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

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
	1 electronic copy	ERM Australia Pty Ltd

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

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

TABLE OF CONTENTS

FIGURES

TABLES

DRAWINGS

APPENDICES

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;
    - o Great Artesian Basin - Eastern Recharge and Southern Recharge;
    - o 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.

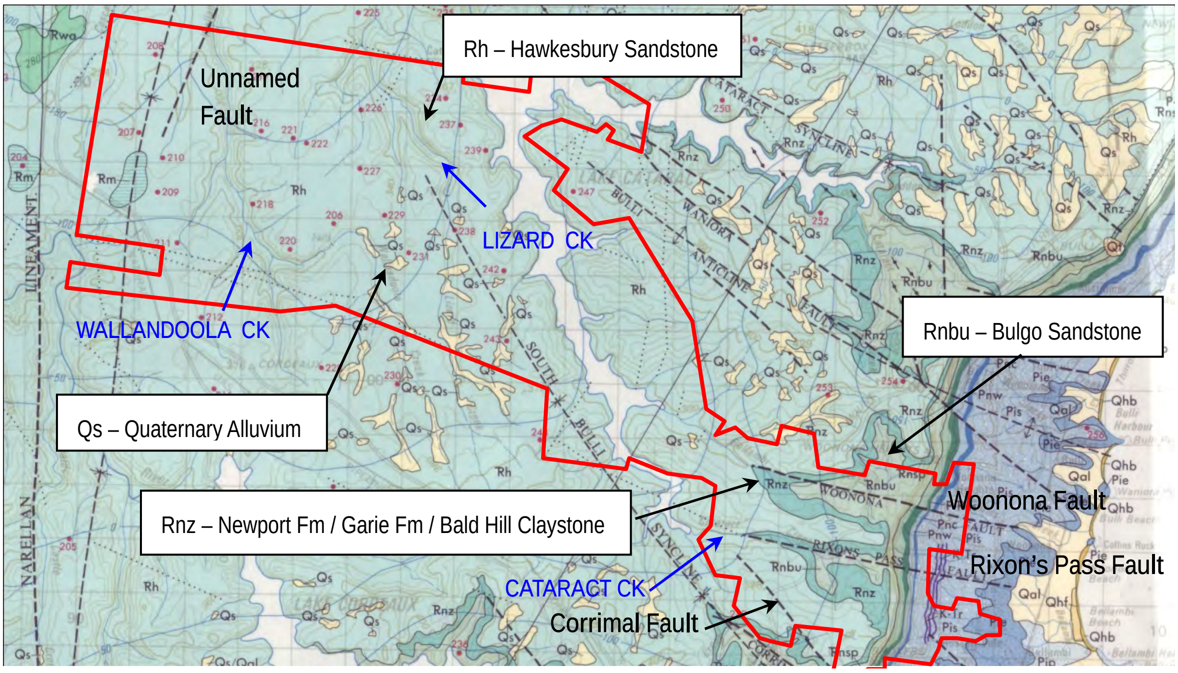


Figure 1 Surficial Geology

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**.

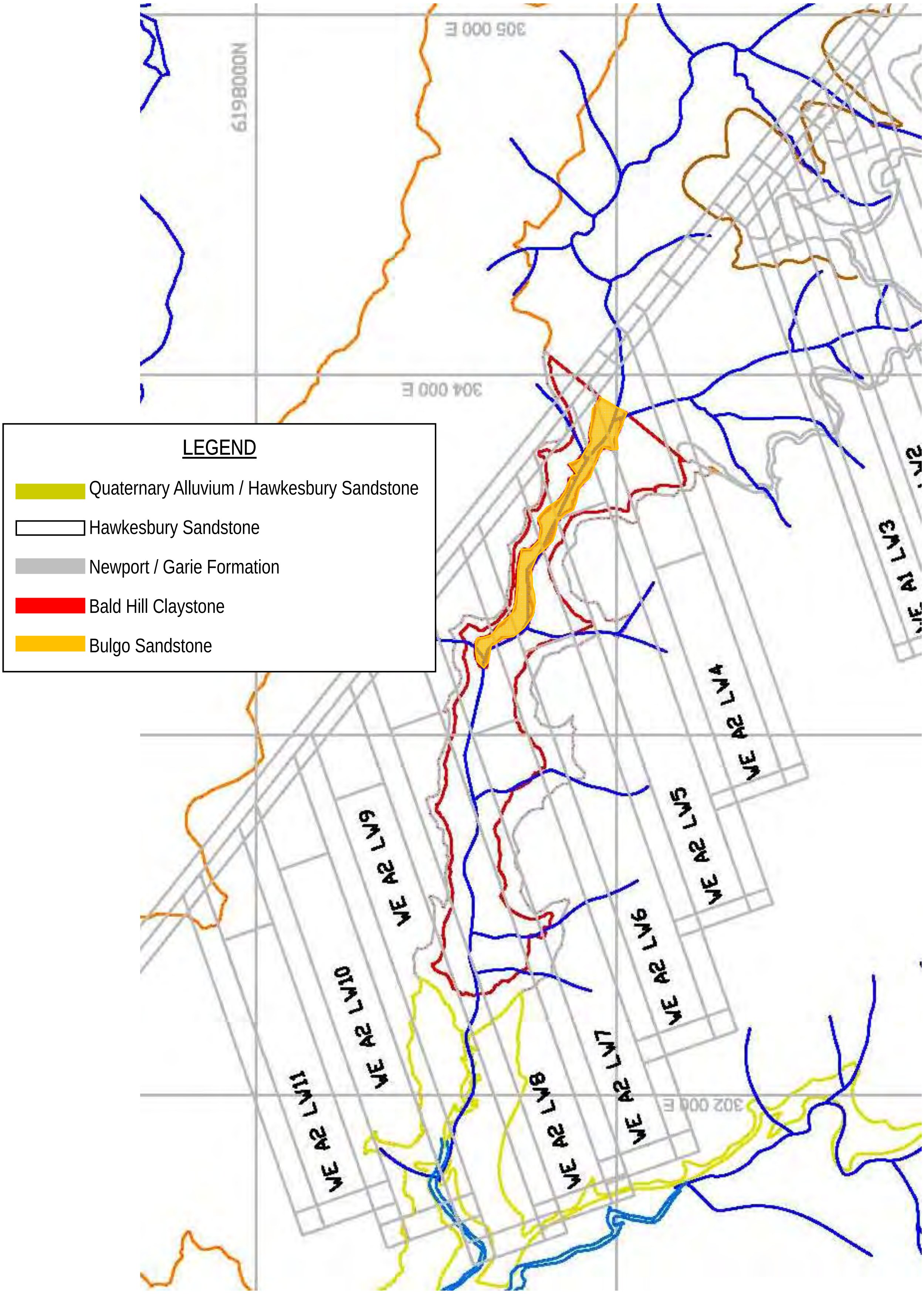


Figure 2 Cataract Creek Outcrop Geology

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.

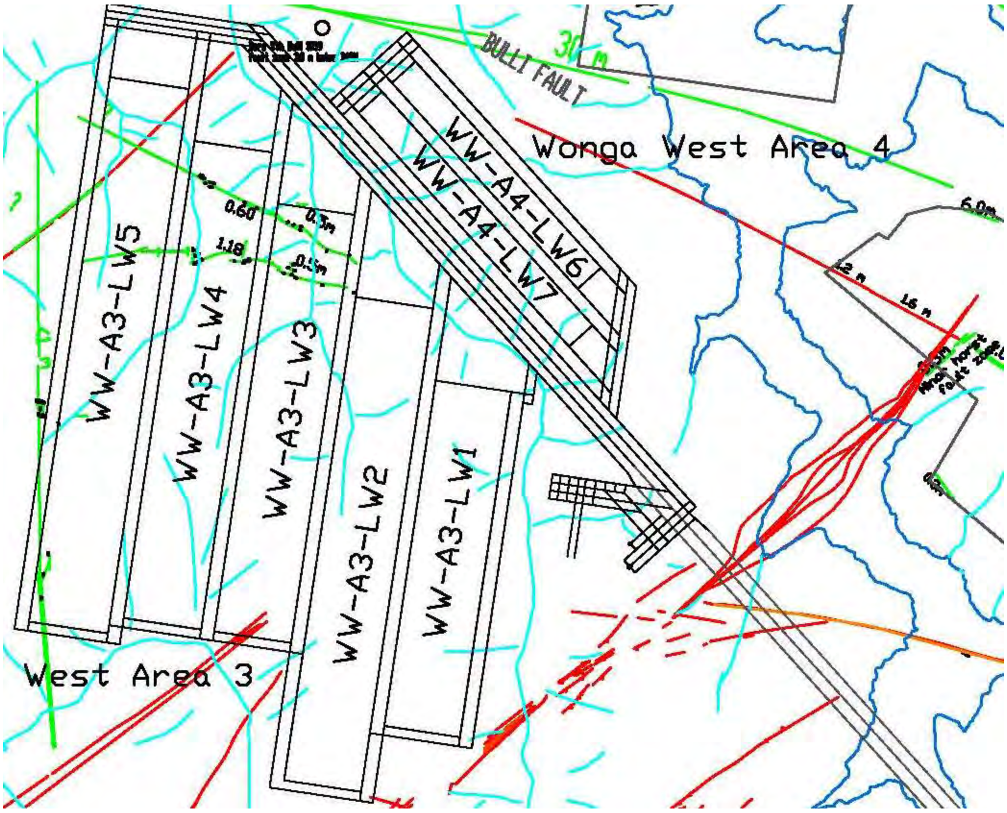


Figure 3 Wonga West Bulli Seam Structures

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**.

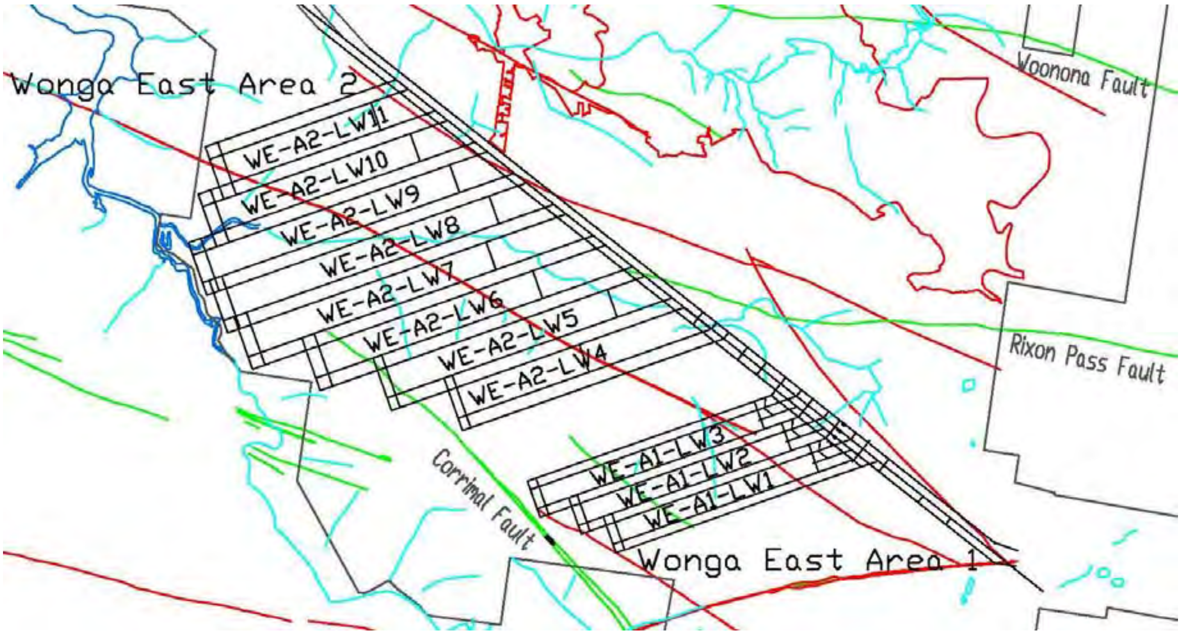


Figure 4 Wonga East Bulli Seam Structures

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.

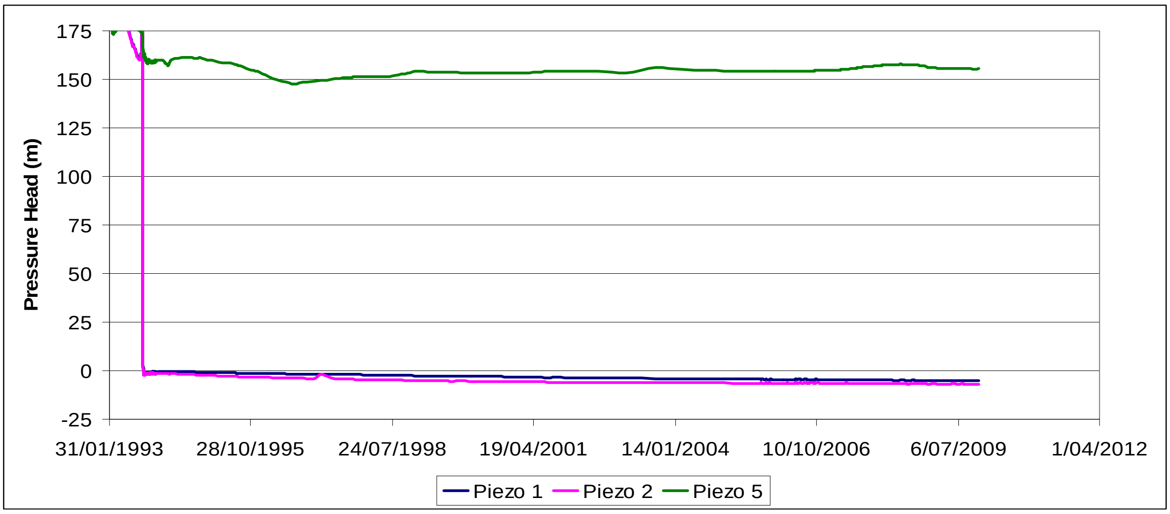


Figure 5 Longwall 501 Water Pressures

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.

