, the majority of upland swamps within the study area were found to occur on slopes less than 10 degrees. An alternate method for the classification of upland swamps was required.

To attempt to differentiate upland swamp types an analysis of slope and flow accumulation modelling (Section 2.2) was undertaken to define the slope and / or flow accumulation that delineated these two swamp types. Interpretation of mean flow accumulation indicated that swamps appeared to differentiate at a mean flow accumulation of 25,000 m^2, with upland swamp located in second and third order drainage lines having flow accumulations higher than this value. Using this differentiation point, each of the vegetation sub-communities was assigned to either headwater or valley infill swamp type.

Upland swamps were then grouped for naming and further analysis. Initially, areas of upland swamp vegetation connected by Fringing Eucalypt Woodland (MU45) or Mallee Heath (MU46), or upland swamp vegetation separated by rocky outcropping, were grouped and considered part of the one upland swamp complex. In areas where connectivity between proximate upland swamps was not obvious, slope and flow accumulation modelling were used to identify whether these swamps are independent or whether these swamps should be considered as the one upland swamp complex. Where upland swamps were located in close geographic proximity and were part of the same flow pathway and / or located along terraced slopes they were grouped together. Following an initial classification using this method, further refinement of swamp groups was undertaken, as initial observation indicated that some swamps that would otherwise be considered part of the same swamp were, in fact, located along different flow pathways. An extreme example of this is shown in Figure 3.

Swamps were then named based on the catchment they were positioned within, generally working from the upstream to downstream extent. Where a valley infill and headwater swamp were connected this was considered to form one functional unit, and therefore considered part of the same upland swamp. However, due to potential differences in type and degree of impacts they have been considered separately where appropriate.

2.2 Analysis of Upland Swamp Using a Geographic Information System

GIS analysis was undertaken using 1 m LiDAR data to create a number of analytical surfaces using ESRI ArcGIS 10.1 Spatial Analyst tools to produce layers and statistics used to categorise the terrain and water flow through individual swamp vegetation communities. The steps used to create this data are outlined below.

2.2.1 Slope and Flow Analysis

One metre thinned ground LiDAR data was converted to a continuous raster digital elevation model (DEM) using the Topo to Raster tool which interpolates point and contour data into a hydrologically corrected, continuous elevation surface that is the basis for many other analyses. The DEM was run through the Spatial Analyst slope tool to produce a surface showing degree of slope across the Study Area. Slope statistics pertaining to the boundaries of vegetation communities within coastal upland swamps previously modelled and ground-truthed by Biosis, were calculated using the Zonal Statistics as Table tool. This produced a table showing the minimum, maximum, sum, mean and standard deviations of slope within each of the vegetation patches. The table was joined to the original swamp vegetation community polygons, which were then symbolised along a range using these statistics in order to characterise the relationship between the vegetation communities and slope.

The 1 m DEM was run through the Fill tool in Spatial Analyst to create a depression-less DEM. This tool fills any sinks in the DEM created by errors in the data or natural areas of pooling to remove barriers to flow through these areas and allow analysis of flow paths and accumulation across the DEM. A flow direction surface was created from the depression-less DEM as an intermediate step required for analysing flow accumulation. A flow accumulation surface was produced from the flow direction model. The flow accumulation model shows for each cell in the accumulation raster, how many cells upstream of the subject cell flow into any given point across the model. This effectively represents how large the catchment area of any given point on the surface and the path the accumulated water will take from its source to its outfall. Although flow accumulation models flow pathways through the landscape based on flow direction, it does not provide a representation of creeks per se, and should not be taken as such.

Similarly, to the slope analysis, statistics of minimum, maximum, mean, total and standard deviation of flow through each mapped upland swamp vegetation community were calculated using the Zonal Statistics tool. The resulting statistics table was joined back to the swamp polygons for further analysis.

2.2.2 Subsidence Calculations

The predicted effects of modelled 'upper bound scenario' mining subsidence were investigated by creating additional slope and flow surfaces using a DEM adjusted to show surface levels following modelled subsidence. The methods used to create these surfaces are as follows:

- Predicted mining subsidence 'worst case scenario' contours provided by Seedsman (2012) were interpolated using the 'Topo to Raster' tool to produce a predicted subsidence surface;
- This subsidence surface was subtracted from the DEM modelled from the LiDAR data to produce a predictive DEM showing adjusted surface levels following 'worst case scenario' vertical shift due to mine subsidence;
- The adjusted DEM was converted to a slope surface as per the method use to model the unadjusted DEM; and
- The adjusted DEM was converted to a flow accumulation layer using the same methods and parameters applied to the original DEM.

Zonal statistics were calculated for each swamp community using the predicted post mining subsidence flow accumulation surface. The resulting data was then joined back to the original swamp vegetation community boundaries polygon layer. The matching pre-mining statistical values were then subtracted from the post mining statistic values. This resulted in negative values where a net loss of flow and positive values where a net gain in flow through a community was predicted. The resulting values were also used to represent the magnitude of the change in water flowing through a given community.

Spatial layers of the flow accumulation models were created to show darkening colour along an identical scale so that pre and post mining flow scenarios could be visually compared to show diversion of water through individual swamps and communities.

2.3 Comparison to Regional Vegetation Mapping (NPWS 2003)

Upland swamp mapping undertaken for this project was compared with mapping of upland swamps from *The Native Vegetation of the Woronora, O'Hares and Sydney Metropolitan Catchments* (NPWS 2003). NPWS (2003) acknowledge the limitations of the mapping, and the data contained within is only meant to provide a guide and should not be relied upon for detailed impact assessment.

Two regional upland swamp mapping layers were created using a Geographic Information System. The first layer included all upland swamp communities representative of the Coastal Upland Swamp EEC, and included:

- MU 42 Upland Swamps: Banksia Thicket;
- MU43 Upland Swamps: Tea-tree Thicket;
- MU44 Upland Swamps: Sedgeland Heath Complex;
    - MU44(a) Sedgeland;
    - MU44(b) Restioid Heath; and
    - MU44(c) Cyperoid Heath.

This layer was cropped at the boundaries of the study area.

A second layer was created where boundaries between vegetation sub-communities were dissolved to create a Coastal Upland Swamp EEC layer. From this layer the number of upland swamps in each area, the total area of upland swamp and the total area for each vegetation sub-community were calculated.

Comparisons were then made between swamp mapping from NPWS (2003) and data obtained as a part of this assessment.

2.4 Significance and Impact Assessment

The impact assessment was undertaken in two stages. The first stage involved the undertaking of an impact assessment according to the Draft *Upland Swamp Environmental Impact Assessment Guidelines* (OEH 2012).

The second stage involved an assessment of the potential for upland swamps of 'special significance' to be impacted based on a variety of features, including an initial risk assessment according to OEH (2012), comparative analysis of upland swamps that have previously been undermined, changes to flow accumulation and potential for fracturing of bedrock and desiccation.

2.4.1 Assessment of 'Special Significance'

The assessment of 'special significance' of upland swamps was undertaken according to OEH (2012). This document sets out five criteria for determining whether upland swamps are considered of 'special significance', including:

- Statutory thresholds;
- Substantial size;
- Unusual complexity;
- Closely proximal habitat (swamp clusters); and,
- Scientific research importance.

An upland swamp is considered to be 'special significance' if it meets three out of the five 'special significance' criteria (OEH 2012).

All upland swamps mapped as a part of this assessment form part of the Coastal Upland Swamp EEC, and therefore meet the statutory threshold criterion. In addition, a number of upland swamps within the study area are, either known to support threatened species and / or provide potential habitat for threatened species.

There are four key clusters of upland swamps on the Woronora plateau; Maddens Plain; Wallandoola Creek; North Pole; and Stockyard. Upland swamps within the study area form part of the Wallandoola Creek cluster, and therefore meet this criterion.

OEH (2012) defines upland swamps as being of scientific research importance if they are important reference sites, contain unique features or resources for scientific study, are part of a network of research sites or are part of a research project. OEH (2012) maps upland swamps of scientific research importance. Upland swamps within the study area are not considered of scientific research importance.

All upland swamps with a size greater than 7.4 ha are considered substantial in size. This size threshold represents the top 10% of upland swamps on the Woronora plateau.

To meet the criterion for unusual complexity (biodiversity), swamps must contain Tea-Tree Thicket (MU43) or contain all vegetation sub-communities. If the assessment is relying solely on NPWS (2003) mapping, the presence of Tea-Tree Thicket (MU43) is used to indicate that other vegetation sub-communities are likely to be present. If independent assessment of vegetation sub-communities is undertaken then an upland swamp must contain all vegetation sub-communities, including Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Sedgeland-Heath Complex (MU44), to be considered unusually complex. As all upland swamps were ground-truthed, and detailed mapping of vegetation sub-communities undertaken, upland swamps must contain all vegetation sub-communities to be considered unusually complex.

2.4.2 Assessment of Potential for Impact

Those upland swamps considered to be of 'special significance' were subject to an impact assessment to determine whether an impact to these upland swamps is predicted to occur.

OEH (2012) requires proponents to undertake a preliminary prediction of subsidence levels under upland swamps and compare this to subsidence criteria outlined in PAC (2010) to determine upland swamps considered to be at risk of negative environmental consequences. These criteria include:

- all swamps subject to systematic tensile strains > 0.5 mm / m;
- all swamps subject to systematic compressive strains > 2 mm / m;
- all swamps with depth of cover less than 1.5 times longwall panel width;
- all swamps subject to tilt (transient or final) > 4 mm/ m;
- all swamps subject to valley closure of > 200 mm / m; and,
- all swamps subject to a maximum observed closure strain > 7.0 mm / m.

However, given the inexact nature of subsidence predictions OEH (2012) also request that a comparative analysis of subsidence levels from past mining operations and observed impacts to upland swamps is undertaken.

Due to the difficulty with obtaining subsidence data on previous mining operations in conjunction with monitoring data from upland swamps an alternate approach was considered warranted by the current assessment. Hydrology, particularly shallow groundwater and surface water flows, is a key component in the formation and maintenance of upland swamps. As detailed in Section 1.2.4, changes in hydrology resulting from subsidence associated with longwall mining have potential to result in impacts to upland swamps. Thus it was deemed that an assessment of hydrology was critically important to undertaking any risk assessment.

For this reason the following work was also undertaken to inform the risk assessment:

- Hydrological assessment undertaken by Geoterra Pty Ltd;
- Analysis of flow accumulation pre- and post-mining, taking into account subsidence predictions (Seedsman 2012); and,
- Predicted compressive and tensile strains to determine areas that may be subject to fracturing of bedrock.

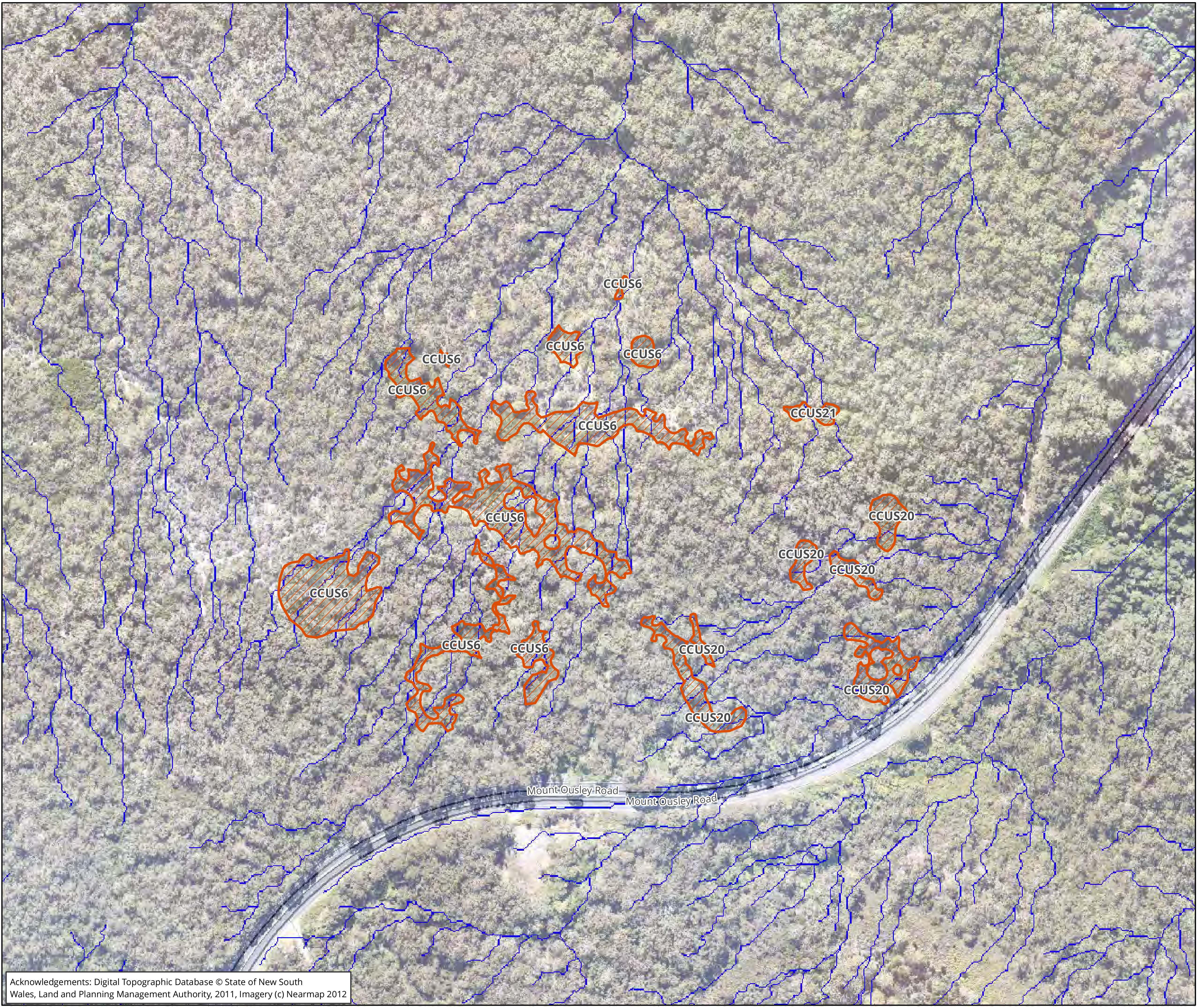
It was deemed that these analyses, considered in conjunction, would provide best practice predictions for upland swamps considered at risk of impact as a result of longwall mining in Wonga East and Wonga West.

2.5 Qualifications

Areas of Upland Swamp: Fringing Eucalypt Woodland (MU45) were not mapped as a part of this assessment. At the margins of swamps this vegetation community intergrades with surrounding Eucalypt woodland, and is difficult to differentiate in many areas. In addition, the methods used for this project to map upland swamps excluded areas of this community due to presence of a tree layer greater than 6 m in height.

Flow accumulation modelling does not provide an assessment of streams within the study area, and should not be used as such. Flow accumulation models flow pathways from the start of a catchment and models catchment areas. Flow accumulation modelling provides an indication of changes to catchment areas and potential pathways.

Subsidence predictions are inexact and provide a guide for understanding potential subsidence effects. Analysis based on these will also have the same level of uncertainty and provide a guide only.



Legend

▨ Upland Swamp

Flow Accumulation

☐ Nil

■ Flow Accumulation

Figure 3: Swamp CCUS6, CCUS20 and CCUS21 showing how slope and flow accumulation can be used to group swamps

0 30 60 90 120 150

Meters

Scale: 1:3,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

N

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3. Results

3.1 Description Classification of Upland Swamps

3.1.1 Wonga East

A total of thirty-nine (39) upland swamps were recorded within Wonga East (Figure 4). Of these, fourteen (14) are within the predicted limits of subsidence.

Size ranged from 0.04 ha to 9.84 ha with an average of 1.26 ha. All swamps within Wonga East are headwater swamps.

The majority of upland swamps in Wonga East (34/39) support Banksia Thicket (MU42), with twenty (20) upland swamps supporting only this vegetation sub-community. Ten (10) upland swamps support Tea-tree Thicket (MU43). Six (6) upland swamps support a complete range of upland swamp vegetation sub-communities (MU42, MU43 and MU44).

Seven (7) uplands swamp in Wonga East are considered to be of 'special significance' according to criteria set out in OEH (2012) (see Section 4.1). All swamps within Wonga East meet criteria for statutory thresholds (Coastal Upland Swamp EEC) and closely proximate habitat (all are part of the Wallandoola Creek cluster). CRUS1 is considered to be of 'special significance' based on size in addition to the criteria above, while CCUS1, CCUS4, CCUS5, CCUS10, CRUS2 and CRUS3 are considered to be of 'special significance' due to the complexity of vegetation sub-communities within these swamps, as all support Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Sedgeland-Heath Complex (MU44a,b,c). Of these significant swamps, five (5) have potential to be subject to subsidence (CCUS1, CCUS4, CCUS5, CCUS10 and CRUS1).

A detailed description of each upland swamp within Wonga East is provided in Appendix 1.

3.1.2 Wonga West

A total of forty-five (45) upland swamps were recorded within Wonga West (Figure 5). Of these, thirty-six (36) are within the predicted limits of subsidence.

Size ranged from 0.06 ha to 129.89 ha with an average of 4.79 ha. Wonga West contains a mix of headwater and valley infill swamps, with four upland swamps (LCUS1, LCUS6, LCUS8 and WCUS4) containing both headwater and valley infill swamp types. However, as these swamps are functioning as one larger swamp they have been named as such.

Upland swamps in Wonga West are diverse in the vegetation sub-communities they support. Restioid Heath (MU44b) was the most abundant vegetation sub-community, with twenty-seven (27) upland swamp supporting this community of which thirteen (13) supporting only this community. Twenty-six (26) upland swamps support Banksia Thicket (MU42), with twelve (12) upland swamps supporting only this vegetation sub-community. Thirteen (13) upland swamps support Tea-tree Thicket (MU43). Six (6) upland swamps support a complete range of upland swamp vegetation sub-communities (MU42, MU43 and MU44).

Eight (8) upland swamps in Wonga West are considered of 'special significance' according to criteria set out in OEH (2012) (see Section 4.1). All swamps within Wonga West meet criteria for statutory thresholds (Coastal Upland Swamp EEC) and closely proximate habitat (all are part of the Wallandoola Creek cluster). WCUS4 is considered to be of 'special significance' based on size in addition to the criteria above. LCUS6, LCUS8, LCUS27, WCUS7 and WCUS11 are considered to be of 'special significance' due to the complexity of vegetation sub-communities within these swamps, as all support Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Sedgeland-Heath Complex (MU44a, b, c). LCUS1 and WCUS1 are considered to be of 'special significance' due to size and complexity. Of these significant swamps, seven (7) are predicted to be subject to subsidence.

A detailed description of each upland swamp within Wonga West is provided in Appendix 1.

3.2 Comparison with Regional Vegetation Mapping (NPWS 2003)

Comparison between mapping of upland swamp with that by NPWS (2003) indicated that upland swamps are more complex, more numerous and differ in extent when compared to data from NPWS (2003). The limitations of the sampling, analysis and mapping are however acknowledged by NPWS (2003).

Summary statistics are provided in Table 4 and Table 5. A visual comparison is provided in Figure 4 and Figure 5.

Table 4: Comparison of upland swamp mapping by Biosis (2012) and NPWS (2003) for Wonga East (600 m buffer)

	Biosis (2012)	NPWS (2003)
Total No. of Upland Swamps	39	28
Total area of Upland Swamps	49.06 ha	68.04 ha
Area of Banksia Thicket (MU42)	35.15 ha	48.35 ha
Area of Tea-tree Thicket (MU43)	5.20 ha	0 ha
Area of Sedgeland-Heath (MU44)	8.71 ha	19.69 ha

Table 5: Comparison of upland swamp mapping by Biosis (2012) and NPWS (2003) for Wonga West (600 m buffer)

	Biosis (2012)	NPWS (2003)
Total No. of Upland Swamps	45	18
Total area of Upland Swamps	72.13 ha	50.79 ha
Area of Banksia Thicket (MU42)	15.76 ha	4.86 ha
Area of Tea-tree Thicket (MU43)	13.92 ha	1.67 ha
Area of Sedgeland-Heath (MU44)	42.44 ha	44.26 ha

Mapping of upland swamp undertaken for this project:

- located an additional eleven (11) upland swamps at ten (10) locations in Wonga East;
- found that two areas mapped as upland swamp by NPWS (2003) in Wonga East were not upland swamp;

- located an additional twenty-six (26) upland swamps at twenty-two (22) location in Wonga West;
- found that there was 18.98 ha less upland swamp within Wonga East than mapped by NPWS (2003);
- found that there was 21.34 ha more upland swamp in Wonga West than mapped by NPWS (2003);
- found that all Banksia Thicket (MU42) and Sedgeland-Heath Complex (MU44) were less prevalent in Wonga East than mapped by NPWS (2003) but there was Tea-tree Thicket (MU43) that had not been mapped;
- found that Banksia Thicket (MU42) and Tea-tree Thicket (MU43) were more prevalent in Wonga West than mapped by NPWS (2003) but Sedgeland-Heath Complex (MU44) was equivalent in extent;
- found that upland swamp are much more complex than reflected by NPWS (2003) with areas mapped as one large swamp by NPWS (2003) were often comprised of several discrete swamps separated by areas of forest or reliant upon surface flows from different locations; and,
- found that the extent and location of vegetation sub-communities was much more complex than as shown by NPWS (2003), with swamps mapped as containing one or two areas of each sub-community were actually comprised of numerous, smaller units of each vegetation sub-community.

Detailed mapping of upland swamp using LiDAR to indicate areas for further investigation, followed by ground-truthing and detailed mapping of vegetation sub-communities within each swamp has shown that mapping of upland swamps by NPWS (2003) does not accurately represent the extent or complexity of upland swamps. As per the limitations of this mapping outlined in Section 2.3, this is to be expected based on a more detailed assessment of vegetation communities within the study area.

This, in turn, means that impact assessments based on data obtained by NPWS (2003) are unlikely to be capable of accurately predicting impacts to upland swamps. Based on observed and predicted impacts to upland swamps this lack of understanding of the micro-scale changes in soil moisture within a swamp and thus the sub-communities reliant upon it, are likely to inhibit the ability of proponents to reliably predict impacts to upland swamps. For example, this project has found that Tea-tree Thicket MU43 was much more prevalent than as mapped by NPWS (2003), with this community more dependant on permanent waterlogging and thus more susceptible to impact. In addition, mapping of Sedgeland-Heath Complex MU44 by NPWS (2003) does not reflect changes between Sedgeland (MU44a), Restioid Heath (MU44b) and Cyperoid Heath (MU44c). As Cyperoid Heath (MU44c) is reliant on intermittent waterlogging when compared to other communities within this complex to accurately predict areas most at risk proponents, need to understand this micro-scale change and complexity.

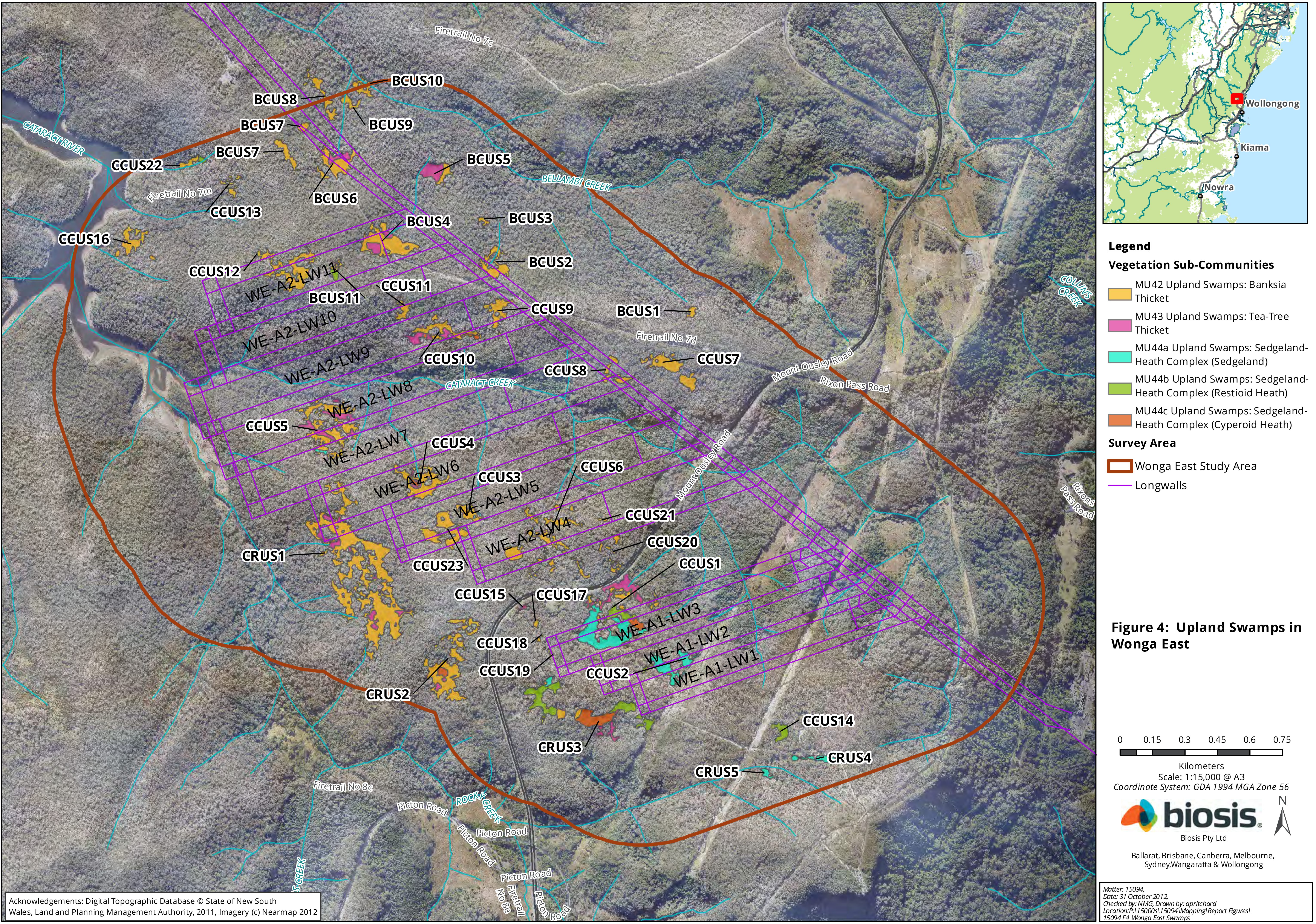

Figure 4: Upland Swamps in Wonga East

Scale: 1:15,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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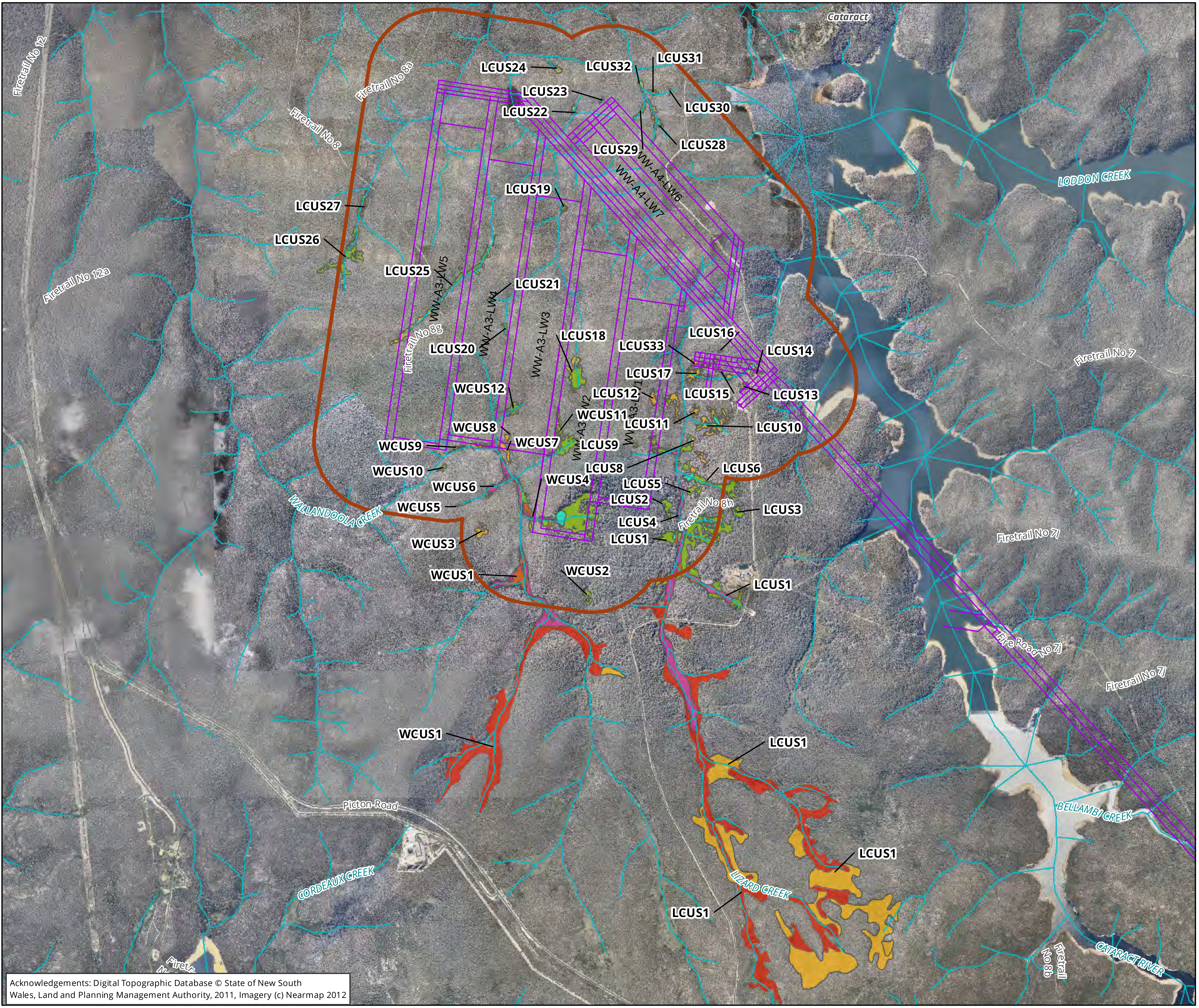

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Legend

Vegetation Sub-Communities

- 🟨 MU42 Upland Swamps: Banksia Thicket
- 🟪 MU43 Upland Swamps: Tea-Tree Thicket
- 🟦 MU44a Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- 🟩 MU44b Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- 🟧 MU44c Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Vegetation Outside Current Study Area (NPWS 2003)

- 🟥 MU44 Upland Swamps: Sedgeland-Heath Complex

Survey Area

- ▭ Wonga West Study Area
- — Longwalls

Figure 5: Upland Swamps in Wonga West

0 0.3 0.6 0.9 1.2 1.5

Kilometers

Scale: 1:30,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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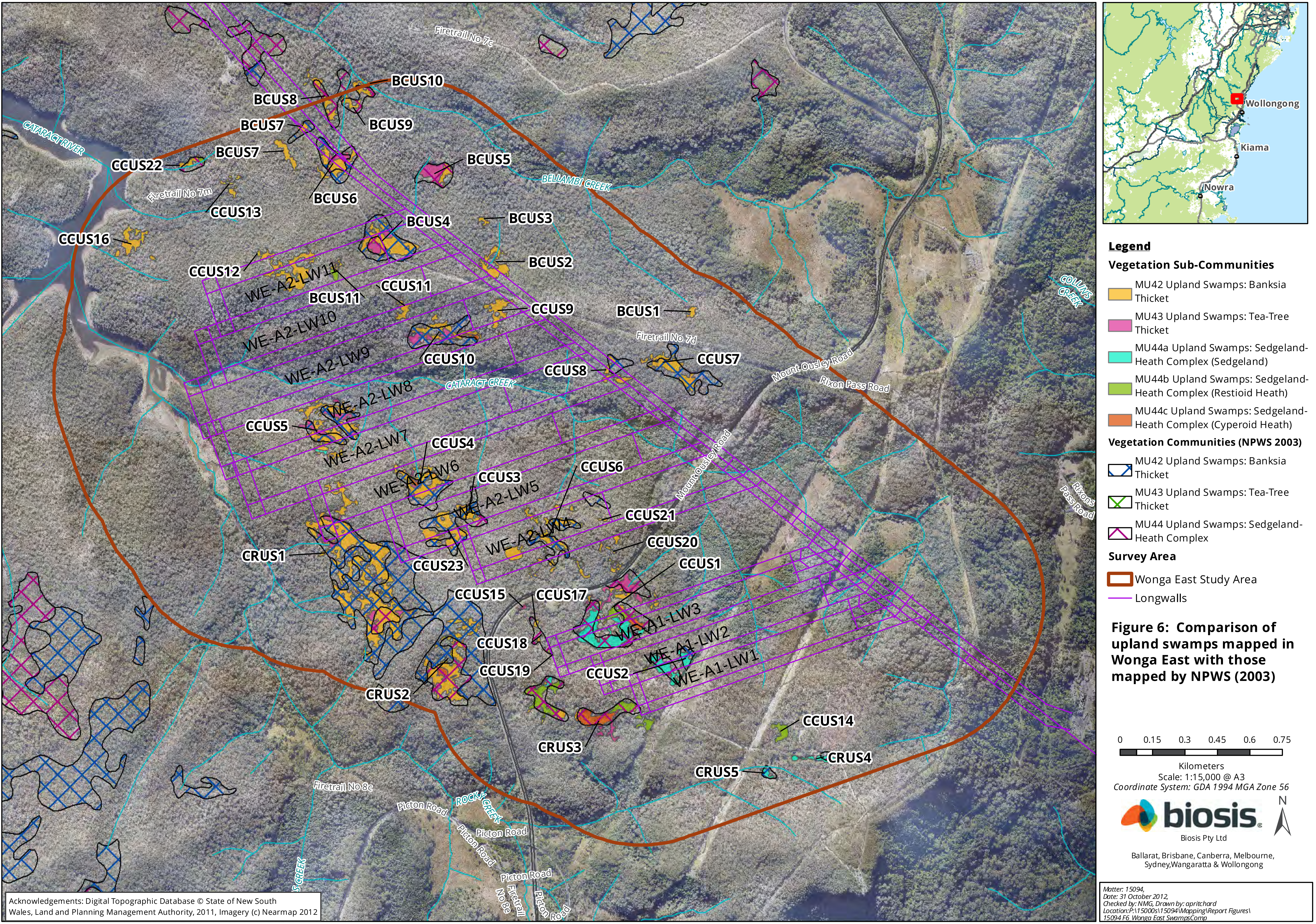

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Vegetation Sub-Communities

- 🟨 MU42 Upland Swamps: Banksia Thicket
- 🟪 MU43 Upland Swamps: Tea-Tree Thicket
- 🟦 MU44a Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- 🟩 MU44b Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- 🟧 MU44c Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Vegetation Communities (NPWS 2003)

- ▨ MU42 Upland Swamps: Banksia Thicket
- ▨ MU43 Upland Swamps: Tea-Tree Thicket
- ▨ MU44 Upland Swamps: Sedgeland-Heath Complex

Survey Area

- ▭ Wonga East Study Area
- — Longwalls

Figure 6: Comparison of upland swamps mapped in Wonga East with those mapped by NPWS (2003)

Scale: 1:15,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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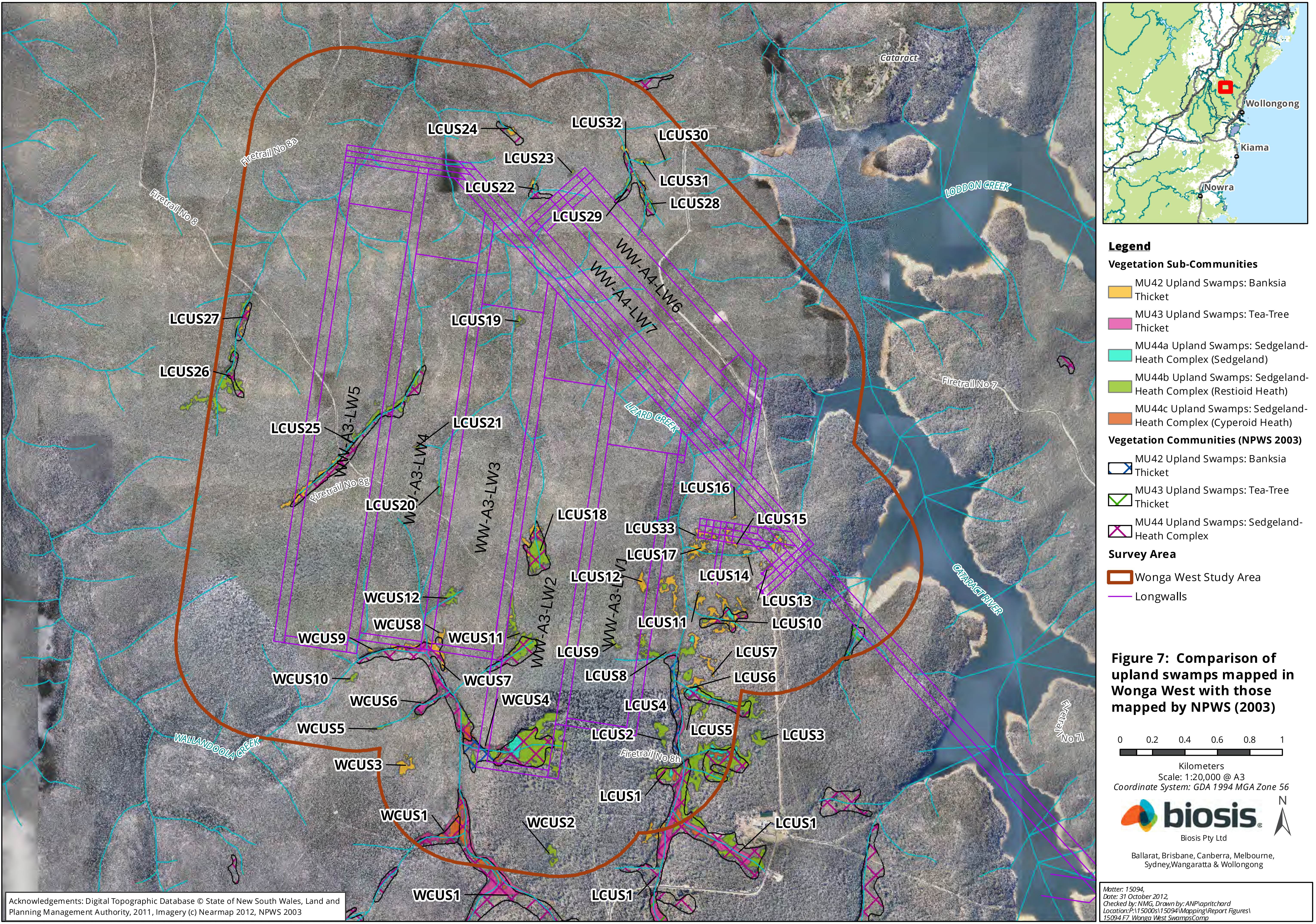

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Vegetation Sub-Communities

- 🟨 MU42 Upland Swamps: Banksia Thicket
- 🟪 MU43 Upland Swamps: Tea-Tree Thicket
- 🟦 MU44a Upland Swamps: Sedgeland-Heath Complex (Sedgeland)
- 🟩 MU44b Upland Swamps: Sedgeland-Heath Complex (Restioid Heath)
- 🟧 MU44c Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)

Vegetation Communities (NPWS 2003)

- ▨ MU42 Upland Swamps: Banksia Thicket
- ▨ MU43 Upland Swamps: Tea-Tree Thicket
- ▨ MU44 Upland Swamps: Sedgeland-Heath Complex

Survey Area

- ▭ Wonga West Study Area
- — Longwalls

Figure 7: Comparison of upland swamps mapped in Wonga West with those mapped by NPWS (2003)

0 0.2 0.4 0.6 0.8 1

Kilometers

Scale: 1:20,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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4. Upland Swamp Significance and Impact Assessment

This section provides an assessment of impacts to upland swamps based on:

- Significance criteria set out in the *Draft Upland Swamp Environmental Impact Assessment Guidelines* (OEH 2012);
- An initial risk assessment based on subsidence criteria outlined in PAC (2010) and OEH (2012);
- A comparative analysis of previous mining and observed impacts to upland swamps;
- An analysis of groundwater levels obtained from piezometers within the study area (GeoTerra Pty Ltd);
- Analysis of slope and flow accumulation pre- and post-mining; and,
- Compressive tilts and strains and potential impacts to upland swamps.

The goal of the impact assessment was to determine upland swamps of 'special significance' considered to be at significant risk of impact as a result of subsidence associated with longwall mining.

4.1 Assessment of 'Special Significance'

All upland swamps within the study area fulfil two out of the five criteria listed in OEH (2012) for determining whether upland swamps are considered to be of 'special significance'. All upland swamps form part of the Coastal Upland Swamp EEC, and all upland swamps are part of the Wallandoola Creek cluster of upland swamps. Thus all upland swamps are considered significant on the basis of statutory thresholds and closely proximate habitat. No upland swamps within the study area are considered to be significant due to the scientific research importance criteria.

The size and complexity for all upland swamps was assessed and level of significance determined. Any upland swamp meeting three out of the five criteria listed in OEH (2012) are considered to be of 'special significance'.

The assessment of 'special significance' identified that seven (7) upland swamps in Wonga East and eight (8) upland swamps in Wonga West are of 'special significance'. Analysis for significant swamps is presented in Table 6 and Table 7. Significant swamps are shown in Figure 8 and Figure 9.

Table 6: Assessment of 'Special Significance' - Wonga East

Swamp Name	Statutory	Size (ha)	Complexity	Cluster	Scientific	Significant	Reason
CCUS1	*Coastal Upland Swamp EEC*	4.81	*MU42, MU43, MU44b, MU 44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CCUS10	*Coastal Upland Swamp EEC*	1.63	*Yes - MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely

Swamp Name	Statutory	Size (ha)	Complexity	Cluster	Scientific	Significant	Reason
							proximate habitat, Complexity
CCUS4	*Coastal Upland Swamp EEC*	1.77	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CCUS5	*Coastal Upland Swamp EEC*	3.45	*MU42, MU43, MU44a*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CRUS1	*Coastal Upland Swamp EEC*	*9.84*	MU42, MU43	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Size
CRUS2	*Coastal Upland Swamp EEC*	3.12	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
CRUS3	*Coastal Upland Swamp EEC*	3.42	*MU42, MU43, MU44a, MU44b, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity

Table 7: Assessment of 'Special Significance' - Wonga West

SwampName	Statutory	Size (ha)	Complexity	Cluster	Scientific	SigAss	Reason
LCUS1	*Coastal Upland Swamp EEC*	*129.9*	*MU42, MU43, MU44b*	*Wallandoola*	No	Yes	Statutory threshold,

SwampName	Statutory	Size (ha)	Complexity	Cluster	Scientific	SigAss	Reason
							Closely proximate habitat, Size, Complexity
LCUS27	*Coastal Upland Swamp EEC*	1.04	*MU42, MU43, MU44b*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
LCUS6	*Coastal Upland Swamp EEC*	3.74	*MU42, MU43, MU44a, MU44b, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
LCUS8	*Coastal Upland Swamp EEC*	2.09	*MU42, MU43, MU44a, MU44b*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
WCUS1	*Coastal Upland Swamp EEC*	*36.16*	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Size, Complexity
WCUS11	*Coastal Upland Swamp EEC*	2.79	*MU42, MU43, MU44b*	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Complexity
WCUS4	*Coastal Upland Swamp EEC*	*11.08*	MU43, MU44a, MU44b, MU44c	*Wallandoola*	No	Yes	Statutory threshold, Closely proximate habitat, Size
WCUS7	*Coastal Upland Swamp EEC*	1.97	*MU42, MU43, MU44c*	*Wallandoola*	No	Yes	Statutory threshold,

SwampName	Statutory	Size (ha)	Complexity	Cluster	Scientific	SigAss	Reason
							Closely proximate habitat, Complexity

Full results are presented in the Swamp matrix shown in Appendix 2. Upland swamps of 'special significance' are considered further below.

4.2 Assessment of Potential Impacts

4.2.1 Initial Risk Assessment

An initial risk assessment on upland swamps of 'special significance' was undertaken according to subsidence criteria outlined in PAC (2010) and OEH (2012). Results are presented in Table 8 and Table 9.

Table 8: Initial Risk Assessment for Wonga East (Figures in bold are greater than criteria outlined in OEH 2012)

SwampName	Ratio Depth of cover : Panel width	Tensile Strain	Compressive Strain	Max Tilt
CCUS1	2.47	**2.65**	**-6.79**	**11.38**
CCUS4	1.91	**4.63**	**-8.03**	**21.04**
CCUS5	1.89	**4.74**	**-8.03**	**21.30**
CCUS10	1.92	**4.60**	**-8.74**	**21.39**
CRUS1	1.85	**4.34**	**-7.20**	**17.51**
CRUS2	-	0.00	0.00	0.00
CRUS3	-	0.00	0.00	0.00

Table 9: Initial Risk Assessment for Wonga West (Figures in bold are greater than criteria outlined in OEH 2012)

SwampName	Ratio Depth of cover : Panel width	Tensile Strain	Compressive Strain	Max Tilt
LCUS1	-	0.00	0.00	0.00
LCUS6	-	0.00	0.00	1.93
LCUS8	**1.27**	**2.75**	**-2.64**	9.15

SwampName	Ratio Depth of cover : Panel width	Tensile Strain	Compressive Strain	Max Tilt
LCUS27	-	0.00	0.00	0.00
WCUS1	-	0.00	0.00	0.00
WCUS4	**1.28**	**5.03**	**-6.97**	10.58
WCUS7	**1.31**	**5.45**	-0.01	10.70
WCUS11	**1.31**	**5.35**	**-3.81**	8.02

Based on this initial risk assessment according to subsidence criteria outlined in PAC (2010) and OEH (2012) 'special significance' upland swamps CCUS1, CCUS4, CCUS5, CCUS10 and CRUS1 in Wonga East and LCUS8, WCUS4, WCUS7 and WCUS11 in Wonga West can be considered at risk of negative environmental consequences based on these subsidence criteria.

Special significance upland swamps CRUS2 and CRUS3 in Wonga East and LCUS1, LCUS6, LCUS27 and WCUS1 in Wonga West are considered not at risk of negative environmental consequences based on these subsidence criteria.

4.2.2 Comparative Analysis

Due to the inexact nature of subsidence predictions OEH (2012) requires an assessment of past mining and subsidence with impacts to upland swamps resulting from this subsidence. In this regard there is a significant paucity of data available to undertake such a comparative analysis.

Impacts to a very small number of upland swamps, located above mining areas, have been observed. The most notable and widely reported include Swamp 37 (Drillhole Swamp) and Swamp 18 in the Avon catchment (EarthTech 2003; Tomkins and Humphrey 2006) and Flatrock Swamp in the Woronora catchment (Tompkins and Humphrey 2006). Although hypothesised to be a contributing factor, subsidence has not been determined to be a sole reason for any observed impacts to upland swamps; however subsidence effects are believed to be a contributing factor.

The following summarises EarthTech (2003), Tompkins and Humphrey (2006) and other relevant the reports and assessments.

EarthTech (2003)

EarthTech (2003) provides an analysis of seven (7) upland swamps where longwall mining has occurred as well as eleven (11) upland swamps where bord and pillar or shortwall mining has been undertaken. These upland swamps, including a mix of headwater and valley infill swamps, were located in proximity to the former Elouera Colliery. Mining in this area has been undertaken across an extensive period of time, with bord and pillar mining being undertaken prior to the extraction of coal from the Elouera mine commencing in 1993 and extending northwards under a number of upland swamps.

Swamps 17, 18, 19, 26 and 27 are located directly above longwalls mined as part of the former Elouera colliery, while Swamps 21a and 31 are located in close proximity to these longwalls. Of these upland swamps, six (6) were found to have been subject to subsidence effects, including subsidence, cracking or collapse of underground workings. Of these, one (1) upland swamp (Swamp 18) was found to have undergone observable impacts including scouring and erosion. Swamp 19 was hypothesised to have undergone some impacts including development of scour pools; however this is likely to be a natural part of cut and fill events within this dynamic vegetation community and is not considered to be an impact per se (see below). Maximum vertical subsidence associated with the extraction of these longwalls was 1.2 m. Earth Tech (2003) hypothesised that impacts to Swamp 18 resulted from drying due to fracturing of bedrock below the swamp and a change in gradient through the swamp resulting in the re-distribution of water within the swamp. Contributing factors include the size of the swamp and alignment perpendicular to, and spanning, longwalls. Swamps where impacts were not observed (Swamps17, 21a, 26 and 27) were smaller and generally aligned with longwalls or were not located directly above longwalls.

Swamps 20, 21b, 22, 24, 28a, 28b, 29, 30, 37a, 37b and 37c are located either partially or wholly above bord and pillar or shortwall workings. Of these upland swamps nine (9) have been subject to known subsidence effects, including subsidence, cracking or collapse of underground workings, while two may have been subject to subsidence effects. Of these, one (1) upland swamp (Swamp 37a) was found to have undergone observable changes including gully erosion and scouring. Although maximum subsidence associated with Swamp 37a was 2.4m, which is comparable to vertical subsidence from longwall extraction, mechanical disturbance (to Swamp 37a formation of a road through the swamp) occurred prior to erosion and scouring. The presence of this form of disturbance confounds any attempts to make a conclusion on the impacts of mining.

Based on data from this report we can cautiously conclude that subsidence of 1.2 m is known to have resulted in dewatering of one (1) out of five (5) upland swamps located directly above the former Elouera colliery. This subsidence effect, in conjunction with other factors such as fire and intense rainfall, may have contributed to the erosion and scouring of Swamp 18. However, a lack of impact to four subsided swamps indicates that mining-induced subsidence is not a sole cause of erosion of upland swamps.

Tompkins and Humphrey (2006)

Tompkins & Humphrey (2006) undertook an assessment of three (3) upland swamps within the Avon and Woronora catchments to assess the causes and triggers for erosion of upland swamps.

Tompkins and Humphrey looked at past aerial photography, swamp stratigraphy, subsidence effects and fire history of Swamp 18, Swamp 37a (Drillhole Swamp) and Flatrock Swamp. All of these swamps have undergone erosion, scouring and gully formation and all have been undermined, either by longwall mining or bord and pillar mining.

By looking at swamp stratigraphy Tompkins and Humprhrey (2006) were able to deduce that the erosion and filling of upland swamps is part of a natural process and that the development of scour pools is the first indication of the potential for such an event. What causes the initial formation of scour pools is not known, but is likely to be triggered by heavy rainfall.

Tompkins and Humphrey (2006) also concluded that upland swamps erode as a result of a unique set of circumstances where internal thresholds are breached. It is likely that a combination of factors, including prior erosion, fire, anthropomorphic impacts and heavy rainfall breach these thresholds.

Tompkins and Humphrey (2006) concluded that dewatering and drying of upland swamps as a result of fracturing of the bedrock may have increased the erosion potential of these upland swamps. This drying, in conjunction with fire and substantial rainfall, is likely to have increased the susceptibility of upland swamps, particularly Swamp 18, to erosion. However, they also found that no single factor could be directly implicated in the erosion of these upland swamps. The presence of scour pools was a likely indicator of future erosion.

Dendrobium Area 2 and 3A

Impacts to groundwater levels around two upland swamps within BHP Billiton's (BHPB) Dendrobium Area 3A mine have been recorded (Comur Consulting 2012). Groundwater levels in four piezometers located within Swamp 12 have exhibited a lack of sustained groundwater recovery following mining of Longwall 7. Groundwater levels in two piezometers have shown a reduced recovery of groundwater following mining of Longwall 7. This lack of sustained groundwater is concurrent with observed fracturing of creeks below both upland swamps. To date no observable impacts to these upland swamps have resulted from this reduction in groundwater levels. Longwall 7 has resulted in a maximum vertical subsidence of 1.4 m, maximum tilt of -14 mm / m and maximum strain of 7 mm / m (MSEC 2012).

At Swamp 1 in Dendrobium Area 2 a reduction if groundwater levels in piezometers located in proximity to Swamp 1 coincides with observations of surface fracturing within this upland swamp (Biosis 2011). Despite these observable subsidence effects, no erosion of Swamp 1 has been observed. Changes in flora species composition within Swamp 1 appears to be changing at a faster rate than control swamps, with species richness and diversity declining since this area was undermined (Biosis 2012). However, this decline in species richness and diversity is to be expected following fire, with obligate seeding shrubs out-competing other species and curtailing their growth (Keith *et al.* 2006).

It is too early to tell whether reductions in groundwater in Swamps 12 and 15a will result in impacts to these swamps. Observed changes in flora composition at Swamp 1 are confounded by the fire history of this swamp, with post-fire successional change occurring as predicted by Keith *et al.* (2006). Future monitoring will provide additional information.

Other Reports

The Bulli Seam Operations PAC Report (PAC 2010) stated that impacts to a number of upland swamps has been observed, including Swamp 18 (see above), Swamp 1 in Dendrobium Area 2 and Swamp 32. Also recorded in PAC (2010) is "*the panel observed that multiple swamps either side of an undermined (and severely impacted) reach of Lizard Creek appeared to be dry and undergoing compositional change from invasion by wattles and eucalypts*" (p. 88).

No specific data on the location of any impacts, or subsidence measurements was available for this report.

Conclusion

Based on literature review completed as a part of this comparative analysis, subsidence of greater than 1.2 m may result in reductions in groundwater and resultant dewatering and drying of upland swamps. Drying of swamps may increase their sensitivity to other natural factors, such as fire and scouring, lowering thresholds for erosion events. However, this drying must be concurrent with these other contributing factors for erosion to occur.

To date there is little evidence as to whether this drying of upland swamps results in changes to the size of, or species composition within, upland swamps. Additional data is required to determine the impacts of reductions in groundwater on upland swamps.

4.2.3 Groundwater

Groundwater data is available for a limited number of upland swamps of special significance within the study area. Data is presented in Table 10 and Table 11.

Table 10: Groundwater data from upland swamps of 'special significance' in Wonga East

Upland Swamp	Peizometer	
CCUS1	-	-
CCUS4	PCc4	Shallow groundwater recharges to surface following rainfall. No drying of piezometer recorded from limited data.
CCUS5	PCc5a, PCc5b	Shallow groundwater recharges to near surface following rainfall. No drying of piezometer recorded from limited data.

Upland Swamp	Peizometer	
CCUS10	-	-
CRUS1	PCr1	Shallow groundwater recharges following rainfall. However, one month following rainfall piezometer appears to dry out.
CRUS2	-	-

Table 11: Groundwater data from upland swamps of 'special significance' in Wonga West

Upland Swamp	Peizometer	
LCUS1	PL1a, PL1b	Shallow groundwater recharges following rainfall. Groundwater has taken 3-4 months to dry out following rainfall.
LCUS6	-	-
LCUS8	-	-
LCUS27	-	-
WCUS1	PW1	Groundwater saturated. Moderated response to rainfall as piezometer is in direct contact with stream seepage along Wallandoola Creek valley.
WCUS4	PW4	Shallow groundwater recharges following rainfall. Groundwater has taken 3-4 months to dry out following rainfall.
WCUS7	-	-
WCUS11	PW11	Shallow groundwater recharges following rainfall. Groundwater has taken 3-4 months to dry out following rainfall.

Based on this assessment of groundwater upland swamps in Wonga East and West have input from seepage associated with shallow ephemeral groundwater systems. However these upland swamps appear to dry out following periods of low rainfall, with the time to drying out varying between one (CRUS1) to several (LCUS1, WCUS4 and WCUS11) months. Drying time is also likely to be strongly influenced by climatic factors, with drying time influenced by top up events. Only one upland swamp currently monitored (WCUS1) was found to be saturated throughout the monitoring period; this upland swamp is in direct contact with stream seepage along Wallandoola Creek.

Assessment by Geoterra Pty Ltd has indicated that shallow ephemeral groundwater that is resent in upland swamps is hydraulically separated, and that upland swamps are more responsive to rainfall and /drying cycles that regional aquifers.

Based on this data we can conclude that WCUS1 is saturated due to direct contact with stream seepage. Upland swamps CCUS4, CCUS5, LCUS1, WCUS4 and WCUS11 are recharged following rainfall events, but dry out during periods of extended low rainfall when the shallow groundwater table is not recharged. CRUS1 appears to dry out rapidly following recharge.

4.2.4 Flow Accumulation

Detailed analysis of flow accumulation for upland swamps determined to be of 'special significance' was undertaken, and is presented below.

Table 12: Discussion of changes in flow accumulation pre- versus post-mining for upland swamp of 'special significance' in Wonga East

Upland Swamp	Discussion of changes in flow accumulation
CCUS1	Flow accumulation modelling pre-mining indicates the presence of two main flow pathways through this upland swamp – one exiting the swamp in the northeast section of the swamp and one in the southeast section of the swamp. These exit points coincide with area of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c), with both sub-communities reliant on permanent to intermittent water logging. Flow accumulation modelling post-mining indicates that tilts associated with Area 1 LW3 may result in changes to flow pathways, particularly for the southern section of the swamp. The area of Cyperoid Heath (MU44c) in the southeast section may be subject to a significant reduction in flow accumulation. This reduction in water availability could result in less waterlogging and potential for changes to vegetation composition.
CCUS4	Flow accumulation modelling pre-mining indicates the presence of two main flow pathways through this upland swamp. One minor flow accumulation passes through the eastern section of the swamp, while the main flow pathway passes through the western section of the swamp. The western flow pathway corresponds with areas of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c). Post-mining, only negligible changes in the eastern flow accumulation pathway are predicted to occur. The western flow pathway changes slightly in response to changes in gradient within the swamp. The upper section of Tea-tree Thicket (MU43) is expected to undergo a reduction in flow accumulation and potential reductions in groundwater availability; however, flow accumulation in lower sections of Tea-tree Ticket (MU43) and Cyperoid Heath (MU44c) are predicted to undergo increases in flow accumulation and potentially increased wetting and waterlogging. Any resultant changes are likely to be small in scale and decreases in flow accumulation are likely to be offset by increases in other areas.
CCUS5	Pre-mining flow accumulation modelling indicates that this upland swamp has a dispersed flow accumulation, with numerous flow pathways through the swamp. There is a significant flow pathway through the eastern section of the swamp, corresponding with an area of Tea-Tree Thicket (MU43). Substantial benching within this swamp

Upland Swamp	Discussion of changes in flow accumulation
	appears to be correlated with vegetation sub-communities; with areas of Tea-Tree Thicket (MU43) corresponding with the location of rockbars within the swamp, and it is likely that community composition in this swamp relates to a combination of flow and these rockbars allowing pooling of water at these locations. Post-mining the flow pathway is still quite dispersed, with flow pathways throughout the swamp. However, changes in gradient, particularly across the top of the swamp at the edge of Area 2 LW8, result in a diversion of the flow pathway in the eastern section of the upland swamp around the exterior of the swamp. This results in a significant reduction in flow accumulation through this eastern section, and may result in a reduction if waterlogging in these areas.
CCUS10	Flow accumulation modelling pre-mining indicates a dispersed flow accumulation across this upland swamp. This swamp has a small catchment area. Vegetation sub-communities appear to correspond with area of benching down the slope, with these rockbars resulting in accumulation of water in these areas. Post-mining flow accumulation modelling indicates that there is not predicted to be a significant change in flow accumulation or pathways across the swamp.
CRUS1	Only the upper northern section of CRUS1 is located above Area 2 LW6. As a result there is little change in flow accumulation, either across the swamp or within thus upper section. No significant changes are expected to result from changes in flow accumulation.
CRUS2	CRUS2 is located outside of the predicted limits of subsidence. Pre- and post mining flow accumulation modelling indicates that there is not predicted to be any significant changes in flow accumulation or pathways within CRUS2.
CRUS3	CRUS3 is located outside of the predicted limits of subsidence. Pre- and post mining flow accumulation modelling indicates that there is not predicted to be any significant changes in flow accumulation or pathways within CRUS3.

Table 13: Discussion of changes in flow accumulation pre- versus post-mining for upland swamp of 'special significance' in Wonga West

Upland Swamp	Discussion of changes in flow accumulation
LCUS1	Although LCUS1 is not located above any of the longwalls, combined Bulli and Wongawilli subsidence predictions indicate that subsidence extends southeast of the longwall and may impact on the downstream reach of this swamp. LCUS1 is a mix of headwater and valley infill swamp. Pre-mining flow accumulation modelling indicates that there is a disperse flow across areas of headwater swamp, with flow accumulation increasing significant through the main channel of Lizard Creek, which supports Tea-tree Ticket (MU43). Post-mining flow accumulation modelling indicates that there will be a significant increase in flow accumulation in the downstream reach of LCUS1, particularly within the main

Upland Swamp	Discussion of changes in flow accumulation
	channel. This increase in flow accumulation is not predicted to result in any significant changes to LCUS1.
LCUS6	Although LCUS6 is not located above any of the longwalls, combined Bulli and Wongawilli subsidence predictions indicate that subsidence extends east of the longwall and may impact on this swamp. LCUS6 is a mix of headwater and valley infill swamp. Pre-mining flow accumulation modelling indicates that the headwater swamp section of LCUS6 supports only very small flow accumulation. Valley infill areas are located along the main channel of Lizard Creek and support more substantial flows accumulation. Post-mining, flow accumulation modelling indicates that there will be reduction if flow accumulation with headwater sections of this swamp, but that these changes will be so small as to be negligible. Valley infill sections will be subject to significant increases in flow accumulation, which may result in increases in species reliant on and resilient to increases in waterlogging.
LCUS8	LCUS8 is a mix of headwater and valley infill swamp, with two areas of headwater swamp located on either side of a valley infill swamp which spans the main channel of Lizard Creek. Pre-mining flow accumulation indicates that areas of headwater swamp are subject to a diversified flow accumulation, with no significant flow pathways. The area of valley infill swamp is subject to substantial flow accumulation from Lizard Creek. Post-mining areas of headwater swamp undergo very small changes in flow accumulation and these are not predicted to be significant. Observed changes to flow accumulation modelling for areas of valley infill swamp indicate an increase in flow accumulation in this area. Any changes in flow accumulation are not predicted to result in any significant changes to this upland swamp.
LCUS27	LCUS27 is located outside of the predicted limits of subsidence. Pre- and post mining flow accumulation modelling indicates that there is unlikely to be any significant changes in flow accumulation or pathways within LCUS27.
WCUS1	Although WCUS1 is not located above any of the longwalls, combined Bulli and Wongawilli subsidence predictions indicate that subsidence extends south of the longwall and may impact on this swamp. Comparison of pre- and post-mining flow accumulation indicates that, as this swamp is located parallel to predicted subsidence there will be negligible changes to flow accumulation pathways. Some minor and localised changes to flow pathways may occur, but these are not predicted to result in a significant effect on this swamp.
WCUS4	WCUS4 consist of a mix of headwater and valley infill swamp. The section of headwater swamp is located above Area 3 LW2, while valley infill areas are located outside of longwalls.

