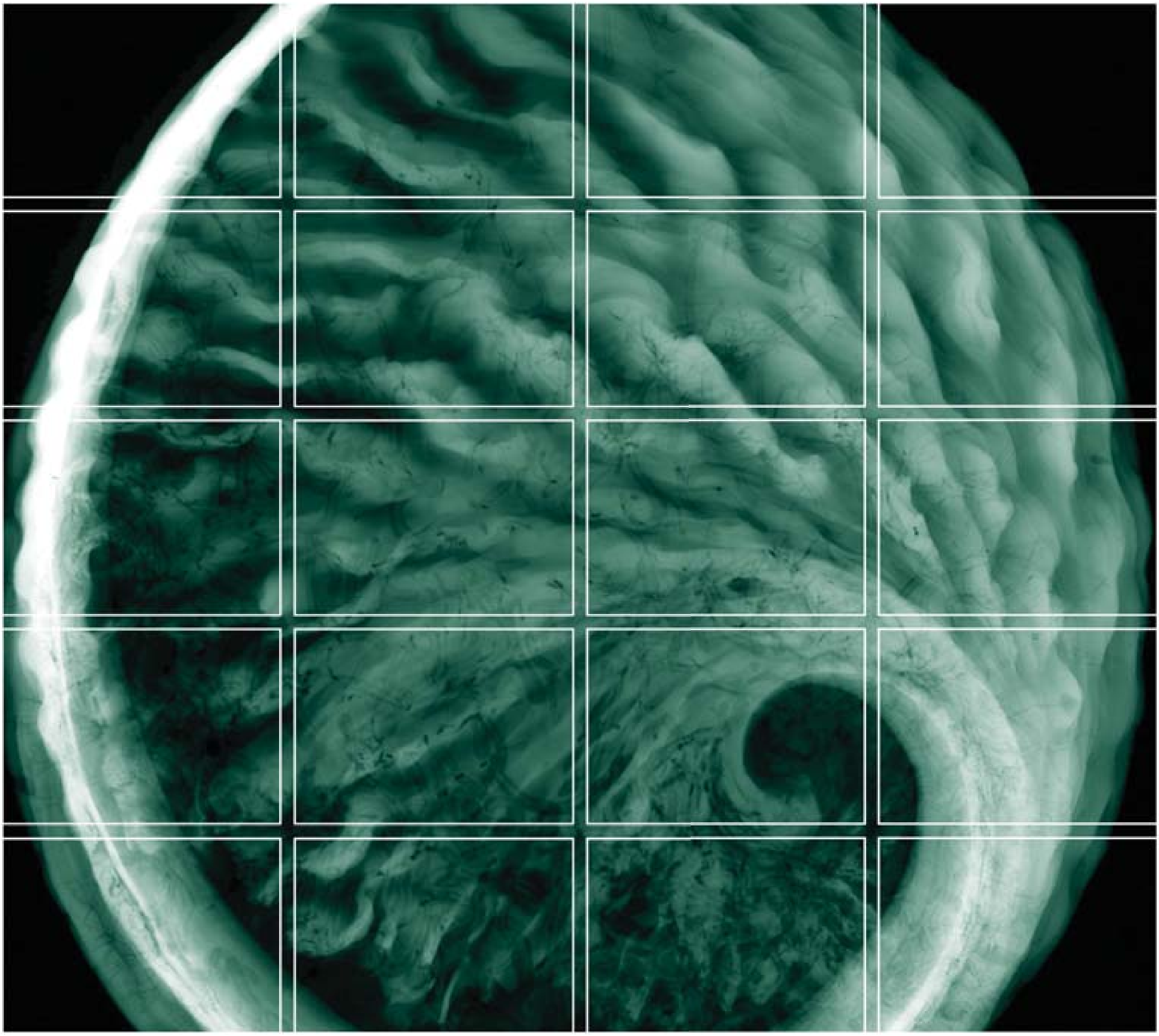

NRE No.1 Colliery Project Application (09_0013)

Environmental Assessment
Volume IV – Annexes K to O

Gujarat NRE Coking Coal Pty Ltd

February 2013

0079383

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Annex K

Photomontage

REFER TO JBK DRAWING 282800.
FOR DETAILED DESCRIPTION OF SITE WORKS

PHOTO LOCATION TABLE				
LOCATION	EASTING/NORTHING	RL	DISTANCE TO RILL TOWER	PHOTO ID
POSITION 1	34° 21′ 49.70″ S 150° 53′ 30.11″ E	80.116	400m	JH035718.JPG
POSITION 2	34° 21′ 50.36″ S 150° 53′ 36.24″ E	68.751	482m	JH035719.JPG
POSITION 3	34° 21′ 48.06″ S 150° 53′ 51.32″ E	55.124	733m	JH035720.JPG
POSITION 4	34° 21′ 47.09″ S 150° 53′ 46.58″ E	55.032	612m	JH035721.JPG
POSITION 5	34° 21′ 34.27″ S 150° 53′ 56.38″ E	54.100	792m	JH035722.JPG
POSITION 6	34° 21′ 31.73″ S 150° 53′ 44.76″ E	61.093	521m	JH035723.JPG
POSITION 7	34° 21′ 31.73″ S 150° 53′ 44.76″ E	61.093	521m	JH035724.JPG
POSITION 8	34° 21′ 39.59″ S 150° 53′ 59.98″ E	49.606	878m	JH035725.JPG
POSITION 9	34° 21′ 40.93″ S 150° 54′ 9.84″ E	50	1140m	P5100002.JPG


Position 6


Position 7

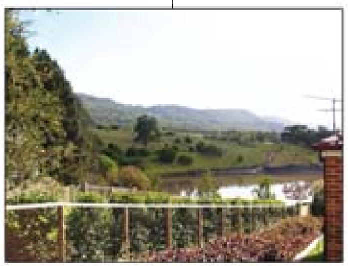

Position 5


Position 8


Position 9


Position 1


Position 2


Position 4


Position 3

REV	DATE	REVISIONS	DRN	APP
B	01/06/10	POSITION 9 ADDED	JAH	DS
A	26/05/10	PRELIMANARY	JAH	-

AS 1100
ALL DIMENSIONS IN MILLIMETRES UNLESS STATED OTHERWISE

	NAME	DATE
DESIGN	JAH	MAY 10
DRAWN	JAH	MAY 10
CHECKED	XXX	XXX
APPROVED	XXX	XXX
SCALE	1 : 10	

JBK Engineering & Mining
Ph. 02 4271 6424 Fax. 02 4272 6424
Workshop: 6 Investigator Drive UNANDERRA
P.O. Box 1184 UNANDERRA DELIVERY CENTRE
UNANDERRA NSW 2526

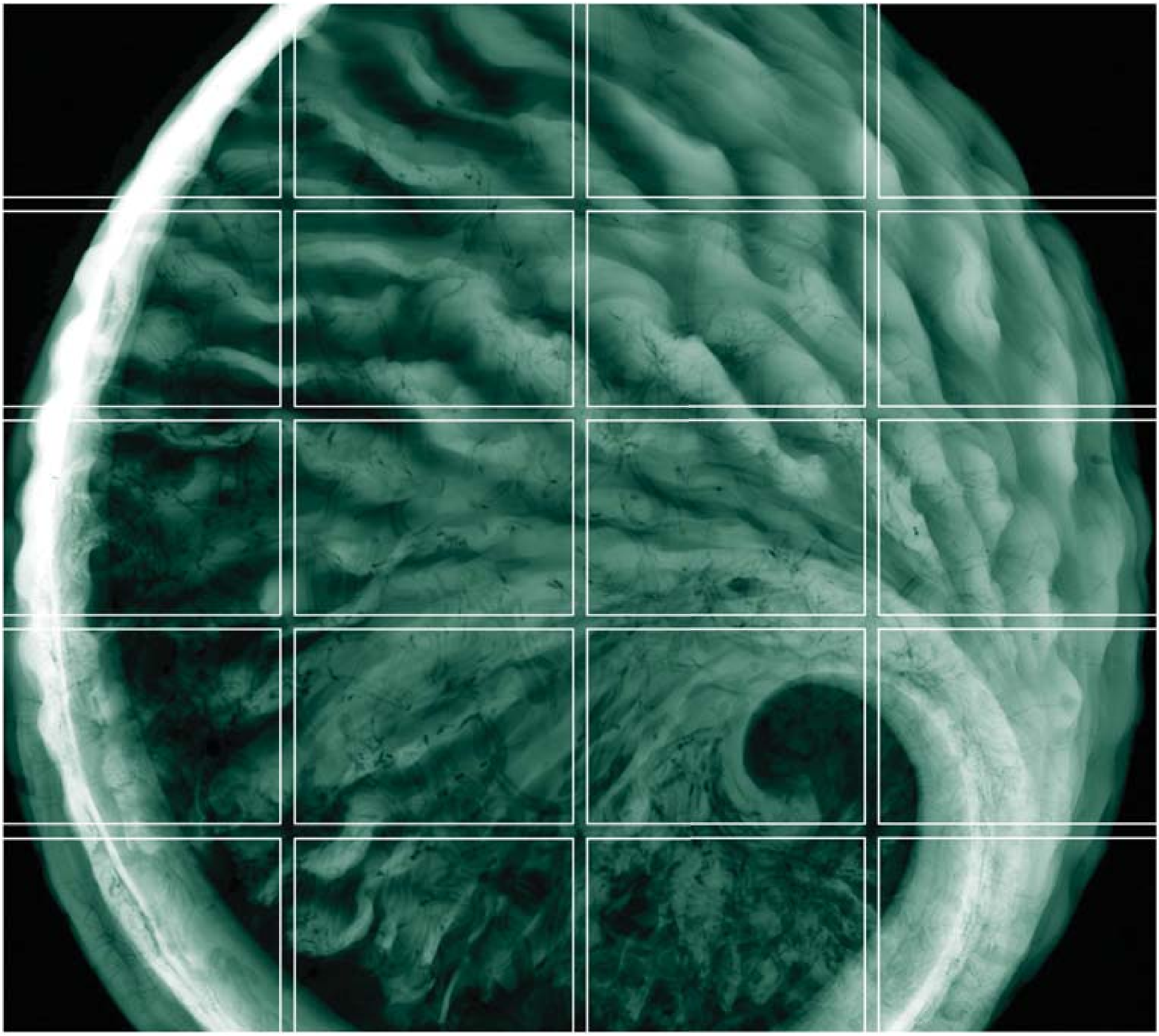
GUJARAT NRE COKING COAL Ltd

No. 1 COLLIERY RUSSELL VALE
PROPOSED UPGRADE
PHOTOMONTAGE

ISSUE PROPOSAL
DWG. SIZE A1
JBK DWG No. 282802
REVISION B

Annex L

Historical Heritage Assessment



NRE No.1 Colliery

Historical Heritage Assessment

Gujarat NRE Coking Coal Pty Ltd

November 2012

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NRE No.1 Colliery

Historical Heritage Assessment

Gujarat NRE Coking Coal Limited

Approved by:	*Steve O'Connor*
Position:	*Technical Director*
Signed:	
Date:	*30 November 2012*

Environmental Resources Management Australia Pty Ltd Quality System

November 2012

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EXECUTIVE SUMMARY

Gujarat NRE Coking Coal Limited (NRE) seeks project approval for the expansion of operations at its No. 1 Colliery at Russell Vale under Part 3A of the Environmental Planning and Assessment Act 1979. Environmental Resources Management Australia Pty Ltd (ERM) has been engaged by NRE to prepare this heritage impact assessment, to form part of the application to gain project approval. This assessment considers the potential impact of the Project upon heritage items and lists measures to be implemented to address potential impacts.

Preparation of this assessment has included the following a review of a review of site specific background information, relevant legislative and regulatory frameworks including Local Environment Plans (LEPs) and database searches of heritage registers to identify heritage listed items within the Project Application Area (PAA).

A review of the heritage status of the PAA has revealed the following:

- *there are no items or places associated with the PAA recorded on the State Heritage Register, the State Heritage Inventory, the National Heritage List, the Commonwealth Heritage List; the Register of National Estate or the National Trust;*

- *Schedule 5 of the Wollongong Local Environmental Plan 2009 includes South Bulli Colliery as an "archaeological site or heritage site with an archaeological component"*

- *Schedule 5 of the Wollondilly Local Environment Plan 2011 identifies Cataract Dam as a heritage item;*

- *Schedule 1 of the Illawarra Regional Environment Plan No.1 identifies seven heritage items within the South Bulli Colliery; and*

- *the Illawarra Escarpment is listed on the Register of National Estate and the NSW National Trust Register.*

In 2004 Godden Mackay Logan (GML, 2004) prepared a Conservation Management Plan (CMP) with regard to the heritage aspects of the site on behalf of the previous site owners. The CMP identified which of the remnant features contributed to the overall heritage significance of the locally listed Colliery.

The Project will not impact on heritage listed items, or items of potential heritage significance. Proposed surface works at the Russell Vale site will be located in an area currently used as the above ground "working" components of the site. the Russell Vale site already has a strong industrial appearance. New mining equipment and infrastructure will add a modern layer of mining technology to the site and that new and old will co-exist and be able to demonstrate temporal changes in mine-related technology.

1 INTRODUCTION

1.1 BACKGROUND

Gujarat NRE Coking Coal Limited (NRE) seeks project approval for the expansion of operations at its No. 1 Colliery at Russell Vale under Part 3A of the *Environmental Planning and Assessment Act 1979*. Environmental Resources Management Australia Pty Ltd (ERM) has been engaged by NRE to prepare this heritage impact assessment, to form part of the application to gain project approval.

NRE No.1 Colliery previously known as South Bulli Colliery has been identified as an "a*rchaeological site or heritage site with an archaeological component"* within Schedule 5 of the Wollongong Local Environmental Plan 2009 (WLEP 2009).

This assessment considers the potential impact of the Project upon heritage items and lists measures to be implemented to address potential impacts.

1.2 SITE LOCATION

NRE No.1 Colliery is within Consolidated Coal Lease (CCL) 745, Mining Lease (ML) 1575 and Mining Purposes Lease (MPL) 271, approximately eight kilometres north of Wollongong, NSW.

The Project Application Area (PAA) is shown in *Figure 1.1*.

1.3 METHODOLOGY

Preparation of this assessment has included the following:

- a review of site specific background information;
- a review of relevant legislative and regulatory framework;
- a review of the Wollongong Local Environment Plan (WLEP) 2009, the Wollondilly Local Environmental Plan 2011 (LEP 2011), and the Illawarra Regional Environmental Plan No.1 (IREP), as well as database searches of the State Heritage Inventory, National Heritage List, Commonwealth Heritage List, National Trust Register and Industrial Archaeology List to identify heritage listed items within the PAA;

- a site inspection, conducted 26 November 2009, to gain an understanding of how the site will function, the physical state of buildings and items, the potential impacts that may arise, and to photograph key site elements;

- a review of the heritage significance assessment contained in the Godden Mackay Logan (2004) Conservation Management Plan for the site and inclusion of relevant information in this report;

- analysis of the project design to identify potential heritage impacts that may arise, based on the assessed heritage values of the site;

- preparation of a heritage impact assessment; and

- development of mitigation measures to ensure that the potential heritage impacts are appropriately managed.

1.4 REPORT STRUCTURE

This report is structured as follows:

Chapter 2 outlines the heritage context and statutory framework relevant to this assessment;

Chapter 3 provides an overview of the history of the study area;

Chapter 4 provides a physical description of the previously identified heritage items located in the vicinity of the proposed area of operations;

Chapter 5 provides the assessment of heritage significance;

Chapter 6 briefly outlines relevant aspects of the Project;

Chapter 7 provides an impact assessment; and

Chapter 8 presents the mitigation measures.

1.5 AUTHORSHIP

Louise Doherty conducted the site inspection and authored this report.

All photographs included within *Chapter 4* were taken by the author, Louise Doherty, on 26 November 2009.

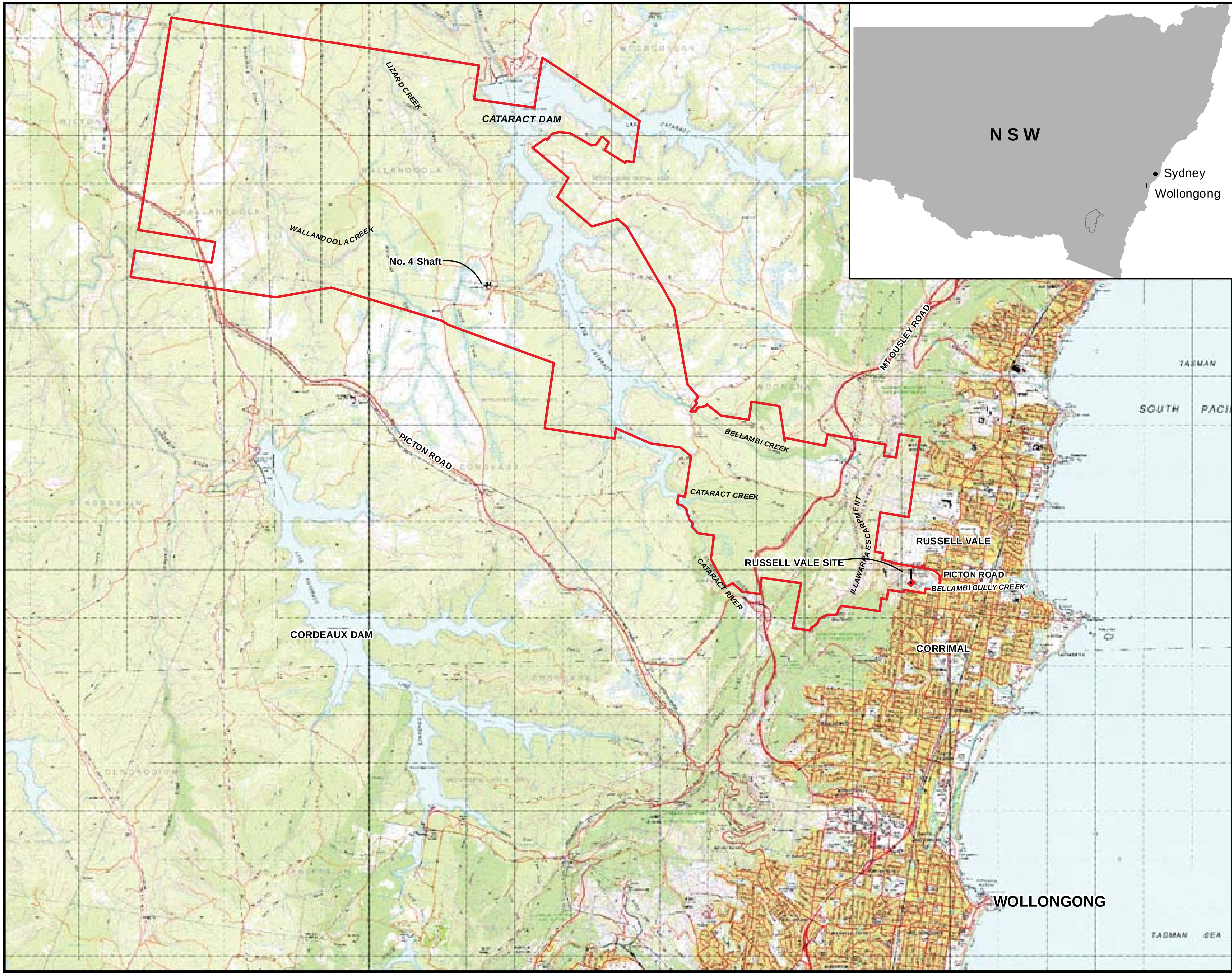

Figure 1.1

Locality Map

Client: Gujarat NRE Coking Coal Limited

Project: NRE No.1 Colliery EAR Post Adequacy 2012 Historic Heritage Assessment

Drawing No: 0079383s_HH_GIS002_R0.mxd

Date: 27/11/2012 Drawing Size: A3

Drawn By: NS Reviewed By: MK

Projection: GCS GDA 1994

Scale: Refer to scale bar

N 0 840 1,680 2,520m

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2 STATUTORY FRAMEWORK AND HERITAGE CONTEXT

2.1 INTRODUCTION

This Chapter outlines the various statutory requirements and considerations which relate to cultural heritage, including those from Wollongong City Council, and advisory heritage bodies. It includes the results of searches of heritage lists and registers for heritage items in the vicinity of the proposed area of operations. A number of these lists and registers include items and places associated with the mining history of the Wollongong region. The statutory framework and identified heritage items have influenced the formulation of the impact assessment and development of mitigation measures. Heritage items are shown on *Figure 2.1*.

2.2 NSW HERITAGE ACT 1977

Non-Indigenous cultural heritage in NSW is protected by the *Heritage Act 1977* (Heritage Act). The Heritage Act aims to conserve the *environmental heritage* of the state, which is defined as the '*buildings, works, relics or places of historic, scientific, cultural, social, archaeological, natural, or aesthetic significance for the State*'.

Under Part 3, 24 (1) of the Heritage Act, the Minister can make an interim heritage order for items of state or local heritage significance for a place, building, work, relic, moveable object that the Minister considers may, on further inquiry or investigation, be found to be of State or local heritage significance.

The Act defines the term relic as applying to deposits, objects or material evidence, which relate to the settlement of the area that comprises New South Wales, not being Aboriginal settlement, and *which is 50 or more years old*.

Heritage items requiring protection under the Heritage Act are listed on the NSW State Heritage Register. A search of the State Heritage Register identified Cataract Dam as a heritage listed item within the PAA.

2.3 THE STATE HERITAGE INVENTORY

The State Heritage Inventory is a database which is maintained by the Heritage Branch of the NSW Department of Planning (Heritage Branch). It includes all heritage items and places identified by local government bodies in NSW, as well as those listed on the State Heritage Register as requiring the permission of the Heritage Council, or the Minister, before development with potential to impact upon them can proceed.

2.4 *WOLLONGONG LOCAL ENVIRONMENTAL PLAN 2009*

The Wollongong Local Environmental Plan 2009 (WLEP 2009) came into effect on 26 February 2009 and applies to the eastern part of the PAA. Schedule 5 of the WLEP 2009 includes South Bulli Colliery as an "*archaeological site or heritage site with an archaeological component*".

The following provisions from the WLEP 2009, relating to heritage, are applicable to this Project:

5.10 Heritage conservation

(1) The objectives of this clause are:

(a) to conserve the environmental heritage of Wollongong, and

(b) to conserve the heritage significance of heritage items and heritage conservation areas including associated fabric, settings and views, and

(c) to conserve archaeological sites, and

(d) to conserve places of Aboriginal heritage significance.

(2) Development consent is required for any of the following:

(a) demolishing or moving a heritage item or a building, work, relic or tree within a heritage conservation area,

(b) altering a heritage item or a building, work, relic, tree or place within a heritage conservation area, including (in the case of a building) making changes to the detail, fabric, finish or appearance of its exterior,

(c) altering a heritage item that is a building by making structural changes to its interior,

(d) disturbing or excavating an archaeological site while knowing, or having reasonable cause to suspect, that the disturbance or excavation will or is likely to result in a relic being discovered, exposed, moved, damaged or destroyed,

(e) disturbing or excavating a heritage conservation area that is a place of Aboriginal heritage significance,

(f) erecting a building on land on which a heritage item is located or that is within a heritage conservation area,

(g) subdividing land on which a heritage item is located or that is within a heritage conservation area.

(4) Effect on heritage significance

The consent authority must, before granting consent under this clause, consider the effect of the proposed development on the heritage significance of the heritage item or heritage conservation area concerned. This subclause applies regardless of whether a heritage impact statement is prepared under subclause (5) or a heritage conservation management plan is submitted under subclause (6).

(5) Heritage impact assessment

The consent authority may, before granting consent to any development on land:

(a) on which a heritage item is situated, or

(b) within a heritage conservation area, or

(c) within the vicinity of land referred to in paragraph (a) or (b), require a heritage impact statement to be prepared that assesses the extent to which the carrying out of the proposed development would affect the heritage significance of the heritage item or heritage conservation area concerned.

2.5 *WOLLONDILLY LOCAL ENVIRONMENTAL PLAN 2011*

The Wollondilly Local Environment Plan 2011 (LEP 2011) came into force on the 23 February 2011 and applies to the western part of the PAA.

Schedule 5 of LEP 2011 lists Cataract Dam as a heritage item.

The following provisions of LEP 2011 relate to the protection of heritage items:

5.10 Heritage conservation

(1) Objectives

The objectives of this clause are:

(a) to conserve the environmental heritage of Wollondilly Shire, and

(b) to conserve the heritage significance of heritage items and heritage conservation areas including associated fabric, settings and views, and

(c) to conserve archaeological sites, and

(d) to conserve places of Aboriginal heritage significance.

2) Requirement for consent

Development consent is required for any of the following:

(a) demolishing or moving a heritage item or a building, work, relic or tree within a heritage conservation area,

(b) altering a heritage item or a building, work, relic, tree or place within a heritage conservation area, including (in the case of a building) making changes to the detail, fabric, finish or appearance of its exterior,

(c) altering a heritage item that is a building by making structural changes to its interior,

(d) disturbing or excavating an archaeological site while knowing, or having reasonable cause to suspect, that the disturbance or excavation will or is likely to result in a relic being discovered, exposed, moved, damaged or destroyed,

(e) disturbing or excavating a heritage conservation area that is a place of Aboriginal heritage significance,

(f) erecting a building on land on which a heritage item is located or that is within a heritage conservation area,

(g) subdividing land on which a heritage item is located or that is within a heritage conservation area.

(4) Effect on heritage significance

The consent authority must, before granting consent under this clause, consider the effect of the proposed development on the heritage significance of the heritage item or heritage conservation area concerned. This subclause applies regardless of whether a heritage impact statement is prepared under subclause (5) or a heritage conservation management plan is submitted under subclause (6).

(5) Heritage impact assessment

The consent authority may, before granting consent to any development on land:

(a) on which a heritage item is situated, or

(b) within a heritage conservation area, or

(c) within the vicinity of land referred to in paragraph (a) or (b), require a heritage impact statement to be prepared that assesses the extent to which the carrying out of the proposed development would affect the heritage significance of the heritage item or heritage conservation area concerned.

2.6 ILLAWARRA REGIONAL ENVIRONMENTAL PLAN NO.1

As of July 2009, Regional Environmental Plans (REPs) were removed from the NSW environmental planning hierarchy. All REPs were deemed as State Environmental Planning Policies (SEPPs), including the Illawarra Regional Environmental Plan.

The Illawarra Regional Environmental Plan No.1 (IREP) lists seven items within the South Bulli Colliery (now the NRE No.1 Colliery), as heritage items under Schedule 1 of the IREP. These items are:

- main portal (S. W. Tunnel 1887);
- 1918 portal for ventilation;
- signal box;
- old washery (1960) (now demolished);
- concrete base for ball mill at pit top (exact location unknown);.

- Bellambi Creek Dam (to Collins No 1 and No 2 and on to power house) or Charlesworth's Dam; and
- former mines office (now demolished).

The following provisions from Part 15 of the IREP relate to the protection of heritage items:

126 Conservation of items of the environmental heritage

(2) The consent authority shall not grant consent pursuant to subclause (1) in respect of an item of the environmental heritage unless it has made an assessment of:

(a) the significance of the item as an item of the environmental heritage of the local government area in which the item is situated,

(b) the extent to which the carrying out of development in accordance with the consent would affect the historic, scientific, cultural, social, archaeological, architectural, natural or aesthetic significance of the item and its site,

(c) whether the setting of the item, and in particular, whether any stylistic, horticultural or archaeological features of the setting should be retained, and

(d) whether the item constitutes a danger to the users or occupiers of that item or to the public.

2.7 THE REGISTER OF THE NATIONAL ESTATE AND NATIONAL AND COMMONWEALTH HERITAGE LISTS

From 1 January 2004 the Register of the National Estate (RNE) became a non-statutory list, by way of amendment to the *Environment Protection and Biodiversity Conservation Act 1999*. This amendment included the creation of the National Heritage List (NHL) and the Commonwealth Heritage List (CHL).

The NHL includes places that have outstanding heritage values to the nation and are in any form of public or private ownership. The CHL includes any Commonwealth owned, managed or leased properties that have significant heritage values. No part or aspects of the site are listed on the NHL or the CHL.

Whilst listing on the RNE no longer has any formal role in the management of Commonwealth owned heritage places and carries no statutory authority for non-Commonwealth owned heritage places, it is a guide to the significance of particular items.

The Illawarra Escarpment has been identified as an indicative item on the RNE. The description is as follows:

> *The Illawarra Escarpment forms a magnificent backdrop to the heavily-developed Wollongong industrial area. Cliffs of the escarpment are generally sheer and spectacular, extending in relatively unbroken lines for a remarkable distance overall. The varying colours of their sandstone exposures contrast with the mixed heath vegetation and low forest at the plateau edge, and the mature eucalypt forest and pockets of lush remnant rainforest near the cliff base and on deeper soils on the slopes. Red cedar Toona australis (also known as Toona ciliate), and other rapidly disappearing plant species are still seen here.*
>
> *The area has a number of historic features from the pioneer cedar-cutting activities and associated settlements, and as well, many mining sites with adits and collieries spanning many years of mining activities.*

NRE No.1 Colliery is not listed on the RNE.

2.8 NATIONAL TRUST REGISTER

The inclusion of a site on the National Trust Register indicates that it has heritage significance and as such should be protected *to encourage and promote public appreciation, knowledge and enjoyment and of future generations as a valuable resource*. The National Trust Register has no legal status, but is recognised as an authoritative statement on the significance of particular items, and is held in high esteem by the public. The National Trust of NSW also has an advocacy role, regularly lobbying all levels of government regarding sensitive heritage issues across the State.

The Illawarra Escarpment has been identified by the NSW National Trust as forming part of the Illawarra Escarpment Conservation Area, which is included on the register. This is described as

> *Including the eastern extremity of the Illawarra Range the western boundary is generally ½ to 2 Kilometres from the escarpment edge and to the east the foothills above the 135 Metre contour. The northern boundary follows Lawrence Hargreaves drive and is contiguous with the Garawarra Landscape Conservation area and the Stanwell Park coastal conservation area. The southern boundary is defined by the Macquarie Pass National Park.*

NRE No.1 Colliery is not listed on the National Trust Register.

2.9 THE STRATEGIC MANAGEMENT PLAN FOR HISTORIC COAL MINING SITES OF THE ILLAWARRA (OHM, 2006)

The Strategic Management Plan for Historic Coal Mining Sites of the Illawarra was prepared by OHM Consultants in 2006 on behalf of Wollongong City Council, Heritage Branch and Department of Primary Industries (now IIN).

The report appears to have been prepared to consider the heritage implications of mine closures and rehabilitation. As well as examining the risk of mine closure to the mining heritage values of the region, the report also provides a range of recommendations to enable the preservation of the region's mining heritage.

The report describes the NRE No.1 Colliery (previously South Bulli Colliery) as being significant as

> *" it is one of the earliest and longest running coal mining operations in the region and in the State.*
>
> *The site also displays the key historical theme of mining from 1887 to the present day in the evolution of land use and character in the Illawarra region."*

NRE plans to continue the mining operation and to extend the life of the Colliery.

OHM (2006) includes a list of generic recommendations for the mine owners to assist in the preservation of mining heritage values. The recommendations relevant to NRE No.1 Colliery as an operating colliery are:

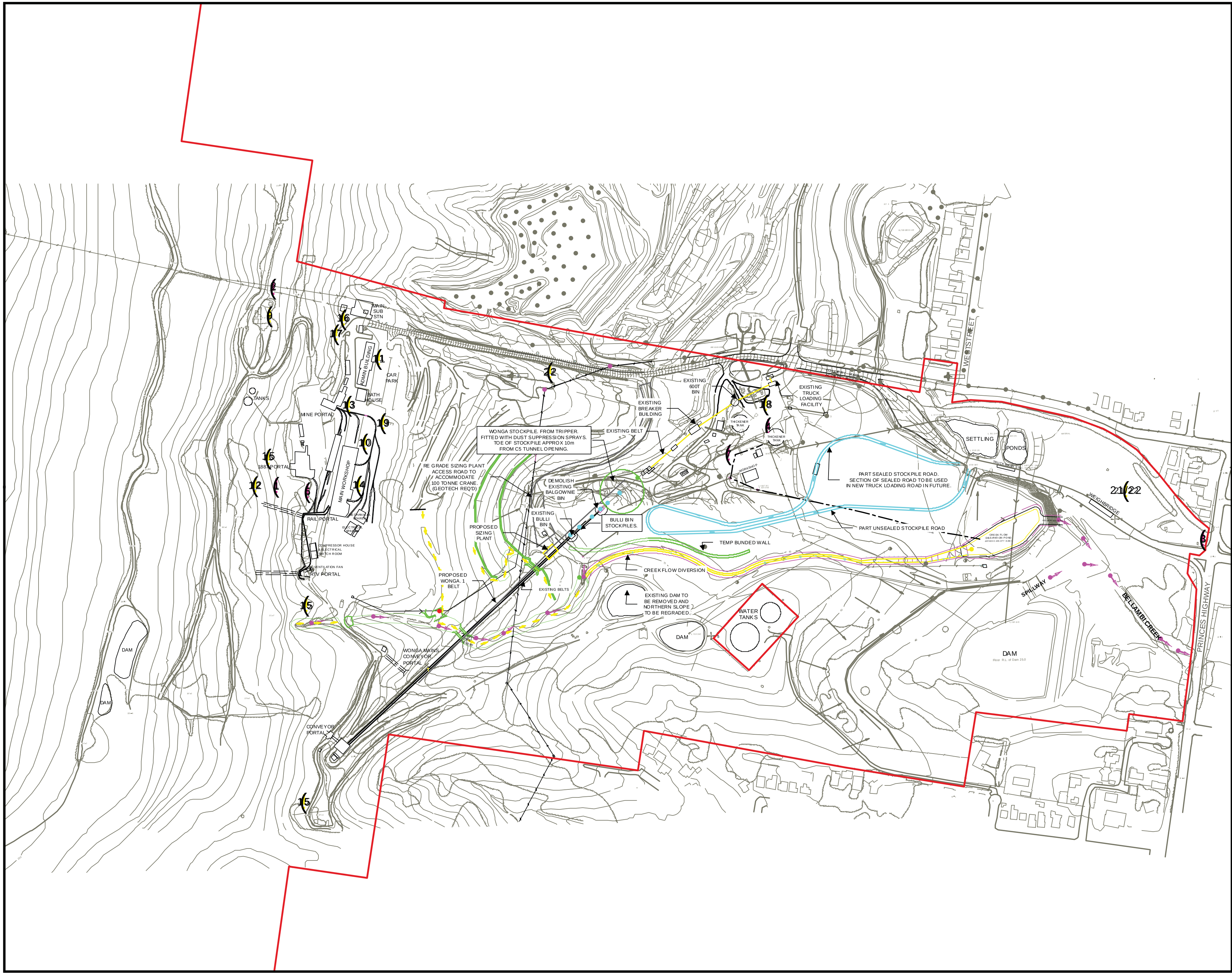
- full documentation of the site including:
  - archival recording of the functioning site, above and below ground;
  - oral histories; and
  - site plans and archives.
- assessment of the site including:
  - identification of structures to be retained; and
  - community consultation.