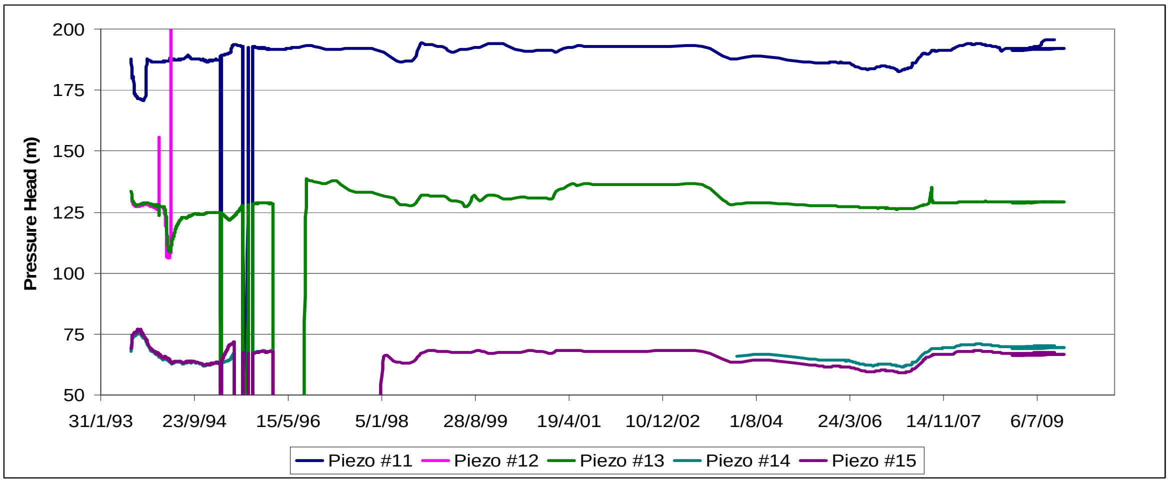


Figure 6 Longwall 502 Water Pressures

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.

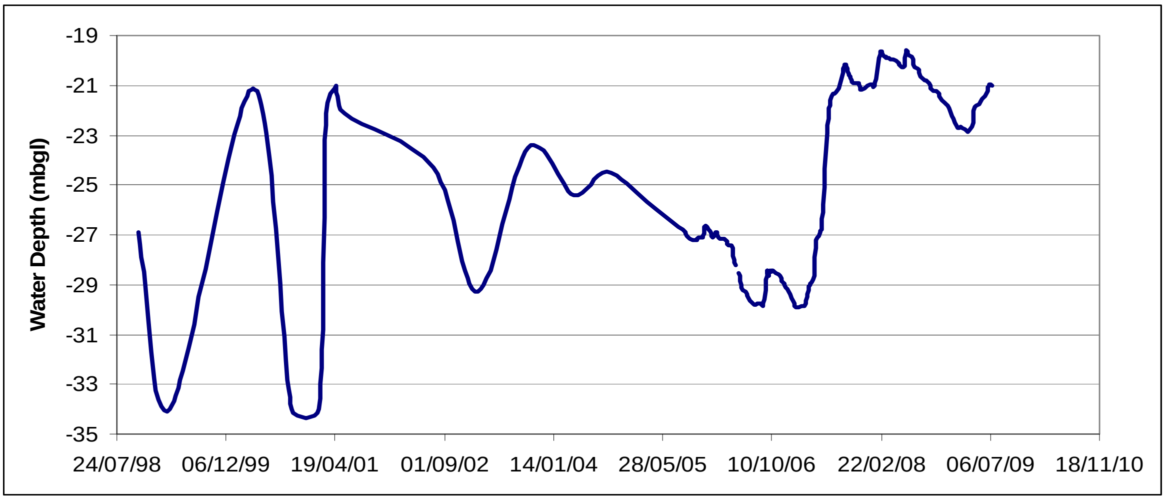


Figure 7 Piezometer 514 Groundwater Levels

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**.

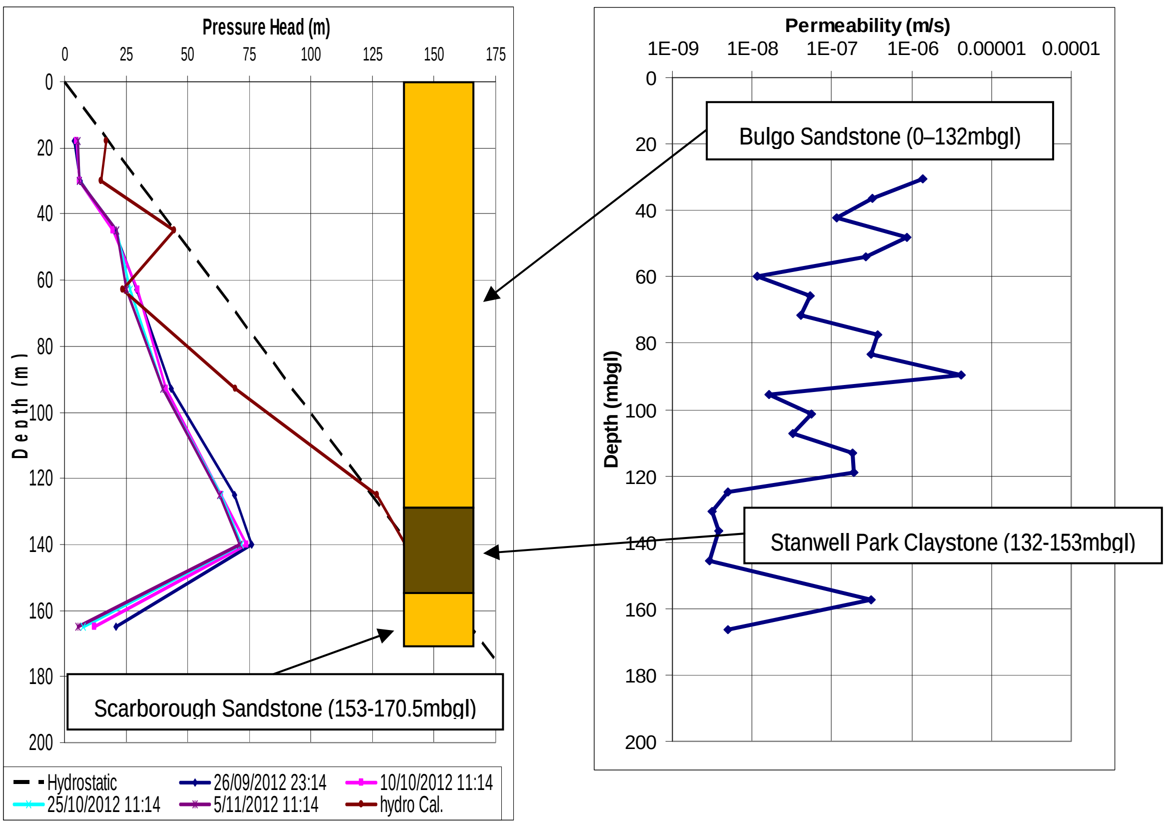


Figure 8 GW1 Pressure Head and Packer Test Data

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

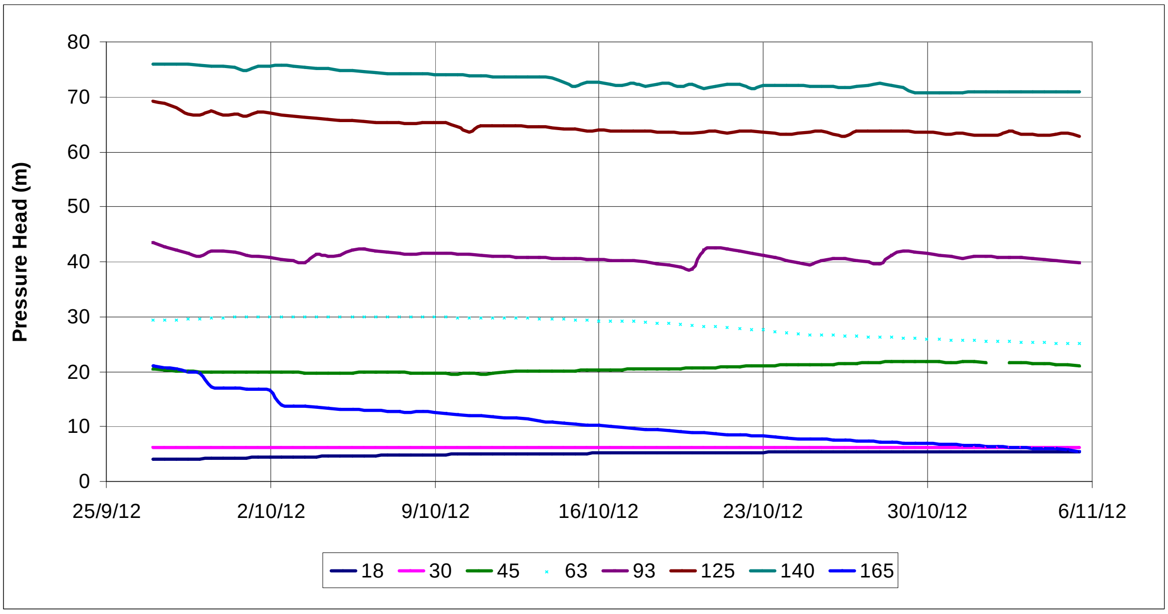


Figure 9 GW1 Pressure Head vs Time

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**.

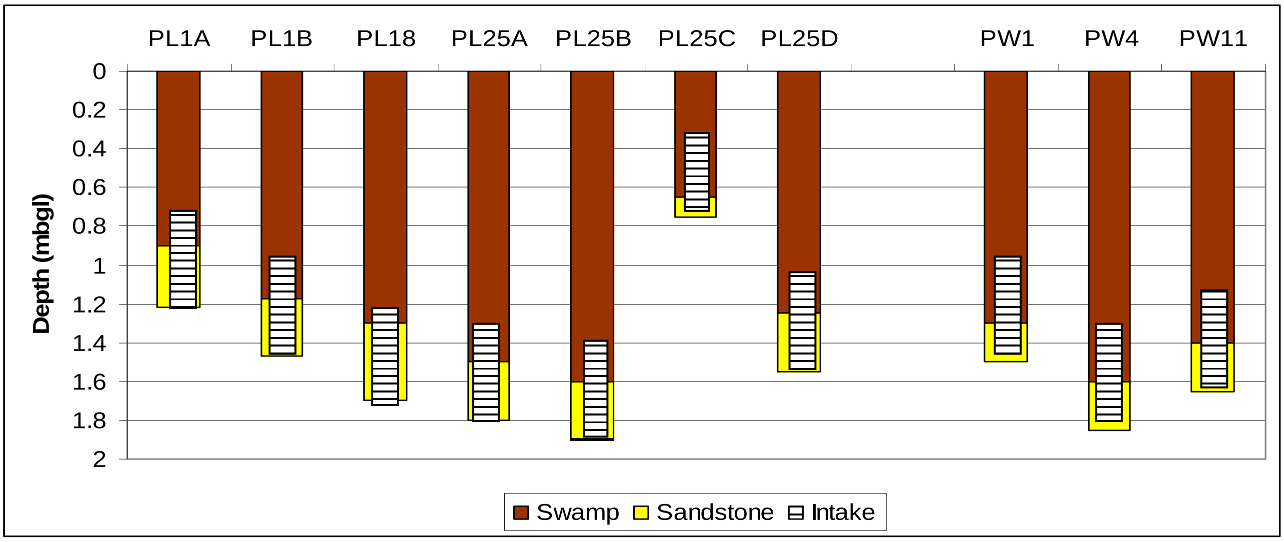


Figure 10 Wonga West Swamp Piezometers

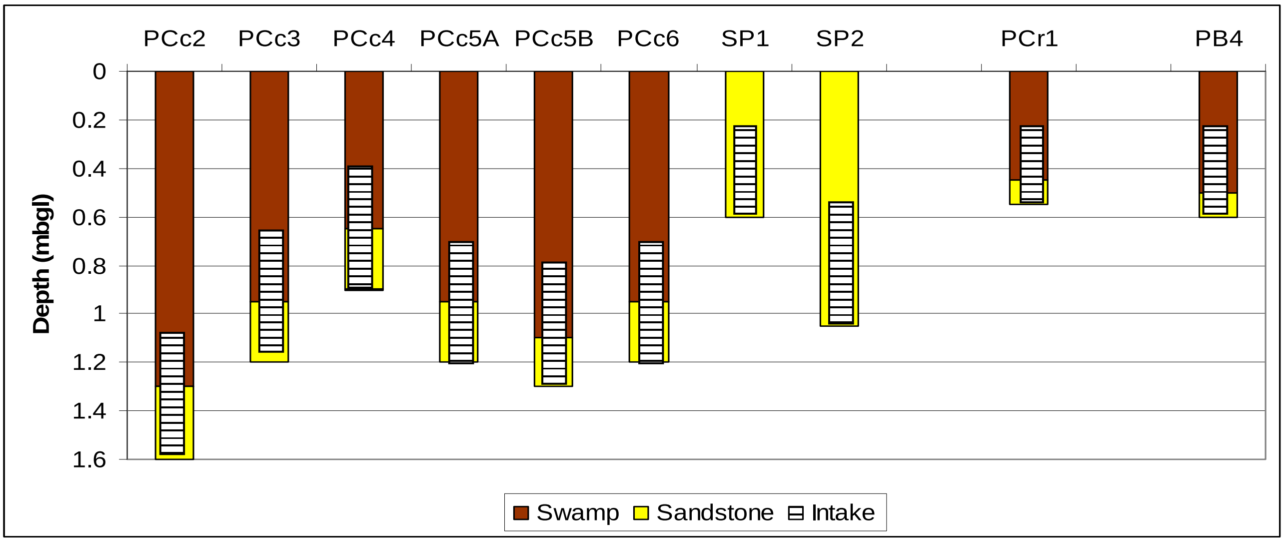


Figure 11 Wonga East Swamp Piezometers

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**.

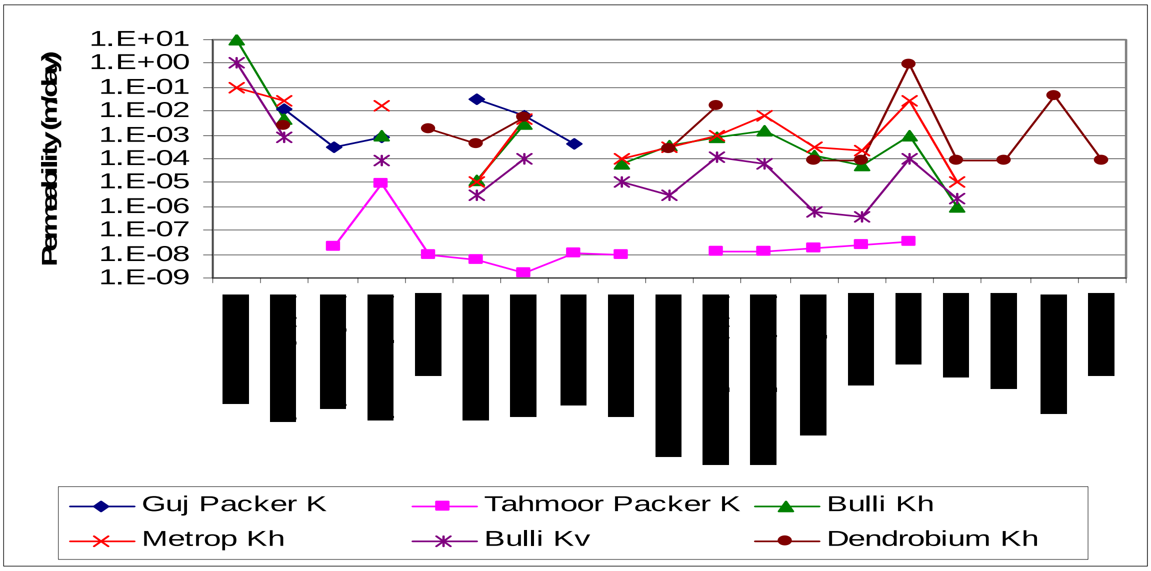


Figure 12 Regional Hydraulic Conductivities Vs Depth

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.