Upland Swamp	Discussion of changes in flow accumulation
	Pre-mining flow accumulation modelling indicates that areas of headwater swamp have diversified flows, but a main flow pathway occurs along the northern boundary of the headwater swamp. This main channel corresponds with areas of Tea-tree Thicket (MU43). The area of valley infill swamp is located along the main channel of Wallandoola Creek. Post-mining flow accumulation modelling indicates that areas of headwater swamp may undergo a small shift in flow pathway further to the north, with vegetation sub-communities along the southern boundary likely to experience low flow accumulation, including an area of Cyperoid Heath (MU44c). However, this area of Cyperoid Heath appears to correspond with a minor bench and this minor change in flow pathway is not predicted to result in any significant effect. For areas of valley infill swamp there is likely to be only minor changes in flow accumulation and no impacts are expected to occur.
WCUS7	WCUS7 is a valley infill swamp located along the main channel of Wallandoola Creek. Comparison of pre- and post-mining flow accumulation modelling indicates that there may be a minor change in flow pathway along Wallandoola Creek. However, any changes in flow accumulation are likely to be constrained by the main channel of Wallandoola Creek, and may be unlikely to occur. No significant effects on WCUS7 are predicted to occur.
WCUS11	Pre-mining flow accumulation modelling indicates that there are two main flow pathways through each arm of this upland swamp. The main flow pathway is through the south-eastern arm, largely due to Fire Road 8 re-directing flows around the north-western arm and into the south-eastern arm. Significant flow accumulation at the downstream extent of WCUS11 corresponds with an area of Tea-tree Thicket (MU43). Post-mining flow accumulation indicates that there will be little change in flow accumulation through WCUS11. No significant effects are predicted to occur.

Flow accumulation modelling for upland swamps meeting criteria for 'special significance' (OEH 2012) has been completed. This modelling predicts flow accumulation (catchment) and flow pathways through upland swamps.

Overall, areas of valley infill swamp in Wonga West are not predicted to undergo significant changes in flow accumulation, largely due to the fact that they are located along the main channels of Lizard and Wallandoola Creek, are not located above longwalls and are thus largely subject to minimal levels of subsidence.

Headwater swamps are likely to be more susceptible to changes in flow accumulation, as vegetation sub-communities reliant on permanent or frequent waterlogging are likely to occur in areas of increased flow accumulation (as in CCUS1 and CCUS4) and along rockbars created by benching of the sandstone.

Flow accumulation modelling indicated that upland swamps CCUS1, CCUS4 , CCUS5 and WCUS4 may undergo changes in flow accumulation that may result in changes in groundwater availability. This change in groundwater availability could result in changes in vegetation communities within these swamps.

4.2.5 Compressive and Tensile Strains

Compressive and tensile strains can be used to predict where fracturing of bedrock may occur, and thus where potential for dewatering and drying of upland swamps may occur.

There are a number of risk factors that may contribute to the fracturing of an upland swamp, particularly the type of swamp (headwater versus valley infill), location and orientation of an upland swamp and the vegetation sub-communities within a swamp.

Valley infill swamps are much more susceptible to impacts (DoP 2008). Valley infill swamps tend to be much more reliant on groundwater flows, and are usually located within lower sections of catchment where flow accumulation is much higher. They tend to support larger areas of vegetation sub-communities reliant on permanent or temporary waterlogging, and as such any loss in groundwater is likely to have a more significant effect on these swamps when compared to headwater swamps. Headwater swamps usually have much lower flow accumulation throughout the swamp, and any areas of wetter vegetation sub-communities are likely to occur in areas of increased flow accumulation, rockbars resulting from benching of sandstone terraces or seepage from perched ephemeral groundwater systems. Thus, unless fracturing results in significant changes in flow accumulation or loss of groundwater, or fracturing of rockbars impacts to headwater swamps are less likely to occur.

The location and orientation of a swamp in relation to longwall geometry is also likely to alter a swamps susceptibility to impact (EarthTech 2003). Swamps located parallel to a longwall and in areas of low tilts and strains are less likely to undergo changes in gradient due to tilts and / or fracturing resulting from strains. Swamps spanning multiple longwall panels undergo significant and multiple changes in gradient and strains, and are most susceptible to impact.

Finally, the vegetation sub-communities within a swamp also determine a swamps susceptibility to impact. Vegetation sub-communities reliant on permanent (Tea-tree Thicket MU43) or frequent (Cyperoid Heath MU44c) waterlogging are most susceptible to losses of groundwater flows (Keith *et al.* 2006). Other vegetation communities are less reliant on groundwater flows and are likely to be able to withstand some losses in groundwater, provided there is a sufficient surface flow and water build up during times of high rainfall to kill any trees that may grow.

Table 14: Assessment of risk factors for swamps of 'special significance' in Wonga East

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
CCUS1	Headwater	Spanning Area 1 LW3 and adjacent pillar. Flow pathway oriented along longwall panel.	MU42, MU43, MU44b, MU 44c	-6.79	2.65
CCUS4	Headwater	Spanning Area 2 LW6. Flow pathway oriented perpendicular to longwall panel.	MU42, MU43, MU44c	-8.03	4.63
CCUS5	Headwater	Spanning Longwalls 7 and 8, straddling	MU42, MU43, MU44a	-8.03	4.74

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
		pillar. Flow pathway oriented perpendicular to longwall panel.			
CCUS10	Headwater	Spanning Area 2 LW 9 and adjacent pillar. Flow pathway oriented perpendicular to longwall panel.	MU42, MU43, MU44c	-8.74	4.60
CRUS1	Headwater	Majority of swamp is located outside longwalls, with only small upper reaches located above Area 2 LW6. No substantial flow above longwall.	MU42, MU43	-7.20	4.34
CRUS2	Headwater	Not located above longwalls.	MU42, MU43, MU44c	0	0
CRUS3	Headwater	Not located above longwalls.	MU42, MU43, MU44a, MU44b, MU44c	0	0

Table 15: Assessment of risk factors for swamps of 'special significance' in Wonga West

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
LCUS1	Headwater / valley infill	Not located above longwalls.	MU42, MU43, MU44b	0	0
LCUS6	Headwater /	Not located	MU42, MU43, MU44a, MU44b,	0	0

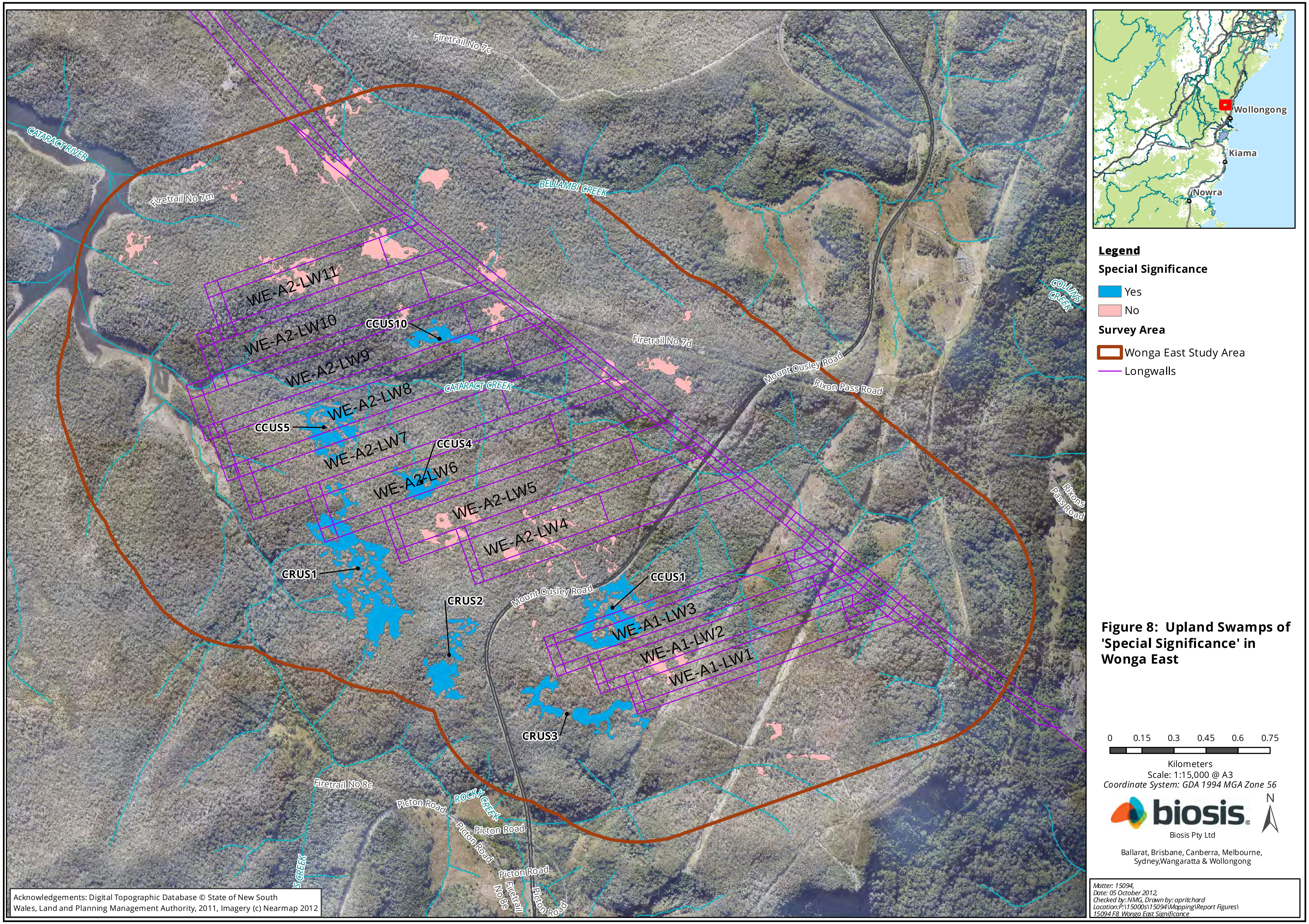
Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
	valley infill	above longwalls.	MU44c		
LCUS8	Headwater / valley infill	Upper extent of headwater swamp located above Area 3 LW1 (mostly above pillar). Flow pathway oriented perpendicular to longwall panel.	MU42, MU43, MU44a, MU44b	-2.64	2.75
LCUS27	Headwater	Not located above longwalls.	MU42, MU43, MU44b	0	0
WCUS1	Valley infill	Not located above longwalls.	MU42, MU43, MU44c	0	0
WCUS4	Headwater / valley infill	Headwater swamp located above Area 3 LW2, with flow pathway oriented perpendicular to longwall. Valley infill swamp not located above longwall.	MU43, MU44a, MU44b, MU44c	-6.97	5.03
WCUS7	Valley infill	Located above pillar for Longwalls 14 and 15. Flow pathway oriented perpendicular to longwalls.	MU42, MU43, MU44c	-0.01	5.45
WCUS11	Headwater	Located above western extent of	MU42, MU43, MU44	-3.81	5.35

Upland Swamp	Swamp type	Location and orientation	Vegetation sub-communitues	Max compressive strain (mm / m)	Max tensile strain (mm / m)
		Area 3 LW2. Flow pathway oriented parallel to longwall.			

Based on this assessment risk factors relating to compressive and tensile strains, and comparison of data above to strains observed at other locations, we can make the following conclusions:

- Upland swamps CRUS1, CRUS2, CRUS3, LCUS1, LCUS6, LCUS27, WCUS1, and valley infill section of WCUS4 do not show significant risk factors that would indicate susceptibility to impact.
- Upland swamps CCUS1 may be subject to strains that would result in fracturing of the bedrock below this swamp. Areas of Cyperoid Heath (MU44c) located above Area 1 LW3, are particularly susceptible to any loss of groundwater in this area.
- Upland swamp CCUS4 may be subject to strains that would result in fracturing of the bedrock below this swamp. However, the location of the base of this swamp in areas subject to lower levels of strains indicates that impacts may be reduced.
- Upland swamp CCUS5 may be subject to strains that would result in fracturing of the bedrock below this swamp. This upland swamp spans two longwalls and a degree of compressive and tensile strains. Further, vegetation sub-communities within this swamp are reliant on benching in the sandstone, creating rockbars that are likely to hold back sections of Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43).
- Upland swamp CCUS10 may be subject to strains that would result in fracturing of the bedrock below this swamp. The swamp spans a large variation in strains and is reliant on benching of sandstone to maintain areas of Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43).
- There is some potential for fracturing of the bedrock below the headwater section of LCUS8; however, it is likely to be limited in extent and degree given the location of this swamp largely above the pillar for Area 3 LW1. Further, this section of the swamp supports sub-communities that are less reliant on presence of permanent and frequent groundwater, and provided surface flows are maintained to a sufficient level to inhibit growth of trees impacts are unlikely to be significant.
- Upland swamp WCUS4 may be subject to strains that would result in fracturing of the bedrock below this swamp. The lower sections of the headwater swamp are subject to greatest strains, and these areas are particularly susceptible to impact as they support areas of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c).
- Upland swamp WCUS7 is likely to be subject to tensile strains sufficient to result in fracturing of bedrock below this swamp. This could result in fracturing of bedrock along Wallandoola Creek. There is substantial iron staining in this section of Wallandoola Creek. The cumulative impacts of mining cannot be adequately assessed.
- Upland swamp WCUS11 may be subject to strains that would result in fracturing of the bedrock below this swamp. However, this swamp supports only small areas of Tea-tree Thicket (MU43) at the base of the swamp that will be subject to small tensile strains. Areas subject to maximum strains support sub-communities that are less reliant on presence of permanent and frequent groundwater, and provided

surface flows are maintained to a sufficient level to ensure trees are killed impacts are not predicted to be significant.



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Special Significance

🟦 Yes

🟥 No

Survey Area

▭ Wonga East Study Area

— Longwalls

Figure 8: Upland Swamps of 'Special Significance' in Wonga East

Kilometers
Scale: 1:15,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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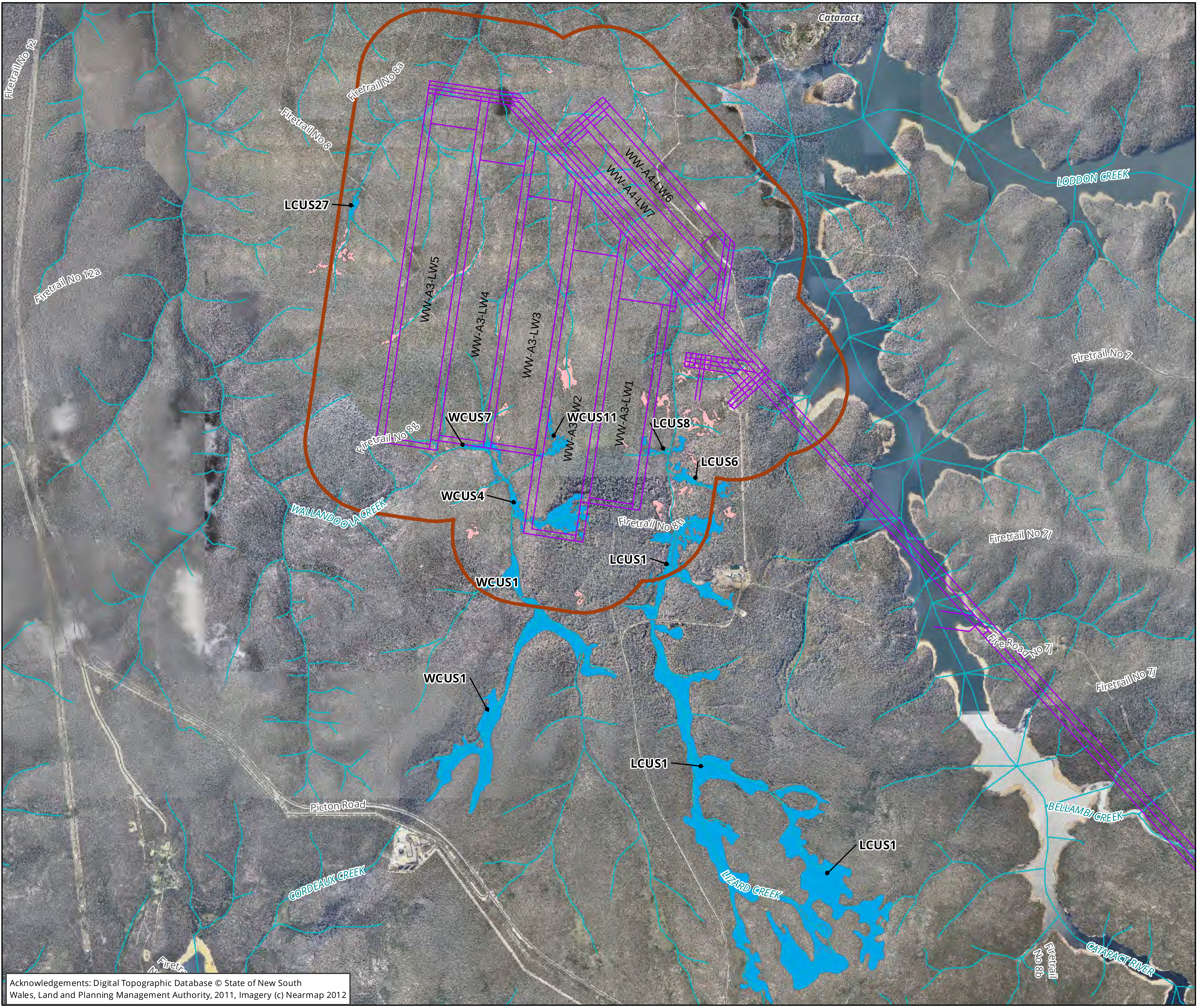

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Legend

Special Significance

🟦 Yes

🟥 No

Survey Area

▭ Wonga West Study Area

— Longwalls

Figure 9: Upland Swamps of 'Special Significance' in Wonga West

0 0.3 0.6 0.9 1.2 1.5

Kilometers

Scale: 1:30,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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5. Conclusions and Recommendations

An analysis of potential impacts to upland swamps based on data located above is provided below, along with conclusion on the risk of negative environmental consequences.

OEH (2012), summarising PAC (2009, 2010) and DoP (2008), states that negative environmental consequences for upland swamps considered to be of 'special significance' are undesirable. If negative environmental consequences to upland swamps of 'special significance' are predicted to occur mine plans should be adjusted so that negative environmental consequences are unlikely.

Table 16 provides recommendations for all upland swamps within the study area. Recommendations are based on reduction of impacts for all upland swamps to ensure objectives outlined in OEH (2012) can be achieved and negative environmental consequences for upland swamps of 'special significance'

Table 16: Conclusion of Risk Assessment and Recommendations

Upland Swamp	Conclusion	Recommendation
CCUS1	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS1 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that a reduction in flow accumulation, particularly to an area of Cyperoid Heath (MU44c) in the southeast, could occur. There is potential for this to result in drying of this area and change in vegetation composition. Risk factors that indicate potential for dewatering of CCUS1 are present. Strains are greatest beneath an area of Cyperoid Heath (MU44c) and fracturing of bedrock beneath this swamp is considered likely to occur. CCUS1 is considered to be at *significant* risk of negative environmental consequences.	Adjust the layout in respect of Area 1 LW3 to avoid and minimise impacts to CCUS1.
CCUS4	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS4 would be unlikely to trigger negative environmental consequences. Groundwater monitoring data indicates presence of shallow groundwater levels, with recharge following rainfall to near surface. No drying observed.	Potential for impacts is considered low. Detailed monitoring of groundwater and vegetation in CCUS4 should be undertaken, particularly in areas subject to greatest change. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be

Upland Swamp	Conclusion	Recommendation
	Flow accumulation modelling indicates that there is a small potential for changes (both decreases and increases in flow accumulation) and that this may result in small scale changes to the distribution of vegetation sub-communities. Risk factors that indicate potential for dewatering of CCUS4 are present. However, the base of this swamp, where water dependent vegetation communities occur and rockbar is present, will be subject to lower levels of strains and risk of fracturing. CCUS1 is considered to be at *low* risk of negative environmental consequences.	developed, and if triggered measures to minimise impacts should be considered.
CCUS5	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS5 would be unlikely to trigger negative environmental consequences. Groundwater monitoring data indicates presence of shallow groundwater levels, with recharge following rainfall to near surface. No drying observed. Flow accumulation modelling predicts that the western and middle sections of the swamp will undergo minimal changes in flow accumulation. The eastern section of this swamp will undergo a significant reduction in flow accumulation and changes in vegetation composition may result due to drying of these areas. Strains are sufficient to induce fracturing of the bedrock beneath CCUS5. The presence of rockbars holding back areas of Cyperoid Heath (MU44c) and Tea-tree Thicket (MU43) indicate a greater risk of potential for harm to this swamp if fracturing occurs. CCUS5 is considered to be at *significant* risk of negative environmental consequences.	Adjust the layout in respect of Area 2 LW7 and LW8 to avoid and minimise impacts to CCUS5. If this is not feasible, detailed monitoring of CCUS5 should be undertaken during the extraction of Longwalls 7 and 8. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
CCUS10	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CCUS10 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely	Potential for impacts is considered to be low, minor changes to layout will reduce the potential for impacts to CCUS10. If this is not feasible, detailed monitoring of CCUS10 should be undertaken during the extraction of

Upland Swamp	Conclusion	Recommendation
	to be a significant change post-mining. Strains in CCUS10 are sufficient to result in fracturing of bedrock beneath this swamp. CCUS10 is considered to be at *low* risk of negative environmental consequences.	Area 2 LW9. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
CRUS1	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that vertical movement in CRUS1 would be unlikely to trigger negative environmental consequences. Groundwater data indicates presence of shallow groundwater, recharging after rainfall but drying rapidly during periods of low rainfall. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. CRUS1 is considered to be at *low* risk of negative environmental consequences.	Potential for impacts is considered low. Minor changes to layout will reduce predicted impact to negligible.
CRUS2	The initial risk assessment indicated that CRUS2 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in CRUS2 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. CRUS2 is considered to be at *negligible* risk of environmental consequences.	Proceed to mining and monitoring.

Upland Swamp	Conclusion	Recommendation
CRUS3	The initial risk assessment indicated that CRUS3 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in CRUS3 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. CRUS3 is considered to be a *negligible* risk of negative environmental consequences.	Proceed to mining and monitoring.
LCUS1	The initial risk assessment indicated that LCUS1 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in LCUS1 would be unlikely to trigger negative environmental consequences. Groundwater monitoring data indicates presence of shallow groundwater, that will dry out following periods of low rainfall. Flow accumulation modelling predicted a significant increase in flow accumulation in the downstream section of the valley infill swamp, but that due to high levels of flow accumulation currently this is unlikely to result in any changes to this swamp. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. LCUS1 is considered to be a *negligible* risk of negative environmental consequences.	Proceed to mining and monitoring.
LCUS6	The initial risk assessment indicated that LCUS6 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in LCUS6 would be unlikely to trigger negative environmental consequences.	Proceed to mining and monitoring.

Upland Swamp	Conclusion	Recommendation
	Flow accumulation modelling predicted a significant increase in flow accumulation in the downstream section of the valley infill swamp, but that due to high levels of flow accumulation currently this is unlikely to result in any changes to this swamp. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. LCUS6 is considered to be a *negligible* risk of negative environmental consequences.	
LCUS8	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that LCUS8 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Flow accumulation modelling predicted a significant increase in flow accumulation in the downstream section of the valley infill swamp, but that due to high levels of flow accumulation currently this is unlikely to result in any changes to this swamp. Analysis of strains indicated that the headwater sections of this swamp may be subject to fracturing. However the location of the swamp above the pillar for Area 3 LW1 and the drier sub-communities within this swamp indicate that impacts are unlikely to be significant. LCUS8 is considered to be at a *low* risk of negative environmental consequences.	Potential for impacts is considered low. Detailed monitoring of groundwater and vegetation in LCUS8 should be undertaken, particularly in areas subject to greatest change. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts should be considered.
LCUS27	The initial risk assessment indicated that LCUS8 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in LCUS27 would be unlikely to trigger negative environmental consequences. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts	Proceed to mining and monitoring.

Upland Swamp	Conclusion	Recommendation
	and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. LCUS27 is considered to be at a *negligible* risk of negative environmental consequences.	
WCUS1	The initial risk assessment indicated that WCUS1 was not at risk of negative environmental consequences. A comparative analysis using limited available data indicated that vertical movement in WCUS1 would be unlikely to trigger negative environmental consequences. Groundwater monitoring indicates this swamp is in direct contact with stream seepage along Wallandoola Creek. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. WCUS1 is considered to be at a *negligible* risk of negative environmental consequences.	Proceed to mining and monitoring.
WCUS4	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that WCUS4 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Groundwater monitoring data indicates presence of shallow groundwater, that will dry out following periods of low rainfall. Flow accumulation modelling indicated that mining may result in a change in flow accumulation pathways, resulting in reduction in flow accumulation along the southern boundary of this swamp. This may impact on an area of Cyperoid Heath (MU44c). However, the localised occurrence of this vegetation sub-community is the result of a rockbar at this location and any is unlikely to result in a significant effect.	Adjust the layout in respect of Area 3 LW2 to avoid and minimise impacts on headwaters of WCUS4.

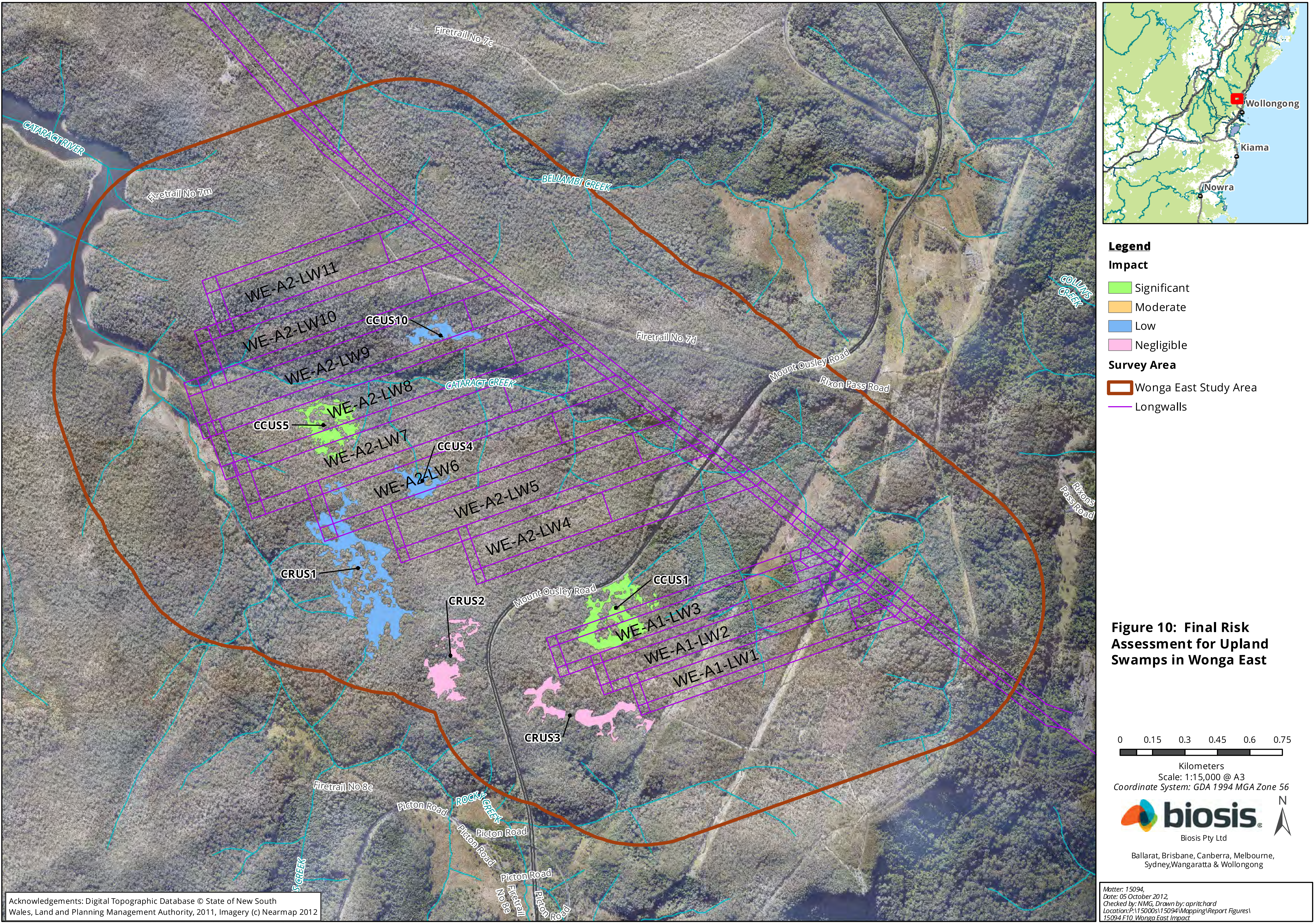
Upland Swamp	Conclusion	Recommendation
	Analysis of swamp type, location and orientation of the swamp, vegetation sub-communities ad compressive tilts and strains indicates that the valley infill section of this upland swamp does not contain risk factors increasing the risk of fracturing and dewatering. However headwater sections of this swamp are likely to be impacted by fracturing of bedrock and areas of Tea-tree Thicket (MU43) and Cyperoid Heath (MU44c) are likely to be susceptible to impact and potential for change. WCUS4 valley infill swamp is considered to be at *negligible* risk of environmental consequences. WCUS headwater swamp is considered to be at *moderate* risk of negative environmental consequences.	
WCUS7	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that WCUS7 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Flow accumulation modelling indicates that there is unlikely to be a significant change post-mining. There is potential for fracturing of bedrock beneath this upland swamp. There is iron staining within this section of Wallandoola Creek and the cumulative impacts of subsidence cannot be adequately ascertained. Taking a precautionary approach there WCUS7 is considered to be at a *moderate* risk of negative environmental consequences.	Adjust the layout in respect of Area 3 Longwalls 3 and 4 to reduce predicted strains to WCUS7 and Wallandoola Creek.
WCUS11	The initial risk assessment indicated that subsidence criteria were sufficient to indicate a risk of negative environmental consequences according to OEH (2012). A comparative analysis using limited available data indicated that WCUS11 will be subject to vertical movement (SMax) similar to that seen in previously impacted upland swamps. Groundwater monitoring data indicates presence of shallow groundwater, that will dry out following periods of low rainfall. Flow accumulation modelling indicates that there is unlikely	Potential for impacts is considered low. Detailed monitoring of groundwater and vegetation in WCUS11 should be undertaken, particularly in areas subject to greatest change. Detailed triggers relating to changes in gradient, groundwater monitoring and / or observational monitoring should be developed, and if triggered measures to minimise impacts

Upland Swamp	Conclusion	Recommendation
	to be a significant change post-mining. Strains are longwall orientation indicate potential for fracturing of bedrock beneath this swamp. However areas likely to be subject to greatest impact do not support vegetation sub-communities reliant on permanent or frequent waterlogging. WCUS11 is considered to be at *low* risk of negative environmental consequences.	should be considered.

The final risk of impact for upland swamps of 'special significance' within the study area is shown in Figure 10 and Figure 11.

Based on an analysis of potential impacts to upland swamps within the study area using multiple criteria we conclude:

- There is a negligible likelihood of negative environmental consequences for seven (7) upland swamps within the study area, including CRUS2, CRUS3, LCUS1, LCUS6, LCUS27, WCUS1 and WCUS4-vfs. NRE can proceed to mining and monitoring in these areas.
- There is a low likelihood of negative environmental consequences for five (5) upland swamps within the study area, including CCUS4, CCUS10, CRUS1, LCUS8 and WCUS11. NRE may wish to consider undertaking monitoring in conjunction with minor changes to longwall layout to reduce impacts to these swamps.
- There is a moderate likelihood of negative environmental consequences for two (2) upland swamps within the study area, including WCUS4-hws and WCUS7. NRE should consider implementation of suitable impact avoidance, minimisation and mitigation measures to reduce impacts to these swamps.
- There is a significant likelihood of negative environmental consequences for two (2) upland swamps within the study area, including CCUS1 and CCUS5. NRE to consider changes to the mine layout and / or suitable avoidance and mitigation measures to reduce the impacts to these swamps.



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Legend

Impact

🟩 Significant
🟧 Moderate
🟦 Low
🟪 Negligible

Survey Area

▭ Wonga East Study Area
— Longwalls

Figure 10: Final Risk Assessment for Upland Swamps in Wonga East

Scale: 1:15,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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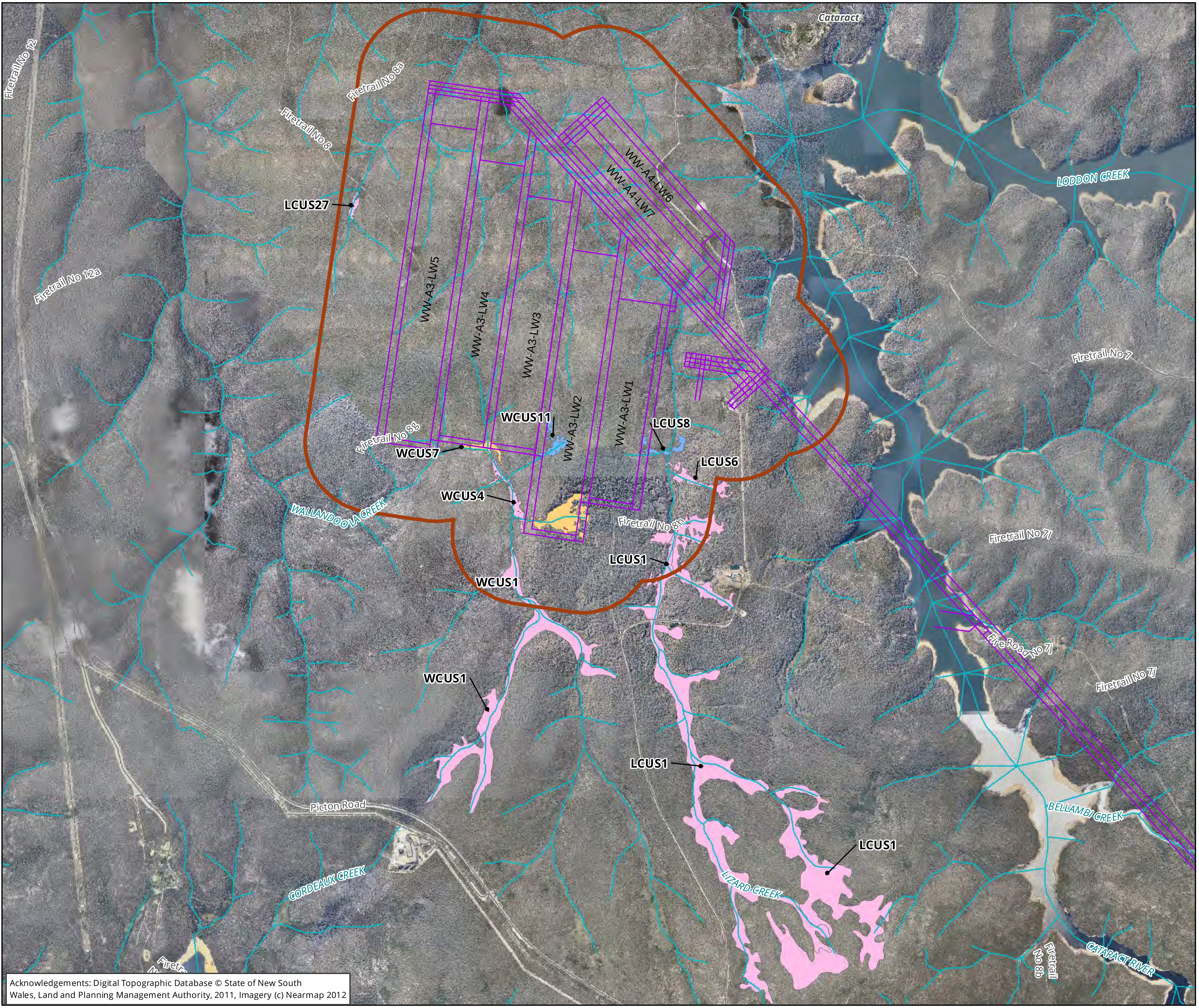

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Legend

Impact

🟩 Significant

🟧 Moderate

🟦 Low

🟪 Negligible

Survey Area

▭ Wonga West Study Area

— Longwalls

Figure 11: Final Risk Assessment for Upland Swamps in Wonga West

Scale: 1:30,000 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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Appendices

Appendix 1: Detailed Data for Upland Swamps

Bellambi Creek Upland Swamp 1 (BCUS1)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.16
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	

Bellambi Creek Upland Swamp 2 (BCUS2)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.89
Vegetation communities	Banksia Thicket (MU42)
Special significance	No

Photo	

Bellambi Creek Upland Swamp 3 (BCUS3)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.12
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Bellambi Creek Upland Swamp 4 (BCUS4)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	2.20
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43)
Special significance	No

Photo	

Bellambi Creek Upland Swamp 5 (BCUS5)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.96
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43)
Special significance	No
Photo	

Bellambi Creek Upland Swamp 6 (BCUS6)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	1.37
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43)
Special significance	No
Photo	

Bellambi Creek Upland Swamp 7 (BCUS7)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.62
Vegetation communities	Banksia Thicket (MU42)
Special significance	No

Photo	

Bellambi Creek Upland Swamp 8 (BCUS8)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.66
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Bellambi Creek Upland Swamp 9 (BCUS9)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.27
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Bellambi Creek Upland Swamp 10 (BCUS10)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.41

Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Bellambi Creek Upland Swamp 11 (BCUS11)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.26
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No
Photo	

Cataract Creek Upland Swamp 1 (CCUS1)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	4.81
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Restioid Heath (MU44b), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity

Photo	

Cataract Creek Upland Swamp 2 (CCUS2)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	1.21
Vegetation communities	Sedgeland (MU44a), Restioid Heath (MU44b)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 3 (CCUS3)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.55
Vegetation communities	Banksia Thicket (MU42), Sedgeland (MU44a)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 4 (CCUS4)	
Area	Wonga East
Swamp type	Headwater

Size (ha)	1.77
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	No

Cataract Creek Upland Swamp 5 (CCUS5)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	3.45
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Sedgeland (MU44a)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	

Cataract Creek Upland Swamp 6 (CCUS6)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	2.05
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 7 (CCUS7)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	1.32
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	

Cataract Creek Upland Swamp 8 (CCUS8)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.46
Vegetation communities	Banksia Thicket (MU42)
Special significance	No

Photo	

Cataract Creek Upland Swamp 9 (CCUS9)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.76
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	

Cataract Creek Upland Swamp 10 (CCUS10)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	1.63
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	

Cataract Creek Upland Swamp 11 (CCUS11)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.34
Vegetation communities	Banksia Thicket (MU42)
Special significance	No

Photo	

Cataract Creek Upland Swamp 12 (CCUS12)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	1.84
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 13 (CCUS13)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.26
Vegetation communities	Banksia Thicket (MU42)
Special significance	No

Photo	

Cataract Creek Upland Swamp 14 (CCUS14)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.37
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	

Cataract Creek Upland Swamp 15 (CCUS15)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.06
Vegetation communities	Tea-tree Thicket (MU43)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 16 (CCUS16)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.87
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	

Cataract Creek Upland Swamp 17 (CCUS17)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.07

Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

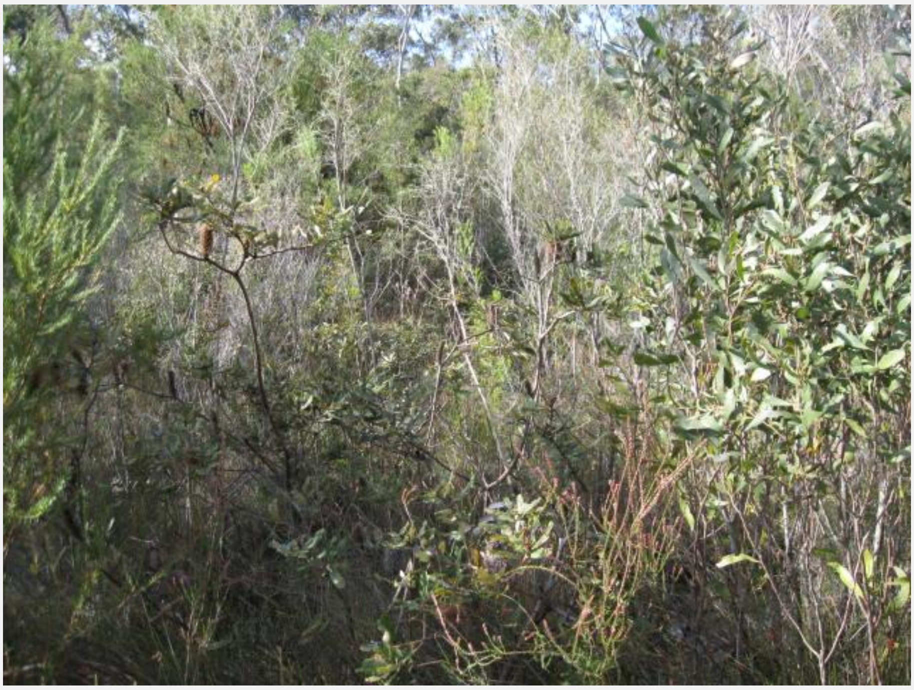
Cataract Creek Upland Swamp 18 (CCUS18)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.05
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 19 (CCUS19)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.04
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 20 (CCUS20)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.55
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 21 (CCUS21)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.05

Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Cataract Creek Upland Swamp 22 (CCUS22)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.31
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No
Photo	

Cataract Creek Upland Swamp 23 (CCUS23)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	1.44
Vegetation communities	Banksia Thicket (MU42), Sedgeland (MU44a)
Special significance	No
Photo	No

Cataract River Upland Swamp 1 (CRUS1)

Area	Wonga East
Swamp type	Headwater
Size (ha)	9.84
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Size
Photo	

Cataract River Upland Swamp 2 (CRUS2)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	3.12
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	No

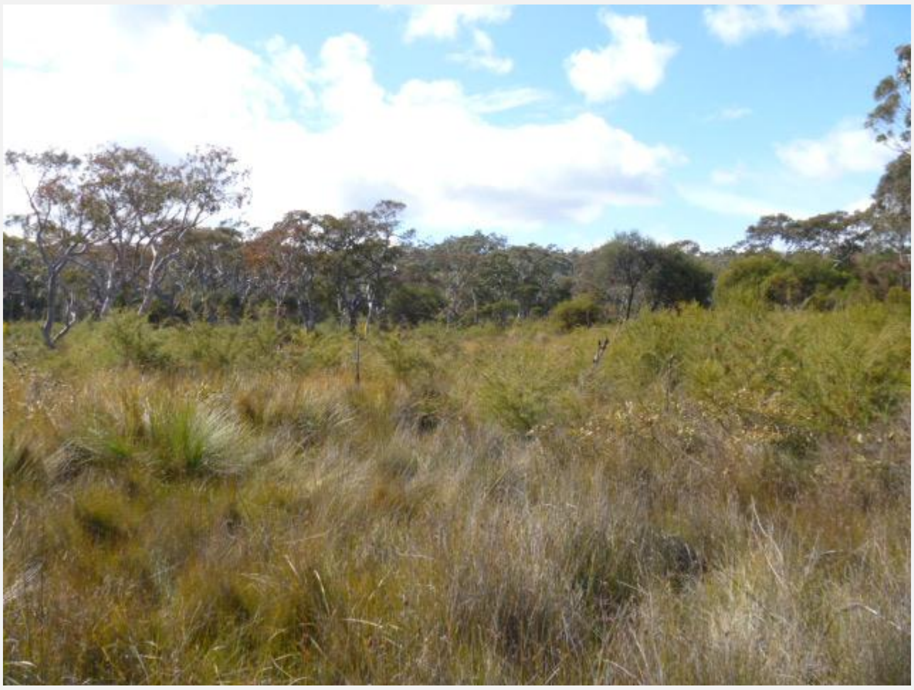
Cataract River Upland Swamp 3 (CRUS3)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	3.42
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Sedgeland (MU44a),

	Restioid Heath (MU44b), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	No

Cataract River Upland Swamp 4 (CRUS4)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.37
Vegetation communities	Sedgeland (MU44a)
Special significance	No
Photo	

Cataract River Upland Swamp 5 (CRUS5)	
Area	Wonga East
Swamp type	Headwater
Size (ha)	0.13
Vegetation communities	Sedgeland (MU44a)
Special significance	No

Photo	

Lizard Creek Upland Swamp 1 (LCUS1)	
Area	Wonga West
Swamp type	Headwater /Valley infill
Size (ha)	129.89
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Restioid Heath (MU44b)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Size, Complexity
Photo	

Lizard Creek Upland Swamp 2 (LCUS2)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.74
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 3 (LCUS3)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.56
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	

Lizard Creek Upland Swamp 4 (LCUS4)	
Area	Wonga West
Swamp type	Valley infill
Size (ha)	0.83

Vegetation communities	Tea-tree Thicket (MU43)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 5 (LCUS5)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.60
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 6 (LCUS6)	
Area	Wonga West
Swamp type	Headwater / Valley infill
Size (ha)	3.74
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Sedgeland (MU44a), Restioid Heath (MU44b), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	

Lizard Creek Upland Swamp 7 (LCUS7)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.41
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 8 (LCUS8)	
Area	Wonga West
Swamp type	Headwater / Valley infill
Size (ha)	2.09
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Sedgeland (MU44a), Restioid Heath (MU44b)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	No

Lizard Creek Upland Swamp 9 (LCUS9)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.20
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 10 (LCUS10)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	2.71
Vegetation communities	Banksia Thicket (MU42), Sedgeland (MU44a), Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 11 (LCUS11)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.35
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 12 (LCUS12)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	1.68
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 13 (LCUS13)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.22
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

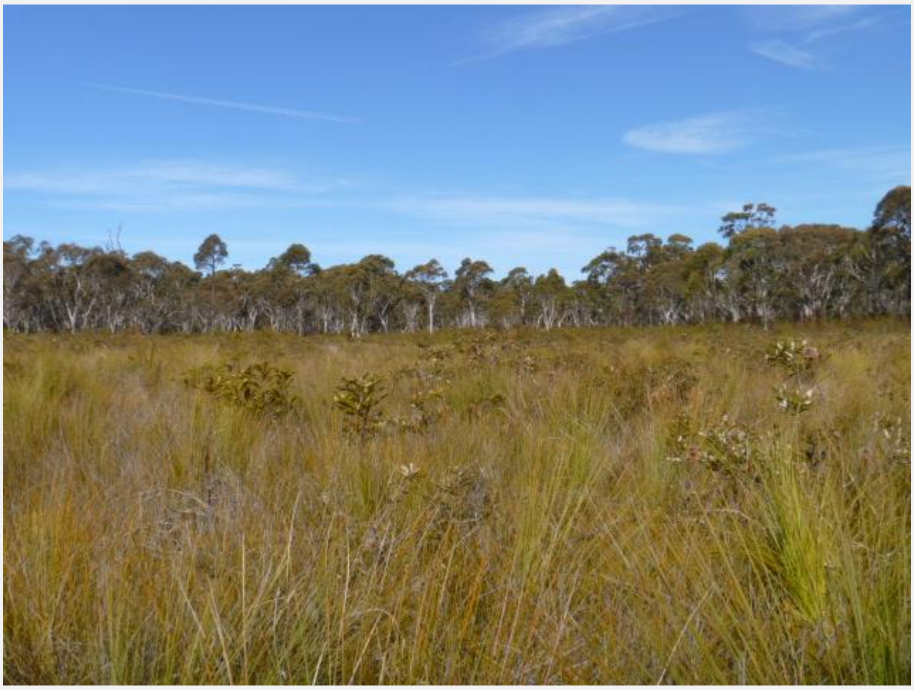
Lizard Creek Upland Swamp 14 (LCUS14)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.91
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 15 (LCUS15)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.43
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 16 (LCUS16)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.06
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 17 (LCUS17)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	1.16
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 18 (LCUS18)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	2.53
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No

Photo	

Lizard Creek Upland Swamp 19 (LCUS19)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.21
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 20 (LCUS20)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.24
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 21 (LCUS21)	
Area	Wonga West
Swamp type	Headwater

Size (ha)	0.11
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 22 (LCUS22)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.26
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

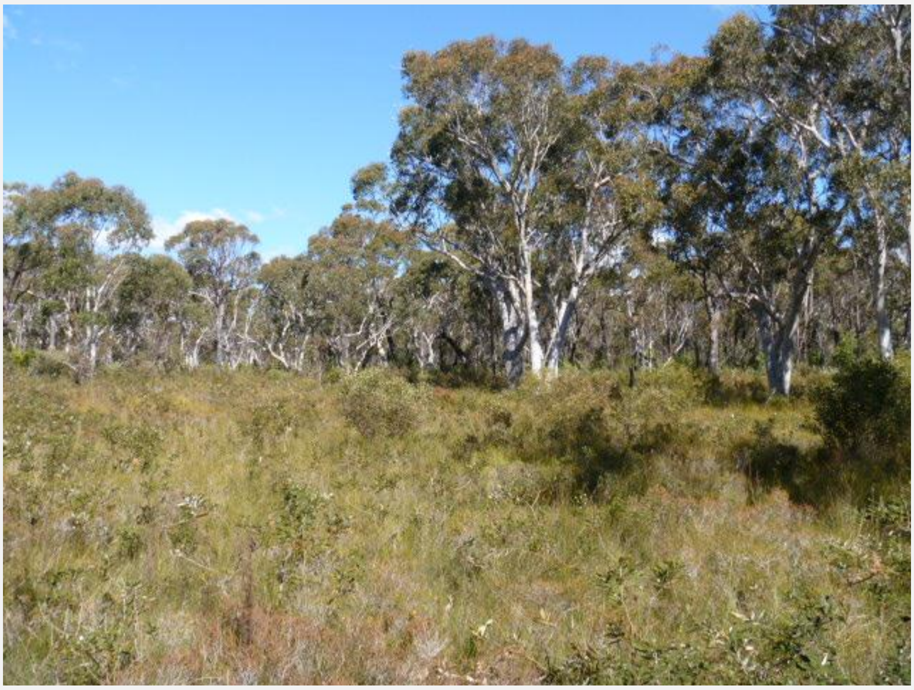
Lizard Creek Upland Swamp 23 (LCUS23)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.08
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 24 (LCUS24)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.35
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 25 (LCUS25)	
Area	Wonga West
Swamp type	Headwater

Size (ha)	3.34
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No
Photo	

Lizard Creek Upland Swamp 26 (LCUS26)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	3.09
Vegetation communities	Tea-tree Thicket (MU43), Restioid Heath (MU44b)
Special significance	No

Photo	

Lizard Creek Upland Swamp 27 (LCUS27)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	1.04
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Restioid Heath (MU44b)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	

Lizard Creek Upland Swamp 28 (LCUS28)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	1.00
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 29 (LCUS29)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.34
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 30 (LCUS30)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.07
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

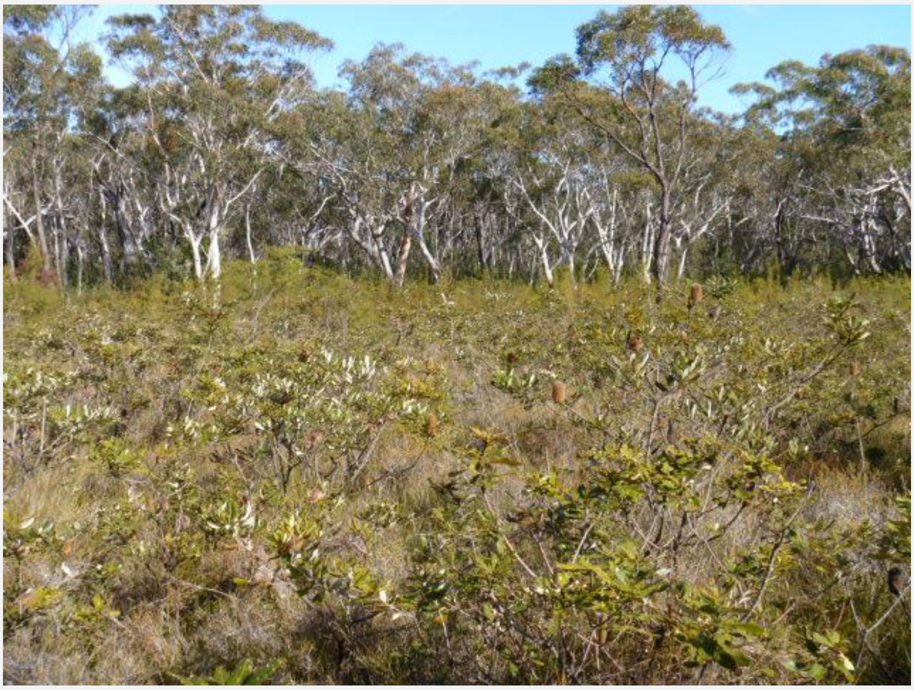
Lizard Creek Upland Swamp 31 (LCUS31)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.25
Vegetation communities	Banksia Thicket (MU42), Restioid Heath (MU44b)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 32 (LCUS32)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.31
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Lizard Creek Upland Swamp 33 (LCUS33)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.35
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Wallandoola Creek Upland Swamp 1 (WCUS1)	
Area	Wonga West
Swamp type	Valley infill
Size (ha)	36.16
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Size, Complexity

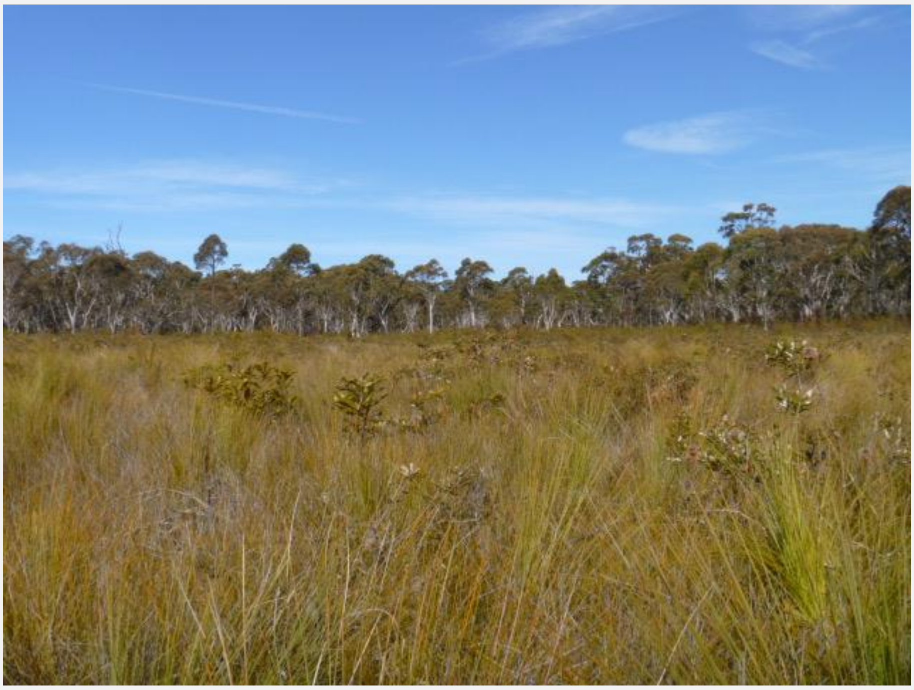
Photo	

Wallandoola Creek Upland Swamp 2 (WCUS2)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.52
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	

Wallandoola Creek Upland Swamp 3 (WCUS3)	
Area	Wonga West
Swamp type	Headwater

Size (ha)	0.71
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	

Wallandoola Creek Upland Swamp 4 (WCUS4)	
Area	Wonga West
Swamp type	Headwater / Valley infill
Size (ha)	11.08
Vegetation communities	Tea-tree Thicket (MU43), Sedgeland (MU44a), Restioid Heath (MU44b), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Size

Photo	

Wallandoola Creek Upland Swamp 5 (WCUS5)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.23
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Wallandoola Creek Upland Swamp 6 (WCUS6)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.55
Vegetation communities	Tea-tree Thicket (MU43), Restioid Heath (MU44b)
Special significance	No
Photo	No

Wallandoola Creek Upland Swamp 7 (WCUS7)	
Area	Wonga West
Swamp type	Valley infill

Size (ha)	1.97
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Cyperoid Heath (MU44c)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	No

Wallandoola Creek Upland Swamp 8 (WCUS8)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.24
Vegetation communities	Banksia Thicket (MU42)
Special significance	No
Photo	No

Wallandoola Creek Upland Swamp 9 (WCUS9)	
Area	Wonga West
Swamp type	Valley infill
Size (ha)	0.27
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43)
Special significance	No
Photo	No

Wallandoola Creek Upland Swamp 10 (WCUS10)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.21
Vegetation communities	Restioid Heath (MU44b)
Special significance	No
Photo	No

Wallandoola Creek Upland Swamp 11 (WCUS11)	
Area	Wonga West

Swamp type	Headwater
Size (ha)	2.79
Vegetation communities	Banksia Thicket (MU42), Tea-tree Thicket (MU43), Restioid Heath (MU44b)
Special significance	Yes – Statutory threshold, Closely proximate habitat, Complexity
Photo	

Wallandoola Creek Upland Swamp 12 (WCUS12)	
Area	Wonga West
Swamp type	Headwater
Size (ha)	0.82
Vegetation communities	Tea-tree Thicket (MU43), Restioid Heath (MU44b)
Special significance	No