NRE have implemented a continuing community consultation process with community meetings to discuss matters of concern and communicate the activities and future plans for the Colliery. A comprehensive assessment of the site structures and their associated heritage values is included in GML (2004). NRE has been guided by this document with regards to building retention, suitable location of new buildings and preservation of heritage values.

2.10 SUMMARY

A review of the heritage status of the PAA has revealed the following key points:

- there are no items or places associated with the PAA recorded on the State Heritage Register, the State Heritage Inventory, the National Heritage List, the Commonwealth Heritage List; the Register of National Estate or the National Trust;
- Schedule 5 of the Wollongong Local Environmental Plan 2009 includes South Bulli Colliery as an "*archaeological site or heritage site with an archaeological component*"
- Schedule 5 of the Wollondilly Local Environment Plan 2011 identifies Cataract Dam as a heritage item;
- Schedule 1 of the Illawarra Regional Environment Plan No.1 identifies seven heritage items within the South Bulli Colliery; and
- the Illawarra Escarpment is listed on the Register of National Estate and the NSW National Trust Register.



Legend

Project Application Area

Register

GML (2004)

Illawarra REP No.1

Historic Heritage Items

1 Main Portal (S.W.Tunnel 1887)
2 1918 Portal for vVentilation
3 Signal Boz
4 Old Washery (1960) (now demolished)
5 Concrete Base for Ball Mill at Pit Top
7 Former Mines Office (now demolished)
9 Power House Precinct
10 Upper Bench Workshops
11 Workshop Offices
12 Brick Retaining Wall
13 Crib Room and First Aid Station
14 Store Room
15 Closed Adits
16 Gibson's Portal
17 Sandstone Retaining Wall
18 The Preparation Plant
19 Rail Tracks and System
20 The Coal Wagon
21 Coal Cutter Head
22 Remanant Incline Haulage Alignments

Figure 2.1

Historic Heritage Items at the Russell Vale site

Client: Gujarat NRE Coking Coal Limited

Project: NRE No. 1 Colliery EAR Post Adequacy 2012 Historic Heritage Assessment

Drawing No: 0079383s_HH_GIS001_R0.mxd

Date: 27/11/2012 Drawing Size: A3

Drawn By: NS Reviewed By: TM

Projection: GDA 1994 MGA Zone 56

Scale: Refer to scale bar

N

0 50 100 150m

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3 OVERVIEW OF SITE HISTORY

This section provides a summarised timeline of the history of the South Bulli Colliery and certain aspects of the Illawarra region. This timeline is taken from the information contained within the Conservation Management Plan (CMP) prepared by Godden Mackay Logan on behalf of the former site owners Belpac Pty Ltd in 2004. The full history as taken from the CMP is provided in *Annex A*.

Table 3.1 Historic Timeline

Date	Event
1797	Coal is first discovered in the Illawarra
1848	Newcastle-based Australian Agricultural Company's lease for exclusive mining of coal expires, thereby opening up the Illawarra region for mining
1849	A small coal mine opens at Mt Keira
Late 1850s	Steam powered coal haulage ships operate to boost export from the Illawarra Coal Industry.
1857	Osborne – Wallsend mine opened
1861	Bulli Colliery and the Taylor & Walker Colliery (later the South Bulli Colliery) commenced mining.
1862	Coal commenced to be delivered to a second jetty
1862	The first coal is extracted from the Taylor & Walker Colliery. The Colliery was located on land leased form the Osborne Family Of Marshall Mount nr Dapto.
1863	Bulli Colliery starts delivering shipments to China from a jetty at Bulli Point
1864	The initial Bulli Colliery drive was a length of five chains (90m) at which point the mine was closed due to the discovered of a basaltic dyke
Late 1860s	Coal was transported from the South Bulli Colliery to the port by a horse drawn tramway
1870s	Collieries opened at Mt Pleasant, Coal Cliff and North Bulli
Late 1870s	Unionism arrives in the Illawarra
1880s	The Illawarra railway line is constructed, linking the region with Sydney
1884	The Taylor & Walker Colliery reopens at the South Bulli Colliery and the first coal was shipped in November 1887
1884	The South Bulli Colliery was acquired by L MacCabe
1886	The National Miners Union is formed
1887	The South Bulli Colliery was formed by a syndicate associated with Thomas Saywell, with W Wilson as manager
1887	Surface working at South Bulli Colliery included erection of a portal entrance, a large boiler house, steam engine, a sawmill and general workshops. The colliery also erected a new jetty, 282 m (820 feet) at Bellambi Point.
1889	Mechanisation of the coal industry starts with a coal cutter being used at Greta Colliery in the Hunter Valley.
1890	Saywell sold South Bulli Colliery to Ebeneza Vickery
1891	A build up of gas in the South Bulli Colliery resulted in an explosion killing one miner
1901	The South Bulli Colliery was acquired by the Melbourne based business Bellambi Coal Company
1906 -1907	A Royal Commission further encourages the mechanisation of the coal mining industry with the recommendation that no new mine be opened without a substantial part of its operations being mechanical.
1908	The *SS Bellambi* joined the fleet of four coastal colliers operated by the Bellambi Coal Company of Melbourne
1908	Coal Miners Federation is formed
1909	First major coal miners strike in the Illawarra
1909	Output from the South Bulli Colliery reached 2,200 tonnes per day and the

Date	Event
	company owned 3,600 hectares of land surrounding the site.
1913	The South Bulli Colliery started to supply electricity to the Bulli Shire from its own power station. This arrangement continued until Dec 1957.
1916	The South Bulli Colliery temporarily closed
1917	The South Bulli Colliery re-opened and the first underground transport system for the employees was installed
1923	The South Bulli Colliery Mine Superintendant applied for the first ventilation shaft site on the catchment. Construction started on 12 Jan 1929
1925	20.5% of coal cut in NSW was by machine
1926	One miner is killed after a mine collapses in the South Bulli Colliery
1926	A mine rescue station covering the South Bulli region is established
1928	The South Bulli Colliery bathhouse and change house were constructed on land outside the adit
1935	A mechanised arc cutter was installed at South Bulli Colliery
1936	One miner is killed by a mine collapse at the South Bulli Colliery
1940	First 'Aeroto' fan at No 1 shaft installed at South Bulli Colliery
1943	The South Bulli Colliery underground transport system is extended
1947	Two scrap loaders are installed at South Bulli Colliery
1949	Four Manor and Coulson loading machines installed at South Bulli Colliery
1952– 1953	The company jetty and adjacent coal crushing plant ceased to operate and coal was shipped from the government facilities at Port Kembla
1954	The South Bulli Colliery scraper loaders were replaced by L600 loading machines, a mechanised cutter and two electric battery locomotives
1955	The South Bulli Colliery skip incline system for transporting coal from the mine down the escarpment was replaced by a belt conveyor
1956	Secon Jeffry L600 loading machine installed at South Bulli Colliery
1959	Electricity for South Bulli Colliery switched to the County Council supply
1959	The first Lee-Norse continuous miner in Australia was installed at South Bulli Colliery
1960	The South Bulli Colliery main haulage system was electrified and another continuous miner was installed
1962	A two year export contract was signed with Japan for coal from South Bulli Colliery
1965	The company pioneered long wall mining in Australia at South Bulli Colliery
Late 1960s	New plant built and new processes were implemented at South Bulli Colliery
1985	After operating the South Bulli Colliery since 1901, the Bellambi Coal Company was sold to Austin and Butta Ltd
1991-1993	Staffing levels at South Bulli Colliery reduced to 405 workers
1992	Austin & Butta sold to the Shell Company

The CMP was prepared for the previous owners Bellpac Pty Ltd who had intended to close the colliery. Subsequent to this the South Bulli Colliery was purchased by NRE in 2004 when it became known as the NRE No.1 Colliery. Mining recommenced at NRE No. 1 Colliery in July 2005.

4 PHYSICAL DESCRIPTION OF HISTORICAL HERITAGE ITEMS IN STUDY AREA

4.1 NRE NO. 1 COLLIERY

NRE No 1 Colliery covers 6,545 hectares at Russell Vale approximately eight kilometres north of Wollongong.

The eastern-most portion of the site is bound by the Princess Highway and the mine lands extend west from here up to and beyond the Illawarra Escarpment. The coal stockpile and loading area (and previously the washery) are located on a flat area adjacent the Highway. The pit top facilities (offices, portals, workshops, bath house, loco yards and the disused power house) are located on a series of benches immediately below the escarpment. The mining area is generally to the west of the escarpment on elevated and dissected sandstone plateaux. Both the pit top and stockpile areas have a strong industrial appearance.

4.2 ITEMS OF SIGNIFICANCE IDENTIFIED BY GODDEN MACKAY LOGAN

This section includes a brief description of identified heritage listed items and other items of heritage significance, identified in 2004 (refer to *Section 5.3* for further details), located within the PAA.

In 2004 Godden Mackay Logan (GML, 2004) prepared a Conservation Management Plan (CMP) with regard to the heritage aspects of the site on behalf of the previous site owners. The CMP was prepared in anticipation of the closure of the Colliery and focused on decommissioning of equipment and provided guidance for future planning and development of the site.

The CMP identified which of the remnant features contributed to the overall heritage significance of the locally listed Colliery (see *Section 5.3* of this report for further details). The GML report included a detailed description of many of the buildings, features and views as detailed in *Table 4.1*. GML identified items are shown on *Figure 2.1*.

In 2009 ERM undertook an investigation of the site. No additional items of heritage were identified during this investigation. ERM also assessed the current condition of the items identified by GML (2004). An update of the condition of the site elements as recorded by ERM in 2009 is also provided in *Table 4.1*.

Table 4.1 Items of Significance identified by Godden Mackay Logan

Item	GML Description	Changes noted in 2009 by ERM
Power House Precinct	GML (2004) identified the following elements as making up the Power House Precinct: • ventilation fan and flue; • square concrete vents; • small and large iron pipes; • terraced landform; • brick structure to the northeast of the fan with associated pipes; and • two water tanks (GML 2004 32).	At the time of ERM's inspection in 2009, the only change to this precinct was the addition of stormwater management channels to the rear of the ventilation fan housing and flue.
Upper Bench Workshops	GML (2004) described the upper bench workshops as comprising the carpenter and loco shops, the workshop offices, diesel shop and diesel fuel tanks and the remnants of a demolished building. The carpenter and loco shops are located in front of the 1887 portal and are in part supported by the portal brick retaining wall. The single storey steel framed sheds were described as being *disused and dilapidated* (GML 2004 44).	At the time of ERM's visit in 2009 the sheds were being used for storage. However, there appeared to have been no changes to these structures.
Workshop Offices	The Workshop Offices, consist of two small rooms linked by a verandah. These are located to the rear of the 1887 portal and parpenters workshop (GML 2004 44).	At the time of ERM's visit in 2009 no changes had been made to this structure
1887 Portal	The 1887 portal is located to the rear of the carpenter shop and loco shop. There are two semi circular arched brick-lined adits. The northern adit is faced with a brick wall portal and is constructed with brick and topped with a pediment bearing the following inscription '*Built A.D. 1887 South Bulli Mining Co'*. The adit has been partially filled with a concrete brick wall. The southern adit which is described in GML (2004) as having *"a similar façade and arched opening but has no parapet or signage"* (GML 2004 49).	The 1887 portal does not appear to have undergone any significant changes since the Godden McKay Logan (2004) report. ERM observed in 2009 that southern adit has been boarded up with corrugated iron and its original function is not easily observed.
Brick Retaining Wall	GML noted that the brick retaining wall was approximately 2.5m high and 30m long. It was described as being in poor condition with noticeable cracks and bulging. (GML 2004, p 49)	ERM saw no changes to the condition of the wall during the site visit of 2009.
Crib Room and First Aid Station	In 2004 these buildings were described by GML as being *"located on the northern side of the Main Portal…Both are free standing, brick, single-storey buildings with corrugated iron clad gable roofs and both are painted green…* *These buildings appear to be relatively intact and in fair condition."*(GML 2004, p 55)	ERM noted no changes to the condition or fabric of these buildings during the site visit of 2009.
Store Room	Located to the north of the crib room and first aid station, the store room is a small square building with hipped gable roof and sash windows. (GML 2004, p 55)	The building had not undergone any alteration since the 2004 GML investigation.

Item	GML Description	Changes noted in 2009 by ERM
Closed Adits	A number of adits have been closed over the years and while some are marked and easy to detect, others are not (GML 2004, p 57)	ERM did not investigate the location or condition of any closed adits.
Gibson's Portal	In 2004 Gibson's Portal was described by GML as consisting *"of a pair of brick-lined adits…Both Adits feature a rectangular brick façade constructed in English Bond, measuring approximately 5m long and 3.5 m high, with a central three course brick arch …* *These portals appear to be in good condition, though they are affected by soil movement and vegetation growth* (GML 2004, p 59)	The item had not undergone any alteration since the 2004 GML investigation.
Sandstone retaining wall	The sandstone retaining wall runs to the south of Gibson's portal. *the sandstone blocks are roughly hewn and vary in size ….The blocks are bound together with concrete mortar and the top of the wall features a coping course of similar dimensioned stones positioned slightly overlapping the alignment of the wall* (GML 2004, p 59)	The sandstone retaining wall was not observed to have been altered from the time of the 2004 CMP
The Preparation Plant	In 2004 the preparation plant was described by GML *"a large, steel framed structure clad in corrugated-iron sheeting, the multi-dimensional form which follows the configuration of the functional elements within … Walkways throughout the plan circumnavigate installed equipment and are constructed of open mesh steel plates,…* (GML 2004, p 60)	By the time of the 2009 site visit this building had been demolished with the exception of the thickener tanks. As part of the current demolition of the washery a report is being finalised by Nexus (heritage consultants). This report will meet the Development Consent requirements for demolition of the washery. It will include a summary of plans and other documents relating to the washery.
Rail Tracks and System	*The …site contains a network of operational and non-operation rail tracks from various periods. Most of the existing tracks are located in the vicinity of the workshops and the operational adit. Sections of abandoned Rail tracks exist near the 1887 Portal and in various locations around the site.* *The Tracks located on the Upper Bench are associated with the former Carpenters and Loco Shops, established following the closure of the adjacent 1887 Portal. A number of manual point switches are located at the entrance to the sheds and to the south along the Tracks. Additional switches are located on the lower bench associated with current workings at the Main Portal.* *The main access road up the escarpment from the main gates to the Administration Building appears to follow the original skip-haulage line for the mine but no physical evidence of the earlier operations is apparent.* (GML 2004, p67)	There have been no changes to the various networks of rail tracks since 2004 and they remain visible in places especially near to the 1887 adit.

Item	GML Description	Changes noted in 2009 by ERM
Signal Box	The signal box was described as being *"two storeys in height with a gabled roof or corrugated iron, it comprises a single room, weatherboard lined to waist height with glazing above sitting upon a brick walled lower floor level. Restored in 1988 as a Bicentennial project is contains a flour slot lever frame with three levers for signals and wheel-driven winch for moving the points* (GML 2004, p67)	This item was rehabilitated in 1988 for about $16,500.00. There are some original items inside the building. The building since 1988 has been vandalised by fire on two occasions. The 2009 inspection undertaken by ERM revealed that the signal box had been damaged by vandals and fire. This may be in part due to its isolated location near the mine entry gates.
The Coal Wagon	The coal wagon is located in the vicinity of the signal box and was also part of the Bicentennial project. It was described as being *"a timber-sided hopper wagon on a steel frane, with four wheels and fixed axles.* (GML 2004, p69)	This item is deteriorating due to vegetation growth and weathering.
Coal Cutter Head	The coal cutter head is located near the coal wagon and is part of a short-wall coal cutter. GML discussed that "*although isolated from its power supply and its transport mechanism and the associated machines, it appears relatively complete"* (GML 2004, p69)	The coal cutter head is subject to weathering and vegetation growth.
Remnant Incline Haulage Alignments	*Of particular interest is the alignment of the incline Haulage route from Gibson's Portals where coal was moved down the escarpment to be loaded from transportation off-site. While there are no remaining tracks associated with this alignment, the route was incorporated into the main access road route and survives as a landscape element. The view lines (to and from the escarpment) associated with the incline haulage alignment and, by association, the front entrance where the coal trucks left the site and crossed the Princess Highway route to Bellambi Jetty. (*GML 2004, p69*)*	The 2009 site inspection revealed no changes to the remnant incline haulage alignments.
Original Haulage line Vistas	*The view lines or vistas looking east from the benched area of the Old portal and Man Portal precincts, across the terraced works area of the site, provide important visual links from the site to other aspects of the colliery operation. In particular, the important visual links are from the 1887 Portals, the Upper Bench Workshops, the Lower Bench Workshop areas over the artificially-terraced benches, the washery precinct and the Incline Haulage route. Beyond the site, the view line continues towards the location of the jetty and is an important and unique visual link between the colliery site and the townships of Russell Vale and Bellambi on the coast (via Broker Street where the rail tracks originally extended to the jetty). This alignment is clearly identified from the colliery escarpment and benched areas. (*GML 2004, p69)	The 2009 site inspection revealed no changes to the original haulage line vistas.

5 ASSESSMENT OF HERITAGE SIGNIFICANCE

5.1 SIGNIFICANCE ASSESSMENT CRITERIA

In NSW, assessments of heritage significance are guided by the principles of the *Burra Charter (1999) (the Australian ICOMOS Charter for places of Cultural significance)* and the Heritage Branch's (2001) publication *Assessing Heritage significance*.

The Heritage Branch considers that an item has State (or local) heritage significance if, in the opinion of the Council, it meets one or more of the following criteria:

Criterion (a) *an item is important in the course, or pattern, of NSW's cultural or natural history (or the cultural or natural history of the local area)*

Criterion (b) *an item has strong or special association with the life or works of a person, or group of persons, of importance in NSW's cultural history (or the cultural or natural history of the local area)*

Criterion (c) *an item is important in demonstrating aesthetic characteristics and/or a high degree of creative or technical achievement in NSW (or the local area)*

Criterion (d) *an item has a strong or special association with a particular community or cultural group in NSW (or the local area) for social, cultural or spiritual reasons*

Criterion (e) *an item has potential to yield information that will contribute to an understanding of NSW's cultural or natural history (or the cultural or natural history of the local area)*

Criterion (f) *an item possesses uncommon, rare or endangered aspects of NSW's cultural or natural history (or the cultural or natural history of the local area)*

Criterion (g) *an item is important in demonstrating the principal characteristics of a class of NSW's*

- *cultural or natural places; or cultural or natural environments;*
- *a class of the local area's cultural or natural places; or*
- *cultural or natural environments.)*

5.2 CULTURAL HERITAGE SIGNIFICANCE OF PAA

Godden Mackay Logan (2004) prepared a Conservation Management Plan (CMP) for the South Bulli Colliery and this report included a Summary Statement of Significance (2004: 82-83) which stated:

> *The South Bulli Colliery site is an important place in the Illawarra's and the state's history because it is one of the earliest established and longest-running coal mining operations in Australia and because it retains structures, machinery, landform and spatial configurations that illustrate and embody its history.*
>
> *The site is also important because, during its operating life, it introduced the first underground transport system installed for employees in New South Wales (1917) and it pioneered longwall mining in New South Wales coal fields (1965). The colliery holds the Australian record for underground coal extraction and this reflects both its long period of operations and its history of investment in technical innovation.*
>
> *The site as a whole is important in the course of the Illawarra's history because was (sic) important in providing the employment and investment that catalysed population growth and established the pattern of settlement of Russell Vale township and the north Wollongong area.*
>
> *The site as a whole has aesthetic qualities of significance to the local area. Its escarpment location and form and its remnant industrial elements together create a striking and unusual landscape that has become a characteristic and, to a degree, an identifying feature of the area.*
>
> *The site has cultural associations with the local community and the broader coal mining community because of its long history, historically-pivotal social and economic role in the area and because it was, at various times, a centre for labour movement and workplace reform activity.* (GML 2004, p82-83)

5.3 CULTURAL HERITAGE SIGNIFICANCE OF SITE ELEMENTS

As part of its assessment, Godden Mackay Logan considered the individual site elements at the colliery and assigned them each a grading in terms of significance. This was intended to demonstrate the degree to which the precincts and elements contributed to the overall heritage value of the site.

Table 5.1 provides a summary of Godden Mackay Logan's rankings

Table 5.1 Significance grading of individual site elements

Item Name	Grading
Power House Precinct	Moderate
Administration Precinct	
Administration building	Low
Pathways and landscape	Low
Car park	Low
Old Portal Precinct	
Workshops – lower bench	Moderate
Work shops upper bench	Moderate
1887 Portal	Exceptional
Brick retaining wall	High
The main portal	Low
New bathroom	Low
Crib Room and First Aid Station	High
Storeroom	High
The extraction portal	Low
The main downhill conveyor	Low
Closed adits	Moderate
Gibson's Portal Precinct	
Gibson's Portal	High
Sandstone retaining wall	Moderate
Fan house	Low
Gibson's sublease portal and associated elements	Low
Electrical Substation	Low
Electrical switchroom	Low
The Washery Precinct	
The preparation plant (now demolished)	Moderate
Conveyor system	Low
Storage silos	Low
Truck loader	Low
Coal stockpiles and reject material	
Coal stockpiles	Low
Reject materials emplacement areas	Low
Settling dams	Low
Other dams	Low
Rail Tracks, Signal Box and Associated Elements	
Rail tracks and system	High
Signal box	High
Movable heritage Elements	
Coal wagon	High
Coal cutter head	Moderate
Landscape and Vistas	
Remnant Incline Haulage alignments	High
Original haulage line vistas	High

Source: GML (2004)

Table 5.2 Explanation of rankings

Ranking	Description
Exceptional	Rare or outstanding building, item or landscape element directly contributing to an item's local or state significance. High degree of intactness of original building fabric and / or design integrity. Item can be interpreted easily.
High	Building, item or landscape element that demonstrates a key aspect of the place's significance. High degree of original fabric and / or design integrity or alteration add to or do not detract substantially from significance or could be easily rectified.
Moderate	Building, item or landscape element of some significance that contributes to the overall significance of the site. May include altered or modified components.
Low	Building, item or landscape element that makes a minor contribution to the overall significance of the site but is nor important in gaining an understanding of the site as a whole. It may also be an alteration or addition to a more significant building that makes it difficult to interpret the significance of that building element.

Source: GML (2004)

The statements of significance prepared by GML in 2004 for items of moderate, high and exceptional heritage value have been included within *Annex B.*

6 PROJECT DESCRIPTION

As part of the Project, infrastructure, plant and equipment associated with proposed mining activities will be constructed or upgraded at the PAA.

The Project will have an estimated capital investment value of $250 million with coal extraction ramping up to three million tonnes per annum (Mtpa) with a projected life of at least 18 years. The project will include the following activities:

- continued westward development of the existing 'Wonga Mains' drivage from Russell Vale to access underground working areas;
- longwall mining of the Wongawilli seam in the 'Wonga East' area, beneath previously mined Balgownie and Bulli seam workings;
- longwall mining of the Wongawilli seam in the 'Wonga West' area beneath the previously mined Bulli seam workings;
- first workings in the Bulli seam in the 'Bulli West' area (anticipated to have no direct subsidence impacts);
- Balgownie seam mining, limited to first workings only, beneath overlying Bulli seam workings (anticipated to have no direct subsidence impacts);
- upgrade of existing mine infrastructure and services at Russell Vale, including surface conveyors and coal handling infrastructure, coal sizing, screening, crushing and load-out facilities, site noise and dust controls and a stockpile for run-of-mine (ROM) coal;
- continued use of No.4 Shaft for mine access (for men and materials), bath house, offices and parking area;
- essential maintenance and refurbishment of existing ventilation shafts and power and water supply arrangements;
- upgrade of all site water management including mine water and stormwater controls;
- continued road haulage of the ROM coal to Port Kembla Coal Terminal (PKCT) for shipment to India, using the existing haulage route; and
- trucking fleet upgrades with current best practice suspension and braking systems and suitable covers for all loads.

7 ASSESSMENT OF HERITAGE IMPACT

7.1 ISSUES CONSIDERED FOR ASSESSMENT OF HERITAGE IMPACT

The following assessment of heritage impact has been developed with consideration to the specific questions posed in the Heritage Branch guideline *Statements of Heritage Impact*. Consideration of these questions has guided the identification of potential positive and negative impacts and the mitigation measures required to address these impacts.

This guideline includes the following issues to consider for major additions to a heritage item, which in this case is the South Bulli Colliery (identified in Schedule 5 of the WLEP 2009), now known as NRE No.1 Colliery:

- *How is the impact of the addition on the heritage significance of the item to be minimised?*
- *Can the additional area be located within an existing structure? If not, why not?*
- *Will the additions tend to visually dominate the heritage item?*
- *Are the additions sited on any known, or potentially significant archaeological deposits? If so, have alternative positions for the additions been considered?*
- *Are the additions sympathetic to the heritage item? In what way (e.g. form, proportions, design)?*

This guideline also includes the following issues to consider for a new development adjacent to a heritage item in this instance this would refer to the additional seven items identified in Schedule 1 of the IREP namely the: Bellambi Creek Dam; ball mill concrete base: main portal (archaeological); portal for ventilation (archaeological), the signal box, old washery; and mine offices (former) (archaeological).

- *How is the impact of the new development on the heritage significance of the item or area to be minimised?*
- *Why is the new development required to be adjacent to a heritage item?*
- *How does the curtilage allowed around the heritage item contribute to the retention of its heritage significance?*
- *How does the new development affect views to and from the heritage item? What has been done to minimise negative effects?*
- *Is the development sited on any known, or potentially significant archaeological deposits? If so, have alternative sites been considered? Why were they rejected?*

- *Is the new development sympathetic to the heritage item? In what way (e.g. form, siting, proportion, design)?*
- *Will the additions visually dominate the heritage item? How has this been minimised?*
- *Will the public, and users of the item, still be able to view and appreciate its significance?*

Based on the project description given in *Chapter 6,* potential impacts to heritage items are most likely to arise from the construction and development of the new coal handling infrastructure.

7.2 IMPACT ASSESSMENT

This section identifies the potential positive and negative impacts of the Project upon items with identified heritage values, so that the positive impacts can be enhanced and the negative impacts mitigated. Impacts from both the development proposed and the adaptive re-use have been assessed.

7.2.1 Positive Impacts and Opportunities

Aspects of the Project with respect or enhance recognised heritage values are discussed below.

New Development

The new stockpile area and associated infrastructure will be located at the site of the existing stockpile and dismantled washery. This section of the site currently has a strong industrial appearance and historically has been one of the pit top working components. New mining equipment and infrastructure will add a modern layer of mining technology to the site demonstrating the temporal changes in mine-related technology whilst enabling the mine to continue operating.

The proposed surface works are not in the immediate vicinity of the locally listed heritage items. No heritage items are to be demolished to facilitate this Project.

The proposed upgrade of the site along with the continuation of mining operations reinforces the historical link with the mining industry, community, employment and the intrinsic history of the site. The continuation of mining operations provides greater context for the identified heritage items.

Underground works in the beneath Cataract Dam include Wonga Mains. These proposed extraction areas will be developed using the first workings mining method, which results in 'zero' subsidence. As such no subsidence will occur in the vicinity of the Cataract Dam as a result of the Wonga Mains. No secondary extraction will occur beneath Cataract Dam or within a 1km radius of the dam wall. Potential impacts to Cataract Dam are further assessed as part of the subsidence impact assessment for this Project.

7.2.2 Risks to Heritage Values

Aspects of the Project, which could potentially have adverse impacts on heritage significance, are described below:

- loss of heritage value caused by a lack of adequate forward planning for items of potential heritage value due changes in site planning and use of out of date heritage policy documents;
- while some buildings and infrastructure on site are locally significant, other elements which have been considered by GML (2004) as contributing to the overall heritage value of the site have not been afforded heritage protection. Therefore these buildings or elements could be at risk of demolition or unconsidered alteration;
- loss or damage of items of moveable heritage;
- non-use of potential heritage items could result in these items falling into a state of severe degradation; and
- changes to the colliery's current phase of life are inadequately recorded prior to the commencement of new work, resulting in an incomplete record of the historical life of the South Bulli Colliery.

8 MANAGEMENT AND MITIGATION MEASURES

8.1 MITIGATION MEASURES

The following measures are recommended to mitigate potential impacts arising from the Project. These recommendations should be taken into consideration in a revised Conservation Management Plan to be prepared for the PAA.

- no items identified as having heritage value or contributing to the heritage value of the site, should be demolished as part of this Project;
- a revised CMP should be prepared to reflect the future need of the site as a continuing mine;
- procedures to follow for the discovery of unanticipated 'Relics';
- a photographic recording of the 1887 portal should be undertaken to Heritage Archival Recording standards. Copies of the recording should be lodged with the appropriate Local and State repositories;
- a photographic recording of the site should be undertaken, to Heritage Archival Recording standards, prior to commencement of construction for the Project, to provide a lasting record of the site prior to the new development. Copies of the recording should be lodged with the appropriate Local and State repositories; and
- items of moveable heritage will be retained at their current location onsite and documented including historical photos, plans, maps and records to Heritage Archival Recording standards. A conservator will provide advice regarding the long term storage of the items to maximise their survival. When the item has been appropriately catalogued its will be donated to a suitable repository. Appropriate repositories will be identified prior to Project works commencing.

8.2 CONCLUSION

The Project has been planned with the intention of continuing extraction from this historic colliery. The new stockpile area and associated infrastructure is proposed to be located in an area currently used as the above ground "working" components of the site and already have a strong industrial appearance. New mining equipment and infrastructure will add a modern layer of mining technology to the site and that new and old will co-exist and be able to demonstrate temporal changes in mine-related technology.

This Project is well planned with minimal impacts to the heritage values of the site.

REFERENCES

Godden Mackay Logan (2004) **South Bulli Colliery Conservation Management Plan – Part 1.** Report Prepared for Bellpac Pty Ltd.

Annex A

History of South Bulli Colliery Prepared By Godden MacKay Logan In 2004

3.0 Historical Development

3.1 Background — The Opening of the Illawarra Coalfields

Illawarra coal was discovered by chance in August 1797. A party of shipwrecked sailors making their way on foot along the coast towards Sydney discovered coal in the rock face at what is now Coal Cliff. The reports were investigated by George Bass, sent by Governor Hunter, who reported the presence of coal in the cliffs some twenty miles south of Botany Bay. Samples were collected, and although the coal was considered excellent quality, acquiring it in quantity appeared difficult as the seam outcropped in the cliff face 6m above the water on a rocky shoreline. Further, discoveries of coal at Newcastle in September of the same year (1797) meant that the Illawarra deposits were temporarily passed over.[1]

In the first half of the nineteenth century, there were many proposals for developing the Illawarra coal seams but the inhospitable shoreline on one side and high escarpment of the region on the other side defeated these attempts. Another inhibition was the exclusive licence to mine coal in New South Wales which was granted to the Australian Agricultural Company, based in the Newcastle region, which lasted till 1848. A small mine was opened at Mt Keira in 1849 but it was not until the end of the 1850s, with steam-powered ships operating and the wealth of the gold discoveries beginning to trickle through the colony's economy, that sufficient investment capital was available to build the coastal jetties and establish the above-ground infrastructure to make mining this coal worthwhile.[2]

After 1857, development was more rapid. The Osborne-Wallsend Mine at Mt Keira opened in 1857, carting the coal to Wollongong Harbour. By the end of 1860, a horse-drawn tramway ran from the mine to the port. In 1861, a colliery opened at Woonona, with the coal shipped from a jetty built for this purpose at Bellambi. The Bulli Colliery and the Taylor and Walker Colliery (now the South Bulli Colliery) also commenced operations in 1861, with the latter delivering coal to a second jetty at Bellambi in 1862. The Bulli Colliery commenced shipments in 1863 from a jetty at Bulli Point and was soon delivering product directly to China using its own steamer. Further collieries opened at Mt Pleasant, Coal Cliff and North Bulli during the next decade but the 1880s were the most notable, with the construction of the Illawarra railway line linking the district with Sydney and providing a more secure and reliable transport route for the coal. Some of the new collieries which appeared were the Metropolitan at Helensburgh, the Mt Kembla Colliery, the North Illawarra Colliery at Austinmer, Bulli A Colliery and Bulli B Colliery, Brokers Nose (later known as Corrimal) Colliery and North Bulli Colliery. The Taylor and Walker Colliery reopened in 1884 as the South Bulli Colliery.[3]

3.2 Early History of the South Bulli Colliery

The first coal extraction from the South Bulli coal mine, which was first known as the Taylor and Walker Colliery, commenced in 1862. The land on which the colliery was located was leased from the Osborne family of Marshall Mount near Dapto. The initial drive was a length of five chains (90m),

at which point a basaltic dyke was encountered, greatly hindering extraction. Around the same time, a depression in the coal trade led to a takeover by a co-operative company. However, the mine was forced to close in 1864 and was not opened again until 1884.[4]

In 1884, the mine was acquired by L MacCabe but proposals lapsed and, in 1887, the South Bulli Mining Company was formed by a syndicate associated with Thomas Saywell, with W Wilson as manager.[5] The surface workings erected included a portal entrance, a large boiler house and steam engine and a sawmill to supply timber for the mines and general workshops. The colliery also erected a new jetty, 252m (820 feet) long, at Bellambi Point. The mine eventually opened as the South Bulli Colliery in 1887 and the first coal was shipped in November 1887. The portal from that date still exists adjacent to the present administration complex.