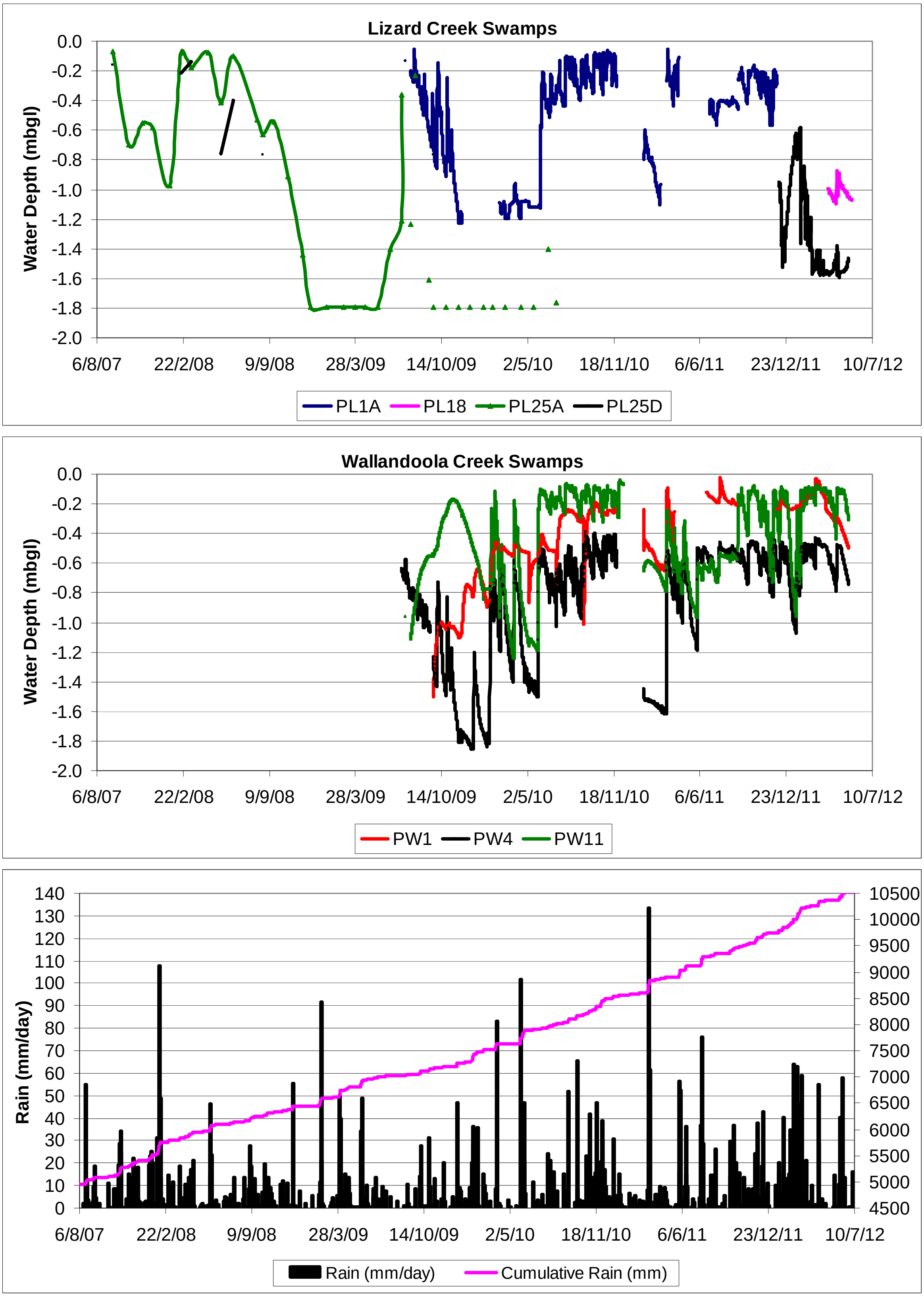


Figure 13 Wonga West Swamp Standing Water Levels and Rainfall

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.

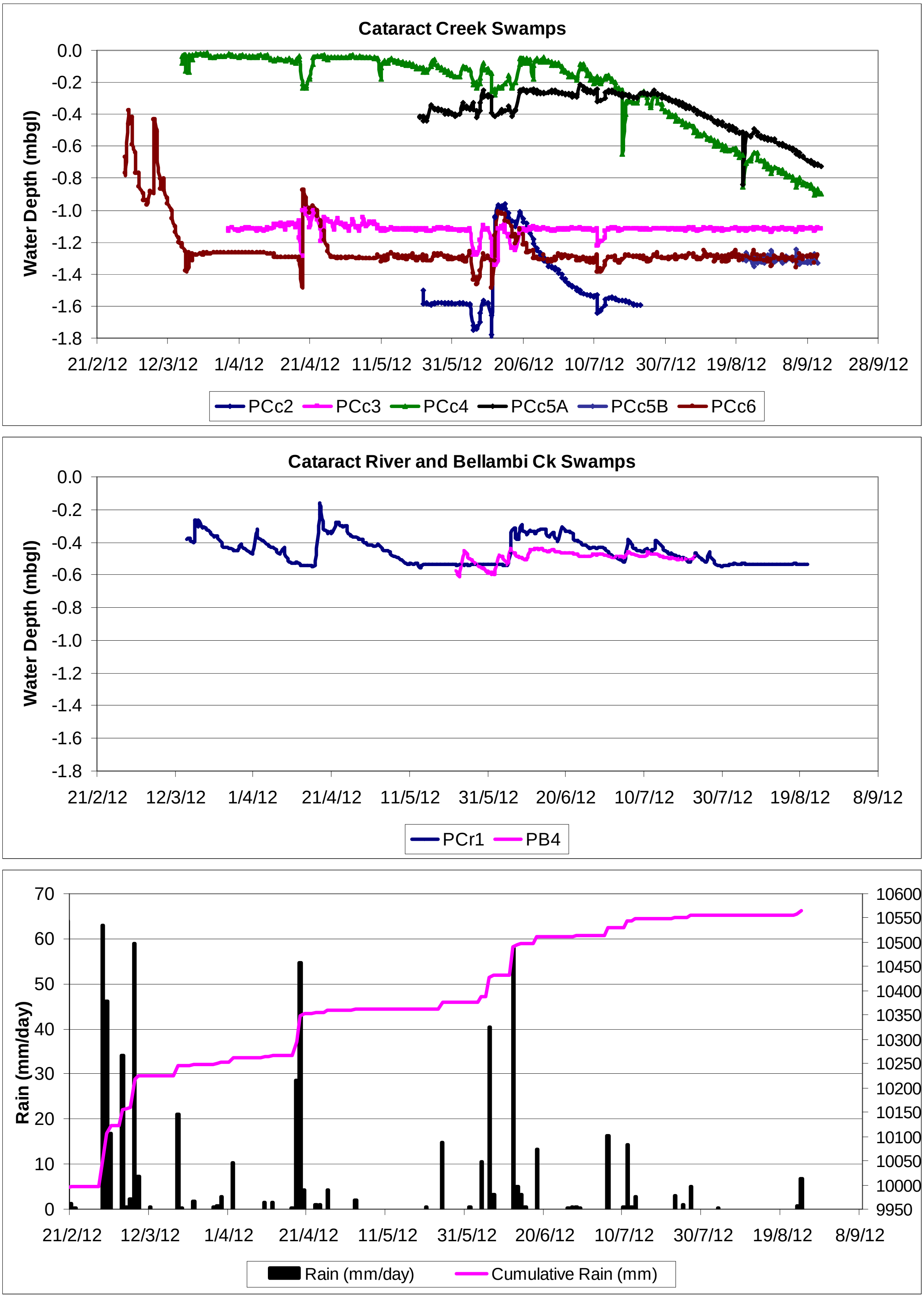


Figure 14 Wonga West Swamp Standing Water Levels and Rainfall

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.

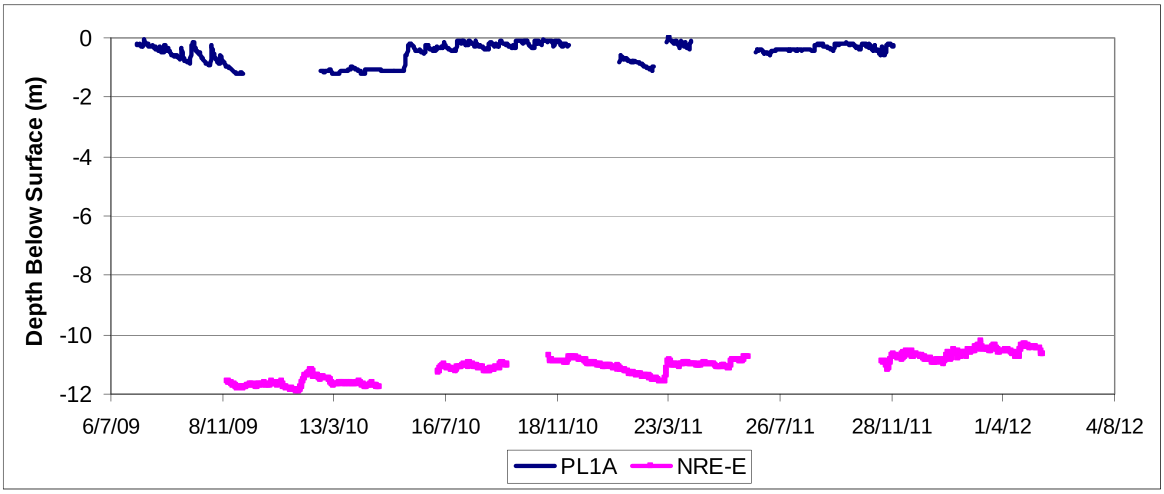


Figure 15 Wonga West Upland Swamp and Hawkesbury Sandstone Water Levels

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.

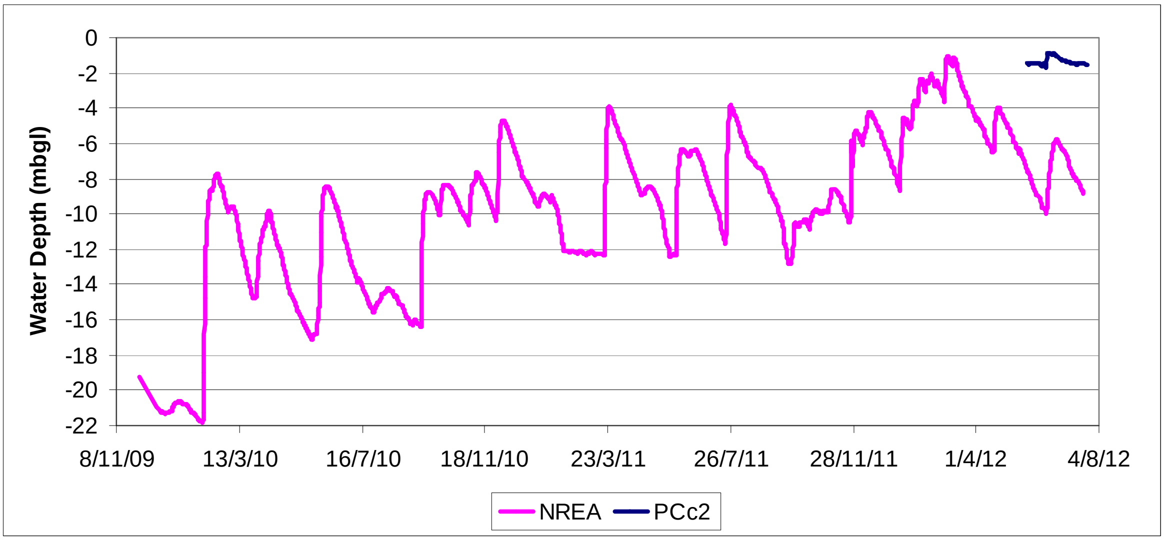


Figure 16 Wonga East Upland Swamp and Hawkesbury Sandstone Water Levels

10.4 Hawkesbury Sandstone Open Standpipe Water levels

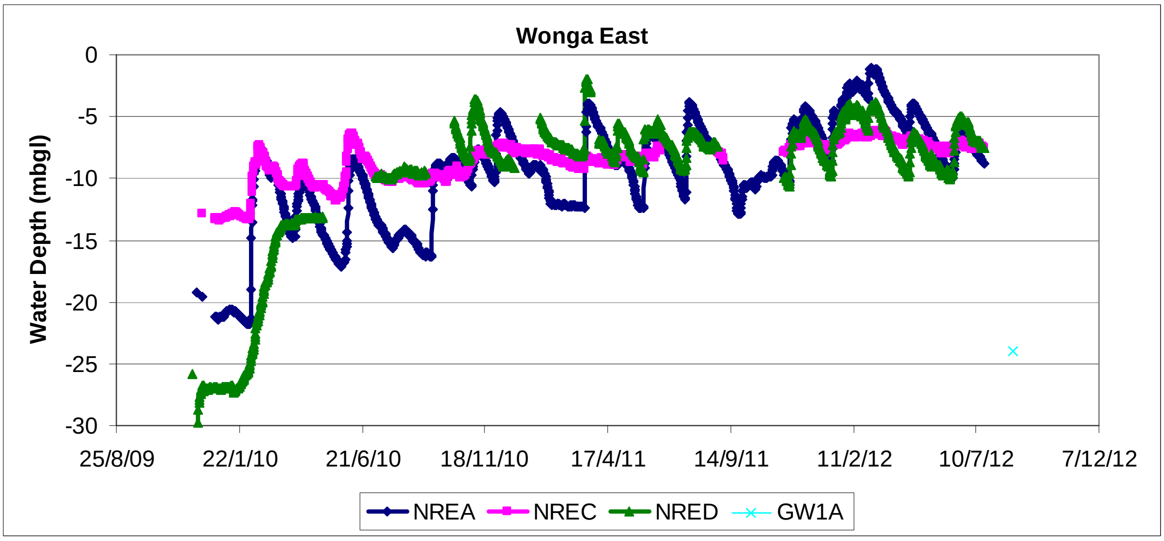
Water levels from open standpipe piezometers installed in the upper Hawkesbury Sandstone are shown in **Figure 17** from locations shown in **Drawing 1**.