Photo	

Appendix 2: Swamp Matrix

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
BCUS1	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.16	MU42	Wallandoola	No		No	282	0		-	0.00	0.00	0.00	0.00	0.00
BCUS10	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.41	MU42	Wallandoola	No		No	317	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS11	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.26	MU42, MU44b	Wallandoola	No		Area 1 LW11	299	149	2.01	Bulli bord and pillar	-0.88	4.14	-7.43	17.07	0.00
BCUS2	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.89	MU42	Wallandoola	No		Mainroad	286	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS3	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.12	MU42	Wallandoola	No		No	288	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS4	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	2.20	MU42, MU43	Wallandoola	No		Area 1 LW11	282	149	1.89	Bulli bord and pillar	-0.81	4.24	-6.48	17.43	0.00
BCUS5	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.96	MU42, MU43	Wallandoola	No		No	291	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS6	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.37	MU42, MU43	Wallandoola	No		Mainroad	307	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS7	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.62	MU42	Wallandoola	No		Mainroad	319	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS8	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.66	MU42	Wallandoola	No		No	320	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
BCUS9	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.27	MU42	Wallandoola	No		No	318	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
CCUS1	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	4.81	MU42, MU43, MU44b, MU 44c	Wallandoola	No	Yes	Area 1 LW3	250	101	2.47	Balgownie LW Bulli bord and pillar	-0.40	2.65	-6.79	11.38	0.00
CCUS10	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.63	MU42, MU43, MU44c	Wallandoola	No	Yes	Area 2 LW9	286	149	1.92	Balgownie LW Bulli bord and pillar	-1.00	4.60	-8.74	21.39	0.00
CCUS11	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.34	MU42	Wallandoola	No		Area 2 LW10	289	151	1.91	Bulli bord and pillar	-0.47	4.37	1.61	17.58	0.00
CCUS12	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.84	MU42	Wallandoola	No		Area 2 LW11	306	149	2.05	Bulli bord and pillar	-0.88	4.24	-7.47	17.50	0.00
CCUS13	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.26	MU42	Wallandoola	No		No	328	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS14	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.37	MU44b	Wallandoola	No		No	224	0			0.00	0.00	0.00	0.00	0.00
CCUS15	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.06	MU43	Wallandoola	No		No	262	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS16	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.87	MU42	Wallandoola	No		No	334	0			0.00	0.00	0.00	0.00	0.00
CCUS17	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.07	MU42	Wallandoola	No		No	259	0		Balgownie LW Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS18	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.05	MU42	Wallandoola	No		No	257	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS19	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.04	MU42	Wallandoola	No		No	254	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS2	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.21	MU44a, MU44b	Wallandoola	No		Area 1 LW1, LW2	240	101	2.38	Bulli bord and pillar	-0.39	2.77	-6.59	11.42	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
CCUS20	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.55	MU42	Wallandoola	No		No	260	0		Balgownie LW Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS21	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.05	MU42	Wallandoola	No		No	267	0		Balgownie LW Bulli bord and pillar	-0.43	4.57	-2.49	19.94	0.00
CCUS22	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.31	MU42, MU44b	Wallandoola	No		No	338	0		Bulli bord and pillar (partial)	0.00	0.00	0.00	0.00	0.00
CCUS23	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.44	MU42, MU44a	Wallandoola	No		Area 2 LW5	275	147	1.87	Balgownie LW Bulli bord and pillar	-0.99	4.41	-8.04	20.04	0.00
CCUS3	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.55	MU42, MU44a	Wallandoola	No		Area 2 LW5	275	147	1.87	Balgownie LW Bulli bord and pillar	-0.99	4.52	-8.04	20.31	0.00
CCUS4	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.77	MU42, MU43, MU44c	Wallandoola	No	Yes	Area 2 LW6	281	147	1.91	Balgownie LW Bulli bord and pillar	-1.00	4.63	-8.03	21.04	0.00
CCUS5	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	3.45	MU42, MU43, MU44a	Wallandoola	No	Yes	Area 2 LW7, LW8	293	155	1.89	Balgownie LW (partial) Bulli bord and pillar	-1.00	4.74	-8.03	21.30	0.00
CCUS6	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	2.05	MU42	Wallandoola	No		Area 2 LW4	264	149	1.77	Balgownie LW Bulli bord and pillar (partial)	-1.02	4.79	-8.05	21.95	0.00
CCUS7	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	1.32	MU42	Wallandoola	No		No	276	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS8	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.46	MU42	Wallandoola	No		Area 2 Mainroad	279	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CCUS9	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.76	MU42	Wallandoola	No		Area 2 Mainroad	285	0		Balgownie LW Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CRUS1	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	9.84	MU42, MU43	Wallandoola	No	Yes	Area 2 LW6	271	147	1.85	Bulli bord and pillar	-0.89	4.34	-7.20	17.51	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
CRUS2	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	3.12	MU42, MU43, MU44c	Wallandoola	No	Yes	No	257	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CRUS3	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	3.42	MU42, MU43, MU44a, MU44b, MU44c	Wallandoola	No	Yes	No	234	0		Bulli bord and pillar	0.00	0.00	0.00	0.00	0.00
CRUS4	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.37	MU44a	Wallandoola	No		No	219	0			0.00	0.00	0.00	0.00	0.00
CRUS5	Wonga East	Headwater swamp	Coastal Upland Swamp EEC	0.13	MU44a	Wallandoola	No		No	217	0			0.00	0.00	0.00	0.00	0.00
LCUS1	Wonga West	Headwater / valley infillswamp	Coastal Upland Swamp EEC	129.89	MU42, MU43, MU44b	Wallandoola	No	Yes	No	441	0		Cordeaux LW Bulli LW	-0.87	0.00	0.00	0.00	0.00
LCUS10	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	2.71	MU42, MU44a, MU44b	Wallandoola	No		No	479	0		Bulli LW	-0.22	0.00	0.00	0.00	0.00
LCUS11	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.35	MU42	Wallandoola	No		No	485	0		Bulli LW	-0.55	0.00	0.00	0.00	0.00
LCUS12	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	1.68	MU42, MU44b	Wallandoola	No		Area 3 LW1	487	385	1.26	Bulli LW	-3.02	3.95	-4.59	9.51	0.00
LCUS13	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.22	MU42	Wallandoola	No		Area 3 Mainroad	471	0		Bulli LW	0.12	0.00	0.00	0.00	0.00
LCUS14	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.91	MU42	Wallandoola	No		Area 3 Mainroad	467	0		Bulli LW	-0.05	0.00	0.00	0.00	0.00
LCUS15	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.43	MU42	Wallandoola	No		Area 3 Mainroad	475	0		Bulli LW	0.03	0.00	0.00	0.00	0.00
LCUS16	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.06	MU42	Wallandoola	No		No	474	0		Bulli LW	-0.06	0.00	0.00	0.00	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
LCUS17	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	1.16	MU42, MU43	Wallandoola	No		Mainroad	477	0		Bulli LW	-0.77	0.00	0.00	1.70	0.00
LCUS18	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	2.53	MU42, MU44b	Wallandoola	No		Area 3 LW2	495	385	1.29	Bulli LW	-3.30	4.04	-3.43	4.45	0.00
LCUS19	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.21	MU44b	Wallandoola	No		Area 3 LW3	473	375	1.26	Bulli LW	-3.33	-4.04	-5.56	11.99	0.00
LCUS2	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.74	MU44b	Wallandoola	No		No	491	0		Bulli LW	-0.52	0.00	0.00	2.43	0.00
LCUS20	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.24	MU44b	Wallandoola	No		Area 3 LW4	489	385	1.27	Bulli LW	-2.18	4.13	-1.39	4.69	0.00
LCUS21	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.11	MU44b	Wallandoola	No		Area 3 LW4	484	385	1.26	Bulli LW	-3.29	-3.64	-3.97	1.86	0.00
LCUS22	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.26	MU42	Wallandoola	No		No	467	0			-0.29	0.00	0.00	0.00	0.00
LCUS23	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.08	MU44b	Wallandoola	No		No	466	0			-0.10	0.00	0.00	0.00	0.00
LCUS24	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.35	MU42	Wallandoola	No		No	468	0			0.00	0.00	0.00	0.00	0.00
LCUS25	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	3.34	MU42, MU44b	Wallandoola	No		Area 3 LW4 and 5	474	395	1.20	Bulli LW	-3.30	9.98	-7.29	13.57	0.00
LCUS26	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	3.09	MU43, MU44b	Wallandoola	No		No	470	0			0.00	0.00	0.00	0.00	0.00
LCUS27	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	1.04	MU42, MU43, MU44b	Wallandoola	No	Yes	No	473	0			0.00	0.00	0.00	0.00	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
LCUS28	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	1.00	MU42, MU44b	Wallandoola	No		Area 4 Mainroad (partial)	464	0		Bulli LW	-1.85	4.71	1.76	9.15	0.00
LCUS29	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.34	MU44b	Wallandoola	No		No	465	0		Bulli LW (partial)	-0.75	5.17	4.00	6.55	0.00
LCUS3	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.56	MU44b	Wallandoola	No		No	478	0			-0.03	0.00	0.00	0.00	0.00
LCUS30	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.07	MU44b	Wallandoola	No		No	462	0			0.00	0.00	0.00	0.00	0.00
LCUS31	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.25	MU42, MU44b	Wallandoola	No		No	463	0			0.00	0.00	0.00	0.00	0.00
LCUS32	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.31	MU42	Wallandoola	No		No	462	0			0.00	0.00	0.00	0.00	0.00
LCUS33	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.35	MU42	Wallandoola	No		Area 3 Mainroad	478	0		Bulli LW	-0.19	0.00	0.00	0.00	0.00
LCUS4	Wonga West	Valley infill swamp	Coastal Upland Swamp EEC	0.83	MU43	Wallandoola	No		No	490	0		Bulli LW	-0.48	0.00	0.00	0.00	0.00
LCUS5	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.60	MU44b	Wallandoola	No		No	487	0		Bulli LW	-0.13	0.00	0.00	0.00	0.00
LCUS6	Wonga West	Headwater / valley infillswamp	Coastal Upland Swamp EEC	3.74	MU42, MU43, MU44a, MU44b, MU44c	Wallandoola	No	Yes	No	478	0		Bulli LW	-0.96	0.00	0.00	1.93	0.00
LCUS7	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.41	MU42	Wallandoola	No		No	487	0		Bulli LW	-0.21	0.00	0.00	0.00	0.00
LCUS8	Wonga West	Headwater / valley infillswamp	Coastal Upland Swamp EEC	2.09	MU42, MU43, MU44a, MU44b	Wallandoola	No	Yes	Area 3 LW1	490	385	1.27	Bulli LW	-2.66	2.75	-2.64	9.15	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
LCUS9	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.20	MU44b	Wallandoola	No		Area 3 LW1	499	385	1.30	Bulli LW	-3.29	-3.88	-4.81	5.09	0.00
WCUS1	Wonga West	Valley infill swamp	Coastal Upland Swamp EEC	36.16	MU42, MU43, MU44c	Wallandoola	No	Yes	No	469	0		Cordeaux LW Bulli LW	-0.72	0.00	0.00	0.00	0.00
WCUS10	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.21	MU44b	Wallandoola	No		No	487	0		Bulli LW	-1.06	0.00	0.00	0.00	0.00
WCUS11	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	2.79	MU42, MU43, MU44b	Wallandoola	No	Yes	Area 3 LW2	503	385	1.31	Bulli LW	-3.27	5.35	-3.81	8.02	0.00
WCUS12	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.82	MU43, MU44b	Wallandoola	No		Area 3 LW4	499	375	1.33	Bulli LW	-3.22	4.50	-2.74	4.07	0.00
WCUS2	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.52	MU44b	Wallandoola	No		No	489	0			0.00	0.00	0.00	0.00	0.00
WCUS3	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.71	MU42	Wallandoola	No		No	487	0		Bulli LW	-0.90	0.00	0.00	0.00	0.00
WCUS4	Wonga West	Headwater / valley infillswamp	Coastal Upland Swamp EEC	11.08	MU43, MU44a, MU44b, MU44c	Wallandoola	No	Yes	Area 3 LW2	494	385	1.28	Bulli LW	-3.35	5.03	-6.97	10.58	0.00
WCUS5	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.23	MU44b	Wallandoola	No		No	487	0		Bulli LW	-1.07	0.00	0.00	0.00	0.00
WCUS6	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.55	MU43, MU44b	Wallandoola	No		No	491	0		Bulli LW	-0.94	0.00	0.00	0.00	0.00
WCUS7	Wonga West	Valley infill swamp	Coastal Upland Swamp EEC	1.97	MU42, MU43, MU44c	Wallandoola	No	Yes	Area 3 Mainroad	492	375	1.31	Bulli LW	-2.19	5.45	-0.01	10.70	0.00
WCUS8	Wonga West	Headwater swamp	Coastal Upland Swamp EEC	0.24	MU42	Wallandoola	No		Area 3 LW3	497	375	1.33	Bulli LW	-2.81	-0.11	-6.27	10.24	0.00

Swamp Name	Area	SwampType	Statutory	Size (ha)	Complexity	Cluster	Scientific	Special Significance	Located above longwall	Depth of cover (m)	Panel width (m)	Ration DoC : Panel width	Previously subsided by	Predicted subsidence	Tensile strain (mm /	Compressive strain (mm /	Tilt (mm / m)	Valley_Closure
WCUS9	Wonga West	Valley infill swamp	Coastal Upland Swamp EEC	0.27	MU42, MU43	Wallandoola	No		No	489	0		Bulli LW	-1.55	5.18	4.00	8.60	0.00

Annex R

Baseline Aquatic Ecology Monitoring

Cardno Ecology Lab

Shaping the Future

Marine and Freshwater Studies

NRE No 1 Mine

Assessment of Mine Subsidence Impacts on Aquatic Habitat and Biota

Job Number: EL0910036

Prepared for Gujarat NRE Coking Coal Limited

Final November 2012

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Cover Image: Cataract Creek, November 2009. Photographer Doug Hazell, Cardno Ecology Lab

Document Control

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Executive Summary

Background

Gujarat NRE Coking Coal Limited (Gujarat NRE) proposes to use longwall mining methods to extract coal from the base of the Wongawilli Seam within the Wongawilli East and Wongawilli West areas of NRE No. 1 Mine at Russell Vale, in the NSW Southern Coalfield. Cardno Ecology Lab has assessed the likelihood and significance of potential impacts on aquatic habitats and biota arising from the extraction of coal within these areas and made recommendations about ongoing aquatic ecology monitoring. The assessment has been prepared on the basis of the latest mine layout proposed by Gujarat NRE, the results of baseline studies on aquatic habitats and biota in significant watercourses above the two areas of the proposed mine conducted by Cardno, and on predictions of mine subsidence and the effects of this subsidence on stream flow, bank stability and water quality made by other specialists. The major watercourses of interest within the mine areas are the 'third order' streams, Lizard Creek and Wallandoola Creek, and the lower 'fourth order' reaches of Cataract Creek and Lizard Creek, all of which contain substantial amounts of permanent aquatic habitat. Baseline data has also been collected from sites in the Upper Cataract River, Loddon Creek, Allen Creek and Cascade Creek, which are situated outside the mine area and serve as controls.

Physical Setting

The proposed longwalls in the Wongawilli West Mine would be divided into two areas to reduce the risk of subsidence along Wallandoola and Lizard Creeks. The longwalls would be situated below watersheds and ephemeral tributaries, but not the main channel of these creeks. The longwalls in the Wongawilli East Mine would also be divided into two areas, one of which would be situated below ephemeral tributaries that flow into the main channel of Cataract Creek downstream of Mount Ousley Road and the other would be below 1st and 2nd order tributaries and the main channel of Cataract Creek. These longwalls would be positioned in a north-east to south-west direction to reduce the risk of vertical subsidence under Cataract Creek.

Existing Environment

Wallandoola Creek and Lizard Creek are deeply-incised streams that flow into the Cataract River between Cataract Dam and Broughton's Pass Weir. Both creeks are surrounded by relatively natural, undisturbed, dry sclerophyll woodland and heath. They contain a variety of aquatic habitats, including deep, permanent pools, shallow areas over bedrock bars, submerged woody debris and aquatic macrophytes. The cascades and waterfalls that occur on the downstream reaches of these creeks are significant barriers to fish passage. Both creeks have been impacted by previous mining activity, with fractured bedrock, iron staining and iron floc all being evident.

Cataract Creek is bordered by temperate rainforest. This creek is shallow and is characterised by alternating series of long pools interspersed with shorter bars and riffles. It also contains submerged snags and dams of large woody debris. The water in Lake Cataract backs up into Cataract Creek with the extent of the incursion depending on the storage level of the dam. There are no barriers that would prevent fish in this lake moving into this section of the creek.

The most recent water quality monitoring programme indicates the water in all three creeks is fairly acidic. The pH values were generally outside the ANZECC/ARMCANZ guidelines for slightly disturbed rivers in south-east Australia, but are typical for Hawkesbury Sandstone watercourses of the Southern Highlands and Illawarra. Salinity was within the guideline range. On some occasions, the filtered zinc, copper and aluminium and total nitrogen and phosphorus levels in the creeks were above the 95% species protection level for freshwater aquatic ecosystem guidelines.

The baseline aquatic ecology monitoring program indicated the dissolved oxygen levels in all three creeks were generally below the lower default trigger value (DTV). The pH and turbidity levels in Wallandoola Creek and electrical conductivity, pH and turbidity levels in Lizard Creek and Cataract Creek deviated from the DTVs occasionally.

Substantial variations in the number of aquatic macroinvertebrate taxa found in these creeks were evident across spring and autumn baseline surveys. The “health” of the macroinvertebrate fauna in Wallandoola Creek varied from more diverse than the AUSRIVAS reference condition to severely impaired, while that in Lizard Creek varied from equivalent to AUSRIVAS reference condition to impoverished. The ‘health” of the fauna in Cataract Creek varied from equivalent to AUSRIVAS reference condition to severely impaired. SIGNAL2 scores indicated that the fauna at monitoring sites on Wallandoola Creek and Lizard Creek were subject to moderate to severe degradation, but those on Cataract Creek were subject to mild degradation.

Two species of fish (Climbing Galaxias and Australian Smelt) were observed in Lizard Creek, but no fish were found in Wallandoola Creek. Macquarie Perch, Silver Perch, Short-finned and Long-finned Eels, Goldfish, Climbing Galaxias and Mountain Galaxias, Eastern Gambusia, Freshwater Catfish and an unidentified Freshwater Cod of the genus *Maccullochella* have been recorded in Cataract Creek. Freshwater crayfish were present in all three creeks.

Risk of Subsidence

Gujarat NRE has indicated an adaptive management plan would be implemented to reduce the risk of major subsidence. At Wongawilli West, extraction of longwalls would not occur under the main or named channels of third or fourth order streams and longwalls would be set back at least 200 m from the centreline of Lizard Creek. At Wongawilli East, the risk of major subsidence would be reduced by using narrow longwall blocks with wide chain pillars, setting the start lines for the longwalls at least 110 m back from the maximum stored water level of Cataract Dam, monitoring the subsidence that occurs as longwalls are extracted and modifying their length and position to ensure subsidence does not exceed a pre-determined trigger level. The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experience greater than minimal impact.

Assessment of Impacts on Aquatic Habitats and Biota

The physical subsidence resulting from extraction of the Wongawilli East longwalls is not expected to have any detectable effects on stream flow, pond drainage or stream gradient of Cataract Creek, provided the adaptive management plan is adhered to. Changes in these attributes are not expected to have any observable effects on the aquatic habitats or biota within the creek. Minor bank and bed erosion may occur above the longwall panels and could lead to minor, transient increases in sediment mobility and turbidity within and downstream of the subsidence area. These would have minimal impact on aquatic habitats and biota, as the sediment loads and turbidity would be smaller than that experienced naturally during heavy rainfall events.

The extraction of the majority of the Wongawilli West longwalls is not expected to have any observable physical, chemical or biological impacts on Wallandoola Creek. Subsidence resulting from extraction of Longwalls 3 and 4, however, could fracture a sandstone rock shelf in the creek and cause the pool immediately upstream to drain. This could result in loss of aquatic habitat and associated biota and prevent fish from accessing potential upstream feeding and spawning areas. This habitat would be re-established as soon as inflows exceed diversionary flows. The diversion of water through the underlying substrata may elevate iron, zinc, copper and aluminium levels and increase iron staining in Wallandoola Creek. Precipitation of iron hydroxide could facilitate growth of bacterially-mediated iron flocs and mats which, in turn, could smother the substratum and reduce the amount and variety of habitats available to aquatic organisms. The water that re-emerges may have different qualities such as lower oxygen levels and elevated metal concentrations. The impacts of the above on diversity and abundance of aquatic organisms are expected to be localised, minor in extent and transient in nature and therefore of no significance.

Mining is not expected to have any detectable effects on stream flow or pools in the reach of Lizard Creek above the Wongawilli West longwalls. Consequently, no flow-on effects are expected on water quality, aquatic habitats or their biota. There is a possibility that additional fracturing of the creek bed, loss of water at rock bars, diversion of flows to underlying substrata and greater pool drainage could occur in a section of Lizard Creek to the north of proposed Longwall 2 that has already been impacted by previous mining. The impacts on water quality, aquatic habitats and biota of the diversion of flow through the underlying substrata would be similar to those described for Wallandoola Creek.

Threatened Species and Assessments of Significance

Two aquatic invertebrate species, Adam's Emerald Dragonfly (*Archaeophya adamsi*), Sydney Hawk Dragonfly (*Austrocordulia leonardi*), listed as threatened under state legislation, could potentially occur within the NRE No.1 Mine Area. There are no records of these species occurring within Cataract, Wallandoola or Lizard Creeks or the greater Cataract River catchment. There is suitable habitat for Adam's Emerald Dragonfly within all three creeks, but not for Sydney Hawk Dragonfly. The latter dragonfly is consequently highly unlikely to be present within the mine areas, so potential impacts on this species have not been considered. The Assessment of Significance indicated that the proposed mining operation is highly unlikely to have a significant impact on any Adam's Emerald Dragonfly that may be present, provided the adaptive management plan is implemented.

Four species of fish, Macquarie Perch (*Macquaria australasica*), Trout Cod (*Maccullochella macquariensis*), Silver Perch (*Bidyanus bidyanus*) and Murray Cod (*Maccullochella peelii peelii*), listed as threatened under state and/or federal legislation are known to have been translocated to Cataract Dam. Targeted fish surveys indicate that Macquarie Perch, Silver Perch and an unidentified Freshwater Cod, that may be either Trout Cod, Murray Cod or a hybrid of these species, occur in the reach of Cataract Creek that traverses the proposed Wongawilli East Mine Area. The Assessments of Significance indicate that the proposed mining operation is highly unlikely to have a significant impact on any Macquarie Perch, Silver Perch, Trout Cod or Murray Cod accessing this mine area, provided the adaptive management plan is implemented.

Conclusions

The assessment of potential impacts on aquatic ecology generally, and threatened species in particular, is consistent with the performance measures specified in the Bulli Seam Operations Approval. Subsidence resulting form the extraction of the proposed longwalls would have negligible environmental consequences for aquatic flora and fauna, including threatened species.

Recommendations

1. The condition of aquatic habitats and biota should be monitored during and following the extraction of the longwalls using the same survey sites, methods and seasons as in the baseline study. The objective of this monitoring would be to validate the predictions about the flow-on effects of subsidence-related disturbances on aquatic habitats and biota and assess any unexpected impacts on these that may occur.
2. If fractures of the stream bed and associated loss of water or significant changes in pH, dissolved oxygen, turbidity or metal concentrations are detected during routine surface monitoring, additional surveys of aquatic habitats and biota should be undertaken to determine whether these have had any flow-on effects on aquatic ecology.

3. If fish or yabby kills are noted during routine surface monitoring, further studies should be undertaken to determine the extent of impact on aquatic ecology and whether there is a need to implement management and/or mitigation measures.
4. If significant effects on aquatic habitats and/or biota are detected during monitoring, consideration should be given to reducing further impacts by modifying the dimensions of future longwalls, increasing their setback from the affected watercourse or remediation of fractured rock bars.

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1 Introduction

1.1 Background and Aims

Gujarat NRE Coking Coal Limited (Gujarat NRE) proposes to extract coal from the base of the Wongawilli Seam within the Wongawilli East and Wongawilli West areas of the NRE No. 1 Mine at Russell Vale, in the NSW Southern Coalfield. The extraction of coal from these areas, using longwall mining methods, has the potential to result in physical subsidence impacts, which could, in turn, have direct effects on stream flow and water quality and indirect effects on aquatic habitats and biota in the surface watercourses located within and downstream of the mine areas.

Cardno Ecology Lab was commissioned by Gujarat NRE to assess the likelihood and significance of potential impacts on aquatic habitat and biota arising from mining of longwalls within the Wongawilli East and Wongawilli West areas and make recommendations for ongoing monitoring. This assessment is to be included in the Environmental Assessment that is being prepared for submission to the Department of Planning as part of the Part 3A approvals process for NRE No. 1 Mine. The Study Area encompasses the predicted 20 mm subsidence zone above the proposed workings, the defined 400 m Risk Management Zones and the 600 m zone from the edge of secondary extraction for assessment of significant natural features (NSW Planning Assessment Commission 2009).

1.2 Study Areas

1.2.1 Wongawilli West

The proposed Wongawilli West longwalls are located within the Cataract River catchment. The Study Area includes two tributaries of the Cataract River: Wallandoola Creek and Lizard Creek that flow into the reach of the Cataract River downstream of Cataract Dam and upstream of Broughtons Pass Weir within the Sydney Water supply system. These are the only watercourses in this area that contain significant areas of permanent aquatic habitat. The reach of Wallandoola Creek that flows through the mine area is classified as a ‘third order’ stream under the Strahler Stream Classification System, but becomes a ‘fourth order’ stream approximately 1.8 km downstream of the proposed longwall panels. Lizard Creek is a ‘third order’ stream upstream of its confluence with LCT1, but a ‘fourth order’ stream downstream of this point.

1.2.2 Wongawilli East

The proposed Wongawilli East longwalls are located within the Lake Cataract catchment, to the north-east of the Cataract River arm of the reservoir. Cataract Creek, the only significant watercourse located within this Study Area flows directly into Lake Cataract. The reach of the creek within the Study Area is classified as a ‘fourth order’ stream.

1.3 Aquatic Ecology Monitoring Program

The baseline aquatic ecology monitoring program for the Wongawilli East and Wongawilli West mine areas was designed to satisfy the recommendations made by the NSW Department of Planning’s ‘Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield’ (NSW Department of Planning 2008). Specific recommendations within the review that are relevant to environmental investigations for project applications lodged under Part 3A include:

- Assessments should focus on Risk Management Zones (RMZs), which in the case of watercourses should include streams within the mine subsidence area classified as 3rd order or above under the Strahler Stream Classification System;

- A minimum of 2 years of baseline data should be collected at an appropriate frequency and scale for significant natural features located within an RMZ or not.
- Before, After, Control, Impact (BACI) designed ecological studies should be used to monitor mine subsidence impacts.

Within each of the significant watercourses identified within the Study Areas, two ‘potential impact’ sites that may be subjected to mine subsidence impacts during and after longwall extraction were selected for monitoring. Ecologically comparable ‘control’ watercourses in the Cataract catchment that are not expected to be undermined were also identified, and within each of these, two sites were selected for monitoring. The control watercourses used in this study were Upper Cataract River, Loddon Creek, Allen Creek and Cascade Creek. These ‘control’ sites provide measures of the natural background environmental variability within the greater Cataract catchment as distinct from any mine subsidence impacts. The position of the ‘potential impact’ and ‘control’ sites relative to the proposed Wongawilli West and Wongawilli East Longwalls is shown in Figure 1.

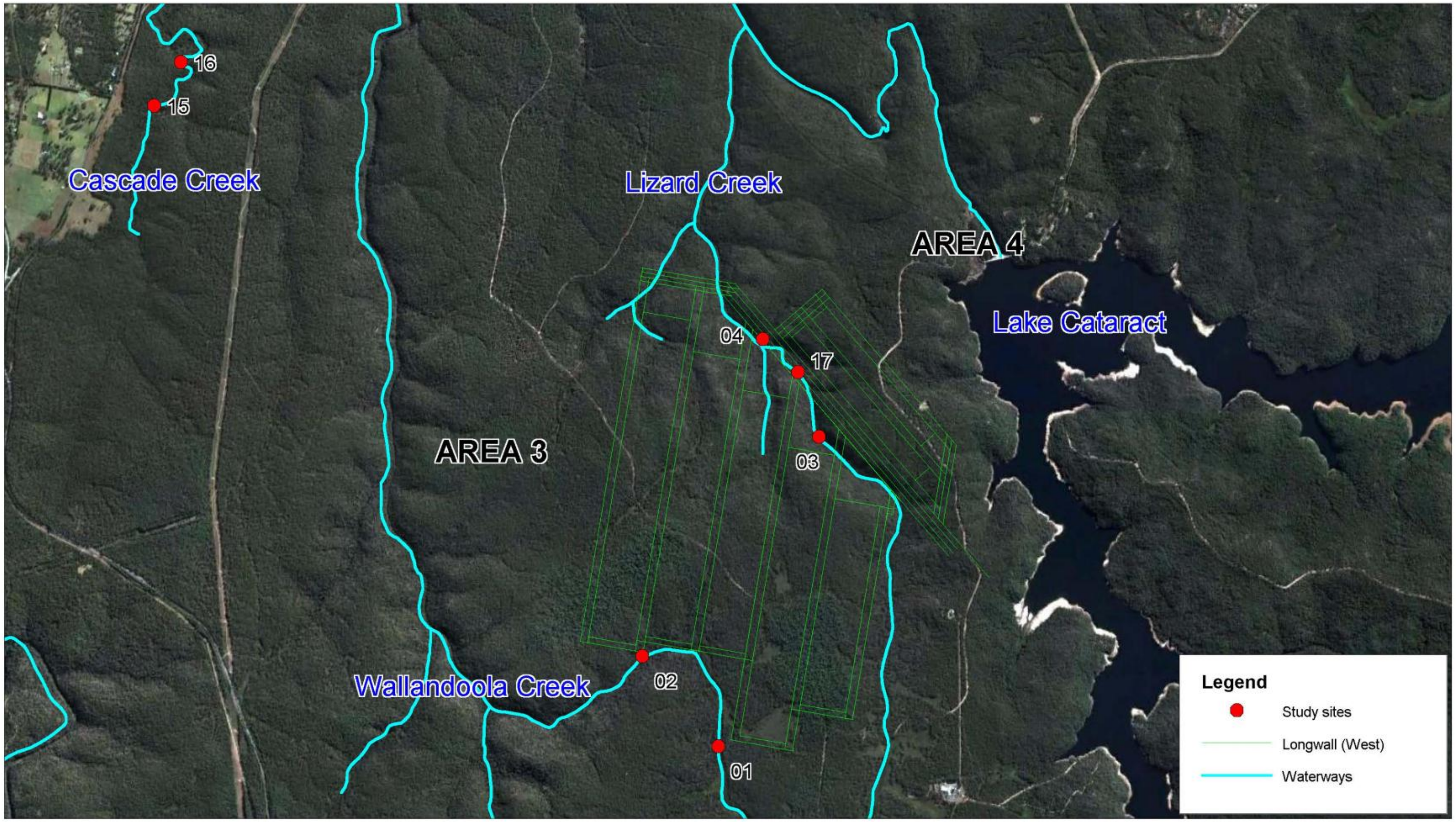
The sampling design chosen for the baseline monitoring program will enable Beyond BACI analyses to be used to assess any potential impacts of mining subsidence on aquatic ecology, provided that similar assessments are made during and after mining. The Beyond BACI technique is a modification to the BACI approach that has been developed specifically to distinguish environmental impacts from natural changes (Underwood 1991, 1992, 1994).

At each monitoring site, the following aquatic ecological indicators were surveyed in spring and autumn:

- Aquatic habitat
- Aquatic macroinvertebrate fauna
- Fish fauna
- Water quality.

Baseline monitoring commenced in spring (October) 2008 and was completed in spring (September) 2011. A summary of the results of the baseline monitoring program is presented in the Review of Existing Information (see Section 2.0). A detailed description of the ecological indicators sampled, methods and the results of the baseline monitoring undertaken at ‘control’ and ‘potential impact’ sites is presented in Cardno Ecology Lab (2011) (see Annexure 1).

The initial site inspection undertaken prior to the selection of monitoring sites indicated that the aquatic habitat within Cataract Creek was suitable for occupation by Macquarie Perch, a threatened species listed under both State and federal legislation (Cardno Ecology Lab 2009). A preliminary survey of fish occurring within these habitats was undertaken between 25 and 26 November 2008 and targeted backpack electrofishing surveys for this and other threatened fish species were undertaken during the summers of 2009/2010, 2010/2011 and 2011/2012. A description of the sampling methods and results of these surveys are presented in Cardno Ecology Lab (2011 and 2012) (see Annexure 1).



0 3
Kilometres

Study Sites in Wongawilli West

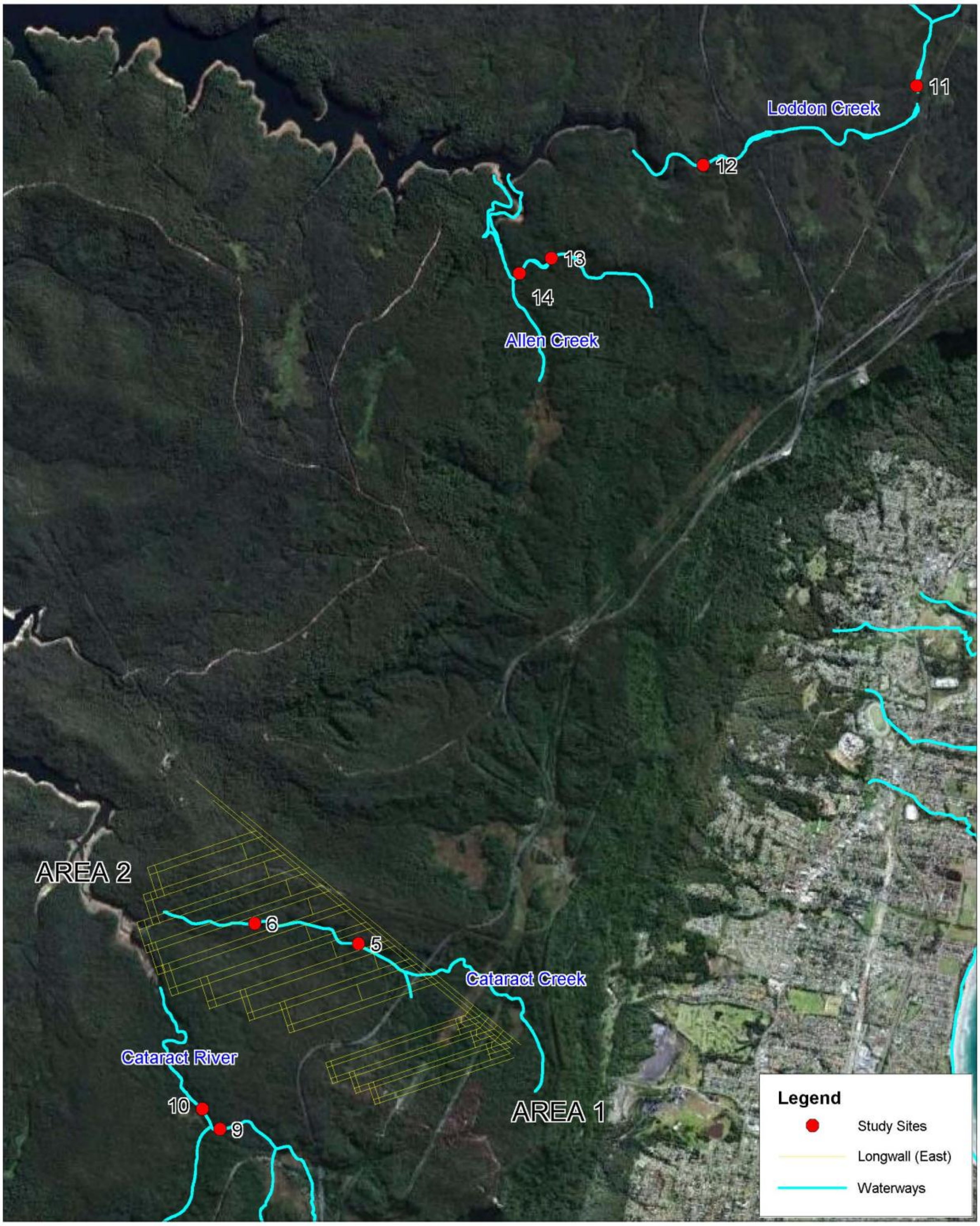
NRE No 1 MINE - EFFECTS OF MINE SUBSIDENCE ON AQUATIC HABITAT AND BIOTA
PREPARED FOR GUJARAT NRE COKING COAL LIMITED

Figure 1a

N
W E
S

Cardno Ecology Lab

Map Produced by Cardno Ecology Lab
Date: 22 October 2012
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: Google Images
EL0910036_WongawilliWest_Figure_1



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Study Sites at Wongawilli East

NRE No 1 MINE -
EFFECTS OF MINE SUBSIDENCE ON AQUATIC HABITAT AND BIOTA
PREPARED FOR GUJARAT NRE COKING COAL LIMITED

Figure 1b

Cardno
Ecology Lab

Map Produced by Cardno Ecology Lab
Date: 22 Oct 2012
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: Google Images
EL0910036_WongawilliEast_Figure_2

2 Review of Existing Information

2.1 Introduction

The natural environment in the two Study Areas is relatively undisturbed due to the restrictions on access and development arising from the inclusion of the greater Cataract River catchment within the Metropolitan Special Area administered by Sydney Catchment Authority (SCA). The flow within the three significant streams traversing the Study Areas is unregulated.

Information on the aquatic ecology of the significant watercourses traversing the proposed mine areas is fairly limited. The results of previous investigations of water quality, aquatic habitats and biota within the reaches of these watercourses, including that from the baseline monitoring program undertaken by Cardno Ecology Lab (2011 and 2012), are summarised in Sections 2.1.1 and 2.1.2. The likely occurrence of threatened species listed under State and Federal legislation is addressed in Section 2.1.3.

2.1.1 Wongawilli West

2.1.1.1 Aquatic Habitat

Wallandoola Creek and Lizard Creek are deeply-incised streams cut into Hawkesbury Sandstone that flow into the Cataract River between Cataract Dam and Broughton's Pass Weir (The Ecology Lab 2007 and 2008). The streams are surrounded by relatively natural, undisturbed, dry sclerophyll woodland and heath (Cardno Ecology Lab 2011). The reaches of the creeks within the Study Area contain a variety of aquatic habitats, including deep, permanent pools, shallow areas over bedrock bars, submerged woody debris and aquatic macrophytes. Some sections of Lizard Creek dry out after lengthy dry periods. The reaches of Wallandoola and Lizard Creek immediately upstream of the Study Area are characterised by headwater swamps, with relatively low gradients (The Ecology Lab 2008). There are numerous cascades and waterfalls on both creeks between the proposed mining area and their confluence with the Cataract River that would pose significant barriers to fish passage.

Both creeks have been impacted by previous mining activity, with fractured bedrock, iron staining and iron floc all being evident. Iron staining has been observed in the reach of Wallandoola Creek to the south of proposed LW's 3 and 4 and the reach of Lizard Creek to the north of proposed LW 1 within Area 3 (Cardno Ecology Lab 2011).

2.1.1.2 Water Quality

The quality of water in Wallandoola Creek and Lizard Creek has been assessed on several occasions (Australian Water Technologies 2001; Seedsman Geotechnics 2001; Geoterra 2002 and 2012; Ecoengineers Pty Ltd, 2008; The Ecology Lab 2008; Cardno Ecology Lab 2011). Only the results of the most recent monitoring programmes are reported below.

The water in Lizard Creek and Wallandoola Creek was generally within the acceptable range for potable water (Geoterra 2012). The water in both creeks was fairly acidic, with median pH levels ranging from 4.6 to 6.5 in Lizard Creek and from 5.5.to 6.2 in Wallandoola Creek. The pH of the water in Lizard Creek was thus occasionally equivalent to the ANZECC/ARMCANZ lower default trigger value (DTV), whereas that in Wallandoola creek was invariably below the lower DTV. Slightly acid streams are quite common in the Hawkesbury Sandstone watercourses of the Southern Highlands and Illawarra. Salinity was within the DTV range, varying from 19 – 290 µS/cm in Lizard Creek and 53 - 199 µS/cm in Wallandoola Creek. In Lizard Creek, both salinity and pH increased with distance downstream. On some occasions, the filtered zinc, copper and aluminium and total nitrogen and phosphorus levels in both creeks were above the 95% species protection level for freshwater aquatic ecosystem guidelines.

The Ecology Lab (2008) noted that turbidity levels in both creeks were generally below the lower DTV and that the dissolved oxygen concentration in Lizard Creek was also below the lower DTV. During the baseline aquatic ecology surveys, the dissolved oxygen levels in both creeks were generally below the lower DTV, suggesting that conditions may not be optimal for aquatic life (Cardno Ecology Lab 2011). The pH and turbidity levels in Wallandoola Creek and electrical conductivity, pH and turbidity levels in Lizard Creek deviated from the DTVs on some occasions.

2.1.1.3 Aquatic Macrophytes

No published information is available on the distribution of aquatic macrophytes within or in the vicinity of the watercourses in the Study Area. The ribbonweed, *Vallisneria* sp., has been recorded in the in-stream section of both creeks, while native plants, such as rushes (*Juncus* sp.), sawsedge (*Gahnia* sp.), and numerous small ferns occur along the stream banks (The Ecology Lab 2008). The report of *Vallisneria* sp. is likely to be a misidentification of the water ribbon, *Triglochin procerum,* a species that is relatively common in the Cataract River catchment (Bioanalysis 2009).

2.1.1.4 Aquatic Macroinvertebrates

Growns *et al.* (1997) found that slightly fewer aquatic macroinvertebrate fauna were associated with riffles (18) than the pool edge habitat (21) at a site within Wallandoola Creek. The Stream Invertebrate Grade Number Average Level (SIGNAL) scores derived from their data indicate that the water at this study site was unpolluted.

The macroinvertebrates associated with the edge habitat at a site in Lizard Creek adjacent to Fire Road 8 were sampled in spring 2004 as part of Sydney Catchment Authority's Macroinvertebrate Monitoring Program: 2004 (Ecowise 2005). The AUSRIVAS bands and SIGNAL2 scores for this site indicate respectively that the fauna was significantly impaired and the water was moderately polluted.

The spring baseline surveys for the NRE No1 Mine indicated there was considerable variation in the aquatic macroinvertebrate associated with the edge habitat, with the number of taxa collected per survey ranging from 7-22 and from 10-26 at the sites in Wallandoola Creek and from 9-25, 9-28 and 12-15 at the sampling sites on Lizard Creek (Cardno Ecology Lab 2011). The 'health" of the fauna at Site 1 on Wallandoola Creek varied from equivalent to AUSRIVAS reference condition to severely impaired, whereas that Site 2 varied from more diverse than the reference condition to significantly impaired. The "health" of the fauna at Sites 3 and 4 on Lizard Creek varied from equivalent to AUSRIVAS reference condition to severely impaired, whereas that at Site 17 was assessed as either significantly impaired or severely impaired. The SIGNAL2 scores indicated that the five sites were subject to moderate to severe degradation.

The baseline surveys conducted in autumn suggested there was less variation in the number of aquatic macroinvertebrate fauna, with the number of taxa collected per survey ranging from 16-25 and from 16-21 at the sites in Wallandoola Creek and from 7-8, 14-21 and 10-20 at the sampling sites on Lizard Creek. The "health" of the fauna at Sites 1 and 2 on Wallandoola Creek varying from more diverse than the reference condition to severely impaired and from equivalent to AUSRIVAS reference condition to significantly impaired, respectively. The fauna at Site 3 on Lizard Creek was rated as significantly impaired, whereas that at Sites 4 and 17 varied from equivalent to AUSRIVAS reference condition to severely impaired and impoverished, respectively. The SIGNAL2 scores derived from the data collected in autumn also indicated that the five sites were subject to moderate to severe degradation.

2.1.1.5 Fish

The Ecology Lab (2003 and 2005) caught three native species, Macquarie Perch, Flathead Gudgeon (*Philypnodon grandiceps*), and Australian Smelt (*Retropinna semoni*) and one introduced species, the Mosquito Fish (*Gambusia holbrooki*) in the Cataract River between Cataract Dam and Broughtons Pass Weir. They also noted that native freshwater crayfish (*Euastacus* sp.) were present throughout this reach of the river.

The "Audit of Sydney Drinking Water Catchment 2007" indicates three endemic fish species were present within Wallandoola Creek, but does not specify their identity (DECC 2007).

Climbing galaxias (*Galaxias olidus*) are known to occur in the reach of this creek overlying Appin Area 3 extended (Bioanalysis 2009).

During the baseline surveys for the NRE No1 Mine, Climbing Galaxias (*Galaxias brevipinnis*) and Australian Smelt (*Retropinna semoni*) were observed in Lizard Creek, but no fish were caught in Wallandoola Creek (Cardno Ecology Lab 2011). The freshwater crayfish, *Euastacus* sp. was present in both creeks.

2.1.2 Wongawilli East

2.1.2.1 Aquatic Habitat

Cataract Creek is bordered by temperate rainforest. The creek is mostly shallow with alternating series of long pools, some of which are deep, interspersed with shorter bars and riffles composed of bedrock, boulders, cobble, pebble and gravel. Dams of large woody debris are fairly. There are also submerged snags in pools. There is no evidence of impacts associated with previous mining. Lake Cataract backs up into the creek, with the extent of the incursion depending on the storage level of the dam. There are no waterfalls or highly-stepped zones in this creek and hence no barrier to the upstream passage of fish from Lake Cataract.

2.1.2.2 Water Quality

The Sydney Catchment Authority (2008) monitored water quality at Cataract Lake 30 meters from the dam wall and found that it generally had a very good aquatic environmental value. Between 68 and 100 percent of samples met the ANZECC guideline levels for all indicators, except for oxidised nitrogen, which met the guideline levels for 36 percent of samples, and ammonia nitrogen, which met the guidelines for 18 percent of samples.

The water in Cataract Creek was also generally within the acceptable range for potable water (Geoterra 2012). The median pH of the water within the creek was below the ANZECC/ARMCANZ (2000) lower DTV, with values ranging from 5.7 to 6.3 (Geoterra 2012). Salinity was within the DTV limits, with median values ranging from 130 – 145 µS/cm. In areas of the creek where there were ferruginous deposits, filtered zinc, copper and aluminium and total nitrogen and phosphorus levels occasionally exceeded the ANZECC/ARMCANZ (2000) guidelines.

During the baseline aquatic ecology surveys, the dissolved oxygen levels in Cataract Creek were generally below the lower DTV, but electrical conductivity, pH and turbidity levels only deviated from the guidelines occasionally (Cardno Ecology Lab 2011).

2.1.2.3 Aquatic Macrophytes

No information was found.

2.1.2.4 Aquatic Macroinvertebrates

The baseline surveys for the NRE No1 Mine indicated there was also considerable variation in the aquatic macroinvertebrate associated with the edge habitat at the sites in Cataract Creek, with the number of taxa collected per spring and autumn survey ranging from 12-23 and from 13-20 at Site 5 and from 9-19 and 16-22 at Site 6, respectively (Cardno Ecology Lab 2011). The ‘health” of the fauna at Site 5 varied from equivalent to AUSRIVAS reference condition to significantly impaired during the spring surveys, but was either significantly impaired or severely impaired in autumn. The “health” of the fauna at Site 6 varied from equivalent to AUSRIVAS reference condition to severely impaired during the spring and autumn surveys. The SIGNAL2 scores indicated that, in general, the two sites were subject to mild degradation.

2.1.2.5 Fish

Gehrke and Harris (1996) caught Trout Cod and Murray Cod (*Maccullochella peelii* x *M. macquariensis*) hybrids and Macquarie Perch in Cataract Dam and recorded climbing galaxias

(*Galaxias brevipinnis*) in the Bellambi Creek tributary of the dam. A NSW Fish Survey conducted in August 2006 found multiple juvenile cod that could have been either Trout Cod, Murray Cod or hybrids of these species (A. Bruce, personal communication, 3 December 2008).

The "Audit of Sydney Drinking Water Catchment 2007" indicated that two endemic, two translocated, and one introduced fish species were present within Cataract Dam (DECC 2007). The only information given about the identity of the fish caught in this location was that Macquarie Perch was present.

During the baseline surveys for the NRE No1 Mine, Climbing Galaxias (*Galaxias brevipinnis*), Eastern Gambusia (*Gambusia holbrooki*) and freshwater crayfish, *Euastacus* sp. were observed in Cataract Creek (Cardno Ecology Lab 2011). The targeted backpack electrofishing surveys that were undertaken in Cataract Creek during the summers of 2009/2010, 2010/2011 and 2011/2012, indicated an additional seven species of fish, Macquarie Perch (*Macquaria australasica*), Silver Perch (*Bidyanus bidyanus*), Short-finned Eel (*Anguilla australis*), Freshwater (Eel-tailed) Catfish (*Tandanus tandanus*), Mountain Galaxias (*Galaxias olidus*), Goldfish (*Carassius auratus*) and an unidentified Freshwater Cod of the genus *Maccullochella* (potentially Murray Cod, Trout Cod or a hybrid of these species) frequent this reach (Cardno Ecology Lab 2011 and 2012). A Long-finned Eel (*Anguillla reinhardtii)* was caught in this reach during a preliminary fish survey undertaken in November 2008.

The Australian Museum tentatively identified a juvenile specimen of the Freshwater Cod caught in Cataract Creek as Eastern Freshwater Cod on the basis of its external morphology (Mark McGrouther pers. comm.). DPI NSW has subsequently suggested that this fish may have been a hybrid of Trout Cod and Murray Cod that are known to occur in this impoundment (Andrew Bruce, pers. comm.).

2.2 Threatened Species

A review of the information that is available on the geographic distribution of aquatic organisms listed as threatened under state and federal legislation indicates that six species could potentially occur within the Study Area. These are:

- Sydney Hawk Dragonfly (*Austrocordulia leonardi*), listed as endangered under the FM Act;
- Adam's Emerald Dragonfly (*Archaeophya adamsi*), listed as endangered under the FM Act;
- Macquarie Perch (*Macquaria australasica*), listed as endanagered under the FM Act and EPBC Act;
- Trout Cod (*Maccullochella macquariensis*), listed as endangered under the FM Act and EPBC Act.
- Murray Cod (*Maccullochella peelii peelii*) listed as vulnerable under the EPBC Act.
- Silver Perch (*Bidyanus bidyanus*) listed as vulnerable under the FM Act

Macquarie Perch, Silver Perch and an unidentified Freshwater Cod (potentially Murray Cod, Trout Cod or a hybrid of these species) have been recorded in the reach of Cataract Creek upstream of Lake Cataract that flows through the Wongawilli East Study Area. Adams Emerald Dragonfly has not been recorded in any of the significant watercourses that flow through the two Study Areas, but suitable habitat for them has been identified in these creeks. Further details of the distribution of these five species and Assessments of Significance for them are presented in Appendices 1-5.

Sydney Hawk Dragonfly is an extremely rare species, having been collected in small numbers at only a few locations to the south of Sydney, between Audley to Picton (NSW DPI, 2005b). There are no records for this species within the Wallandoola or Lizard Creek catchments or within the greater Cataract River catchment. Most of the lifecycle of this species is spent as an aquatic larva, while adults are present for only a few weeks. The larvae of Sydney Hawk Dragonfly appear to have specific habitat requirements, including deep, cool, slow-flowing water in rocky rivers with steep sides (NSW DPI, 2005b). Relative environmental stability appears to be an important habitat feature, with rapid variation in water level and flow rate likely to have a negative effect on the suitability of habitat for larvae (G. Theischinger, pers. comm.). The nearest watercourse to the proposed mine area containing suitable habitat for the Sydney Hawk Dragonfly is likely to be the Cataract River, which is beyond the influence of significant subsidence impacts. An Assessment of Significance has consequently not been prepared for this species.

3 Assessment of Impacts

This assessment of impacts on aquatic habitat and biota as a result of physical subsidence from extraction of the proposed Wongawilli East and Wongawilli West mine areas is based on:

- the most recent mine layout provided by Gujarat NRE;
- predictions of mine subsidence (Seedsman Geotechnics 2012);
- assessment of the effects of subsidence on surface water and groundwater quality (Geoterra 2012); and
- data from the baseline aquatic ecology monitoring program (Cardno Ecology Lab 2011 and 2012).

3.1 Proposed Mine Layout

Gujarat NRE intends to reduce the risk of major subsidence by:

- Not extracting longwalls under the main or named channels of third or fourth order streams in the Wongawilli West mine area;
- Undertaking mining in Area 4 that will not have any impact on Cataract Dam and in accordance with consent of the NSW Dam Safety Committee);
- Setting each of the nominally 380 m wide longwall panels in the Wongawilli West mine area 200 m back from the centreline of Lizard Creek;
- Using narrow (nominally 150 m wide) longwall blocks with wide (60 m) chain pillars in the Wongawilli East mine area to access coal in the Cataract Reservoir Notification Area and under Cataract Creek;
- Setting the start lines for the panels in the Wongawilli East mine area at least 110 m back from the maximum stored water level of Cataract Dam;
- Monitoring the subsidence that arises as longwalls in the Wongawilli East mine area are extracted and changing the start and finish lines of panels, if necessary (Seedsman Geotechnics 2012).

The proponent has also provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experience greater than minimal impact.

Further details of the layouts of the two mines and their relationship to the overlying watercourses are presented below. Note that use of narrow longwall panels would not be economic in the Wongawilli West mine area.

3.1.1 Wongawilli East

The Wongawilli East workings would be divided into two areas to reduce the risk of subsidence along Mount Ousley Road, with Areas 1 and 2 being situated to the east and west of this road, respectively (Figure 1a). The longwalls would also be positioned in a north-east to south-west direction, in order to restrict vertical subsidence under significant watercourses. The three longwalls below Area 1 would be situated beneath ephemeral 1st order and intermittent 2nd order tributaries that flow into the main channel of Cataract Creek downstream of Mount Ousley Road. The eight longwalls below Area 2 would be located beneath 1st and 2nd order tributaries of Cataract Creek, but the main channel of the creek would only be undermined by Longwalls 7, 8 and 9. The depth to the floor of the Wongawilli Seam varies from 280 m below Cataract Creek to 340m to the south (Seedsman Geotechnics 2012). The section of the Seam that would be extracted is likely to vary from 2.7 -3.2 m.

3.1.2 Wongawilli West

The Wongawilli West workings would be divided into two areas to reduce the risk of subsidence along Wallandoola and Lizard Creeks, with Area 3 and 4 being located to the west and east of Lizard Creek, respectively. The five longwalls within Area 3 would be positioned in a north-south direction and would terminate immediately to the north of Wallandoola Creek. The two longwalls within Area 4 would be oriented from north-west to south-east. The longwalls within Areas 3 and 4 would not be situated below the main channel of Lizard Creek or Wallandoola Creek, but would undermine several watersheds and 1st to 3rd order tributaries that drain into these creeks. The depth to the floor of the Wongawilli Seam varies from 440-500 m (Seedsman Geotechnics 2012).

3.2 Subsidence Predictions

The Bulli Seam, and some parts of the Balgownie Seam, within the Wongawilli East and Wongawilli West areas have been extracted previously using either longwall, pillar or bord and pillar extraction techniques (Seedsman Geotechnics 2012). Previous mining operations have resulted in subsidence within both the Wongawilli East and Wongawilli West areas (Seedsman Geotechnics 2012). Mining has already occurred under Cataract, Lizard and Wallandoola Creeks, but only the creeks within the Wongawilli West Study Area appear to have been impacted, with fractured bedrock, iron staining and iron floc being common in both. Localised loss of surface water flows is also evident in Lizard Creek (Cardno Ecology Lab 2011; Geoterra 2012).

Subsidence within the Wongawilli East and Wongawilli West mine areas is expected to be non-conventional, because of the extraction of multiple coal seams, lack of isolation between longwalls in previously mined seams and proposed longwalls, the Bulgo Sandstone overlying the Bulli Seam and irregular topographic surface (Seedsman Geotechnics 2012). The extent of the subsidence deformations will depend on whether or not the Balgownie longwalls have disrupted the spanning capacity of the Bulgo Sandstone above large Bulli Seam pillars. As this is not yet known, subsidence can not be accurately predicted. Seedsman Geotechnics (2012) have consequently provided subsidence, strain and tilt predictions for extraction of the Wongawilli Seam only for both the Wongawilli and Bulli Seams. The predictions provided for each of the mine areas and the reaches of Cataract Creek crossing Longwalls 8-10 in Wongawilli East are summarised in Table1. Note that the worse case predicted subsidence (1.2 m) is only expected to occur above Longwalls 5 and 6 if the Bulli pillars collapse.

Table 1: Predicted subsidence, tilt and strain parameters for Wongawilli East and Wongawilli West (additional values inside brackets represent extraction of the Wongawilli + Bulli Seams).

Mine Area	Location	Subsidence (m)	Tilt (mm/m)	Strain (mm/m)
Wongawilli East		0.0-1.2	0.0-25.0	-10.0-6.0
	Area 1	0.02-0.6		
	Area 2	0.02-1.2		
	Cataract Creek above Longwall 8	0.02-1.0 (0.02-1.2)		
	Cataract Creek above Longwall 9	0.02-0.04 (0.02-0.2)		
	Cataract Creek above Longwall 10	0.02-0.2		
Wongawilli West		0.0-3.6	0.0-16.0	
	Area 3	0.0-2.0 (0.0-2.5)		
	Area 4	0.0-2.5 (0.02-3.0)		

3.3 Impacts on Creeks

3.3.1 Alterations to Flow and Ponding

Mining-induced subsidence has the potential to alter flow in the creeks by:

- Diverting surface water flows through fractures and joints in the bedrock into subterranean flows;
- Draining water in pools and ponds through fractures and joints in rock bars;
- Reducing inflow into pools as a result of upstream diversion of surface flows into the near surface groundwater system; and
- Creating inter-connected cracks between the seam and surface which lead to loss of surface water into the mine.

The predictions made by Geoterra (2012) about the likelihood of alterations to flows and drainage of pools in significant creeks as a result of extraction of the proposed Wongawilli West and Wongawilli East longwalls are summarised in the following sections. In the case of the Wongawilli East mine area, this assessment assumes that an adaptive management plan that prevents subsidence-induced fracturing of the Cataract Creek bed would be implemented. Such a plan would require the subsidence that develops as the longwalls are progressively extracted to be monitored closely and, if a certain threshold that could lead to fracturing is exceeded, the layout of the longwalls would need to be revised.

Extraction of the longwalls will also lead to depressurisation of the Hawkesbury Sandstone which, in turn, will reduce the gradient of the water table draining to the watercourses and the overall height of the water table. This will lead to a reduction in baseflow recharge to the streams (Geoterra 2012).

3.3.1.1 Wongawilli East

The physical subsidence arising as a result of extraction of the Wongawilli East longwalls is unlikely to have any detectable effects on stream flow or ponding or stream gradient of Cataract Creek, provided that the adaptive management plan is adhered to (Geoterra 2012). The reduction in baseflow recharge to the Cataract Creek due to changes in the water table resulting from depressurisation of the Hawkesbury sandstone would be negligible (0.07 ML/d), so it is highly unlikely that it would have any detectable effects on the availability of aquatic habitat in this creek.

3.3.1.2 Wongawilli West

The predicted 20 mm total subsidence is not expected to have any detectable effects on the pools up to the main bend in Wallandoola Creek, which is situated to the south of proposed LW 3 within Area 3. The predicted strains (< 3 mm/m) for this section of the creek are also not expected to have any detectable effects on stream flow or pool drainage. The northern part of the main bend is likely to experience greater subsidence (0.25-0.5 m), but this is still not expected to have any detectable effects on flow or ponding. The predicted strains (~ 6 mm/m) in the stream bed to the south of proposed LW's 3 and 4 could fracture the sandstone rock shelf and lead to drainage of the pool situated upstream of this shelf. The flow into the cracks is expected to reappear downstream. There is a possibility of stream bed fractures migrating progressively downstream as proposed LW's 2 to 4 are extracted within Area 3. In this case, fracturing of the creek bed could lead to loss of water to the voids. The predicted subsidence (0.02-0.25 m) and strains (1-3 mm/m) of the rock shelf constrained pool situated close to the southern end of proposed LW 5 and upstream of the waterfall on Wallandoola Creek are not expected to alter stream flow or ponding. The channel of Wallandoola Creek is not expected to experience any significant detectable uplift.

The predicted subsidence (20 mm to 0.25 m) and strains (< 3 mm/m) are not expected to have any adverse detectable effects on stream flow or pools in the reach of Lizard Creek situated within Wongawilli West. In the area to the north of proposed LW 2, maximum strains of between 3 mm/m and 7 mm/m could occur over a 300 m long stretch of the creek. This could lead to further fracturing of the creek bed and associated loss of water at rock bars, diversion of flows to underlying substrata and greater pool drainage.

Reductions in baseflow recharge to Wallandoola and Lizard Creek due to changes in the water table are expected to negligible (0.25 and 0.10 ML/d, respectively) (Geoterra 2012), so this is unlikely to have any detectable effects on the availability of aquatic habitat in this creek.

3.3.2 Surface Water Quality

Fracturing of bedrock and diversion of flows has the potential to alter water quality by:

- Increasing groundwater discharge to streams;
- Reducing dissolved oxygen and pH levels;
- Elevating concentrations of dissolved iron, nickel, aluminium, zinc and manganese, sulphate and salinity through weathering of newly-exposed rock faces;
- Increasing rainfall recharge through cracked Wianamatta Shale and discharge out of the interface between shale and Hawkesbury sandstone;
- Elevating salinity and decreasing oxygen concentrations in pools through reduction in their depth, enhanced evaporation and stagnation; and
- Facilitating periodic emission of gases, such as methane, into watercourses.

The most obvious change in water quality is the orange-brown iron hydroxide staining, resulting from the dissolution of iron sulphide or iron carbonate exposed when sandstone fractures. The dissolution of these minerals leads to localised changes in water quality such as reduced pH and elevated concentrations of iron, manganese, aluminium, nickel and zinc. It is important to note that precipitation of iron hydroxide also occurs within streams that are not affected by mining. Emission of gases at the surface is not expected given the pre-existing fractures in the stream beds.

The predictions made by Geoterra (2012) about the likelihood of changes in surface water quality arising as a result of extraction of the Wongawilli West and Wongawilli East longwalls are summarised below.

3.3.2.1 Wongawilli East

As extraction of the longwalls is not expected to result in fracturing of bedrock or diversion of flows in Cataract Creek and Cataract River, these are not expected to have any adverse effects on surface water quality. Emission of gases is not expected to have any adverse effects on water quality because of the pre-existing subsidence and fracturing. Minor bank and bed erosion may occur over the longwall panels, particularly at the ends of the subsidence troughs and over chain pillars. This could lead to minor, transient increases in sediment mobility within and downstream of the subsidence area and minor, transient increases in turbidity of the water. These impacts are likely to be much smaller than those that occur naturally during heavy rainfall and are therefore considered to be of no significance.

3.3.2.2 Wongawilli West

If mining results in fracturing of the creek bed to the south of proposed Longwall 3 and 4 and diversion of flows through the underlying sandstone, the amount of iron staining and concentrations of iron, aluminium, copper and zinc could increase in Wallandoola Creek. The water at the point where flow re-emerges could exhibit localised changes in quality such as slightly lower pH and slightly elevated salinity. The quality of the emerging water would depend on whether the fractures in the bedrock are new or old and the extent to which it is diluted by surface flows, with effects being greater if the bedrock has not been weathered previously.

There are not expected to be any adverse effects on water quality in the other sections of Wallandoola Creek or Lizard Creek, because the predicted subsidence and strain parameters indicate fracturing of bedrock and flow diversion is unlikely to occur.

3.3.3 Aquatic Habitats and Biota

The aquatic habitats within some sections of Wallandoola Creek and Lizard Creek overlying the proposed Wongawilli West workings have already been degraded by previous mining operations.

3.3.3.1 Wongawilli East

Extraction of the proposed longwalls is not expected to result in any detectable effects on stream flow, pond drainage or water quality within Cataract Creek or Cataract River. The changes in these factors, in turn, are unlikely to have any observable effects on aquatic habitats, flora or fauna within these watercourses. The reduction in baseflow recharge of the creek due to depressurisation of the Hawkesbury sandstone is expected to be negligible, so this is also unlikely to have any detectable effect on the availability of aquatic habitat. Minor, transient increases in sediment mobility and turbidity of the water that occur within and downstream of the subsidence area are likely to have only a minimal impact on aquatic habitats and biota, because of their periodic exposure to such conditions during heavy rainfall events.