In August 1890, Saywell sold the mine to Ebeneza Vickery, who sold it later to Mitchell and Waley.

3.3 Bellambi Coal Company 1901–1985

3.3.1 The Early Years 1901–1930

In May 1901, the Bellambi Coal Company of Melbourne acquired the whole of the South Bulli Coal Mining Company and commenced the first large-scale mining on the site. By 1909, the output had reached 2,200 tonnes per day, which was in excess of 800,000 tonnes per year. By this time, the company owned 3,600 hectares of land surrounding the mining site.

By 1908, the company was operating a fleet of four coastal colliers. In 1908, with the backing of its own shipping line, the fleet was joined by a new collier, the SS *Bellambi*. With a capacity of 1,600 tons, the ship was built to a design set down by the Bellambi Coal Company.[6] Coal was loaded from the company's jetty, which extended 970 feet (295m) seawards from the high water mark..

The jetty was originally operated on a gravity system. Loaded coal wagons were pushed by a locomotive to the loading area and, after loading, the empty wagons were shunted on to the down line, where they returned to the shore end of the jetty by gravity on a descending incline. Back on shore, the wagons were attached to a locomotive and hauled uphill back to the mine[7] (see Figures 3.7 and 3.8).

Further developments included the introduction of a standard-gauge skip haulage-incline up the escarpment, drawing straight out of a new adit from the underground workings, and an endless-rope haulage system.[8] This incline adit, known as Gibsons Portal, is still extant and the line of the haulage incline is the route of the present vehicular road from the main entrance to the upper part of the site (see Figure 3.9).

In 1913, the colliery commenced to supply electricity to the Bulli Shire from its own power station located on the escarpment above the incline. The powerhouse continued to supply power to Bulli until December 1957. It stopped supplying power to the mine in April 1959, when the company changed to the County Council electricity supply.[9]

Mining continued through the first two years of the First World War but, as the major purchaser of South Bulli coal was German industry, the mine closed briefly during 1916–1917. The mine reopened in 1917, when the first underground transport system for employees was installed, commencing operations in December 1917.

In 1923, the mine superintendent applied for the first ventilation shaft site on the catchment. The ventilation shaft was sunk on 12 January 1929, striking the coal workings at 323m.[10]

In 1928, the bath house and change house had been constructed on the land outside the adit. Until this time, most miners would be required to travel home in their dirty work clothes to bathe, a practice that was seen to cause some considerable discomfort to the workers and their fellow commuters. The miners at the time described the bath house addition as a great thing, allowing them to clean up and change clothes before heading home.[11]

3.3.2 Mechanisation 1930–1985

The mechanisation of New South Wales coal mines had begun in the later 1800s, with the installation of a compressed-air coal cutter in 1889 at Greta Colliery in the Hunter Valley. By the early years of the twentieth century, a number of mines, particularly in the Newcastle area, were beginning to introduce mechanical coal cutting to their operations. Although coal still needed to be loaded into wagons by hand, the coal cutters did begin to have an impact on the physical nature of coal mining. A Royal Commission in 1906–07 further encouraged the mechanisation of the coal mining industry, with the recommendation that no new mine be opened without a substantial part of its operations being mechanical.[12]

Despite this, progress was slow due to a combination of factors, from the unsuitability of older mines to workers' fear of job losses, so that by 1925, only 20.5 per cent of coal cut in New South Wales was done by machine, rising to only 37 per cent by 1946.[13]

At South Bulli, an arc-wall cutter was installed in 1935, followed by a second cutter some twelve months later. These coal cutters were fully-enclosed CA12 type cutters for centre cutting, mounted on a self-propelled truck. The cutters were used to eliminate the undercutting method used when the mine was operated purely by hand, although miners still continued to bore and fill the shot.[14] At this time, transport within the mine itself was still done by pit ponies, which were used to haul the coal wagons to the transfer point for conveying to the surface. The coal was taken to the surface in rail trucks pulled on a continuous rope system.[15]

Further improvements to the ventilation were carried out in 1940, with the addition of the first 'Aeroto' Fan at No. 1 Shaft. In 1943, the Underground Transport System was also extended within the operating area.

In the years preceding the Second World War, the South Bulli Colliery underwent a rapid transformation in terms of its mechanical operations. The next major step in the mechanisation of the mine occurred in 1947 with the installation of two scraper-loaders, which contributed to a greatly

increased productivity.[16] These were joined two years later (1949) by four Mavor and Coulson loading machines. In August, 1954, the scraper-loaders were replaced with a track-mounted L600 loading machine, a mechanised cutter and two electric battery locomotives (see Figure 3.12).

A major change in the operations of the mine came in 1952–53 when it was decided to cease the operations of the company jetty and shut the adjacent coal crushing plant. The declining quantity of coal being shipped from Port Bellambi led to the decision to abandon the jetty and instead use the government facilities at Port Kembla for sea transport. The last ship to use the jetty was the SS *Tuggerah* in December 1953.[17] Soon after, in January 1955, the skip incline system for transporting coal from the mine down the escarpment was replaced by a belt conveyor.

The increasing advantages of mechanisation for both productivity and safety were widely recognised by the 1950s and led to increasing use of machines in the mine. A second Jeffrey L600 loading machine was installed in 1956. In March 1959, this was joined by the first Lee-Norse Continuous-miner in Australia. Continuous-miners combined three stages previously carried out separately into one process, being cutting, boring and loading. Through the use of rotating cutter picks, the continuous-miner could tear the coal from the face (avoiding the use of explosives), gather the cut coal and convey it to the means of transport being used.[18] The introduction of the continuous-miners meant the end of the hand-cut mining system and resulted in a drastic change in the mines' operation.

In September and October 1960, further upgrades included the electrification of the Main Haulage System and the introduction of another continuous-miner with a 'Joy' roof-bolting machine and two Jeffrey shuttle-cars. The shuttle-cars had an 8.5 ton capacity and transported the coal from the face back to the transfer point out of the mine, dumping the coal onto a conveyor or into skips.

The increasing levels of mechanisation, and a growing demand on the world market for coking coal, required a reorganisation of the way in which the mine was operated. From late 1960, new plants were built and processes implemented at South Bulli. Work included the construction of a new coal preparation plant (washery), with coal handling, stockpile storage and recovery facilities at the base of the incline, the completion of the main conveyor system from the underground storage bin to the surface coal preparation plant, completion of the coal face to underground bin conveyer, completion of the underground face ventilation system, construction of new underground storage bins and a new pit top and transport system.[19] The whole of the work was completed by the target date of 17 January 1962.

In 1962, an export contract was signed with Japan to supply 410,000 tonnes of coking coal for the next two years. This was the first of the Bellambi Coal Company's export drives.

In 1965, the company pioneered longwall coal mining technology in Australia. The use of longwall technology allowed for a continuous seam of coal to be extracted, with an overhead advancing roof support system in place for safety. The most common method used was a retreating longwall, whereby two parallel entry roadways are driven into the coal seam for a predetermined distance.

These are then connected with a longwall face and a continuous-miner begins extraction at the furthest end. As the face moves back towards the start area, the moving overhead support allows the mined area to collapse behind the process, filling the mined section in as it goes. Although a second longwall miner was installed in 1970, it was not until the mid-1970s, when Japanese designed Taiheiyo systems were introduced, that the process met with real success (see Figure 3.13).

In 1976, a further ventilation shaft was sunk with the view to it becoming the future means for manpower access to the workings but this is not located within the South Bulli Colliery site. The shaft was 4.57m in diameter and 490m deep. A single hoist, tower-mounted, four-rope friction winder was installed and administration and bathroom buildings with associated surface works were constructed.[20]

3.4 South Bulli Colliery 1985–2004

In early 1985, Austin and Butta Ltd acquired the whole of the assets of the Bellambi Coal Company Pty Limited and, by 1 July, were the new owners of the South Bulli Colliery. In June 1992, Austin and Butta sold the total assets of the colliery to the Shell company. As well as the changes in ownership, the early 1990s represented years in which significant restructuring of the workforce led to job reductions. Between October 1991 and July 1993, the workforce was reduced by 405 workers via redundancies or the non-replacement of those jobs after retirement from South Bulli.[21]

During its 100 years of operations, the colliery (up to 1990) produced a total of 58 million tonnes of coal, with its extraction significantly changing the topography of the area on the escarpment. Over five million tonnes of reject material from the washery has been placed in the immediate area.

Since the ownership of Shell, the South Bulli Colliery has been through a number of different corporate ownerships. While the mine continues to operate to date (2004), production is on a limited scale with coal supplied direct to the steel works at Port Kembla.

3.5 The Mine and the Community

Throughout the working life of the South Bulli Mine, there has been a close connection to the surrounding communities and villages. Common to many of the mines in the Illawarra area, the opening of the South Bulli mine precipitated the establishment of a village settlements nearby, such as Bellambi, Corrimal and Russell Vale. From 1884, when the South Bulli mine had reopened following a twenty-year closure, the continual extraction of coal created ongoing employment opportunities. Close ties between the nearby villages and the mine were formed through generations of the same family working at South Bulli. It was not unusual for fathers and sons to be working together underground. One such miner, Jack Potter, recalled in 1994 that he had started working as an apprentice at South Bulli in 1938 as a sixteen year old. His first two years were then spent apprenticed under his father working with the pit ponies and haulage rope system. After two years

he found a work mate and began work on the coal face.[22] Jack was still working with his father when his father turned sixty.

Although South Bulli mine was never the scene of a disaster on the scale of the nearby Bulli mine, where in March 1887 eighty-one miners were killed in an explosion and the resulting collapse, there were tragedies nonetheless. In June 1891, a build up of gas in the mine resulted in a small explosion in which one miner was killed.[23] Further, the dangers inherent in family groups working in the mine are illustrated by another father-son team interviewed by the Russell Vale Local History Group. Betty Postans' grandfather was killed in a mine collapse in 1936, while her father, who was working alongside, survived.[24] The dangers of mine work had resulted in the establishment of mines rescue stations in the Illawarra from the 1920s, including one covering South Bulli from 1926.

Union membership was a major feature of working in South Bulli mine. The earliest form of unionism had appeared in the Illawarra from the later 1870s. The Bulli Miners Lodge was formed in 1879, with lodges at Coal Cliff and Woonona formed soon after. However, it was not until 1886 that solidarity between the various groups was established, with the formation of the National Miners Union along with miners from Lithgow and the Hunter region.[25] In 1908, the Coal Miners Federation was formed and, in 1909, a major strike was called in the Illawarra, with South Bulli miners joining in. Union membership and activism remained a constant part of local community life throughout the mines' working life. As well, outside the mine proper, Women's Auxiliarys involved families and communities of the miners and provided support during industrial disputes.

Further research on the social aspects of the South Bulli Colliery would further illustrate the role the mine has played in the community.

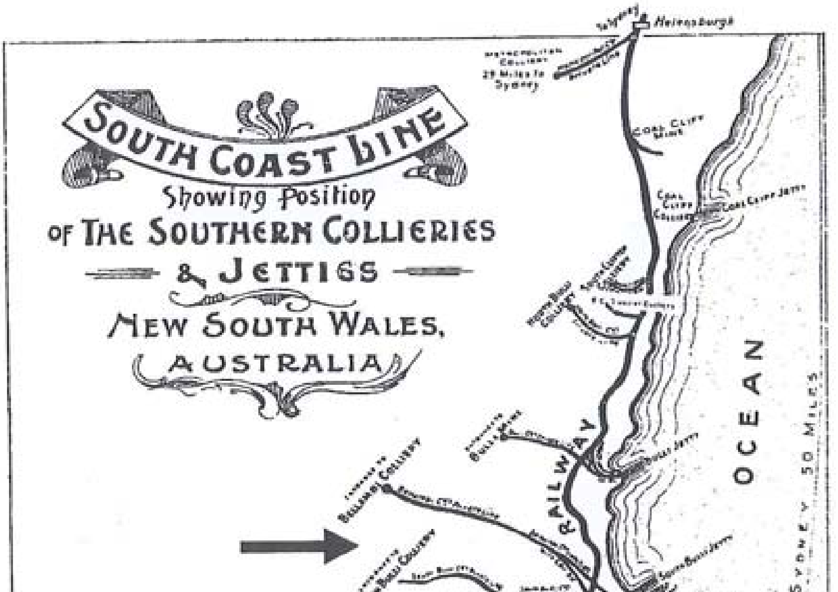

Figure 3.1 Plan of the South Coast Railway Line, showing the location of the collieries and jetties, c1900. Notice the number of jetties still in operation in the 1930s. Although Port Kembla was the main port and the railway was increasingly used, smaller colliery jetties were still practicable for use by the smaller colliers trading to Sydney. South Bulli Mine is indicated. (Source: Southern Coal Owners Agency pamphlet, Wollongong Local History Library)

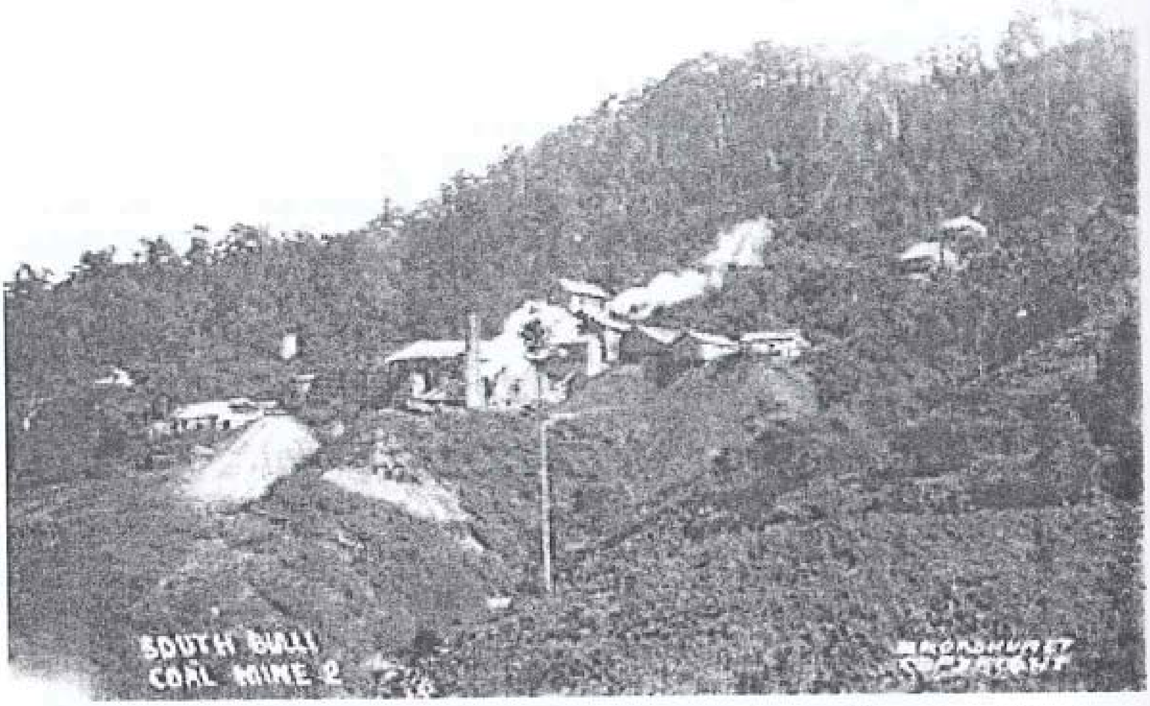

Figure 3.2 South Bulli Coal Mine c1910. This photo clearly illustrates the precipitous nature of the mine site. (Source: Wollongong City Library)

Figure 3.3
Men at the entrance to South Bulli 'B' pit, c1890. The photograph was taken soon after the mine had reopened as a full time concern.
(Source: Wollongong City Library)

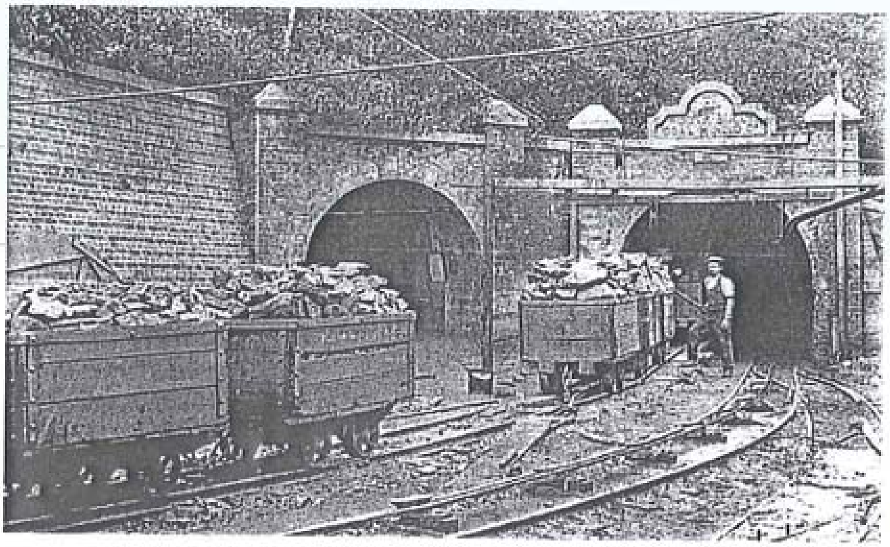

Figure 3.4
Coal skips hauled to the surface by the endless rope system, c1890. The man next to the skips holds a wooden sprag in his hand, used to chock the wheels of the skips once on the surface.

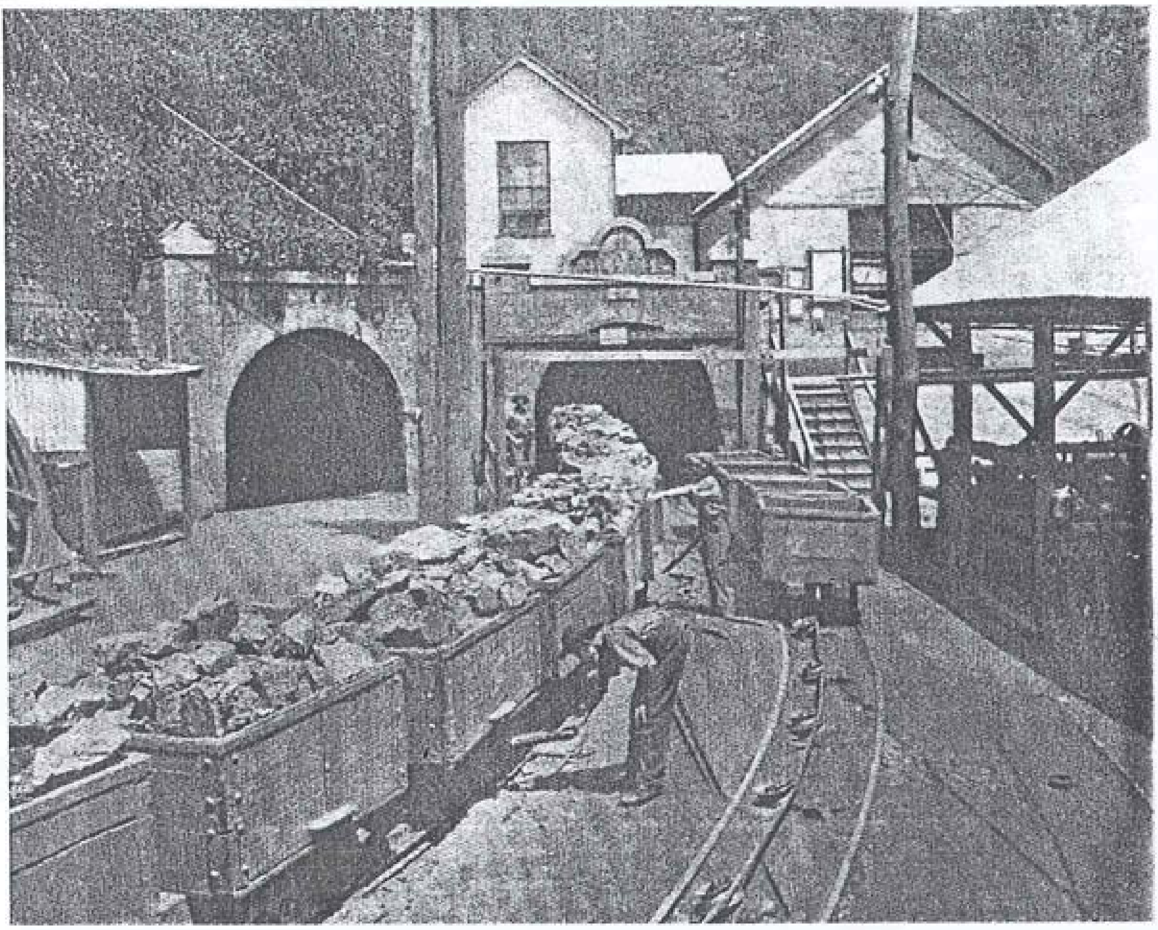

Figure 3.5 1909 photograph with the same view as Figure 2.4 but taken some twenty years later. The endless rope system for moving the skips in and out of the mine is clearly visible. Note also the development above the portal entrance in comparison to Figure 2.4. (Source: History of Coal Mining in Australia, Monograph 21)

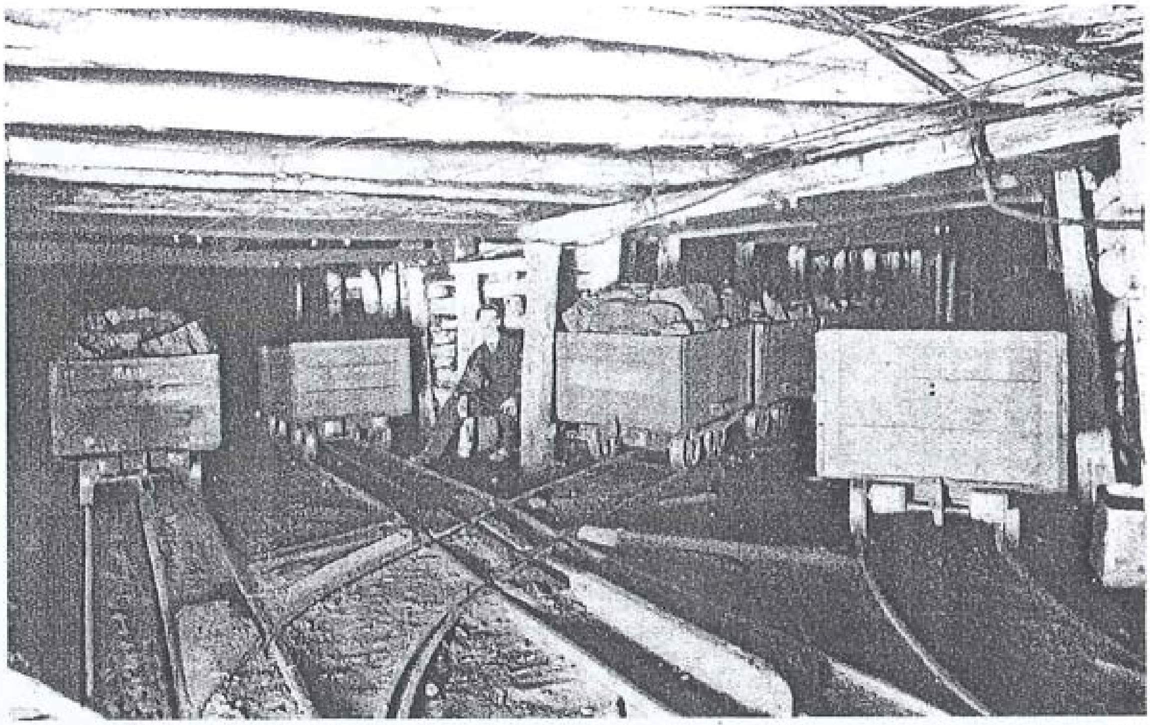

Figure 3.6 Coal skips, full and empty, at an underground junction. The continuous-rope haulage system allowed for an increased rate of coal extraction. (Source: History of Coal Mining in Australia, Monograph 21)

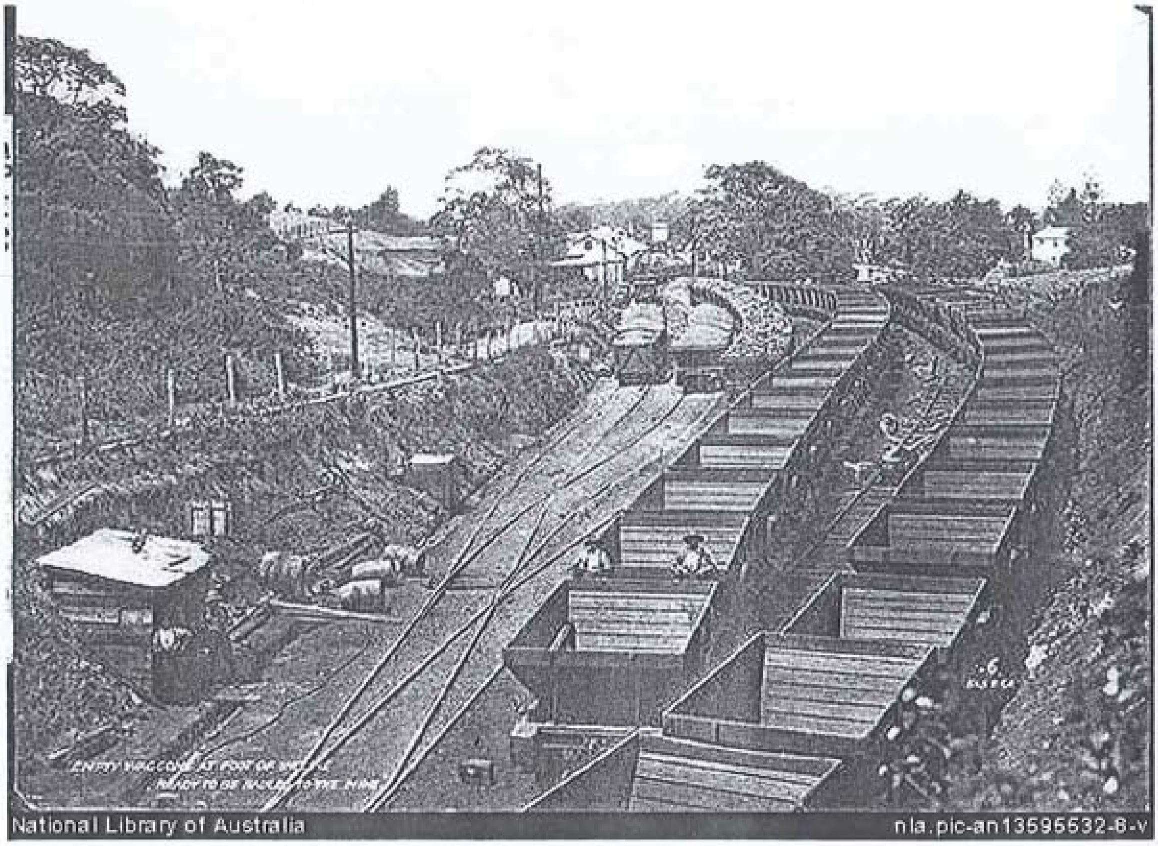

Figure 3.7 Empty wagons at the base of the incline ready to be returned to the mine. (Source: National Library of Australia)

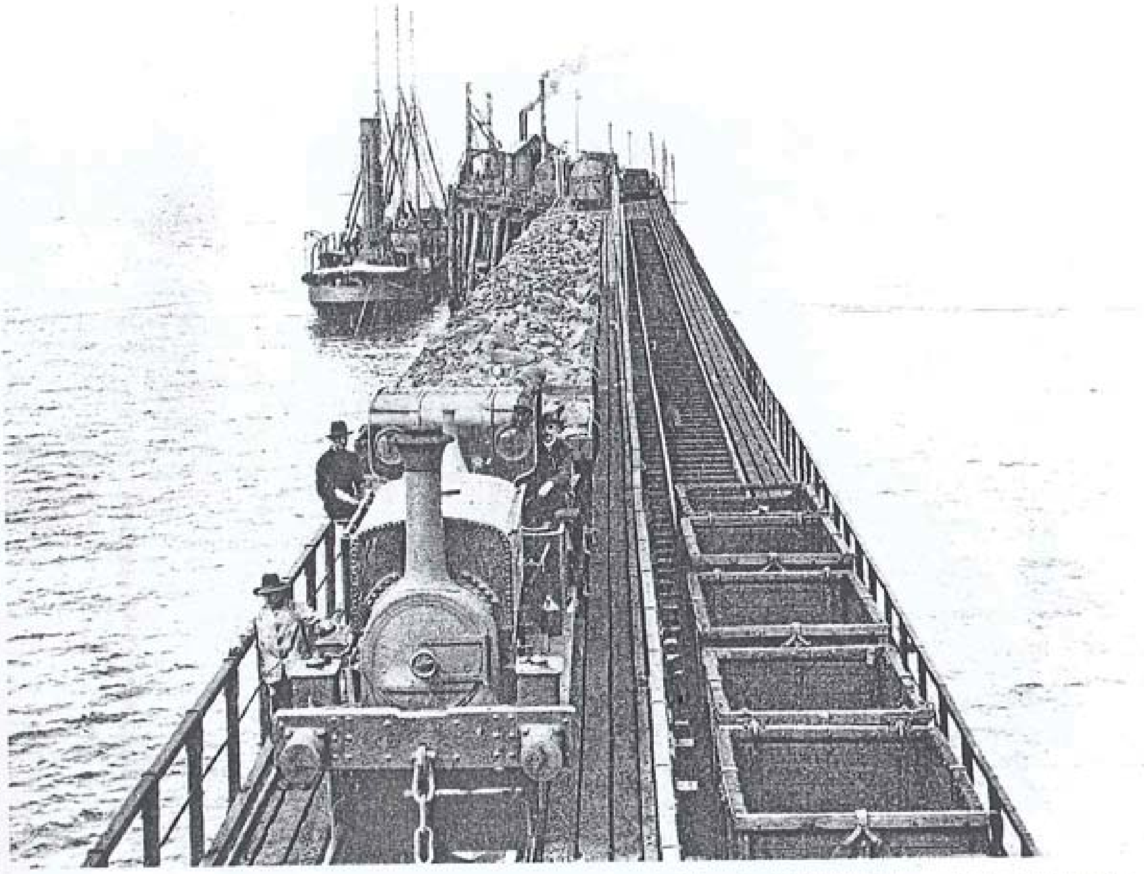

Figure 3.8 1909 photograph of the Bellambi jetty which serviced the South Bulli Colliery. Full coal wagons were shunted by locomotive for unloading onto waiting colliers. The empty wagons were then returned to the shore by gravity. The collier at the jetty is the SS *Bellambi*. (Source: University of Wollongong Archives, Bellambi Coal Company collection D185)

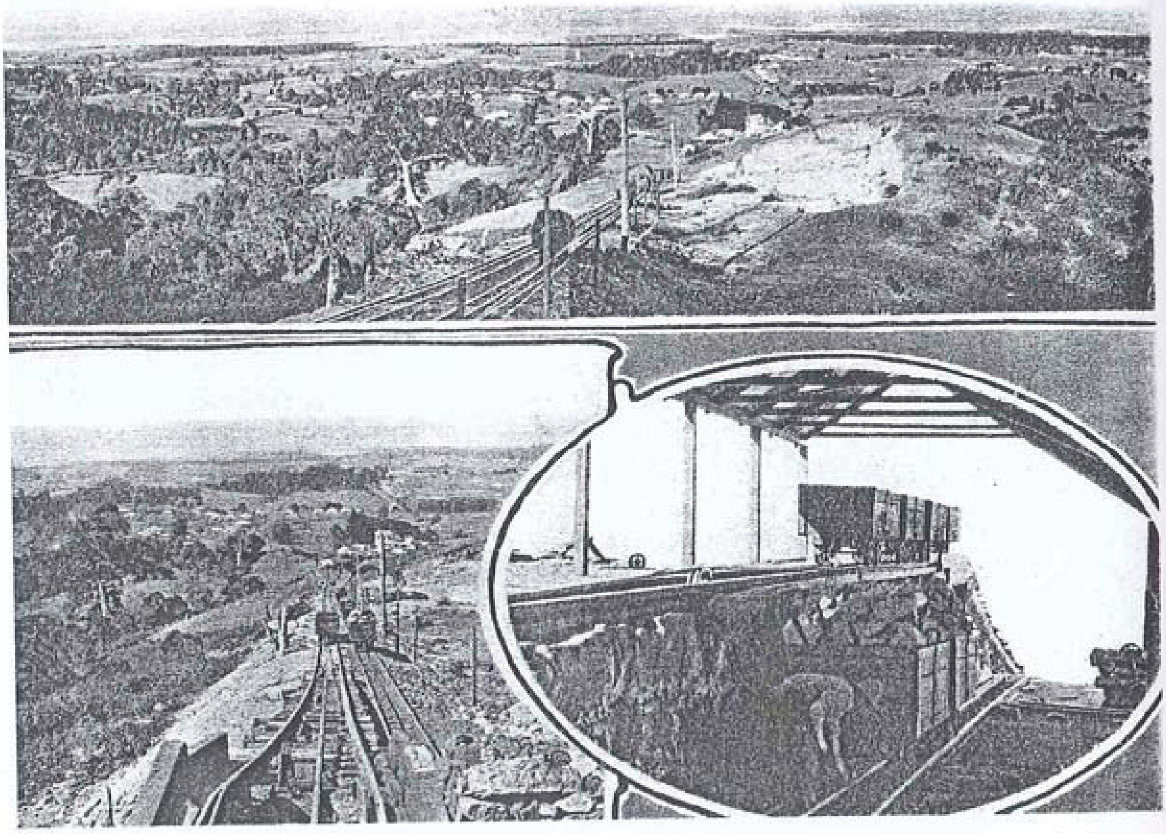

Figure 3.9 Views looking from the mine showing the incline running wagons down to the jetty and rail facilities on the coast. The bottom right-hand photograph illustrates the crossover of full and empty wagons. (Source: University of Wollongong Archives, Bellambi Coal Company collection D185)

Figure 3.10 c1962 view with the washery in the foreground and the mine to the rear. The new washery and coal handling facilities were built to cope with the mechanisation of the mine operations and were completed in 1962. Notice in the middle background the belt conveyor which was installed in 1955 to replace the former continuous rope and skip/wagon system of coal transportation.