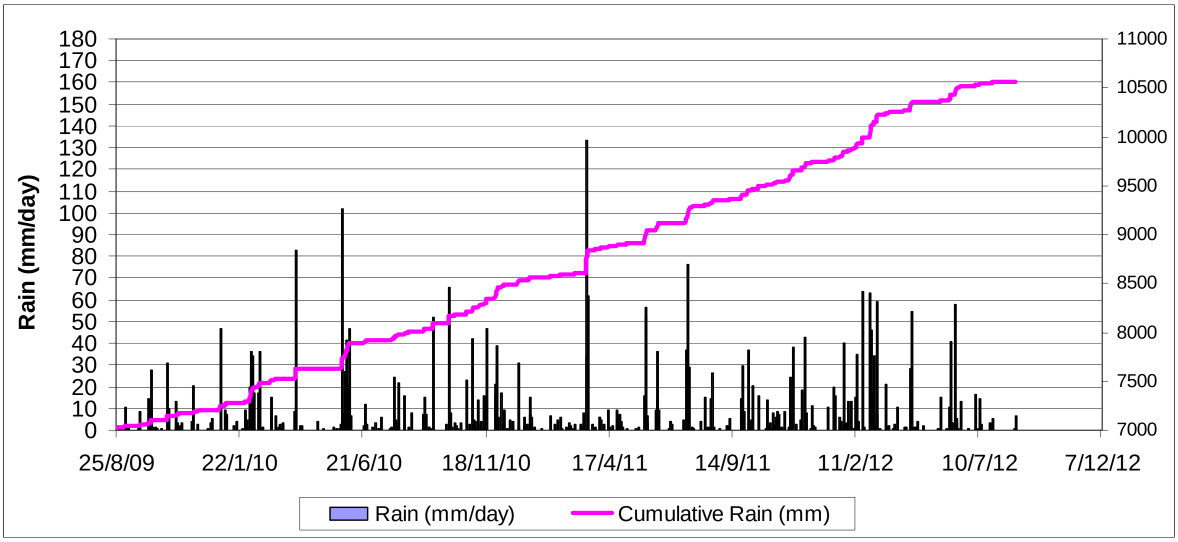
The Wonga East piezometers are generally more responsive to rainfall than at Wonga West (except for NE3) as shown in **Table 7**.

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.





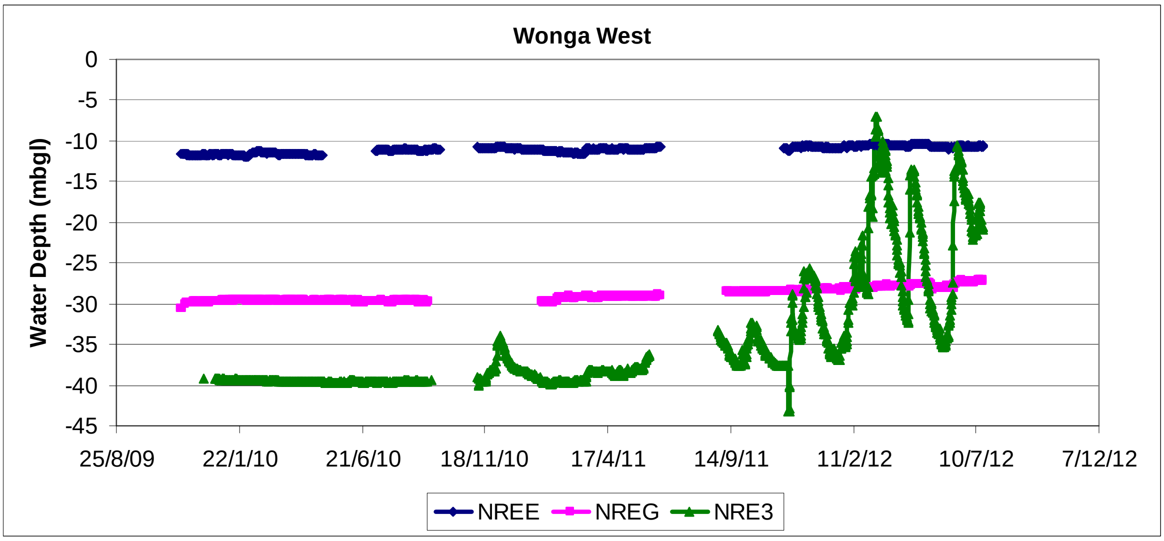


Figure 17 Hawkesbury Sandstone Water Levels and Rainfall

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.

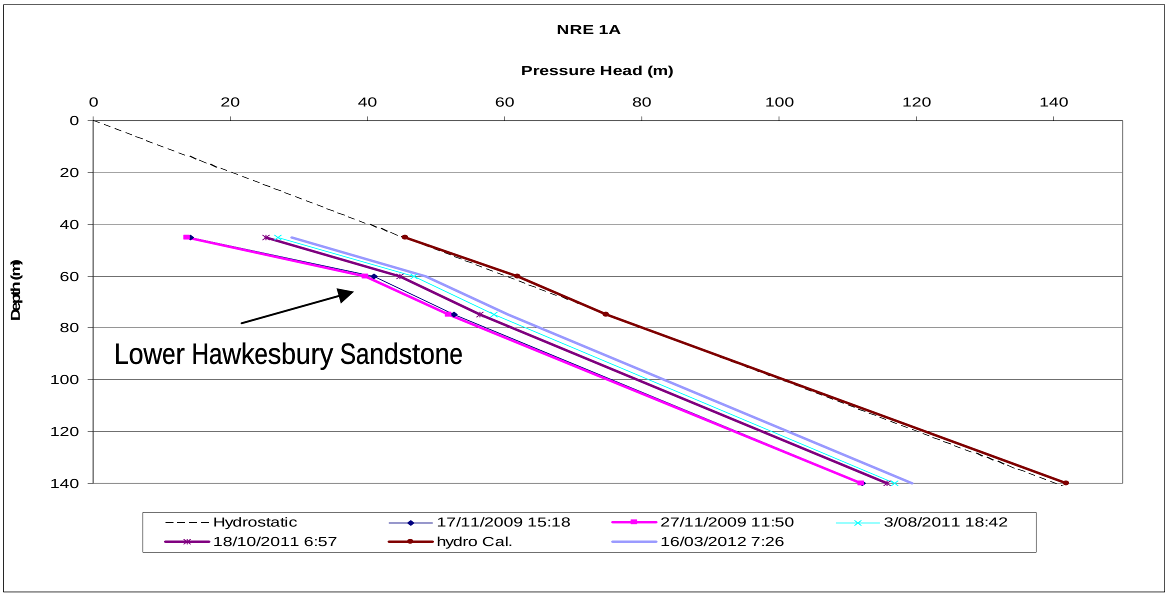
Table 8 Vibrating Wire Piezometers

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.



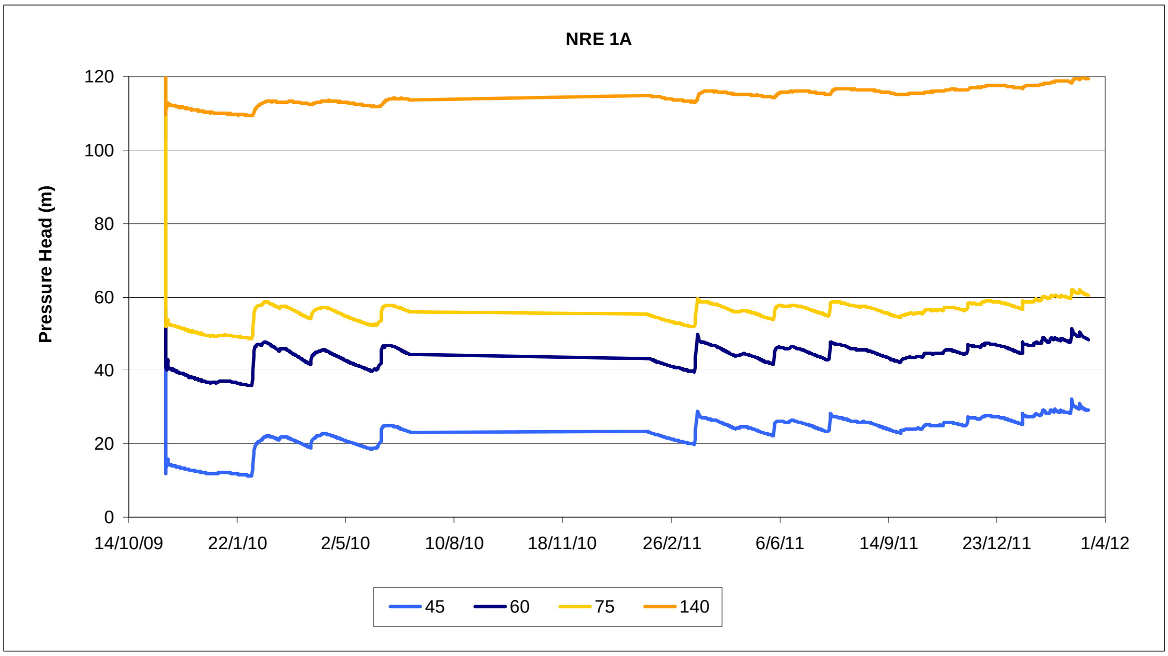


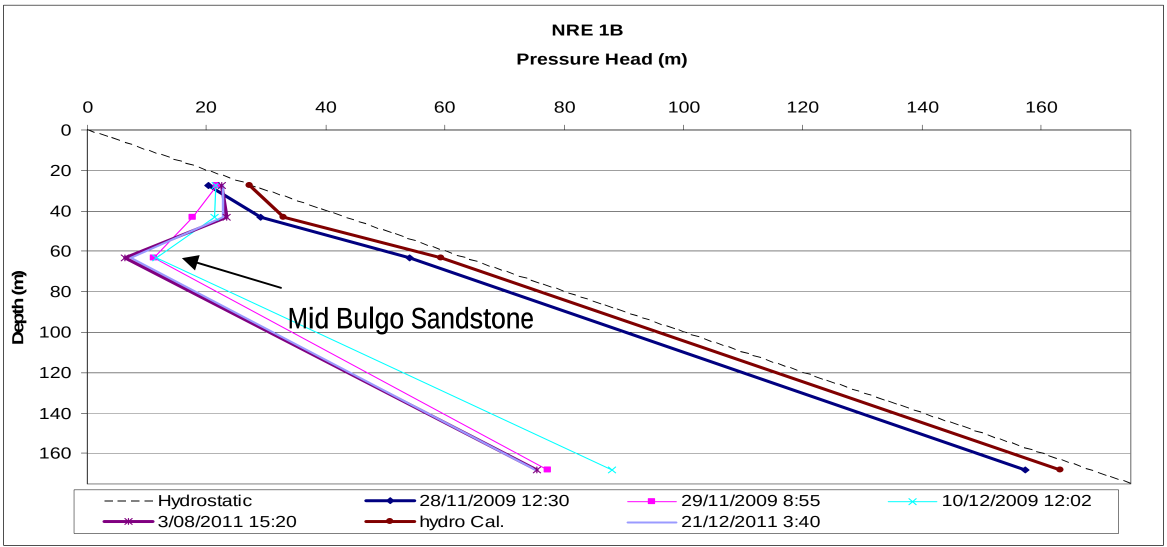
Figure 18 Wonga East NRE-A VWP Pressure Head Levels

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.



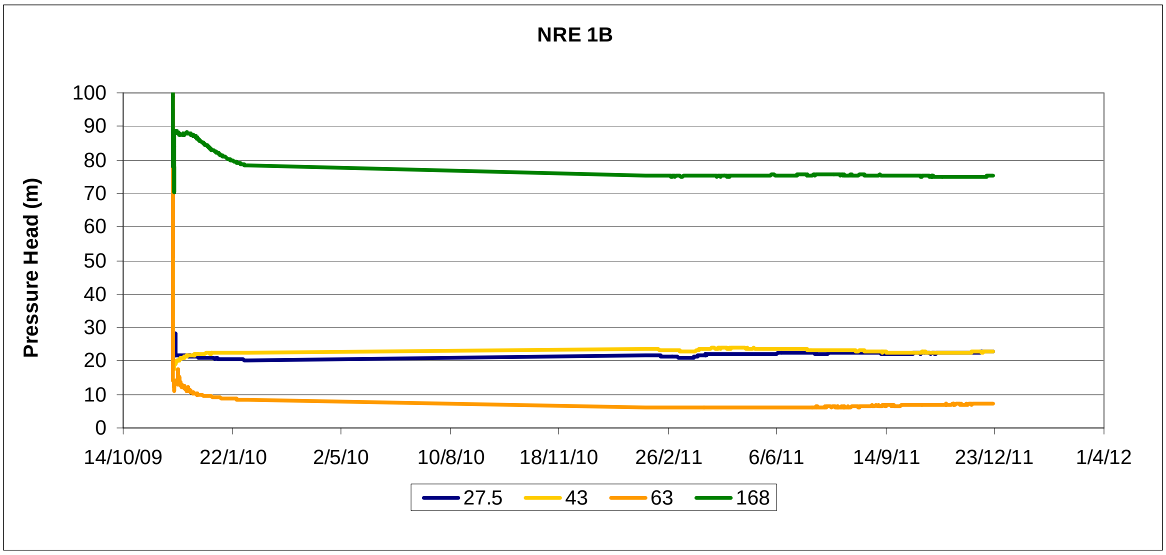
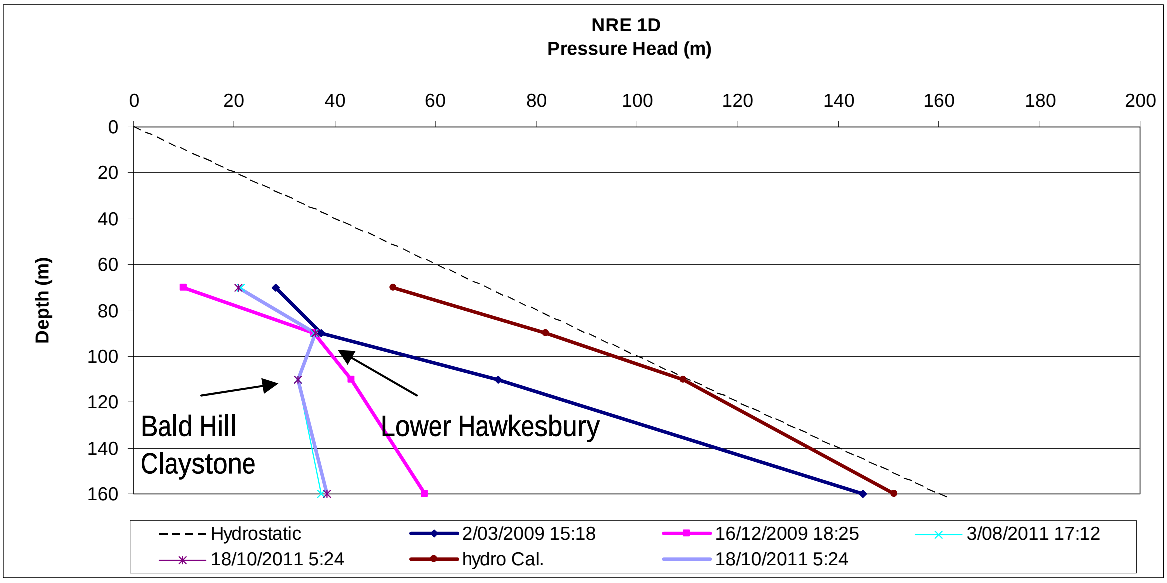


Figure 19 Wonga East NRE-1B VWP Pressure Head

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.