3.3.3.2 Wongawilli West

If extraction fractures the sandstone rock shelf in the bed of Wallandoola Creek to the south of proposed LW’s 3 and 4 and causes the pool upstream of the shelf to drain, there would be loss of aquatic habitat and associated biota within this pool. Organisms that are left stranded in air or that are unable to move to areas that are damp or submerged would suffer the greatest losses. The ability of organisms to cope with pool drainage varies, depending on their tolerance, response to desiccation and rapid changes in water level, ability to move, weather conditions at the time, the underlying substratum and duration of exposure. The drainage of this pool would also reduce longitudinal connectivity along the creek and prevent mobile aquatic fauna, particularly fish, from accessing upstream habitat for feeding or spawning purposes. The extent and duration of these losses would depend on the degree of drainage, rainfall and inflows from further upstream, with pool habitat being re-established once inflows exceed diversionary flows. Losses would be greater and more prolonged during periods of low rainfall. Downstream transfer of fine sediments, nutrients, organic materials, seeds, spores, vegetative fragments of aquatic plants and drift of macroinvertebrates is unlikely to be adversely affected, because the water lost is expected to re-emerge further downstream.

The diversion of the water lost from the pool through the underlying sandstone substratum could lead to iron staining and elevated dissolved metal concentrations in the water where the flows re-emerges on the surface. The precipitation of iron hydroxide may be followed by the growth of bacterially-mediated iron flocs and mats in pools which can, in turn, cause a reduction in dissolved oxygen levels. High levels of iron floc within a watercourse can also smother the surface of aquatic macrophytes, snags, boulders and bank edge and reduce the amount and variety of habitats suitable for occupation by aquatic organisms. The varying water quality along with reduced oxygen concentrations and elevated metal concentrations in the re-emerging water may also affect the diversity and abundance of aquatic organisms. These changes would be restricted to the area immediately downstream of rock fractures, where the flow re-emerges. The duration of these impacts would depend on the dilution, flushing and re-aeration effects of surface flows. Impacts would be more protracted during periods of low flows. It should be noted that the quality of the water within Wallandoola and Lizard Creeks is already highly variable and that pH and filtered zinc levels often exceed the ANZECC/ARMCANZ (2000) criteria (Geoterra 2012).

These impacts would be localised, minor in extent and transient in nature and therefore unlikely to be significant. There are not expected to be any adverse effects on the aquatic habitats, flora and fauna in the other sections of Wallandoola Creek and Lizard Creek.

3.4 Threatened Species

The Assessments of Significance presented in Appendices 1-5 indicate that the proposed mining operation is highly unlikely to have a significant impact on any viable populations of Adams Emerald Dragonfly, Macquarie Perch, Silver Perch, Trout Cod or Murray Cod that may be present in the Study Areas, provided the adaptive management plan is implemented.

3.5 Sensitive Aquatic Habitats

None of the aquatic reserves declared under the FM Act, proclaimed Ramsar or nationally important wetlands occur within or proximal to the proposed Application Area, hence there is no need to assess the effects of the proposed mine area on sensitive aquatic habitats.

3.6 Conclusions

The Bulli Seam Operations Approval specifies subsidence impact performance measures for natural features that must not be exceeded by underground mining operations. The following are relevant to aquatic ecology:

- Watercourses must not be subject to greater subsidence impact or environmental consequences than predicted in the Environmental Assessment;
- Subsidence must have negligible environmental consequences for threatened species, threatened populations, or endangered ecological communities.

The term negligible is defined in the BSO Project Approval as small and unimportant, such as to be not worth considering.

The assessment of potential impacts on aquatic ecology generally, and threatened species in particular, is consistent with these performance measures. The assessment indicates that changes in stream flow, ponding, stream gradient of Cataract Creek resulting from extraction of the Wongawilli East longwalls would not have any observable effects on the aquatic habitats or biota within Cataract Creek. Minor bank and bed erosion may occur above these longwalls and could lead to minor, transient increases in sediment mobility and turbidity within and downstream of the subsidence area. These would have a minimal impact on aquatic habitats and biota, because of their periodic exposure to such conditions during heavy rainfall events. Subsidence resulting from extraction of the proposed longwalls within the Wongawilli West Study Area is expected to have some impact on the aquatic habitats and biota within part of Wallandoola Creek. These impacts would be localised, minor in extent and transient in nature and therefore unlikely to be significant. They are not expected to be any observable effects on the aquatic habitats, flora and fauna in the other sections of Wallandoola Creek or in Lizard Creek.

4 Recommendations

4.1 Aquatic Environmental Monitoring

The monitoring of the ecological impacts of longwall mining is expected to be done in accordance with the recommendations made in the "Strategic Review of Impacts of Coal Mining on Natural Features in the Southern Coalfields" (NSW Planning 2008). The pertinent recommendations in that report are:

- Collection of a minimum of two years of baseline data (including threatened species monitoring);
- Use of Before, After, Control, Impact (BACI) designs for monitoring (current best practice); and
- Monitoring of third order or higher streams in the vicinity of predicted subsidence footprints.

Cardno Ecology Lab has now collected three years of baseline data from 'potential impact' sites on the significant creeks (Cataract, Wallandoola and Lizard) that traverse the proposed Wongawilli East and Wongawilli West Mine Areas and 'control' sites on nearby streams (Allen, Loddon and Cascade Creeks and the Upper Cataract River) (See Figure1). These data constitute the "before" component of the BACI ("Before, After, Control, Impact") study design. The following components have been monitored using the methods specified:

- Physico-chemical water quality parameters measured with a portable multi-probe meter;
- Condition of aquatic habitat based on standard scoring for variables listed within the AUSRIVAS protocol;
- Macroinvertebrates in pool edge habitats collected using (i) the standard AUSRIVAS rapid assessment methodology and SIGNAL2 scores and (ii) artificial collectors, a sampling method that provides a standardised habitat unit for macroinvertebrates to colonise and results in quantitative estimates of abundance and diversity that are independent of the quality or quantity of habitat present within the creeks;
- Fish sampled using dip nets.

The above have generally been monitored during spring and autumn. Targeted surveys of Macquarie Perch and other threatened fish species within the reach of Cataract Creek overlying the Wongawilli East Mine Area have been undertaken in the summer of 2009/2010, 2010/2011 and 2011/2012.

It is recommended that further monitoring of all of these components be undertaken during and following the extraction of these longwalls using the same survey sites and methods and during the same seasons as used for the baseline study. This will provide best practice environmental monitoring of aquatic ecology and allow statistically powerful analysis of the nature and extent of mine subsidence impacts, if any. The objective of this monitoring is to validate the predictions about the flow-on effects of subsidence-related disturbances on aquatic habitats and biota and assess any unexpected impacts on these that may occur.

Additional surveys of aquatic habitats and biota should be undertaken as soon as possible if fractures of the stream bed and associated loss of water from pools or significant changes in water quality are detected during routine surface monitoring of the potential impact creeks. The objective of these surveys would be to determine whether there have been any flow-effects on aquatic ecology. If fish or yabby kills are noted during routine surface monitoring, further studies should be undertaken to determine the extent of impact on aquatic ecology and whether there is a need for management/mitigation measures.

4.2 Management/Mitigation Measures

If significant effects on aquatic habitats and/or biota are detected during monitoring it may be necessary to reduce further impacts by adopting one of the following strategies:

- The commitment by the proponent that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experience greater than minimal impact;
- Modifying mine layout to further reduce potential subsidence impacts;
- Increasing the setback of the longwall being extracted and future longwalls from the affected watercourse;
- Implementing remediation measures to reduce the extent of fracturing of the stream bed (e.g. grouting of rock bars);
- Using standard erosion and sediment control measures to prevent mobilised sediments entering watercourses.

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6 Appendices

6.1 Appendix 1: Adam's Emerald Dragonfly

6.1.1 Background Information

Adam's Emerald Dragonfly is extremely rare, having been collected in small numbers from only a few locations in the greater Sydney region (NSW DPI 2005b). There are no records of Adam's Emerald Dragonfly occurring south of Sydney despite active collecting in the Hawkesbury-Nepean River catchment (Fisheries Scientific Committee 2008). This species was not sampled during the baseline surveys of aquatic macroinvertebrates in Wallandoola, Lizard and Cataract creeks, but aquatic habitat suitable for this species was identified within these watercourses (Cardno Ecology Lab 2011).

Although the current distribution records suggest that this species is unlikely to occur within the Study Area, an Assessment of Significance has been prepared as a precautionary measure (see below).

6.1.2 Assessment of Significance

(a) Is the proposed mining likely to have an adverse effect on the life cycle of Adam's Emerald Dragonfly that would result in a risk of extinction of a viable local population of the species?

The Adam's Emerald Dragonfly has a predominantly aquatic life cycle, with larvae living for approximately seven years before metamorphosing into adults, which fly away from water to mature (NSW DPI 2005b). The adults are believed to live for only a few months. They return to water to breed, with males congregating at breeding sites and guarding a territory and females laying their eggs into the water. Larval Adam's Emerald Dragonfly have been found in small creeks with gravel or sandy bottoms and narrow shaded riffle zones with moss and extensive riparian vegetation. This species appears to have a low natural rate of recruitment and limited dispersal abilities.

Disturbances that result in significant degradation or loss of habitat, water quality pollution and siltation could potentially have an adverse effect on the life cycle of this dragonfly (NSW DPI 2005b).

Mine subsidence is not predicted to result in significant adverse impacts on aquatic habitat or water quality within Cataract Creek or Lizard Creek (Section 2.2), so it is highly unlikely that there would be any adverse effects on the life cycle of Adam's Emerald Dragonfly, if a viable population exists within these watercourses.

There is a possibility that mining subsidence could fracture the sandstone rock shelf in the bed of Wallandoola Creek to the south of Longwalls 3 and 4 in Wongawilli West Area 3. This could lead to drainage of the pool upstream of the shelf and loss of aquatic habitat and associated biota, including any larval Adam's Emerald Dragonfly, present within the pool. Changes in water quality, including iron staining, could occur where the diverted flows re-emerge downstream. The increase in iron concentration could lead to the formation of iron-mediated bacterial flocs and smothering of aquatic habitats occupied by larvae or used for breeding by adults. The changes in availability of aquatic habitat and water quality that would occur as a result of mining, however, would be temporary, localised and minor in nature and would therefore not be significant relative to the total amount of potential habitat within Area 3. The duration of such impacts on any larval Adam's Emerald Dragonfly present in the area would depend on the degree of drainage, rainfall and inflows from further upstream, with pool habitat being re-established and water quality improving once inflows exceed diversionary flows. If a population of this species were to exist within Wongawilli West Area 3, it is highly unlikely that the proposed mining would disrupt the lifecycle of this species to such an extent that it would threaten the viability of a local population of Adam's Emerald Dragonfly.

(b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

There are no threatened populations of Adam's Emerald Dragonfly listed on the Threatened Species Schedules of the *FM Act*.

(c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

Adam's Emerald Dragonfly is not part of an endangered ecological community listed on the Threatened Species Schedules of the *FM Act*.

(d) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed, and

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Larval Adam's Emerald Dragonfly are aquatic and inhabit small creeks with gravel or sandy bottoms and narrow shaded riffle zones with moss and extensive riparian vegetation (NSW DPI 2005b). The adults are terrestrial, but return to water to breed. Some of the aquatic habitat within the reaches of Cataract, Wallandoola and Lizard Creeks that traverse the proposed mine areas is suitable for the larvae (Cardno Ecology Lab 2011).

Mine subsidence is not expected to result in removal, fragmentation or modification of the aquatic habitat within Cataract Creek and Lizard Creek that is suitable for larval Adam's Emerald Dragonfly. If mining subsidence fractures the sandstone rock shelf in the bed of Wallandoola Creek to the south of Longwalls 3 and 4 in Wongawilli West Area 3, this could result in temporary drainage of the pool upstream of the shelf and loss of aquatic habitat for any larval Adam's Emerald Dragonfly that may exist within the pool. If iron staining occurs, where the diverted flows re-emerge downstream, the increase in iron concentration could lead to the formation of iron-mediated bacterial flocs and smothering of aquatic habitats that are occupied by larvae and used for breeding by adults. The changes in availability and quality of aquatic habitat that could occur would be temporary, localised and minor in nature and therefore not significant relative to the total amount of potential habitat within Area 3. The extent and duration of these impacts would depend on the degree of drainage, rainfall and inflows from further upstream, with pool habitat being re-established and water quality improving once inflows exceed diversionary flows. If a population of this species were to exist within Wongawilli West Area 3, it is highly unlikely that the proposed mining would have a significant effect on the overall amount or connectivity of habitat within this locality.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There are no areas of critical habitat for Adam's Emerald Dragonfly listed on the NSW Register of Critical Habitat.

(f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

At present there is no recovery or threat abatement plan for Adam's Emerald Dragonfly.

(g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not classed as a Key Threatening Process under the FM Act 1994, under which Adam's Emerald Dragonfly is listed.

Conclusion

If a viable population of this species is present within Cataract Creek or Lizard Creek, it is highly unlikely that the proposed mining operations would have any significant impact on the species, because no alteration of habitat is expected. If a viable population of the species exists in Wallandoola Creek, it may be subject to temporary, localised, minor impacts.

6.2 Appendix 2: Macquarie Perch

6.2.1 Background Information

Macquarie Perch are found in the Murray-Darling Basin, particularly the upstream reaches of the Lachlan, Murrumbidgee and Murray rivers, and parts of south-eastern coastal NSW, including the Hawkesbury and Shoalhaven catchments (NSW Fisheries 2005c). There has been a marked decline in their distribution and abundance in NSW. Macquarie Perch are now considered to be restricted to the upper reaches of the Lachlan and Murrumbidgee Rivers in southern NSW (Ingram *et al.* 1990). This species has also been translocated to numerous sites within and outside its natural range, including Lake Cataract, with the population at this locality having been translocated from the Murray River (Lintermans 2006).

The baseline aquatic ecology studies undertaken for NRE No. 1 Mine have established that Macquarie Perch are present in the Cataract Creek arm of Lake Cataract and that they extend into the proposed Wongawilli East Mine Area (Cardno Ecology Lab 2011). There is also a viable population of Macquarie Perch in the reach of the Cataract River between the Cataract Dam and Broughtons Pass Weir (Gehrke and Harris 1996; The Ecology Lab 2003 and 2005). This species is unlikely to be present in the Wongawilli West Study Area, because a number of waterfalls between Wallandoola Creek and Lizard Creek and the Cataract River would prevent their upstream passage.

An Assessment of Significance has therefore been prepared for this species within the Wongawilli East Mine Area, but not that at Wongawilli West (see Appendix 2).

6.2.2 Assessment of Significance

(a) *In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.*

Macquarie Perch is known to migrate from impoundments into rivers to spawn in areas with small boulders, pebbles and gravel. Spawning generally occurs during spring and early summer in shallow, fast-flowing water over gravel beds. The eggs are adhesive and stick to gravel (Lake 1971; Wharton 1973). Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11–18 °C (Wharton 1973). Newly-hatched larvae shelter amongst pebbles (Cadwallader & Rogan 1977). In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites (Cadwallader & Douglas 1986).

The absence of any significant barriers to fish passage means that individuals of the translocated Macquarie Perch populations within Lake Cataract could potentially migrate up the reach of Cataract Creek that traverses the proposed Wongawilli East Mine Area. The baseline aquatic ecology surveys undertaken for NRE No. 1 Mine indicate that greater numbers of Macquarie Perch occur within these reach as summer progresses and that their distribution extends from the confluence with Cataract River as far up as the rock bar below Site 6, which would overlies proposed Longwalls 7 and 8 (Cardno Ecology Lab 2011). The fish caught ranged in size from 80 -370 mm, so it is possible that some of the fish may have been migrating upstream to spawn.

The subsidence predictions indicate that extraction of the proposed longwalls within this area is unlikely to alter stream flow, ponding or water quality in this reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Macquarie Perch would be placed at risk of extinction.

(b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Macquarie Perch have been listed on the Schedules of the *FM Act*.

(c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

Macquarie Perch is not part of a listed endangered ecological community.

(d) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Macquarie Perch is a schooling species that prefers clear water and deep, rocky holes with lots of cover in the form of aquatic vegetation, large boulders, debris and overhanging banks (Cadwallader & Eden 1979). This species is known to migrate from impoundments into rivers to spawn in areas with small boulders, pebbles and gravel. Newly-hatched larvae shelter amongst pebbles, but move back downstream to lake habitat (Cadwallader & Rogan 1977Cadwallader & Douglas 1986).

The subsidence predictions indicate that there are not likely to be any physical impacts on the aquatic habitat that Macquarie Perch periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. Nor are any flow-on effects on water quality expected. The potential Macquarie Perch habitat in Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Macquarie Perch within the Study Area.

(f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.
At present, there is no recovery or threat abatement plan for Macquarie Perch.

(g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

Longwall mining is not classed as a Key Threatening Process under the *FM Act or EPBC Act*, under which Macquarie Perch are listed.

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to local Macquarie Perch populations within the Cataract River catchment.

6.3 Appendix 3: Silver Perch

6.3.1 Background Information

Historical records show that Silver Perch occurred throughout most of the Murray-Darling drainage (NSW DPI 2006). This species has undergone a dramatic decline in abundance and distribution over the last few decades and is now absent from most of its natural range. Silver perch have been stocked at numerous sites within the Murray-Darling Basin. This fish has also been translocated into many areas outside their natural range, including some catchments along the east coast of NSW and Lake Cataract (NSW DPI 2006). The population in Lake Cataract was translocated in the early part of the 20th century and is secure and self-sustaining. I&I NSW research surveys indicate that Silver Perch were still present in this dam in 1994 and 2006.

6.3.2 Assessment of Significance

(a) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Adult Silver Perch migrate upstream from November to February and juveniles over one year old do so from October to April (Mallen-Cooper *et al.* 1995). These movements appear to be stimulated by increases in water temperature above 20ºC and water level. The reasons for this movement are not well understood, but there is evidence that adults move upstream prior to spawning (Mallen-Cooper *et al.* 1995). Females release non-adhesive, floating eggs (Merrick 1996), which hatch within 36 hours. The larvae commence feeding after about 5 days and develop into juvenile fish measuring approximately 11 mm after 18 days (Rowland *et al.* 1983).

The subsidence predictions indicate that extraction of the proposed longwalls within this area is unlikely to alter stream flow, ponding or water quality in this reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Silver Perch, if one exists, would be placed at risk of extinction.

(b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Silver Perch have been listed on the Schedules of the FM Act.

(c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

The Silver Perch is not part of a listed endangered ecological community.

(d) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Silver perch are found in a variety of habitats and climates across the Murray-Darling Basin, including the cool, clear, gravel-bed streams of the upper reaches and the lower, slow flowing, turbid rivers of the west and north (Rowland 1995, Clunie & Koehn 2001). They also occur in lakes and reservoirs. Little is known about their specific habitat requirements or the extent to which they depend on structural habitat components (Clunie & Koehn 2001). NSW DPI sampling records indicate that this species was generally caught near snags, however, in impoundments they have been observed in open waters.

The subsidence predictions indicate that there are not likely to be any physical or chemical impacts on the aquatic habitat that Silver Perch may periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. The existing Silver Perch habitat in the Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Silver Perch within the Wongawilli East Study Area.

(f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

There is a Recovery Plan for Silver Perch in NSW (NSW DPI 2006a). The primary objective of the plan is to prevent the extinction and ensure the recovery of silver perch populations, while the specific objectives are to:

- Increase awareness of the species current status throughout its range;
- Increase scientific knowledge of its current distribution, ecological and habitat requirements and population genetics;
- Protect and enhance the remaining natural populations;
- Minimise the impacts of known major threats, including fishing impacts on natural populations;
- Improve management of aquaculture and stocking programs.
- Encourage and support the involvement of indigenous communities in the implementation of recovery actions.
- Establish a program to monitor the status of silver perch and evaluate the effectiveness of recovery actions.

The recovery actions identified in the plan focus on:

- Research and information needs – e.g. current distribution and abundance, genetic variation within natural and stocked populations, identification of habitat requirements, ecology and key threats to wild populations
- Habitat protection and restoration, particularly reducing the impacts of altered river flows, improving fish passage in the Murray-Darling Basin, investigating the impacts of cold water pollution, minimisation of impacts on habitat, protection and rehabilitation of river reaches known to support important silver perch populations.
- Introduced species and diseases - by investigating their potential impact on natural populations, preventing the transfer of disease agents from stocked to natural populations
- Fishing – by improving awareness of the status of silver perch and compliance with fishing regulations, the cultural importance of the species to indigenous communities, and reviewing existing regulations

- Aquaculture and stocking – minimising the risk of genetic impacts from hatchery-bred fish on wild populations, encouraging hatcheries to comply with regulations and guidelines, preventing stocked fish impacting on natural populations.

The proposed mining will not affect the objectives or actions of the Silver Perch Recovery Plan.

(g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not a listed Key Threatening Process under the *FM Act 1994.*

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to the populations of Silver Perch within the Cataract River catchment.

6.4 Appendix 4: Trout Cod

6.4.1 Background Information

The Trout Cod is endemic to the southern Murray-Darling river system, including the Murrumbidgee and Murray Rivers, and the Macquarie River in central NSW (NSW DPI 2005c). This species has undergone dramatic declines in its distributional range and abundance over the past century. Hatchery-bred Trout Cod have been released into sites in its former distribution range. Trout Cod have also been translocated into areas outside their natural range, including Lake Cataract, with that introduction taking place before 1915 (Rimmer 1988; Douglas *et al.* 1994). The survival rate of translocated Trout Cod is poor, with few records of fish surviving past three years of age. I&I NSW research surveys indicate that Trout Cod were still present in this dam in 1994. The Trout Cod Recovery Team (2010) indicates that the cod population within this lake is composed largely of hybrids of Trout Cod and Murray Cod.

The absence of any significant barriers to fish passage within this reach of the creek, means that any surviving individuals present in Lake Cataract could potentially migrate upstream and utilise habitats overlying the proposed longwalls. Juvenile and adult specimens of an unidentified species within this genus, that could potentially be Trout Cod, were found in the reach of Cataract Creek upstream of Lake Cataract that traverses the Wongawilli East Study Area (Cardno Ecology Lab 2011). In view of the uncertainty as to the identification of these fish, Assessments of Significance have been prepared for both Trout Cod and Murray Cod.

6.4.2 Assessment of Significance

(h) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Little is known about the biology and ecology of Trout Cod in the wild. This species was originally thought to undertake significant upstream migrations, possibly for spawning (Brown *et al.* 1998), however, recent radio tracking studies in the Murray River suggest it does not move beyond a small home range (Brown & Nicol 1998). Trout Cod spawn in late October to early November when water temperatures reach about 16°C (Ingram & Rimmer 1992; ACT Government 1999). Spawning does not appear to be dependent on flow conditions (Gilligan & Schiller 2003. The adhesive eggs are probably deposited on hard surfaces on or near the stream bottom. Hatching begins 5-10 days after fertilisation at a temperature of 20 °C and larvae live off the yolk sac for about 17 days. Larvae begin feeding on zooplankton at 6-9 mm and disperse downstream in the flow for a short distance. Larval dispersal reaches a peak in November (Gilligan & Schiller 2003). The environmental conditions favouring successful recruitment are not known.

The subsidence predictions indicate that extraction of the proposed longwalls within this area is unlikely to alter stream flow, ponding or water quality in this reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Trout Cod, if one exists, would be placed at risk of extinction.

(i) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Trout Cod have been listed on the Schedules of the FM Act.

(j) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

The Trout Cod is not part of a listed endangered ecological community.

(k) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Trout Cod utilise several types of aquatic habitat. The existing self-sustaining populations occur in deep, flowing rivers with sand, silt or clay substrata and numerous snags and in relatively narrow streams with rock, gravel and sand substrata, and shallow pools (generally <2m deep) interspersed with rapids and cascades up to 4 m high (Brown *et al.* 1998).

The subsidence predictions indicate that there are not likely to be any physical or chemical impacts on the aquatic habitat that Trout Cod may periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. The existing Trout Cod habitat in Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(l) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

The critical habitat requirements of Trout Cod appear to be sites with large woody debris, or snags, particularly those located away from the stream bank (Nicol *et al.* 2002). There is no listed critical habitat for Trout Cod within the Wongawilli East Study Area.

(m) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

There is both a National and NSW Recovery Plan for Trout Cod (Trout Cod Recovery Team 2008; NSW DPI 2006b). The overall objective of the NSW Plan is to ensure the recovery and natural viability of this species throughout its former range within the state. The specific objectives of the plan are to:

- Ensure the security of the existing trout cod population in the Murray River by maintaining and improving aquatic habitat;
- Establish and protect additional stocked populations of Trout Cod at selected locations throughout the species former range;
- Reduce fishing related mortality of Trout Cod by setting appropriate regulatory controls and maximising angler compliance;
- Improve our understanding of the population size, distribution, ecological requirements, and genetic status of Trout Cod;
- Improve our understanding of the threats to the survival of this species and identify management actions to minimise these;
- Increasing awareness about the status of Trout Cod.

The recovery actions specified in the plan include:

- Habitat protection and restoration – minimising habitat degradation, improved protection and rehabilitation of key habitat;
- Reducing the impact of Illegal fishing and incidental capture;

- Minimising risks from inter-specific competition with stocked, translocated and introduced species;
- Establishing new self-sustaining populations through stocking;
- Research and monitoring of Trout Cod populations;
- Community awareness, involvement and support.

The proposed mining will not affect the objectives or actions of the Trout Cod Recovery Plan.

(n) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not classed as a Key Threatening Process under the *FM Act 1994,* under which Trout Cod are listed.

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to the local populations of Trout Cod within the Cataract River catchment.

6.5 Appendix 5: Murray Cod

6.5.1 Background Information

The historic distribution of Murray Cod included the entire Murray Darling Basin in the south-eastern region of Australia, except for the upper reaches of some tributaries. This fish still occurs throughout most of the Basin. Translocated populations have also been established in impoundments and waterways in NSW and Victoria outside the natural distribution, including Lake Cataract (TSSC 2003). Translocated populations are maintained by the release of hatchery-bred fish and often persist for several years, but few have established self-sustaining populations. I &I NSW research surveys indicate that Murray Cod were present in this lake in 1994, 2002, 2006 and 2007. The Trout Cod Recovery Team (2010) indicates that the cod population within this lake is composed largely of hybrids of Trout Cod and Murray Cod.

6.5.2 Assessment of Significance

(o) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

During late summer, autumn and winter Murray Cod remain within a "territory", consisting of a specific hole, snag or area of a river or lake (Kearney & Kildea 2001). In late spring and early summer, when the water reaches a temperature of between 16-21°C, the adults migrate upstream to spawn (Kearney & Kildea 2001). In upland streams, spawning occurs in the vicinity of submerged rocks. Murray Cod may also lay their eggs in depressions excavated in clay banks. The eggs are adhesive and are deposited as a large mat on the spawning surface. After spawning, the adults move back downstream to their territory (Koehn 1997). The eggs hatch occurs 5-7 days after fertilisation, with a batch of eggs taking several days to hatch (Kearney & Kildea 2001). The larvae drift downstream and the fry settle out in suitable protected habitat (TSSC 2003).

The subsidence predictions indicate that extraction of the proposed longwalls within the Wongawilli East area is unlikely to alter stream flow, ponding or water quality in the overlying reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Murray Cod, if one exists, would be placed at risk of extinction.

(p) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Murray Cod have been listed on the Schedules of the *FM Act.*

(q) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

Murray Cod is not part of a listed endangered ecological community.

(r) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Murray Cod occur in a variety of habitats, including clear rocky streams, slow flowing, turbid rivers, and billabongs (McDowall 1996). This fish is usually found in sheltered areas, where there is extensive cover in the form of large rocks, snags, overhanging vegetation or other woody structures (Kearney and Kildea 2001). Juveniles are usually found in the main river channel.

The subsidence predictions indicate that there are not likely to be any physico-chemical impacts on the aquatic habitat that Murray Cod may periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. The existing Murray Cod habitat in Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(s) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Murray Cod within the Wongawilli East Study Area.

(t) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

There is a National Recovery Plan for Murray Cod (National Murray Cod Recovery Team 2010). The overall objective of this plan is to have self-sustaining Murray Cod populations managed for conservation, fishing and culture. The specific objectives of the plan include:

- Assessing the distribution, structure and dynamics of populations across the Murray Darling Basin;
- Managing river flows to enhance recruitment;
- Evaluating the risks of threats and benefits of recovery options on populations for each management unit;
- Determining the habitat requirements of life stages and populations; and
- Management of a sustainable recreational fishery.

The plan identifies seventy-one actions to address the range of threats and management issues, with priority actions including:

- Determining the distribution, structure and dynamics of populations across the Murray Darling Basin;
- Identifying and quantifying the environmental parameters that control recruitment and population growth;
- Identifying, protecting and repairing key aquatic and riparian habitats in each Spatial Management Unit; and
- Managing the recreational fishery in a sustainable manner.

The proposed mining will not affect the objectives or actions of the Murray Cod Recovery Plan.

(u) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not classed as a Key Threatening Process under the *EPBC Act 1994,* under which Murray Cod are listed.

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to the local populations of Murray Cod within the Cataract River catchment.

Annexures

1. Cardno Ecology Lab (2011). NRE No. 1 Mine, Russell Vale – Baseline Aquatic Ecology Monitoring.

Cardno Ecology Lab

Shaping the Future

Marine and Freshwater Studies

NRE No. 1 Mine, Russellvale Baseline Aquatic Ecology Monitoring

Job Number: EL0910036

Prepared for Gujarat NRE Coking Coal Limited

November 2011

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Cover Image: Cataract Creek, 17 December 2008. Photographer Bob Hunt, Cardno Ecology Lab

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EL0910036D	Draft	16 November 2011	Dr Theresa Dye	TAD	Dr Arthur Dye	AHD

Executive Summary

Gujarat NRE Coking Coal Limited (NRE) proposes to extract coal from the Wongawilli West and Wongawilli East areas of the NRE No. 1 Mine at Russellvale, in the New South Wales Southern Coalfield. The submission to the NSW government for approval to mine these areas under the Part 3A (NSW EP&A Act) process is being co-ordinated by Environmental Resources Management (Australia) Pty Ltd (ERM). Cardno Ecology Lab was commissioned by ERM, and subsequently NRE, to undertake the aquatic ecology component of the environmental monitoring for the Wongawilli West and Wongawilli East mine areas, which are located within the Cataract River catchment and the Lake Cataract catchment, to the north-east of the Cataract River arm of the reservoir, respectively.

This report summarises the results of the baseline aquatic ecology monitoring undertaken over a three year period between spring 2008 and spring 2011. The monitoring program was designed in accordance with the recommendations made by the NSW Department of Planning's 'Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield'. The Wongawilli West Study Area includes two 'potential impact' sites each on Wallandoola Creek and Lizard Creek and two 'control' sites with comparable aquatic habitat and surroundings each on Loddon Creek and Cascade River. The Wongawilli East Study Area comprises two 'potential impact' sites on Cataract Creek and two 'control' sites each on Cataract River and Allens Creek. This sampling design will enable Beyond BACI (Before/After, Control/Impact) analyses to be used to distinguish any impacts on aquatic ecology associated with mining subsidence from natural variability. The baseline monitoring program involves repeated spring and autumn sampling of the following indicators:

- Aquatic habitat
- Water quality
- Aquatic macroinvertebrates
- Fish.

The results of a preliminary survey of fish occurring within aquatic habitats identified as being suitable for occupation by Macquarie Perch and of a more intensive targeted survey designed to assess the distribution of the population of this species within Cataract Creek are also described. The latter is based on backpack electrofishing undertaken on four occasions during the summers of 2009-2010 and 2010/2011.

Results

Wongawilli West

The 'potential impact' and 'control' sites are surrounded by relatively natural, undisturbed, dry sclerophyll woodland and heath. Wallandoola Creek and Lizard Creek contain a variety of aquatic habitats, including deep, permanent pools, shallow areas over bedrock bars, submerged woody debris and aquatic macrophytes. Both creeks have been impacted by previous mining activity, with fractured bedrock, iron staining and iron floc being common features. There are substantial waterfalls on Lizard Creek and between the Study Area and the Cataract River that pose significant barriers to fish passage.

The overall water quality at the 'potential impact' sites was either similar to or better than that at the 'control' sites. The electrical conductivity in Cascade Creek, one of the 'control' streams, generally exceeded the appropriate ANZECC/ARMCANZ (2000) guidelines. The pH levels at the 'control' sites were often below guidelines. The dissolved oxygen levels at both the 'potential impact' and 'control' sites were generally below that considered favourable for aquatic life.

AUSRIVAS analyses indicated the "health" of the aquatic macroinvertebrate fauna varied across spring and autumn surveys, with changes generally being greater at 'potential impact' sites than at ‘control’ sites. Large changes in “health” were common at the majority of monitoring sites, indicating the composition of the fauna is naturally variable. The SIGNAL2 score, an indicator of sensitivity to pollution, suggested the ‘potential impact’ sites were more degraded than ‘control’ sites, but only those in one creek. The SIGNAL2 scores were less variable than the AUSRIVAS indices and could consequently be a more useful indicator of effects associated with mining.

Artificial collectors, in the form of bundles of chopsticks, were also used to examine spatial and temporal differences in the aquatic macroinvertebrate fauna. The collectors yielded fewer taxa than the AUSRIVAS samples, however, it should be noted that only one deployment was totally successful. Statistical analyses based on these data showed that the fauna varied more between sites than among creeks.

The fish fauna at ‘potential impact’ and ‘control’ sites appeared to be depauperate, with number of species varying from zero in Wallandoola Creek to three in Loddon Creek. Freshwater crayfish, *Euastacus* sp. were present in three creeks, but not Cascade Creek. It should, however, be noted that only limited sampling of fish was undertaken at these sites.

Wongawilli East

The terrestrial habitat surrounding the monitoring sites on the major watercourses in the Wongawilli East Study Area consists of undisturbed, temperate rainforest. The aquatic habitats at the ‘potential impact’ sites within Cataract Creek comprise long pools with sandy substrata interspersed with bars and riffles composed of bedrock, boulders, pebbles and gravel. Large woody debris is common. The channel forms and substrata at the ‘control’ sites on Cataract River and Allens Creek are similar.

The overall water quality at this set of ‘potential impact’ sites was also either similar to or better than that at the ‘control’ sites. Most water quality parameters showed only occasional deviations from the accepted guidelines. The dissolved oxygen levels at both the ‘potential impact’ and ‘control’ sites, however, were generally below that considered favourable for aquatic life.

The “health” of the aquatic macroinvertebrate fauna varied across spring and autumn surveys, with changes generally being similar or smaller at ‘potential impact’ sites than at ‘control’ sites in spring and larger at two sites than at others in autumn. At most sites, the “health” of the macroinvertebrate fauna was less variable than in the other Study Area. The SIGNAL2 scores indicated the fauna was generally in a similar condition at the ‘potential impact’ and ‘control’ sites. The SIGNAL2 scores were less variable than the AUSRIVAS indices, as was the case in the Wongawilli West Study Area.

The deployment of artificial collectors was more successful in this Study Area, but they still yielded fewer taxa than the AUSRIVAS samples. Statistical analyses based on these data also showed that differences in the fauna between sites were more common than among creeks.

The observations during the baseline monitoring suggested that the fish fauna at this set of ‘potential impact’ and ‘control’ sites was also depauperate, with number of species varying from zero in Allens Creek to two in Cataract Creek and Cataract River. Freshwater crayfish, however, were present in all three creeks. Targeted fish surveys, however, indicated that at least seven species, three of which are subject to protection under State and/or Federal Legislation, were present in Cataract Creek. One of the threatened species, Macquarie Perch, occurs naturally in this part of NSW but is known to have been translocated from the Murray River into Lake Cataract. This species appears to migrate upstream as the summer progresses, with individuals occurring as far up as the rock bar at Site 6, which would be above two of the proposed longwalls. The other two threatened species, Freshwater Cod (identity not yet confirmed and possibly a hybrid) and Silver Perch, have been translocated into Lake Cataract, although this is outside their natural range.

Issues Identified

The baseline monitoring has identified three major issues relating to aquatic ecology that require consideration as part of the Part 3A approval process for the Wongawilli East and Wongawilli West mining areas. These are:

- The occurrence of threatened fish species, particularly Macquarie Perch, within the Wongawilli East mine area;
- The existence of prior mine subsidence related impacts in the form of rockbar fractures and iron staining within the watercourses overlying the Wongawilli West mine area;
- The variability in the “health’ of the aquatic macroinvertebrate fauna suggests that AUSRIVAS indices may not be an effective indicator of impacts associated with mining.

Recommendations

1. Further aquatic ecology monitoring should be conducted during and after the extraction of the longwalls within Wongawilli West and Wongawilli East using the same survey sites and methods as in this study. This will provide best practice environmental monitoring of aquatic ecology and will allow statistically powerful tests of the effects of any impacts on aquatic habitats and biota arising from mine subsidence.
2. In view of the apparent variability in the ‘health” of the aquatic macroinvertebrate fauna, it is recommended that SIGNAL2 scores continue to be calculated in future in addition to AUSRIVAS indices.
3. Further attempts should be made to identify the Freshwater Cod caught during the 2011/2012 summer season.
4. The position and extent of existing rockbar fractures within the watercourses overlying the proposed mine area should be recorded prior to the extraction of coal, so that fractures resulting from extraction of the proposed longwalls can be distinguished from past fractures and the consequences of any additional fracturing for aquatic ecology can be assessed.
5. The occurrence and extent of iron staining and flocs should be monitored regularly in areas expected to undergo subsidence. This should be done before, during and after mining of the longwalls. A sudden marked increase in the extent of iron staining should trigger an assessment of its impacts on aquatic habitats and biota.

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1 Introduction

1.1 Background and Aims

The NRE No. 1 Colliery (formerly known as South Bulli Colliery) extends across 6421 hectares and is estimated to have reserves of around 300 million tonnes of coking coal spread across the Bulli, Balgownie and Wongawilli Seams (Gujarat NRE Minerals 2005). Gujarat NRE Coking Coal Limited (NRE) proposes to extract coal from the Wongawilli East and Wongawilli West areas of the NRE No. 1 Mine at Russellvale, in the New South Wales Southern Coalfield. The application to the NSW government for approval to mine these areas under the Part 3A (NSW EP&A Act) process is being co-ordinated by Environmental Resources Management (Australia) Pty Ltd (ERM). Cardno (NSW/ACT) Pty Ltd trading as Cardno Ecology Lab (formally The Ecology Lab Pty Ltd) was commissioned by ERM to undertake the aquatic ecology component of the environmental monitoring for the two mine areas.

The baseline aquatic ecology monitoring program focuses on two separate areas of the NRE No. 1 Mine at Russellvale: Wongawilli West and Wongawilli East, which are located within the Cataract River catchment and the Lake Cataract catchment, to the north-east of the Cataract River arm of the reservoir, respectively. Baseline monitoring commenced in spring 2008 and focuses on the following components:

- Aquatic habitat
- Water quality
- Aquatic plants
- Aquatic macroinvertebrates
- Fish
- Threatened species of freshwater fish and aquatic macroinvertebrates.

This report comprises:

- A description of the sampling design, methodologies used and results of the baseline monitoring undertaken between September 2008 and September 2011;
- Identification of issues relevant to environmental assessment of aquatic ecology for this project;
- Recommendations for ongoing monitoring.

1.2 Baseline Monitoring Program

The baseline monitoring program was designed in accordance with relevant recommendations in the NSW Department of Planning's 'Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield' (NSW DoP, 2008). The specific recommendations of relevance to aquatic ecological investigations were:

- Streams within mine subsidence areas classified as 3rd order or above under the Strahler stream classification scheme should be considered Risk Management Zones (RMZs);
- A minimum of 18-24 months of baseline data should be collected at an appropriate frequency and scale for significant natural features;
- A Before, After, Control, Impact (BACI) sampling design should be used for monitoring mine subsidence impacts on flora and fauna, so that advanced statistical techniques can be used to detect impacts.

The baseline monitoring program designed by Cardno Ecology Lab is based on the results of an initial site inspection undertaken on 22-23 October 2008 (Cardno Ecology Lab 2009). The monitoring program involves repeated spring and autumn surveys of key aquatic ecological indicators at two 'potential impact' sites located on each of the significant watercourses (third order or higher) overlying the Wongawilli West and Wongawilli East areas and two 'control' sites on four ecologically comparable watercourses located nearby that will not be affected by mining. The 'control' sites provide a measure of the background variability in aquatic ecology within the greater Cataract catchment as distinct from any mine subsidence impacts. This sampling design will enable Beyond BACI (Before/After, Control/Impact) analyses to be used to assess the potential impacts of mining subsidence on aquatic ecology in the Wongawilli West and Wongawilli East areas of NRE No.1 Mine, provided that similar assessments are made during or after mining. The Beyond BACI technique is a modification to the BACI approach that has been developed specifically to distinguish environmental impacts from natural changes (Underwood 1991, 1992 and 1994). The surveys undertaken to date provide three years (four sampling events, two seasons) of aquatic ecological baseline data for "control" and "potential impact" locations. This constitutes the "before" component of the Beyond BACI study design.

During each baseline survey, the state of the following key indicators was assessed:

- Aquatic habitat
- Water quality
- Aquatic macroinvertebrate fauna
- Fish fauna

The monitoring sites and methodologies used to assess each key indicator are described in Section 4.

1.3 Targeted Fish Surveys

A preliminary survey of fish occurring within the aquatic habitats identified as being suitable for occupation by Macquarie Perch during the initial site inspection was undertaken in Cataract Creek between 25 and 26 November 2008. The distribution of the Macquarie Perch population within Cataract Creek has been assessed during the summers of 2009/2010 and 2010/2011. The sampling program involves backpack electrofishing surveys on four occasions each summer.

2 Study Methods

2.1 Study Areas

The positions of the monitoring sites established on the 'potential impact' and 'control' creeks with the Wongawilli West and Wongawilli East Study Areas are shown in Figure 1. The GPS co-ordinates of the monitoring sites and dates of each survey are listed in Appendix 1.

1.2.1 Wongawilli West

During the initial site inspection in September 2008, two 'potential impact' sites were identified on the reaches of Wallandoola Creek and Lizard Creek that flow through the mine area (The Ecology Lab 2009).

The two 'potential impact' sites (Sites 1 and 2) on Wallandoola Creek are located downstream of the headwater swamp, in an area where there is a well-defined, permanent creek channel, but upstream of a series of waterfalls that pose significant barriers to fish passage. This reach of the Cataract River is highly regulated as it is used as a conduit for the Sydney water supply and is managed by the Sydney Catchment Authority (SCA). The upstream 'potential impact' site (Site 3) on Lizard Creek is located within a chain of deep pools upstream and downstream of sections of the creek where the bedrock has been fractured by previous mining activity. Site 3 drained completely during the initial phases of the monitoring, so in autumn 2009 an alternative upstream 'potential impact' site (Site 17) was established in Lizard Creek approximately 0.5km downstream. The other 'potential impact' site (Site 4) on Lizard Creek is situated over 1 km downstream of Site 3. Site 4 is separated from the two upstream 'potential impact' sites by a significant waterfall. Both creeks flow into the Cataract River downstream of Cataract Dam and upstream of Broughtons Pass Weir (Figure 1).

The riparian vegetation in Loddon Creek is dominated by heath with some sections of open dry sclerophyll woodland. The channel is characterised by long pool sections with infrequent riffles. Swamp habitat is present above the upstream monitoring site (Site 11) and there is a large waterfall below the downstream site (Site 12). The bed in the shallower sections of Loddon Creek, particularly at Site 12, is characterised by bedrock.

1.2.2 Wongawilli East

The 'potential impact' sites within the Wongawilli East area are located on Cataract Creek (Figure 1). The Upper Cataract River is very similar to Cataract Creek, in terms of channel forms and bed composition. The riparian vegetation surrounding both watercourses consists of dense temperate rainforest.

The mine layout provided by NRE indicates that Lake Cataract will not be undermined by the proposed longwalls and there will be sufficient distance between the edge of the longwalls and the lake that direct mine subsidence impacts will not occur in the lake. The aquatic habitat within Lake Cataract is therefore not considered part of the Study Area. No other significant areas of aquatic habitat have been identified in this area.

2.2 Baseline Monitoring Methodology

2.2.1 Aquatic Habitat Condition

During the first survey, a standardised description of the adjacent land and the condition of riverbanks, channel and bed at each site was prepared using a modified version of the Riparian, Channel and Environmental Inventory (RCE) (Chessman *et al.* 1997). This assessment gives an overall score for each site based on the natural characteristics and to a lesser extent degree of disturbance evident. Any changes to the initial scores were recorded in subsequent surveys.

The habitat descriptors used included:

- geomorphological characteristics of the waterways (e.g. gully, intermittent stream, major river; deep pools or gravel beds; waterways interconnecting with other waterways or wetlands upstream or downstream);
- flow regime of the waterways (e.g. intermittent or permanently flowing, flow velocity);
- types of land use along the waterway (e.g. industries associated with the river, recreational uses);
- riparian vegetation and instream vegetation (e.g. presence/absence, native or exotic, condition);
- presence of instream or offstream wetlands;
- substratum type (e.g. rock, sand, gravel, alluvial substrates);
- presence of refuge areas (e.g. wetlands nearby could be interlinked by the waterway during flow, pools of water above/below the licensed discharge point could be fish habitat);
- presence of spawning areas (e.g. gravel beds, riparian vegetation, snags) and nests; and
- presence of natural or artificial barriers to fish passage both upstream and downstream (e.g. weirs, dams, waterfalls, causeways).

A qualitative description of the aquatic habitats at the study sites in each watercourse was also undertaken based on the following attributes:

- surrounding landform;
- instream features such as sequence of pools, runs and riffles (shallow areas with broken water);
- presence, extent and type of aquatic vegetation;
- stream substratum;

- potential refuge areas during periods of low flow (e.g. large deep pools);
- presence of fish habitat including snags, bank undercuts and aquatic plants; and
- presence of barriers to fish passage into and beyond the study area.

A comprehensive photo record was also assembled for each site during each survey. Standardized photos were taken (with a 2 m tall x 1 m wide T-bar) at the top of the site looking downstream, at the middle of the site looking upstream, at the middle of the site looking downstream, and at the bottom of the site looking upstream to gain an understanding of environmental variation within the watercourses.

2.2.2 Water Quality

Surface water quality was measured in situ using a Yeokal 611 water quality probe. Two readings of the following parameters were recorded at each site:

- Temperature (˚C);
- Electrical Conductivity (µS/cm);
- pH;
- Oxidation – Reduction Potential (ORP) (mV);
- Dissolved Oxygen (% saturation); and
- Turbidity (ntu).

The electrical conductivity pH, dissolved oxygen and turbidity measurements were compared with the ANZECC (2000) default trigger values for physical and chemical stressors for protection of slightly disturbed upland aquatic ecosystems in south-eastern Australia.

2.2.3 Aquatic Macroinvertebrate Sampling

Aquatic macroinvertebrates were collected using two methods: the AUSRIVAS protocol for NSW streams (Turak et al. 2004), and aquatic macroinvertebrate collectors, a quantitative method developed by Cardno Ecology Lab for freshwater environmental impact assessment.

2.2.3.1 AUSRIVAS Sampling

AUSRIVAS surveys were undertaken twice in spring 2008 and autumn 2009, but only once each in the subsequent spring and autumn survey periods. During each survey, the aquatic macroinvertebrates associated with pool edge habitats at each site were sampled using dip nets (250 µm mesh) in accordance with the AUSRIVAS Rapid Assessment Method (RAM) (Turak et al. 2004). The dip net was used to agitate and scoop up material from vegetated river edges (Plate 1a). Each RAM sample was collected over a period of 3-5 minutes from a 10 m length of representative edge habitat along the reach of the site. If the required habitat was discontinuous, patches of habitats with a total length of 10 m were sampled.

Each RAM sample was rinsed from the net onto a white sorting tray from which animals were picked using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten minute intervals for either a total of one hour or until no new specimens were found. Care was taken to collect cryptic and fast moving animals in addition to those that were conspicuous or slow. The animals collected at each site were placed into a labelled jar containing 70% alcohol.

Chemical and physical variables such as alkalinity of the water, modal water depth and river width, percentage of bedrock, boulder or cobble on the substratum, latitude and longitude that are required for running the AUSRIVAS predictive model were also recorded at each site. The other variables required for the predictive mode (i.e. distance from source, altitude, land-slope and rainfall) were determined in the lab.

In the laboratory, RAM samples were sorted under a binocular microscope (at 40 X magnification), identified to family level and up to ten animals of each taxon counted, in accordance with the AUSRIVAS protocol (Turak *et al.* 2004). A randomly chosen 10% of the RAM sample identifications were checked by a second experienced scientist to validate macroinvertebrate identifications.

2.2.3.2 Artificial Collectors

The macroinvertebrate collectors were deployed in spring 2008 and autumn 2009 at the Wongawilli West monitoring sites and in spring 2008, autumn 2009, spring 2009 and autumn 2010.

During each of these surveys, eight replicate artificial collector units providing habitat structure for aquatic macroinvertebrates were deployed at each site. The collectors consisted of 24 cm long x 3 cm diameter bundles of 18 wooden chopsticks held together with plastic cable ties (Plate 1b-c). The collectors were attached to vegetation with nylon twine and submerged 1 meter apart at the edge of pools in 30-60 cm of water (Plate 1d). The collectors were retrieved during the second and fourth surveys, approximately six weeks after being deployed. During retrieval the collectors were carefully cut away from their anchors, placed individually into plastic bags, labelled and preserved in 70% ethanol for subsequent laboratory identification and analysis.

The aquatic macroinvertebrates that had colonised each bundle of chopsticks were rinsed onto a 0.5 mm mesh sieve and examined in the laboratory using a binocular microscope. The macroinvertebrates were sorted, identified to family (most invertebrate taxa), sub-family (chironomids) or class (flatworms and leeches) level and then counted.

Artificial collectors have been used in a wide range of studies involving freshwater macroinvertebrates (Rosenberg and Resh 1982, Cairns and Pratt 1993, Czerniawska Kusza, 2004). They provide a standard habitat for macroinvertebrates to colonise and result in data that exhibit less variability between samples (greater precision) and sites than fauna associated with natural substrata. They are also quicker and easier to sample and hence a more cost-effective sampling methodology (Hellawell 1978; Rosenburg and Resh 1982). The disadvantage is that they are artificial and cannot simulate all the conditions that may prevail in all habitats. Thus, the assemblages that might develop within or on the collectors are unlikely to be identical to those that occur in natural habitats at the same location. Provided that the collectors resemble some elements of the local habitat, it is not necessary for the assemblages on the collectors to be the same as those on natural substrata; what is important is how the sites differ. The artificial collectors and therefore provide quantitative data that are independent of the quality or quantity of habitat present within the creeks.

2.2.4 Fish Sampling

During each survey, fish sampling was conducted at all sites using dip nets (250 µm mesh) in conjunction with the AUSRIVAS macroinvertebrate collection. A 10 m length of representative edge habitat at each site was selected and thoroughly agitated and scooped for a period of 3–5 minutes. All captured fish and large crustaceans were immediately transferred to a fish box, filled with stream water, for identification and released as quickly as practicably possible. Additional fish observed in-stream along the length of each site over an approximately 30 minute period were also recorded.

2.3 Targeted Fish Surveys

A preliminary fish survey was undertaken in watercourses in the vicinity of the Wongawilli East investigation area identified as potential habitat for Macquarie Perch and Trout Cod. This survey was undertaken on the 25th and 26th of November 2008 in Cataract Creek, and the uppermost inundation of Lake Cataract within these drainages. Fish and large mobile invertebrates, such as freshwater crayfish, occurring at the sites were sampled using a back-pack electrofisher (Model Smith-Root LR24). The operator of the electrofisher discharged an electric pulse into the water which stunned the fish, allowing them to be easily netted, counted, identified and released. Electrofishing was done in riffles, pools, beds of aquatic macrophytes and beneath overhanging banks, snags and vegetation. One staff member used the electrofisher, whilst a second handled a dip net and was primarily responsible for capture of stunned fish. Captured fish were placed into a fish box, filled with stream water, which was handled by a third person on the bank. The third person acted as a safety officer for the other two. Electrofishing “shots” of approximately 30 seconds of continuous fishing time were done at locations within the creeks with potential fish habitat. Exhaustive fishing techniques were conducted in an attempt to record all fish present in the targeted areas. The reaches of Cataract Creek surveyed are shown in Figure 2.

Native fish caught were identified and released as quickly as practicably possible. Fish that could not be identified in the field were brought back to be examined under a binocular microscope. Individuals whose identity still remained in doubt were sent to an expert at The Australian Museum for further investigation. Exotic fish were not returned to the water in accordance with Cardno Ecology Lab's scientific research permit.

As Macquarie Perch are known to migrate upstream to spawn in riffles in late Spring/Summer, and there are no significant existing barriers to this migration in Cataract Creek, additional targeted surveys for Macquarie Perch surveys were undertaken on four separate occasions during the summers of 2009/2010 and 2010/2011. The survey area extended from the confluence of Cataract Creek and Cataract River or the most upstream extent of the current supply level within the Cataract Creek arm of Lake Cataract if this had inundated this confluence, upstream as far as a rockbar identified as a likely barrier to further upstream migration. The GPS coordinates of the study area and dates of surveys are presented in Appendix 1. Sampling was timed so that it coincided with high water temperatures and was conducted after heavy rainfall and high levels of runoff to maximise the potential for observing the upstream and downstream movement of this species. Electrofishing was undertaken using a Smith-Root LR24 backpack electrofisher throughout the entire reach of the watercourse within the survey area to achieve as close as possible to 100% coverage. The water depth was generally within the limitation of backpack electrofishing (wading depth) and as such, all habitats were accessible. The habitat surveyed and the backpack electrofishing technique is illustrated in Plate 2.

The GPS position of any Macquarie Perch caught were recorded. All specimens were measured (Caudal Fork Length), photographed, and fin clip samples were taken and preserved in alcohol for genetic analysis (beyond the scope of this study). All captured fish were handled with care to minimise stress, and released as soon as possible. All other species caught were identified and counted. Introduced pest species were not returned to the water in accordance with our NSW Fisheries research permit.

During each of these targeted surveys, the quality of water at the upstream and downstream extent of the survey area was recorded with a hand held probe (Yeo Kal 611), as described in Section 3.2. The supply level of Lake Cataract at the time of each survey, as indicated in the SCA records, is presented in Appendix 1.

2.4 Data Analysis

2.4.1 AUSRIVAS Samples

Macroinvertebrate data from the dip netting were analysed using the AUSRIVAS predictive spring and autumn models for NSW pool edge habitats (Coysh *et al.* 2000). The following indices generated by the AUSRIVAS model were examined:

- OE50Taxa Score - This is the ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50 % probability of occurrence. OE50 taxa values range from 0 to 1 and provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.
- Overall Bands derived from OE50Taxa scores which indicate the level of impairment of the assemblage. These bands are graded as follows:

  Band X = Richer invertebrate assemblage than reference condition.

  Band A = Equivalent to reference condition.

  Band B = Sites below reference condition (i.e. significantly impaired).

  Band C = Sites well below reference condition (i.e. severely impaired).

  Band D = Impoverished (i.e. extremely impaired).

The revised SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (1995; 2003) was also used to determine the “environmental quality” of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers to each macroinvertebrate family or taxa found, based largely on their responses to chemical pollutants. Grade values range from 1 to 10, with a value of 1 indicating a family tolerant to chemical pollution and a value of 10 indicating a sensitive family. The sum of all grade numbers for that habitat is then divided by the total number of families recorded in each habitat to calculate the SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values greater than 6, between 5 and 6, 4 and 5 and less than 4 indicate that the quality of the water is clean, mildly, moderately or severely degraded, respectively.

2.4.2 Artificial Collectors

Differences in the types and relative abundance of the macroinvertebrate taxa found in each pair of collectors were estimated by calculating their respective Bray-Curtis similarity coefficients. Spatial patterns in the composition of the assemblages were examined by means of non-metric Multi

Dimensional Scaling (MDS) (Clarke 1993). MDS provides a graphical representation of assemblages based on their similarity within and among places or times sampled. In MDS plots, samples which have similar sets of organisms are grouped closer together than ones containing different sets of organisms. The upstream location in Lizard Creek (Site 3) completely dried up during the spring 2008 season, which left the collectors at this site with significantly less macroinvertebrate colonisation. Due to this result, this outlying point was removed from the spring 2008 MDS analysis. MDS ordinations were done with the software package Primer 6 (Plymouth Routines in Multivariate Ecological Research 6 2008) (Clarke and Gorley 2006). PERMANOVA, a non-parametric permutation test, was used to examine differences in the structure of assemblages among Sites and Creeks (Anderson 2001; Anderson *et al.* 2008).

3 Results

3.1 Aquatic Habitats

3.1.1 Wongawilli West

Wallandoola, Lizard and Cascade Creeks are surrounded by open dry sclerophyll woodland and heath (Plate 3a-b). The creeks are generally unshaded. The substratum is dominated by bedrock and boulders with sand and fine sediment accumulations in some of the deeper pools and channel sections. A variety of habitat features are present within the creeks, including relatively deep, permanent pools, sections of shallow flow over bedrock bars. There are also soft sediment banks with overhanging vegetation and instream features such as submerged woody debris and aquatic macrophytes. The upper reach of Wallandoola Creek comprises a headwater swamp and lacks a clearly defined channel. In the downstream reach there is a series of waterfalls as the creek drops from the plateau before eventually entering Cataract River downstream of Cataract Dam. These waterfalls pose significant barriers to fish passage. Fractured bedrock bars are evident throughout the downstream reach of the creek (Plate 4a). Iron staining and associated iron flocculant is also common (Plate 4b). There are also extensive areas of fractured bedrock in the upstream reaches of Lizard Creek and considerable amounts of iron floc throughout the reach that flows through the Study Area (Plate 4c-d). The cracking of the bedrock observed Site 3 in Lizard Creek appears to have resulted in drainage of water. There is a significant waterfall between Site 4 and the two upstream sites and other significant waterfalls between the Study Area and the Cataract River. These waterfalls are barriers to fish passage.

The riparian vegetation in Loddon Creek is dominated by heath with some sections of open dry sclerophyll woodland. The channel is characterised by long pool sections with infrequent riffles. The reach above the upstream site (Site 11) contains swamp habitat. There is a large waterfall below the downstream site (Site 12). The bed in the shallower sections of Loddon Creek, particularly at Site 12, is characterized by bedrock.

3.1.2 Wongawilli East

Allen Creek and Cataract Creek are bordered by temperate rainforest riparian vegetation. The canopy is closed and the creek is shaded (Plate 3c-d). The channel morphology is characterised by alternating series of long pools and shorter bars and riffles (Plates 1a – 1d). The creek is generally shallow, but there are occasional deep holes. The beds of the pools are sandy. The bars and riffles are composed of various combinations of bedrock, boulders, cobble, pebble and gravel. Large woody debris is relatively common, forming dams and submerged snags in pools. Cataract Creek contains aquatic habitats suitable for Macquarie Perch, a threatened fish species. The current supply level of Cataract Lake extends upstream into Cataract Creek and contains suitable habitat for

Macquarie Perch (Plate 2b). Occasional riffles and bars further upstream in the creek may be barriers to fish passage during low to moderate flows.

The riparian vegetation in the Upper Cataract River also consists of dense temperate rainforest. The channel forms and bed composition of the river are similar to that found in Cataract Creek.

3.2 Water Quality

3.2.1 Wongawilli West

The mean (± S.E.) water quality measurements recorded per survey at the monitoring sites in the Wongawilli West Study Area are presented in Appendix 2. In Table 1 the water quality measurements taken within the Wongawilli West Study Area are compared with the ANZECC/ARMCANZ guidelines for slightly disturbed upland rivers in south-east Australia. Deviations from the default trigger values (DTV) are indicated below.

Electrical conductivity

- Below the lower DTV at Sites 3 and 4 on Lizard Creek in September 2010 and Sites 11 and 12 on Loddon Creek in March 2009;
- Above the upper DTV at Site16 on Cascade Creek during all surveys and at Site 15 on 5 out of 7 surveys.

pH

- Below the lower DTV at Sites 15 and 16 on Cascade Creek during all surveys, at Sites 11 and 12 on Loddon Creek during most surveys, at Sites 1 and 2 on Wallandoola Creek and Sites 3, 4 and 17 on Lizard Creek in September 2010, April 2011 and September 2011, but at only some of these sites during the earlier surveys.

DO (% saturation)

- Below the lower DTV at Sites 15 and 16 on Cascade Creek during all surveys and at Sites 1 and 2 on Wallandoola Creek, Sites 3, 4 and 17 on Lizard Creek on most sampling occasions and at Sites 11 and 12 on Loddon Creek during at least half the surveys
- Above the upper DTV on occasion at Sites 1 and 2 on Wallandoola Creek, Site 17 on Lizard Creek and Sites 11 and 12 on Loddon Creek.

Turbidity

- Below the lower DTV during a few surveys undertaken at Sites 1 and 2 on Wallandoola Creek, Sites 3,4 and 17 on Lizard Creek, Sites 11 and 12 on Loddon Creek and on one or two occasions at Sites 15 and 16 on Cascade Creek.

- Above the upper DTV on one or two occasions at Sites 4 and17 on Lizard Creek.

3.2.2 Wongawilli East

The mean (± S.E.) water quality measurements recorded per survey at the monitoring sites in the Wongawilli East Study Area are presented in Appendix 3. Table 2 compares the water quality measurements taken within the Wongawilli East Study Area with the ANZECC/ARMCANZ guidelines for slightly disturbed upland rivers in south-east Australia. Deviations from the default trigger values (DTV) are indicated below.