Figure 3.11 Example of hand-cutting and loading from a coal face. Although not at South Bulli, this photo does illustrate the physical nature of the work and the number of workers involved. (Source: History of Coal Mining in Australia, Monograph 21)

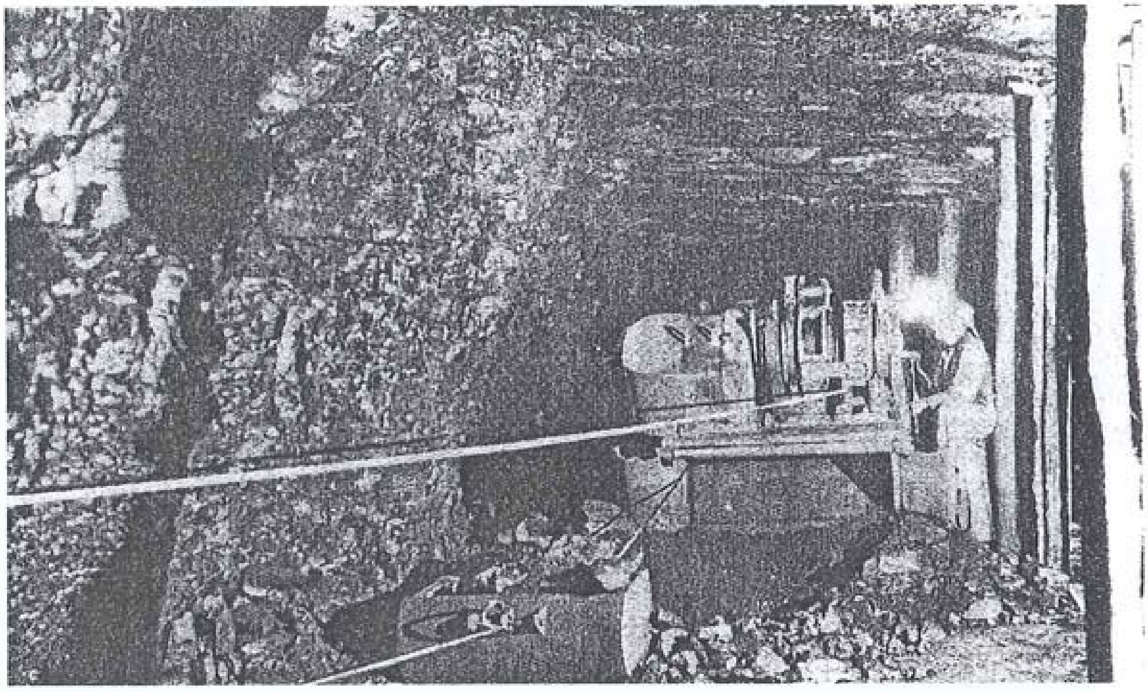

Figure 3.12 A scraper loader in operation. The beginnings of mechanisation in the mine was at first met with some opposition. However, the advantages in increased productivity and safety meant that, from the 1930s onwards, increased mechanisation was inevitable in the coal industry. This type of loader was used at South Bulli from 1947. (Source: History of Coal Mining in Australia, Monograph 21)

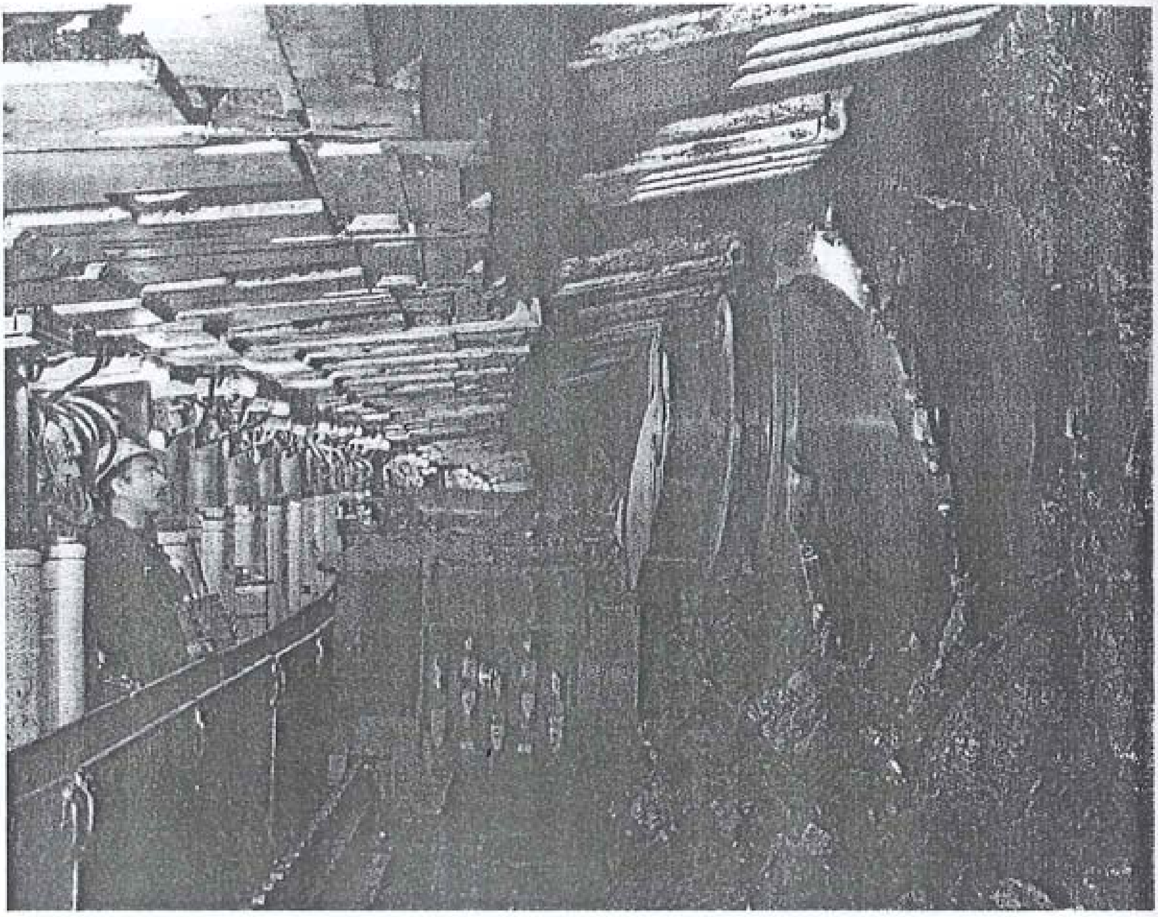

Figure 3.13 View along a longwall face showing the roof supports, coal conveyor and a drum shear cutter. South Bulli was an industry leader in the introduction of longwall operations in Australia. This style of mining greatly increased the productivity, efficiency and safety of underground operations. (Source: History of Coal Mining in Australia, Monograph 21)

3.6 Endnotes

[1] Bayley, WA 1956, *Black Diamonds: History of Bulli District NSW*, Council of the City of Greater Wollongong, p 1.
[2] Parbo, A, 1991, *Down Under: Mineral Heritage in Australasian – An Illustrated History of Mining and Metallurgy in Australia, New Zealand, Fiji and Papua New Guinea*, Monograph 18, The Australasian Institute of Mining and Metallurgy, p 29.
[3] Bayley, op cit, p 7–9.
[4] Austen & Butta Limited, 1991, 'South Bulli Colliery, Russell Vale NSW, Historic Overview', prepared for First National Coal Week Exhibition, Wollongong, p 2.
[5] Bayley, op cit, p 7.
[6] History of Bellambi Coal Company and South Bulli Colliery, manuscript, 1986, Wollongong University Archives, D185 Bellambi Coal Company collection.
[7] The Mines of The Bellambi Coal Co., Limited, 1909, Wollongong University Archives, D185 Bellambi Coal Company collection.
[8] Austen & Butta Limited, op cit, p 2.
[9] ibid, p 2.
[10] As mines had been dug deeper, gas build up and accidents involving fire had become an increasing concern. Ventilation shafts at mines had become an increasingly common feature since the later 1890s in response to a mine explosion at Dudley, near Newcastle. Hargraves, AJ (ed), 1993, *History of Coal Mining in Australia, Monograph Series No. 21*, Australasian Institute of Mining and Metallurgy, Parkville (Vic), p 37.
[11] Austen & Butta, op cit, p 2.
[12] Hargraves, op cit, p 113.
[13] ibid, p 113.
[14] Undercutting meant simply that the miners hand-cut a section of the coal seam approximately three feet from the mine floor to a width of between six and eighteen feet. Holes were then bored above this cut and explosive charges set to collapse the section and allow for the extraction of the coal.
[15] History of Bellambi Coal Company and South Bulli Colliery, manuscript, 1986, Wollongong University Archives, D185 Bellambi Coal Company collection, p 8.
[16] History of Bellambi Coal Company and South Bulli Colliery, manuscript, 1986, Wollongong University Archives, D185 Bellambi Coal Company collection.
[17] Austen & Butta, op cit, p 3.
[18] Morse, R 1988, 'Energy', in *Technology in Australia 1788–1988: A Condensed history of Australian technological innovation and adaptation during the first two hundred years*, Australia Academy of Technological Sciences and Engineering, Melbourne, p 789.
[19] History of Bellambi Coal Company and South Bulli Colliery, manuscript, 1986, Wollongong University Archives, D185 Bellambi Coal Company collection, p 5.
[20] Austen & Butta, op cit, p 5.
[21] Illawarra Mercury 1991–1993, Illawarra Library Local Studies Collection, Vertical Files.
[22] Russell Vale Local History Group, 1994, *As We Remember: A History of the Russell Vale Community from the early 1900s to the 1950s*, Russell Vale Community Arts Association, p 9.
[23] Bayley, op cit, p 14.
[24] Russell Vale Local History Group, op cit, p 9.
[25] Bayley, op cit, p 9.

Annex B

Significance Statements for Site Elements of Exceptional, High and Moderate Heritage Value as Identified by Godden Mackay Logan in 2004

B1 THE POWER HOUSE PRECINCT – MODERATE SIGNIFICANCE

The Power House (now demolished) provided electric power to the shire of Bulli for the period 1913-1957 and to the South Bulli Colliery until 1959. This dual function indicates that the Power House precinct potentially has historic value to the Russell Vale township, as well as the Colliery, as it was the town's initial supplier of electricity. In addition, the Power House represents, in part, the important shift towards mechanisation of mining operations that could utilise the power source available at site.

The two Original Reservoirs are located near the site of the power house and they provided a ready supply of water for use in boilers and condensers. As elements associated with the Power House they are relics of electricity operations at the site, however, as the Power House precinct no longer retains its primary elements, the reservoirs exist in relative isolation. This reduces their significance because their primary function cannot be demonstrated or interpreted.

As the Power House and the elements that made up the Power House Precinct are not intact, however, their form and function cannot be demonstrated or interpreted through its existing elements, spatial configuration or material remains. In its current state, the Power House Precinct only makes a minor contribution to the history and significance of the site. (GML 2004, p87)

B1.1 Workshops – Upper Bench – Moderate Significance

The workshops located on the Upper Bench relate to the late-twentieth century phase of coal mining at the South Bulli Colliery. They consist of a number of corrugated-iron clad sheds that have clearly been extended and modified progressively over the years. The sheds are located over and adjacent to the 1887 portal, demonstrating the value of terraced ladn on the escarpment and the parsimony characteristics of coal mining, in the reutilisation of the land and infrastructure after the closure of this portal.

Individually, the sheds have low heritage value but they are illustrative of the continual expansion and development of the Colliery as a whole. (GML 2004, p89)

B1.2 Workshop Offices - Moderate Significance

The Workshop Offices are located at the rear of the 1887 Portal and Carpenters Workshop and consist of two small rooms linked by an verandah. These offices are relics of the daily administration activities that occur in association with the workshops. Their historic value relates to their contextual relationship to the workshop and the evidence they provide of on-going operations and development at the Colliery. (GML 2004, p89)

B1.3 1887 Portal - Exceptional Significance

The 1887 Portal and Adits are extant and identifiable key element s of the early mine workings. They are part of the earliest mining episodes on the site and, in association with the rail track immediately to their east, clearly illustrate the relationship between the underground workings and the early rail system that transported coal to the jetty. They are an integral part of the site's history.

Their formal design is aesthetically imposing and evidences a level of long-term investment and pride in the establishment of mining activities. The Adits demonstrate the construction of the entrances to undergrounds workings.

They are in good external condition, although they may require some stabilisation, and are rare examples of the industrial culture of the nineteenth century which frequently expressed the virtues of investment and stability with decorative industrial elements. (GML 2004, p89-90)

B1.4 Brick retaining wall – High Significance

The curved Brick Retaining Wall adjacent to the 1887 portal for its association with the Adits and stabilisation of the surrounding earth to prevent land-slippage onto the rail tracks and workshop area. The retaining wall has also been used to support roofing attachments for the Carpenters Shops.

While the wall may have no strong significance in its own right, it forms, with the rail track and the Portals, an easily recognisable and interpreted ensemble that clearly illustrates the physical process necessary to gain access to the coal deposits and to transport the output to market. (GML 2004, p90)

B1.5 Crib Room and First Aid Station – High Significance

The Crib Room and First Aid Station (formerly the Lamp Room, for replenishment, service and storage of the portable lamps used by miners underground) is an relic of early mining operations at South Bulli. Whilst the associated equipment has been removed and no lamps are located within the building, it nevertheless represents an evocative relic of mining practices. The Crib Room and First Aid Station is one of the few surviving buildings at the colliery that date to the early phases of mining operation and it has value in providing visual evidence of the long period of operations at the site.

The heritage significance of the building is in its association with a replaced lighting technology, its location immediately adjacent to the Main Portal, with which it forms an interpretable ensemble, and its ability for its form to reflect the era in which it was constructed. (GML 2004, p91)

B1.6 Storeroom - High Significance

The Storeroom is a small building immediately adjacent to the Crib Room and First Aid Station and is of similar form and materials. The Storeroom is one of the few surviving buildings at the colliery that date to the early phases of mining operations and its has value in providing visual evidence of the long period of operations at the site.

The heritage significance of the building is in its close physical association with the Crib Room and First Aid Station, its location immediately adjacent to the Main Portal, with which it forms an interpretable ensemble, and its ability for its form to reflect the era in which it was constructed. (GML 2004, p91)

B1.7 Closed Adits - Moderate Significance

The remnant landforms indicating the location of closed Adits are evidence of the intensity and extent of mining activities in this vicinity. The existing signage associated with these Adits is important to the interpretation of the history of its use and are historical relics which authenticate and reference documentary records. They are significant for their existing and potential contribution to knowledge concerning the site as a whole. (GML 2004, p92)

B1.8 Gibson's Portal - High Significance

Gibson's Portal began its use as a pair of entrance and coal extraction Adits and was an important main entrance in its own right. It was later adapted to be a ventilation portal with associated infrastructure (fan house). The Ventilation was an integral aspect of the viability of mining operation and worker safety in the underground workings.

Gibson's portal is a relic of early-twentieth century mining operations and illustrates the early development of independent pits which eventually amalgamated both underground and in their pit top processing works. The close association with the Main and 1887 Portals at South Bulli illustrates the growth and change inherent in long-term mining and its history of use demonstrates the expansion of underground ventilation requirements as both safety standards were raised and the extent of underground working increased. (GML 2004, p92-93)

B1.9 Sandstone Retaining Wall - Moderate Significance

The Sandstone Retaining Wall associated with Gibson's Portal has an ongoing role in the stabilisation of the escarpment surrounding the adit. The wall is similar in function to the curved Retaining Wall at the 1887 Portal and demonstrates, through its different materials a different phase of mining operation to the other Portals across the site.

While the wall may have no strong significance in its own right, it forms, with the portal, an easily recognisable ensemble that illustrates the physical processes necessary to gain access to the coal deposits and to transport the output to market. (GML 2004, p93)

B1.10 Rail Tracks and System - High Significance

The rail track system, with its associated points and switches and supporting elements (while modified) is a relic of the coal transport system that was an aspect of the Colliery for most of its operating life. They are remnants of a transport system that moved coal from the mine underground to the portals on the escarpment, through the various processing stages, then through the township to the loading jetty at Bellambi Point.

The rail system influenced the spatial and working arrangements of the site throughtout the major part of its history, with buildings and other services located to service its requirements or to avoid interference in its operations. It utilised, for the most part, two separate interconnected systems, that operating to bring coal to the surface and that operating from the mine to the jetty.

The rail system however, is now fragmentary, with the only relatively intact sections of track surviving immediately outside the 1887 Portal at the Upper

Bench. Owing to the incomplete nature of the track system and associated infrastructure, the system does not demonstrate the technical configuration and details of the rail system. Those remaining areas of relatively intact track on the Upper Bench, however, remain as significant features that illustrate the coal transport system associated with the mining activities from 1887 onwards to the 1970s, when rail was replaced by road transport. (GML 2004, p96)

B1.11 Signal Box - High Significance

The Signal Box is the most evocative remnant of the rail transport system at the South Bulli Colliery. It is positioned adjacent to the Pacific Highway at the entrance to the sites and it once controlled the level crossing of the Colliery railway line across the Pacific Highway. The Signal Box retains its basic lever frame and it remains am interesting technical feature of rail operations at the site.

The Signal Box is significant as one of the very few surviving features in the district of the once numerous Colliery railways and tramways that crossed the Pacific Highway on their way between mine and jetty. It is also an important element of the South Bulli Colliery, providing evidence of the original transportation system to Bellambi Jetty. (GML 2004, p97)

B1.12 Coal Wagon - High Significance

The timber Coal Wagon is significant as an example of the wagons utilised by the South Bulli Colliery for approximately eighty years and is representative of the wagons used throughout the Illawarra district for coal transportation. Although numerous examples of similar coal wagons exist in various situations, this wagon displays signage which identifies it as a South Bulli Coal wagon (its actual provenance is unknown) and this provides a strong association with this location. (GML 2004, p97)

B1.13 Coal Cutter Head - Moderate Significance

The Coal Cutter Head is a remnant item of underground coal mining machinery which is believed to have been utilised at South Bulli. Althought relatively complete, it is detached from the assemblage of machines with which it would normally operate and missing power and transport mechanisms. It is an interesting example of coal machinery which is relevant to South Bulli. (GML 2004, p97-98)

B1.14 Remnant Incline Haulage Alignments - High Significance

The incline Haulage alignments are … the only tangible remaining aspect of the haulage system, and embody both the historical and technical aspects of the coal haulage systems that were so important in the history, growth and success of the

South Bulli mine. The incline haulage alignments are evocative of the process of transportation of coal from the mine mouth to the market and important indicators of the operations of the mine, where extraction from underground was a mere preliminary stage. In their conversion to lines of conveyors and vehicular roads, the operational associations of the alignments have been maintained through the technological evolution of transport technologies and the alignments are representative of most of the phases of mining that has occurred at South Bulli. (GML 2004, p98)

B1.15 Original Haulage line Vistas - High Significance

The converse aspect of the sight of the haulage lines in the vegetation of the escarpment are the vistas from the mine Portals and terraces down the alignment of the inclines and across the coastal flats to the ocean in the east. The vista extends towards Bellambi Point, where the loading jetty for the Colliery was located and access to the view is an important visual link between the Colliery and the townships of Russell Vale and Bellambi. While haulage systems no longer exist, the view lines from the Old and Gibsons Portals are important vistas for the interpretation and understanding of the site. (GML 2004, p99)

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Annex M

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Dr C Harvey
Mining Superintendent
Gujarat NRE Minerals
PO Box 281
Fairy Meadow NSW 2519

Dear Chris,

Re: Review of subsidence predictions after the extraction of LW4.

Our subsidence report for the major expansion project was submitted on 30 July 2011 and included the following:

> *4.1.4 Recent 2012 Wongawilli extraction*
>
> *The centreline of WE-A2-LW4 was surveyed on 27 June 2110 (Figure 22) and for the following discussion it is assumed the face had retreated sufficiently past the survey line such that the subsidence will not further increase. On this basis, manipulation of this data reveals the following key points:*

- *Panel width/panel depth = 150/340 = 0.44*
- *Maximum vertical subsidence = 1.1 m*
- *Maximum subsidence/Extraction thickness = 1.1/3.2 = 34%*
- *Maximum tilt = 20 or 9 mm/m K3= 6.2 or 3.4*
- *Maximum strains = 1.4 and -3.4 mm/m : K1= 0.4 and K2= 1.0*
- *Goaf edge subsidence = 0.1m*
- *Location of inflexion point = 40m into the goaf from the goaf edge*

From this data, a series of influence function analyses were conducted with input parameters of maximum vertical subsidence of 1.2m, a K3 value of 5.8, a strain factor of 0.15, and a goaf edge offset of 40m.

There have been further surveys since June 2012 and this letter discusses the implication to the predictions made for the major expansion project. The surveys discussed below were conducted in mid October 2012, and there were no material changes in the survey results up

to 7 January 2013. There was a significant rise in the elevation of the P line based on surveys between 7 January 2013 and 31 January 2013 and this also discussed.

1 LW4 RESULTS

Longwall 4 was extracted between 19 April 2012 and 18 September 2012. Subsidence surveys were conducted along Mount Ousley Road, along the centreline of LW4, and on two crosslines – SX and NX (Figure 1). .

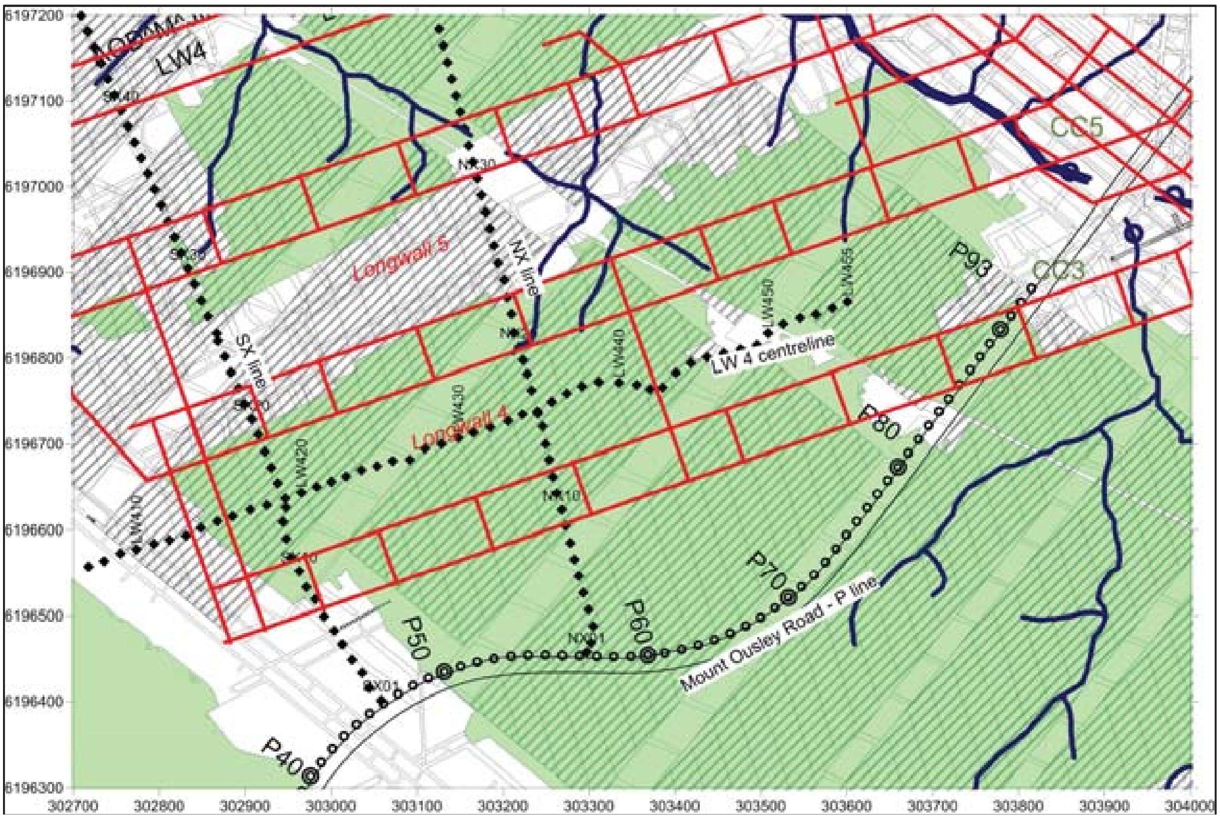


Figure 1 Location plan

Inspection of Figure 1 reveals that LW4 was located fully under extracted Balgownie and Bulli Seam workings. A 3m section of the Wongawilli Seam was extracted at a representative depth of 340m. The panel width was 150m and the pillar between LW4 and the future LW5 is 60m wide.

1.1 LW4 Centreline

The centreline data (Figure 2) shows that the average maximum subsidence along the centreline was 1.33m, with the actual value along the base of the subsidence trough varying between 1.28m and 1.384m. This can be compared to the maximum of 1.1m recorded in June 2012.

The maximum tensile strain was 3.10 mm/m, the maximum compressive strain was 1.72 mm/m, and the maximum tilt was 22.7 mm/m. It is noted that the secondary maximum tilts

and strains at the north eastern end of the line may be lower because the survey line is not parallel to the longwall centreline.

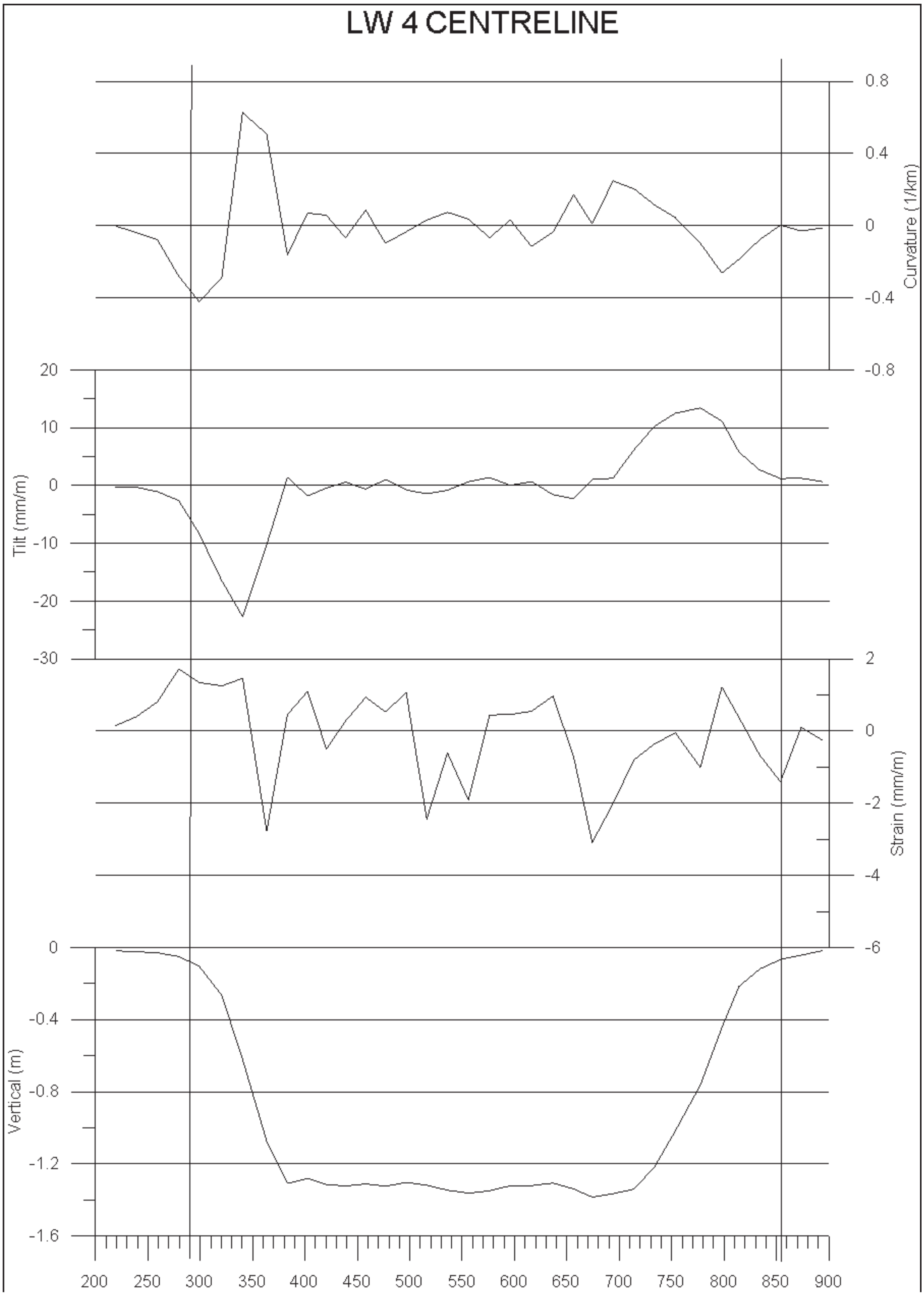


Figure 2 LW4 centreline (vertical lines are start and end lines)

The locations of the inflexion points in the survey data (same as the location of maximum tilt) are at stations LW417 and LW439. The goaf edges at located at stations LW415.5 and LW442.5, so the offsets are 25m +/-10m. Less than 20mm of vertical subsidence was recorded at stations LW445 and LW411.

There is no evidence of the Balgownie seam chain pillar in the subsidence profile (pegs LW424 to LW427). There is no evidence of a pillar run having been induced in the Bulli Seam.

1.2 NX Cross line

The NX crossline data (Figure 3) indicates the following:

- Smax = 1.37m,
- +Emax=4.37 mm/m,
- - Emax=5.04 mm/m,
- Tmax=19.7 mm/m,
- Rmin=-0.478 km^{-1}

The offset from the maximum tilt to the goaf edge is approximately 40m. There is no evidence of a pillar run.

In Figure 4, the distribution of vertical movements less than 0.1m is presented and it can be seen that the north western side of the line out to chainage 1000m has apparently moved downwards by 20mm. This is considered anomalous and related to shrink/swell movements of the clayey surface soils. (see discussion on P line and Section 2.1).

1.3 SX line

SX line (Figure 5) was not fully installed prior to the start of LW4 so less reliance can be placed on this data. The key index parameters from this crossline are:

- Smax = 1.30 m,
- +Emax= 3.5 mm/m,
- -Emax=4.8 mm/m,
- Tmax= 27 mm/m,

Figure 6 shows the subsidence less than 0.1m. The south eastern side has a small offset to 20mm, compared to the north western end which shows more than 40mm for some distance, and then more than 20mm for the rest. The 40mm offset corresponds to the part of the line where some data manipulation was required due to the delayed installation of the pegs.