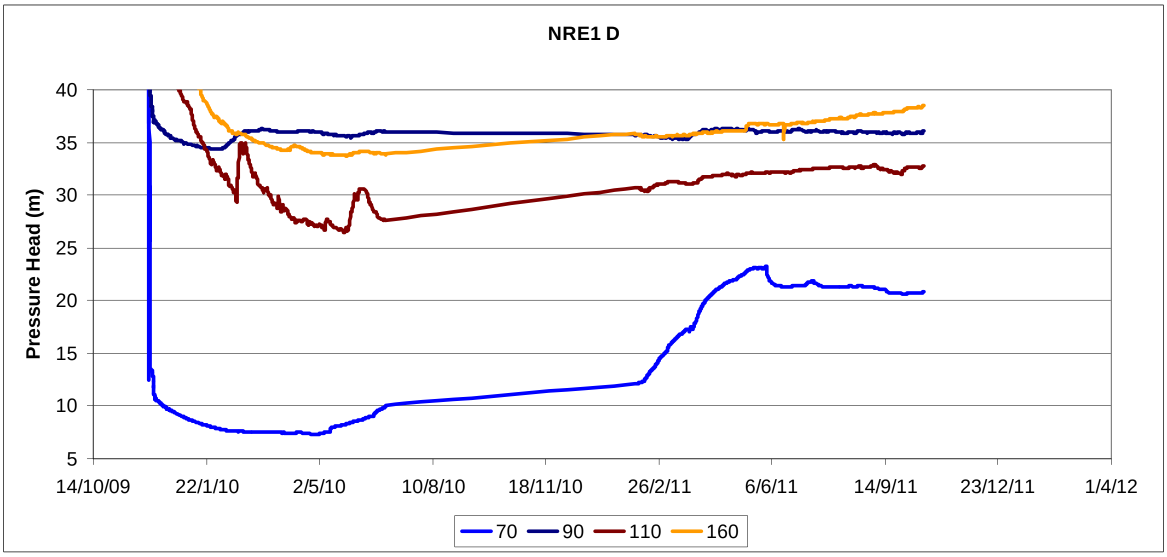
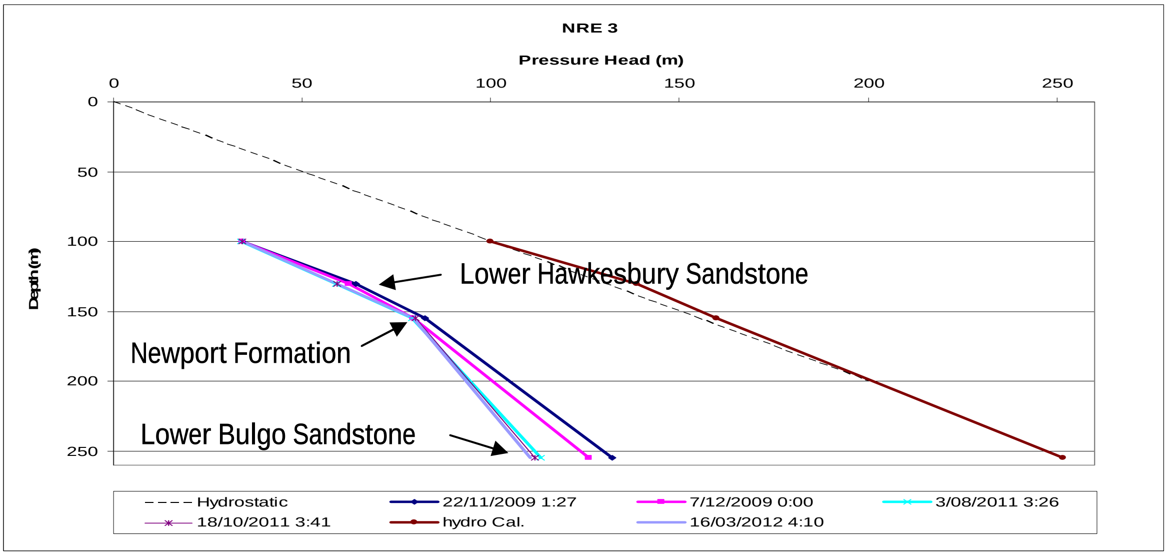


Figure 20 Wonga East VWP Pressure Head

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.



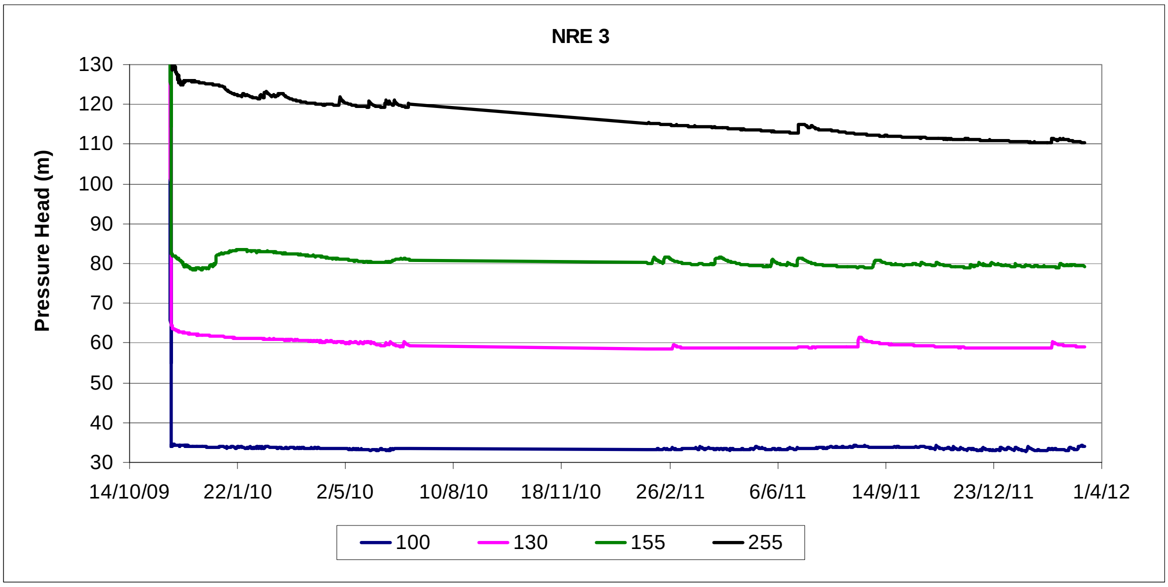


Figure 21 Wonga West NRE-3 VWP Pressure Head

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**.

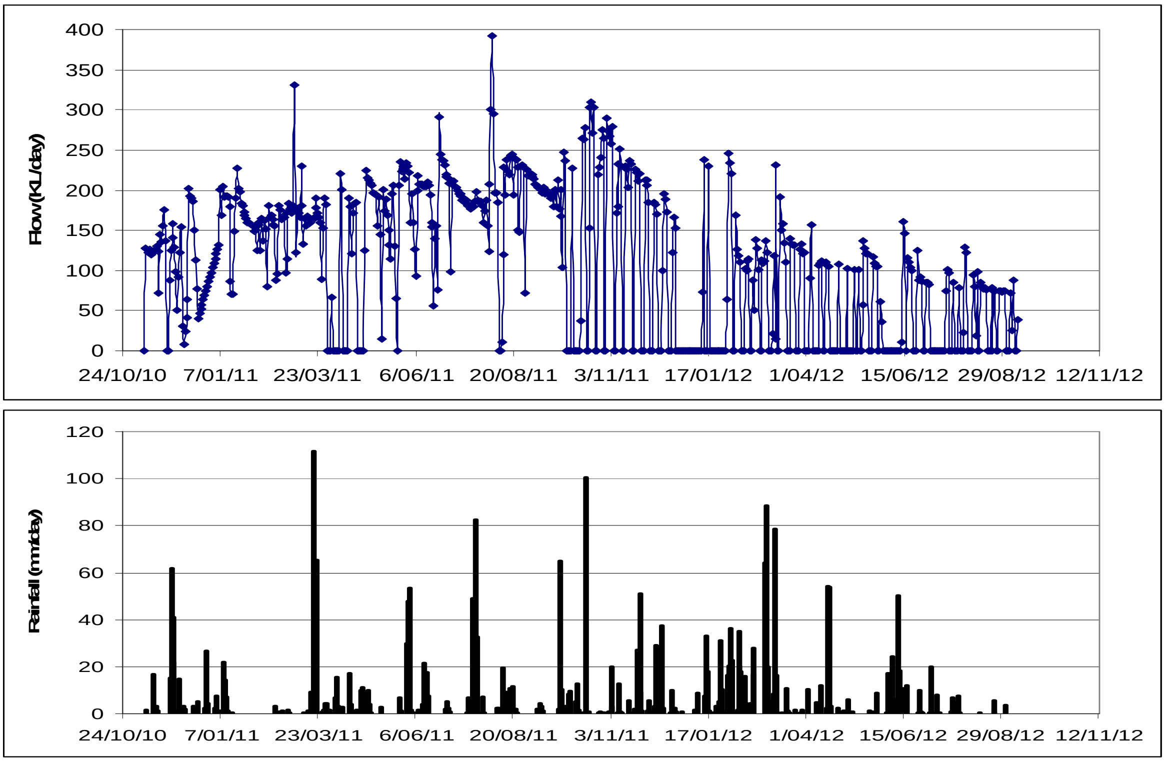


Figure 22 Wonga East (27 Cut through) Groundwater Extraction and Rainfall

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.

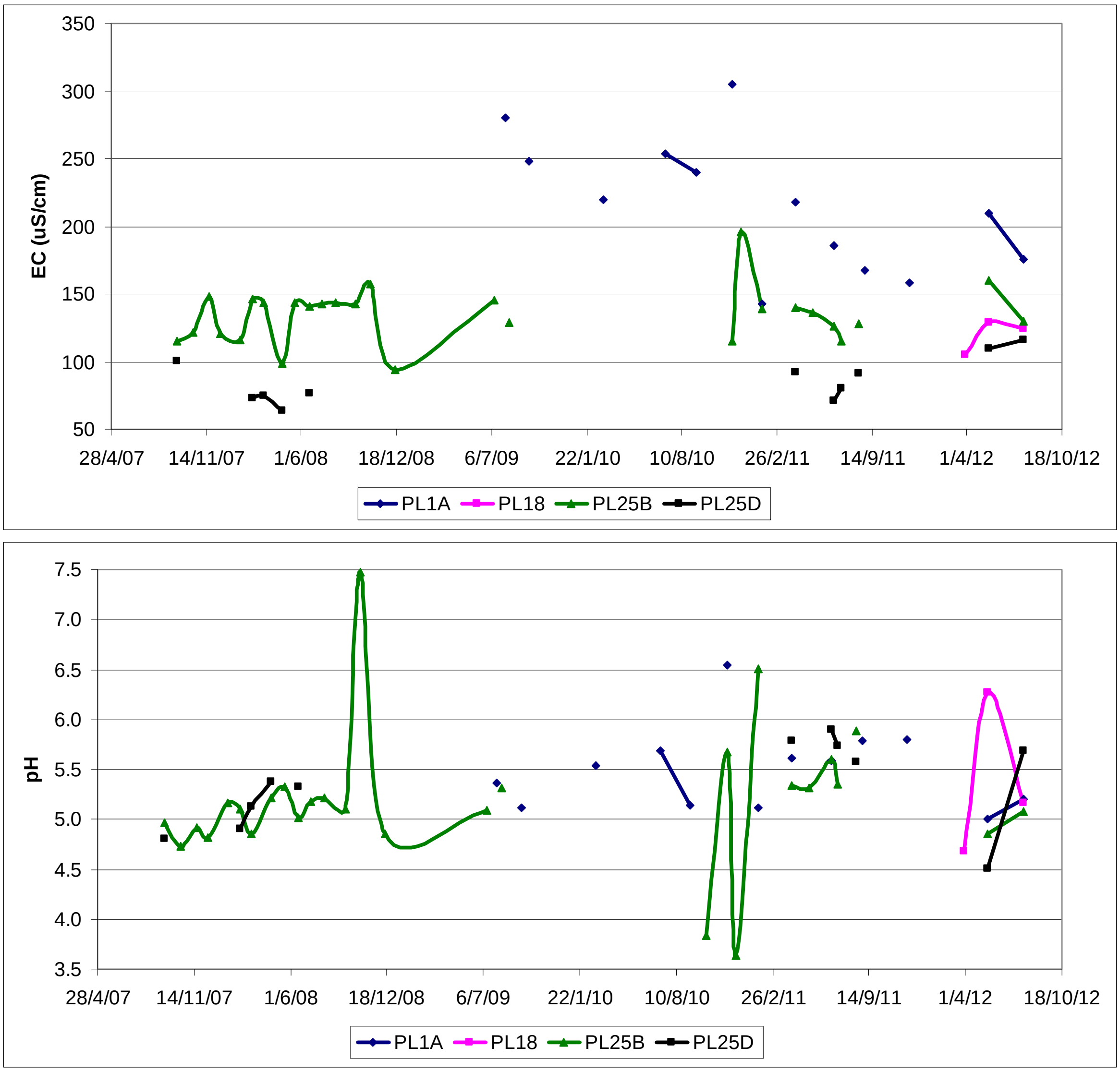


Figure 23 Lizard Creek Swamps Field Water Quality

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.