Electrical conductivity

- Below the lower DTV on one occasion at Site 5 on Cataract Creek and Site 10 on Cataract River.

pH

- Below the lower DTV on two occasions at Site 6 on Cataract Creek and Site 14 on Allens Creek and three occasions at Site 13 on Allens Creek.

DO (% saturation)

- Below the lower DTV during most surveys undertaken at Sites 5 and 6 on Cataract Creek and Sites 9 and 10 on Cataract River and during four of the seven surveys of Sites 13 and 14 in Allens Creek.
- Above the upper DTV on occasion at Site 6 on Cataract Creek and Site 14 on Allens Creek.

Turbidity

- Below the lower DTV on one or two surveys undertaken at Sites 5 and 6 on Cataract Creek and Sites 9 and 10 on Cataract River and on two to three of the surveys of Sites 13 and 14 in Allens Creek.
- Above the upper DTV on one or two occasions at Sites 5 and 6 on Cataract Creek, Site 9 on Cataract River and Site 14 on Allens creek.

3.3 Aquatic Macroinvertebrates

3.3.1 AUSRIVAS Samples

3.3.1.1 Wongawilli West

3.3.1.1.1 Spring

The numbers of each macroinvertebrate taxon found in each AUSRIVAS sample collected from the monitoring sites in the Wongawilli West Study Area are presented in Appendix 4. The number of taxa collected per site varied 7 (Site 1 in spring 2011) to 28 (Site 4 in December

2008) (Figure 3a). At Site 1 in Wallandoola Creek, the number of taxa declined from 22 in October and December 2008 to 7 in spring 2011. Marked declines in the number of taxa were also found at Site 2 on Wallandoola Creek, Site 4 on Lizard Creek, Site 11 on Loddon Creek and Site 15 on Cascade Creek, but only during the last three surveys. There was also a marked difference in the number of taxa found at Site 3, with this site having the most diverse fauna in October 2008 but the least diverse in December 2008. No particular trend was evident at the other sites.

The "health" of the macroinvertebrate fauna at all the study sites bar one (site 11 in Loddon Creek) varied across the spring surveys (Figure 4a). The fauna at Site 1 on Wallandoola Creek declined from equivalent to AUSRIVAS reference condition (band A) in spring 2008, to significantly impaired (band B) in 2009 and 2010 and severely impaired (band C) in 2011. The fauna at Site 2 on this creek did not show any particular trend, being equivalent to reference condition on two occasions, more diverse on one occasion and significantly impaired on two occasions. The fauna at two of the sites on Lizard Creek also declined, with that at Site 3 changing from equivalent to reference condition at the beginning of spring 2008 to severely impaired in the second 2008 survey and 2011 and that at Site 4 changing from equivalent to reference condition at the beginning of spring 2008 to significantly impaired from the second survey in 2008 until spring 2010 and to significantly impaired in 2011. The fauna at Site 17 on Lizard creek was more impaired in spring 2009 than in the two subsequent surveys. The fauna in Lizard Creek was thus in a poorer overall condition than that in Wallandoola Creek.

The fauna at Site 11 on Loddon Creek was significantly impaired during all five spring surveys, but that at Site 12 did not show any particular trend, fluctuating between equivalent to reference condition and significantly impaired during the first four surveys, but being severely impaired in spring 2011. The health of the fauna at the sites on Cascade Creek was significantly impaired in spring 2009 and 2011, but equivalent to the reference condition in spring 2010. It should be noted that monitoring of these sites did not commenced until spring 2009.

The OE50 taxa scores for the six sites with severely impaired fauna show that between 50% and 75 % of macroinvertebrate taxa with a 50% probability of occurrence were missing (Figure 4b).

The SIGNAL2 scores indicated the sites on Wallandoola Creek and Lizard Creek were subject to moderate pollution on some occasions, but to severe pollution on others (Figure 4c). A decline in SIGNAL2 scores over the last three surveys was evident at Sites 1 and 2 on Wallandoola Creek and Sites 4 and 17 in Lizard Creek, but at none of the 'control' sites on Loddon Creek or Cascade Creek. The scores for Site 11 on Loddon Creek were indicative of either moderate or mild pollution, as were those for Site 12, except in Spring 2011 when the score was indicative of severe pollution. The scores for the sites on Cascade Creek were indicative of either moderate or severe pollution, with an improvement over time being evident at Site 16.

3.3.1.1.2 Autumn

The number of taxa collected per site varied from 7 (Site 3 in May 2009) to 29 (Site 15 in March 2009) (Figure 3b). The changes in numbers of taxa at most sites were not consistent over time. However, at Site 1 in Wallandoola Creek there was an increase in numbers from 16 in March 2009 to 25 in autumn 2011 and at Sites 11 and 12 in Loddon Creek more taxa were collected in autumn 2009 than in the two subsequent surveys.

The health of the aquatic macroinvertebrate fauna at the majority of study sites also varied across the autumn surveys (Figure 5a). The fauna at Site 1 on Wallandoola Creek declined from equivalent to AUSRIVAS reference condition during the two autumn 2009 surveys to severely impaired (band C) in autumn 2010, but was more diverse than the reference condition (band X) in autumn 2011. The fauna at Site 2 on this creek was equivalent to reference condition on three occasions, but significantly impaired during the other survey. The fauna at Site 3 on Lizard Creek was significantly impaired during all three surveys undertaken at this site. The fauna at Site 4 on Lizard Creek was either equivalent to reference condition or significantly impaired. The condition of the fauna at Site 17 on Lizard Creek was more variable, being equivalent to reference condition in March 2009 and autumn 2011, but significantly impaired in May 2009 and impoverished (band D) in autumn 2010. The fauna at Sites 11 and 12 on Loddon Creek was also variable, changing from equivalent to reference condition to severely impaired. The trends in fauna at Sites 15 and 16 on Cascade Creek were similar, ranging on condition from more diverse than the reference condition to significantly impaired.

The OE50 taxa scores for the four sites with severely impaired fauna show they lacked between 63% and 91 % of the expected macroinvertebrate taxa with a 50% probability of occurrence (Figure 5b).

The SIGNAL2 scores indicated the sites on Wallandoola Creek were generally subject to moderate pollution, except at Site 1 in May 2009 when the score was indicative of severe pollution (Figure 5c). Site 3 on Lizard Creek was subject to severe pollution on both of the occasions it was surveyed, but the other sites on this creek were generally subject to moderate pollution, except for Sites 4 which was assessed as severely polluted in May 2009 and Site 17 which was mild polluted in autumn 2010. The scores for Site 11 on Loddon Creek were indicative of moderate pollution, except in survey 2, whereas those for Site 12 were indicative of either mild or moderate pollution. The sites on Cascade Creek were generally severely polluted, but moderately polluted on one occasion.

3.3.1.2 Wongawilli East

3.3.1.2.1 Spring

The numbers of each macroinvertebrate taxon found in each AUSRIVAS sample collected from the monitoring sites in the Wongawilli East Study Area are presented in Appendix 5. The number of taxa collected per site varied from 9 (Site 6 in spring 2011) to 30 (Site 10 in spring 2010) (Figure 6a). The samples collected at Sites 5 and 6 on Cataract Creek were generally less diverse than those collected at Sites 9 and 10 on Cataract River and Sites 13 and 14 in Allens Creek. The changes in numbers of taxa over time at the sites on Cataract Creek and Cataract River and Site 13 on Allens Creek were not consistent over time, however, there does appear to have been a gradual decrease in numbers at Site 14 over the last three spring surveys. The fauna at all the study sites was less diverse in spring 2011 than during the other spring surveys.

The health of the aquatic macroinvertebrate fauna at all the study sites varied across the spring surveys, with no particular trends evident, except possibly at one of the sites on Allens Creek (Site 14) (Figure 7a). In Cataract Creek, the fauna at Site 5 was either equivalent to AUSRIVAS reference condition or significantly impaired, whereas that at Site 6 was significantly impaired during the first three surveys, equivalent to reference condition in spring 2010, but severely impaired during the most recent survey. The fauna at Site 9 on the Cataract River fluctuated between equivalent to reference condition and significantly impaired during the first four spring surveys, but was severely impaired in spring 2011. The fauna at Site 10 on the Cataract River also fluctuated between equivalent to reference condition and significantly impaired, except in spring 2010 when it was more diverse than the reference condition. The fauna at the sites on Allens Creek was assessed only during the last three surveys springs. At these sites, the fauna was either equivalent to reference condition or significantly impaired.

The OE50 taxa scores for the two sites with severely impaired fauna show they lacked 63% and 67 % of macroinvertebrate taxa with a 50% probability of occurrence, respectively (Figure 7b).

The SIGNAL2 scores indicated that both the ‘potential impact’ and ‘control’ sites were generally subject to moderate pollution (Figure 7c). In spring 2011, SIGNAL2 scores indicative of severe pollution were recorded at one of the sites on each watercourse. SIGNAL2 scores indicative of mild pollution were also recorded on occasion, but only at Sites 9 and 10 on the Cataract River and Site 14 on Allens Creek.

3.3.1.2.2 Autumn

The number of taxa collected per site varied 13 (Site 5 in autumn 2010) to 33 (Site 9 in March 2009) (Figure 6b). The samples collected at Sites 5 and 6 on Cataract Creek were also less diverse during these surveys than those collected at Sites 9 and 10 on Cataract River and Sites 13 and 14 in Allens Creek. The pattern of changes in numbers of taxa over time was similar at the sites on Cataract River and Allens Creek and Site 5 on Cascade Creek, with a decline being evident between March 2009 and autumn 2010 followed by an increase in numbers. At Site 6 on Cascade Creek there was a gradual decline in number of taxa collected over time.

The health of the aquatic macroinvertebrate fauna at all the study sites also varied across the autumn surveys (Figure 8a). The fauna at Site 5 on Cataract Creek was significantly impaired, except in autumn 2010 when it was rated severely impaired. The fauna at Site 6 was equivalent to reference condition during the first two survey, severely impaired in autumn 2010, but significantly impaired in autumn 2011. The fauna at Site 10 on the Cataract River and Sites 13 and 14 on Allens Creek was generally equivalent to reference condition, except in autumn 2010 when it was significantly impaired. The fauna at Site 9 on Cataract River was more variable, being either equivalent to reference condition, significantly impaired or severely impaired.

The OE50 taxa scores show that the severely impaired fauna lacked between 62% and 72 % of the expected macroinvertebrate taxa with a 50% probability of occurrence (Figure 8b).

The SIGNAL2 scores for the autumn surveys indicated that the ‘potential impact’ and ‘control’ sites were generally subject to moderate pollution (Figure 8c). SIGNAL2 scores indicative of severe pollution, however, were recorded on one occasion at the sites on Allens Creek. SIGNAL2 scores indicative of mild pollution were recorded on one occasion at each ‘control site’ but at only one ‘potential impact’ site (Site 5 on Cataract Creek).

3.3.2 Collectors

3.3.2.1 Wongawilli West

The total numbers of each macroinvertebrate taxon found on the collectors retrieved from the monitoring sites in the Wongawilli West Study Area in spring 2008 and autumn 2009 are presented in Appendix 6. In spring 2008, the average number of macroinvertebrate taxa colonising the collectors varied from 1.2 at Site 3 on Lizard Creek to 7.4 at Site 12 on Loddon Creek, while average number of macroinvertebrate animals varied from 3 at Site 3 to 94 at Site 4 on Lizard Creek (Figure 9). Chironomidae (non-biting midges) and Leptoceridae (stick caddisflies) were two most abundant taxa found on the collectors retrieved at Sites 1 and 2 on Wallandoola Creek (Figure10). The collectors at the Sites in Lizard Creek were dominated by different taxa, with Entomobryidae followed by Chironomidae being the most abundant taxa at Site 3 and Chironomidae and Oligochaete the two numerically dominant taxa at Site 4. Chironomidae and Leptophlebiidae (leptofleb mayflies) were the dominant taxa at Site 12 on Loddon Creek. Some of the aquatic macroinvertebrates found on the collectors are depicted on Plates 5a-e. It should be noted that collectors deployed at some sites were not processed because they had been stranded on dry land and that none were deployed at the study sites on Cascade River. As the data from this deployment of collectors is incomplete it has not been subject to statistical comparison.

In autumn 2009, the average number of macroinvertebrate taxa colonising the collectors varied from 2 at Site 16 on Cascade Creek to 7 at Sites 11 and 12 on Loddon Creek, while average number of macroinvertebrate animals varied from 16 at Site 1 on Wallandoola Creek to 273 at Site 12 on Loddon Creek (Figure 11). Chironomidae and Oligochaeta were the two most abundant taxa on the collectors retrieved from Site 2 on Wallandoola Creek, Sites 4 and 17 on Lizard Creek and Site 15 in Cascade Creek. The collectors retrieved from Sites 11 and 12 on Loddon Creek and Site 16 in Cascade Creek were dominated by Chironomidae followed by Leptophlebiidae, while those at Site 1 on Wallandoola Creek were dominated by Anclylidae (freshwater limpets) and Chironomidae (Figure 10). The MDS plot indicates the assemblages at Sites 1 and 2 on Wallandoola Creek were distinct from each other, as were those at Sites 4 and 17 on Lizard Creek (Figure 12). The differences in the structure of the macroinvertebrate assemblage, total numbers of taxa and macroinvertebrates within location were statistically significant but not those among locations (Table 3; Appendix 8).

3.3.2.2 Wongawilli East

The total numbers of each macroinvertebrate taxon found per survey on the collectors retrieved from the monitoring sites in the Wongawilli East Study Area are presented in Appendix 7. In spring 2008, the average number of macroinvertebrate taxa colonising the collectors varied from 4 at Site 6 on Cataract Creek to 9 at Site 10 on Cataract River, while average number of macroinvertebrate animals varied from 35 at Site 6 on Cataract Creek to 149 at Site 9 on Cataract River (Figure 13). Chironomidae and Oligochaete were the two most abundant taxa found on the collectors retrieved from Sites 5 and 6 on Cataract Creek and Site 10 on Cataract River (Figure 14). Chironomidae followed by Ancylidae were the numerically dominant taxa on the collectors from Site 9 on Cataract River. It should be noted that on this occasion no collectors were deployed at the study sites on Allens Creek. As the data from this deployment of collectors is incomplete it has not been subject to statistical comparison.

In autumn 2009, the average number of macroinvertebrate taxa colonising the collectors varied from 9 at Site 13 on Allens Creek to 11 at Site 9 on Cataract River, while average number of macroinvertebrate animals varied from 83 at Site 14 on Allens Creek to 377 at Site 10 on Cataract River (Figure 15). Chironomidae and Oligochaeta were the two most abundant taxa found on the collectors retrieved from Sites 5 and 6 on Cataract Creek, Site 10 on Cataract River and Site13 on Allens Creek (Figure 16). Ancylidae followed by Oligochaeta were the numerically dominant taxa on the collectors from Site 9 on Cataract River. The collectors from Site 14 on Allens Creek were dominated by Chironomidae followed by Leptophlebiidae. The MDS plot indicates the assemblages at the paired sites on the three watercourses were more or less distinct from each other (Figure 17). There were significant differences in the structure of the macroinvertebrate assemblage and total numbers of macroinvertebrates within but not among locations (Table 3; Appendix 9). The total number of taxa, however, differed among but not within locations.

In spring 2009, the average number of macroinvertebrate taxa colonising the collectors varied from 4.6 at Site 5 on Cataract Creek to 9.3 at Site 10 on Cataract River, while average number of macroinvertebrate animals varied from 68 at Site 13 on Allens Creek to 86 at Site 9 on Cataract River (Figure 18). Oligochaeta followed by Chironomidae were the two most abundant taxa found on the collectors retrieved from Sites 5 and 6 on Cataract Creek and Site 14 on Allens Creek (Figure 14). The collectors from Sites 10 and 13 were dominated by Chironomidae followed by Leptophlebiidae, while that at Site 9 was dominated by Chironomidae followed by Oligochaeta. The MDS plot indicates the assemblages at the paired sites on Cataract River and Allens Creek were more or less distinct from each other (Figure 19). In spring 2009, the only statistically significant differences detected were in assemblages within locations and total numbers of taxa among locations (Table 3; Appendix 10).

In autumn 2010, the average number of macroinvertebrate taxa colonising the collectors varied from 8 at Site 6 on Cataract Creek to 15 at Site 9 on Cataract River, while average number of macroinvertebrate animals varied from 85 at Site 13 on Allens Creek to 452 at Site 5 on Cataract Creek (Figure 20). In autumn 2010, Chironomidae followed by Leptophlebiidae were the most abundant taxa on the collectors retrieved from the sites in Cataract River and Allens Creek. The collectors from the Cataract Creek sites were dominated by Oligochaeta and Chironomidae. The MDS plot indicates the assemblages at the paired sites on the three watercourses were more or less distinct from each other (Figure 21). In autumn 2010, statistically significant differences in all three indicators were found within locations (Table 3: Appendix 11). The structure of the assemblages also differed among locations.

3.4 Fish

3.4.1 Targeted Fish Surveys

3.4.1.1 Preliminary Survey of Wongawilli East

The species and numbers of fish collected in Cataract Creek in November 2008 are shown in Table 4. Two specimens of Macquarie Perch, a species listed as threatened under both State and Federal legislation, were caught within the current supply level and another specimen was caught at the inflow of the creek (Plate 6a). Numerous juvenile cod that may have been Murray cod (*Maccullochella peelii*), Trout Cod (*Maccullochella macquariensi*s) or a hybrid of these species (Andrew Bruce of DPI, pers. comm.) were also caught (Plate 6b). A specimen sent to The Australian Museum for further analysis could not be positively identified. A native long-finned eel and a number of climbing galaxias were caught in the riffle/pool sequences upstream of the dam storage level.

3.4.1.2 Summer 2009/2010

Six species of fish were caught (Table 5a).

The number of Macquarie Perch caught per survey increased from 3 in December 2009, to 6 in the January surveys and 15 in February 2010. The geographic location and length of each Macquarie Perch caught is presented in Appendix 12. The fish caught ranged in length from 80 mm to 230 mm. Macquarie Perch were caught further upstream during each successive survey, with the most upstream records being up to the rock bar at the upstream extent of the survey area in Survey 4.

Juvenile Freshwater Ccod were recorded in all four surveys. Silver Perch (*Bidyanus bidyanus)* were recorded in Survey 4 (Plate 6c). All three species are known to have been stocked in Lake Cataract, although it is outside their natural distribution range. A small endemic species, Mountain galaxias (*Galaxias olidus*), was caught in all four surveys (Plate 6d). Two introduced pest species, Eastern gambusia (*Gambusia holbrooki)* and goldfish (*Carassius auratus*) (Plate 6e) were also caught in all four surveys. Gambusia was the most abundant species of fish caught.

Freshwater crayfish (*Euastacus* sp.) were found throughout the study area (Plate 5f), but their numbers were not recorded.

The water quality parameters recorded during the targeted fish survey are presented in Appendix 14a. During the December 2009 survey, the water temperature at the confluence of the Cataract River was 21.7°C but it was only 17°C at Site 6, which is below the spawning trigger temperature (18°C) for this species. A distinct temperature gradient was also evident during the other surveys, with temperatures at these sites being 21°C and 18°C respectively, at the beginning of January, but rising to 19°C and 22.3°C towards the end of January. During the February survey, the temperature at the confluence was 19.9°C, whereas that at site 6 was 16.5°C.

3.4.1.3 Summer 2010/2011

Seven species of fish were caught during the summer 2010-2011 surveys (Table 5b).

Macquarie Perch were found within Cataract Creek from the confluence with Cataract River, to upstream well above the full supply level, and as far as the rock bar located at Site 6. This is approximately 100 m further upstream than this species was recorded in the final survey of summer 2009-2010. The individuals recorded furthest upstream were caught on 21 February 2011. This species was found much further upstream during the first survey of 2010/2011 than that of the 2009/2010 monitoring period. As in the previous year, individual Macquarie Perch were found further upstream as the season progressed. However, significantly more Macquarie Perch were caught in 2010/2011, with numbers increasing from 11 in December 2010 to 37 in

January 2011 and 28 in February 2011. The geographic location and length of each Macquarie Perch caught are presented in Appendix 13. The Macquarie Perch fish caught ranged in length from 90 mm to 370 mm. The geographic co-ordinates of each Freshwater Cod and Silver Perch caught are listed in Appendix 15.

Freshwater cod were recorded in all four surveys, with numbers also increasing as the season progressed (i.e. 5 in December 2010 to 22 in February 2011). Silver Perch (*Bidyanus bidyanus)* were recorded only in late January and February 2011. Eastern Gambusia and Mountain Galaxias were also caught during all four surveys, with the former again being the most abundant species caught. Goldfish were only caught in December 2010 and February 2011 and were less abundant than during the previous season. The seventh species caught, the short-finned eel (*Anguilla australis*) was caught only in January.

Freshwater crayfish (*Euastacus* sp.) were again found throughout the survey area.

The water quality parameters recorded during the targeted fish survey are presented in Appendix 14b. During the December 2010 survey, the water temperature at the confluence of the Cataract River was 24.9°C but it was only 17.4°C at Site 6, which is below the spawning trigger temperature (18°C) for this species. A distinct temperature gradient was also evident during the other surveys, with temperatures at these sites being 21.7°C and 16.6°C respectively, at the beginning of January, but rising to 19°C and 22.3°C towards the end of January. During the February survey, the temperature at the confluence was 19.9°C, whereas that at site 6 was 16.5°C.

3.4.2 Baseline Monitoring

Three species of fish, eastern gambusia (*Gambusia holbrooki*), climbing galaxias (*Galaxias brevipinnis*) and Australian smelt (*Retropinna semoni*) and one crustacean, the freshwater crayfish (*Euastacus* sp.) were either caught in dip nets or observed at the study sites (Table 6). All four species were present within the Wongawilli West and Wongawilli East Study Areas, but not at all sites. Eastern gambusia was recorded only at Sites 5 (Cataract Creek) and 12 (Loddon Creek). Climbing galaxias and Australian smelt (Plate 6f) had an intermediate distribution, with both being recorded at five sites. Freshwater crayfish had the widest distribution range, being found at 11 study sites. No fish were observed or caught at the Wallandoola Creek sites, but freshwater crayfish (*Euastacus* sp.) were present.

4 Discussion

4.1 Wongawilli West

4.1.1 Aquatic Habitat

The reaches of Wallandoola Creek and Lizard Creek within the Wongawilli West Study Area have clearly been degraded by previous underground mining operations. Numerous fractures are evident in the sandstone rock bars within these creeks. In Lizard Creek, the fractures appear to have led to sub-surface flow diversion and drainage of pools. There are also high levels of iron staining and associated bacterially-mediated iron flocculant and matting within these creeks. This is most likely due to dissolution into the surface water of iron sulphides and iron oxy-hydroxides exposed by fracturing of the bedrock. The iron floc is likely to have smothered the surfaces of aquatic macrophytes, snags, boulders and bank edge and in so doing reduced the amount of aquatic habitat suitable for occupation by aquatic organisms. Despite this, a variety of different aquatic habitats, including pools, overhanging vegetation, boulders, bedrock, sediment accumulations, submerged woody debris, aquatic macrophytes are still present. The occupation of these habitats by fish is limited by waterfalls in the downstream reaches of both creeks that are significant barriers to fish passage.

4.1.2 Water Quality

Although the water quality parameters measured during the surveys often deviated from the ANZECC/ARMCANZ (2000) guidelines, there was no evidence to suggest that the overall quality of the water at the ‘potential impact’ sites in Wallandoola and Lizard Creek was poorer than that at the ‘control’ sites. Table 1, in fact, shows that on some occasions (e.g. May 2009) the number of water quality parameters outside the accepted guidelines was similar at the ‘control’ and ‘potential impact’ sites, but on others (e.g. September 2010 and September 2011) the water quality was better at the ‘potential impact’ sites. The deviations in some of the individual water quality parameters were consistent, with dissolved oxygen, a major factor influencing aquatic biota, generally being below the lower DTV in all four watercourses. pH levels were more frequently below the lower DTV at the ‘control sites’ than at the ‘potential impact’ sites. The electrical conductivity of the water in one of the ‘control’ creeks (Cascade) also differed from that in the other watercourses in generally being in excess rather than within the accepted guidelines.

4.1.3 Aquatic Macroinvertebrates

The “health” of the macroinvertebrate fauna at the majority of monitoring sites was not consistent across either the spring or autumn surveys. During the spring surveys, the changes in condition of the fauna, as indicated by differences in AUSRIVAS banding, was generally greater at the ‘potential impact’ sites than at the ‘control’ sites. During the autumn surveys, two of the ‘potential impact’ sites on Lizard Creek showed smaller changes in “health” than the other ‘potential impact’ and ‘control sites’. The amount of change in AUSRIVAS bands observed at some of the monitoring sites is of concern (e.g. X to B or A to C or D), because it indicates the composition of the macroinvertebrate fauna is naturally highly variable. This implies that AUSRIVAS bands, and the OE50 taxa scores from which they are derived, may not be effective indicators of any impacts on aquatic macroinvertebrates associated with the proposed mining activities. The variability in these indicators may be due to differences in reproduction and development of the aquatic macroinvertebrate fauna towards the beginning, middle or end of the spring survey period (September to December) and the lack of a temporally consistent sampling regime. This potential source of variability could be reduced by restricting the timing of monitoring (e.g. to a three week period in the middle of the AUSRIVAS sampling periods). It should, of course, be noted that some flexibility in the monitoring program is needed to cope with the variability in rainfall and flows.

The SIGNAL2 scores from the spring surveys indicated the fauna at the ‘potential impact’ sites on Wallandoola Creek and Lizard Creek was more degraded than that at the ‘control sites’ in Loddon Creek, but not necessarily those in Cascade Creek. A similar trend was evident in the SIGNAL2 scores from the autumn surveys. The SIGNAL2 scores were less variable than the AUSRIVAS bands, particularly in autumn, and could therefore be a better indicator of changes in the macroinvertebrate fauna associated with mine-induced subsidence. However, as these scores are based primarily on the sensitivity of individual taxa to pollution, it is not clear whether they will respond to changes in aquatic habitats arising from the impact of subsidence on physical features.

4.1.4 Fish

The limited sampling and observations made during the baseline monitoring program suggest that the fish fauna in the watercourses above the proposed longwalls is depauperate. No fish species were observed at the ‘potential impact’ sites in Wallandoola Creek and only two species were found at those in Lizard Creek. The ‘control sites’ also appeared to be depauperate with only one and three species being recorded in Cascade Creek and Loddon Creek, respectively. The paucity of fish species is most likely due to the presence of barriers to fish passage in the form of waterfalls downstream of the study sites. The difference in results from the baseline monitoring and backpack electrofishing surveys in Wongawilli East suggest that use of a more effective sampling technique may result in the capture of other species.

4.2 Wongawilli East

4.2.1 Aquatic Habitat

There is also evidence of habitat degradation within the Wongawilli East Study Area, with iron staining and floc being present in both Cataract Creek and Cataract River.

4.2.2 Water Quality

There was no evidence to suggest that the overall quality of the water at the 'potential impact' sites on Cataract Creek was poorer than that at the 'control' sites. Table 2, in fact, shows that on some occasions (e.g. May 2009) the number of water quality parameters outside the accepted guidelines was similar at the 'control' and 'potential impact' sites, but on others (e.g. March 2009, November 20009 and September 2010) the water quality was better at the 'potential impact' sites. Dissolved oxygen was the parameter that showed the most frequent deviation from the accepted guidelines, with values generally being below the lower DTV at the 'potential impact' sites on Cataract Creek and the 'control' sites on Cataract River and also frequently at the 'control' sites in Allens Creek. The overall water quality was generally better than in the Wongawilli East Study Area.

4.2.3 Aquatic Macroinvertebrates

The "health" of the macroinvertebrate fauna at the monitoring sites was not consistent across either the spring or autumn surveys. During the spring surveys, the changes in condition of the fauna, as indicated by differences in AUSRIVAS banding, was generally greater at the 'control' sites on Cataract River than at the 'potential impact sites on Cataract Creek and 'control' sites on Allens Creek. During the autumn surveys, one of the 'potential impact' sites on Cataract Creek and one of the 'control sites' on Cataract River showed larger changes in "health" than the other monitoring sites. The amount of change in AUSRIVAS bands observed at the more variable sites was in the same order as that observed in the Wongawilli West Study Area (i.e. X to B or A to C). The less variable nature of the monitoring sites in this Study Area suggests that AUSRIVAS bands, and the OE50 taxa scores from which they are derived, may be more effective indicators of impacts on aquatic macroinvertebrates associated with extraction of the Wongawilli East longwalls.

The SIGNAL2 scores from both the spring and autumn surveys indicated the fauna at the 'potential impact' sites on Cataract Creek was generally in a similar state to that at the 'control sites' on Cataract River and Allens Creek. The SIGNAL2 scores were less variable than the AUSRIVAS bands, as was the case in the Wongawilli West Study Area, suggesting that it might potentially be a better indicator of changes in the macroinvertebrate fauna associated with mine-induced subsidence.

One of the supposed advantages associated with the use of artificial collectors is that they provide a standard habitat for macroinvertebrates to colonise and result in data that exhibit less variability between samples (greater precision) and sites than fauna associated with natural substrata. The current study, however, has shown that statistically significant differences in the structure of the assemblages, total numbers of taxa and macroinvertebrates were more common between paired sites than among watercourses in Wongawilli East. This small-scale spatial variability is likely to hinder our ability to detect any impacts associated with extraction of the proposed longwalls.

4.2.4 Fish

The limited sampling and observations made during the baseline monitoring program suggest that the fish fauna in the watercourses in the Wongawilli East Study Area is also depauperate. No fish species were observed at the 'control' sites in Allens Creek and only two species were found in Cataract Creek and Cataract River.

The backpack electrofishing survey undertaken on Cataract Creek between its confluence with Cataract River and Site 6, however, indicates that at least seven species are present. Three of the species caught, Macquarie Perch, Freshwater Cod (identification not confirmed could be Trout Cod, Murray Cod or a hybrid between the two species) (Gehrke & Harris 1996, Douglas *et al.* 1994) and Silver Perch are threatened species listed under State and/or Federal legislation. It should be noted that the Study Area is outside the natural distribution range of the latter species and that their presence is most likely due to upstream migration of individuals that have been translocated to Cataract Dam. The translocated populations of Trout Cod that exist in NSW are generally maintained by the release of hatchery-bred fish, however, that in Cataract Dam is known to be self-sustaining (NSW DPI 2006). Stocking of impoundments with hatchery-reared silver perch has generally not resulted in self-reproducing populations, so this species is still considered under threat in the wild. The translocated population that is present, in Cataract Dam, however, is known to be self-sustaining (Fisheries Scientific Committee 1999). Macquarie Perch are known to occur within the Cataract River between Broughtons Pass Weir and the Cataract Dam, but have also been translocated from the Murray River to Cataract Dam (Lintermans 2006). It is therefore not known whether the fish caught are part of a natural or translocated population. The targeted surveys indicate this species moves upstream as the summer season progresses, with individuals extending as far up as the rock bar below Site 6, which is situated above proposed Longwalls 7 and 8. The larger numbers of Macquarie Perch caught during the 2010/2011 summer may be related to the supply level extending further up the creek than the previous year (Appendix1). Freshwater Cod and Silver Perch were also present throughout the reach of the creek electro-fished.

Assessments of the impact of the proposed mining on the threatened species will need to be prepared and included within the Subsidence Management Plan (SMP). If there is evidence that the proposed mining work is likely to have a significant impact on this species or scientific uncertainty about the potential for impacts, a referral will need to be submitted to the Federal Department of Environment and Heritage for a decision as to whether assessment and approval is needed under the *EPBC Act.*

4.3 Conclusion

During the baseline monitoring, three major issues relating to aquatic ecology that require consideration as part of the Part 3A approval process for the Wongawilli East and Wongawilli West mining areas have been identified. These are:

1. The occurrence of threatened fish species, particularly Macquarie Perch, within or adjacent to the Wongawilli East mine area;
2. The existence of prior mine subsidence related impacts in the form of rockbar fractures and iron staining within the watercourses overlying the Wongawilli West mine area;
3. The variability in the “health’ of the aquatic macroinvertebrate fauna which suggests that AUSRIVAS indices may not be an effective indicator of impacts associated with mining.

5 Recommendations

1. Further aquatic ecology monitoring should be conducted during and after the extraction of the longwalls within Wongawilli West and Wongawilli East using the same survey sites and methods as in this study. This will provide best practice environmental monitoring of aquatic ecology and will allow statistically powerful tests of the effects of any impacts on aquatic habitats and biota arising from mine subsidence. This monitoring plan conforms to the recommendations made by the NSW Department of Planning's 'Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield' (NSW DoP, 2008).

2. In view of the apparent variability in the 'health" of the aquatic macroinvertebrate fauna, it is recommended that SIGNAL2 scores continue to be calculated in addition to AUSRIVAS indices.

3. Further attempt should be made to identify the freshwater cod caught during the 2011/2012 summer season. The retention of some specimens for screening of otoliths for hatchery chemical batch marks could facilitate this process.

4. The position and extent (i.e. length and width) of existing rockbar fractures within the watercourses overlying the proposed mine area should be recorded prior to the extraction of coal from the Wongawilli East and Wongawilli West Longwalls. This will enable future fractures in the bedrock due to subsidence resulting from extraction of the proposed longwalls, if any, to be distinguished from past fractures and the effects of additional mining on existing fractures and their consequences for aquatic ecology to be assessed.

5. Iron staining can lead to the proliferation of iron-oxidising bacteria that can smother the surface of aquatic macrophytes, snags, boulders and bank edge and thereby reduce the amount of habitat suitable for occupation by aquatic organisms. In view of this, it is recommended that the occurrence and extent of iron stains be monitored regularly in areas expected to undergo subsidence. This should be done before, during and after mining of the longwalls. The observation of a sudden marked increase in the extent of iron staining should trigger an assessment of impacts on aquatic habitats and biota.

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8 Tables

Table 1: Comparison of water quality data from the monitoring sites in the Wongawilli West Study Area in relation to ANZECC guidelines for slightly disturbed upland streams in south-east Australia.

Table 2: Comparison of water quality data from the monitoring sites in the Wongawilli East Study Area in relation to ANZECC guidelines for slightly disturbed upland streams in south-east Australia.

Table 3: Summary of the results of PERMANOVA tests based on aquatic macroinvertebrate assemblages, total number of taxa and macroinvertebrates found on collectors retrieved from monitoring sites in (a) Wongawilli West and (b) Wongawilli East Study Areas.

Table 4: Fish sampled with a backpack electrofishing unit in Cataract Creek from 25-26 November, 2008.

Table 5: Numbers of each species of fish caught during the targeted surveys for Macquarie Perch undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.

Table 6: Species of fish and large crustaceans observed at the monitoring sites in the Wongawilli West and Wongawilli East Study Areas.

Table 1: Comparison of water quality data from the monitoring sites in the Wongawilli West Study Area in relation to ANZECC guidelines for slightly distrubed upland streams in south-east Australia. (= within guidelines; > above; < below; ND = no data. See Appendix 2 for complete data.

		Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
Survey/Parameter		1	2	3	4	17	11	12	15	16
Oct-08										
Conductivity	30-350 uS/cm	=	=	=	=	ND	=	=	ND	ND
pH	6.5-8.0	=	=	=	=	ND	<	<	ND	ND
DO saturation	90-110%	<	<	<	<	ND	<	<	ND	ND
Turbidity	2-25 NTU	=	=	=	=	ND	=	=	ND	ND
Dec-08										
Conductivity		ND	ND	ND	ND	ND	ND	ND	ND	ND
pH		=	=	<	=	ND	<	<	ND	ND
DO sat.		<	<	<	<	ND	<	<	ND	ND
Turbidity		<	=	<	=	ND	<	<	ND	ND
Mar-09										
Conductivity		=	=	ND	=	=	<	<	>	>
pH		ND	ND	ND	ND	ND	<	<	ND	ND
DO sat.		<	=	ND	<	<	<	<	<	<
Turbidity		ND	ND	ND	>	>	ND	ND	=	=
May-09										
Conductivity		=	=	=	=	=	=	=	>	>
pH		<	=	<	=	=	<	<	<	<
DO sat.		>	>	<	=	>	>	>	<	<
Turbidity		<	ND	=	=	ND	ND	ND	=	=
Nov-09										
Conductivity		=	=	ND	=	=	=	=	>	>
pH		<	<	ND	<	=	<	=	<	<
DO sat.		=	<	ND	<	<	=	<	<	<
Turbidity		=	<	ND	=	>	<	<	<	<
Mar-10										
Conductivity		=	=	ND	=	=	=	=	>	>
pH		<	=	ND	<	=	<	<	<	<
DO sat.		<	<	ND	<	<	<	<	<	<
Turbidity		=	<	ND	<	<	=	<	=	<
Sep-10										
Conductivity		=	=	<	<	=	=	=	>	>
pH		<	<	<	<	<	<	<	<	<
DO sat.		<	<	<	<	<	>	=	<	<
Turbidity		=	=	=	=	=	<	<	=	=
Apr-11										
Conductivity		=	=	=	=	=	=	=	=	>
pH		<	<	<	<	<	<	<	<	<
DO sat.		<	=	<	<	<	<	=	<	<
Turbidity		=	=	<	=	<	=	<	=	=
Sep-11										
Conductivity		=	=	=	=	=	=	=	=	>
pH		<	<	<	<	<	<	<	<	<
DO sat.		<	<	<	<	<	<	<	<	<
Turbidity		<	=	<	=	=	<	=	=	=

Table 2: Summary of water quality data for Wongawilli East and Control sites in relation to ANZECC guidelines for upland streams in NSW. = within guidelines; > above; < below; ND = no data. See Appendix 3 for complete data.

		Wongawilli East		Controls			
Survey/Parameter		5	6	9	10	13	14
Oct-08							
Conductivity	30-350 uS/cm	=	=	=	=	ND	ND
pH	6.5-8.0	=	=	=	=	ND	ND
DO saturation	90-110%	<	<	<	<	ND	ND
Turbidity	2-25 NTU	=	=	=	=	ND	ND
Dec-08							
Conductivity		ND	ND	ND	ND	ND	ND
pH		=	=	=	=	ND	ND
DO sat.		<	<	<	<	ND	ND
Turbidity		=	=	=	=	ND	ND
Mar-09							
Conductivity		<	=	=	<	=	=
pH		=	=	=	=	=	=
DO sat.		<	<	<	<	<	<
Turbidity		=	=	=	=	<	<
May-09							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	=	=
DO sat.		<	<	<	<	<	<
Turbidity		<	<	<	<	<	<
Nov-09							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	=	=
DO sat.		=	>	<	<	<	>
Turbidity		=	>	<	<	<	>
Mar-10							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	=	=
DO sat.		<	<	<	=	<	=
Turbidity		=	=	>	=	=	=
Sep-10							
Conductivity		=	=	=	=	=	=
pH		=	<	=	=	<	<
DO sat.		<	<	<	<	=	<
Turbidity		=	=	=	=	<	=
Apr-11							
Conductivity		=	=	=	=	=	=
pH		=	<	=	=	<	=
DO sat.		=	<	<	<	=	=
Turbidity		>	=	=	=	=	=
Sep-11							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	<	<
DO sat.		<	<	<	<	<	<
Turbidity		<	=	=	=	=	=

Table 3: Summary of the results of PERMANOVA tests based on aquatic macroinvertebrate assemblages, total number of taxa and macroinvertebrates found on collectors retrieved from monitoring sites in (a) Wongawilli West and (b) Wongawilli East Study Areas.

(a) Wongawilli West

Survey	Indicator	Source of Variation	
		Location	Sites(location)
Autumn 2009	Assemblage	ns	**
	No. of taxa	ns	***
	No. of macroinvertebrates	ns	***

b) Wongawilli East

Survey	Indicator	Source of Variation	
		Location	Sites(location)
Autumn 2009	Assemblage	ns	***
	No. of taxa	*	ns
	No. of macroinvertebrates	ns	*
Spring 2009	Assemblage	ns	***
	No. of taxa	*	ns
	No. of macroinvertebrates	ns	ns
Autumn 2010	Assemblage	**	**
	No. of taxa	ns	**
	No. of macroinvertebrates	ns	***

Table 4: Fish sampled with a backpack electrofishing unit in Cataract Creek from 25-26 November, 2008. * indicates exotic species (introduced from outside Australia).

	Murray/Trout Cod	Macquarie Perch	Climbing Galaxias	Longfinned Eel	Mosquito Fish*	Goldfish*
Location	*(Maccullochella peelii peelii / macquariensis)*	*(Macquaria australasica)*	*(Galaxias brevipinnis)*	*(Anguilla reinhardtii)*	*(Gambusia holbrooki)*	*(Carassius auratus)*
Cataract Creek						
Within current supply level	4	2	-	-	> 1000	>500
Inflow of creek	-	3	1	-	-	20
Upstream of inflow	1	-	19	-	-	-
Upstream of maximum supply level	-	-	13	1	-	-

Table 5: Numbers of each species of fish caught during the targeted surveys for Macquarie Perch undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.

A. Summer 2009/2010

Common Name	Scientific Name	Survey Date			
		15/12/2009	8/01/2010	29/01/2010	25/02/2010
Macquarie Perch	*Macquaria australasica*	3	6	6	15
Freshwater Cod	*Maccullochella* sp.	5	2	5	53
Silver Perch	*Bidyanus bidyanus*	0	0	0	9
Goldfish	*Carrassius auratus*	93	27	11	8
Eastern Gambusia	*Gambusia holbrooki*	>1000	>1000	>1000	>1000
Mountain Galaxias	*Galaxias olidus*	49	19	4	56

B. Summer 2010/2011

Common Name	Scientific Name	Survey Date			
		8/12/2010	7/01/2011	25/01/2011	21/02/2011
Macquarie Perch	*Macquaria australasica*	11	14	37	28
Freshwater Cod	*Maccullochella* sp.	5	8	18	22
Silver Perch	*Bidyanus bidyanus*	0	0	5	4
Goldfish	*Carrassius auratus*	1	0	0	12
Gambusia	*Gambusia holbrooki*	193	42	189	>500
Mountain Galaxias	*Galaxias olidus*	249	34	82	57
Short-finned Eel	*Anguilla australis*	0	2	1	0

Table 6: Species of fish and large crustaceans observed at the monitoring sites in the Wonga West and Wonga East Study Areas (* = introduced species, X = present)

Common name	Scientific name	Creek	Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck		Cataract Ck		Cataract River		Allens Ck	
		Site	1	2	3	4	17	11	12	15	16	5	6	9	10	13	14
FISH																	
Mosquito fish*	*Gambusia holbrooki*								X			X					
Climbing galaxias	*Galaxias brevipinnis*					X		X	X			X		X			
Smelt	*Retropinna semoni*					X	X		X	X					X		
CRUSTACEANS																	
Freshwater crayfish	*Euastacus* sp.		X	X		X		X	X			X	X	X	X	X	X

9 Figures

Figure 1: Map showing the position of aquatic ecology monitoring sites in relation to the proposed Wongawilli East and Wongawilli West Mine Areas.
Figure 2: Map showing the reach of Cataract Creek (blue dotted line) in which targeted Macquarie Perch surveys were undertaken.
Figure 3: Wongawilli West Study Area – Number of taxa found in the AUSRIVAS samples collected at the monitoring sites in Wallandoola, Lizard, Loddon and Cascade Creeks in (a) the spring 2008-2011 surveys and (b) autumn 2009-2011 surveys.
Figure 4: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.
Figure 5: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.
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Figure 7: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.
Figure 8: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.
Figure 9: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from monitoring sites in the Wongawilli West Study Area in spring 2008.
Figure 10: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in spring 2008 and autumn 2009.
Figure 11: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in autumn 2009.
Figure 12: MDS of macroinvertebrates assemblages found on collectors at the study sites on Wallandoola Creek, Lizard Creek, Loddon Creek and Cascade Creek in autumn 2009.
Figure 13: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008.
Figure 14: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008 and 2009.
Figure 15: Mean number of taxa and mean numbers of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009.
Figure 16: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009 and 2010.
Figure 17: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2009.
Figure 18: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2009.
Figure 19: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in spring 2009.
Figure 20: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2010.
Figure 21: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2010.

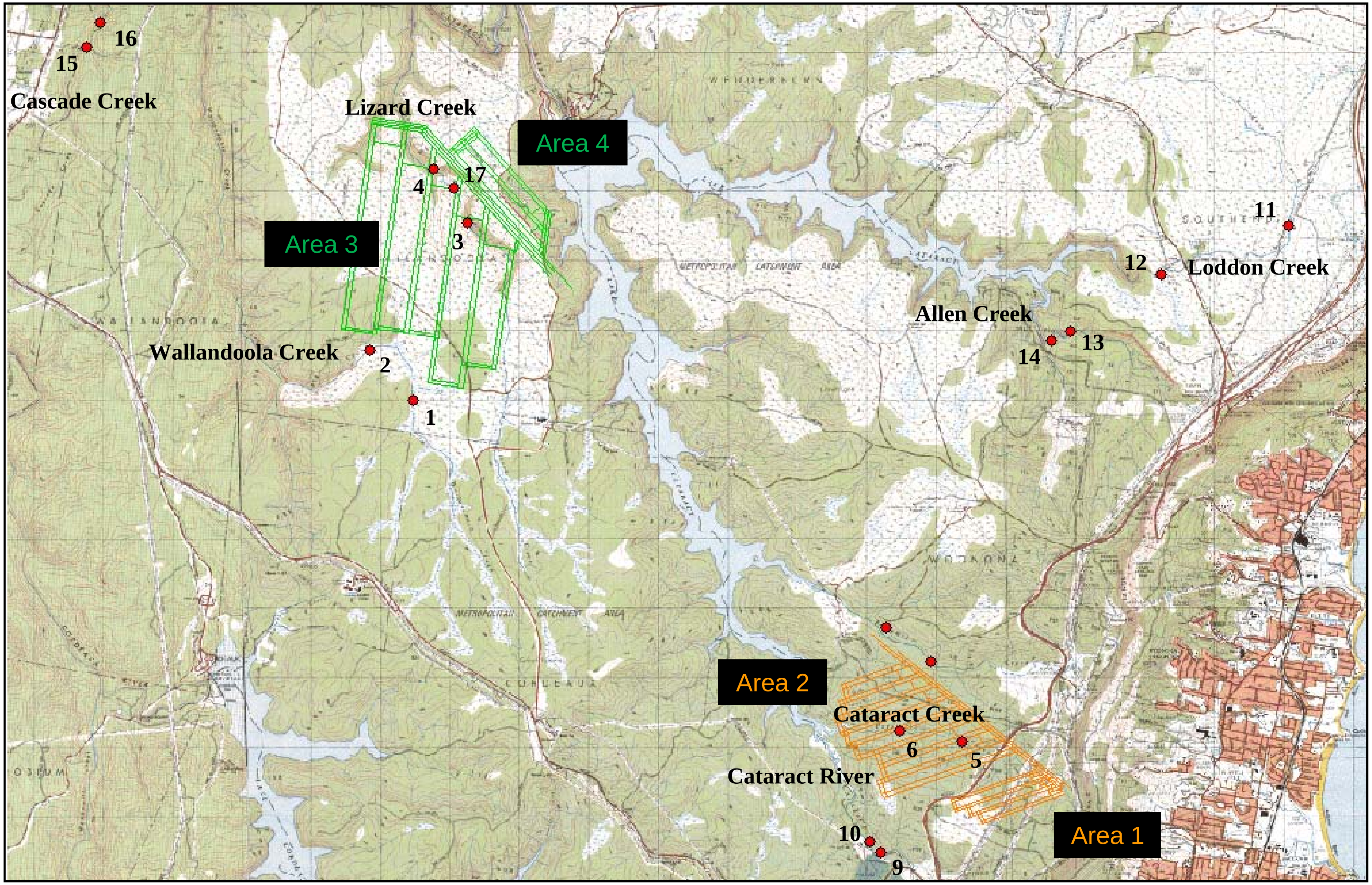


Figure 1: Map showing the position of aquatic ecology monitoring sites in relation to the Wongawilli East (orange lines) and Wongawilli West (green lines) Mine Areas.

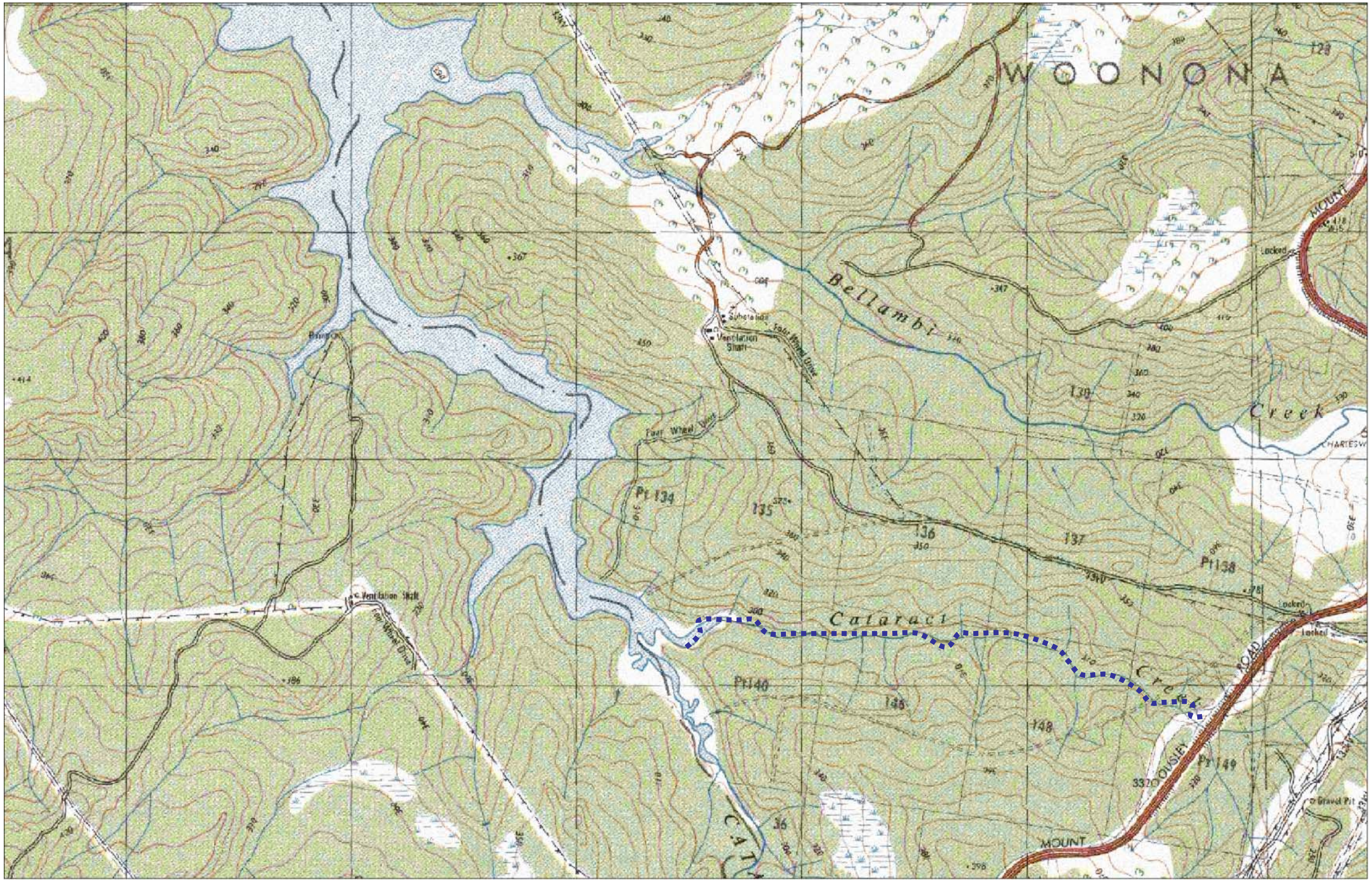
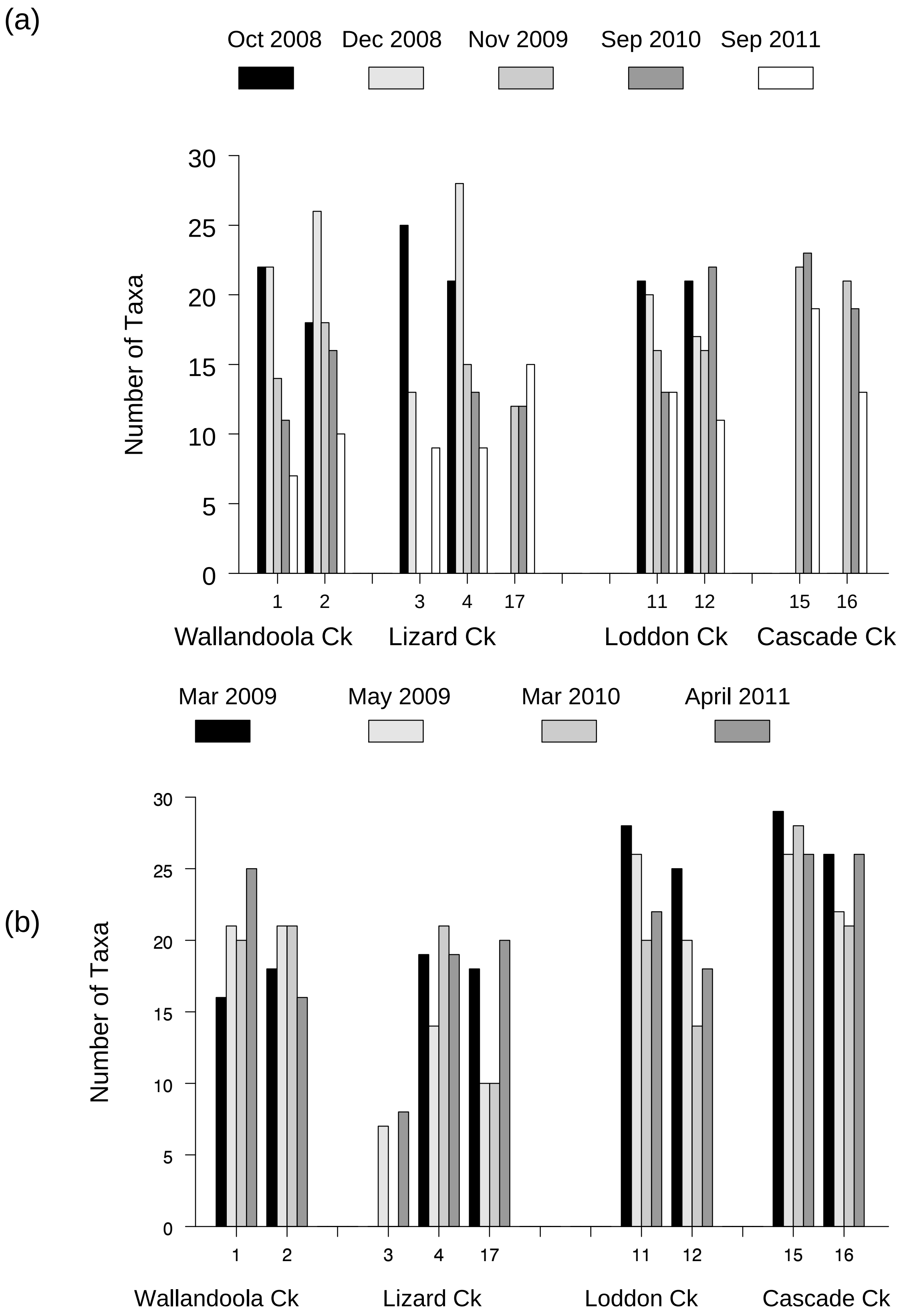


Figure 2: Map showing the reach of Cataract Creek (blue dotted line) in which targeted Macquarie Perch surveys were undertaken.



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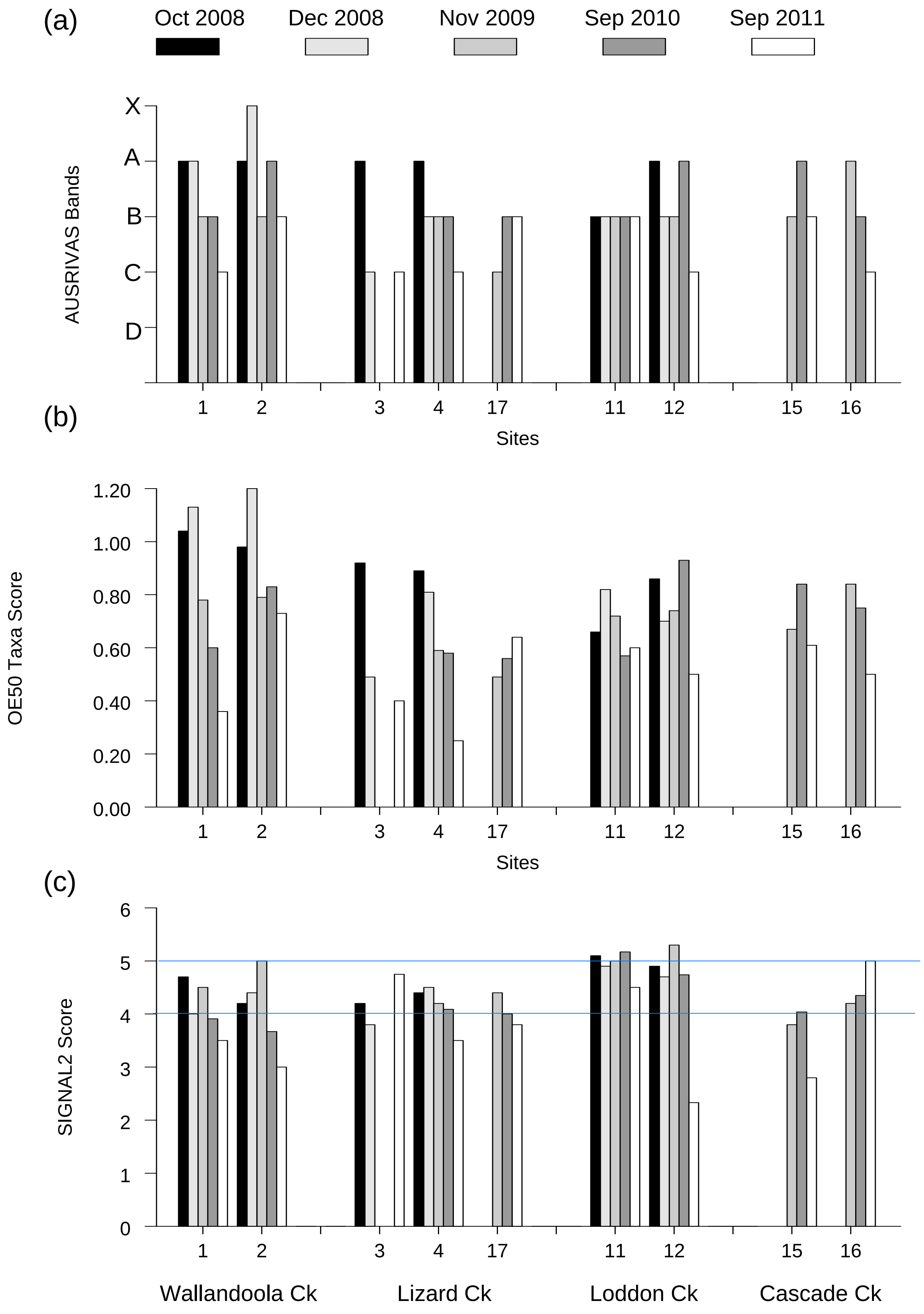


Figure 4: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.

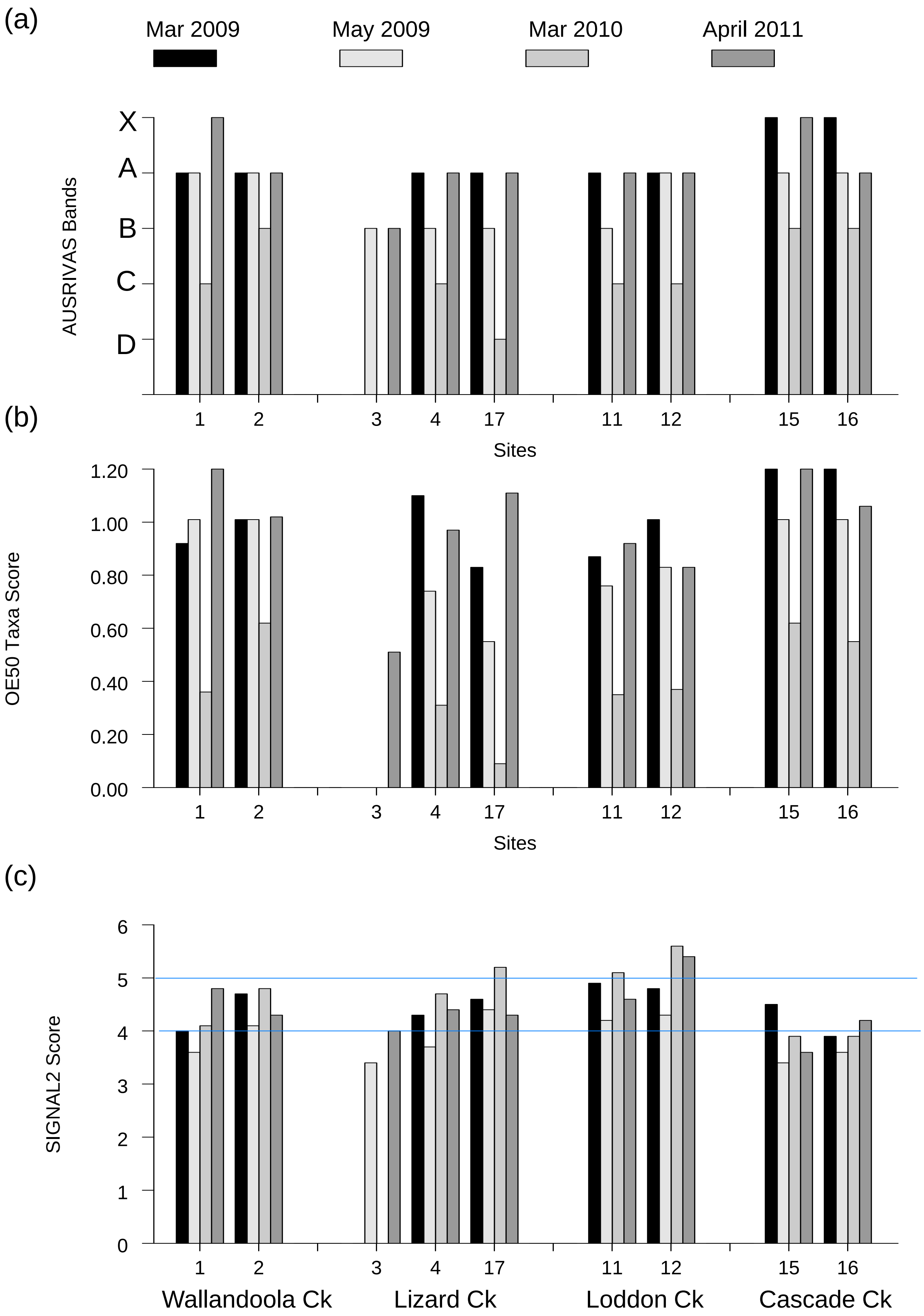


Figure 5: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.