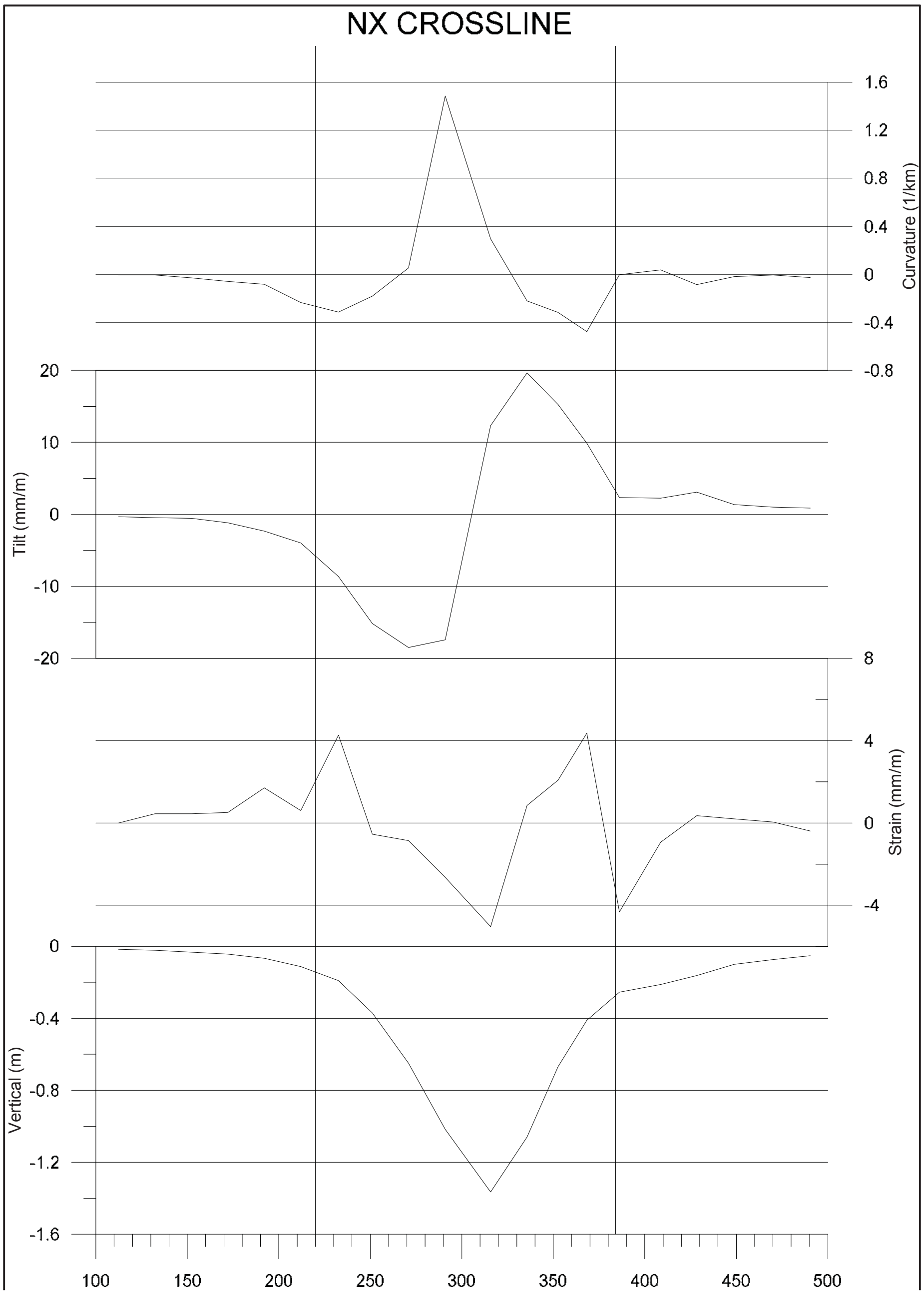


Figure 3 NX crossline (vertical lines are start and end lines)

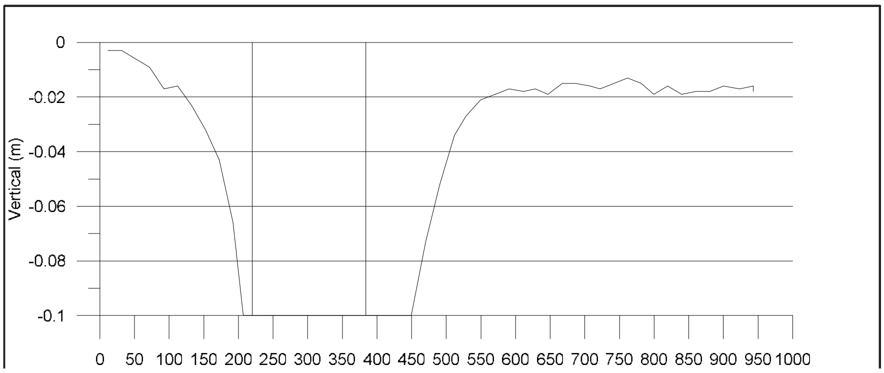


Figure 4 Vertical movements less than 0.1m on NX line

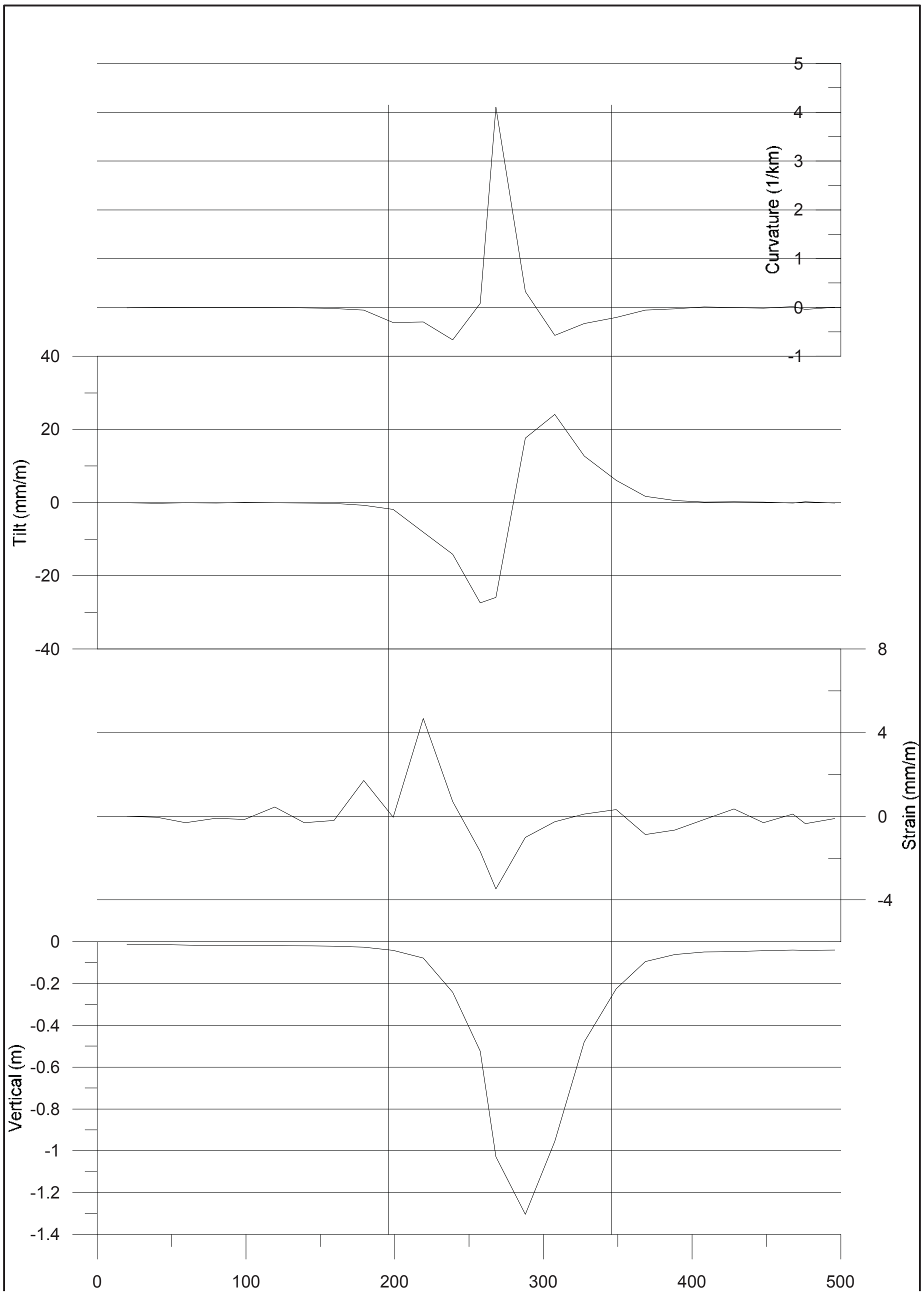


Figure 5 SX crossline (vertical lines are start and end lines)

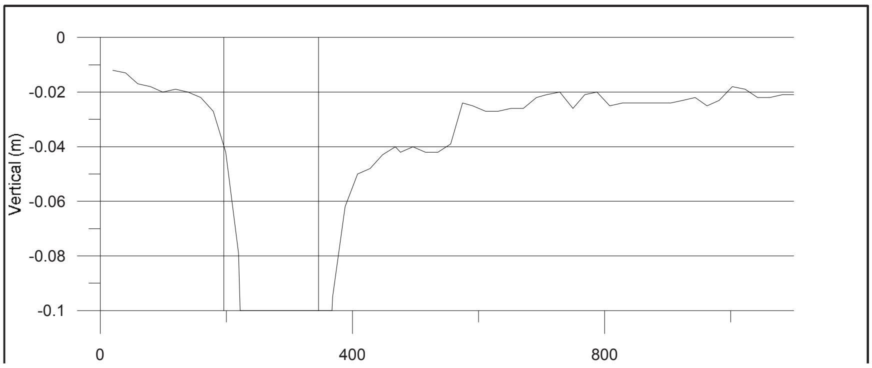


Figure 6 Vertical movements less than 0.1m on SX line

1.4 P Line

The P line along Mount Ousley Road has recorded vertical movements in excess of 20mm up until January 2013 when there was an apparent 15mm reduction in the movement (Figures 7 and 8). It is highly likely that these vertical movements are related to soil shrink/swell – we have previously speculated the upward movements in early July and mid August correspond to rainfall events, and this appears to have been validated by the larger movements in early January which correspond with extensive rainfall all along the east coast of Australia.

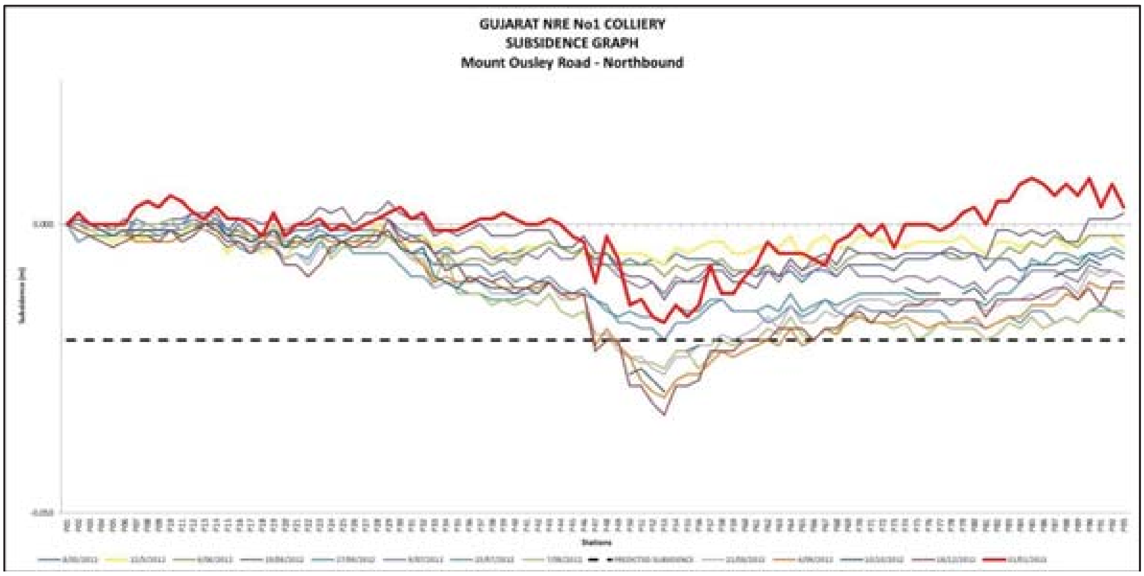


Figure 7 Vertical movements recorded along P line – Mt Ousley Road

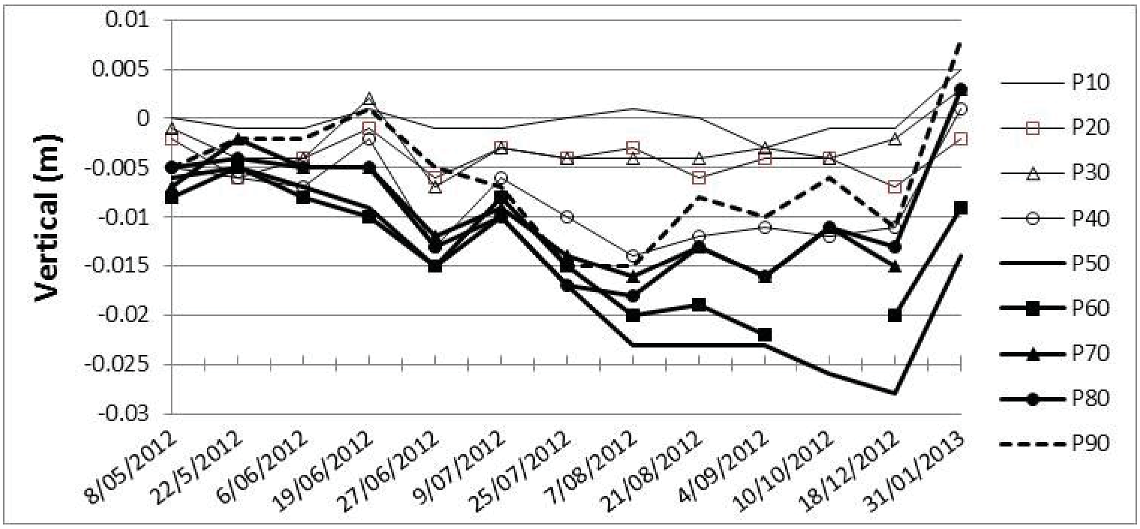


Figure 8 Movements of selected stations along Mount Ousley Road as a function of the date of the survey

There have been mining-related movements as evidenced by the opening of tension cracks in the pavement, but these lateral movements cannot be resolved in the survey along the road (Figure 9).

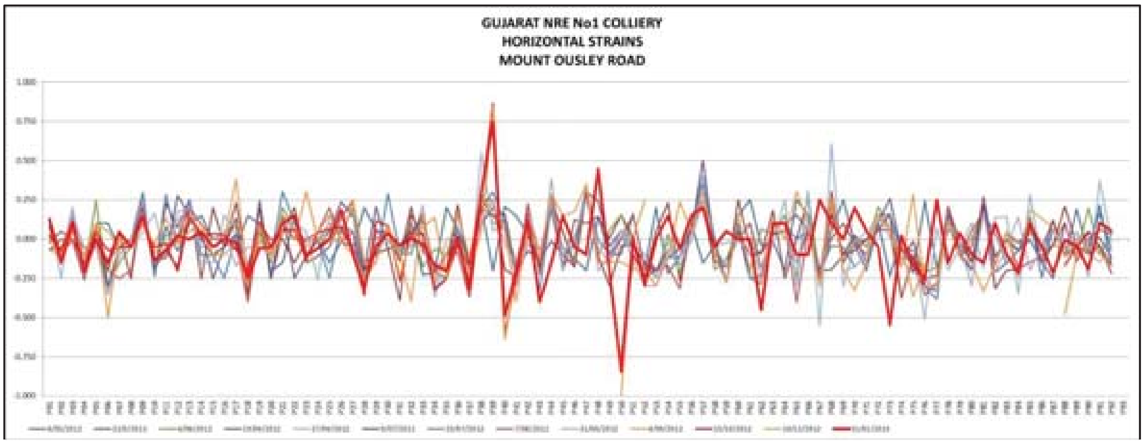


Figure 9 Horizontal strains recorded along P line.

2 DISCUSSION

2.1 LW 4 data

Table 1 compares measured values of various subsidence parameters to those which were predicted or produced by the influence function manipulation in July 2012. It can be seen that the maximum vertical subsidence was greater than the prediction, and this was somewhat anticipated in July 2012 (see introduction to this letter). The measured tensile and compressive strains are less than those predicted. The measured tilts have been above and below the prediction.

Table 1 Comparison of measured and prediction on cross lines

	NX	SX	Prediction
Smax	1.37	1.3	1.2
Tensile strain	4.37	3.5	4.9
Compressive strain	5.043	4.8	8.13
Tilt	19.7	27	21.2

Holla and Barclay[1] provide a figure that shows the typical thickness of the Hawkesbury Sandstone above the coal mines in the Southern Coalfield – it is never less than 60m thick. By comparison, above LW 4 and the next few longwall panels there is a relatively thin surface layer of Hawkesbury Sandstone and the near-surface rocks include the Newport Formation (interbedded clayshales and sandstones) and the Bald Hill Claystone (Figure 10). An implication of this will be the soils in this area will be more exposed to shrink swell factors than the thin sandy soils that develop on Hawkesbury Sandstone and this has already been detected in the survey along Mount Ousley Road. It is likely that rainfall-related vertical movements of at least 15mm, and possibly 30mm - 40mm, will impact on the subsidence surveys above LW 4- LW 6 and beyond.

[1] Holla, L. and Barclay, E. 2000. Mine Subsidence in the Southern Coalfield, NSW, Australia. Department of Mineral Resources, NSW.

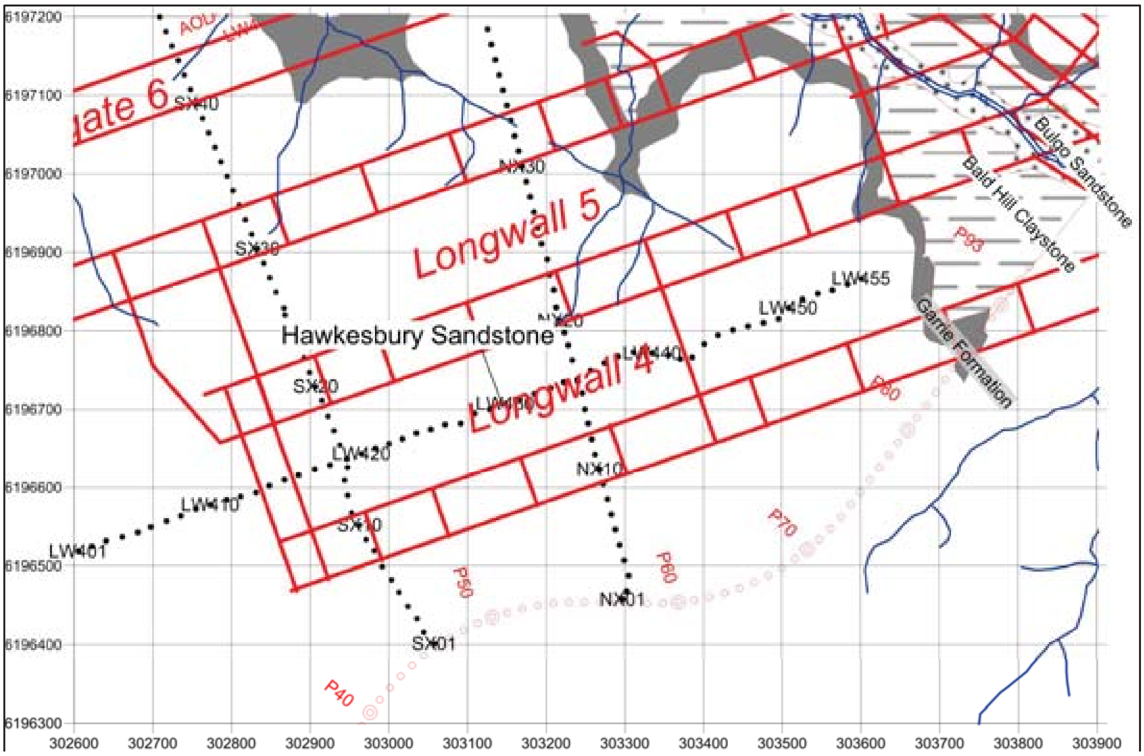


Figure 10 Surface outcrop geology

2.2 *Comparison with single seams in the Southern coalfield*

From the data in Figure 11, the vertical subsidence is greater than for a single seam (as expected), and the strains are much lower than expected from the measured curvatures. The evolving model is that the subsidence is more related to vertical block collapse than to simple bending of the overburden.

With the data obtianed to date, the angles of draw to 20mm of vertical subsidence vary between 7^{o} and in excess of 45^{o}. The cause of this variation is considered to be related to the presence of clayey soils and weathered rocks and the onset of shrinkage over what was a relativley dry weather period. A greater reliance has been placed on the angle of draw data from the start line where the Hawkesbury Sandstone is the thickest.

2.3 *Predictions for multiple seams*

In our earlier reports we have discussed the substantial uncertainties with the prediction of multiple seam subsidence at the site and have been reluctant to provide a numerical prediction until there was some calibration data from the site. The timing of the reports required us to make a set of numerical predictions with only one set of data. With the hindsight available now that LW 4 has been extracted, it can be seen that the predictions for maximum strain have been shown too high, the prediction for maximum tilt has been midway between the measured maximums and the vertical subsidence has been underestimated.

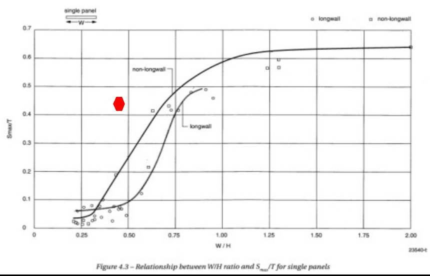
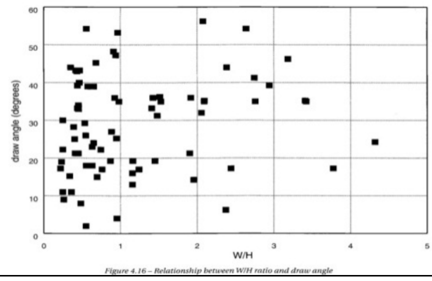
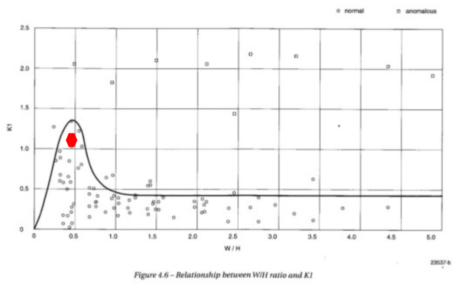
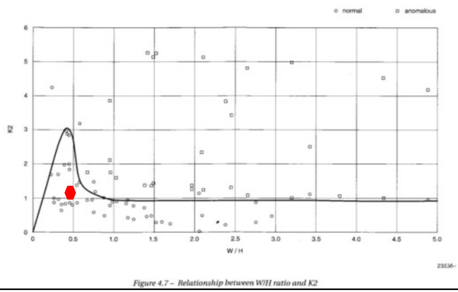
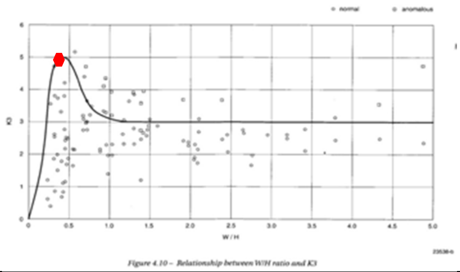
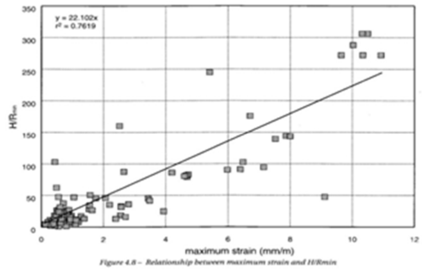
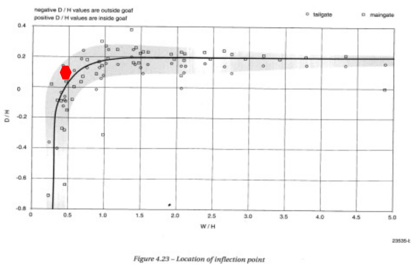
	
Vertical (w/h=0.44, Smax/T=0.455)	Angle of draw (7^{o})
	
Tensile strain factor (K1=1.09)	Compressive strain factor (K2=1.26)
	
Tilt factor (K3=4.88)	Strain – curvature (H/Rmin=711)
	
Goaf edge offset (D/H=0.12)	

Figure 11 Comparison with single seam longwall extraction

The only published database on multiple seam longwalls in Australia (Li et al 2010[2]) suggests that the subsidence related to the Wongawilli Seam should have been in excess of 80% of the extracted thickness (or 2.4m), and possibly closer to 3.0m so that the final subsidence of all three seams would be in excess of 80% of the aggregate seam thicknesses. This level of subsidence was not observed, possibly in part due to the site-specific conditions such as the low panel width/depth ratio along with the particular geological conditions that related to

[2] Li, G, Steuart, P., Pâquet, R., and Ramage, R. A case study on mine subsidence due to multi-seam longwall extraction. Second Australasian Ground Control in Mining Conference. Sydney, NSW, November 2010. AusIMM.

LW4. These are two factors which were not specifically referenced in the Li et al model which also has no reference to potential levels of tilt or strain.

3 PREDICTIONS FOR MAJOR PROJECT

3.1 Site conditions for LW5

Inspection of Figure 1 reveals that, compared to LW4, the previous mining of the upper seams is substantially different for subsequent panels. There is an overlying Balgownie longwall mine and the Bulli Seam is mostly first working (there are relatively small areas where the Bulli has been extracted). In contrast to LW4, LW5 will mine through the dyke that was not mined by the Balgownie walls.

The data set from LW4 provides the only precedent and it is not directly applicable because of the differences in the Bulli Seam layout. Similar surface rocks are present, so the same shrink/swell effects may be observed in the survey data depending on rainfall conditions.

3.2 Specific predictions for LW5

Accepting the limitations of the prediction method and the different overburden conditions, the maximum vertical subsidence above LW5 is predicted to be 1.4m if the overburden conditions are similar to LW4. There is a lower bound prediction for LW5 of 300mm if the mining in the Bulli Seam has not damaged the spanning capacity of the overburden. The maximum tilt will be similar to that over LW4 – 25 mm/m if the vertical subsidence is in the order of 1.4m. The angle of draw to less than 20mm of mining-induced vertical movement is predicted to be less than 10^{o}. There will be no mining-related vertical movements at Mount Ousley Road; but there may be some further opening of the tension cracks in the road. There will be no pillar run induced by LW5. There may be at least 15mm and possibly twice that amount of surveyed vertical movement related to rainfall variations.

The chain pillar between LW4 and LW5 is not expected to undergo a significant amount of vertical subsidence and there is predicted to be a negligible increase in vertical subsidence above LW4. We note that there is arching in the overburden and an unrecognised mechanism may cause loss of some arching above the chain pillar and possibly some further movement above LW4 –if so the quantum will not be significant.

3.3 Visualisation using influence functions

We have used the influence function method SDPS to visualise the subsidence bowls and this information is then used by the various environmental consultants. It is understood that the main parameter used by these consultants is strain – as it can be related to the possible onset of surface cracking. It is important to note that the SDPS visualisation have so far overestimated the maximum tensile and compressive strains.

Given the reliance that some parties place on the strain and tilt contours produced by SDPS and the influence function method it is important to appreciate some of the limitations of the method. The method uses 4 variables and one constant:

- The shape of the subsidence bowl is given by a continuous mathematical function (Gaussian in the case of SDPS)
- A "panel width" defined by the distance between the inflexion points of a panel cross line. Theoretically, the Inflexion points are the location of maximum tilt, zero strain, or half the vertical subsidence. SDPS uses the distance from the inflexion points to the goaf. For Wongawilli East we have used a value of 40m.
- The maximum vertical subsidence. For Wongawilli East we now use a value of 1.4m
- A measure of the maximum tilt. For Wongawilli East we have used a value of 5.8.
- A factor to convert curvatures to strains. For Wongawilli East we have used a value of 0.15.

For relatively narrow panels, it is possible that the predicted subsidence bowl does not/cannot fit all the data. As an example, Figure 12 shows how the maximum vertical subsidence calculated by SDPS changes for different values of the tilt factor and the goaf offset even when a maximum vertical subsidence value of 1.4m is used. To achieve a fit to 1.4m would require a higher tilt factor or a lower goaf edge offset than so far measured. Given the greater environmental significance of tilts and strains, we have provided a set of predictions that produce better estimates of these.

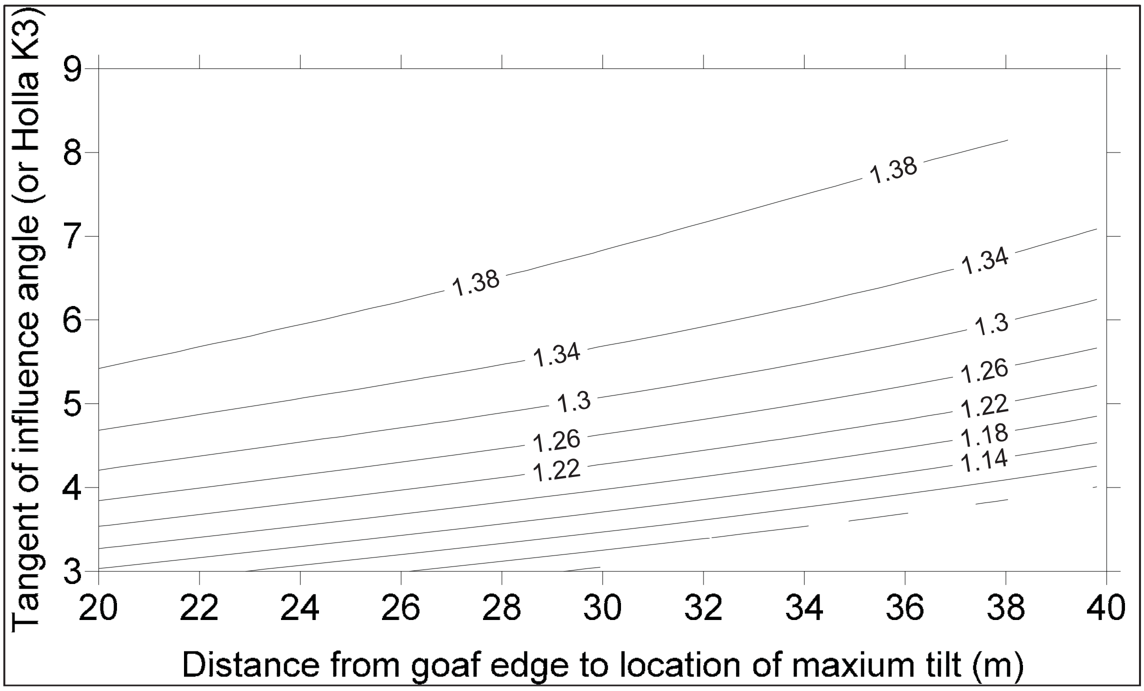


Figure 12 Changes in the calculated maximum vertical deformation (in metres) as a function of the goaf edge offset and the maximum tilt factor.

3.4 Visualisation for Wonga East

The influence function analysis over the Wonga East area have been re-run so as to capture the approved LW4 and LW5 layouts, which are shorter than those proposed in July 2012. The opportunity has been taken to use the set of input parameters obtained at the end of LW4. The revised distribution of vertical subsidence is shown in Figure 13. The reduced lengths of LW4 and LW5 means that there are areas where the predicted subsidence

deformations have decreased and Figure 14 shows where there are increases in the predicted values based on the revised inputs. Vertical movements in the centre of some of the panels have increased by up to 180mm.

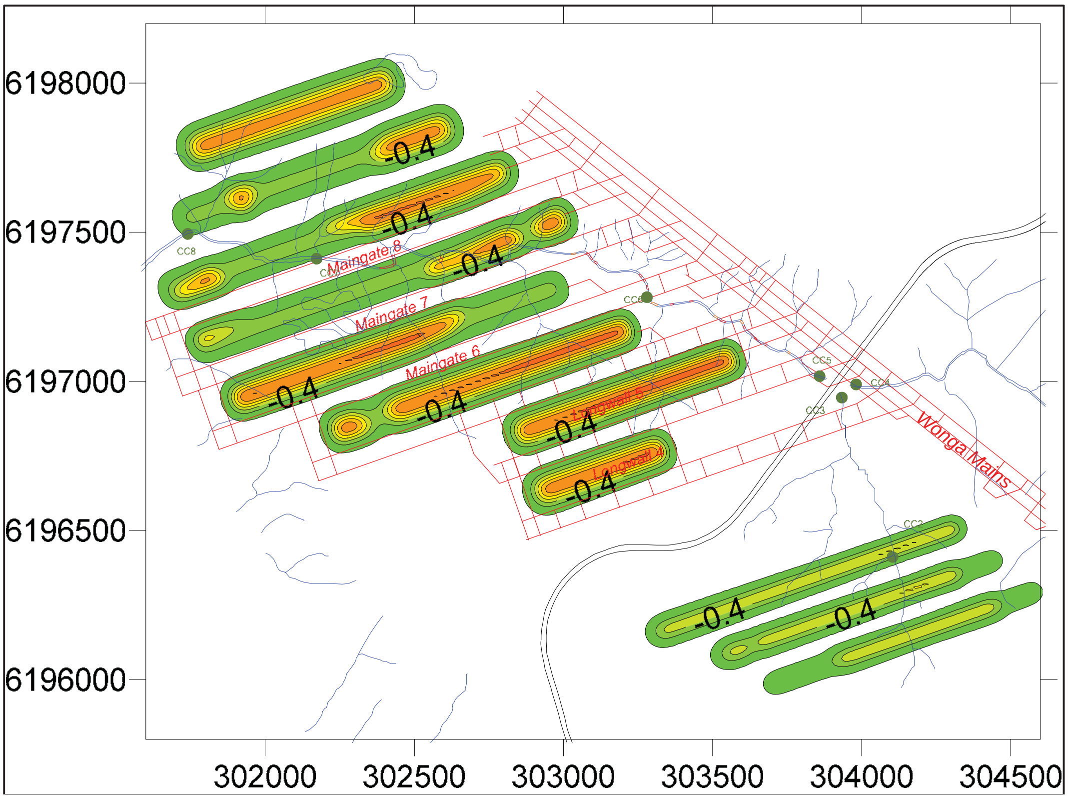


Figure 13 Visualisation of subsidence (worse case) using the mine plan as of 31 January 2013

The shortened finish line of LW4 and the start and finish lines of LW5 show major changes in the strains as expected (Figure 15). There are increases in the compressive strains of about 1 mm/m above the extraction panels but no changes in the predicted tensile strain (Figure 15). Tilts have increased by up to 3mm/m above the extraction panels (Figure 16).

4 DISCUSSION OF UNCERTAINTIES

As has been previously highlighted, there are significant uncertainties with the prediction of subsidence deformations for this three-seam mining layout. There is a relatively high confidence in the prediction of the extent of the subsidence bowls, but there is a lower level of confidence regarding deformations within the bowls. In addition it is important to emphasise that the SDPS visualisations are provided for communication purposes and do not necessarily represent the specific predictions.

As discussed above and based on the surveys above LW4, it appears that maximum strains are being over-predicted, maximum tilts are being reasonably predicted, and the maximum vertical subsidence in the contours is possibly too low.