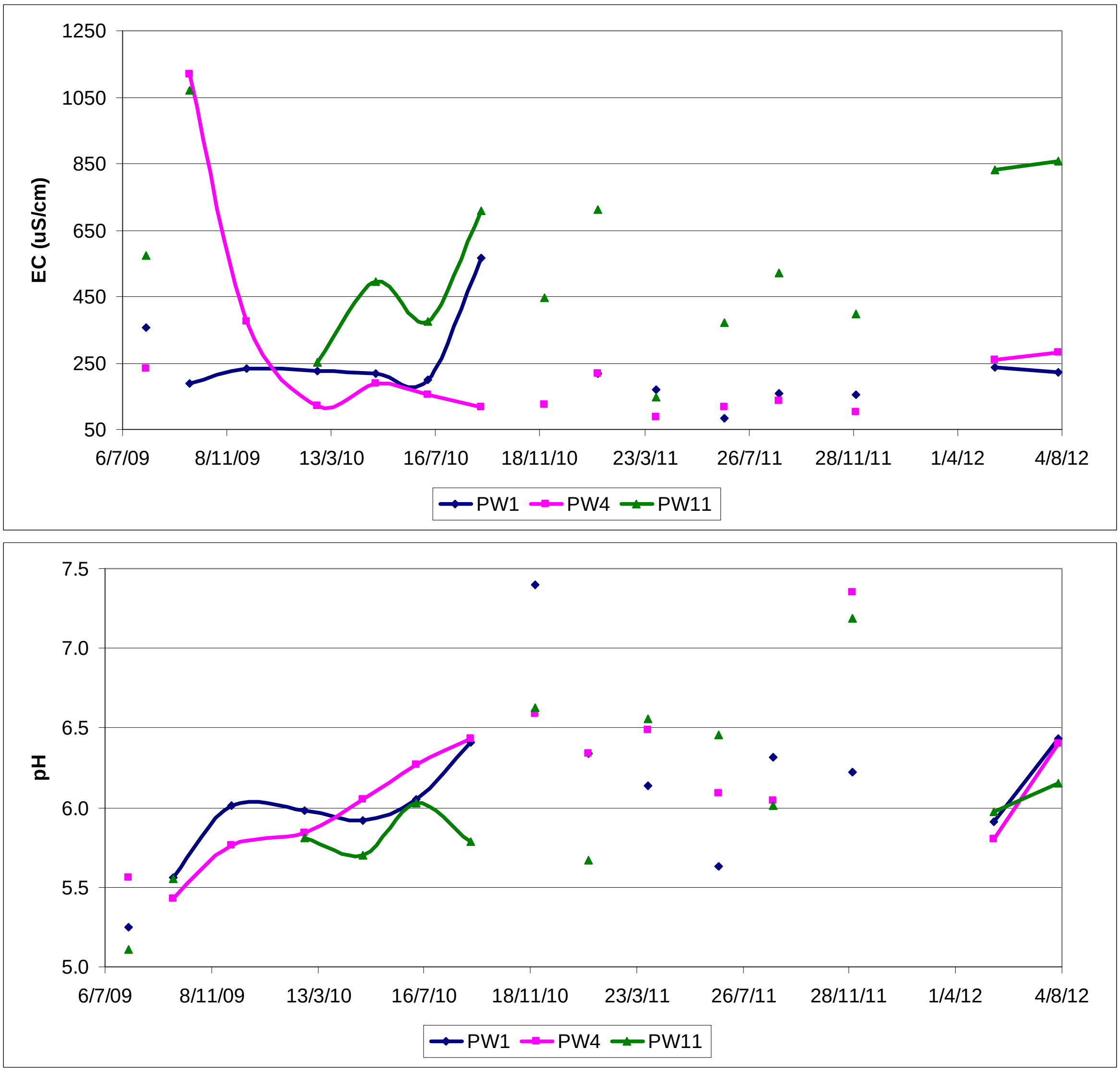


Figure 24 Wallandoola Creek Swamps Field Water Quality

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.

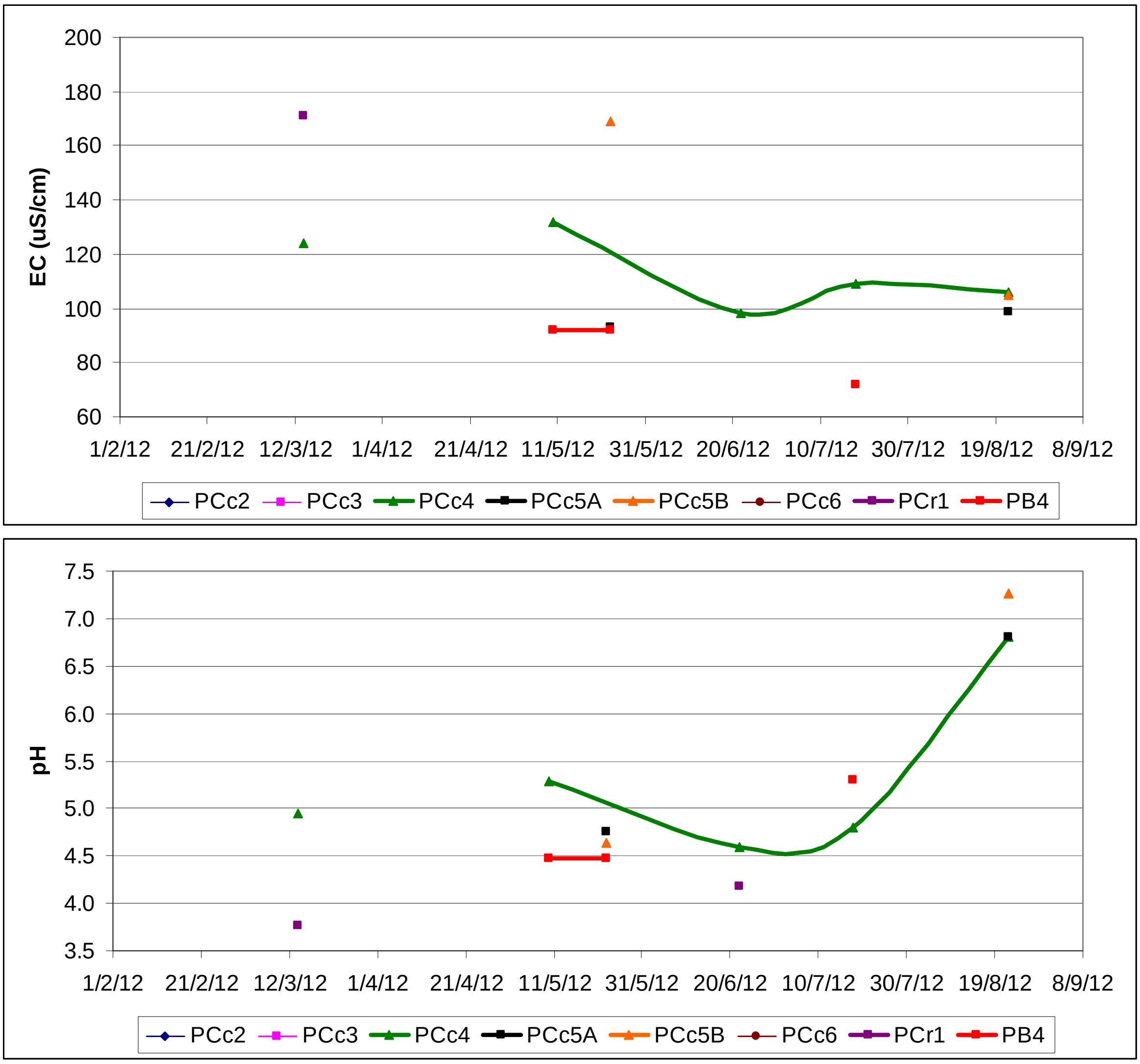


Figure 25 Wonga East Swamps Field Water Quality

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.

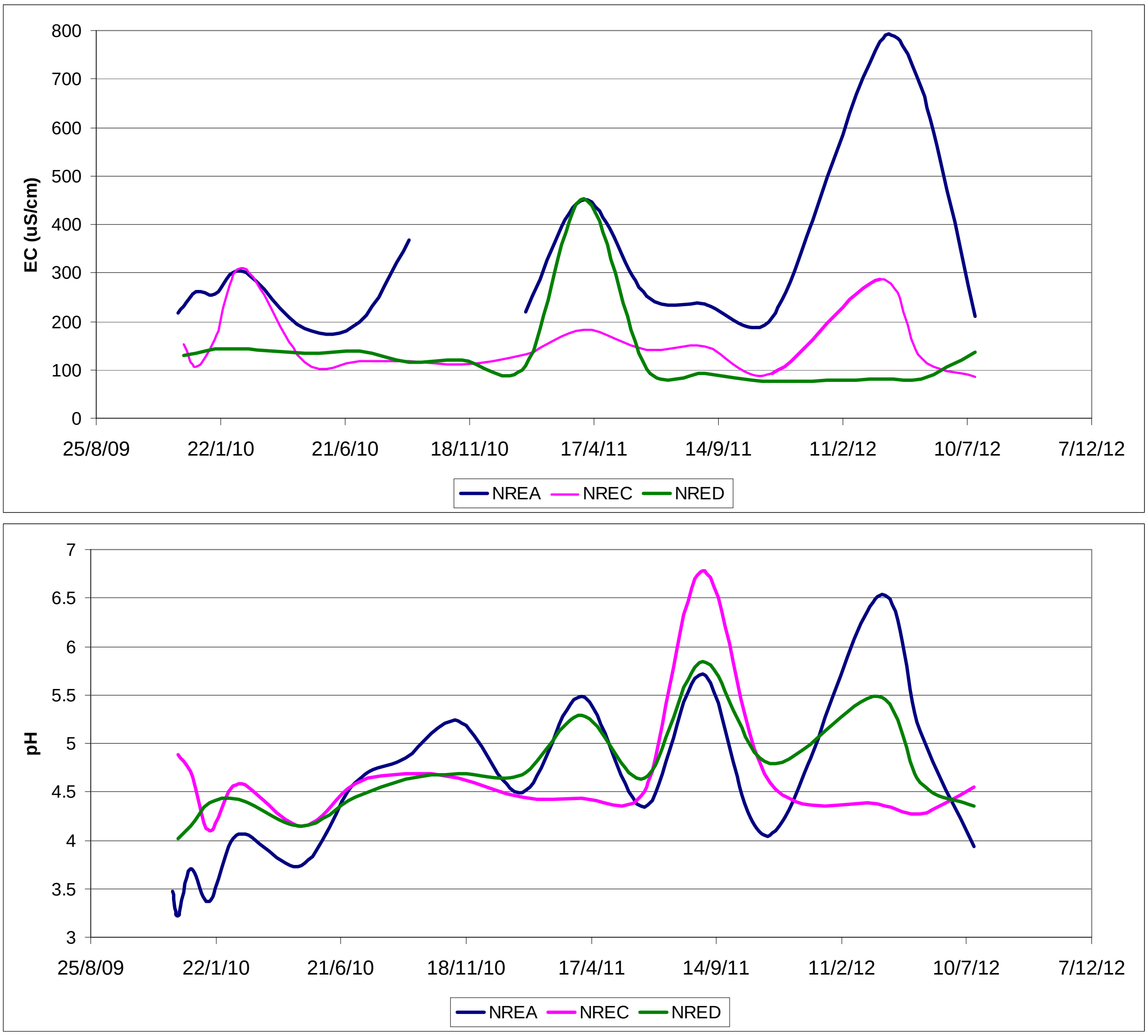


Figure 27 Wonga East Hawkesbury Sandstone Salinity and pH

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.

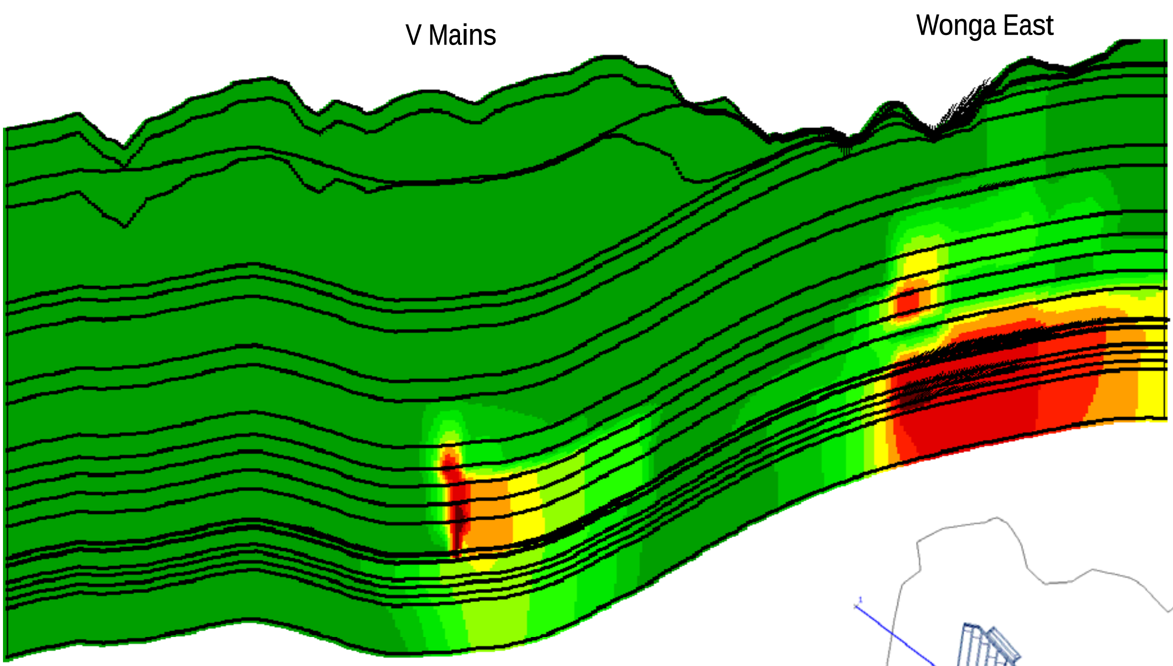
As no valley fill swamps are proposed to be directly undermined, then it is not anticipated that swamp erosion and / or scouring is a high risk impact due to the proposed mining.

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.