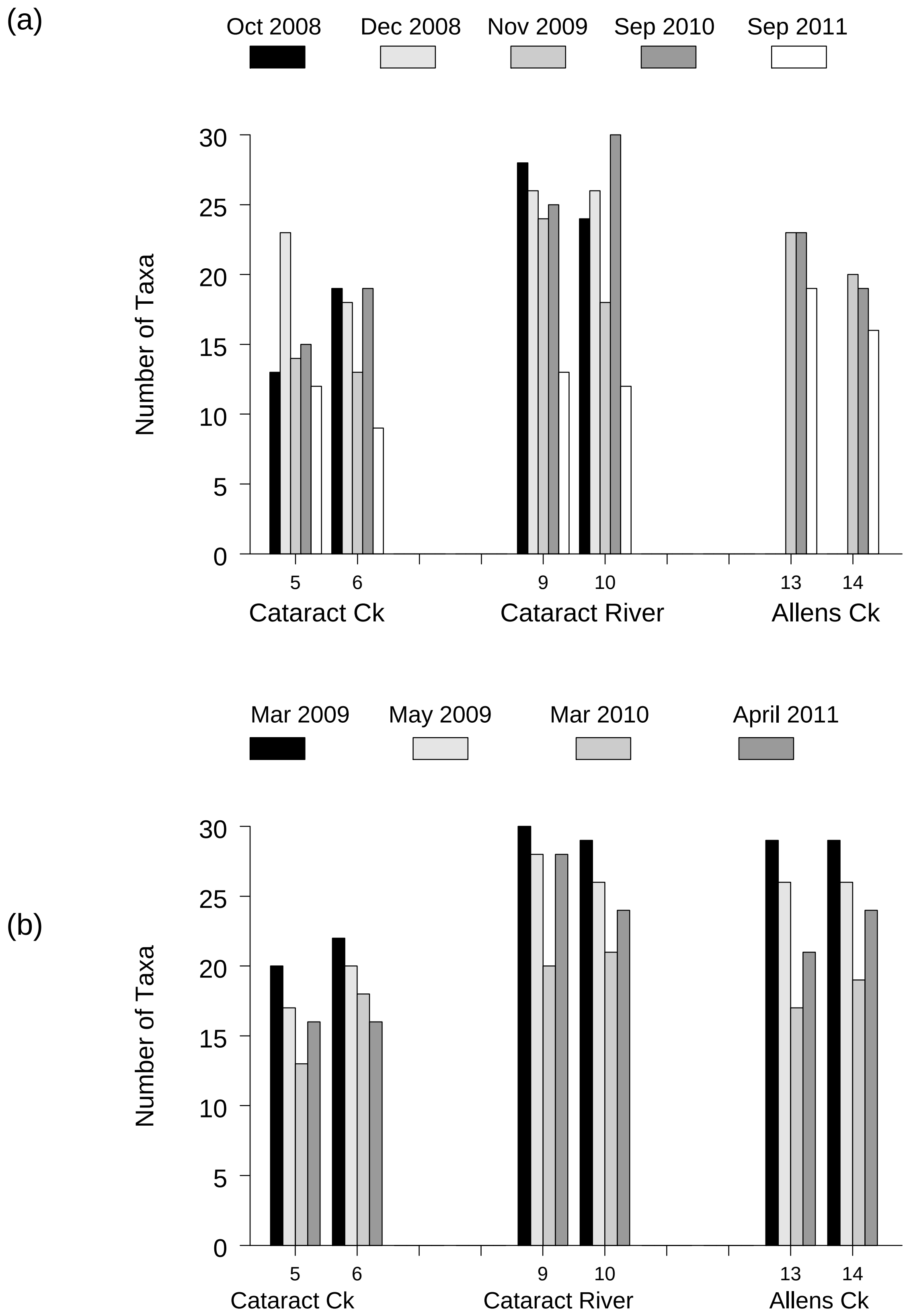


Figure 6: Wongawilli East Study Area – Number of taxa found in the AUSRIVAS samples collected at the monitoring sites in Cataract Creek, Cataract River and Allens Creek in (a) the spring 2008-2011 surveys and (b) autumn 2009-2011 surveys.

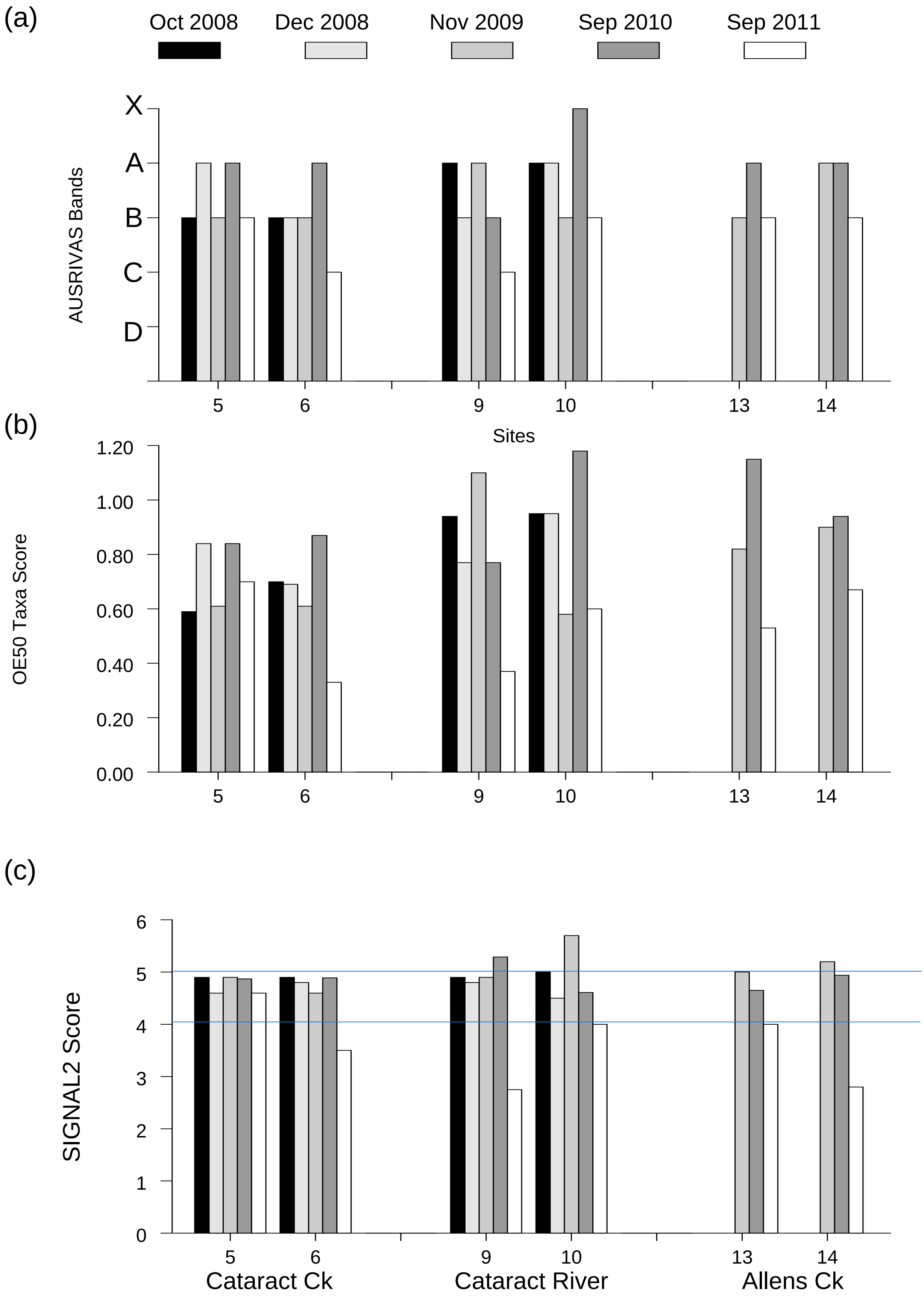


Figure 7: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.

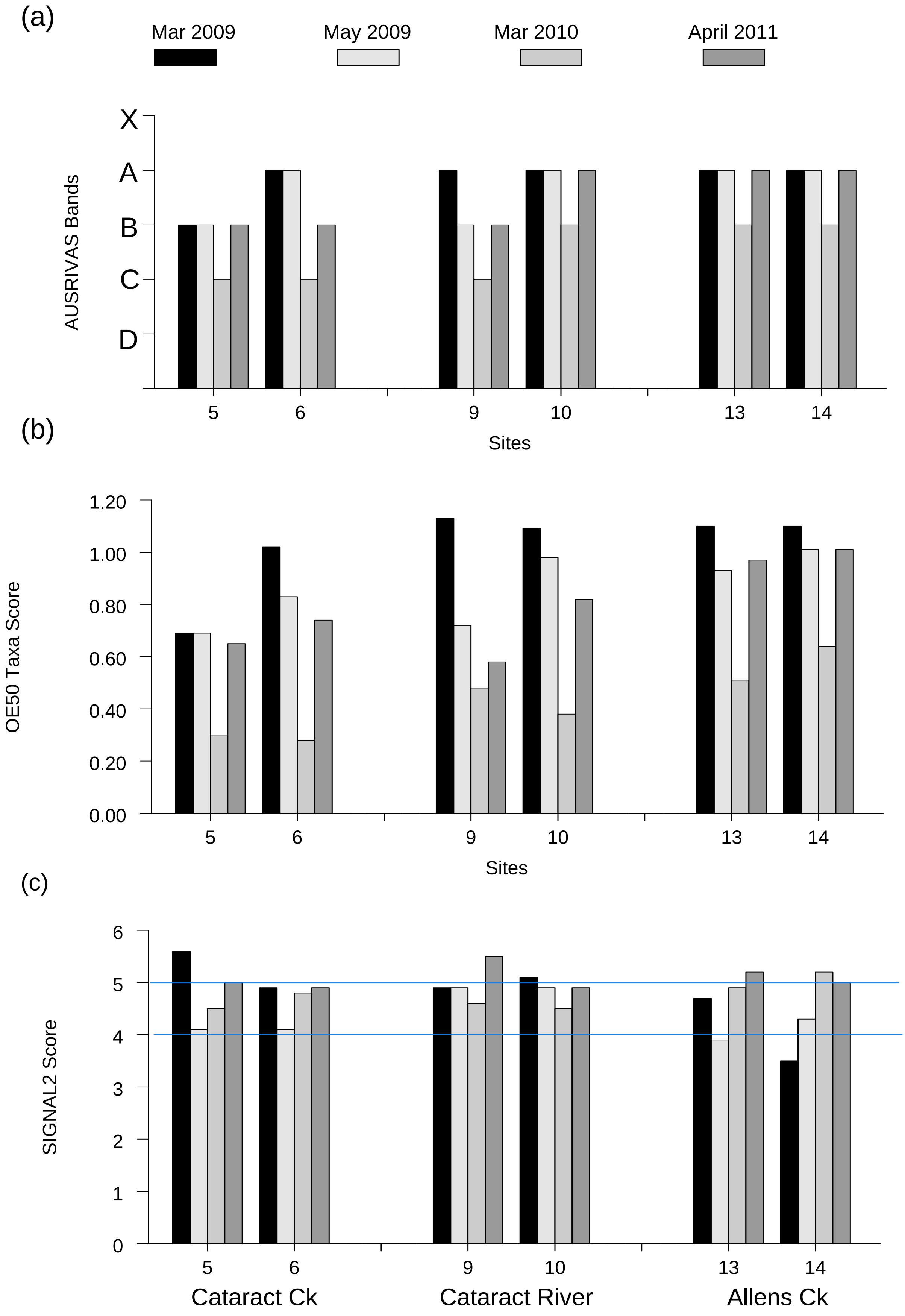


Figure 8: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.

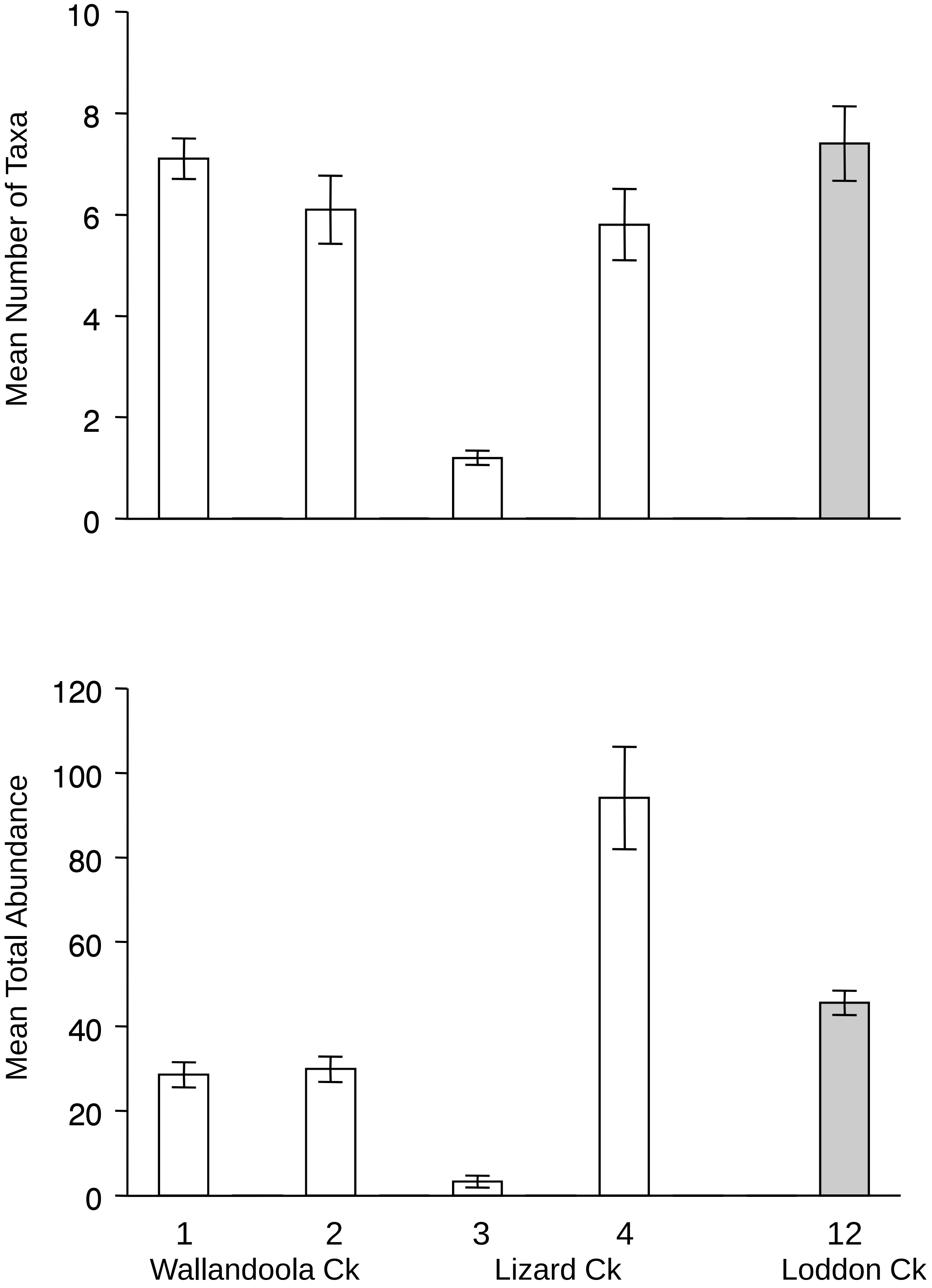


Figure 9: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from monitoring sites in the Wongawilli West Study Area in spring 2008.

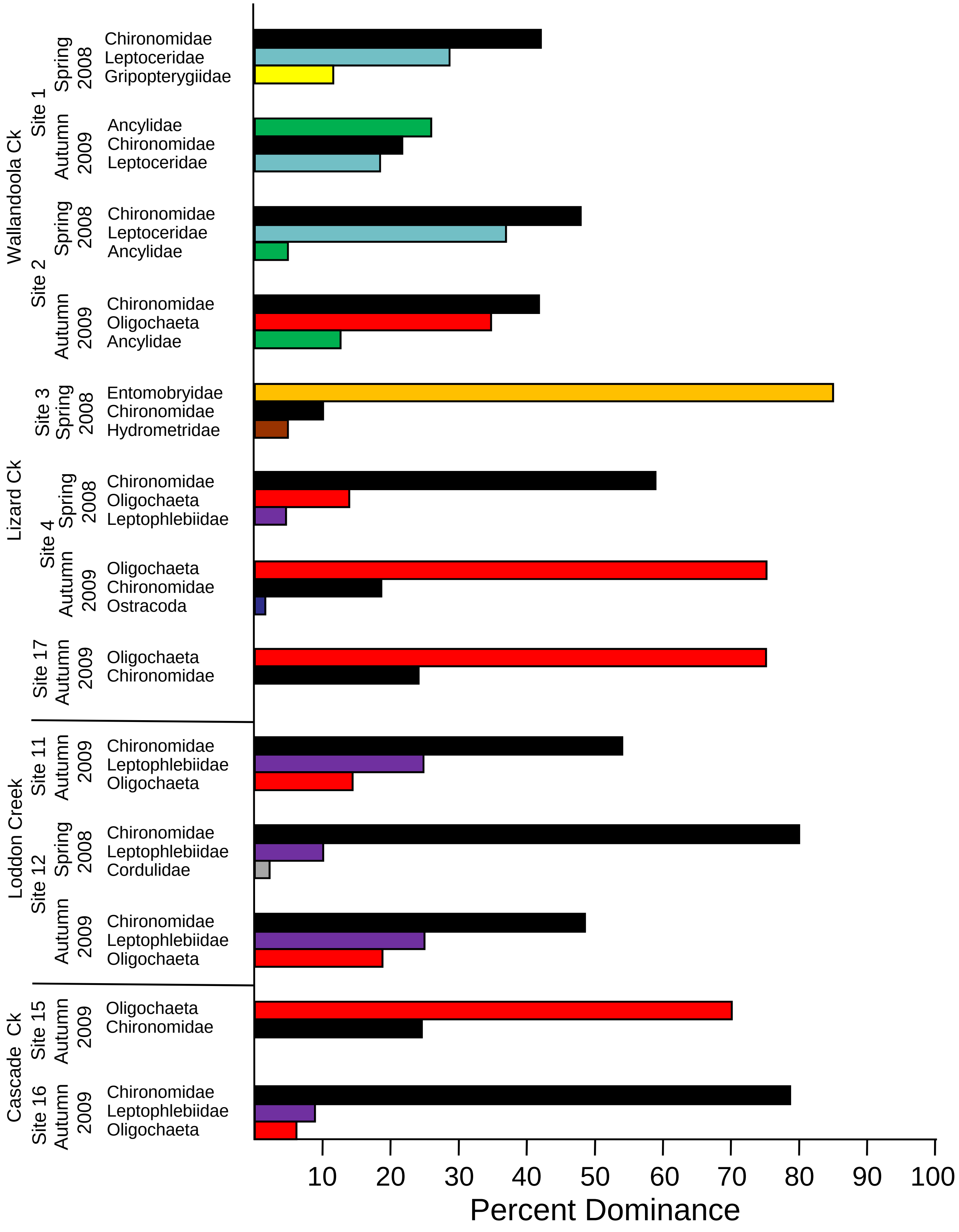


Figure 10: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in spring 2008 and autumn 2009.

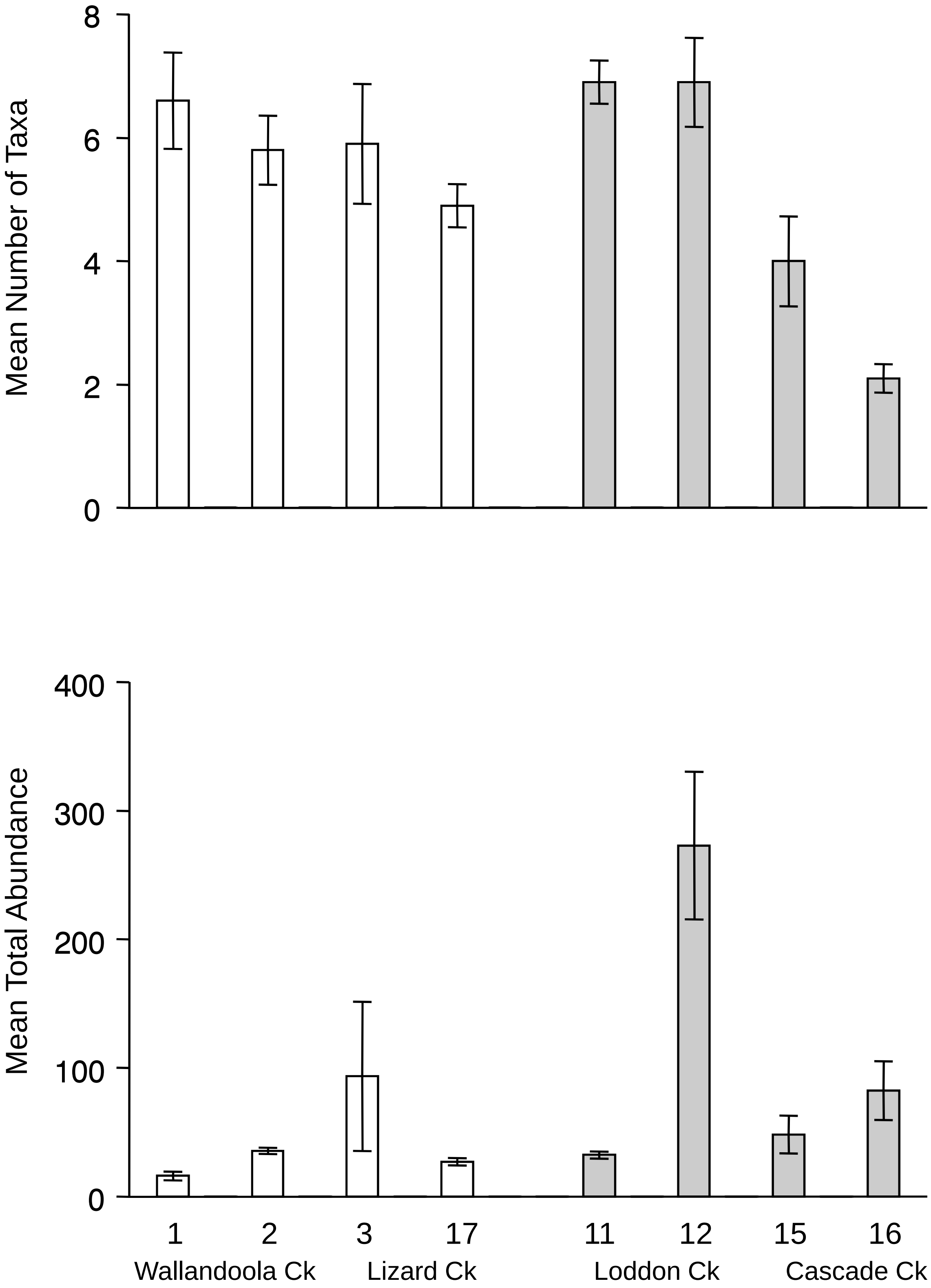


Figure 11: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in autumn 2009.

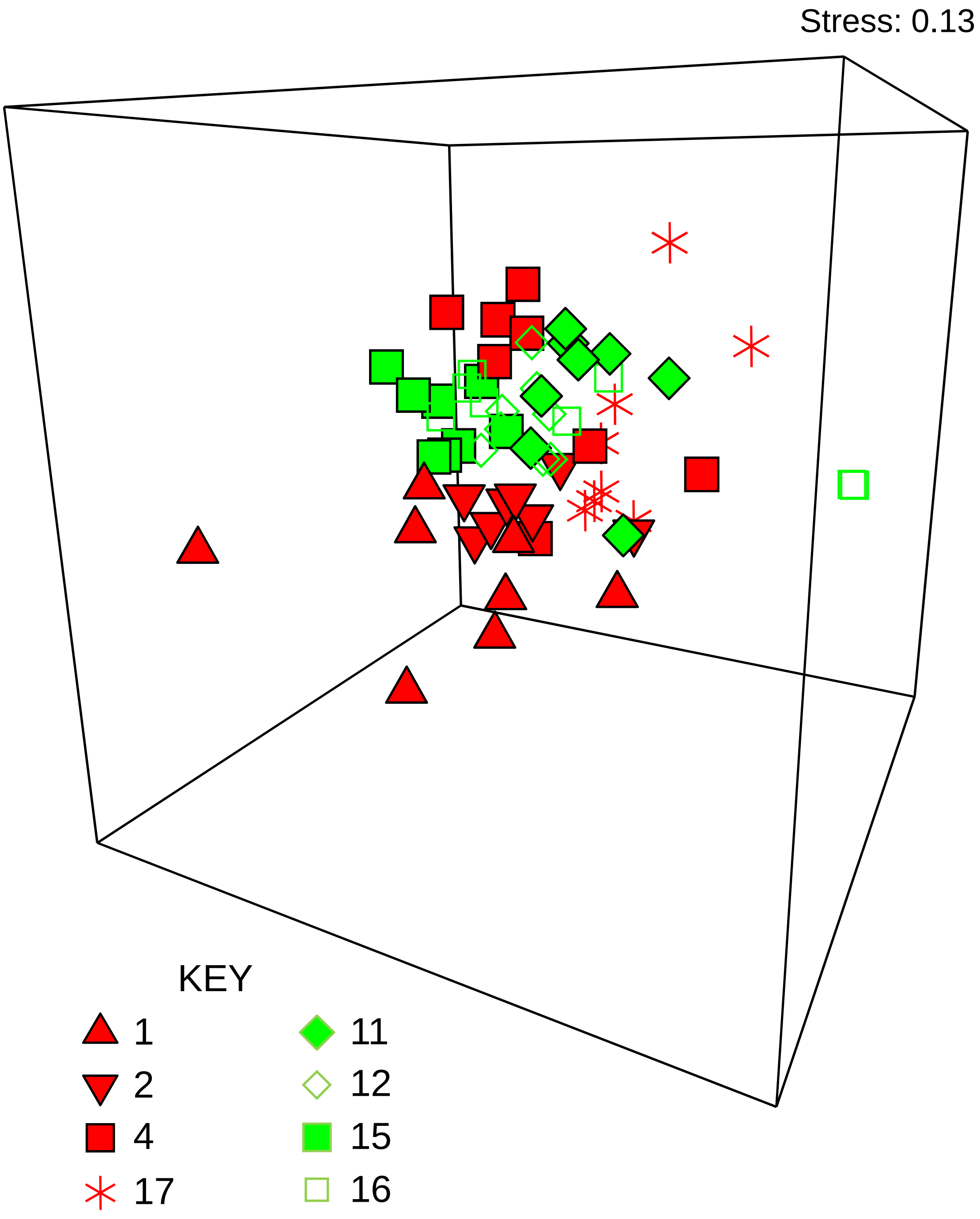


Figure 12: MDS of macroinvertebrates assemblages found on collectors at the study sites on Wallandoola Creek (1 & 2), Lizard Creek (4 & 17), Loddon Creek (11 and 12) and Cascade Creek (15 &16) in autumn 2009.

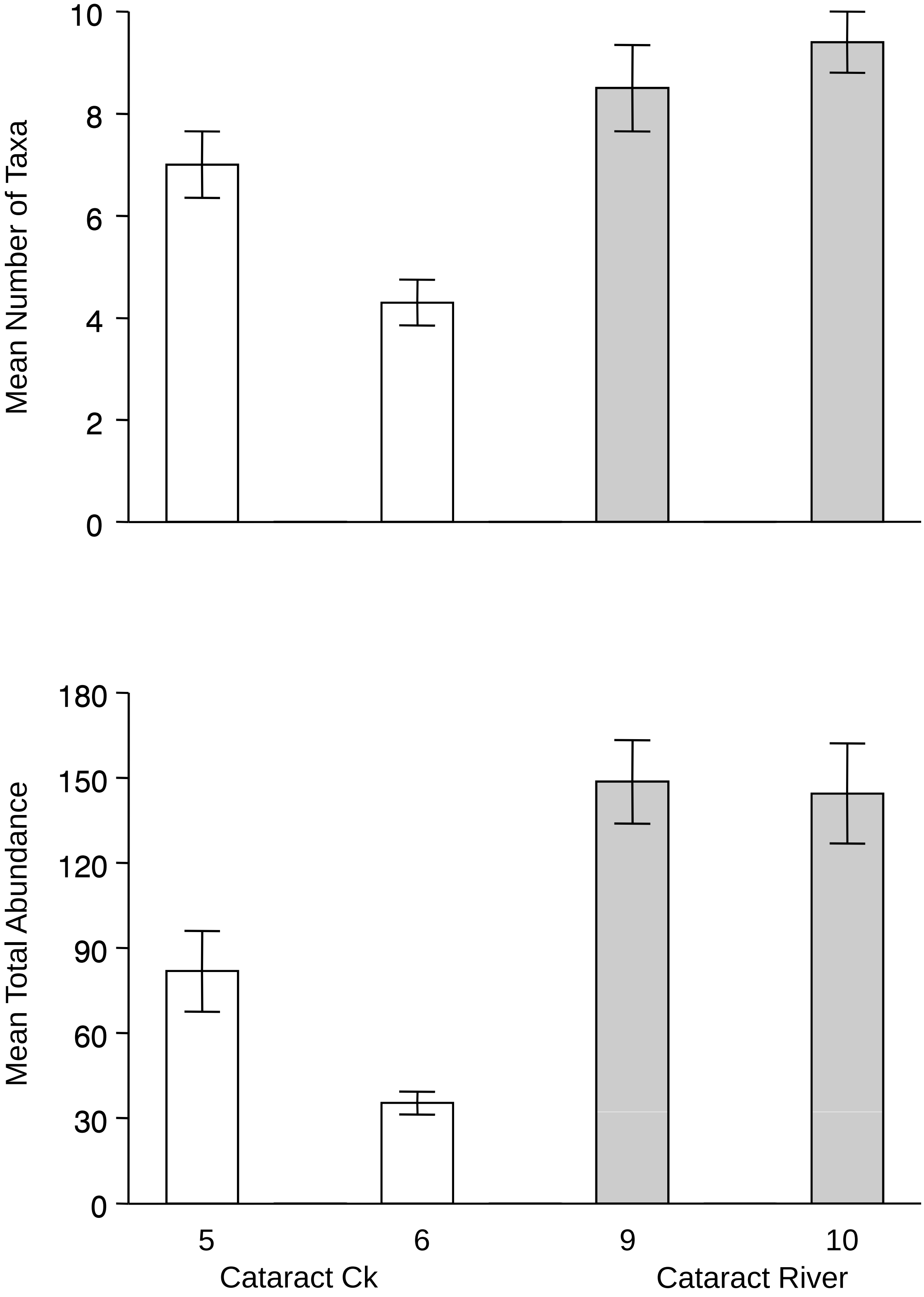
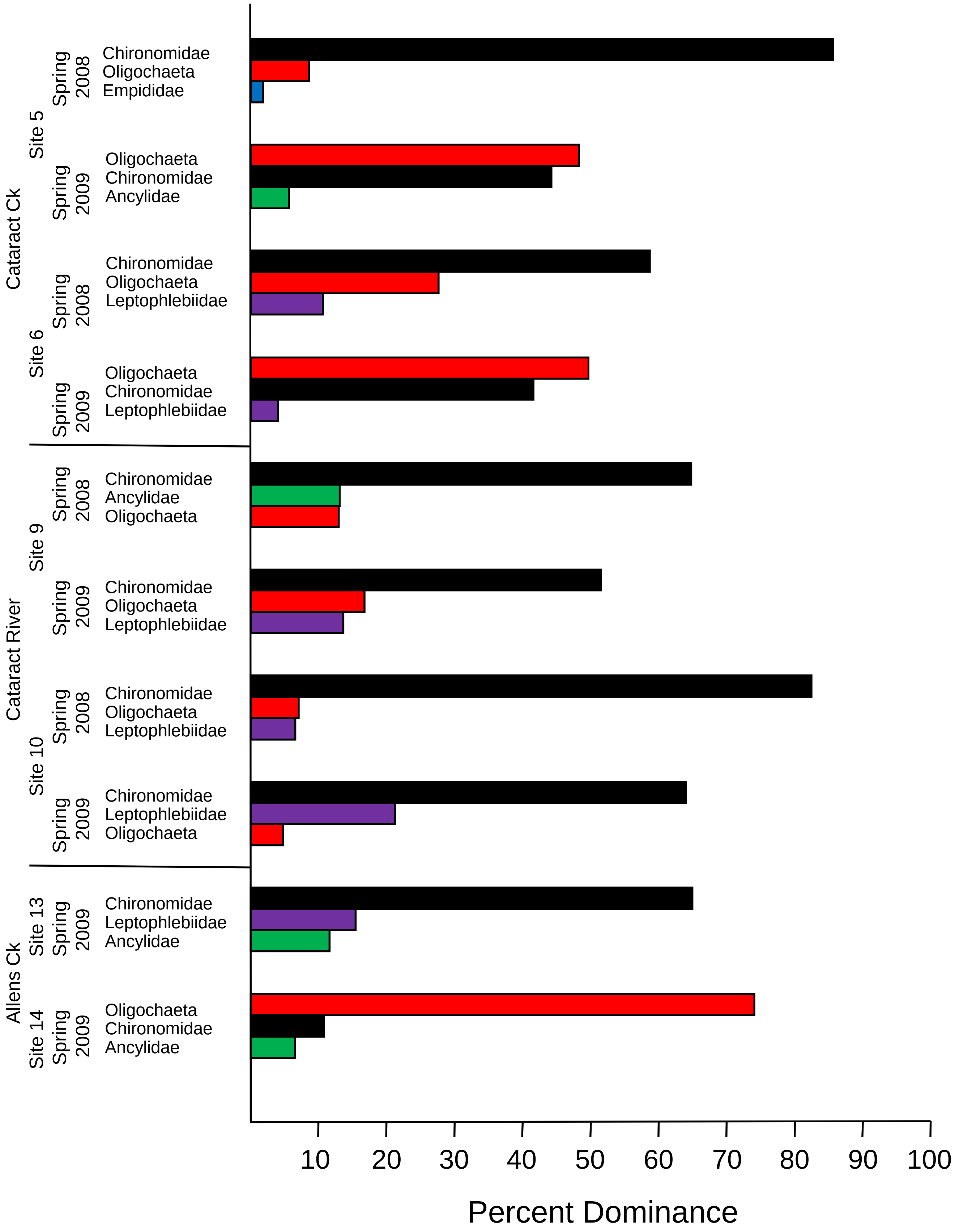


Figure 13: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008 (*n* = 8).



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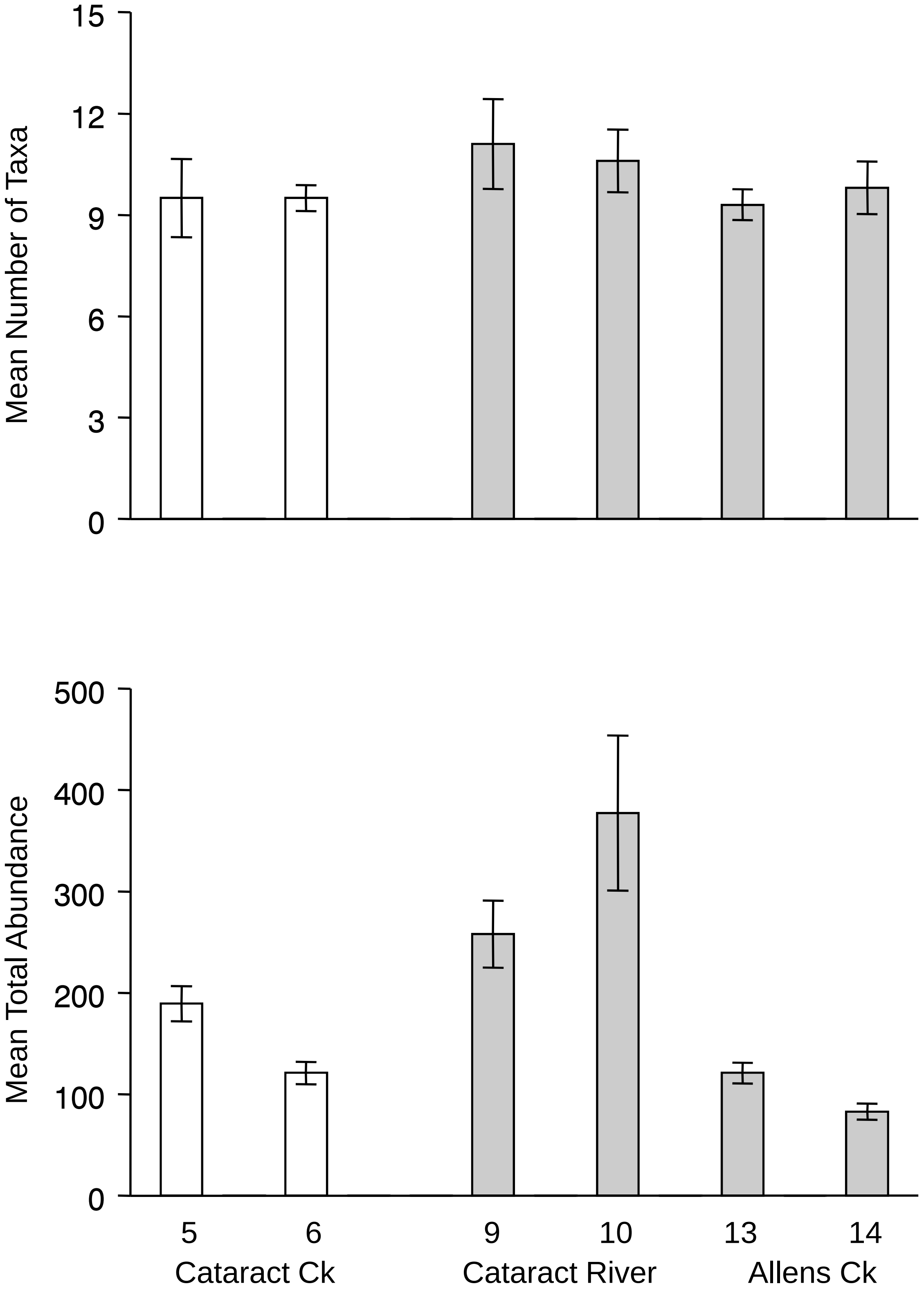
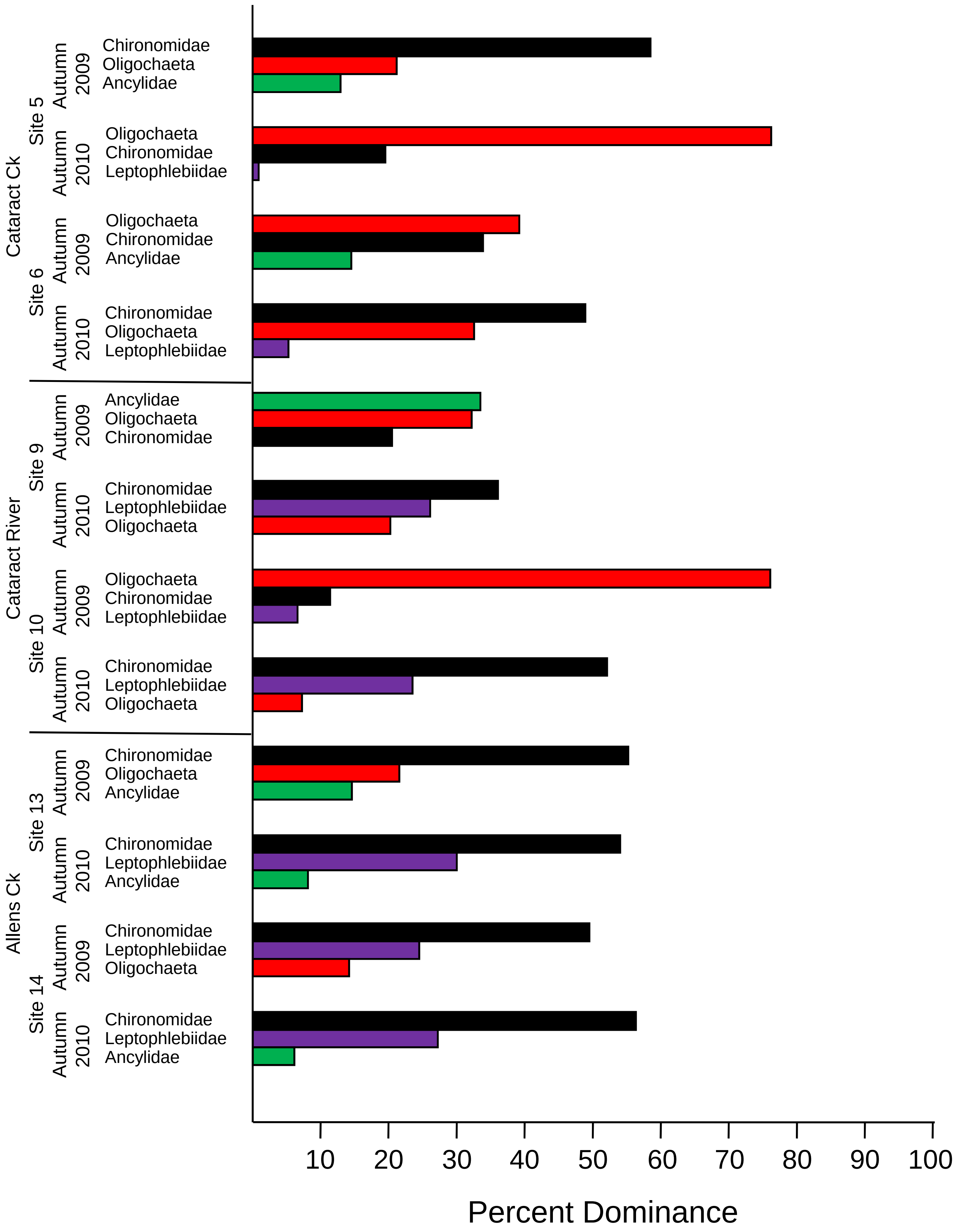


Figure 15: Mean (± S.E.) number of taxa and mean numbers of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009 (*n* = 8).



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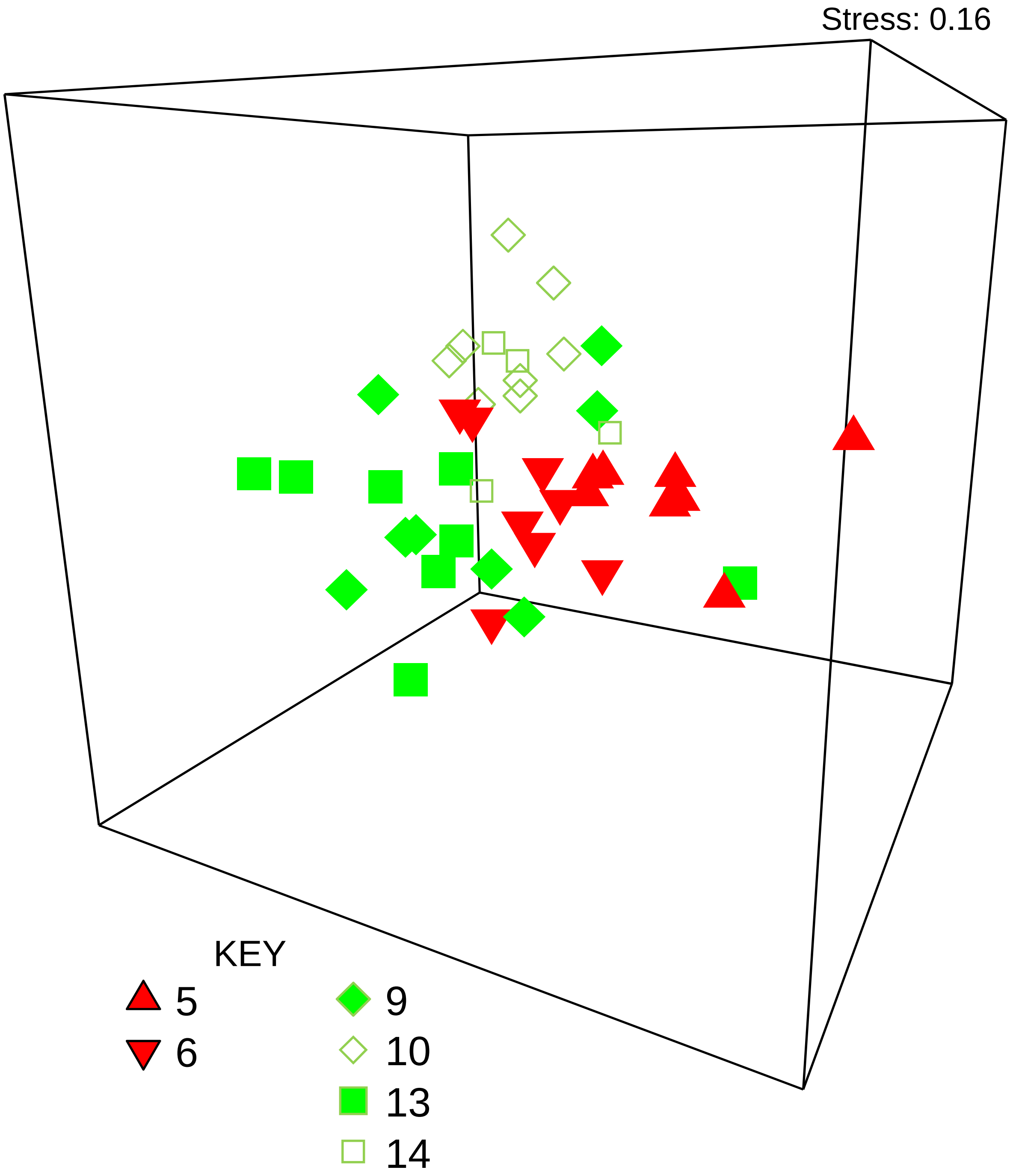

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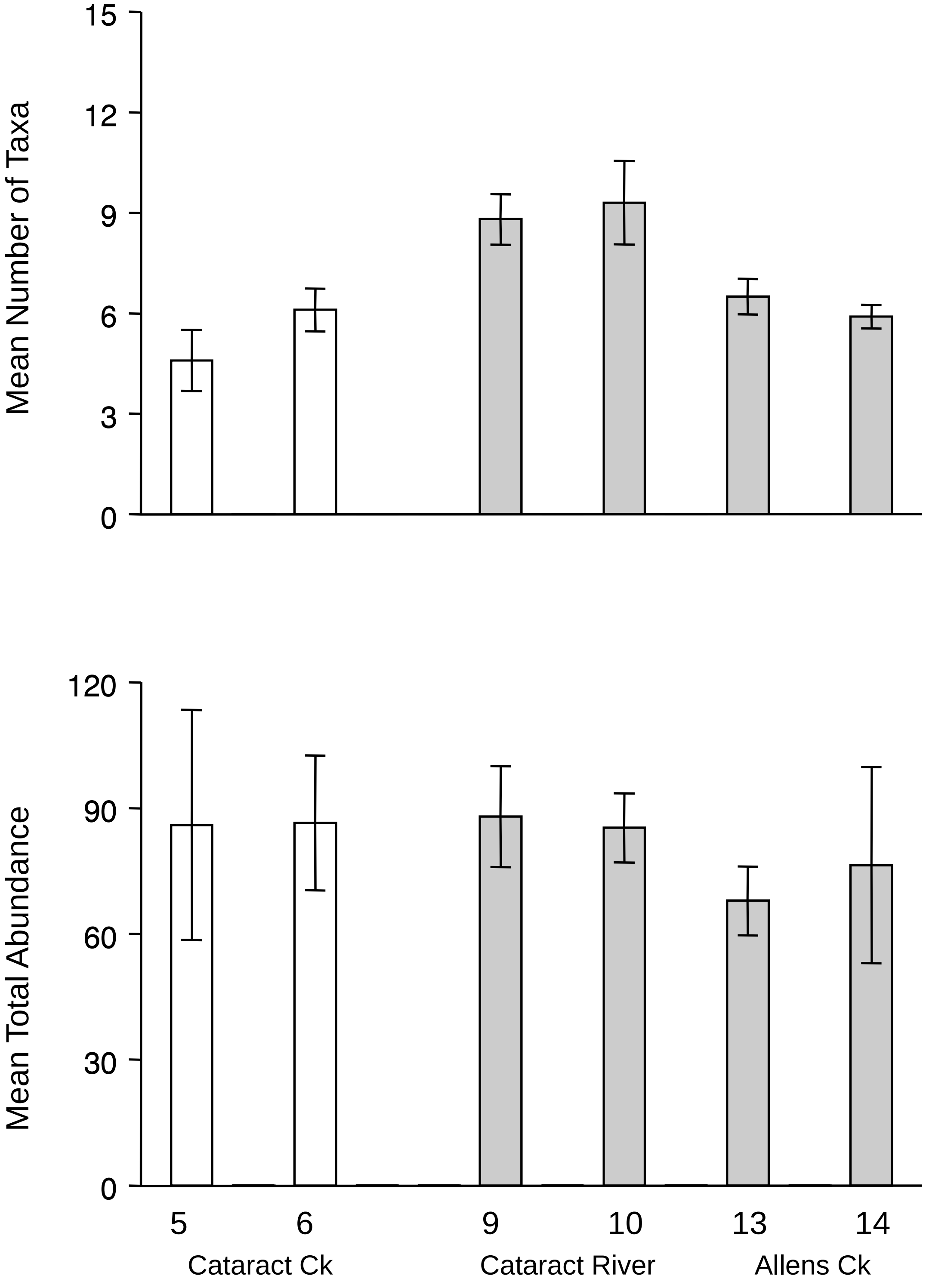

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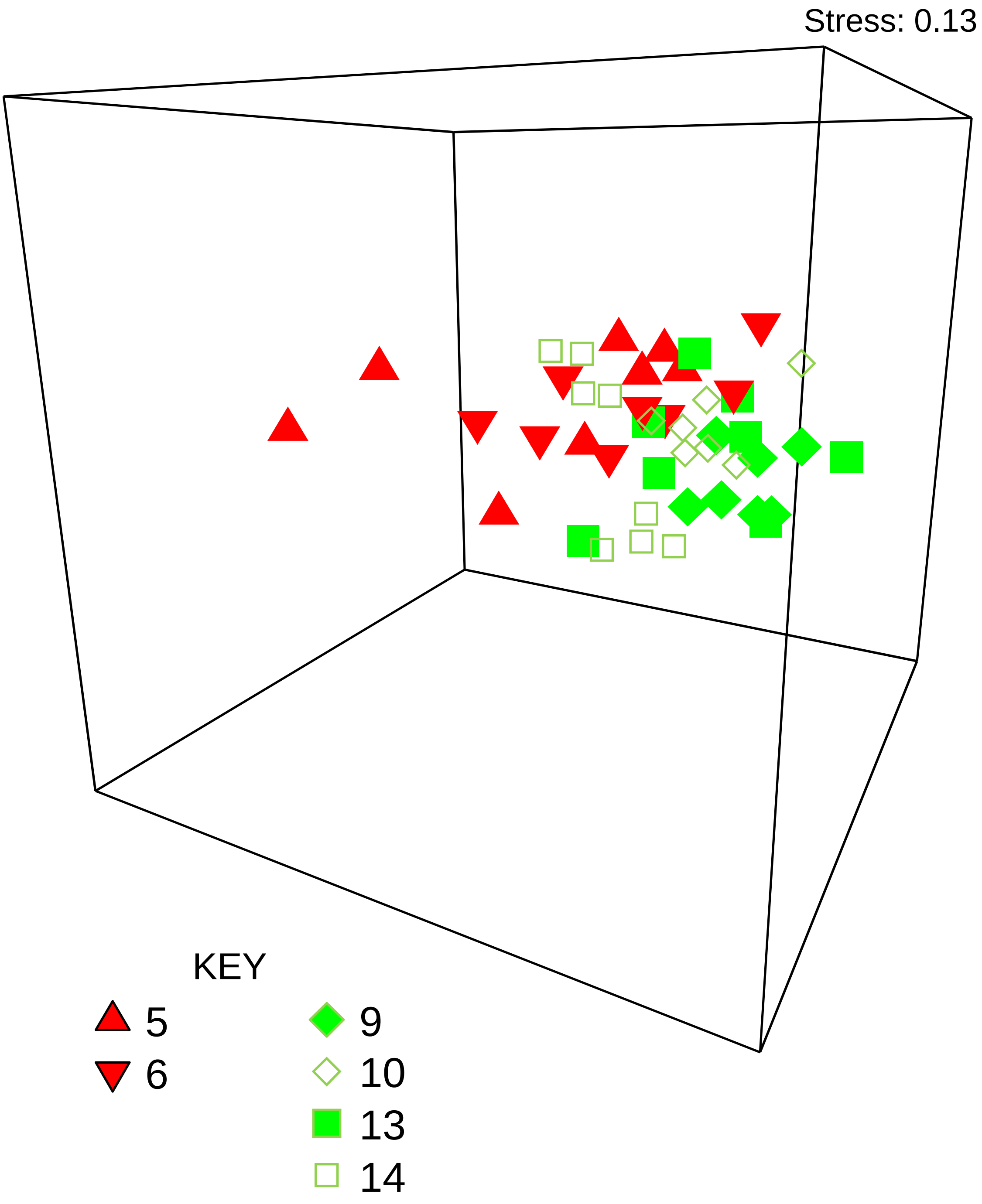


Figure 19: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in spring 2009.

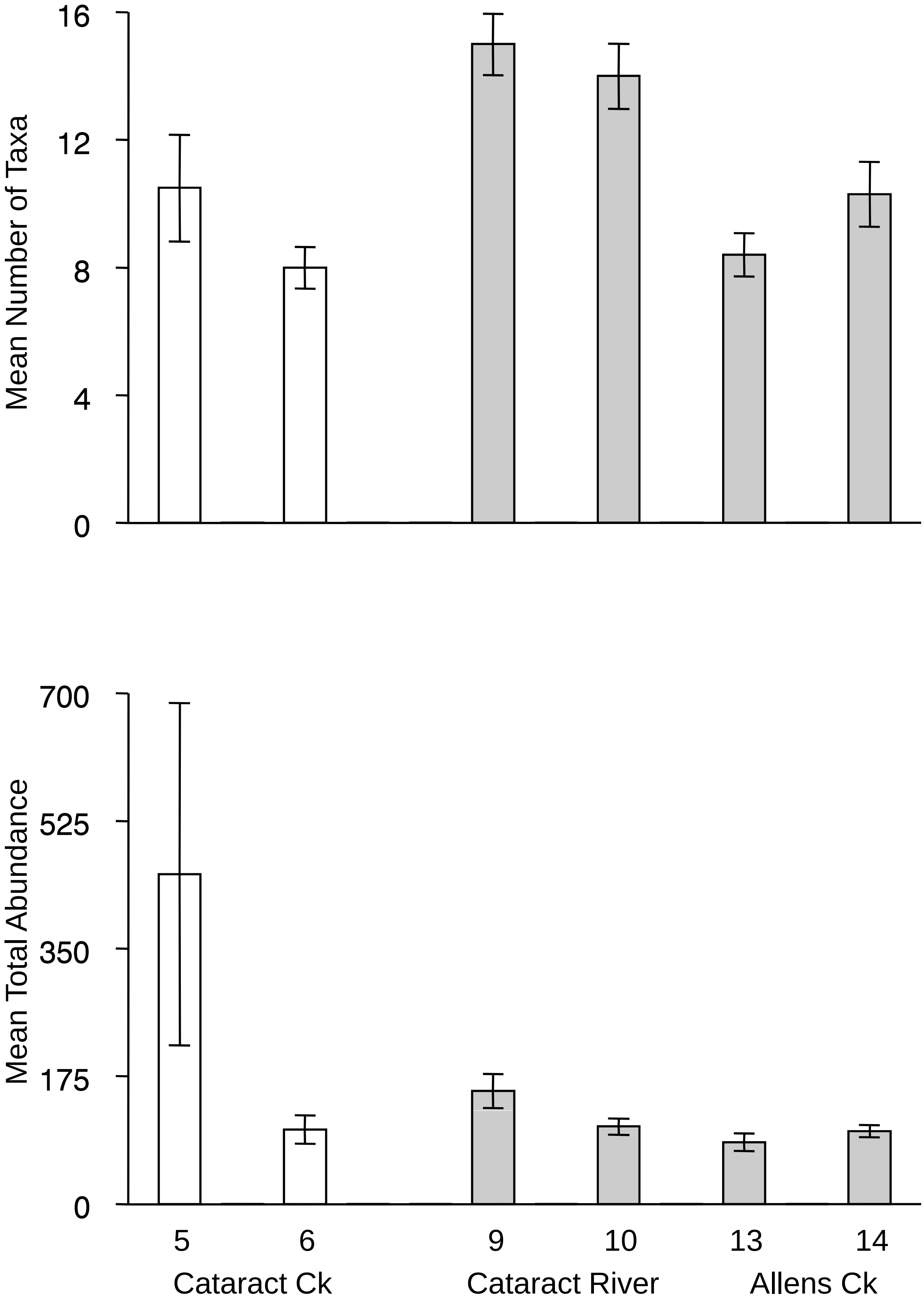


Figure 20: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2010.

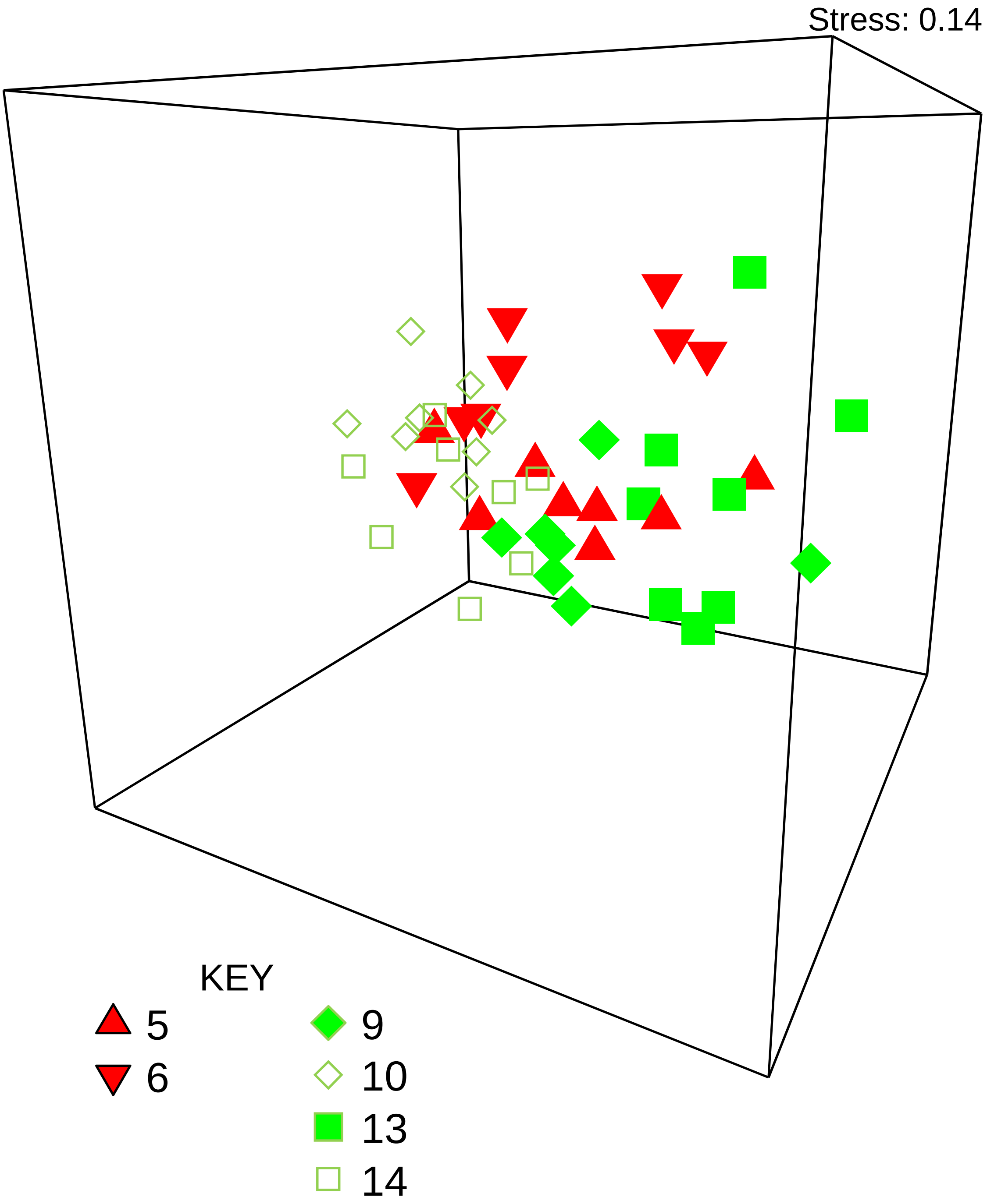


Figure 21: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2010.