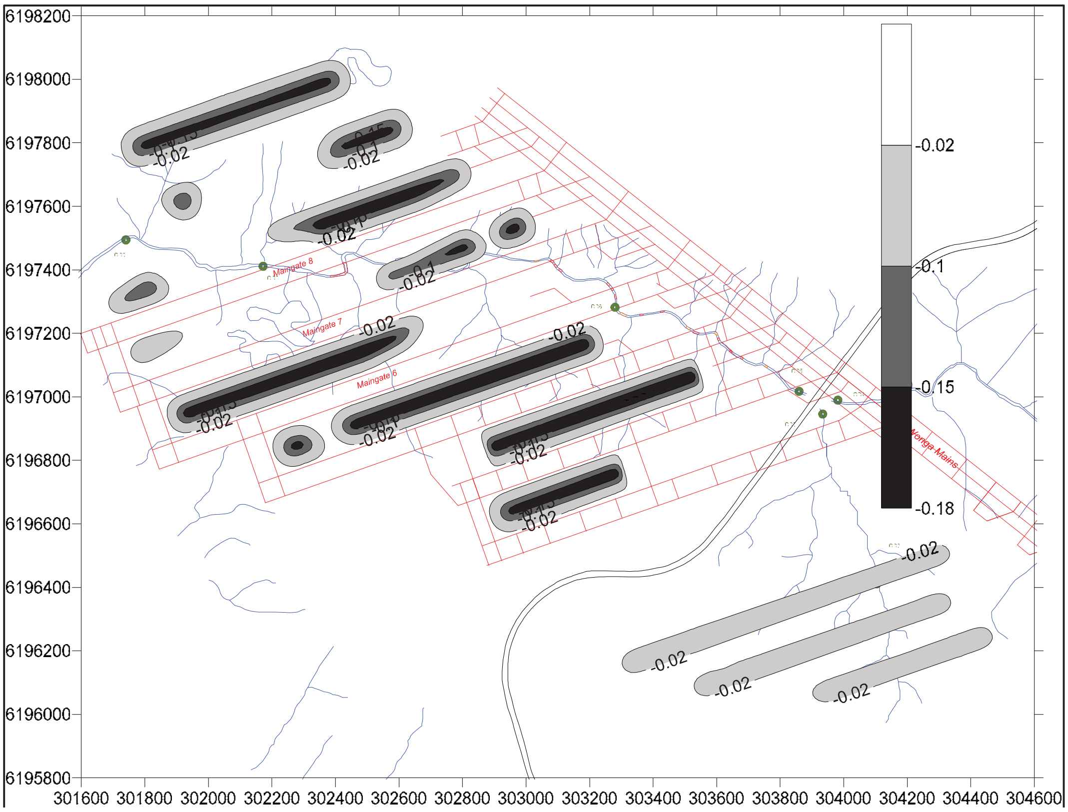


Figure 14 Changes in the vertical subsidence related to revised input parameters obtained after LW4 extraction.

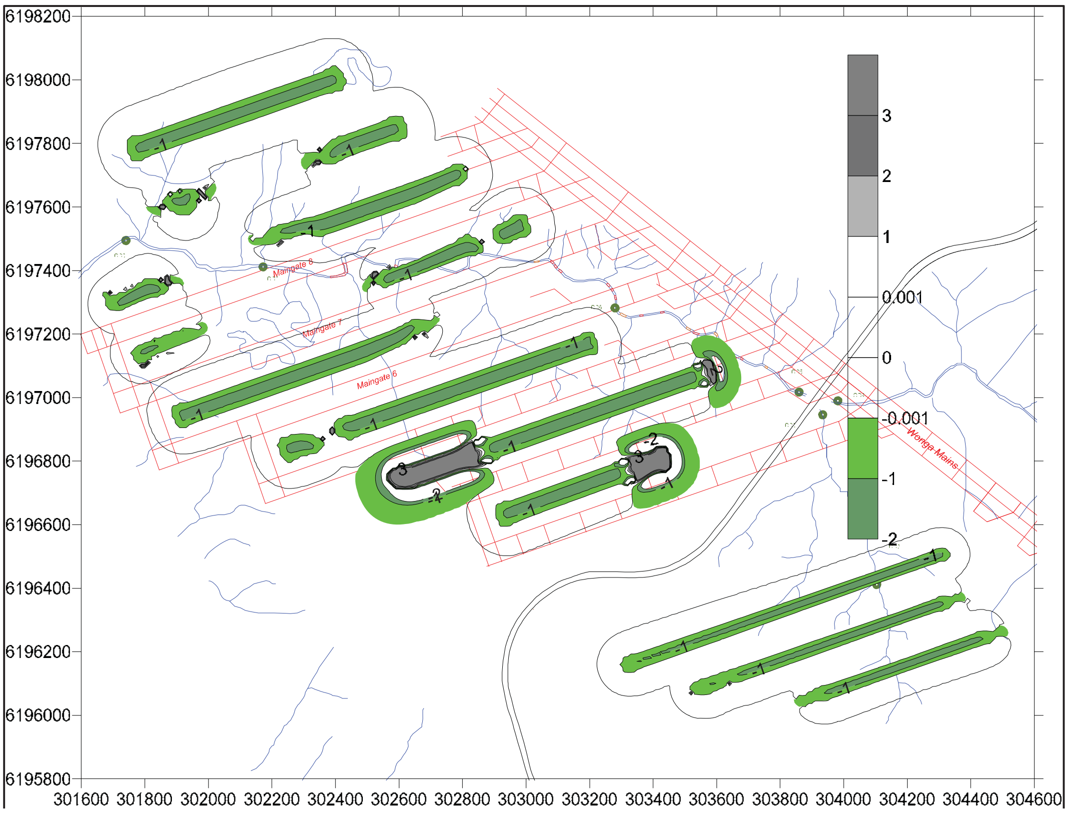


Figure 15 Changes in the strains related to revised input parameters obtained after LW4 extraction.

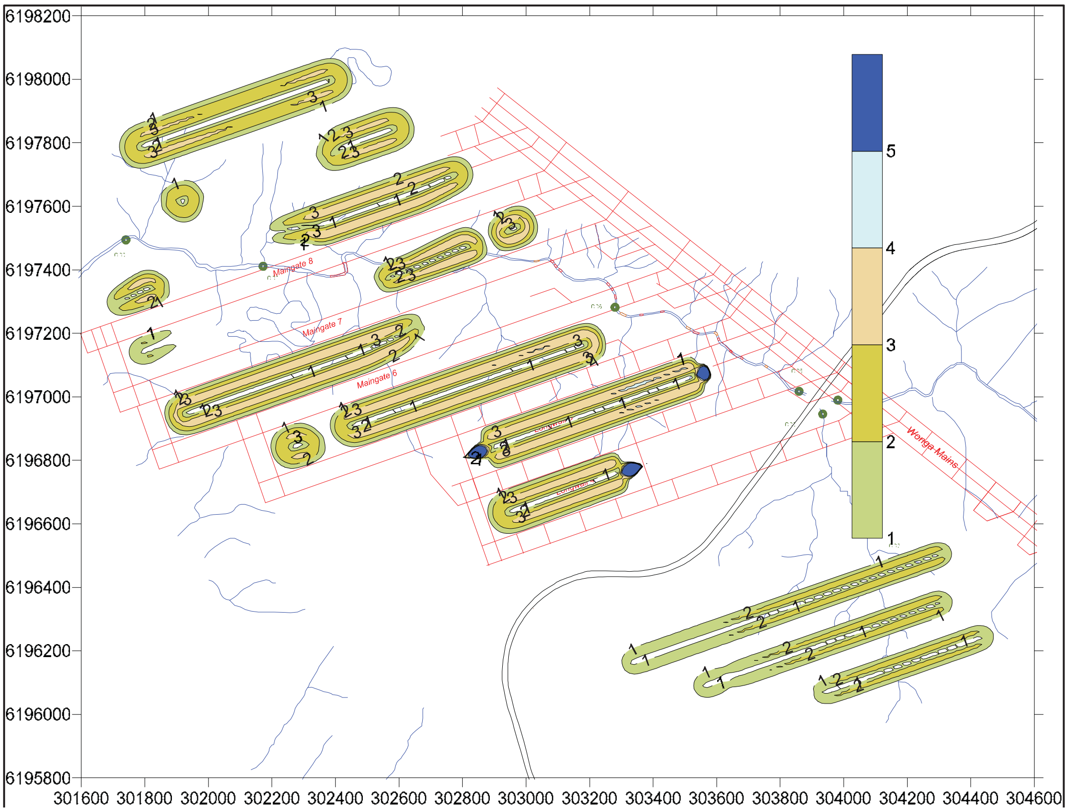


Figure 16 Changes in the tilt related to revised input parameters obtained after LW4 extraction.

It is understood that the various environmental consultants are fully aware of the uncertainties of the predictions and it is assessed that there is no need to revise the information previously supplied fro the Wonga East area in the light of LW4 retreat. There has been no additional data on which to base a review or change in the predictions and visualisations for the Wongawilli West area.

Regards,

Ross Seedsman

SEEDSMAN GEOTECHNICS PTY LTD
ACN 082 109 082

Telephone 0417279556
Facsimile 0248722535

GUJARAT NRE NO 1 COLLIERY

MANAGEMENT OF SUBSIDENCE RISKS ASSOCIATED WITH WONGAWILLI SEAM EXTRACTION

GNE - 136.docx JULY 2012

SEEDSMAN GEOTECHNICS PTY LTD
ACN 082 109 082

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Facsimile 0248722535

Monday 30 July 2012

Ref: GNE - 136.docx

Dr C Harvey
Mining Superintendent
Gujarat NRE Minerals
PO Box 281
Fairy Meadow NSW 2519

Dear Chris

Re: Subsidence associated with Wongawilli extraction at NRE No 1 colliery

We are pleased to submit the following prediction of subsidence deformations that may be associated with the extraction of the Wongawilli Seam at Gujarat NRE No 1 Colliery. The work reported herein has been conducted over the last 3 years and includes, where appropriate, additions and modifications in response to adequacy assessments by others.

Please contact the undersigned if you require further information.

Yours truly

Ross Seedsman, PhD, MAusIMM, CP.

EXECUTIVE SUMMARY

It is proposed to extract Wongawilli Seam coal by longwall methods in the eastern and western areas of the NRE No 1 Colliery lease. The extracted thickness will be approximately 3.2m and typical depths are 300m and 500m respectively.

There are a number of features which can be considered to be of special significance – Illawarra Escarpment, Mount Ousley Road, Cataract Reservoir, and fourth order streams. In addition there are a number of environmentally and ecologically significant areas.

For both the Wongawilli East and Wongawilli West areas the Bulli Seam, and in some areas the Balgownie Seam, have already been extracted by either longwall or pillar extraction techniques. As a result there are a number of constraints and assumptions that are fundamental to the validity of the subsidence predictions and these will require ongoing review and assessment to support the subsidence predictions for the proposed Wongawilli seam extraction.

This report accepts that the uncertainties in subsidence predictions are even greater for multiple seam layouts. In common with modern engineering practice, recognition of the prediction uncertainties leads to a risk management approach.

A hierarchy of risk management strategies has been applied to the mining proposals.

<u>Elimination</u> – Longwall extraction is not to be conducted under or in close proximity to the identified features of special significance.

<u>Substitution</u> – Narrow longwall blocks (nominally 150m) with wide chain pillars are proposed for the Wongawilli East area so that the coal within the Cataract Reservoir Notification Area can be extracted. This strategy reduces prediction uncertainty in areas where both the overlying seams have been extracted. The use of narrow panels was not economic for the western area and here the longwall faces are proposed to be nominally 380m.

Because of the need to progressively validate model assumptions that underpin the prediction of subsidence with multiple seam extraction and the resultant subsidence impacts, <u>engineering</u> and <u>administrative</u> controls are proposed to manage the mining in terms of the start and end lines of the longwall panels. These controls will need to be developed progressively as monitoring data are collected and prediction models refined.

The report examines the proposed layouts that seek to include these risk management strategies. The mine design approach has been to reduce exposure to key surface features while recognising that the majority of the surface can be safely subsided even when the prediction uncertainties are high.

The associated first workings in the Bulli and Wongawilli Seams required to access the proposed extraction areas will not result in any surface subsidence greater than 20mm and the associated tilts and strains will not be significant or measureable with standard survey techniques.

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GLOSSARY

Term	Definition
Angle of draw	Angle from the vertical between the edge of the extraction to a selected deformation at the surface - often the locus of points with vertical subsidence less than 20mm
Bord and pillar	The mining system used to form up first workings
Face	Extraction panel
First workings	A general terms covering the formation of mains and gateroads
Gateroads	The roadways in the coal seam (usually 2 parallel) that are used to form up a longwall extraction panel.
Goaf	The rock above an extraction panel that was intentionally left to collapse
Goaf	The void left by longwall or pillar extraction that may subsequently be filled of collapse material
H	Depth of the coal seam
h	height of pillars
Influence angle	Parameter used in the influence function method. Approximately, but not equal to, the compliment of the angle of draw.
K1, K2, K3	Parameters that relate maximum strains or tilt to Smax and H.
Longwall	A fully mechanised mining system that extracts coal between gateroads.
Main Headings	The multiple roadways that provide access from the surface to the extraction panels
Pillar compression	Deflection of the surface above a chain pillar
Pillar extraction	The excavation of pillars formed up in first workings
Pw	Width of the chain pillar between extraction panels
Risk	Assessment of an outcome based on considerations of likelihood and consequence
Sag, panel sag	The deflection of the surface above an extraction panel between 2 chain pillars
Smax	The maximum vertical subsidence recorded
Strain	Compression or elongation of the surface
Subsidence	Deformation of the surface as a result of underground mining. Often used to refer to vertical movements
T	Thickness of coal extracted
Tilt	Result of differential vertical movement between 2 points often expressed as mm/m
Tributary area loading	Way of estimating the load on pillars based on the assumption that each pillar carries is share of the full overburden.
Uncertainty	Lack of absolute knowledge
Upsidence	Vertical subsidence movements that are less than the local trend of deformations.
W	Width of an extraction pane
w	width of pillars

1 INTRODUCTION

1.1 MINING PROPOSAL

The mining proposal is to conduct longwall extraction in the working section at the base of the Wongawilli Seam in both the Wongawilli East and Wongawilli West areas. The Wongawilli East area lies astride Mount Ousley Road and is crossed by the down-stream end of Cataract Creek. The western side of Area 2 lies within the NSW Dams Safety Committee Notification Area for the Cataract Reservoir (Figure 1). At the current market conditions (July 2012) it is understood Area 1 will not be the first are extracted but will be considered for extraction at some time in the future. The topographic relief is in the order of 60m and the crest of the Illawarra Escarpment is approximately 500m to the east of Mount Ousley Road in this area.

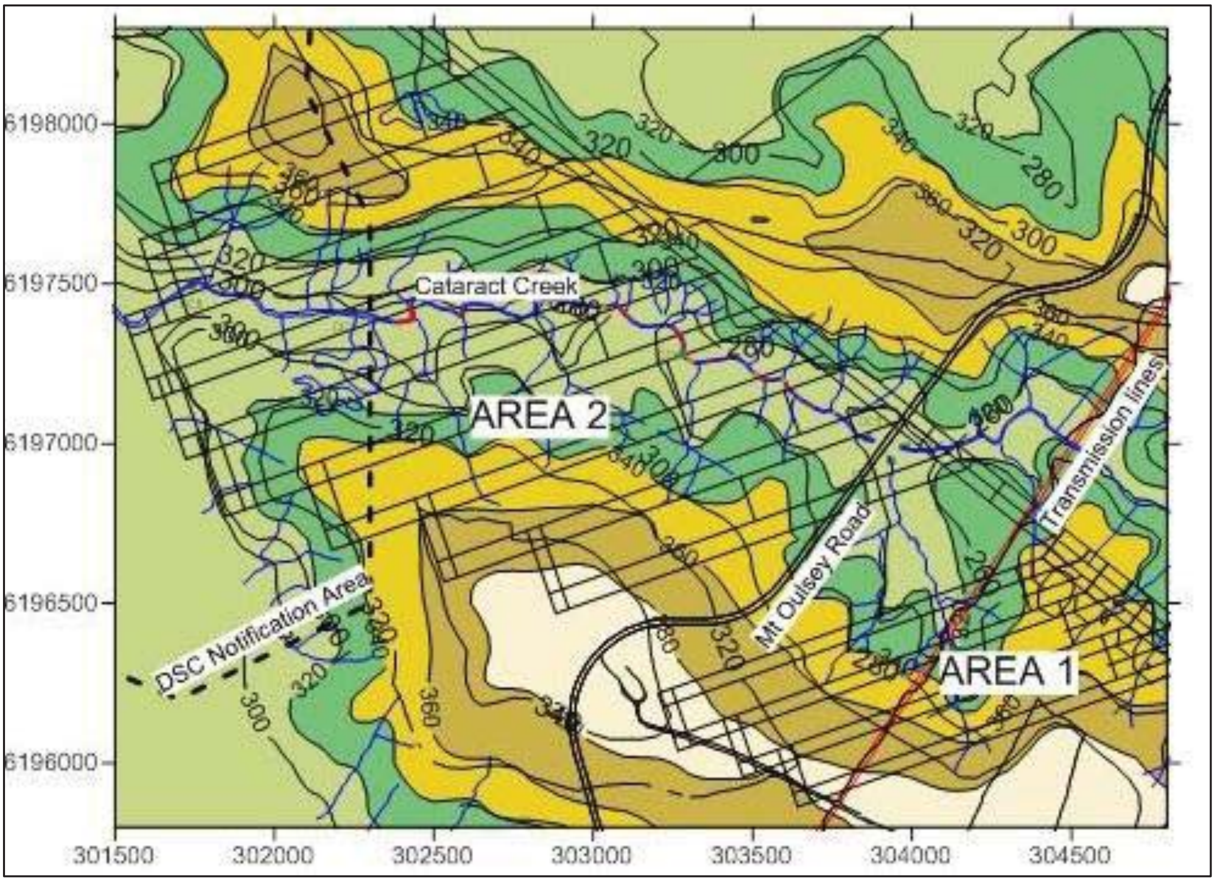


Figure 1 Topography and proposed layout for longwall extraction in the Wongawilli East area

The Wongawilli West area lies to the west of Cataract Reservoir and partially within the same Notification Area for Cataract Reservoir (Figure 2). The area is crossed by fire trials and a Telstra cable and drained by two 3rd order streams. Topographic relief is in the order of 40m -50m.

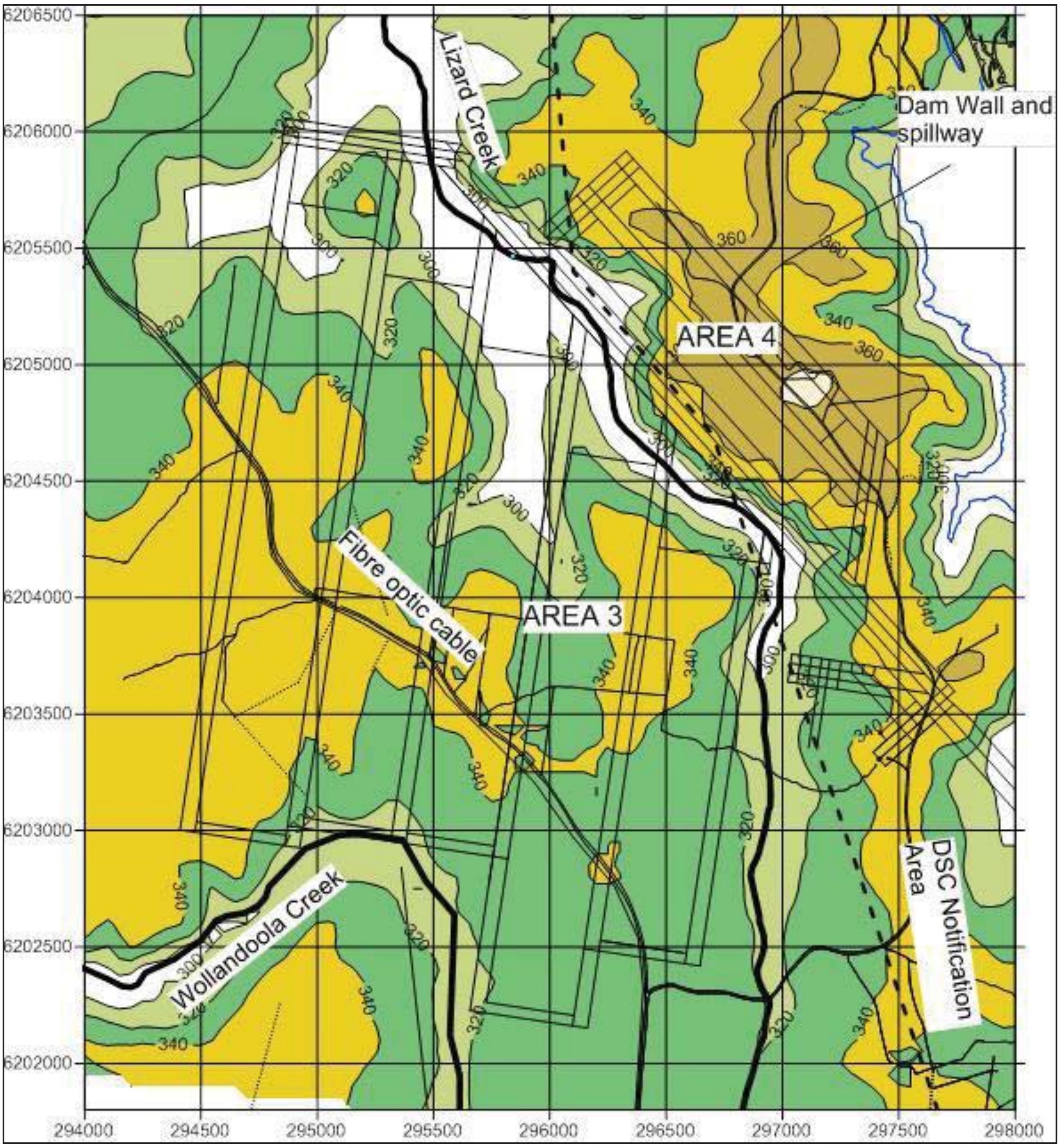


Figure 2 Topography and proposed layout for longwall extraction in the Wongawilli West area

In both areas identified for longwall extraction, there are overlying workings in the Bulli Seam and there are additional Balgownie Seam workings in the Wongawilli East area. The Bulli workings date from early last century, and the Balgownie workings, which were longwalls, date from the late 1970s.

Both areas have a number of surface constraints and these require special consideration. The focus of mine planning has been to eliminate the subsidence impacts (both actual and perceived) as much as possible, consistent with business requirements. Several specific mining options have been submitted for subsidence assessment over the last 3 years. The options that have been rejected are outlined in Appendix A .

This report outlines how the major subsidence risks have been eliminated by the mine layout and in the case of Wongawilli West and alternative mining system substituted in the plan. The report then examines the engineering and administrative controls that are required to manage the remaining risks.

As with all longwall extraction the use of key subsidence assumptions will need to be tested by ongoing review and validation of prediction assumptions associated with multiple seam extraction such that subsidence is managed and coal extraction can be optimised. The proposed layouts show the mine design based on the current level of information on subsidence in this multiple seam environment. It is anticipated that the progressive extraction of longwall panels will provide key information on how the mine should be finally delivered to the required constraints.

1.2 OPERATIONAL LAYOUT CONSTRAINTS

Not only subsidence prediction but also the underground operations in multiple seam layouts are subject to design constraints that are additional to those normally encountered for single seams. Many of these extra constraints are related to the lack of multiple seam mining experience in Australia and hence limited available data to confirm prediction models and parameters. Multiple seams layouts are currently being proposed for several Hunter Valley operations but these are modern layouts where the seams are planned together: these layouts are parallel and staggered (Table 1).

Table 1 Multiple seam longwall definitions

	Definition	Aspects
Parallel	Gate roads in different seams are parallel	Ideal layout as no need to manage different stress fields under or above pillars
Non-parallel	Gate roads in different seams are not parallel	Often a legacy from much earlier mining, or if earlier mining was no longwall. Stress footprint means more emphasis needed on alignment of subsequent longwalls with respect to the cleat and joint fields.
Parallel Staggered	Gateroads are located under the goaf of the overlying seams	Ideally, subsequent gateroads subtend more than 45^{o} to earlier pillars.
Parallel Superimposed (= stacked)	Gateroads are located under the gateroads of the overlying seam	Gateroad driveage conditions will be very difficult.

For all the NRE No 1 areas, the extraction of seams will be in a descending order. For Wongawilli East, the layout is non-parallel because the Bulli Seam was based on pillar extraction and hence has no dominant orientation, and the Balgownie orientation is assessed to be inappropriate for the Wongawilli Seam as it would place the longwall face parallel to the regional joint and cleat structure and result in unsafe mining conditions.

For Wongawilli West, the approach has been taken to adopt a parallel staggered layout which is assessed to have the lowest mining risk. It should be noted that the decisions on the layout have primarily been developed to support safe mining operations. The need to manage subsidence impacts then follows from these considerations.

2 SITE CONSTRAINTS

It is understood that others have prepared detailed reports on the topography, geomorphology, aboriginal and European heritage, and a variety of ecological issues. Based on discussions with colliery representatives and consultants, it is understood that there are a number of surface features that can be considered to have “Special Significance Status” and hence require separate

consideration. There are other features which require additional consideration so the subsidence impacts can be managed during operations.

2.1 SITES OF SPECIAL SIGNIFICANCE

A - Mount Ousley Road is the major road access to Wollongong. It is understood that this road was realigned sometime after the Balgownie extraction as it lies directly above a Balgownie Seam chain pillar and over Bulli Seam extracted areas. Discussions with the Road and Traffic Authority and a review of literature indicate that the limiting subsidence deformation for road pavements is strain (such that the pavement does not crack).

B – Cataract Dam wall and spillway The NSW Dam Safety Committee (DSC) recognises that far-field horizontal movements were induced by previous mining at South Bulli Colliery within about 620m of the spillway. They have set a 1.5km line within their Notification Area whereby they pay greater attention to mining. Given the state of the art in terms of far-field movements and the ability to validate any predictive model, it has been decided that the 1.5km line should form a boundary to longwall extraction.

C - Stored water and Notification Area of Cataract Reservoir Previous operators on the mining lease (Austen and Butta, Allied Mining) successfully extracted narrow longwalls in the Bulli Seam below the stored water adjacent to the Wongawilli West area. Economic longwall extraction in the Wongawilli Seam in this area would require undermining the Bulli Seam chain pillars which would then be associated with an unacceptable risk to the stored water both from a mining safety and a water supply perspective. No additional longwalling below the Cataract Reservoir in the Western Area is proposed. In the Wongawilli East area there has been no longwall extraction of the upper seams inside the Notification Area. Wongawilli coal in the eastern area is considered a mining target with a layout that produces vertical subsidence similar to or less than those from the western area.

D – Illawarra Escarpment The elevation at the lip of the escarpment is approximately 320m AHD. The land slopes steeply from the top of the escarpment to the Russell Vale Site offices, which are at approximately 140m AHD. From here the terrain slopes relatively gently to the east. Vertical faces of Bulgo Sandstone are exposed in the upper portions of the escarpment.

E – Fourth order streams The lower reaches of Cataract Creek and Lizard Creek are indicated to be 4^{th} order streams.

2.2 SIGNIFICANT NATURAL FEATURES

The majority of the ground surface area above the proposed mining areas is on a westerly dipping plateau to the west of the escarpment. There are no significant cliff lines above the proposed longwall mining areas.

F – Third order streams All three creeks (Cataract, Lizard, Wollandoola) have already been undermined at the site. Inspections of the three creeks have indentified mining impacts (cracking of bars, localised loss of surface water flows) in sections of Wollandoola and Lizard Creeks. There are no flows of water into the mine that can be related to drainage of any of these creeks. Recognising the current community sensitivities to mining near creeks, NRE have made the decision not to extract wide longwalls under major (named) 3^{rd} order stream channels – the use of narrow longwalls will be discussed later in this report. The selection of a stand-off distance is discussed later in this report.

G – Upland swamps Contiguous networks of intact upland swamps, including the Wollandoola Creek swamp cluster are present in both the Wongawilli East and Wongawilli West areas. The swamps were noted to be in good condition in the upper regions of Wollandoola Creek and Lizard Creek, and were observed to provide habitat for a number of threatened species listed under the TSC Act. In some parts of the study area sections of swamps were observed to be very dry, with evidence of scouring and erosion in some areas as a result of decreased water availability for reasons that were not determined.

H - Transitional Shale Forests. Open Blue Gum and Stringy Bark forests are present above Area 3 in Wongawilli West area. In the study area the understorey composition indicates a history of disturbance including fire.

2.3 OTHER FEATURES

I Heritage sties

There are a large number of aboriginal heritage sites in the overall lease area, and some of them are within the expected subsidence footprint.

J Telstra cable

There is a fibre optic cable located alongside one of the fire trails in Area 3 above the Wongawilli West area. The proposed mining in V Mains (subject of an earlier SMP submission) will occur under this cable as well.

K Transmission lines

Transgrid owns/maintains the 330kV & a 132kV power lines; and Integral owns/maintains the 33kV power line which run in a NE/SW direction above LW's 1-3 in Wonga East Area 1).

2.4 PROPOSED RISK MANAGEMENT

The entire surface could be considered as a risk management zone of one type or another; partly because of the sites of special significance and other features, and partly because of the additional uncertainties of multiple seam subsidence which will be discussed later. A key strategy adopted to address prediction uncertainties was the convening of a Failure Mode and Effects Analysis report on the predictions attended by other recognised subsidence engineers (Appendix B).

The hierarchy of risk management controls involves elimination, substitution, engineering, and administration. Whilst these have been developed in an occupational health and safety context, they can be applied equally to environmental risks in longwall mining.

For Mount Ousley Road, Cataract Dam Wall, fourth order streams, and the Illawarra Escarpment, the adopted control should be elimination where possible. In general, no longwall extraction should be conducted under or near these features. By adopting elimination, the risks associated with prediction uncertainty are removed by the fact that the deformations, if any, will be negligible.

In the longwall mining context, substitution can be viewed in terms of narrower longwall faces than the current standards of 250m to 400m, combined with wider chain pillars. The economics of longwall

mining leads to as wide a face as possible. The use of narrow longwalls is not economic in the Wongawilli West area because their width would need to be as little as 40m-50m. In the Wongawilli East area, narrow longwall panels and wide pillars would allow access to coal in the Notification Area and under Cataract Creek by limiting subsidence to say 250mm.

For the other features, engineering and administrative controls should be used to modify panel widths and stand-off distances once better site specific data is available on which to make decisions.

Elsewhere, the risk management approach would be based on the acceptance that any consequences of subsidence will be acceptable in terms of either no identified hazard or a hazard that applies to only a small proportion of the total population.

Clearly, the validity of this risk management strategy depends in part on the robustness of the predictions of subsidence deformations. To better understand the potential limitations of this approach, a risk workshop was convened with other subsidence engineers – Mr Arthur Waddington of MSEC and Dr Ken Mills of SCT (Appendix B). These experts developed a ranking system based on the likelihood the subsidence predictions would be found to be too low, and whether the consequences of such an under-prediction would be material to the implementation of the engineering and administrative controls. The nature of the task meant that quantification of the prediction risk was not possible. In all cases, the likelihood of an under-prediction was recorded as high, so the highest rankings, which were low-to-medium, related to the severity of any outcomes.

- Illawarra Escarpment – there was a request to updated and “endorsed” plans of the Bulli Seam workings. A registered colliery surveyor has since provided this plans.
- Mount Ousley Road – discussion with the RTA are well advanced and they and their subsidence/geotechnical consultants are satisfied with the management plan that has been developed. The expert panel dismissed pillar run as a hazard.
- Cataract Dam wall and spillway – the panel noted it was the role of the DSC to determine this
- Stored water and the DSC Notification Area – the panel requested specific analysis of the chain pillars to be used in the substitution strategy in Wonga East.
- Fourth order streams – the panel suggested that estimates of closure and upsidence given by the MSEC plots should be doubled.
- Shallow ground water systems – no definite statement was possible regarding loss of surface water to the mine. Subsequently this issue has been addressed more fully.

Following meetings with various government agencies, it was apparent there were still several concerns with various aspects of the subsidence predictions. Stable Strata[1] independently concluded that there would be no subsidence impacts on Mount Ousley Road and that the likelihood of a pillar run at any other location was unlikely to negligible. Pells Consulting[2] noted the inherent uncertainties in subsidence prediction both in terms of predicting systematic subsidence and anomalies associated with faults and other geological structures, determined that the old mine plans could be validly used, and supported the view that a pillar run to Mount Ousley Road is not credible. In March 2012 a risk review on pillar run was conducted and it concluded that any collapse of Bulli Seam pillars (which all parties accept could happen at a localised scale) could not develop into a pillar run that would threaten any sites of special significance, and would present a negligible risk for other sites.

[1] Stable Strata Consulting. 2011. Investigations into impact of Wongawilli Seam mining on stability of previously mined Bulli and Balgownie Seams, Gujarat NRE Mine. Report to Gujarat NRE.

[2] Pells Consulting, 2011. Review of subsidence and groundwater facets of the NRE No 1 Colliery – underground expansion project draft environmental assessment. Report to Gujarat NRE.

3 GEOTECHNICAL AND HYDROGEOLOGICAL CONDITIONS

3.1 SEAM GEOMETRY

Extraction thickness in the Wongawilli Seam will range between 2.7m and 3.2m depending on the specific coal quality and market process at the time of extraction. Depth to the floor of the Wongawilli Seam is shown in Figures 3 and 4. In the Wongawilli East area the depth ranges from 280 m below Cataract Creek to 340m to the south. In the Wongawilli West area, the depths to the Wongawilli Seam are much greater – 440m to 500m.