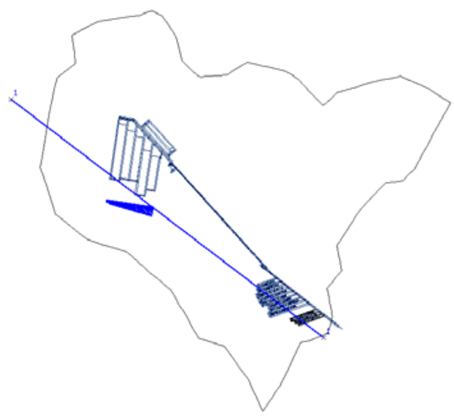


Figure 28 Depressurisation Following Extraction of V Mains and Wonga East Areas 1 and 2

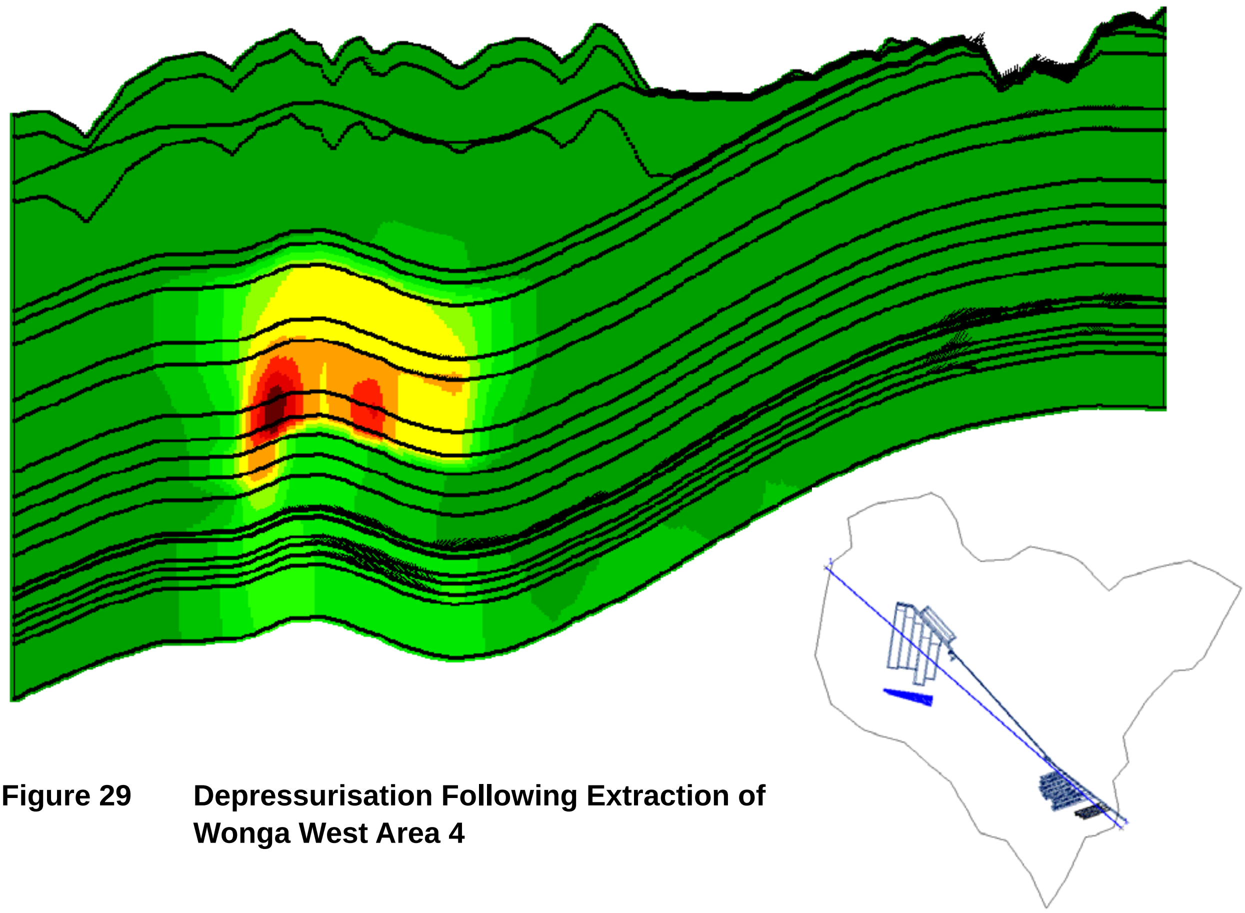


Figure 29 Depressurisation Following Extraction of Wonga West Area 4

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.

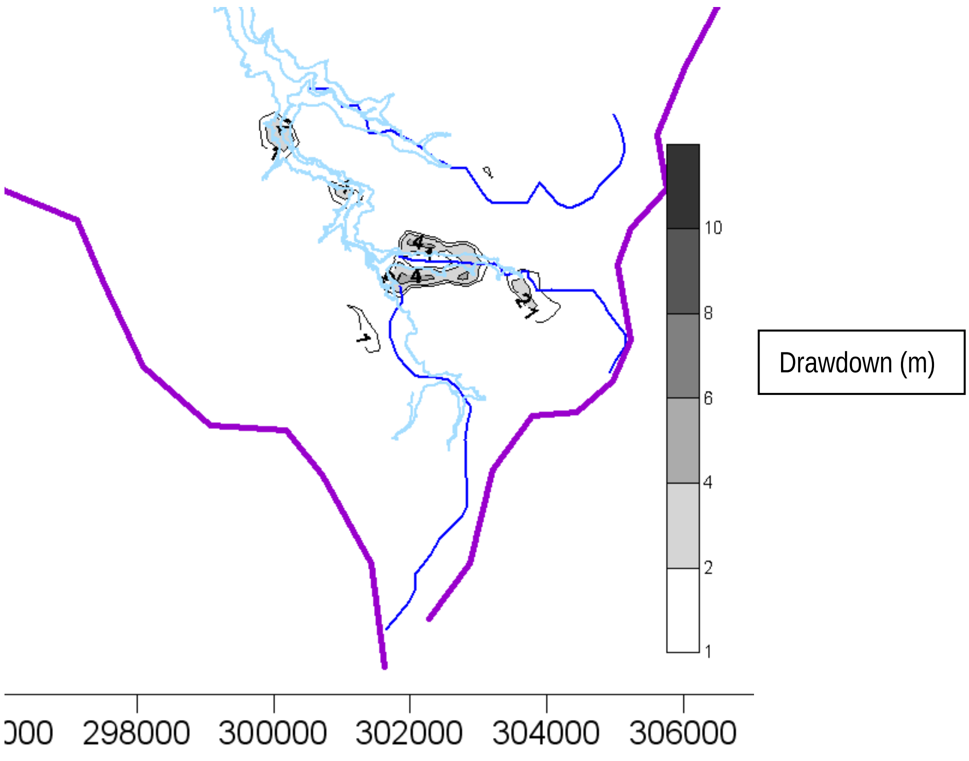


Figure 30 Upper Hawkesbury Sandstone (Layer 2) Drawdown After Mining Wonga East Areas 1 and 2 and V Mains

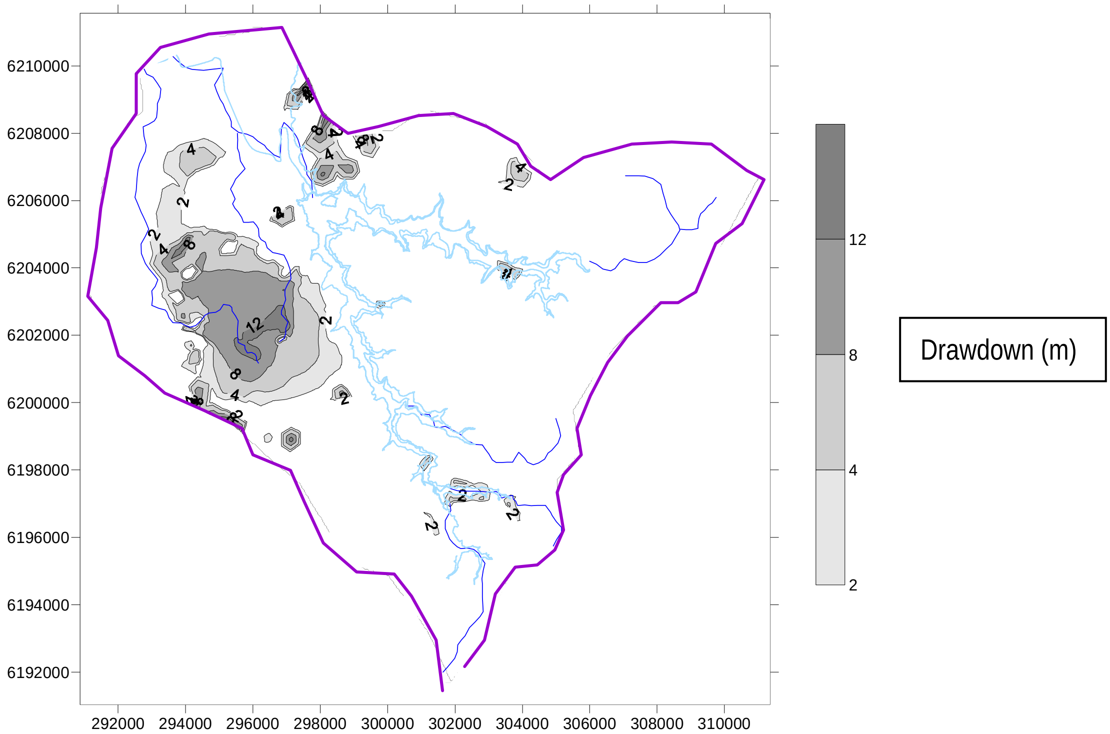


Figure 31 **Upper Hawkesbury Sandstone (Layer 2) Drawdown After Mining Wonga West Areas 3 and 4**

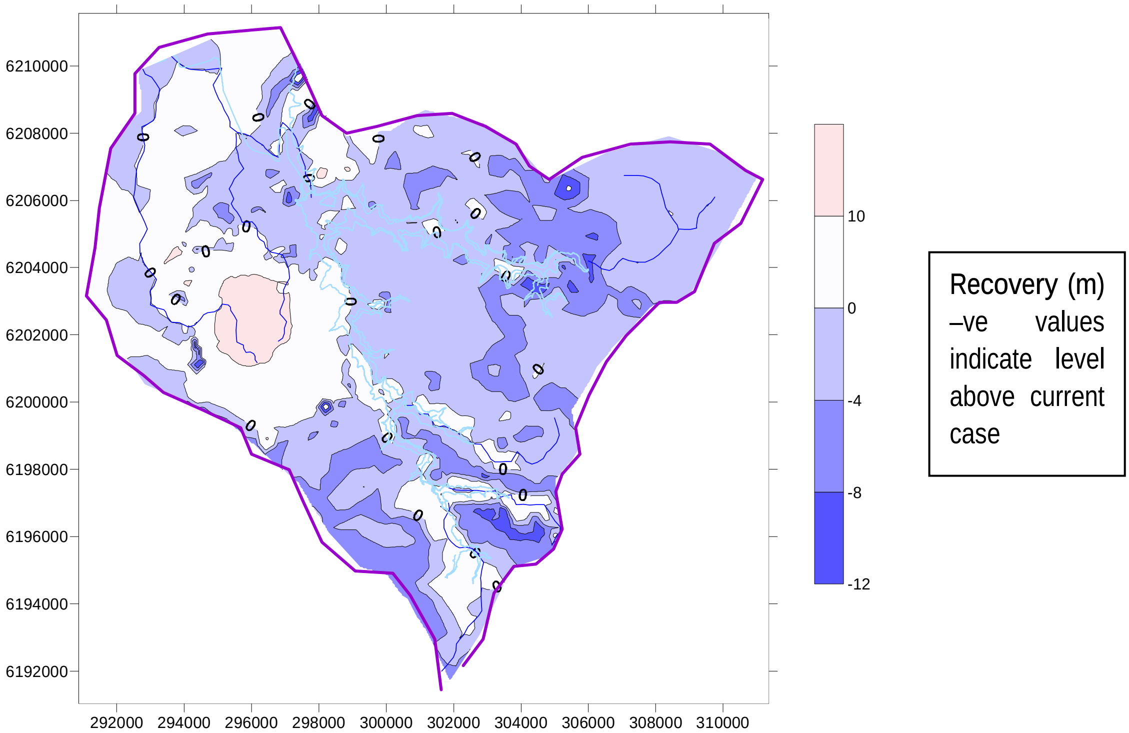


Figure 32 **Upper Hawkesbury Sandstone (Layer 2) Recovery 10 Years After Mining Area 4**

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.

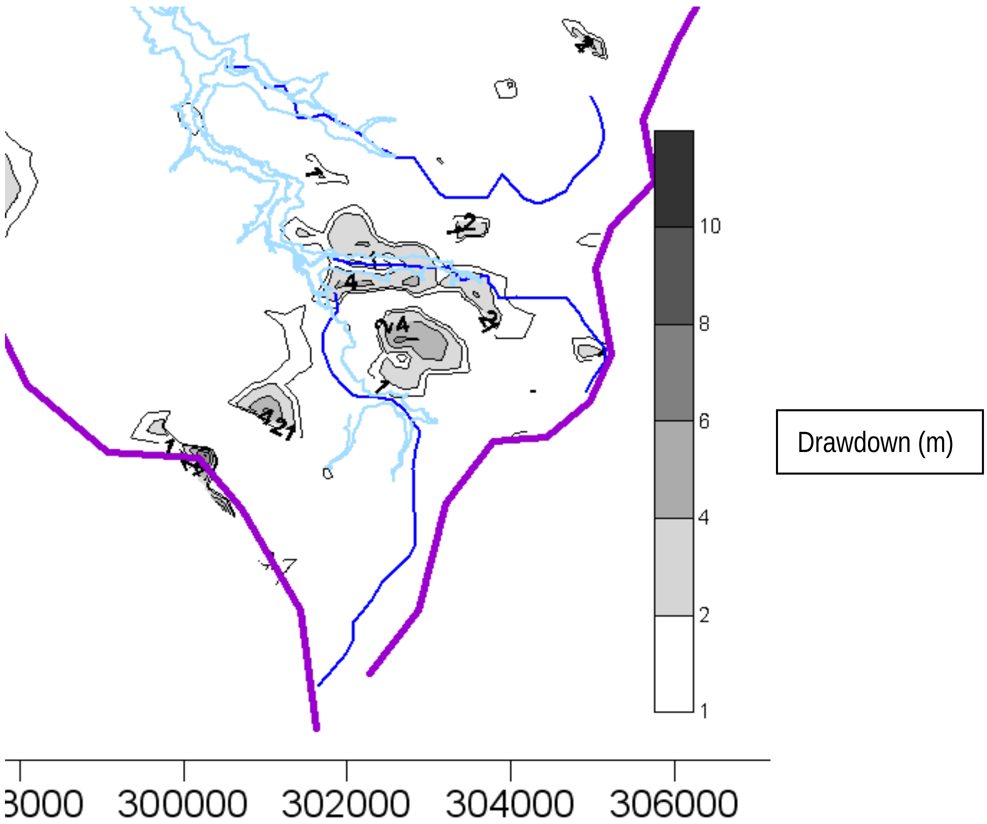


Figure 33 **Lower Hawkesbury Sandstone (Layer 4) Drawdown After Mining Wonga East Areas 1, 2 and V Mains**

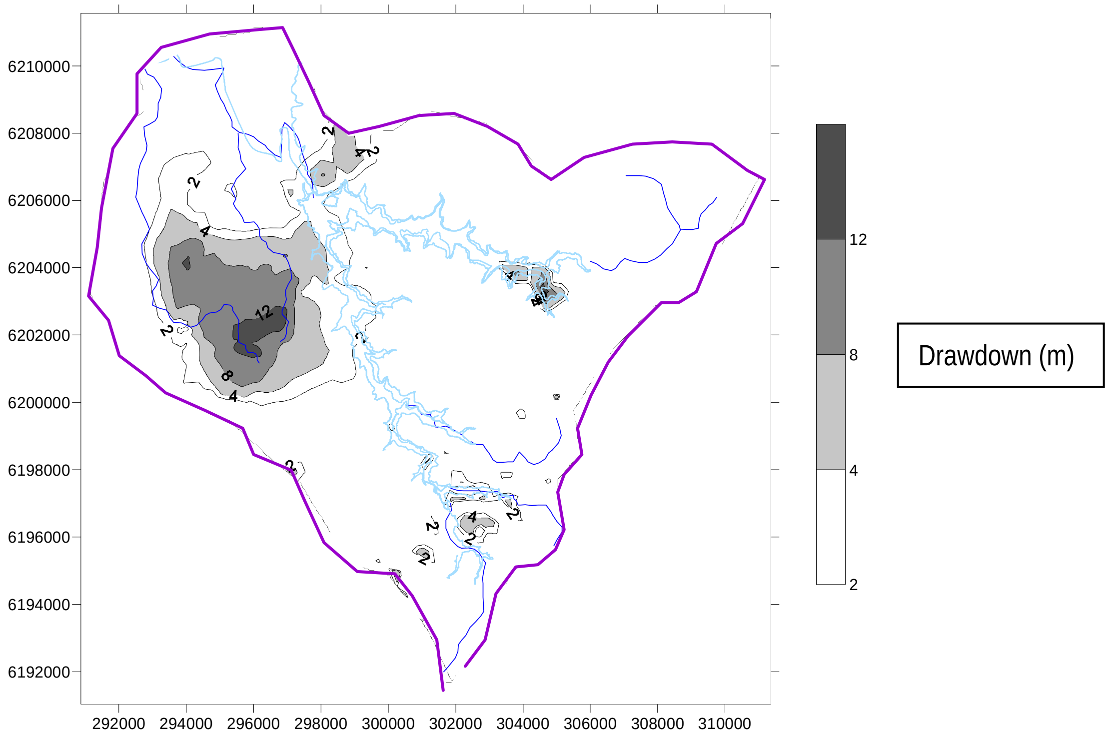


Figure 34 Lower Hawkesbury Sandstone (Layer 4) Drawdown After Mining Wonga West Area 4