10 Plates

Plate 1: Aquatic macroinvertebrate collecting techniques used in baseline survey: (a) AUSRIVAS macroinvertebrate edge sampling technique; (b) Macroinvertebrate artificial collector, viewed head-on; (c) Macroinvertebrate artificial collector, side view; (d) Four artificial collectors (see arrows) in pool edge habitat.

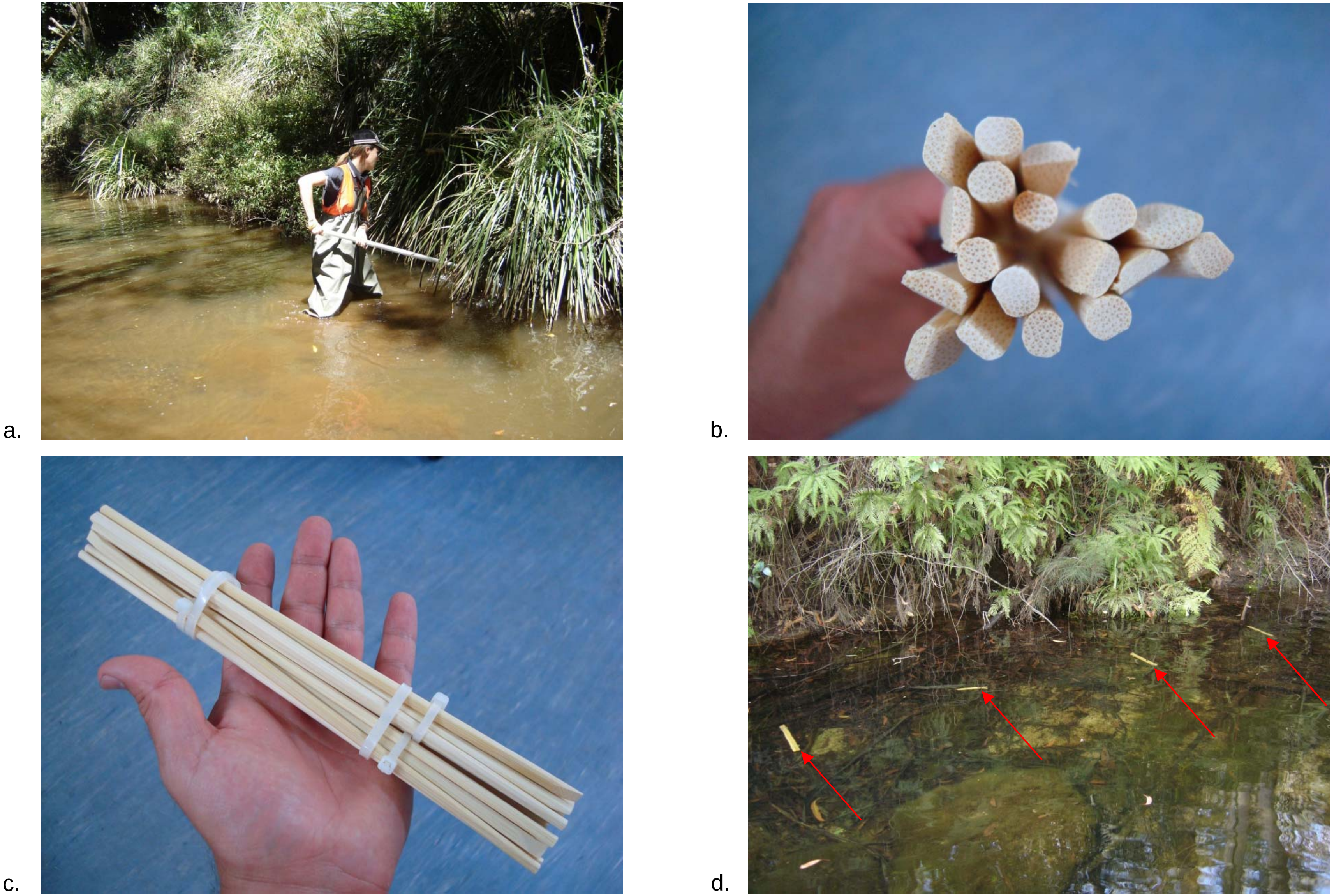
Plate 2: Macquarie Perch survey sites - (a) Confluence of Cataract River and Cataract Creek - the downstream limit of the Macquarie Perch survey; (b) Cataract Creek near the upstream limit of the full supply level; (c) Cataract Creek upstream of the full supply level.

Plate 3: Aquatic habitats in (a) Cascade Creek and (b) Lizard Creek surrounded by open sclerophyll woodland/heath and with a substratum consisting of primarily bedrock and soft sediment; (c) Allen Creek and (d) Cataract Creek surrounded by closed temperate rainforest and with a substratum consisting of a combination of bedrock, boulder, cobble, and pebble.

Plate 4: Downstream site within Wallandoola Creek, where (a) cracking and (b) iron floc was observed and potential impact site within Lizard Creek exhibiting (c) extensive cracking and (d) iron floc associated with previous mining activity.

Plate 5: Aquatic macroinvertebrates found at monitoring sites in NRE No 1 Mine Area.

Plate 6: Various species of fish caught during backpack electrofishing surveys of Cataract Creek.



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(a)

(b)

(c)

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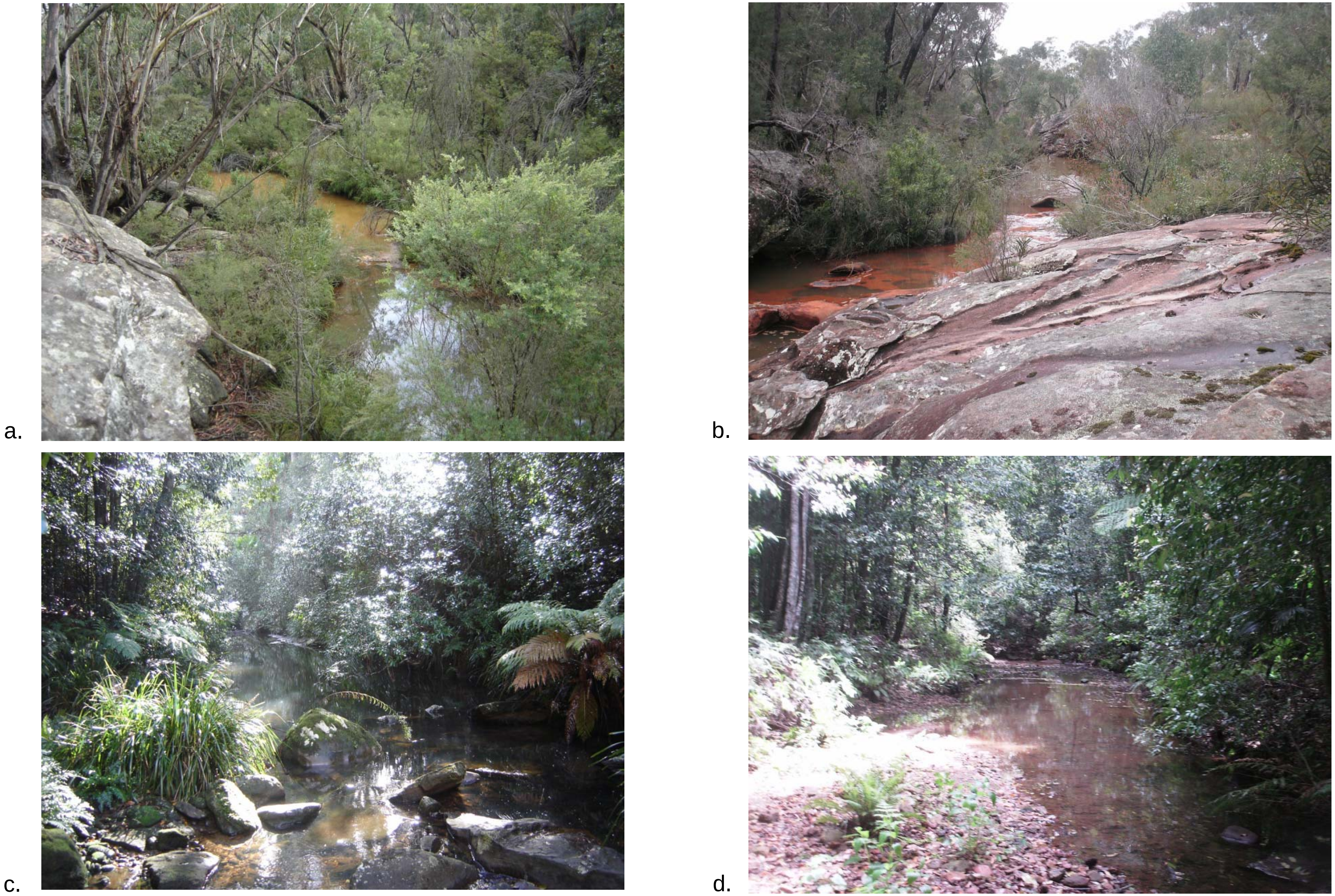

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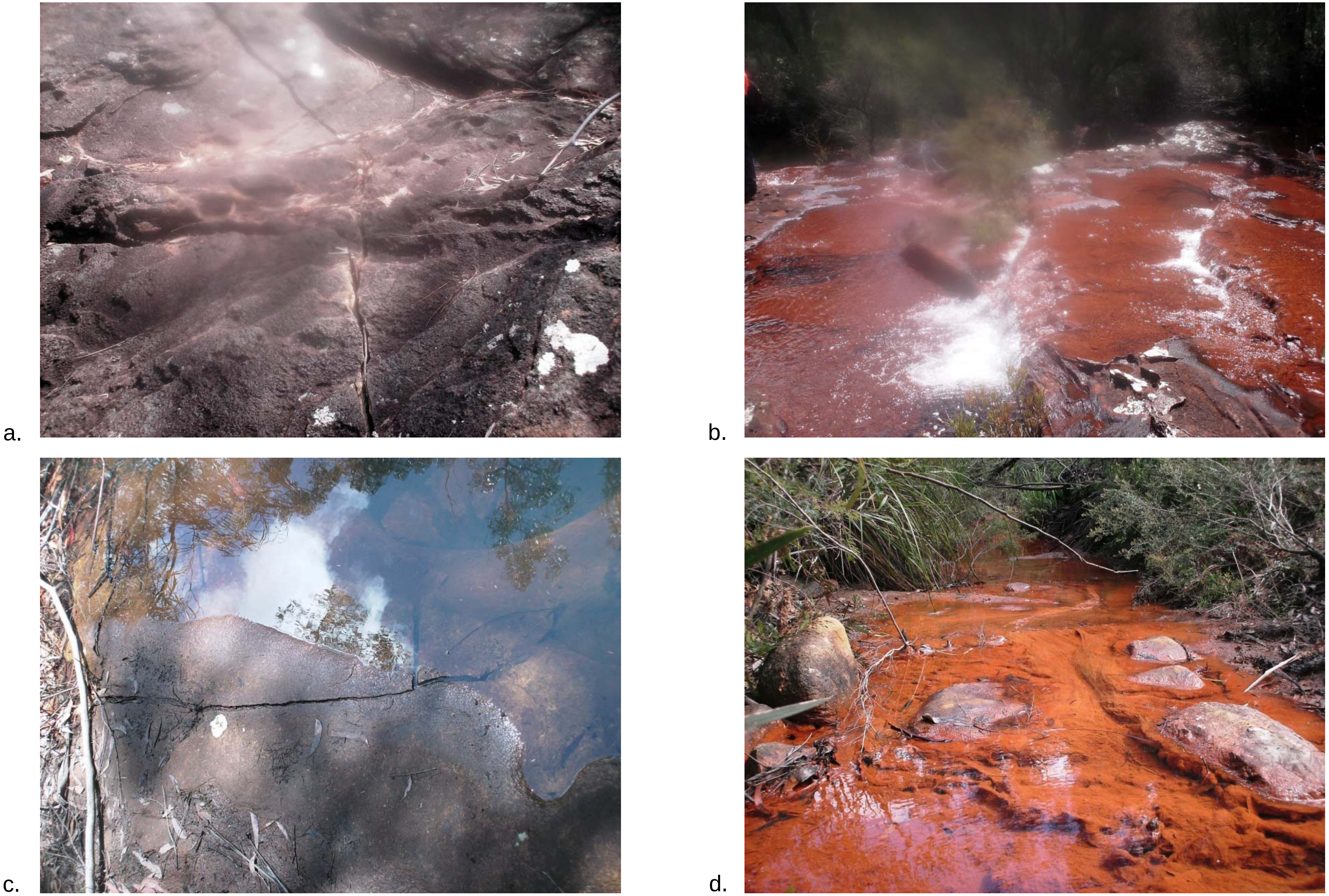
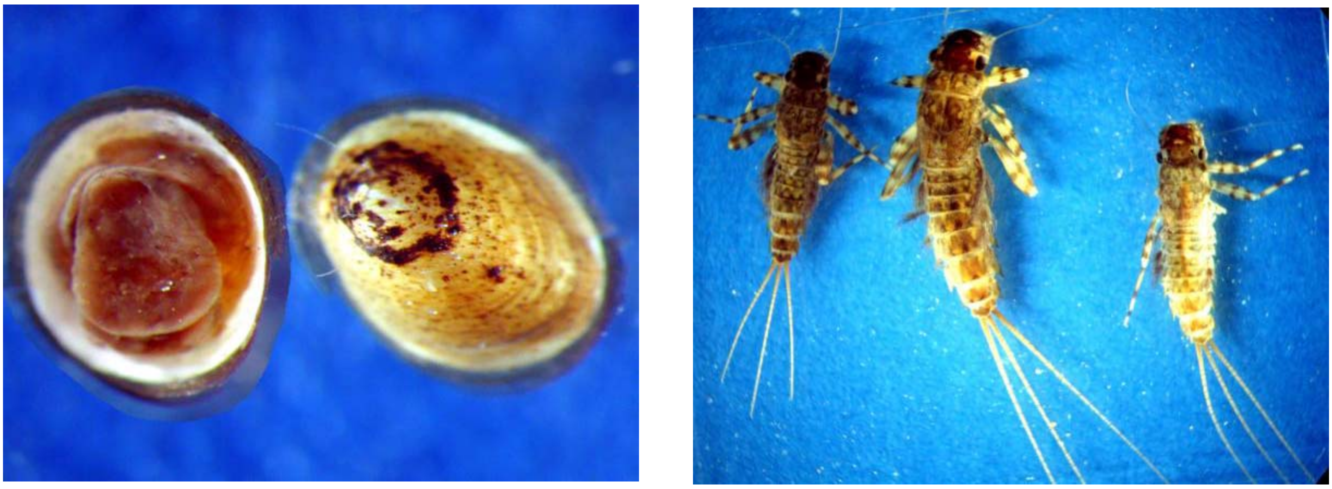


Plate 4: Downstream site within Wallandoola Creek, where (a) cracking and (b) iron floc was observed, and potential impact site within Lizard Creek exhibiting (c) extensive cracking and (d) iron floc associated with previous mining activity.

(a) Chironomidae (Non-biting midges)

(b) Oligochaeta (Segmented Worms)



(c) Ancylidae (Freshwater limpets

(d) Leptophlebiidae (Prong Gilled Mayflies)

(e): Entomobryidae (Springtails)

(f) Freshwater crayfish sampled in Cataract Creek

Plate 5: Aquatic macroinvertebrates found at monitoring sites in NRE No 1 Mine Area.

(a) Macquarie Perch

(b) Juvenile Cod

(c) Silver Perch

(d) Mountain Galaxid

(e) Goldfish

(f) Australian Smelt

·**Plate 6:** Various species of fish caught during backpack electrofishing surveys of Cataract Creek.

11 Appendices

Appendix 1: (a) Geographic coordinates of the NRE No. 1 Mine aquatic ecology monitoring sites and (b) survey dates.
Appendix 2: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011.
Appendix 3: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli East Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011.
Appendix 4: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.
Appendix 5: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.
Appendix 6: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli West Study Area in (a) spring 2008 and (b) autumn 2009. Species of fish and large crustaceans observed at the monitoring sites in the Wongawilli West and Wongawilli East Study Areas.
Appendix 7: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli East Study Area in (a) spring 2008; (b) autumn 2009; (c) spring 2009 and (d) autumn 2010.
Appendix 8: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli West in autumn 2009.
Appendix 9: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2009.
Appendix 10: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in spring 2009.
Appendix 11: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2010.
Appendix 12: Geographic location and caudal length of each specimen of Macquarie Perch sampled by backpack electrofishing in Cataract Creek in (a) 15 December 2009; (b) 8 January 2010; (c) 29 January 2010, and (d) 25 February 2010.
Appendix 13: Geographic location and caudal length of each specimen of Macquarie Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011.
Appendix 14: Mean (± S.E.) water quality parameters recorded in Cataract Creek downstream of the confluence with Cataract River and at Site 6 the most upstream site sampled during the targeted Macquarie Perch surveys undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.
Appendix 15: Geographic co-ordinates of each specimen of Freshwater Cod and Silver Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011.

Appendix 1: (a) Geographic coordinates of the NRE No. 1 Mine aquatic ecology monitoring sites and (b) survey dates. Datum: WGS84 Zone: 56H.

b. Geographic Coordinates

Study Area	Watercourse	Location	Site	Easting	Northing
Wongawilli West	Wallandoola Creek	Upstream	1	295553	6202172
	Wallandoola Creek	Downstream	2	294921	6202891
	Lizard Creek	Upstream	3	296328	6204716
	Lizard Creek	Downstream	4	295852	6205499
	Lizard Creek	Upstream	17	296143	6205240
	Loddon Creek	Upstream	11	308176	6204692
	Loddon Creek	Downstream	12	306327	6203985
	Cascade Creek	Upstream	15	290854	6207283
	Cascade Creek	Downstream	16	291065	6207641
Wongawilli East	Cataract Creek	Upstream	5	303466	6197246
	Cataract Creek	Downstream	6	302558	6197048
	Cataract River	Upstream	9	302290	6195634
	Cataract River	Downstream	10	302136	6195806
	Allen Creek	Upstream	13	305020	6203163
	Allen Creek	Downstream	14	304744	6203029
Targeted Macquarie Perch survey	Cataract Creek	Downstream		301376	6197498
		Upstream		302558	6197048

a. Sampling Dates

Season	Date	Cataract Dam Storage Level (m)
Spring 2008 -1st	28/10/2008-31/10/2008	
Spring 2008 -2nd	16-18/12/2008	
Autumn 2009 - 1st	24/03/2209-27/03/2009	
Autumn 2009 - 2nd	5/05/0009-08/05/2009	
Spring 2009	6/11/2009 and 10/11/2009 - 11/11/2009	
Spring 2009	15/12/2009 - 16/12/2009	
Autumn 2010	29/3/2010 - 31/3/2010	
Autumn 2010	11/5/2010 - 13/5/2010	
Spring 2010	27/9/2010 - 1/10/2010	
Autumn 2011	04/04/2011 - 08/4/2011	
Spring 2011	20/9/2011 - 23/9/2011	
Macquarie Perch - 1st	15/12/2009	-6.5
Macquarie Perch - 2nd	8/01/2010	-7.35
Macquarie Perch - 3rd	29/01/2010	-7.82
Macquarie Perch - 4th	25/02/2010	-6.10
Macquarie Perch - 5th	8/12/2010	-3.39
Macquarie Perch - 6th	7/01/2011	-3.53
Macquarie Perch - 7th	25/01/2011	-3.6
Macquarie Perch - 8th	21/02/2011	-4.1

Appendix 2: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011. Values outside available ANZECC guidelines for upland streams are highlighted.

A. October 2008

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (^{0}C)		14.5	0.1	17.2	0.2	15.9	0.0	15.9	0.1	NS*		14.8	0.0	14.7	0.0	NS		NS	
Conductivity (µS/cm)		170.5	25.5	232.5	2.5	75.0	5.0	105.0	0.0			136.0	8.0	133.5	5.5				
pH		6.6	0.0	6.5	0.0	6.8	0.0	6.7	0.0			5.9	0.0	6.2	0.0				
ORP (mV)		490.0	1.0	414.0	3.0	411.5	2.5	278.0	7.0			509.0	0.0	489.0	0.0				
DO (mg/L)		8.1	0.0	8.3	0.1	6.6	0.1	7.5	0.0			8.2	0.0	8.7	0.0				
DO (%sat'n)		78.7	0.9	85.4	0.1	66.5	0.9	76.3	0.3			80.3	0.5	85.3	0.1				
Turbidity (ntu)		4.0	0.4	4.3	0.1	3.0	0.0	6.7	0.1			7.1	0.3	5.1	0.2				

B. December 2008

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (^{0}C)		15.6	0.0	18.0	0.1	15.9	0.1	15.9	0.0	NS		18.5	0.0	19.7	0.0	NS		NS	
Conductivity (µS/cm)		FP[#]		FP		FP		FP		NS		FP		FP		NS		NS	
pH		6.6	0.0	6.5	0.1	6.4	0.2	6.8	0.0			5.9	0.1	6.2	0.1				
ORP (mV)		356.5	52.5	443.5	0.5	504.5	1.5	417.5	18.5			561.0	4.0	526.0	5.0				
DO (mg/L)		7.4	0.0	7.3	0.0	2.1	0.1	4.9	0.1			7.0	0.0	7.5	0.0				
DO (%sat'n)		75.1	0.5	73.9	2.2	22.2	1.1	49.3	0.5			74.6	0.9	82.1	0.9				
Turbidity (ntu)		1.7	0.6	2.3	0.1	1.2	0.1	4.8	0.2			1.3	0.1	1.2	0.1				

C. March 2009

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (^{0}C)		25.7	0.0	27.8	0.0	DRY		18.1	0.1	17.1	0.1	22.3	0.0	25.2	0.1	19.8	0.0	19.2	0.0
Conductivity (µS/cm)		57.0	4.0	109.5	7.5			199.5	4.5	245.5	9.5	8.0	0.0	0.0	0.0	685.0	0.0	1133.5	4.5
pH		FP		FP				FP		FP		6.0	0.0	5.7	0.0	FP		FP	
ORP (mV)		547.0	4.0	519.0	0.0			363.0	9.0	248.0	45.0	495.0	1.0	532.0	3.0	537.0	1.0	451.5	3.5
DO (mg/L)		6.6	0.0	7.5	0.0			1.3	0.7	0.8	0.2	7.0	0.0	7.2	0.1	3.1	0.1	2.4	0.1
DO (%sat'n)		80.6	0.0	95.1	0.0			14.1	7.5	7.8	1.2	80.2	0.1	86.9	0.1	33.6	0.6	25.4	0.1
Turbidity (ntu)		FP		FP				32.0	0.3	36.6	14.3	FP		FP		6.5	0.1	8.5	0.2

continued

Appendix 2: Continued.

D. May 2009

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		12.1	0.0	14.2	0.0	14.4	0.0	14.6	0.0	14.7	0.0	12.9	0.0	13.6	0.0	12.3	0.0	12.5	0.0
Conductivity (µS/cm)		100.0	0.0	124.0	0.0	142.0	0.0	155.5	4.5	141.0	0.0	88.0	0.0	97.0	0.0	674.0	5.0	989.0	5.0
pH		5.8	0.0	6.5	0.0	6.3	0.0	6.8	0.0	6.7	0.0	5.9	0.0	5.8	0.0	6.1	0.0	5.6	0.0
ORP (mV)		324.5	2.5	327.5	1.5	373.5	1.5	472.0	3.0	459.5	5.5	376.5	1.5	566.0	4.0	262.0	0.0	283.0	3.0
DO (mg/L)		14.7	0.3	17.2	0.0	6.8	0.1	10.3	0.1	13.1	0.4	15.0	0.1	15.3	0.1	9.4	0.1	8.6	0.1
DO (%sat'n)		137.3	2.8	165.9	0.7	67.0	0.5	100.4	0.0	129.0	4.0	142.1	0.5	159.7	14.7	88.3	1.2	80.8	1.3
Turbidity (ntu)		0.5	0.2	FP	0.0	7.5	0.4	3.0	0.4	FP	0.1	FP	0.0	FP	0.1	2.0	0.0	15.5	0.3

E. November 2009

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		15.7	0.0	20.8	0.0			16.3	0.1	14.7	0.0	18.5	0.0	18.6	0.0	20.1	0.2	26.3	0.1
Conductivity (µS/cm)		117.0	0.0	142.5	0.5			194.5	0.5	208.0	2.0	86.5	0.5	87.0	0.0	641.5	1.5	1007.0	2.0
pH		5.8	0.0	6.3	0.0			6.4	0.0	6.7	0.0	5.6	0.0	5.5	0.0	5.8	0.0	5.3	0.0
ORP (mV)		191.5	1.5	184.0	1.0			146.0	4.0	95.0	2.0	227.0	1.0	240.5	0.5	192.5	4.5	143.0	0.0
DO (mg/L)		9.1	0.2	7.4	0.0			2.7	0.0	2.6	0.1	8.6	0.0	7.3	0.2	6.9	0.2	2.5	0.0
DO (%sat'n)		92.0	1.6	82.8	0.7			27.7	0.2	24.9	0.4	90.2	0.9	84.3	1.8	76.4	2.0	30.4	0.8
Turbidity (ntu)		7.8	0.4	0.7	0.0			23.4	0.1	181.7	0.2	1.8	0.3	1.8	0.5	0.4	0.1	1.3	0.1

F. March 2010

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		19.7	0.0	20.8	0.0			18.5	0.0	17.7	0.0	21.4	0.0	21.7	0.0	20.6	0.0	19.6	0.0
Conductivity (µS/cm)		303.0	2.0	223.5	1.5			191.0	0.0	215.5	0.5	104.0	0.0	97.0	2.0	805.0	0.0	1096.5	0.5
pH		5.8	0.0	6.5	0.0			6.4	0.0	6.5	0.0	5.7	0.0	5.5	0.0	6.1	0.0	5.7	0.0
ORP (mV)		83.0	5.0	201.0	1.0			406.0	0.0	265.0	3.0	463.5	0.5	460.5	2.5	413.5	1.5	292.5	2.5
DO (mg/L)		4.9	0.0	6.6	0.0			1.2	0.0	1.9	0.0	7.2	0.0	7.2	0.0	4.8	0.0	0.3	0.0
DO (%sat'n)		53.2	0.4	73.9	0.1			13.1	0.1	20.0	0.1	81.7	0.1	82.0	0.1	53.8	0.1	2.9	0.1
Turbidity (ntu)		15.1	0.5	1.4	0.1			40.7	0.5	90.4	1.8	2.2	0.0	0.5	0.1	16.3	0.2	55.1	1.2

continued

Appendix 2: Continued.

G. September 201

WQ Paramete	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (ºC)		12.1	0.0	15.6	0.1	13.1	0.0	14.2	0.0	13.4	0.0	13.6	0.0	16.7	0.0	14.0	0.0	13.9	0.0
Conductivity (µS/cm)		101.5	0.5	98.5	22.5	2.0	2.0	0.0	0.0	132.0	9.0	89.0	0.0	95.0	8.0	448.5	3.5	808.5	2.5
pH		5.8	0.0	5.9	0.0	6.1	0.0	6.3	0.0	6.3	0.0	5.6	0.0	5.6	0.0	5.8	0.0	5.3	0.0
ORP (mV)		456.0	0.0	458.5	3.5	414.5	4.5	419.5	2.5	393.5	1.5	439.0	1.0	448.5	0.5	448.0	0.0	435.5	2.5
DO (mg/L)		6.2	0.1	4.7	0.1	5.9	0.1	6.1	0.3	3.7	0.0	12.9	0.1	9.6	0.3	4.8	0.4	6.2	0.1
DO (%sat'n)		56.5	0.5	46.9	0.1	55.8	0.3	60.0	3.1	32.1	0.7	123.5	0.6	98.8	2.8	47.0	3.7	59.1	1.0
Turbidity (ntu)		2.6	0.0	2.4	0.1	4.2	0.0	5.9	0.1	3.1	0.1	1.7	0.1	1.4	0.1	4.9	0.2	2.8	0.1

H. April 2011

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (ºC)		17.2	0.0	18.1	0.1	16.4	0.1	16.8	0.0	16.7	0.0	17.5	0.2	18.6	0.0	17.1	0.0	17.4	0.1
Conductivity (µS/cm)		76.0	12.0	93.0	16.0	106.0	12.0	158.5	0.5	122.0	0.0	73.0	23.0	71.5	0.5	241.0	0.0	401.0	29.0
pH		5.9	0.0	6.3	0.0	6.0	0.1	6.3	0.0	6.3	0.0	5.9	0.0	6.1	0.0	6.0	0.0	5.6	0.0
ORP (mV)		346.5	0.5	308.0	4.0	423.0	2.0	256.5	4.5	239.5	7.5	326.5	2.5	297.5	3.5	320.5	0.5	271.5	4.5
DO (mg/L)		8.4	0.0	9.0	0.0	3.2	0.1	6.6	0.0	2.1	0.1	8.5	0.0	9.1	0.0	4.6	0.0	5.7	0.8
DO (%sat'n)		86.8	0.3	95.5	0.1	32.5	0.9	67.8	0.4	21.1	0.6	88.4	0.5	96.8	0.1	47.6	0.3	58.4	9.3
Turbidity (ntu)		3.1	0.1	3.1	0.1	1.0	0.1	4.3	0.1	0.8	0.1	3.0	0.1	1.3	0.1	4.5	0.1	5.1	0.1

I. September 2011

WQ Parameter	Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (ºC)		12.9	0.0	14.9	0.0	12.4	0.0	13.0	0.0	12.7	0.0	14.5	0.0	15.5	0.0	12.6	0.0	13.9	0.0
Conductivity (µS/cm)		93.0	0.0	114.0	0.0	120.5	0.5	174.0	0.0	143.5	2.5	97.0	1.0	128.0	0.0	343.5	0.5	603.5	29.5
pH		5.4	0.0	5.7	0.0	6.1	0.0	6.1	0.0	6.0	0.0	5.6	0.0	5.8	0.0	5.6	0.0	5.3	0.0
ORP (mV)		224.0	1.0	146.0	0.0	173.0	1.0	55.0	0.0	54.0	7.0	196.5	2.5	225.5	0.5	189.0	0.0	103.5	2.5
DO (mg/L)		7.0	0.0	7.4	0.0	6.3	0.0	6.2	0.0	3.6	0.0	6.9	0.1	7.1	0.0	5.3	0.0	3.6	0.2
DO (%sat'n)		65.8	0.3	43.4	30.1	59.0	0.2	58.8	0.5	34.0	0.1	67.2	0.3	71.4	0.1	49.2	0.1	35.0	2.3
Turbidity (ntu)		0.7	0.1	2.0	0.4	0.6	0.0	18.7	1.1	8.9	1.3	3.3	0.4	6.7	0.2	0.6	0.0	13.7	0.1

*NS = no sampl
FP = faulty prob

Appendix 3: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli East Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011. Values outside available ANZECC guidelines for upland streams are highlighted.

A. October 2008

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		13.4	0.0	13.5	0.0	14.4	0.0	14.3	0.0	NS*		NS	
Conductivity (µS/cm)		138.0	0.0	146.5	1.5	161.0	0.0	161.0	0.0				
pH		7.3	0.0	6.9	0.0	7.1	0.1	7.1	0.1				
ORP (mV)		442.5	2.5	378.0	9.0	456.0	17.0	494.0	5.0				
DO (mg/L)		8.5	0.0	6.7	0.1	7.1	0.0	7.4	0.1				
DO (%sat'n)		80.9	0.7	63.9	0.3	67.5	1.8	72.2	0.6				
Turbidity (ntu)		7.9	0.1	9.6	0.2	18.1	0.1	11.5	0.1				

B. December 2008

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		14.2	0.0	14.6	0.0	15.8	0.2	16.0	0.1	NS		NS	
Conductivity (µS/cm)		FP#		FP		FP		FP					
pH		7.2	0.1	7.0	0.1	6.8	0.0	6.8	0.0				
ORP (mV)		393.0	7.0	402.5	9.5	445.0	6.0	460.5	0.5				
DO (mg/L)		7.4	0.1	6.1	0.0	6.5	0.1	7.0	0.1				
DO (%sat'n)		72.0	0.9	59.8	0.5	66.2	1.3	71.2	0.8				
Turbidity (ntu)		9.7	0.1	9.0	0.4	4.5	0.1	16.0	0.5				

C. March 2009

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		17.8	0.0	17.4	0.0	17.3	0.1	17.1	0.0	18.2	0.0	18.3	0.0
Conductivity (µS/cm)		4.0	4.0	126.0	0.0	131.0	5.0	9.0	0.0	110.5	4.5	115.0	9.0
pH		6.9	0.0	6.5	0.0	6.8	0.0	6.6	0.0	13.4	0.0	13.4	0.0
ORP (mV)		478.5	1.5	437.0	0.0	393.0	9.0	429.0	1.0	563.0	0.0	523.0	1.0
DO (mg/L)		7.4	0.1	5.0	0.1	5.4	1.0	5.7	0.1	6.9	0.0	7.3	0.0
DO (%sat'n)		77.6	0.6	51.8	0.3	56.1	10.4	58.6	0.2	72.8	0.2	77.8	0.0
Turbidity (ntu)		2.2	0.1	22.1	1.0	5.9	1.2	2.3	0.1	0.1	0.0	0.7	0.0

continued

Appendix 3: Continued.

D. May 2009

WQ Parameter Creek	Cataract Ck				Cataract River				Allens Ck			
Site	5		6		9		10		13		14	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	11.3	0.0	11.5	0.0	12.7	0.0	12.8	0.0	12.4	0.0	12.0	0.0
Conductivity (µS/cm)	112.0	0.0	112.0	0.0	108.0	0.0	98.0	0.0	114.0	5.0	110.0	0.0
pH	7.0	0.0	6.9	0.0	6.8	0.0	6.5	0.0	6.6	0.0	6.6	0.0
ORP (mV)	369.5	0.5	387.0	2.0	413.5	2.5	379.5	3.5	283.5	49.5	327.5	0.5
DO (mg/L)	16.6	0.1	15.8	0.6	15.7	0.4	15.5	0.4	15.8	0.5	14.9	0.0
DO (%sat'n)	150.7	0.5	145.2	5.1	148.1	3.9	146.1	2.9	153.3	0.1	138.5	0.1
Turbidity (ntu)	1.8	0.1	0.5	0.0	0.4	0.2	1.3	0.1	0.7	0.3	0.1	0.0

E. November 2009

WQ Parameter Creek	Cataract Ck				Cataract River				Allens Ck			
Site	5		6		9		10		13		14	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	14.4	0.0	14.6	0.0	14.9	0.0	14.7	0.0	15.1	0.0	15.0	0.0
Conductivity (µS/cm)	112.0	0.0	72.5	2.5	96.0	2.0	94.0	0.0	102.0	0.0	64.5	4.5
pH	6.8	0.0	6.8	0.0	6.6	0.0	6.4	0.1	6.5	0.0	6.8	0.0
ORP (mV)	362.0	0.0	352.5	0.5	147.0	0.0	142.0	2.0	184.0	1.0	409.5	0.5
DO (mg/L)	10.6	0.0	18.9	0.9	6.9	0.0	8.7	0.0	8.1	0.5	11.8	0.2
DO (%sat'n)	101.4	4.7	177.2	19.0	68.1	0.1	85.8	0.2	79.8	4.6	119.5	1.8
Turbidity (ntu)	20.9	0.6	28.8	1.3	0.6	0.1	1.2	0.3	1.9	0.1	31.4	0.9

F. March 2010

WQ Parameter Creek	Cataract Ck				Cataract River				Allens Ck			
Site	5		6		9		10		13		14	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	17.9	0.0	17.9	0.0	17.4	0.0	17.5	0.0	17.7	0.0	17.8	0.0
Conductivity (µS/cm)	214.0	0.0	126.5	2.5	188.5	5.5	56.0	0.0	224.5	1.5	73.0	0.0
pH	6.7	0.0	6.4	0.0	6.2	0.0	5.8	0.0	5.9	0.0	5.9	0.0
ORP (mV)	148.0	0.0	474.0	0.0	188.0	0.0	483.0	3.0	206.0	1.0	499.5	1.5
DO (mg/L)	7.0	0.0	6.6	0.0	7.9	0.1	9.0	0.1	8.0	0.0	10.3	0.3
DO (%sat'n)	74.1	0.0	69.7	0.2	82.4	0.8	94.7	1.3	84.0	0.1	105.7	0.6
Turbidity (ntu)	19.2	0.3	5.5	0.1	51.8	4.7	13.9	0.2	20.7	0.5	10.4	0.2

continued

Appendix 3: Continued.

G. September 2010

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		9.4	0.0	9.8	0.0	11.7	0.0	11.8	0.0	11.8	0.0	11.9	0.0
Conductivity (µS/cm)		108.5	10.5	123.0	0.0	112.0	0.0	102.5	0.5	127.0	0.0	104.5	2.5
pH		6.5	0.0	6.3	0.0	6.6	0.0	6.6	0.0	6.2	0.0	6.4	0.0
ORP (mV)		410.0	0.0	420.5	0.5	456.5	2.5	472.0	2.0	416.5	0.5	357.0	3.0
DO (mg/L)		8.5	0.5	8.7	0.0	8.3	0.3	9.2	0.1	10.4	0.0	7.8	0.3
DO (%sat'n)		74.7	4.3	77.8	0.5	75.9	2.3	84.0	0.3	96.9	0.9	72.2	1.3
Turbidity (ntu)		3.4	0.1	4.2	0.1	7.2	0.4	5.4	0.3	1.9	0.1	2.5	0.1

H. April 2011

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		14.9	0.0	15.0	0.0	14.8	0.0	14.9	0.0	15.4	0.0	15.4	0.0
Conductivity (µS/cm)		114.5	2.5	117.0	1.0	122.0	0.0	112.0	0.0	120.0	0.0	98.5	2.5
pH		6.5	0.0	6.4	0.0	6.8	0.0	6.9	0.0	6.3	0.1	6.6	0.0
ORP (mV)		287.5	2.5	266.5	2.5	250.5	3.5	229.5	2.5	348.5	8.5	387.5	2.5
DO (mg/L)		10.2	0.0	7.1	0.0	9.1	0.0	9.1	0.0	9.8	0.0	10.6	0.1
DO (%sat'n)		101.1	0.5	72.3	1.1	89.7	0.6	89.9	0.6	98.1	0.1	106.3	1.1
Turbidity (ntu)		27.3	0.5	9.8	0.2	4.1	0.0	7.3	0.1	6.0	0.1	8.6	0.3

I. September 2011

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		13.0	0.0	13.0	0.0	12.9	0.0	13.8	0.0	11.0	0.0	11.4	0.0
Conductivity (µS/cm)		146.0	1.0	162.5	31.5	215.0	2.0	282.0	2.0	202.5	2.5	194.0	0.0
pH		6.5	0.0	6.5	0.0	6.5	0.0	6.6	0.0	6.3	0.0	6.3	0.0
ORP (mV)		42.5	5.5	10.0	2.0	12.5	0.5	57.0	0.0	133.0	1.0	142.5	0.5
DO (mg/L)		8.1	0.0	7.4	0.1	7.1	0.0	7.6	0.0	7.7	0.0	7.4	0.0
DO (%sat'n)		85.1	0.3	77.6	0.8	67.0	0.7	72.9	0.3	69.6	0.3	67.7	0.2
Turbidity (ntu)		1.4	0.2	6.1	0.4	5.7	0.4	2.8	0.3	2.5	0.1	2.3	0.2

*NS = no sample

FP = faulty probe

Appendix 4: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.

(a) October 2008

Order or Family	Location	Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		5	0	0	2		0	0		
Araneae		0	0	1	4		1	0		
Athericidae		0	0	0	0		0	0		
Atyidae		10	10	4	2		10	10		
Austrocorduliidae		2	0	0	0		0	0		
Baetidae		0	0	3	1		0	0		
Caenidae		0	10	0	0		0	1		
Ceinidae		1	1	0	0		0	0		
Ceratopogonidae		0	0	0	2		0	1		
Chironomidae/Chironominae		5	1	0	2		4	10		
Chironomidae/Orthocladiinae		2	0	1	2		1	1		
Chironomidae/Tanypodinae		5	5	2	2		0	1		
Chrysomelidae		0	0	0	0		1	0		
Coenagrionidae		0	0	1	0		0	0		
Copepoda		2	0	1	0		0	0		
Corbiculidae/ Sphaeriidae		0	0	0	0		0	0		
Cordulephyidae		5	1	0	2		0	3		
Corixidae		1	0	1	0		0	0		
Corydalidae		0	0	0	0		0	0		
Culicidae		0	0	1	0		0	0		
Diphlebiidae		0	0	0	0		0	2		
Dixidae		7	9	0	0		0	0		
Dytiscidae		3	7	2	0		2	1		
Ecnomidae		0	0	0	0		0	0		
Elmidae		0	0	0	0		8	1		
Gelastocoridae		0	0	0	0		0	0		
Gerridae		2	1	1	2		1	1		
Gomphidae		1	2	0	0		0	0		
Gripopterygiidae		10	8	2	0		10	10		
Gyrinidae		0	1	1	1		0	0		
Hirudinidae		0	0	0	0		0	0		
Hydracarina		6	10	0	2		10	4		
Hydraenidae		0	0	0	0		0	0		
Hydrometridae		0	0	1	0		0	0		
Hydrophilidae		0	0	0	0		0	0		
Hydropsychidae		0	0	0	0		0	0		
Hydroptilidae		0	0	0	0		2	0		
Leptoceridae		10	10	10	10		10	10		
Leptophlebiidae		10	10	10	10		10	1		
Megapodagrionidae		1	0	5	3		0	1		
Nematoda		0	0	0	0		0	1		
Noteridae		0	0	0	0		0	0		
Notonectidae		3	4	1	5		0	0		
Oligochaeta		0	0	10	0		0	1		
Oniscidae		0	0	0	0		0	0		
Oniscigastridae		0	0	0	0		1	0		
Ostracoda		6	3	3	3		1	0		
Parastacidae		0	0	0	1		0	0		
Psephenidae		0	0	0	0		1	0		
Pyralidae		0	0	1	2		1	0		
Scirtidae		2	0	6	3		0	0		
Sialidae		0	0	0	0		0	0		
Simuliidae		0	0	0	0		1	0		
Synlestidae		0	0	3	10		3	1		
Synthemistidae		0	1	0	0		1	0		
Telephlebiidae		0	0	1	0		1	1		
Tipulidae		0	0	0	0		0	0		
Veliidae		0	0	5	0		0	1		
Total number of taxa		**22**	**18**	**25**	**21**		**21**	**21**		

Appendix 4 continued:

(b) December 2008

Order or Family	Location	Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		1	0	0	0		0	0		
Araneae		2	0	0	2		0	1		
Athericidae		0	0	0	0		0	0		
Atyidae		10	10	0	0		10	7		
Baetidae		0	2	0	4		0	0		
Ceinidae		3	0	0	0		0	0		
Ceratopogonidae		0	1	0	7		0	0		
Chironomidae/Chironominae		2	4	0	9		5	1		
Chironomidae/Orthocladiinae		1	1	0	1		0	2		
Chironomidae/Tanypodinae		1	1	0	7		1	1		
Cladocera		0	0	0	0		0	0		
Coenagrionidae		1	0	0	0		0	0		
Copepoda		1	0	0	1		1	1		
Corbiculidae/ Sphaeriidae		0	0	0	1		0	0		
Corixidae		1	1	0	0		0	0		
Culicidae		0	1	0	0		0	0		
Dixidae		5	0	1	0		0	0		
Dytiscidae		1	2	3	0		1	0		
Ecnomidae		0	0	0	1		0	0		
Elmidae		0	0	0	0		1	4		
Empididae		0	0	0	0		0	0		
Entomobryidae		0	0	0	1		0	0		
Gelastocoridae		0	0	0	0		0	0		
Gerridae		3	1	1	0		0	0		
Gomphidae		2	1	0	0		2	0		
Gripopterygiidae		10	10	0	0		10	10		
Gyrinidae		0	1	1	4		0	0		
Hirudinidae		0	0	0	0		0	0		
Hydracarina		3	8	2	4		10	10		
Hydraenidae		0	0	1	0		0	0		
Hydrobiosidae		0	0	0	0		0	0		
Hydrophilidae		2	0	0	0		2	0		
Hydroptilidae		0	0	0	1		2	1		
Leptoceridae		10	10	4	10		10	10		
Leptophlebiidae		10	10	0	10		10	3		
Megapodagrionidae		0	1	2	10		1	0		
Nematoda		0	0	0	0		0	0		
Noteridae		0	0	0	0		0	0		
Notonectidae		4	10	2	7		0	2		
Oligochaeta		0	1	3	1		1	1		
Oniscigastridae		0	0	0	0		0	0		
Ostracoda		0	1	4	9		2	2		
Parastacidae		1	1	0	1		4	1		
Polycentropodidae		0	0	0	3		0	0		
Psychodidae		0	0	0	0		0	0		
Pyralidae		0	0	0	1		0	0		
Sciomyzidae		0	0	0	0		0	0		
Scirtidae		0	2	1	2		0	0		
Sialidae		0	0	0	0		0	0		
Synlestidae		0	2	0	10		1	0		
Synthemistidae		0	0	2	1		0	0		
Telephlebiidae		0	3	0	1		1	4		
Tipulidae		0	1	0	1		0	0		
Veliidae		1	1	0	2		1	0		
Total number of taxa		**22**	**26**	**13**	**28**		**20**	**17**		

Appendix 4 continued:

(c) March 2009

Order or Family	Location	Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		8	1	DRY	2	8	0	0	4	2
Ancylidae		0	0	DRY	0	0	0	0	0	0
Araneae		0	0	DRY	0	0	1	0	0	0
Athericidae		0	0	DRY	0	0	0	0	0	0
Atyidae		10	7	DRY	0	0	6	10	5	8
Austrocorduliidae		0	1	DRY	0	0	0	3	0	2
Baetidae		0	0	DRY	0	0	3	2	0	0
Caenidae		0	10	DRY	0	0	1	2	0	0
Calamoceratidae		0	0	DRY	0	0	0	0	0	0
Ceinidae		1	0	DRY	0	0	0	0	10	9
Ceratopogonidae		0	0	DRY	0	0	1	0	2	0
Chironomidae/Aphroteniinae		0	0	DRY	0	0	0	0	0	0
Chironomidae/Chironominae		0	1	DRY	7	10	0	2	7	2
Chironomidae/Orthocladiinae		0	0	DRY	0	0	0	1	0	0
Chironomidae/Tanypodinae		0	0	DRY	1	0	1	2	8	5
Cladocera		0	0	DRY	0	1	0	0	1	0
Coenagrionidae		0	0	DRY	0	0	2	0	10	0
Copepoda		0	0	DRY	0	10	2	0	10	3
Corbiculidae/ Sphaeriidae		0	0	DRY	4	3	0	0	5	10
Cordulephyidae		0	0	DRY	0	0	3	3	1	1
Corixidae		0	0	DRY	0	0	2	0	0	4
Corydalidae		0	0	DRY	0	1	0	0	0	0
Dixidae		0	0	DRY	0	0	0	0	0	0
Dugesiidae		0	0	DRY	0	0	0	0	1	0
Dytiscidae		3	2	DRY	2	10	7	10	3	6
Ecnomidae		0	1	DRY	0	0	1	2	0	0
Elmidae		0	0	DRY	1	0	8	10	0	0
Empididae		0	0	DRY	0	0	0	0	0	0
Gelastocoridae		1	0	DRY	0	0	0	0	0	0
Gerridae		1	1	DRY	1	1	0	1	1	1
Gomphidae		4	4	DRY	1	0	4	10	1	1
Gripopterygiidae		0	6	DRY	0	0	10	10	0	0
Gyrinidae		1	1	DRY	1	1	0	0	1	1
Haliplidae		0	0	DRY	0	0	0	0	3	1
Hemicorduliidae		1	0	DRY	0	7	0	0	1	8
Hirudinidae		0	0	DRY	0	0	0	0	0	0
Hydracarina		4	2	DRY	1	3	10	10	7	3
Hydraenidae		0	0	DRY	0	1	0	0	0	0
Hydrochidae		0	0	DRY	0	0	0	0	0	0
Hydrometridae		0	0	DRY	0	1	0	0	0	0
Hydrophilidae		3	0	DRY	1	2	0	0	0	0
Hydroptilidae		0	1	DRY	0	0	1	0	0	0
Leptoceridae		9	10	DRY	2	0	10	10	10	10
Leptophlebiidae		2	2	DRY	10	0	10	5	10	10
Lestidae		0	0	DRY	0	0	0	0	1	0
Megapodagrionidae		1	2	DRY	5	10	0	1	10	10
Nematomorpha		0	0	DRY	0	0	2	0	0	1
Nepidae		0	0	DRY	0	0	0	0	1	0
Noteridae		0	0	DRY	0	0	0	0	0	0
Notonectidae		8	10	DRY	10	1	0	3	10	10
Notonemouridae		0	0	DRY	0	0	0	0	0	0
Odontoceridae		0	0	DRY	0	0	0	0	0	1
Oligochaeta		0	0	DRY	0	0	0	0	1	0
Oniscigastridae		0	0	DRY	0	0	0	0	0	0
Ostracoda		1	0	DRY	7	3	3	2	10	10
Parastacidae		0	0	DRY	0	0	0	1	0	0
Philorheithridae		0	0	DRY	0	0	0	0	0	0
Planorbidae		0	0	DRY	0	0	0	0	0	0
Psephenidae		0	0	DRY	0	0	4	1	0	0
Pyralidae		0	0	DRY	3	0	2	0	0	1
Scirtidae		0	0	DRY	1	3	4	0	0	1
Sialidae		0	0	DRY	0	0	0	0	4	0
Sminthuridae		0	0	DRY	0	0	0	0	0	0
Synlestidae		0	1	DRY	0	0	1	0	0	0
Synthemistidae		0	0	DRY	0	0	0	0	1	0
Telephlebiidae		0	0	DRY	0	0	1	3	0	0
Tipulidae		0	0	DRY	1	0	1	1	0	0
Veliidae		0	0	DRY	0	0	2	2	0	0
Total number of taxa		**16**	**18**	DRY	**19**	**18**	**28**	**25**	**29**	**26**

Appendix 4 continued:

(d) May 2009

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		0	1	0	0	1	0	0	4	1
Ancylidae		0	0	0	0	0	0	0	0	0
Araneae		0	0	0	0	0	0	0	0	0
Athericidae		0	0	0	0	0	0	0	0	0
Atyidae		10	10	0	0	0	6	10	3	2
Austrocorduliidae		1	0	0	0	0	0	3	0	1
Baetidae		1	1	0	0	0	1	1	0	0
Caenidae		10	10	0	0	0	0	2	0	0
Calamoceratidae		0	0	0	0	0	0	0	0	0
Ceinidae		1	0	0	0	0	0	0	10	10
Ceratopogonidae		0	0	0	2	0	3	0	2	6
Chironomidae/Aphroteniinae		0	0	0	0	0	0	1	0	0
Chironomidae/Chironominae		1	1	1	0	10	10	6	2	7
Chironomidae/Orthocladiinae		0	0	0	0	0	1	0	0	0
Chironomidae/Tanypodinae		4	2	2	5	0	2	1	3	6
Cladocera		0	0	0	0	0	0	0	1	0
Coenagrionidae		0	0	0	0	0	7	0	10	0
Copepoda		1	1	0	1	8	1	0	4	1
Corbiculidae/ Sphaeriidae		0	0	0	5	7	0	2	0	3
Cordulephyidae		1	2	0	0	0	0	2	1	1
Corixidae		2	1	0	1	0	6	0	1	4
Corydalidae		0	0	0	0	0	0	0	0	0
Dixidae		0	0	0	0	0	0	0	0	0
Dytiscidae		2	10	1	0	6	3	4	6	3
Ecnomidae		1	0	0	0	0	3	3	0	0
Elmidae		0	0	0	0	0	0	6	0	0
Gelastocoridae		0	0	0	0	0	0	0	0	0
Gerridae		1	1	0	1	1	0	0	4	0
Gomphidae		4	2	1	0	0	2	5	1	1
Gripopterygiidae		0	2	0	0	0	7	8	0	0
Gyrinidae		1	1	0	1	1	0	0	1	1
Haliplidae		0	0	0	0	0	0	0	1	0
Hemicorduliidae		0	0	0	0	2	6	0	6	7
Hirudinidae		0	0	0	0	0	0	0	0	0
Hydracarina		4	3	2	7	7	10	10	2	7
Hydridae		0	0	0	0	0	0	0	1	0
Hydrobiosidae		0	0	0	0	0	0	0	0	0
Hydrophilidae		0	0	0	0	0	0	0	0	1
Hydroptilidae		0	0	0	0	0	4	3	0	0
Isostictidae		1	0	0	0	0	0	0	0	0
Leptoceridae		10	10	1	1	1	10	10	1	6
Leptophlebiidae		5	1	0	10	0	4	6	7	7
Lestidae		0	0	0	0	0	1	0	10	0
Megapodagrionidae		0	2	0	2	0	1	0	4	7
Nematoda		0	0	0	0	0	0	0	0	0
Noteridae		0	0	0	0	0	0	0	0	0
Notonectidae		1	10	1	0	0	0	0	10	6
Odontoceridae		0	0	0	0	0	0	0	0	0
Oligochaeta		0	0	0	0	0	3	0	0	0
Oniscigastridae		0	0	0	0	0	0	0	0	0
Ostracoda		1	1	0	10	0	5	0	4	3
Parastacidae		0	0	0	0	0	0	0	0	0
Philopotamidae		0	0	0	0	0	0	0	0	0
Philorheithridae		0	0	0	0	0	0	0	0	0
Ptilodactylidae		0	0	0	0	0	0	0	0	0
Pyralidae		0	0	0	0	0	4	0	0	0
Scirtidae		0	0	0	1	0	0	0	0	0
Sialidae		0	0	0	0	0	0	0	3	0
Simuliidae		0	0	0	0	0	0	1	0	0
Synthemistidae		0	1	0	0	0	1	0	0	0
Tanyderidae		0	0	0	0	0	0	0	0	0
Telephlebiidae		0	0	0	0	0	1	1	0	0
Tipulidae		0	0	0	1	0	1	0	0	0
Veliidae		0	0	0	0	0	0	0	0	0
Total number of taxa		**21**	**21**	**7**	**14**	**10**	**26**	**20**	**26**	**22**

Appendix 4 continued:

(e) November 2009

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		1	0	DRY	0	0	0	0	1	1
Araneae		0	0	DRY	2	0	0	0	1	0
Athericidae		0	0	DRY	0	0	0	1	0	0
Atyidae		5	10	DRY	0	0	7	10	6	10
Austrocorduliidae		0	1	DRY	0	0	0	0	0	3
Baetidae		0	0	DRY	0	0	1	2	0	1
Caenidae		0	10	DRY	0	0	0	2	0	0
Calamoceratidae		0	0	DRY	0	0	0	0	0	0
Ceinidae		0	0	DRY	0	1	0	0	10	10
Ceratopogonidae		1	1	DRY	1	0	0	0	2	0
Chironomidae/Chironominae		4	0	DRY	10	5	3	2	10	6
Chironomidae/Orthocladiinae		0	0	DRY	0	0	1	0	0	0
Chironomidae/Tanypodinae		3	0	DRY	0	1	1	1	4	2
Cladocera		0	0	DRY	1	0	0	0	0	0
Coenagrionidae		0	0	DRY	1	0	0	0	3	1
Copepoda		0	0	DRY	0	2	0	0	5	2
Corbiculidae/ Sphaeriidae		0	0	DRY	2	3	0	0	3	2
Cordulephyidae		0	0	DRY	0	0	0	0	1	4
Corixidae		0	1	DRY	2	0	0	0	6	3
Corydalidae		0	0	DRY	0	0	0	0	1	0
Culicidae		0	0	DRY	0	0	0	0	0	0
Dixidae		0	0	DRY	0	0	0	0	0	0
Dytiscidae		4	4	DRY	2	1	7	2	2	6
Ecnomidae		0	1	DRY	0	0	0	0	0	0
Elmidae		0	0	DRY	0	0	2	8	0	0
Gelastocoridae		0	0	DRY	0	0	0	0	0	0
Gerridae		0	0	DRY	0	0	0	0	1	0
Gomphidae		1	7	DRY	0	0	3	3	1	0
Gripopterygiidae		9	6	DRY	0	0	10	10	0	0
Gyrinidae		0	0	DRY	2	1	0	0	0	0
Hemicorduliidae		0	0	DRY	0	2	0	0	3	0
Hirudinidae		0	0	DRY	0	0	0	0	0	0
Hydracarina		3	4	DRY	3	4	10	4	1	3
Hydraenidae		0	0	DRY	0	0	0	0	0	0
Hydrobiosidae		0	0	DRY	0	0	0	1	0	0
Hydrophilidae		0	0	DRY	0	0	0	0	0	0
Hypogastruridae		0	0	DRY	0	0	0	0	0	0
Leptoceridae		7	10	DRY	1	0	7	6	0	10
Leptophlebiidae		10	4	DRY	2	1	8	5	9	10
Lestidae		0	0	DRY	0	0	0	0	1	0
Megapodagrionidae		0	0	DRY	0	0	0	0	0	2
Nematoda		0	0	DRY	0	0	0	0	0	0
Noteridae		0	0	DRY	0	0	0	0	0	0
Notonectidae		1	3	DRY	3	0	0	0	2	7
Oligochaeta		0	0	DRY	0	0	2	1	0	0
Oniscigastridae		0	0	DRY	0	0	0	0	0	0
Ostracoda		0	1	DRY	10	1	6	1	5	2
Parastacidae		0	0	DRY	0	0	0	0	0	0
Scirtidae		0	1	DRY	0	0	0	0	0	0
Simuliidae		0	0	DRY	0	1	0	0	0	0
Synlestidae		0	0	DRY	1	0	1	0	0	2
Synthemistidae		1	2	DRY	0	0	0	0	0	0
Telephlebiidae		1	3	DRY	0	0	0	0	0	0
Tipulidae		0	1	DRY	0	0	3	0	0	0
Urothemistidae		0	0	DRY	0	0	0	0	0	1
Veliidae		0	0	DRY	0	0	0	0	0	0
Total number of taxa		**14**	**18**	DRY	**15**	**12**	**16**	**16**	**22**	**21**

Appendix 4 continued:

(f) March 2010

Order or Family / Location	Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
Site	1	2	3	4	17	11	12	15	16
Aeshnidae	6	1	DRY	2	2	0	0	2	0
Araneae	0	1	DRY	0	1	0	0	1	0
Athericidae	0	0	DRY	0	0	0	0	0	0
Atyidae	2	5	DRY	0	0	6	6	3	10
Austrocorduliidae	0	2	DRY	1	0	1	1	0	0
Caenidae	0	10	DRY	0	0	0	0	10	0
Ceinidae	2	0	DRY	0	0	0	0	0	10
Ceratopogonidae	0	0	DRY	1	0	1	1	7	0
Chironomidae/Chironominae	0	1	DRY	10	0	0	2	4	6
Chironomidae/Orthocladiinae	0	0	DRY	0	0	1	0	0	0
Chironomidae/Tanypodinae	2	1	DRY	3	0	0	0	4	1
Cladocera	0	0	DRY	0	1	1	0	1	1
Coenagrionidae	0	0	DRY	0	0	1	0	2	0
Copepoda	1	1	DRY	0	10	0	0	4	10
Corbiculidae/ Sphaeriidae	0	0	DRY	1	1	0	0	0	1
Cordulephyidae	0	0	DRY	0	0	1	1	2	6
Corixidae	6	1	DRY	0	0	1	0	7	6
Corydalidae	1	0	DRY	1	0	0	0	0	0
Culicidae	0	0	DRY	0	0	0	0	1	0
Diphlebiidae	0	0	DRY	0	0	0	1	0	0
Dixidae	0	0	DRY	0	0	0	0	0	0
Dytiscidae	7	3	DRY	1	5	3	10	3	5
Elmidae	0	1	DRY	0	0	7	3	0	0
Gerridae	0	2	DRY	1	0	0	0	0	2
Gomphidae	0	5	DRY	0	0	1	2	1	1
Gripopterygiidae	0	7	DRY	0	0	10	8	0	0
Gyrinidae	0	0	DRY	1	0	0	0	0	1
Haliplidae	0	0	DRY	0	0	0	0	0	1
Hebridae	1	0	DRY	0	0	0	0	0	0
Hemicorduliidae	1	0	DRY	0	0	0	0	3	5
Hirudinidae	0	0	DRY	0	0	0	0	0	0
Hydracarina	3	1	DRY	2	1	10	8	4	4
Hydrobiosidae	0	1	DRY	0	0	0	0	0	0
Hydrometridae	1	0	DRY	0	0	0	0	0	0
Hydrophilidae	0	0	DRY	0	0	0	0	0	0
Hydroptilidae	0	0	DRY	0	0	2	0	0	0
Hypogastruridae	0	0	DRY	0	1	0	0	0	0
Leptoceridae	6	10	DRY	1	0	10	10	1	3
Leptophlebiidae	0	5	DRY	10	1	8	1	10	10
Lestidae	0	0	DRY	0	0	0	0	4	0
Libellulidae	0	0	DRY	0	0	0	0	1	0
Megapodagrionidae	1	2	DRY	1	0	0	0	2	7
Mesoveliidae	0	0	DRY	0	0	0	0	0	0
Nematoda	0	0	DRY	0	0	0	0	2	0
Notonectidae	4	8	DRY	3	0	0	0	4	10
Oligochaeta	0	0	DRY	0	0	0	0	1	0
Oniscigastridae	0	0	DRY	0	0	0	0	0	0
Ostracoda	1	0	DRY	4	0	0	0	8	3
Parastacidae	2	0	DRY	1	0	1	0	0	0
Philopotamidae	0	0	DRY	0	0	0	0	0	0
Philorheithridae	1	0	DRY	0	0	0	0	0	0
Psephenidae	0	0	DRY	0	0	1	0	0	0
Pyralidae	0	0	DRY	1	0	2	0	0	0
Scirtidae	0	0	DRY	0	4	0	0	0	0
Sialidae	0	0	DRY	2	0	0	0	2	0
Simuliidae	0	0	DRY	0	0	0	0	0	0
Synlestidae	0	0	DRY	1	0	0	0	0	0
Synthemistidae	0	1	DRY	0	0	0	0	0	0
Telephlebiidae	0	0	DRY	0	0	0	0	1	0
Temnocephalidae	1	0	DRY	0	0	0	0	0	0
Tipulidae	0	0	DRY	1	0	2	1	0	0
Veliidae	2	0	DRY	0	0	0	0	0	0
Total number of taxa	**20**	**21**	DRY	**21**	**10**	**20**	**14**	**28**	**21**