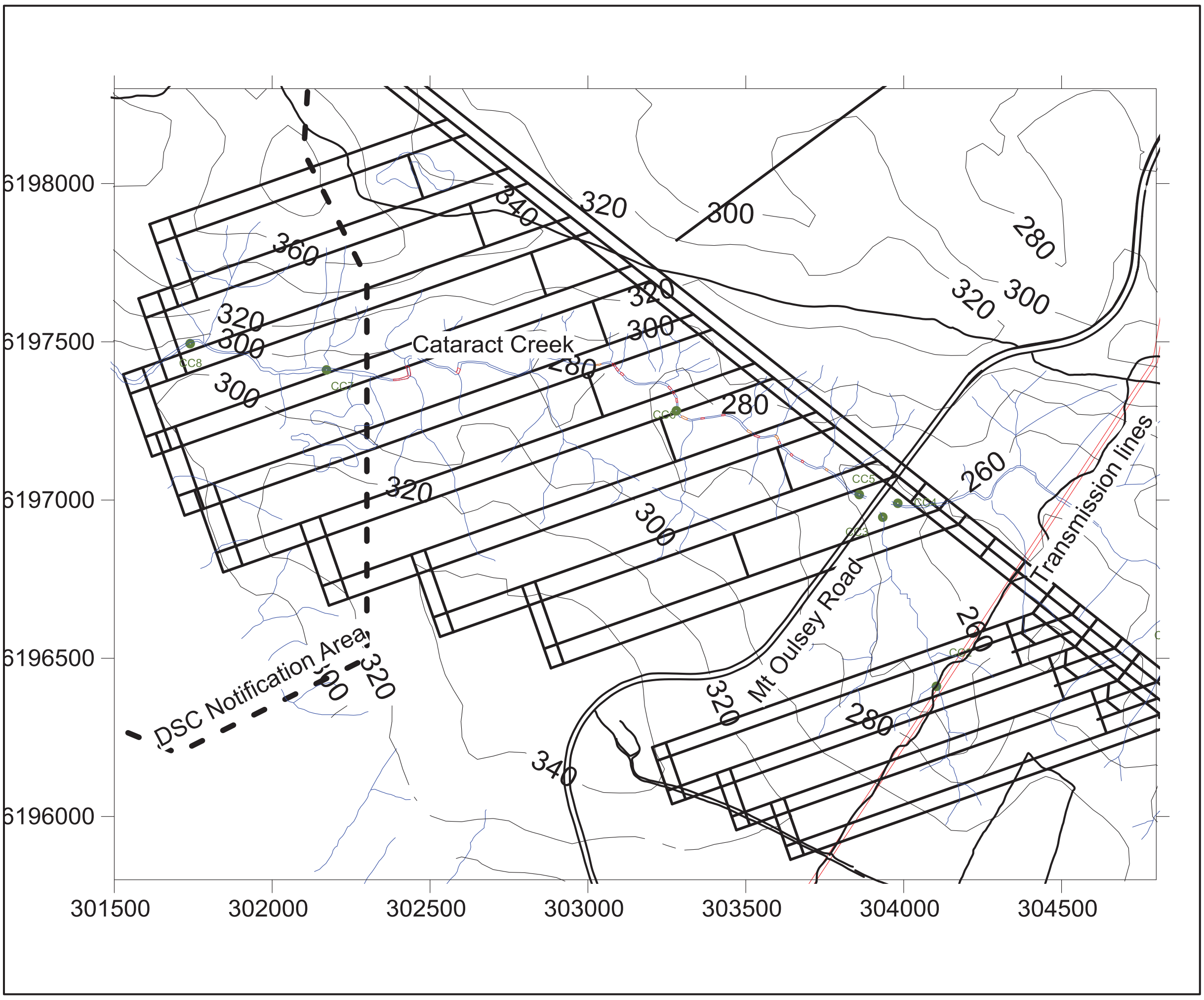


Figure 3 Depth to Wongawilli Seam – Wongawilli East

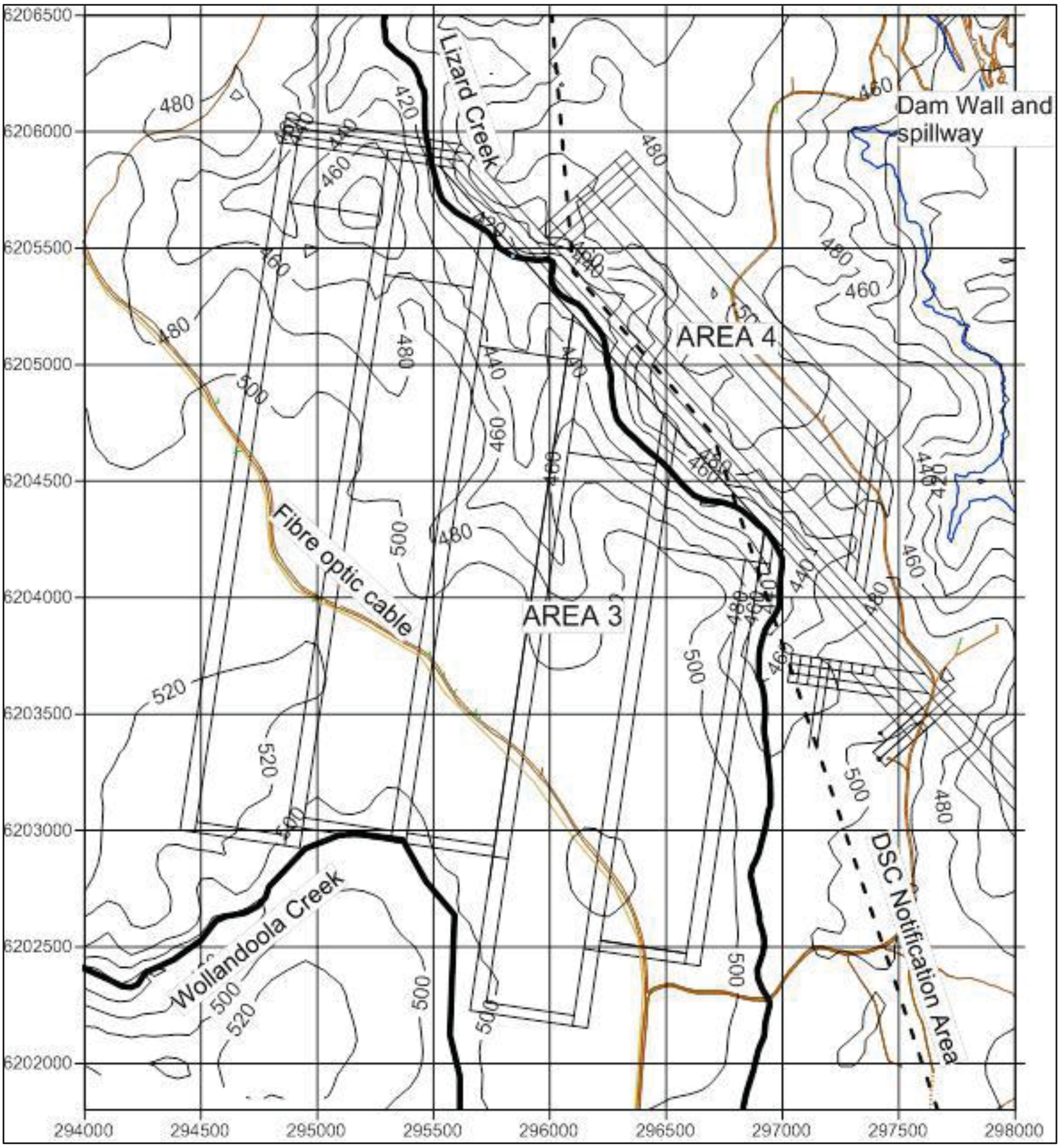


Figure 4 Depth to Wongawilli Seam – Wongawilli West

The overburden sequence is typical of the Southern Coalfield and includes the Bulgo and Hawkesbury Sandstones (Figure 5). In the Wongawilli East area, the Hawkesbury Sandstone is about 40m thick, and in the Wongawilli West area this unit is thicker – in the order of 160m. The Bulgo Sandstone is about 140m thick. The Wongawilli Seam lies approximately 45m below the Bulli Seam and 38m below the Balgownie Seam (Figure 6).

Whilst the Wongawilli Seam is often referred to as being in the order of 10m thick, in NRE No 1 Colliery the upper portion of the seam is mostly stone (Figure 6). In detail, the Wongawilli Seam in the Western area is better considered to be in the order of 3m thick with some coal horizons in the

immediate roof. The Wongawilli Sandstone Band is well developed in both areas – it is noted that this is a local mining term only as the band is actually a tuffaceous unit.

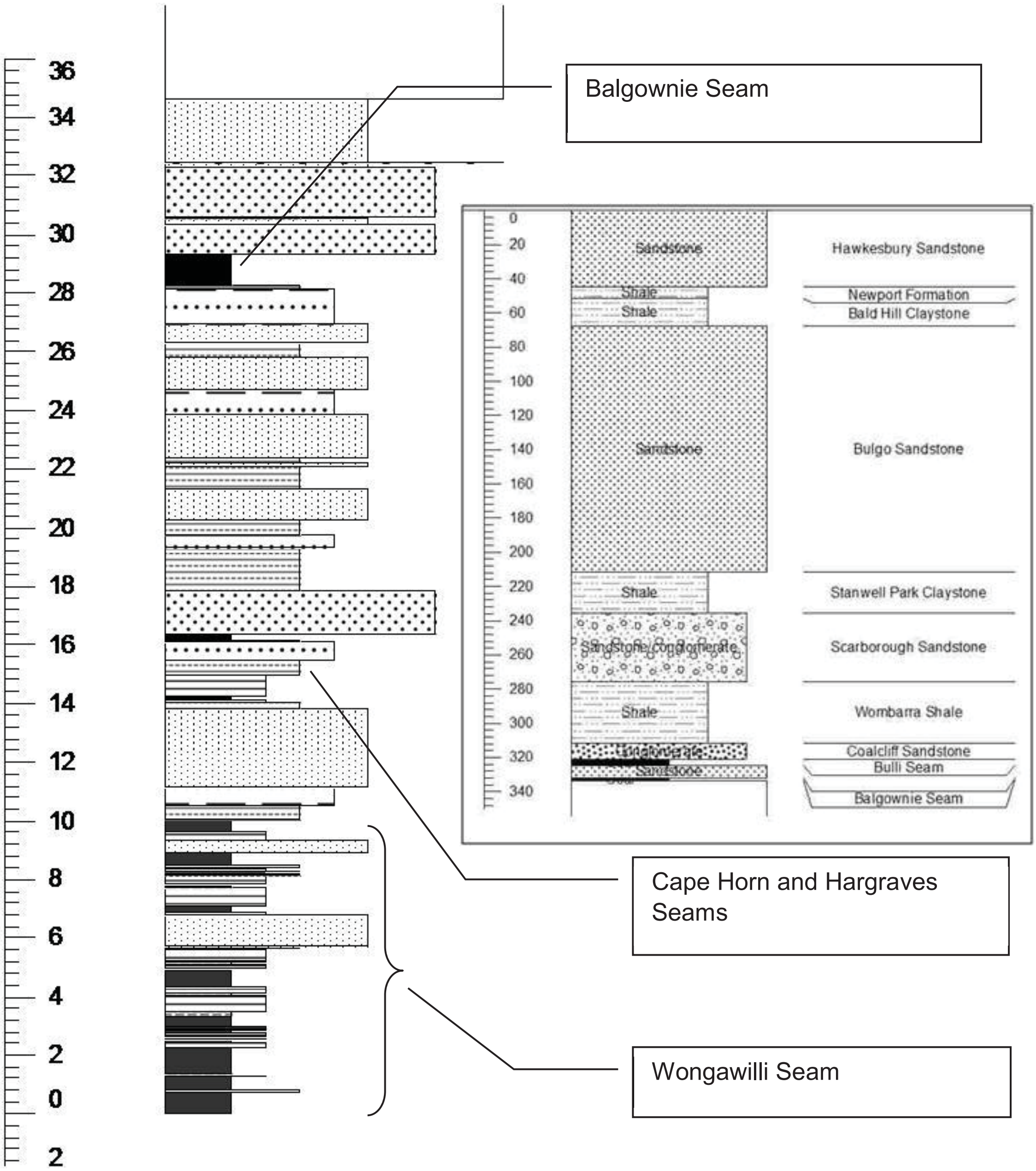


Figure 5 Typical overburden sequence - No 1 Shaft (insert No 5 shaft)

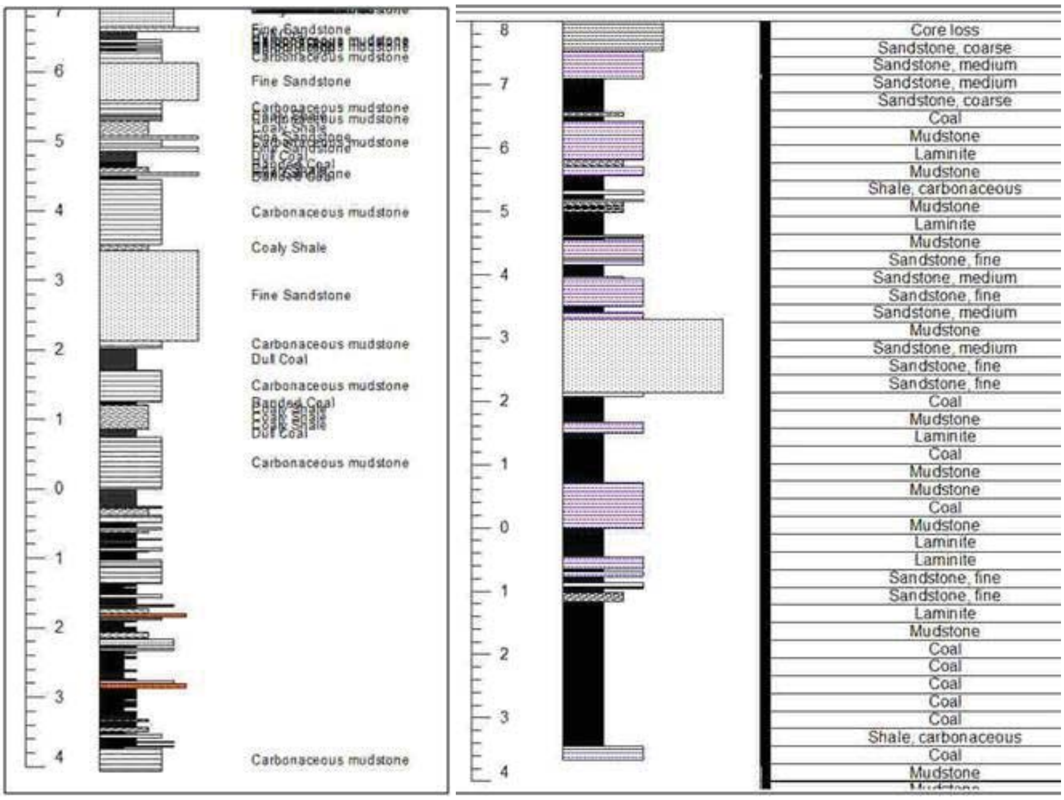


Figure 6 Detail of the Wongawilli Seam – West and East areas

3.2 FAULTS, DYKES AND OTHER GEOLOGICAL STRUCTURES

The extensive workings of the Bulli Seam and information from surrounding collieries have been used to develop an understanding of the structural nature of the Bulli Seam (Figure 7). The majority of the structures proven or inferred in the Bulli seam have been projected down to the Wongawilli seam. The likelihood of intersecting other large faults in the Wongawilli Seam is very low.

Within the mine workings of the PAA and surrounding collieries igneous intrusions of dykes, sills and plugs or diatremes have been intersected. Dykes are the most common form of igneous intrusion and are generally oriented in a NE – SW or WNW – ESE direction. The dykes are generally soft, altered to clays, and occur as individual dykes or as dyke swarms. Dyke thickness is generally less than three metres. Strike length of the dykes can be variable from intermittent lengths of 10's of metres as part of dyke swarms to kilometres for the major dyke intrusions.

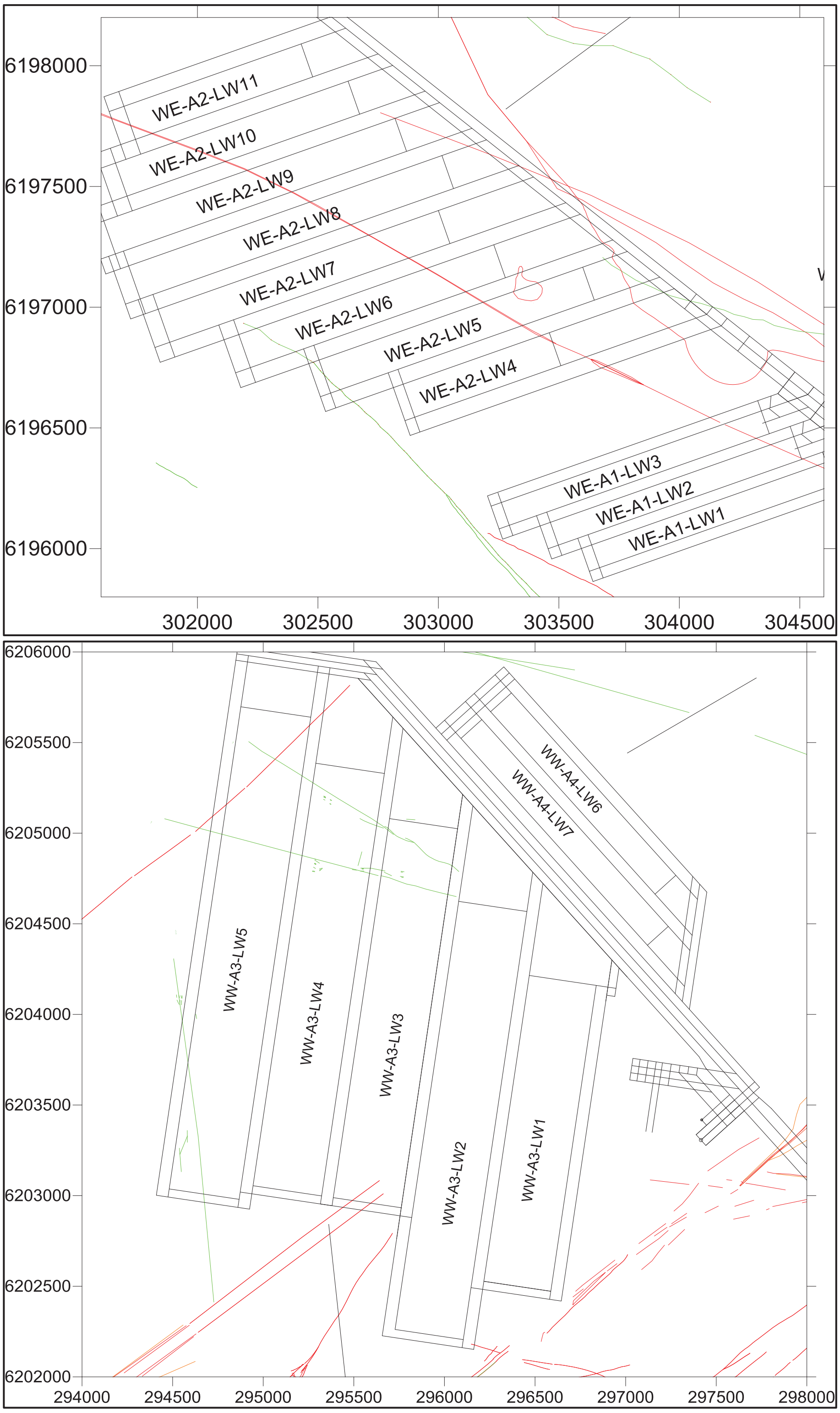


Figure 7 Geological structures impacting on the mining areas (red- dykes, green – faults)

3.3 PREVIOUS MINING

3.3.1 Wongawilli East extraction

Details of the Bulli and Balgownie Seam extraction are shown generally in Figures 8 and 9. The Bulli Seam mining was conducted in the early parts of the last century, at least 70-80 years ago. The layouts are chaotic compared to modern practice but it is possible to interpret some general trends. Roadways were probably driven at 16 ft width (5m) with pillars about 25m wide. In some cases the plans show that the pillars were then split diagonally. There are a number of wider areas (between 190m and 490m) that are shown as extraction goaf. Because of the safety concerns with accessing old workings, the accuracy of the mine plans cannot be verified. We are not aware of any remote sensing technology that could be used over the full areas. It is noted that Dr Seedsman was involved with the mining of the Balgownie seam in the immediately adjacent area and the ground conditions encountered well matched the recorded mine workings in the overlying Bulli Seam.

The Balgownie longwalls were extracted in the 1970s and 1980s. There is a very high confidence in the accuracy of these plans as the gate road locations are still accessible. There is some published information on this mining and there are still records available at the mine. The Balgownie Seam in this area was about 1.35m thick; the mining height may have been slightly greater. Panel widths ranged from 144m to 186m and the pillar widths were initially 25m increasing to 40m. The depth of cover was about 280m - 290m. Close inspection of Figure 9 shows where the face was relocated around a northwest trending structure - a hard dyke.

Figure 8 Bulli Seam workings in Wongawilli East area (green areas show pillar extraction, heavy black lines are the proposed Wongawilli roadways)

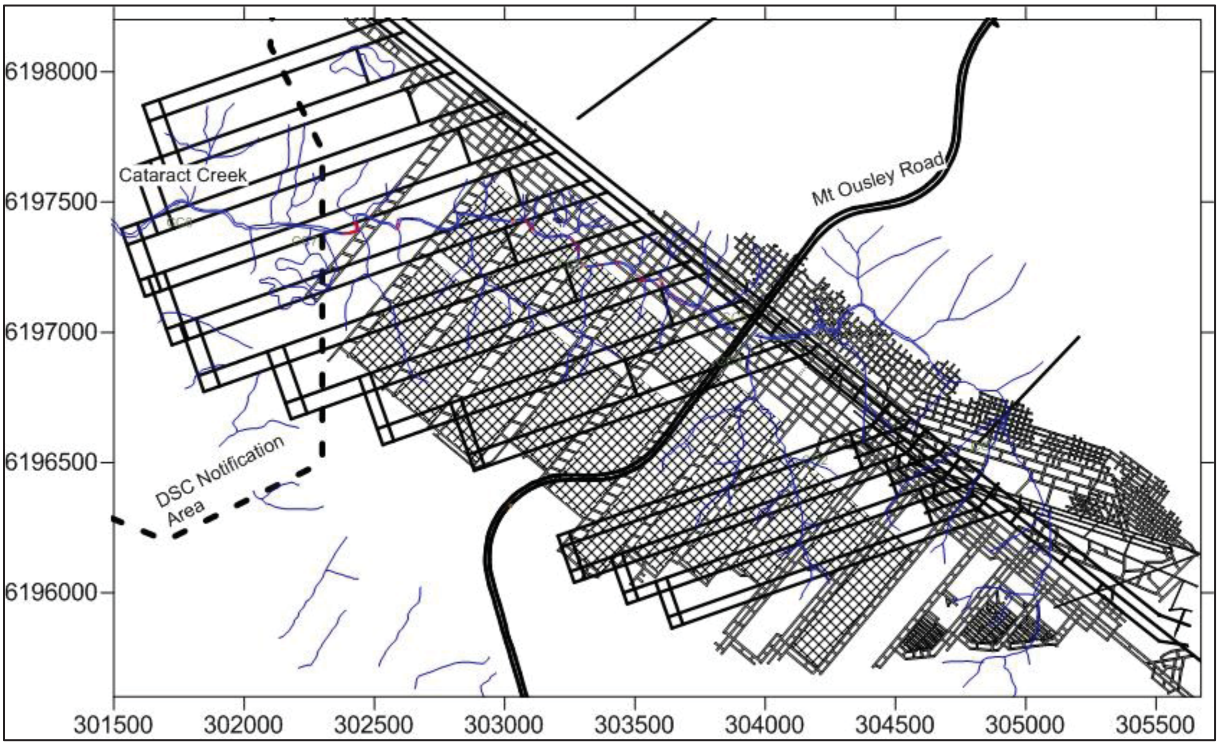


Figure 9 Balgownie Seam workings in Wongawilli East area

There has already been Balgownie Seam longwall extraction and Bulli Seam pillar extraction under Cataract Creek (Figure 10). In this area Cataract Creek is a 4th order stream. Whilst the mining was conducted a long time ago, there are no records of any impacts (adverse or benign) on the creek.

Figure 10 Details of previous extraction panels under Cataract Creek (green – Bulli seam goafs, black stripes – Balgownie Seam goafs, black outline – Wongawilli proposal)

In May 2012, extraction of WE-A2- LW4 in the Wongawilli seam commenced (Figure 11). This panel is located just to the north and west of Mount Ousley Road near Cataract Creek.

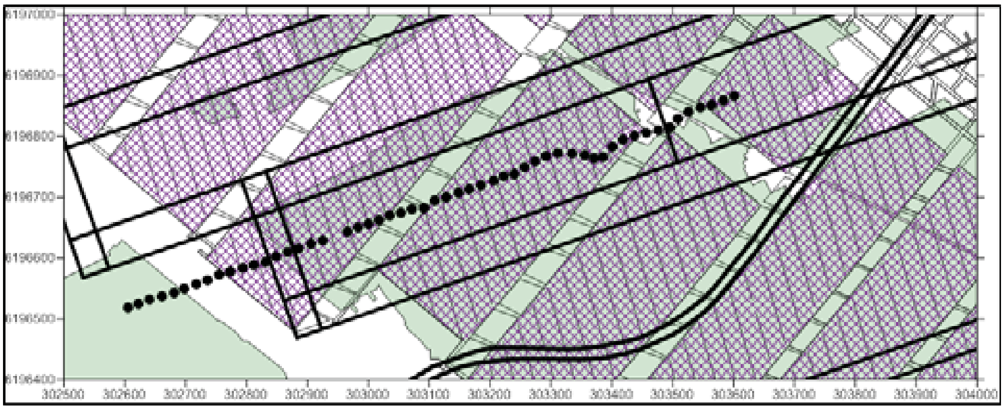


Figure 11 WE-A2-LW4 Wongawilli Seam showing relationship with Bulli (green) and Balgownie (cross hatching) workings and subsidence line

3.3.2 Wongawilli West extraction

The Bulli Seam has been extracted by longwall methods in the Wongawilli West area (Figure 12). The north/south aligned panels (200 and 300 series) are of interest in this report. These panels were extracted in the 1980 and 1990s and there is a large amount of information available. This portion of the mine is still largely accessible.

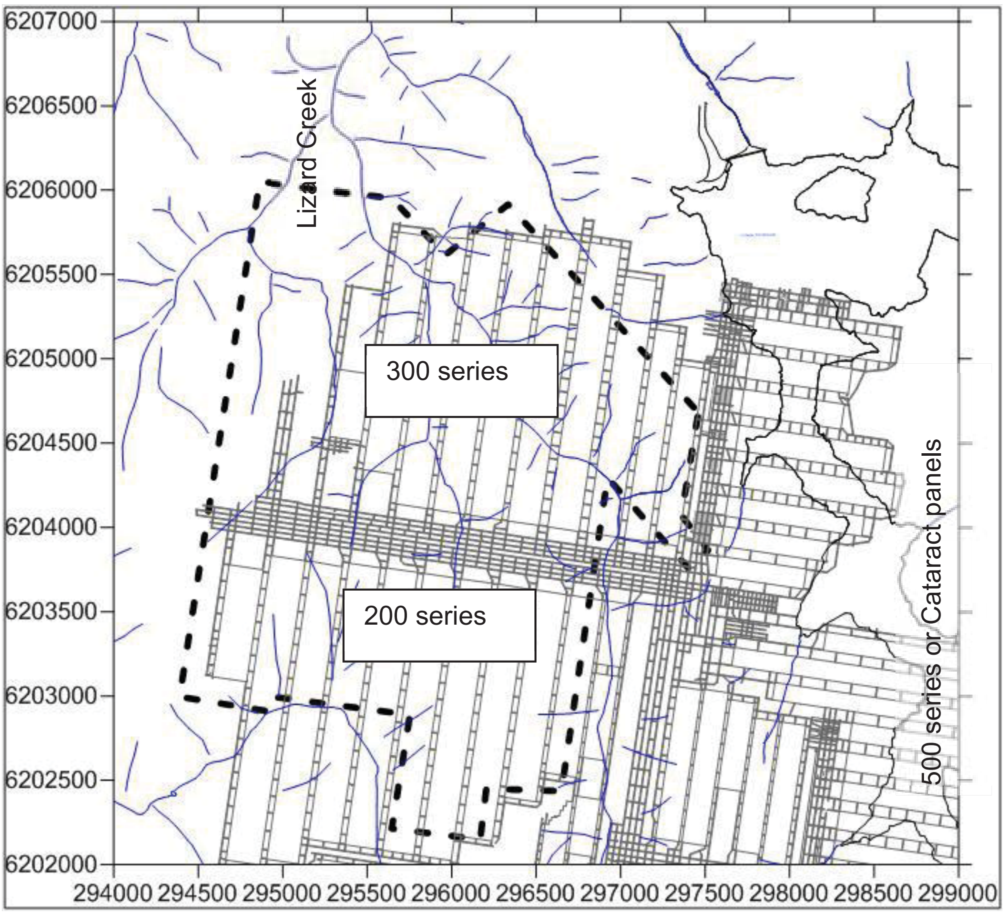


Figure 12 Bulli seam workings – Wongawilli West area (dashes show outline of Wongawilli proposal)

The panel widths were 142m initially and then increased to 188m. Pillar widths were initially 19m increasing to 35m, with some experiments with wider ones at 51m. The depth of cover ranged between 400m and 450m and the seam thickness was typically 2.5m

Recent inspections have revealed that there is some cracking of rock layers in Lizard Creek and localised diversion of water to underflow beneath the creek bed; water quality leaving the lease area is still high (Geoterra – personal communication). The localised diversion would appear to be more prominent during extended dry periods. Similar cracking has also been noted in a waterfall in Wallondoola Creek.

3.4 HYDROGEOLOGY

General aspects of the groundwater regime include:

- Unconsolidated material in the regional drainage recharged by rainfall
- Localised perched aquifers in the Hawkesbury Sandstone recharged by rainfall
- Regional fractured rock aquifer in the Hawkesbury Sandstone with a base level controlled by the streams and stored water.

Rainfall runoff is rapid where outcrop occurs or where the regolith is thin. The Hawkesbury Sandstone areas are unlikely to accommodate substantive groundwater recharge or to contribute significantly to stream base flow unless substantial secondary permeability and porosity is developed in fractures (Geoterra – personal communication).

The deeper sandstones and the coal seams are also aquifers that are regarded to be of no significance to the surface ecosystems.

Detailed monitoring of the longwalls under Cataract Reservoir under the auspices of the DSC has shown that there is no induced water inflow to the mine. Piezometers installed in the Bulgo Sandstone showed a rapid temporary loss of head and then a recovery over about 3-5 years consistent with stress-driven changes in storativity in the Bulgo Sandstone. This behaviour suggests no fracture connection to the underground workings, and this is supported by microseismic studies connected at this site[3] and also at the adjacent Appin Colliery.

4 SUBSIDENCE HISTORY

4.1 PREVIOUS WONGAWILLI EAST SUBSIDENCE

There is no data available on the subsidence induced by the Bulli Seam extraction.

4.1.1 Balgownie Seam

There was subsidence monitoring of the Balgownie Seam extraction with centrelines down each panel and a number of cross lines. Through the use of three cross lines, full coverage across the panels was achieved (Figure 13). The general subsidence pattern was for about 0.55m of subsidence above

[3] [3] Seedsman R.W. and Kerr, G. 2001. Coal extraction beneath Cataract Reservoir: Mining at Bellambi West from 1998 to 2001. 5th Triennial Conference Proceedings. Mine Subsidence Technological Society.

the chain pillars and additional sag between the pillars of 0.2m to 0.8m. A maximum subsidence of 1.4m was measured. A maximum of 3mm/m strain was measured above large Bulli pillars and a maximum of about 6mm/m above Bulli extracted areas. Tilts ranged up to 20mm/m.