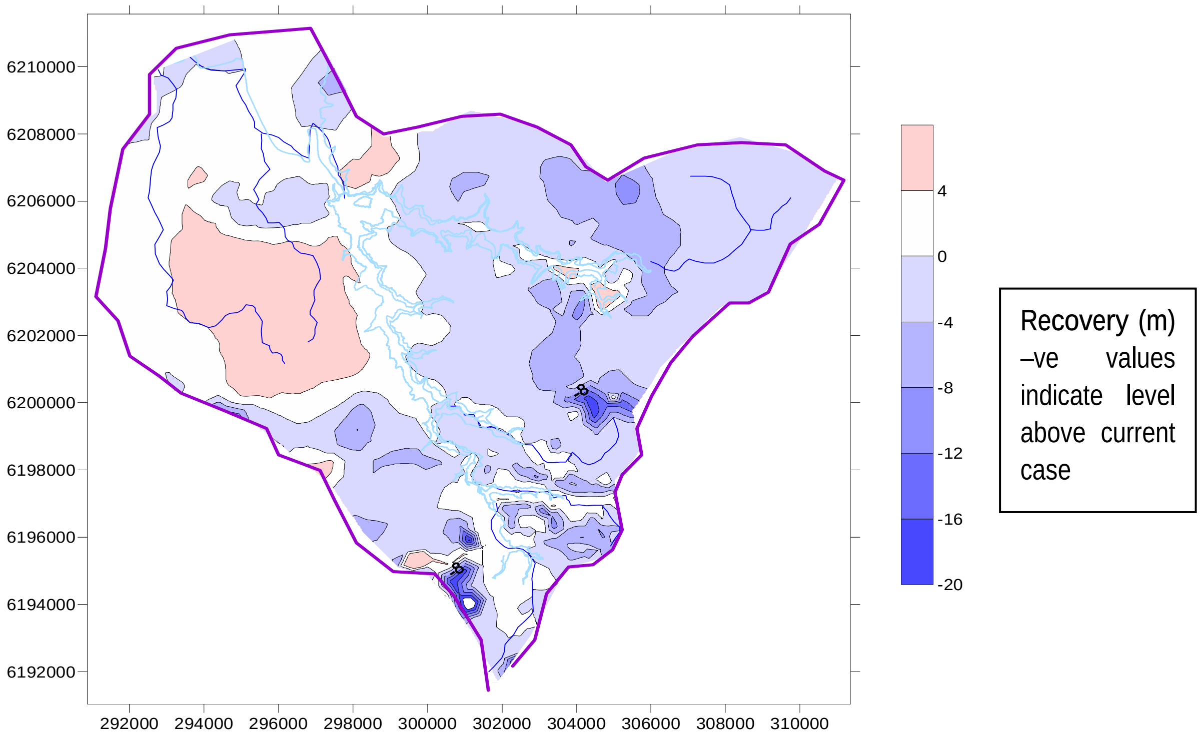


Figure 35 Lower Hawkesbury Sandstone (Layer 4) Recovery 10 Years After Mining Area 4

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.

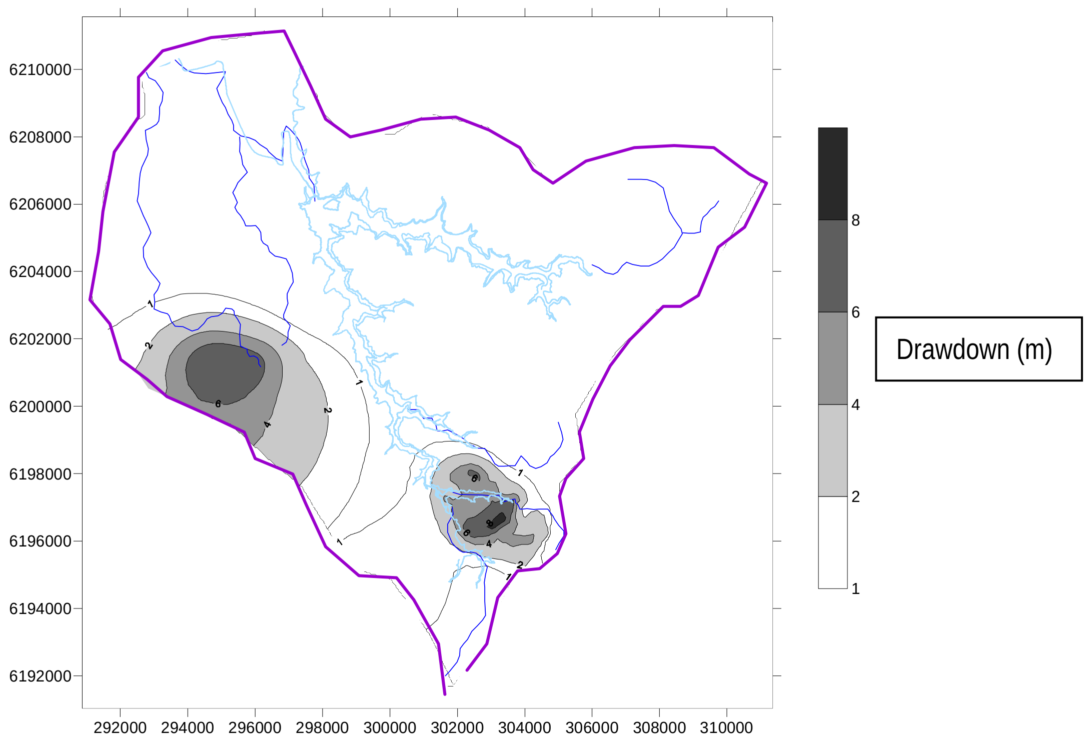


Figure 36 Upper Bulgo Sandstone Drawdown After Mining Wonga East Areas 1, 2 and V Mains

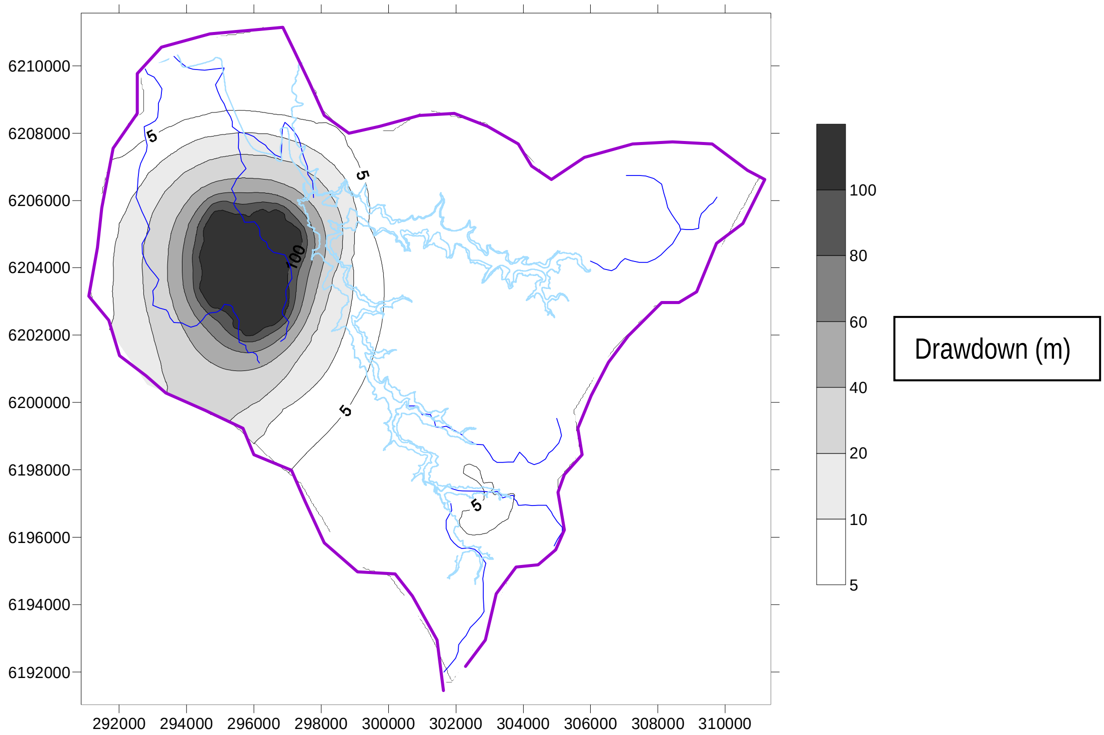


Figure 37 **Upper Bulgo Sandstone Drawdown After Mining Wonga West Area 4**

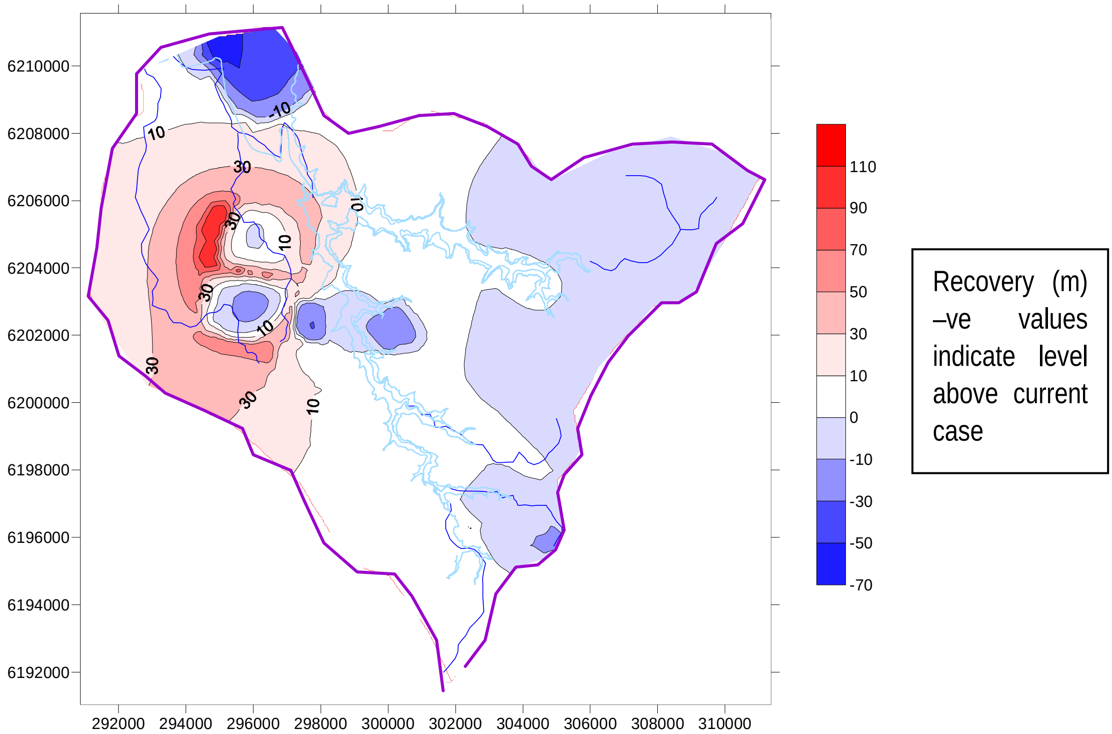


Figure 38 **Upper Bulgo Sandstone Recovery 10 Years After Mining Area 4**

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.

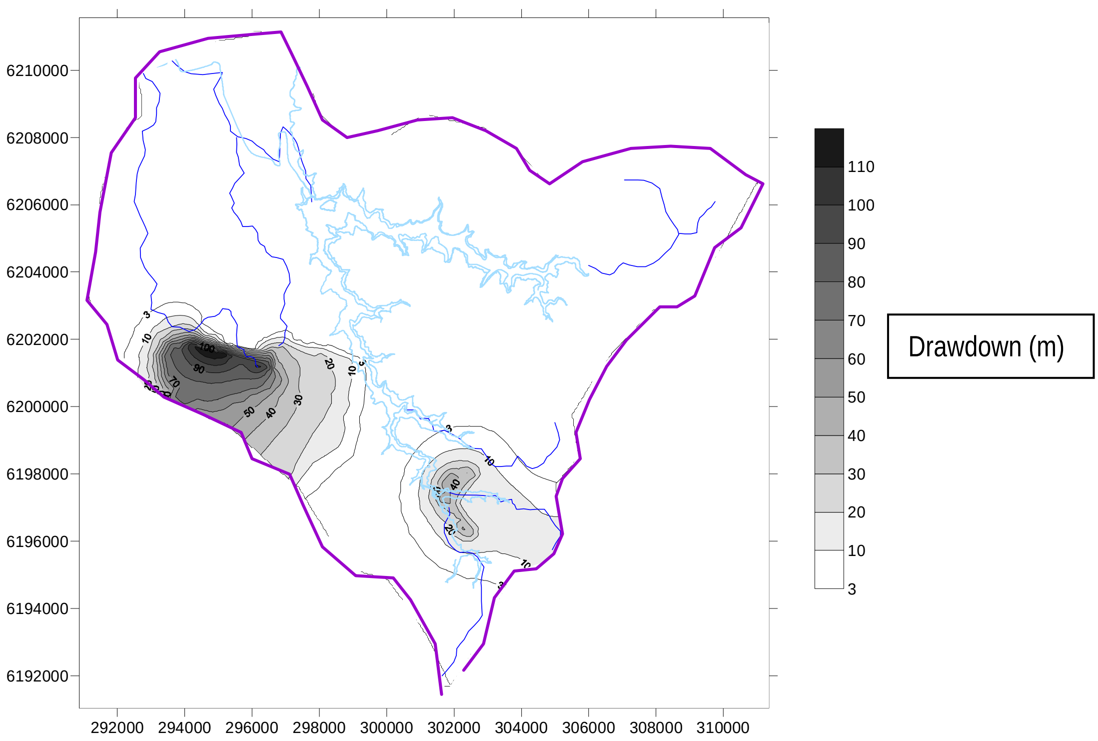


Figure 39 Scarborough Sandstone Drawdown After Mining Wonga East Area 2 and V Mains