Appendix 4 continued:

(g) September 2010

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		1	3		1	0	0	0	3	2
Araneae		0	0		1	0	3	0	0	2
Atyidae		4	7		0	0	10	6	6	10
Baetidae		0	0		0	0	0	1	0	0
Caenidae		0	10		0	0	0	5	0	0
Ceinidae		0	2		0	0	0	0	0	7
Ceratopogonidae		1	0		0	0	0	0	2	0
Chironomidae/Chironominae		0	4		1	0	3	10	2	3
Chironomidae/Orthocladiinae		0	0		2	1	3	5	0	0
Chironomidae/Tanypodinae		1	0		0	0	0	2	1	0
Cladocera		0	0		0	1	0	0	0	1
Coenagrionidae		0	0		0	0	0	0	6	0
Copepoda		0	0		0	1	0	0	0	0
Corbiculidae/ Sphaeriidae		0	0		0	0	0	0	4	1
Cordulephyidae		0	1		0	0	0	1	0	2
Corixidae		0	0		1	0	0	1	0	0
Corydalidae		0	0		0	0	0	0	0	0
Curculionidae		0	0		0	0	1	0	0	0
Dixidae		0	0		0	0	0	0	0	0
Dytiscidae		4	2		0	2	0	4	2	1
Ecnomidae		0	0		0	0	0	0	0	0
Elmidae		0	0		0	0	4	2	0	1
Eusiridae		0	0		0	0	0	0	10	0
Gelastocoridae		0	0		0	0	0	0	3	0
Gerridae		0	1		1	1	1	0	0	0
Gomphidae		0	0		0	0	0	5	1	1
Gripopterygiidae		0	10		0	0	3	10	0	0
Gyrinidae		0	1		0	0	0	0	0	1
Hemicorduliidae		0	0		0	0	0	0	5	0
Hydracarina		1	6		0	0	4	7	3	1
Hydraenidae		0	0		0	0	0	0	2	0
Hydrobiosidae		0	0		0	0	0	1	0	0
Hydrometridae		0	1		0	0	0	2	0	0
Hydrophilidae		1	0		0	1	0	0	0	0
Hypogastruridae		0	0		0	0	0	0	0	0
Leptoceridae		10	10		8	1	9	7	10	10
Leptophlebiidae		0	0		5	4	3	4	5	10
Lestidae		0	0		0	0	0	0	1	0
Megapodagrionidae		0	0		0	0	0	0	1	2
Noteridae		0	0		0	0	0	0	0	0
Notonectidae		4	3		2	1	0	0	7	7
Oligochaeta		0	0		0	0	0	2	0	0
Oniscigastridae		0	0		0	0	0	0	0	0
Ostracoda		2	1		3	2	0	1	3	0
Parastacidae		0	0		0	0	1	1	0	0
Pyralidae		0	0		0	0	0	0	4	0
Scirtidae		0	0		1	5	0	1	4	1
Synlestidae		0	0		0	0	2	0	0	0
Synthemistidae		0	0		1	0	0	1	0	0
Telephlebiidae		1	0		0	0	0	0	0	0
Tipulidae		0	0		2	1	0	0	0	1
Veliidae		0	4		0	0	0	0	1	0
Total number of taxa		**11**	**16**		**13**	**12**	**13**	**22**	**23**	**19**

Appendix 4 continued:

(h) April 2011

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		4	0	0	1	2	0	0	4	10
Ancylidae		0	0	0	0	0	1	0	0	0
Araneae		0	0	0	0	3	0	0	1	0
Athericidae		0	0	0	0	0	0	0	0	0
Atriplectididae		0	0	0	0	0	1	0	0	0
Atyidae		10	10	0	0	0	10	9	3	3
Austrocorduliidae		3	0	0	0	0	0	0	0	2
Caenidae		0	10	0	0	0	0	0	0	0
Calamoceratidae		0	0	0	0	0	0	0	0	0
Ceinidae		0	0	0	0	0	0	0	6	6
Ceratopogonidae		0	3	0	1	2	1	0	4	1
Chironomidae/Aphroteniinae		1	0	0	0	0	0	0	0	0
Chironomidae/Chironominae		1	1	0	1	0	4	1	1	10
Chironomidae/Orthocladiinae		2	0	0	0	0	0	0	0	0
Chironomidae/Tanypodinae		1	1	9	1	3	1	0	8	10
Cladocera		0	0	0	0	0	0	0	0	1
Coenagrionidae		0	0	0	0	0	0	0	10	0
Copepoda		0	0	0	3	5	0	0	0	10
Corbiculidae/ Sphaeriidae		0	0	0	0	5	0	0	0	5
Cordulephyidae		6	2	0	0	0	0	3	0	5
Corixidae		2	0	0	0	0	0	0	1	2
Corydalidae		0	0	0	0	1	0	0	0	0
Culicidae		0	0	0	0	0	1	0	0	0
Curculionidae		0	0	0	0	0	0	0	0	0
Diphlebiidae		0	0	0	0	0	0	1	0	0
Dixidae		0	0	0	0	0	0	0	0	0
Dugesiidae		0	0	0	0	0	0	0	3	0
Dytiscidae		7	3	0	0	6	3	10	6	2
Ecnomidae		0	0	0	0	0	0	0	0	0
Elmidae		0	0	0	0	0	1	0	0	0
Empididae		0	0	0	0	0	0	0	0	0
Gerridae		1	1	1	4	1	6	1	3	1
Gomphidae		8	1	0	0	0	2	1	1	1
Gripopterygiidae		5	4	0	0	0	10	9	0	0
Gyrinidae		1	1	0	5	2	0	0	1	2
Haliplidae		0	0	0	0	0	0	0	1	5
Hemicorduliidae		3	0	1	2	1	0	0	0	4
Hirudinidae		0	0	0	0	0	0	0	0	0
Hydracarina		6	4	0	1	1	4	3	2	1
Hydrobiosidae		0	0	0	0	0	0	0	0	0
Hydrometridae		0	0	0	0	0	0	0	0	0
Hydrophilidae		0	0	0	0	0	0	0	0	0
Hydroptilidae		0	0	0	1	0	5	4	0	0
Leptoceridae		10	7	3	3	6	9	10	1	5
Leptophlebiidae		4	2	0	10	10	10	4	10	10
Lestidae		0	0	0	0	0	0	0	6	1
Megapodagrionidae		1	0	0	10	4	1	0	2	8
Nematomorpha		0	0	0	0	0	0	1	0	0
Nepidae		0	0	0	0	0	0	0	0	0
Noteridae		0	0	0	0	0	0	0	0	0
Notonectidae		8	6	1	2	2	0	0	6	8
Odontoceridae		0	0	0	0	0	0	1	0	0
Oligochaeta		0	0	0	0	3	0	0	2	0
Ostracoda		0	1	0	1	0	1	1	4	1
Parastacidae		1	0	0	3	1	1	0	0	0
Philorheithridae		3	0	0	0	0	0	0	3	0
Polycentropodidae		0	0	0	0	0	0	0	0	0
Psephenidae		0	0	0	0	0	1	0	0	1
Pyralidae		0	0	1	1	2	1	0	0	0
Scirtidae		0	0	1	0	1	0	0	0	0
Sialidae		0	0	1	0	0	0	0	3	0
Simuliidae		0	0	0	0	0	0	1	0	0
Synlestidae		0	0	0	1	0	0	0	0	0
Synthemistidae		1	0	0	0	0	0	0	2	0
Telephlebiidae		0	0	0	0	0	0	1	0	0
Tipulidae		1	0	0	3	0	0	2	0	0
Veliidae		1	0	0	0	0	2	0	0	0
Total number of taxa		**25**	**16**	**8**	**19**	**20**	**22**	**18**	**26**	**26**

Appendix 4 continued:

(i) September 2011

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		0	0	0	0	0	0	0	0	3
Ancylidae		0	0	0	0	0	0	0	0	0
Atyidae		0	10	0	0	0	7	10	8	0
Austrocorduliidae		0	1	0	0	0	0	0	0	0
Baetidae		0	0	0	0	0	1	0	0	0
Caenidae		0	0	0	2	0	0	0	0	0
Ceinidae		0	0	0	0	0	0	0	10	8
Ceratopogonidae		0	0	0	0	3	0	0	0	0
Chironomidae/Chironominae		0	2	0	2	2	2	2	2	0
Chironomidae/Orthocladiinae		0	0	0	0	2	0	0	0	0
Chironomidae/Tanypodinae		0	0	5	0	2	0	0	3	5
Coenagrionidae		0	0	0	0	0	0	0	2	0
Copepoda		1	0	0	0	0	0	0	0	0
Corbiculidae/ Sphaeriidae		0	0	0	1	1	0	0	3	2
Corixidae		0	0	0	0	0	0	0	0	0
Corydalidae		0	0	0	0	0	0	0	0	0
Dixidae		1	0	0	0	0	0	0	0	0
Dytiscidae		1	1	1	1	1	1	4	0	1
Ecnomidae		0	0	0	0	0	0	3	2	0
Elmidae		0	0	0	0	0	5	0	0	0
Gelastocoridae		0	0	0	1	0	0	0	1	0
Gomphidae		0	0	0	0	0	2	3	1	0
Gripopterygiidae		0	2	0	0	0	10	3	5	0
Gyrinidae		1	1	0	0	1	0	0	0	0
Helicopsychidae		0	0	0	0	0	0	0	0	0
Hemicorduliidae		0	0	0	0	0	0	0	1	0
Hydracarina		0	2	0	0	3	10	3	0	3
Hydraenidae		0	0	1	0	0	0	0	0	0
Hydrobiosidae		0	0	0	0	0	0	0	0	0
Hydrometridae		0	0	0	0	1	0	0	0	1
Leptoceridae		0	7	1	0	1	3	5	1	1
Leptophlebiidae		9	1	6	10	10	6	3	10	10
Libellulidae		0	0	0	0	1	0	0	0	1
Megapodagrionidae		0	0	0	1	2	1	0	6	3
Naucoridae		0	0	0	0	0	0	1	0	0
Nematoda		1	0	0	0	0	0	0	0	0
Noteridae		0	0	0	0	0	0	0	1	0
Notonectidae		1	3	0	0	0	0	0	1	0
Odontoceridae		0	0	0	0	0	0	0	0	0
Oligochaeta		0	0	6	0	0	0	4	0	0
Oniscigastridae		0	0	0	0	0	0	0	0	0
Ostracoda		0	0	0	0	0	0	0	1	0
Philorheithridae		0	0	0	0	0	0	0	0	0
Pyralidae		0	0	0	0	2	0	0	0	2
Scirtidae		0	0	10	0	1	0	0	0	1
Sialidae		0	0	1	0	0	0	0	0	0
Synthemistidae		0	0	1	2	0	3	0	1	0
Telephlebiidae		0	0	0	0	0	0	0	1	0
Tipulidae		0	0	0	3	0	2	0	0	0
Veliidae		0	0	0	0	0	0	0	0	0
Total number of taxa		**7**	**10**	**9**	**9**	**15**	**13**	**11**	**19**	**13**

Appendix 5: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.

(a) October 2008

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0		
Araneae		0	2	0	2		
Athericidae		1	0	1	1		
Atyidae		0	0	0	0		
Austrocorduliidae		0	0	0	0		
Baetidae		0	0	0	0		
Caenidae		0	0	0	0		
Ceinidae		0	0	0	0		
Ceratopogonidae		0	1	8	1		
Chironomidae/Chironominae		2	4	10	7		
Chironomidae/Orthocladiinae		1	4	2	1		
Chironomidae/Tanypodinae		4	4	10	1		
Chrysomelidae		0	0	0	0		
Coenagrionidae		0	0	0	0		
Copepoda		0	0	1	0		
Corbiculidae/ Sphaeriidae		0	0	1	0		
Cordulephyidae		0	0	0	0		
Corixidae		0	0	2	0		
Corydalidae		1	0	0	0		
Culicidae		0	0	0	0		
Diphlebiidae		0	0	0	0		
Dixidae		0	1	3	3		
Dytiscidae		0	0	4	1		
Ecnomidae		1	1	0	0		
Elmidae		0	0	0	2		
Gelastocoridae		0	1	1	0		
Gerridae		0	0	0	0		
Gomphidae		0	0	4	1		
Gripopterygiidae		0	4	2	7		
Gyrinidae		3	2	5	1		
Hirudinidae		0	3	0	1		
Hydracarina		6	10	7	8		
Hydraenidae		0	3	1	0		
Hydrometridae		0	0	0	0		
Hydrophilidae		0	0	3	4		
Hydropsychidae		0	0	0	0		
Hydroptilidae		0	0	0	0		
Leptoceridae		10	10	10	10		
Leptophlebiidae		10	10	10	10		
Megapodagrionidae		0	2	3	0		
Nematoda		0	0	0	0		
Noteridae		0	0	1	1		
Notonectidae		0	0	0	1		
Oligochaeta		0	0	1	0		
Oniscidae		0	0	0	0		
Oniscigastridae		0	0	10	4		
Ostracoda		0	0	0	0		
Parastacidae		0	0	0	1		
Psephenidae		0	0	0	0		
Pyralidae		0	0	0	1		
Scirtidae		0	1	1	5		
Sialidae		0	0	3	0		
Simuliidae		0	0	0	0		
Synlestidae		0	0	1	0		
Synthemistidae		5	2	2	0		
Telephlebiidae		0	0	0	1		
Tipulidae		2	1	1	0		
Veliidae		1	0	0	0		
Total number of taxa		**13**	**19**	**28**	**24**		

Appendix 5 continued:

(b) December 2008

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0		
Araneae		2	0	2	4		
Athericidae		0	1	1	0		
Atyidae		0	0	0	1		
Baetidae		0	0	0	0		
Ceinidae		0	1	0	0		
Ceratopogonidae		6	0	4	5		
Chironomidae/Chironominae		1	2	5	3		
Chironomidae/Orthocladiinae		1	0	3	2		
Chironomidae/Tanypodinae		4	0	6	4		
Cladocera		0	0	0	0		
Coenagrionidae		0	0	0	0		
Copepoda		1	0	0	0		
Corbiculidae/ Sphaeriidae		0	2	0	0		
Corixidae		0	0	0	0		
Culicidae		1	0	1	2		
Dixidae		10	10	4	7		
Dytiscidae		0	0	2	1		
Ecnomidae		3	3	10	2		
Elmidae		0	0	0	0		
Empididae		0	0	0	0		
Entomobryidae		1	0	0	0		
Gelastocoridae		0	0	1	1		
Gerridae		0	0	0	0		
Gomphidae		0	0	2	1		
Gripopterygiidae		0	0	0	4		
Gyrinidae		2	1	2	3		
Hirudinidae		1	0	0	0		
Hydracarina		10	10	3	4		
Hydraenidae		0	1	1	2		
Hydrobiosidae		0	0	0	0		
Hydrophilidae		0	0	0	1		
Hydroptilidae		0	0	0	0		
Leptoceridae		10	10	10	10		
Leptophlebiidae		9	8	10	10		
Megapodagrionidae		0	5	1	6		
Nematoda		0	2	0	0		
Noteridae		0	3	2	1		
Notonectidae		0	0	0	0		
Oligochaeta		1	0	1	2		
Oniscigastridae		0	0	0	7		
Ostracoda		0	0	0	0		
Parastacidae		0	0	0	0		
Polycentropodidae		0	0	0	0		
Psychodidae		0	0	0	0		
Pyralidae		0	1	0	0		
Sciomyzidae		1	0	0	0		
Scirtidae		3	4	4	0		
Sialidae		0	0	1	0		
Synlestidae		4	2	4	10		
Synthemistidae		6	0	0	0		
Telephlebiidae		3	0	1	0		
Tipulidae		1	0	6	3		
Veliidae		3	1	1	4		
Total number of taxa		**23**	**18**	**26**	**26**		

Appendix 5 continued:

(c) March 2009

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		1	0	1	0	2	1
Araneae		1	3	5	3	3	0
Athericidae		10	0	0	0	0	0
Atyidae		0	10	0	10	4	10
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	1	1
Calamoceratidae		0	0	0	0	0	1
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		0	0	1	0	1	0
Chironomidae/Aphroteniinae		0	0	0	0	0	0
Chironomidae/Chironominae		2	2	10	1	3	3
Chironomidae/Orthocladiinae		1	0	0	0	2	1
Chironomidae/Tanypodinae		4	5	4	1	9	1
Cladocera		0	0	1	1	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	0	0	0	0
Corbiculidae/ Sphaeriidae		1	2	2	0	1	0
Cordulephyidae		0	0	0	0	0	1
Corixidae		0	0	5	0	10	3
Corydalidae		0	0	0	0	0	0
Dixidae		1	0	1	6	4	0
Dugesiidae		0	0	0	1	0	0
Dytiscidae		0	0	9	0	0	6
Ecnomidae		0	1	0	1	0	0
Elmidae		0	0	0	0	1	1
Empididae		2	0	0	0	0	0
Gelastocoridae		0	2	1	2	0	0
Gerridae		0	0	5	3	3	2
Gomphidae		0	1	4	3	3	3
Gripopterygiidae		0	0	10	10	6	2
Gyrinidae		5	2	1	1	2	3
Haliplidae		0	0	0	0	0	0
Hemicorduliidae		0	0	1	0	0	1
Hirudinidae		0	0	1	0	0	1
Hydracarina		6	10	10	10	10	10
Hydraenidae		0	0	0	1	0	0
Hydrochidae		0	0	0	3	0	0
Hydrometridae		0	0	0	0	0	0
Hydrophilidae		0	0	4	0	0	0
Hydroptilidae		0	0	5	0	0	2
Leptoceridae		10	10	10	10	10	10
Leptophlebiidae		7	7	10	8	10	3
Lestidae		0	0	0	0	0	0
Megapodagrionidae		1	1	3	2	1	0
Nematomorpha		0	0	0	0	0	0
Nepidae		0	0	0	0	0	0
Noteridae		0	3	5	3	2	2
Notonectidae		0	0	2	3	1	1
Notonemouridae		1	0	0	0	0	0
Odontoceridae		0	0	0	0	0	0
Oligochaeta		0	0	0	0	0	0
Oniscigastridae		0	3	0	1	1	0
Ostracoda		0	0	2	1	1	0
Parastacidae		3	7	1	0	1	1
Philorheithridae		0	0	0	0	0	0
Planorbidae		0	0	1	0	0	0
Psephenidae		0	0	0	0	0	1
Pyralidae		0	0	0	0	0	0
Scirtidae		2	1	2	6	3	1
Sialidae		0	0	0	1	0	0
Sminthuridae		0	1	0	0	0	0
Synlestidae		1	1	1	2	0	0
Synthemistidae		0	8	0	0	1	0
Telephlebiidae		2	0	3	3	5	2
Tipulidae		2	3	2	1	0	1
Veliidae		0	1	4	9	1	2
Total number of taxa		**20**	**22**	**33**	**29**	**29**	**29**

Appendix 5 continued:

(d) May 2009

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		0	1	1	1	1	2
Araneae		0	1	0	0	0	0
Athericidae		3	1	2	0	0	0
Atyidae		0	10	0	10	4	10
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	1	1
Calamoceratidae		0	0	0	0	0	2
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		1	0	6	0	3	1
Chironomidae/Aphroteniinae		1	0	0	1	0	1
Chironomidae/Chironominae		1	2	6	1	3	2
Chironomidae/Orthocladiinae		0	0	0	0	0	1
Chironomidae/Tanypodinae		7	3	7	7	3	3
Cladocera		0	0	0	0	1	0
Coenagrionidae		0	0	0	1	0	0
Copepoda		0	1	0	1	1	0
Corbiculidae/ Sphaeriidae		0	3	6	0	2	2
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	5	0	3	2
Corydalidae		2	0	0	0	0	0
Dixidae		1	0	3	2	4	3
Dytiscidae		0	0	4	2	0	2
Ecnomidae		0	0	1	4	0	0
Elmidae		0	0	1	1	1	0
Gelastocoridae		1	0	1	0	0	0
Gerridae		0	0	0	0	2	2
Gomphidae		0	1	7	5	4	5
Gripopterygiidae		0	1	1	7	0	0
Gyrinidae		1	7	1	3	5	2
Haliplidae		0	0	0	0	0	0
Hemicorduliidae		0	0	0	2	0	0
Hirudinidae		0	0	0	0	0	1
Hydracarina		3	10	8	10	6	5
Hydridae		0	0	0	0	0	0
Hydrobiosidae		0	0	1	0	0	0
Hydrophilidae		0	0	0	1	0	0
Hydroptilidae		0	0	4	1	5	2
Isostictidae		0	0	0	0	0	0
Leptoceridae		10	10	8	10	10	10
Leptophlebiidae		10	10	10	10	10	5
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	4	2	3	2	0
Nematoda		0	0	1	0	0	0
Noteridae		0	0	1	0	0	1
Notonectidae		0	0	0	1	0	1
Odontoceridae		0	0	0	0	0	1
Oligochaeta		0	1	2	0	0	0
Oniscigastridae		0	0	1	1	0	0
Ostracoda		0	0	1	1	3	0
Parastacidae		0	1	0	0	1	0
Philopotamidae		0	0	0	0	0	0
Philorheithridae		0	1	0	0	0	0
Ptilodactylidae		0	0	0	0	0	0
Pyralidae		0	0	0	0	0	0
Scirtidae		10	0	2	0	1	1
Sialidae		0	0	0	0	0	0
Simuliidae		1	0	0	0	0	0
Synthemistidae		4	0	0	1	1	0
Tanyderidae		0	1	0	0	0	0
Telephlebiidae		1	0	0	0	2	0
Tipulidae		8	0	6	2	2	3
Veliidae		0	2	0	0	0	0
Total number of taxa		**17**	**20**	**28**	**26**	**26**	**26**

Appendix 5 continued:

(e) November 2009

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Araneae		0	0	0	0	1	0
Athericidae		4	1	0	0	0	0
Atyidae		0	5	0	0	1	10
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	0	4
Calamoceratidae		0	0	0	0	0	3
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		10	4	5	4	3	8
Chironomidae/Chironominae		0	2	3	4	0	1
Chironomidae/Orthocladiinae		0	0	0	1	1	1
Chironomidae/Tanypodinae		4	0	0	0	2	3
Cladocera		0	0	0	0	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	0	3	1	0
Corbiculidae/ Sphaeriidae		2	2	0	0	0	0
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	1	0	0	10
Corydalidae		0	0	0	0	0	0
Culicidae		0	0	3	0	0	0
Dixidae		2	0	4	3	8	0
Dytiscidae		0	0	4	1	2	5
Ecnomidae		0	0	0	0	0	0
Elmidae		0	0	0	1	1	1
Gelastocoridae		0	0	0	0	1	0
Gerridae		0	0	1	0	1	0
Gomphidae		0	2	2	0	0	6
Gripopterygiidae		0	0	1	4	1	2
Gyrinidae		2	2	3	1	2	1
Hemicorduliidae		0	0	0	0	0	0
Hirudinidae		1	0	0	2	2	1
Hydracarina		10	10	5	5	0	10
Hydraenidae		0	0	0	0	1	0
Hydrobiosidae		0	0	1	0	0	0
Hydrophilidae		0	2	4	0	0	0
Hypogastruridae		0	0	0	0	1	0
Leptoceridae		5	10	10	10	10	10
Leptophlebiidae		3	6	10	10	3	6
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	0	1	0	0	0
Nematoda		1	0	0	0	0	0
Noteridae		0	1	1	0	0	0
Notonectidae		0	0	0	0	0	0
Oligochaeta		0	0	1	0	0	0
Oniscigastridae		0	0	1	7	0	7
Ostracoda		0	0	1	1	1	2
Parastacidae		0	0	0	0	1	0
Scirtidae		0	0	1	4	2	0
Simuliidae		0	0	0	0	0	0
Synlestidae		0	0	2	0	0	2
Synthemistidae		8	2	0	0	0	0
Telephlebiidae		0	0	0	1	4	0
Tipulidae		2	0	1	2	0	0
Urothemistidae		0	0	0	0	0	0
Veliidae		1	0	1	0	2	0
Total number of taxa		**14**	**13**	**24**	**18**	**23**	**20**

Appendix 5 continued:

(f) March 2010

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Araneae		0	0	1	0	0	1
Athericidae		0	1	0	0	0	0
Atyidae		0	10	0	10	9	10
Austrocorduliidae		0	0	0	0	0	0
Caenidae		0	0	0	0	0	0
Ceinidae		0	0	1	0	0	0
Ceratopogonidae		0	2	0	0	0	0
Chironomidae/Chironominae		4	2	6	1	1	5
Chironomidae/Orthocladiinae		0	0	0	1	0	0
Chironomidae/Tanypodinae		1	8	1	3	2	4
Cladocera		0	0	0	0	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	4	2	0	0	0
Corbiculidae/ Sphaeriidae		0	0	0	0	0	0
Cordulephyidae		0	1	0	0	0	0
Corixidae		0	0	3	8	3	10
Corydalidae		0	0	0	0	0	0
Culicidae		0	0	0	0	0	0
Diphlebiidae		0	0	0	0	0	0
Dixidae		1	0	1	2	2	0
Dytiscidae		0	1	0	0	0	1
Elmidae		0	0	0	1	1	2
Gerridae		0	0	6	4	3	3
Gomphidae		1	0	0	5	0	0
Gripopterygiidae		0	0	0	2	9	0
Gyrinidae		2	1	4	2	3	3
Haliplidae		0	0	0	0	0	0
Hebridae		0	0	0	0	0	0
Hemicorduliidae		0	0	0	1	0	0
Hirudinidae		1	1	5	0	10	0
Hydracarina		1	4	2	0	3	4
Hydrobiosidae		0	0	0	0	0	0
Hydrometridae		0	0	0	0	0	0
Hydrophilidae		0	0	0	1	0	0
Hydroptilidae		0	0	0	0	1	1
Hypogastruridae		0	0	0	2	0	0
Leptoceridae		10	10	10	10	10	10
Leptophlebiidae		2	4	6	7	1	7
Lestidae		0	0	0	0	0	0
Libellulidae		0	0	0	0	0	0
Megapodagrionidae		1	0	0	0	0	0
Mesoveliidae		1	0	3	0	0	0
Nematoda		0	0	0	0	0	0
Notonectidae		0	0	4	1	4	0
Oligochaeta		0	0	0	2	0	0
Oniscigastridae		0	0	3	1	6	10
Ostracoda		0	0	0	0	0	0
Parastacidae		0	0	0	0	0	0
Philopotamidae		0	0	0	0	0	1
Philorheithridae		0	1	0	0	0	2
Psephenidae		0	0	0	0	0	0
Pyralidae		0	1	0	0	0	1
Scirtidae		0	1	0	0	0	0
Sialidae		0	0	0	0	0	0
Simuliidae		0	0	7	0	1	0
Synlestidae		0	0	0	0	0	0
Synthemistidae		1	4	0	1	0	1
Telephlebiidae		0	0	1	0	0	1
Temnocephalidae		0	0	0	0	0	0
Tipulidae		0	1	2	1	0	0
Veliidae		1	0	4	0	0	0
Total number of taxa		**13**	**18**	**20**	**21**	**17**	**19**

Appendix 5 continued:

(g) September 2010

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Araneae		0	0	2	2	3	1
Atyidae		1	1	0	2	9	4
Baetidae		0	0	0	1	0	0
Caenidae		0	0	0	0	0	0
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		9	5	6	8	5	3
Chironomidae/Chironominae		3	3	0	3	0	1
Chironomidae/Orthocladiinae		0	0	6	1	0	0
Chironomidae/Tanypodinae		2	6	7	7	1	4
Cladocera		0	0	0	0	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	1	2	0	0
Corbiculidae/ Sphaeriidae		1	1	1	0	0	0
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	1	0	0	0
Corydalidae		0	1	0	0	0	0
Curculionidae		0	0	0	0	0	0
Dixidae		1	2	0	0	2	0
Dytiscidae		0	0	0	2	1	3
Ecnomidae		2	1	0	3	0	0
Elmidae		2	0	0	1	0	1
Eusiridae		0	0	0	0	0	0
Gelastocoridae		0	0	1	2	2	0
Gerridae		0	0	0	0	1	1
Gomphidae		0	0	10	5	0	1
Gripopterygiidae		0	2	4	5	6	3
Gyrinidae		7	2	5	1	1	1
Hemicorduliidae		0	0	1	0	0	0
Hydracarina		2	3	2	5	6	5
Hydraenidae		2	1	0	0	2	1
Hydrobiosidae		0	0	0	0	0	0
Hydrometridae		0	0	2	0	0	0
Hydrophilidae		0	0	0	1	1	0
Hypogastruridae		0	0	2	1	0	0
Leptoceridae		10	10	10	10	9	10
Leptophlebiidae		3	10	10	10	7	10
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	5	5	5	2	0
Noteridae		0	0	5	5	4	1
Notonectidae		0	0	0	2	2	0
Oligochaeta		0	0	3	2	0	0
Oniscigastridae		0	0	5	3	0	0
Ostracoda		0	0	0	0	0	0
Parastacidae		0	0	0	0	1	0
Pyralidae		0	0	0	0	0	0
Scirtidae		1	3	3	3	3	1
Synlestidae		0	0	6	1	1	0
Synthemistidae		0	3	0	1	0	0
Telephlebiidae		0	0	3	2	3	1
Tipulidae		0	3	0	0	0	0
Veliidae		1	4	4	3	4	3
Total number of taxa		**15**	**19**	**25**	**30**	**23**	**19**

Appendix 5 continued:

(h) April 2011

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		0	0	0	0	0	1
Araneae		1	0	2	2	1	0
Athericidae		1	3	0	0	0	2
Atriplectididae		0	0	0	0	0	0
Atyidae		0	4	0	4	3	10
Austrocorduliidae		0	0	0	0	0	0
Caenidae		0	0	0	0	0	0
Calamoceratidae		0	0	0	0	0	1
Ceinidae		0	0	0	1	0	0
Ceratopogonidae		1	5	5	1	1	1
Chironomidae/Aphroteniinae		0	0	0	0	0	0
Chironomidae/Chironominae		0	3	4	3	0	1
Chironomidae/Orthocladiinae		0	0	0	0	0	0
Chironomidae/Tanypodinae		2	4	3	0	2	0
Cladocera		0	0	0	1	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	3	0	0	0	0
Corbiculidae/ Sphaeriidae		0	0	0	0	3	0
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	5	0	3	5
Corydalidae		1	0	1	1	0	0
Culicidae		0	0	0	0	0	0
Curculionidae		1	0	0	0	0	0
Diphlebiidae		0	0	0	0	0	0
Dixidae		0	0	2	0	0	0
Dugesiidae		0	0	0	0	0	0
Dytiscidae		0	0	10	0	4	4
Ecnomidae		0	0	1	0	0	0
Elmidae		0	0	2	1	0	2
Empididae		0	1	0	0	0	0
Gerridae		0	0	0	1	2	0
Gomphidae		0	4	8	3	0	4
Gripopterygiidae		0	3	4	6	4	1
Gyrinidae		3	1	5	3	2	2
Haliplidae		0	0	0	0	0	0
Hemicorduliidae		0	0	2	1	0	0
Hirudinidae		1	0	0	0	0	1
Hydracarina		3	0	4	8	3	8
Hydrobiosidae		0	0	1	0	0	0
Hydrometridae		0	0	0	0	1	0
Hydrophilidae		1	0	0	0	0	0
Hydroptilidae		0	0	0	0	3	5
Leptoceridae		10	10	10	10	10	10
Leptophlebiidae		2	10	10	10	10	5
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	3	6	0	0	2
Nematomorpha		0	0	0	0	0	0
Nepidae		0	0	0	0	1	0
Noteridae		0	0	2	2	0	0
Notonectidae		0	0	0	2	0	2
Odontoceridae		0	0	0	0	0	0
Oligochaeta		0	0	6	0	0	0
Ostracoda		0	0	0	1	0	0
Parastacidae		4	1	0	2	0	2
Philorheithridae		0	0	1	0	2	8
Polycentropodidae		0	0	2	1	0	0
Psephenidae		0	0	0	0	1	0
Pyralidae		0	0	0	0	0	0
Scirtidae		0	0	0	0	1	0
Sialidae		0	0	0	0	0	0
Simuliidae		0	0	1	0	0	0
Synlestidae		0	0	1	0	0	0
Synthemistidae		1	5	1	0	0	1
Telephlebiidae		1	0	2	2	1	2
Tipulidae		4	2	1	3	3	4
Veliidae		0	0	0	3	0	0
Total number of taxa		**16**	**16**	**28**	**24**	**21**	**24**

Appendix 5 continued:

(i) September 2011

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		0	1	0	0	0	0
Atyidae		0	0	0	0	0	4
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	3	1
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		0	0	1	0	2	0
Chironomidae/Chironominae		1	0	1	2	2	3
Chironomidae/Orthocladiinae		0	0	0	0	0	0
Chironomidae/Tanypodinae		2	0	1	2	2	2
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	0	0	0	0
Corbiculidae/ Sphaeriidae		0	2	0	0	0	0
Corixidae		0	0	0	0	1	1
Corydalidae		1	0	0	0	0	0
Dixidae		0	0	0	0	0	0
Dytiscidae		0	0	0	4	0	0
Ecnomidae		0	0	0	0	0	0
Elmidae		0	0	0	1	0	1
Gelastocoridae		1	0	1	0	1	1
Gomphidae		0	0	2	0	2	1
Gripopterygiidae		1	1	2	3	7	7
Gyrinidae		1	3	0	1	0	0
Helicopsychidae		0	0	0	0	1	0
Hemicorduliidae		0	0	0	0	0	0
Hydracarina		1	1	0	0	10	6
Hydraenidae		0	0	1	0	2	0
Hydrobiosidae		0	0	0	1	0	0
Hydrometridae		0	0	0	0	0	0
Leptoceridae		2	8	6	5	10	10
Leptophlebiidae		10	4	8	6	10	6
Libellulidae		0	0	0	0	0	0
Megapodagrionidae		0	0	0	0	1	0
Naucoridae		0	0	0	0	0	0
Nematoda		0	0	0	0	0	0
Noteridae		0	0	1	1	3	7
Notonectidae		0	0	0	0	0	0
Odontoceridae		0	2	0	0	0	0
Oligochaeta		0	0	0	0	0	0
Oniscigastridae		0	0	4	1	2	0
Ostracoda		0	0	0	0	0	0
Philorheithridae		0	0	0	0	0	1
Pyralidae		0	0	0	0	0	0
Scirtidae		1	0	0	0	5	0
Sialidae		0	0	0	0	0	0
Synthemistidae		3	1	0	0	0	1
Telephlebiidae		0	0	1	0	3	2
Tipulidae		2	0	2	3	3	0
Veliidae		1	0	0	1	0	2
Total number of taxa		**12**	**9**	**13**	**12**	**19**	**16**

Appendix 6: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli West Study Area in (a) Spring 2008 and (b) Autumn 2009. **ND = no data.**

(a) Spring 2008

Order or Family	Wallandoola Ck		Lizard Creek		Loddon Ck	
	1	2	3	4	11	12
Ancylidae	0	13	0	43	0	1
Araneae	0	0	0	0	0	0
Athericidae	0	0	0	0	0	0
Austrocorduliidae	5	7	0	0	0	6
Ceratopogonidae	0	0	0	0	0	0
Chironomidae/Aphroteniinae	0	0	0	0	0	0
Chironomidae/Chironominae	66	89	0	449	0	186
Chironomidae/Orthocladiinae	4	4	0	8	0	35
Chironomidae/Tanypodinae	26	22	0	60	0	68
Cladocera	0	1	0	0	0	0
Copepoda	0	0	0	0	0	1
Corbiculidae/ Sphaeriidae	1	0	0	2	0	0
Corydalidae	0	0	0	1	0	0
Diptera	0	0	0	0	0	0
Dugesiidae	0	0	0	0	0	1
Dytiscidae	0	0	0	0	0	1
Ecnomidae	2	1	0	1	0	3
Elmidae	0	1	0	1	0	1
Empididae	2	0	0	1	0	0
Entomobryidae/Isotomidae	0	0	0	0	0	0
Glacidorbidae	0	0	0	0	0	0
Gripopterygiidae	26	0	0	1	0	3
Gyrinidae	2	0	0	2	0	0
Hydracarina	0	0	0	1	0	2
Hydridae	0	0	0	2	0	6
Hydrobiosidae	0	0	0	0	0	0
Hydrometridae	0	0	0	0	0	0
Hydroptilidae	0	0	0	0	0	0
Leptoceridae	21	5	0	0	0	5
Leptophlebiidae	67	88	0	76	0	38
Libellulidae	1	1	0	0	0	0
Megapodagrionidae	1	3	0	1	0	3
Nematoda	0	0	0	0	0	0
Notonemouridae	0	0	0	0	0	0
Oligochaeta	3	2	0	102	0	1
Oniscigastridae	0	0	0	0	0	0
Ostracoda	2	2	0	1	0	4
Physidae	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	0
Scirtidae	0	0	0	1	0	0
Synlestidae	0	0	0	0	0	0
Tanyderidae	0	0	0	0	0	0
Tipulidae	0	0	0	0	0	0

continued

Appendix 6 continued:

(b) Autumn 2009

	Wallandoola Ck		Lizard Creek		Loddon Ck	
Order or Family	1	2	3	4	11	12
Ancylidae	34	37	ND	0	0	0
Araneae	0	0	ND	0	0	0
Athericidae	0	0	ND	0	0	0
Austrocorduliidae	7	6	ND	0	0	0
Ceinidae	4	0	ND	0	0	0
Ceratopogonidae	0	0	ND	3	0	0
Chironomidae/Aphroteniinae	0	0	ND	0	0	0
Chironomidae/Chironominae	10	64	ND	128	64	86
Chironomidae/Orthocladiinae	5	3	ND	0	34	8
Chironomidae/Tanypodinae	13	52	ND	8	18	30
Cladocera	0	0	ND	3	0	0
Coenagrionidae	0	0	ND	0	0	0
Copepoda	3	0	ND	10	1	3
Corbiculidae/ Sphaeriidae	0	0	ND	4	0	2
Corydalidae	0	0	ND	0	0	1
Dixidae	0	0	ND	0	0	0
Dugesiidae	0	0	ND	0	0	0
Dytiscidae	0	0	ND	0	0	0
Ecnomidae	0	0	ND	0	0	3
Elmidae	0	0	ND	0	0	0
Empididae	0	1	ND	0	0	0
Gerridae	0	0	ND	0	0	0
Gomphidae	0	0	ND	0	0	0
Gripopterygiidae	3	0	ND	0	9	1
Gyrinidae	0	1	ND	1	0	0
Hydracarina	0	0	ND	3	0	1
Hydraenidae	0	0	ND	0	0	0
Hydridae	0	0	ND	3	0	0
Hydrobiosidae	0	0	ND	0	0	0
Hydrophilidae	0	0	ND	0	0	0
Hydroptilidae	0	0	ND	0	0	0
Leptoceridae	23	5	ND	1	3	12
Leptophlebiidae	14	15	ND	6	55	61
Megapodagrionidae	5	1	ND	0	0	0
Nematoda	0	0	ND	1	0	0
Nemertea	0	0	ND	0	0	0
Oligochaeta	8	98	ND	560	31	48
Ostracoda	0	1	ND	17	0	1
Planorbidae	0	0	ND	0	0	0
Psychodidae	0	0	ND	0	0	0
Scirtidae	0	0	ND	0	0	0
Tanyderidae	0	0	ND	0	0	0
Telephlebiidae	0	0	ND	0	1	1
Tipulidae	0	0	ND	0	0	0

Appendix 7: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli East Study Area in (a) Spring 2008; (b) Autumn 2009; (c) Spring 2009 and (d) Autumn 2010. ND = no data.

(a) Spring 2008

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	2	0	156	7	ND	ND
Araneae	0	1	0	0	ND	ND
Athericidae	0	0	0	1	ND	ND
Austrocorduliidae (=Corduliidae)	0	0	0	0	ND	ND
Ceratopogonidae	0	1	4	4	ND	ND
Chironomidae/Aphroteniinae	0	0	0	0	ND	ND
Chironomidae/Chironominae	406	110	663	818	ND	ND
Chironomidae/Orthocladiinae	94	1	4	28	ND	ND
Chironomidae/Tanypodinae	60	4	103	108	ND	ND
Cladocera	0	0	0	2	ND	ND
Copepoda	0	0	0	0	ND	ND
Corbiculidae/ Sphaeriidae	3	0	1	0	ND	ND
Corydalidae	1	0	0	1	ND	ND
Diptera	0	0	0	0	ND	ND
Dugesiidae	0	0	0	0	ND	ND
Dytiscidae	0	0	4	4	ND	ND
Ecnomidae	0	2	0	2	ND	ND
Elmidae	0	0	0	0	ND	ND
Empididae	12	0	1	7	ND	ND
Entomobryidae/Isotomidae	0	0	0	0	ND	ND
Glacidorbidae	0	0	5	0	ND	ND
Gripopterygiidae	0	0	5	4	ND	ND
Gyrinidae	7	1	2	5	ND	ND
Hydracarina	0	0	1	2	ND	ND
Hydridae	0	0	0	1	ND	ND
Hydrobiosidae	0	0	0	0	ND	ND
Hydrometridae	0	0	0	0	ND	ND
Hydroptilidae	0	0	1	0	ND	ND
Leptoceridae	2	1	2	4	ND	ND
Leptophlebiidae	9	21	78	76	ND	ND
Libellulidae	0	0	0	0	ND	ND
Megapodagrionidae	0	0	0	0	ND	ND
Nematoda	0	0	1	0	ND	ND
Notonemouridae	1	0	0	0	ND	ND
Oligochaeta	56	54	154	82	ND	ND
Oniscigastridae	0	0	0	0	ND	ND
Ostracoda	0	0	2	0	ND	ND
Physidae	0	0	1	0	ND	ND
Psychodidae	0	0	1	0	ND	ND
Scirtidae (= Helodidae, Cyphonidae)	0	0	0	0	ND	ND
Synlestidae	0	0	0	0	ND	ND
Tanyderidae	0	0	0	0	ND	ND
Tipulidae	1	0	0	0	ND	ND

continued

Appendix 7 continued:

(b) Autumn 2009

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	196	140	691	99	141	21
Araneae	1	0	0	0	0	0
Athericidae	11	0	4	1	0	0
Austrocorduliidae (=Corduliidae)	0	0	0	0	0	0
Ceinidae	0	0	0	0	0	0
Ceratopogonidae	2	12	14	7	4	1
Chironomidae/Aphroteniinae	0	0	2	0	0	0
Chironomidae/Chironominae	575	177	241	168	309	98
Chironomidae/Orthocladiinae	163	25	4	71	23	19
Chironomidae/Tanypodinae	150	126	176	106	202	47
Cladocera	0	0	2	1	21	0
Coenagrionidae	0	0	0	0	0	0
Copepoda	3	0	0	0	3	1
Corbiculidae/ Sphaeriidae	0	1	0	0	0	0
Corydalidae	3	2	0	0	0	0
Dixidae	0	0	1	0	0	0
Dugesiidae	0	0	2	0	0	2
Dytiscidae	0	0	3	4	0	2
Ecnomidae	2	6	0	8	2	1
Elmidae	0	0	3	1	5	2
Empididae	4	0	1	3	0	0
Gerridae	0	0	0	0	0	0
Gomphidae	0	0	2	0	0	0
Gripopterygiidae	1	3	0	4	2	0
Gyrinidae	1	4	1	2	4	1
Hydracarina	55	5	3	5	0	3
Hydraenidae (= Limnebiidae)	0	0	1	0	0	0
Hydridae	0	2	6	0	0	0
Hydrobiosidae	1	0	0	1	0	0
Hydrophilidae	0	0	7	2	0	0
Hydroptilidae	0	0	5	0	4	0
Leptoceridae	5	11	7	2	2	1
Leptophlebiidae	18	63	206	198	36	81
Megapodagrionidae	0	0	2	0	0	1
Nematoda	0	0	4	1	0	0
Nemertea	0	0	0	0	0	0
Oligochaeta	322	379	665	2298	209	47
Ostracoda	0	0	4	3	0	0
Planorbidae	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	1
Scirtidae (= Helodidae, Cyphonidae)	1	0	0	19	0	1
Tanyderidae	0	12	5	14	0	0
Telephlebiidae (=Aeshnidae)	0	0	0	0	1	1
Tipulidae	3	0	1	2	0	0

continued

Appendix 7 continued:

(c) Spring 2009

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	31	8	52	12	63	40
Ceratopogonidae	3	2	8	7	0	0
Chironomidae/Chironominae	273	230	248	320	266	41
Chironomidae/Orthocladiinae	0	3	0	5	0	0
Chironomidae/Tanypodinae	31	55	115	112	87	25
Copepoda	0	0	0	0	1	0
Corbiculidae/ Sphaeriidae	1	0	0	0	0	0
Cordulephyidae	0	0	1	0	0	0
Culicidae	0	0	0	0	1	0
Curculionidae	0	0	1	1	0	0
Dixidae	4	1	0	0	0	0
Dytiscidae	2	0	5	5	0	1
Ecnomidae	1	1	0	5	0	0
Elmidae	0	0	2	1	2	7
Empididae	3	3	5	9	4	1
Entomobryidae/Isotomidae	1	0	2	0	0	0
Glossiphoniidae	0	0	3	0	0	0
Glossosomatidae	0	0	0	0	1	0
Gomphidae	0	0	1	0	0	0
Gripopterygiidae	1	4	4	1	1	4
Gyrinidae	1	6	1	0	1	1
Helicopsychidae	0	0	1	0	0	0
Hydracarina	0	3	0	4	0	1
Hydrobiosidae	0	0	0	0	1	0
Hydrophilidae	0	0	7	0	0	0
Hydroptilidae	0	0	1	3	1	0
Leptoceridae	0	0	1	2	0	1
Leptophlebiidae	3	28	96	145	84	35
Megapodagrionidae	0	4	0	0	0	0
Oligochaeta	332	344	118	33	26	453
Ostracoda	0	0	3	8	3	0
Physidae	0	0	0	0	1	0
Psephenidae	0	0	0	2	0	0
Synlestidae	0	0	1	0	0	0
Tanyderidae	0	0	28	5	0	0
Telephlebiidae	0	0	0	1	0	1
Temnocephalidae	0	0	0	1	0	0
Thysanoptera	1	0	0	0	0	0

continued

Appendix 7: Continued

(d) Autumn 2010

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	26	33	1	15	55	49
Araneae	0	0	1	1	0	0
Athericidae	2	1	0	0	0	0
Calamoceratidae	0	0	1	0	0	1
Ceinidae	0	1	0	0	0	0
Ceratopogonidae	10	13	30	2	1	0
Chironomidae/Chironominae	575	360	304	236	273	330
Chironomidae/Orthocladiinae	40	0	32	65	2	15
Chironomidae/Tanypodinae	92	41	111	85	92	104
Copepoda	1	0	0	1	0	0
Corbiculidae/ Sphaeriidae	0	0	4	1	0	0
Corydalidae	5	1	1	5	1	0
Dixidae	1	0	4	1	1	0
Dolichopodidae	0	0	0	0	1	0
Dugesiidae	2	0	18	5	0	1
Dytiscidae	0	0	1	3	4	9
Ecnomidae	0	1	4	7	1	1
Elmidae	1	1	8	3	1	2
Empididae	15	0	2	7	3	10
Entomobryidae/Isotomidae	0	0	1	2	0	0
Gelastocoridae	0	0	0	1	0	0
Glossiphoniidae	0	0	2	0	1	0
Gordiidae	0	0	1	0	0	0
Gripopterygiidae	1	1	5	5	2	9
Gyrinidae	1	2	2	4	5	9
Helicopsychidae	0	0	0	0	1	1
Hydracarina	6	3	23	21	4	2
Hydraenidae	7	0	9	3	0	1
Hydridae	0	0	2	0	1	2
Hydrobiidae	1	0	0	0	0	0
Hydrobiosidae	3	0	0	8	0	8
Hydrophilidae	3	1	2	0	0	0
Hydroptilidae	0	0	3	0	3	2
Hypogastruridae	0	0	2	0	0	0
Leptoceridae	3	8	13	4	0	2
Leptophlebiidae	33	43	324	174	204	217
Megapodagrionidae	0	2	3	1	1	0
Nematoda	0	0	1	0	0	0
Nemertea	2	0	0	0	0	0
Noteridae	0	0	1	8	0	0
Oligochaeta	2759	267	251	54	20	17
Ostracoda	0	0	2	0	0	0
Physidae	0	0	1	0	0	0
Psephenidae	0	2	0	0	0	1
Psychodidae	1	3	0	0	0	0
Scirtidae	16	22	56	6	1	0
Simuliidae	0	0	0	1	0	1
Sminthuridae	0	0	1	0	0	0
Stratiomyidae	0	0	2	0	0	0
Tanyderidae	10	10	5	10	0	0
Telephlebiidae	0	0	2	1	0	1
Temnocephalidae	0	0	3	1	1	2
Tipulidae	3	4	1	0	0	0

Appendix 8: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli West in autumn 2009. Significant factors in bold.

Source	df	SS	MS	*F*	*p**
a)					
Location	2	14394	7197	1.11	0.399
Sites (Location)	**5**	**32344**	**6469**	**7.02**	**0.001**
Residual	56	51595	921		
Total	63	98333			
b)					
Location	2	7	3	0.11	0.916
Sites (Location)	**5**	**147**	**29**	**9.14**	**<0.001**
Residual	56	180	3		
Total	63	333			
c)					
Location	2	6	3.1	1.05	0.445
Sites (Location)	**5**	**15**	**2.9**	**9.22**	**<0.001**
Residual	56	18	0.3		
Total	63	38			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 9: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2009. Significant factors in bold.

Source	df	SS	MS	*F*	*p**
a)					
Location	2	5265	2632	1.35	0.090
Sites (Location)	**3**	**5938**	**1980**	**3.93**	**<0.001**
Residual	38	19142	504		
Total	43	30852			
b)					
Location	**2**	**18.9**	**9.5**	**14.51**	**0.012**
Sites (Location)	3	1.7	0.6	0.08	0.969
Residual	38	255.0	6.7		
Total	43	277.0			
c)					
Location	2	6.5	3.2	8.11	0.057
Sites (Location)	3	1.2	0.4	2.74	0.051
Residual	38	5.6	0.1		
Total	43	13.0			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 10: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in spring 2009. Significant factors in bold.

Source	df	SS	MS	*F*	*p* *
a)					
Location	2	10335	5167	2.26	0.060
Sites (Location)	**3**	**6872**	**2291**	**2.52**	**<0.001**
Residual	42	38148	908		
Total	47	55355			
b)					
Location	**2**	**115.8**	**57.9**	**15.02**	**0.028**
Sites (Location)	3	11.6	3.9	0.78	0.519
Residual	42	208.6	5.0		
Total	47	336.0			
c)					
Location	2	0.40	0.20	2.41	0.232
Sites (Location)	3	0.25	0.08	0.32	0.821
Residual	42	11.03	0.26		
Total	47	11.69			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 11: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2010. Significant factors in bold.

Source	df	SS	MS	*F*	*p**
a)					
Location	**2**	**12057**	**6028**	**3.65**	**0.004**
Sites (Location)	**3**	**4956**	**1652**	**2.17**	**0.002**
Residual	41	31193	761		
Total	46	48390			
b)					
Location	2	654230	327120	1.10	0.437
Sites (Location)	**3**	**894870**	**298290**	**1.82**	**0.005**
Residual	41	6705000	163540		
Total	46	8251500			
c)					
Location	2	2.63	1.32	0.79	0.554
Sites (Location)	**3**	**4.97**	**1.66**	**5.99**	**<0.001**
Residual	41	11.35	0.28		
Total	46	18.95			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 12: Geographic location and caudal length of each specimen of Macquarie Perch sampled by back pack electrofishing in Cataract Creek in (a) 15 December 2009; (b) 8 January 2010; (c) 29 January 2010, and (d) 25 February 2010. GPS data is datum: WGS 84 zone: 56H

a. 15 December 2009

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301660	6197447	80	1.1
301660	6197447	90	1.2
301759	6197509	140	1.3

b. 8 January 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301652	6197442	80	2.1
301652	6197442	180	2.2
301652	6197442	125	2.3
301652	6197442	125	2.4
301909	6197469	105	2.5
302059	6197405	120	N/A

c. 29 January 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301655	6197449	80	3.1
301655	6197449	190	3.2
301942	6197445	165	3.3
301942	6197445	100	3.4
302086	6197404	100	3.5
302162	6197431	155	3.6

d. 25 February 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301376	6197498	230	4.1
301623	6197414	145	4.2
301623	6197414	190	4.3
301623	6197414	175	4.4
301623	6197414	100	4.5
301623	6197414	130	4.6
301650	6197442	200	4.7
301650	6197442	95	4.8
301901	6197467	95	4.9
301901	6197467	190	4.10
301978	6197412	155	4.11
302173	6197413	95	4.12
302372	6197376	175	4.13
302432	6197382	130	4.14
302432	6197382	180	4.15

Appendix 13: Geographic location and caudal length of each specimen of Macquarie Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011. GPS data is datum: WGS 84 zone: 56H

a. 8 December 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301719	6197488	370	1.1
301847	6197467	155	1.2
301874	6197472	185	1.3
301969	6197415	180	1.4
302018	6197406	150	1.5
302168	6197424	190	1.6
302254	6197398	130	1.7
302341	6197377	130	1.8
302366	6197386	210	1.9
302366	6197386	130	1.10
302435	6197400	125	1.11

b. 7 January 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301674	6197464	150	2.1
301701	6197481	195	2.2
301749	6197502	105	2.3
301849	6197470	190	2.4
301849	6197470	125	2.5
301849	6197470	150	2.6
301977	6197410	180	2.7
302016	6197405	130	2.8
302116	6197412	135	2.9
302139	6197412	145	2.10
302174	6197414	225	2.11
302174	6197414	175	2.12
302174	6197414	200	2.13
302256	6197404	120	2.14

c. 25 January 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301698	6197480	150	3.1
301698	6197480	135	3.2
301726	6197497	120	3.3
301726	6197497	135	3.4
301726	6197497	120	3.5
301726	6197497	100	3.6
301726	6197497	215	3.7
301726	6197497	145	3.8
301726	6197497	115	3.9
301726	6197497	90	3.10
301726	6197497	135	3.11
301763	6197504	175	3.12
301763	6197504	260	3.13
301847	6197463	150	3.14
301847	6197463	155	3.15
301847	6197463	215	3.16
301847	6197463	170	3.17
301939	6197448	150	3.18
301939	6197448	145	3.19
301963	6197424	190	3.20

Appendix 13 continued:

c. 25 January 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301963	6197424	165	3.21
301963	6197424	180	3.22
302113	6197403	155	3.23
302144	6197406	150	3.24
302169	6197405	150	3.25
302169	6197405	200	3.26
302169	6197405	245	3.27
302169	6197405	220	3.28
302169	6197405	170	3.29
302169	6197405	190	3.30
302169	6197405	140	3.31
302301	6197405	115	3.32
302301	6197405	140	3.33
302357	6197382	135	3.34
302357	6197382	140	3.35
302514	6197434	125	3.36
302515	6197432	175	3.37

d. 21 February 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301598	6197401	255	4.1
301598	6197401	180	4.2
301598	6197401	135	4.3
301598	6197401	210	4.4
301621	6197423	160	4.5
301621	6197423	125	4.6
301621	6197423	245	4.7
301635	6197436	165	4.8
301710	6197487	120	4.9
301710	6197487	115	4.10
301710	6197487	110	4.11
301710	6197487	120	4.12
301710	6197487	170	4.13
301710	6197487	130	4.14
301710	6197487	170	4.15
301754	6197505	175	4.16
301754	6197505	165	4.17
301847	6197460	120	4.18
301847	6197460	135	4.19
301971	6197412	205	4.20
301971	6197412	165	4.21
302143	6197407	190	4.22
302144	6197406	235	4.23
302144	6197406	150	4.24
302144	6197406	110	4.25
302264	6197375	145	4.26
302517	6197384	180	4.27
302517	6197384	170	4.28

Appendix 14: Mean (± S.E.) water quality parameters recorded in Cataract Creek downstream of the confluence with Cataract River and at Site 6 the most upstream site sampled during the targeted Macquarie Perch surveys undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.

A. Summer 2009/2010

Date	15/12/2009		15/12/2009		8/01/2010		8/01/2010		29/01/2010		29/01/2010		25/02/2010		25/02/2010	
Creek	Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek	
Site	confluence w/ Cataract River		6		confluence w/ Cataract River		6		confluence w/ Cataract River		Near Full Supply Level		confluence w/ Cataract River		Near Full Supply Level	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature °C	21.8	0.0	17.0	0.0	20.1	0.0	18.0	0.0	19.6	0.0	22.3	0.0	19.9	0.3	16.5	0.0
Conductivity (µS/cm)	111.5	6.5	121.0	0.0	109.0	0.0	39.0	9.0	45.0	20.0	91.5	18.5	FP	FP	199.5	7.5
pH	6.6	0.0	6.7	0.0	6.6	0.0	6.7	0.0	7.2	0.1	7.1	0.0	FP	FP	6.8	0.0
ORP (mV)	278.5	3.5	388.0	2.0	267.0	1.0	407.5	0.5	379.5	10.5	349.0	3.0	FP	FP	FP	FP
DO (mg/L)	13.4	0.2	7.9	0.2	9.2	0.0	12.1	0.5	2.3	0.0	3.6	0.3	FP	FP	8.5	0.2
DO (%sat'n)	145.0	5.0	81.0	5.7	100.3	1.6	126.7	6.0	24.7	0.3	40.6	1.8	FP	FP	85.4	0.8
Turbidity (ntu)	10.9	0.1	5.5	0.1	5.4	0.1	4.1	0.1	6.1	0.1	9.2	1.5	FP	FP	FP	FP

B. Summer 2010/2011

Date	8/12/2010		8/12/2010		7/01/2011		7/01/2011		25/01/2011		25/01/2011		21/02/2011		21/02/2011	
Creek	Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek	
Site	confluence w/ Cataract River		6		confluence w/ Cataract River		6		confluence w/ Cataract River		Near Full Supply Level		confluence w/ Cataract River		Near Full Supply Level	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature °C	24.9	0.0	17.4	0.0	21.7	0.0	16.6	0.0	18.5	0.5	25.3	0.1	19.0	0.0	25.6	0.0
Conductivity (µS/cm)	FP	FP	120.0	0.0	109.0	0.0	131.0	0.0	FP	FP	FP	FP	179.0	2.0	134.0	4.0
pH	5.6	0.0	6.1	0.0	6.3	0.0	6.6	0.0	6.8	0.0	7.0	0.0	6.6	0.0	6.7	0.1
ORP (mV)	436.0	3.0	441.5	0.5	437.5	7.5	390.5	12.5	277.0	2.0	330.0	1.0	362.5	0.5	325.0	5.0
DO (mg/L)	5.4	0.0	4.2	0.1	4.7	0.1	2.9	0.5	4.8	0.1	8.2	0.4	20.0	0.0	20.0	0.0
DO (%sat'n)	64.8	2.4	43.8	1.3	54.3	0.8	29.2	4.1	97.3	4.5	51.4	0.6	300.0	0.0	163.8	136.3
Turbidity (ntu)	5.4	0.3	11.6	0.2	4.4	0.2	15.5	0.7	2.1	0.3	17.6	1.9	2.2	0.5	22.7	0.3

Appendix 15: Geographic co-ordinates of each specimen of Freshwater Cod and Silver Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011. GPS data is datum: WGS 84 zone: 56H.

a. 8 December 2010

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301874	6197472	1	0
302018	6197406	1	0
302168	6197424	1	0
302435	6197400	2	0

b. 7 January 2011

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301701	6197481	1	0
301749	6197502	3	0
301849	6197470	1	0
302139	6197412	1	0
302174	6197414	1	0
302256	6197404	1	0

c. 25 January 2011

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301698	6197480	2	1
301763	6197504	5	1
301847	6197463	1	1
301963	6197424	2	1
302030	6197409	1	0
302113	6197403	2	0
302169	6197405	1	0
302357	6197382	3	1
302515	6197432	1	0

d. 21 February 2011

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301390	6197492	4	0
301598	6197401	2	0
301621	6197423	1	1
301635	6197436	3	0
301710	6197487	1	0
301754	6197505	1	0
301847	6197460	2	1
301971	6197412	2	2
302143	6197407	2	0
302144	6197406	0	0
302264	6197375	5	0
302517	6197384	1	0