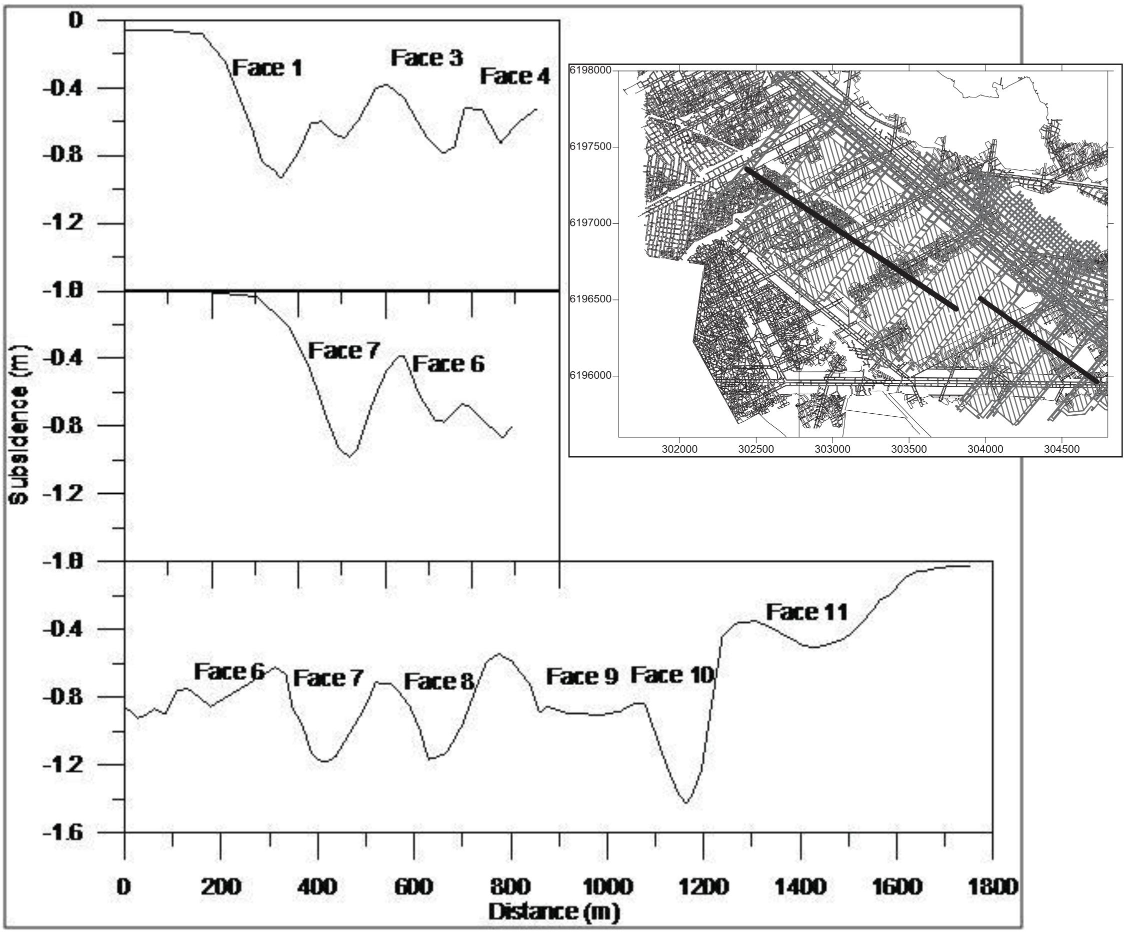


Figure 13 Balgownie longwall cross line subsidence data

Figures 14 and 15 present the subsidence results during Balgownie Seam extraction along the length of Faces 6 and 7. It is noted that the age of these drawings is such that they were drawn in feet and inches (1 foot = 304.8mm).

4.1.1 Vertical movements associated with Balgownie extraction

When both the centreline and cross line data are examined in detail, there is a distinct difference in the behaviour of the overburden where the Bulli Seam is shown to have been extracted compared to where there are large pillars and barriers in the Bulli Seam. The maximum vertical subsidence that develops in the former case varies between 0.8m and 1.3m (average 1.1m) and in the latter case 0.6m to 0.8m, averaging 0.76m. The vertical subsidence above the pillars averages about 0.55m with little difference with different pillar widths (Figure 16a).

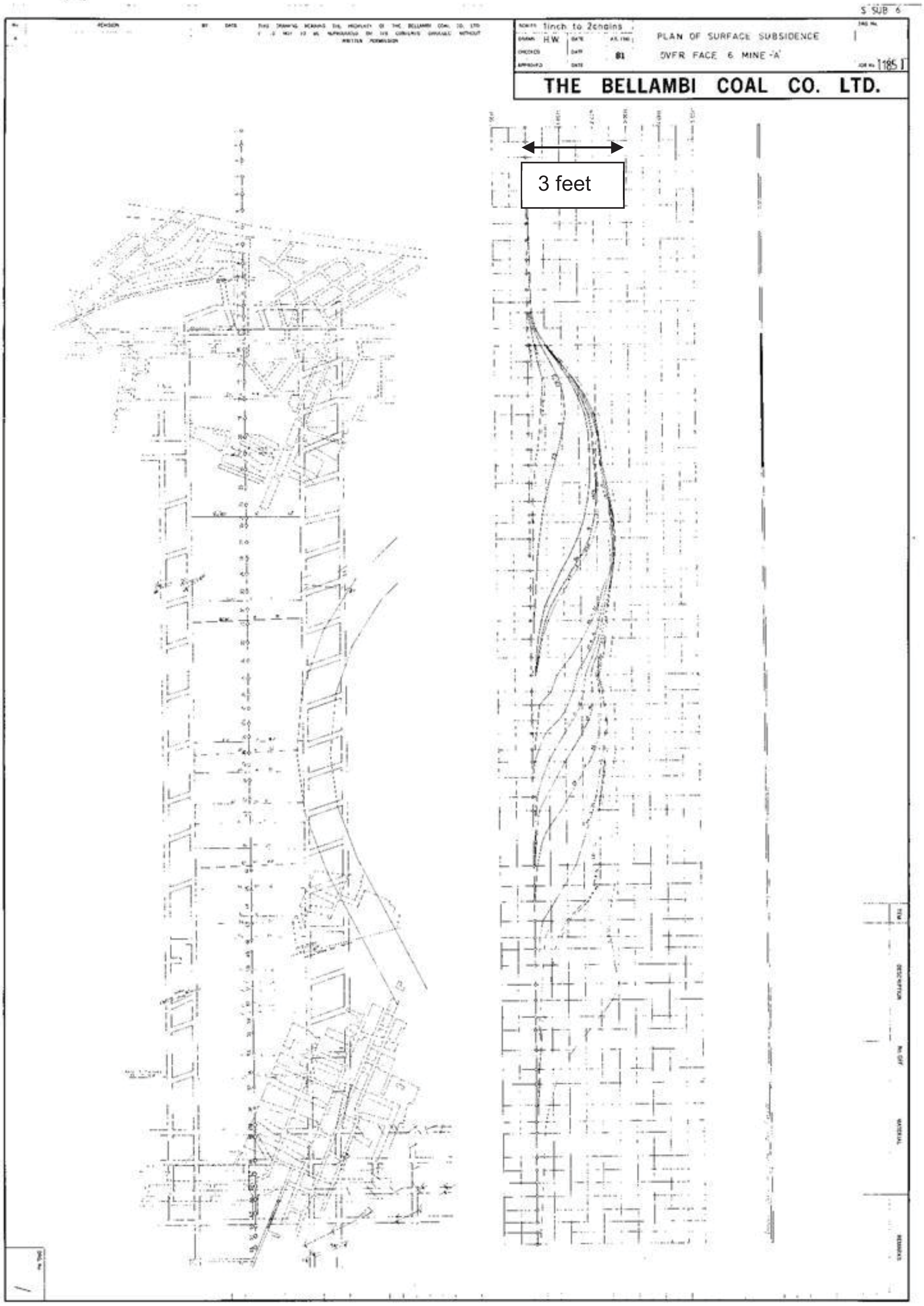


Figure 14 Subsidence along the centreline of Face 6.

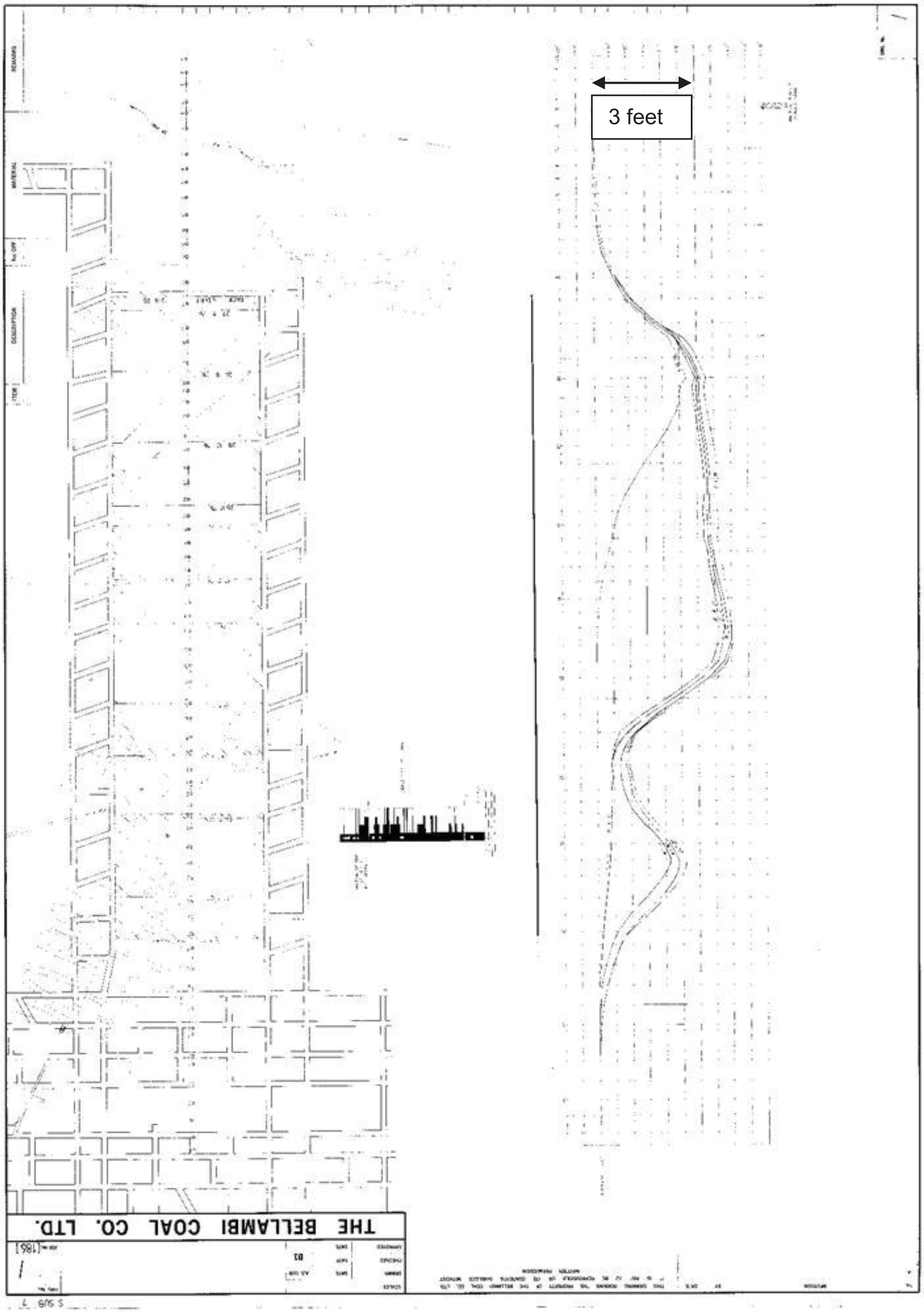


Figure 15 Subsidence along the centreline of Face 7

For the case of the broad areas of Bulli first workings, the sag above the Balgownie longwalls between Balgownie Seam pillars is about 0.2m (Figure 16b). This compares well with a fractured rock beam calculation (Figure 17) whereby voids of 150m to 190m widths would induce centreline deflections within the Bulgo Sandstone of about 100mm - 200mm.

Interestingly, the Bulli extraction areas had widths of up to 490m and Figure 17 suggests that these should have caused the collapse of the overburden as failure is indicated at 320m span. The vertical subsidence in these areas is greater and reflects about 80% of the extracted Balgownie thickness. This apparent lack of bulking is considered reasonable once it is recognised that there is only the thin interseam of about 6m - 8m to the Bulli that is available for bulking

Above Face 10, the area where subsidence was the greatest, and approaches if not exceeds the Balgownie extraction thickness, the mine plan shows very small pillars and possibly extracted pillars in a panel that is 188m wide – it is possible that this is the only area where there was delayed caving of the Bulli Seam.

Figure 18 provides a simple cartoon that seeks to provide an explanation for the 3 different subsidence outcomes.

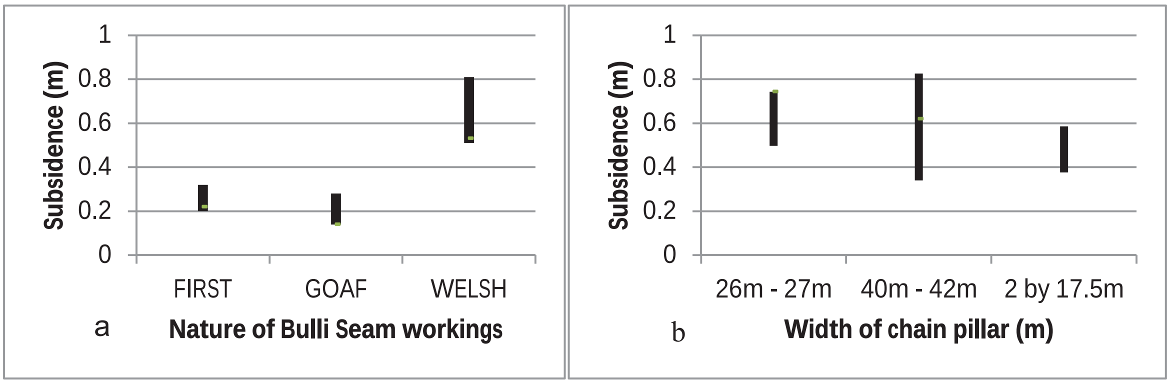


Figure 16 Sag and pillar compression data from Balgownie longwalls

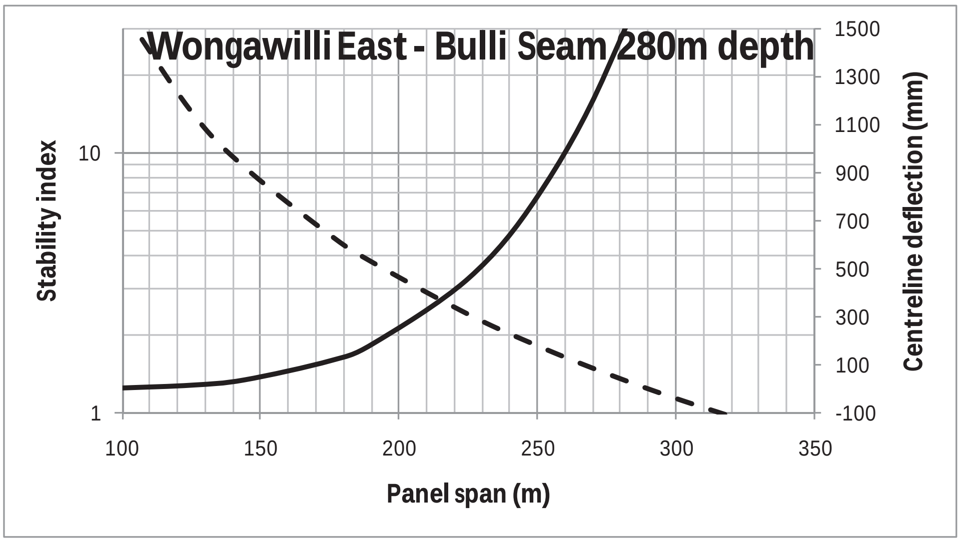


Figure 17 Fractured rock beam analysis for the Wongawilli East area (dashed line – stability, solid line – deflection).

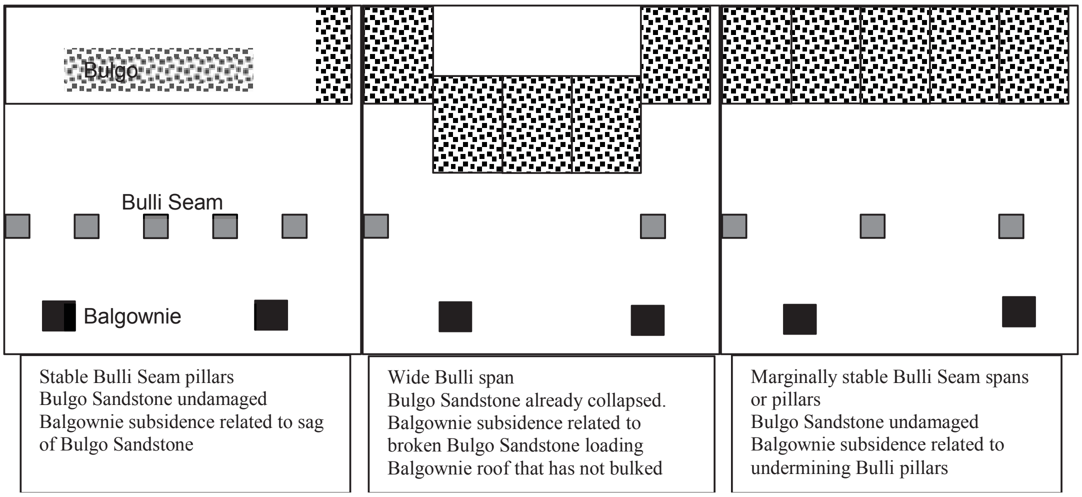


Figure 18 Cartoon explaining different Balgownie subsidence outcomes

4.1.2 Shape of profiles for Balgownie extraction

An angle of draw to negligible vertical subsidence (< 20mm) is indicated to be 5 ^{o} - 34 ^{o} (Table 2), which is consistent with other mines in the Southern Coalfield. The goaf-edge subsidence is also consistent with the regional patterns. The subsidence data are conclusive in demonstrating Face 6 and Face 7 did not induce a pillar run in the adjacent Bulli Seam pillars that lay within 6-8m of the extraction – this is a key piece of data to consider when assessing the onset of a pillar run induced by the mining of a deeper seam.

Table 2 Details of Balgownie subsidence near Mount Ousley Road

Parameter	Face 6	Face 7
Width	142	192
Width/Depth	0.5	0.68
Maximum subsidence	840mm	1200mm
Sag	150mm	500mm
Sag/Thickness	0.11	0.38
Pillar compression	750mm	750mm
Distance to negligible vertical subsidence	22m, 187m	97m, 83m
Angle of draw to negligible vertical subsidence	5 ^{o}, 34 ^{o}	19 ^{o}, 17 ^{o}
Goaf edge subsidence	228mm, 228mm	228mm, 76mm
Goaf edge subsidence/maximum subsidence	0.27,0.27	0.19, 0.06

4.1.3 Maximum tilts and strains from Balgownie extraction

Maximum tilts can be measured off the crossline data and from the start and finish lines along the centrelines (Table 3). For the centreline data, the maximum vertical subsidence corresponds to the value applying in the immediate vicinity and for the cross line data the quoted subsidence is the calculated sag. Whilst there is a general trend of increasing tilt with increasing subsidence, there is

not a strong linear relationship (Figure 19). The corresponding K3 values[4] for the cross line data plot above the Southern Coalfield guideline[5] and off-scale (Figure 20).

Table 3 Maximum tilt and strain data from the Balgownie subsidence surveys

Centreline			Crossline		
Face	**Smax(m)**	**Tilt max (mm/m)**	**Face**	**Smax**	**Tilt max (mm/m)**
1	1.14	11	1	0.51	8.6
1	0.91	7.9	2	0.20	4.7
2	0.99	10.3	3	0.32	9.8
3	0.91	6	4	0.22	4.6
3	1.30	15.9	6	0.23	6.5
4	1.10	10	7	0.72	7.85
4	1.10	7	6	0.14	2.2
5	0.84	7.3	7	0.53	9.2
5	0.91	8.7	8	0.54	9.6
6	0.76	6.3	9	0.22	8.4
6	0.82	6	10	0.81	18.5
7	0.79	8.5	11	0.28	4.3
7	0.91	15.1			
8	0.80	9.2			
8	1.00	7.2			
9	0.85	15.4			
9	1.15	11.1			
10	0.85	7.7			
10	1.40	4.2			
11	1.30	17.3			
11	0.80	5.8			

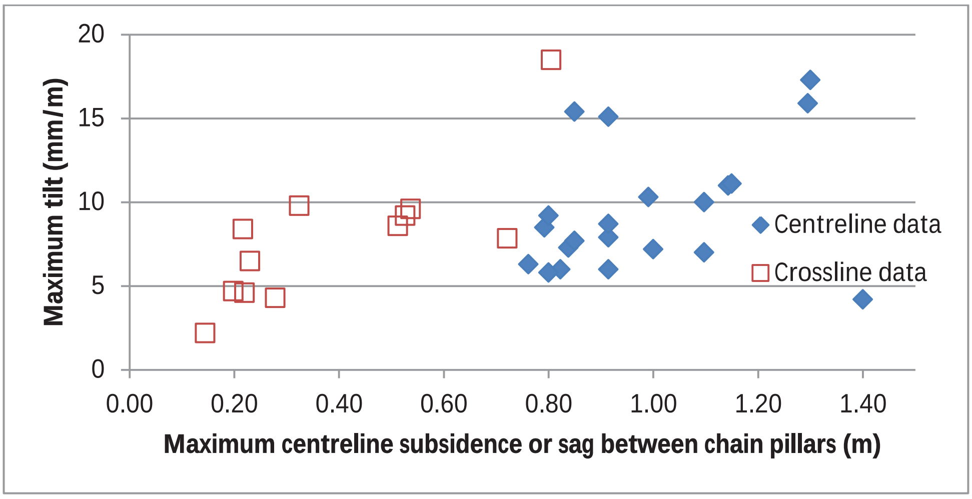


Figure 19 Maximum tilt and associated maximum vertical subsidence from Balgownie surveys

[4] Kn=max *H/Smax, where max = maximum value of tensile strain (n=1), compressive strain (n=2), and tilt (n=3).
[5] Holla, L. & Barclay, E. 2000. Mine Subsidence in the Southern Coalfield, NSW, Australia. NSW Department of Mineral Resources.

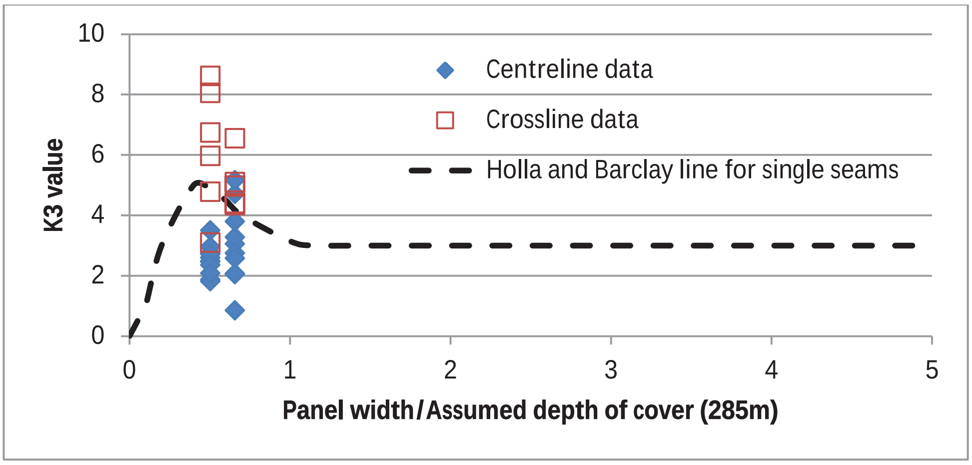


Figure 20 K3 values and panel width/depth ratio for Balgownie subsidence lines

Strains were measured only along the centreline of Face 11. At the inbye end of the face, the maximum subsidence was about 0.9m and the maximum strains were 3mm/m both tensile and compressive. The K1 and K2 values are 1.0. At the outbye end, the maximum subsidence was about 1.3m and the maximum strains were 9mm/m tension and 13mm/m compression. The K1 and K2 values are 2.0 and 2.9. Three of these points plot well with respect to the Holla and Barclay guidelines (Figure 21) and the compressive strains for the inbye end plot above the line.

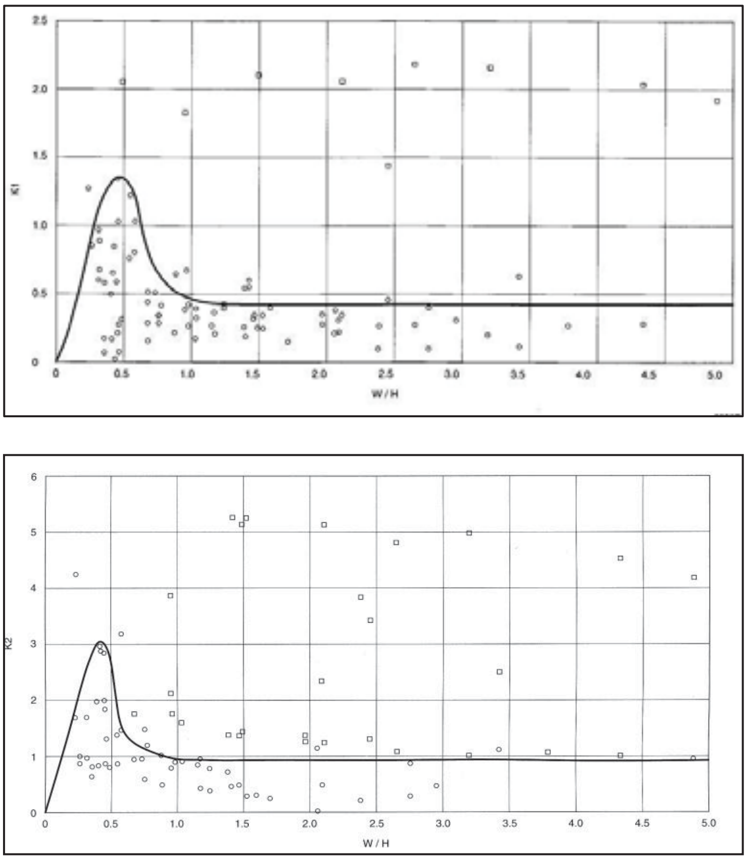


Figure 21 Holla and Barclay guidelines for K1 and K2.

4.1.4 Recent 2012 Wongawilli extraction

The centreline of WE-A2-LW4 was surveyed on 27 June 2110 (Figure 22) and for the following discussion it is assumed the face had retreated sufficiently past the survey line such that the subsidence will not further increase. On this basis, manipulation of this data reveals the following key points:

- Panel width/panel depth = 150/340 = 0.44
- Maximum vertical subsidence = 1.1 m
- Maximum subsidence/Extraction thickness = 1.1/3.2 = 34%
- Maximum tilt = 20 or 9 mm/m K3= 6.2 or 3.4
- Maximum strains = 1.4 and -3.4 mm/m : K1= 0.4 and K2= 1.0
- Goaf edge subsidence = 0.1m
- Location of inflexion point = 40m into the goaf from the goaf edge

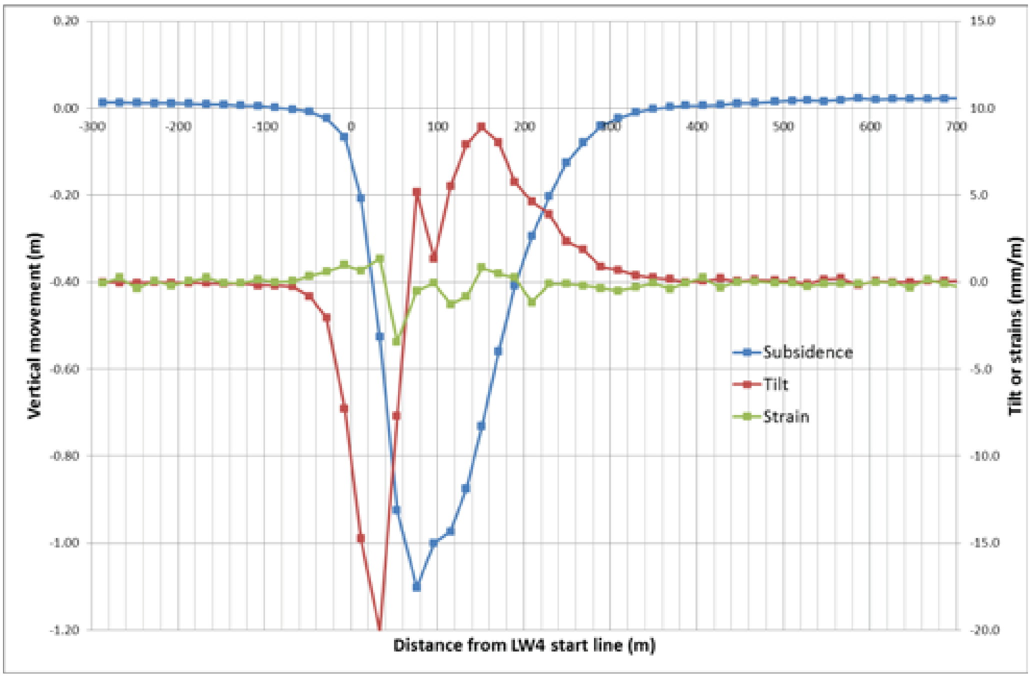


Figure 22 Subsidence along centreline of WE-A2-LW 4 Wongawilli Seam - 27 June 2012

For an isolated panel, all of the subsidence parameters are substantially different to the recommended design lines in Holla and Barclay (op cit) for isolated panels in a single seam. It is noted that our previous reports have reluctantly offered a specific numerical prediction while highlighting the lack of precedent fro three seam extraction. The measured vertical subsidence is greater than anticipated: it appears that the Bulli and Balgownie extraction has had a greater impact on the spanning of the overburden than anticipated. However, the subsidence associated with the Wongawilli extraction is only 39% of the extracted thickness and cannot be considered to represent “supercritical” conditions.

4.2 PREVIOUS WONGAWILLI WEST SUBSIDENCE

4.2.1 300 series longwalls

Because of the interest of the NSW Dams Safety Committee the first four longwalls in the 300 series area were extensively monitored (Figure 23). Typical data from one of the crosslines (Figure 24) shows the pattern of sag above the panels between the chain pillars together with even greater deformation above the chain pillars. The vertical subsidence was about 1m, the maximum tilts were about 4.5 mm/m and the maximum strains about 1.5mm/m. The magnitude of the sag matches that predicted from fractured rock theory and the subsidence above the pillars is well predicted with elastic compression concepts for the roof and floor once the yield of the chain pillars is included. The impact of the two wider 51m pillars can be seen in the crossline data.

The available subsidence data has been manipulated to give an indicative contour plan of the vertical subsidence across the first four panels (Figure 23). The data was also processed in SDPS to allow a visualisation of the likely subsidence across the full western area (Figure 25).

Figure 23 Contours drawn on survey data

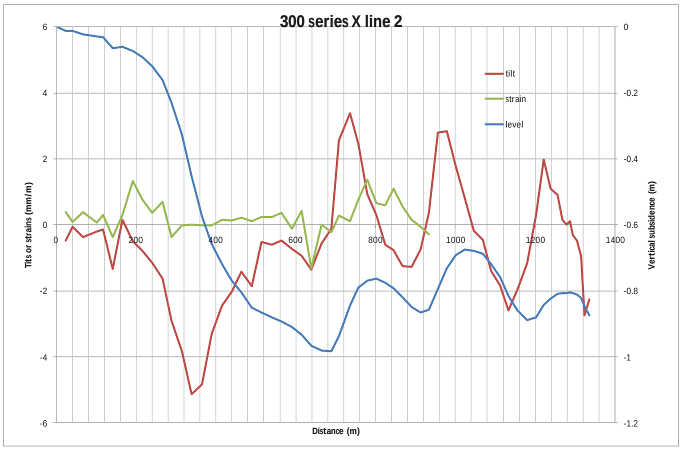


Figure 24 A subsidence line above South Bulli longwalls

Figure 25 Visualisation of likely subsidence to have developed after Bulli Seam extraction

4.2.2 500 series longwalls – Cataract Panels

The original layout for the 500 series panels under Cataract Dam involved 110m - 120m wide panels and 60m pillars, and from 1998 the panel widths were increased to 150m and the pillars to 65m. For the first of the wider 150m wide panels, which was the only one that could be surveyed, the maximum vertical subsidence is approximately 300mm combining 240mm of pillar compression and approximately 60mm of sag (Figure 26). The maximum tensile strains are 0.8mm/m, maximum compressive strains of 1.3m m/m, and maximum tilts of 0.8 mm/m. No closure across the arm of the reservoir was measured and no cracking of the rock outcrops was observed. Over the earlier 110m - 120m wide panels, the maximum vertical subsidence was 202mm with tensile strains less than 0.2 mm/m and compressive strains less than 0.4 mm/m.

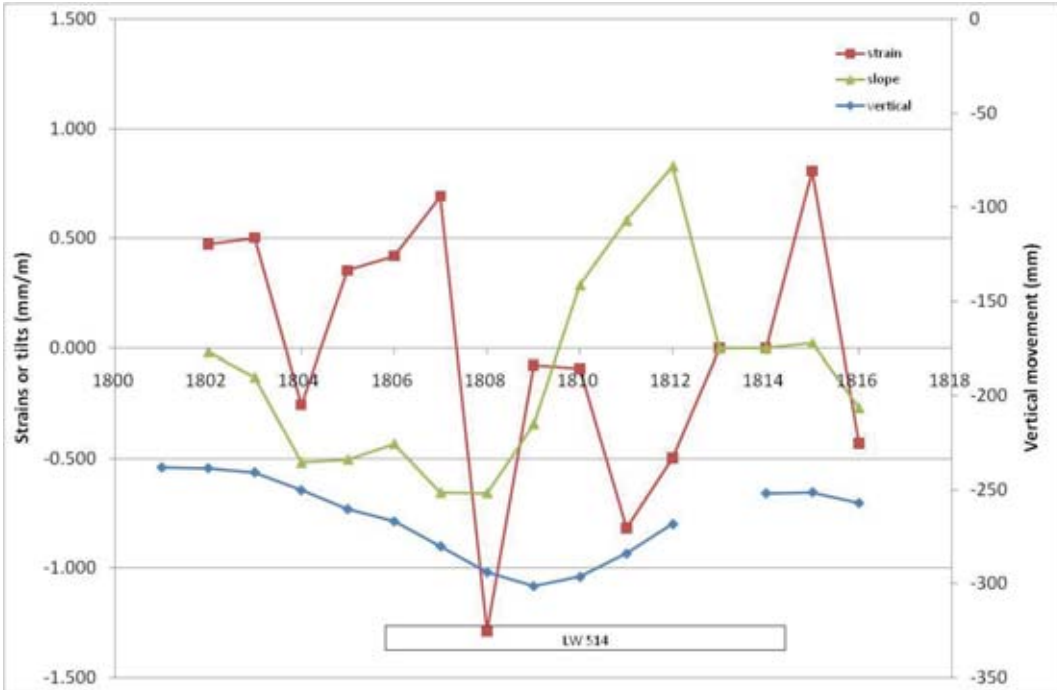


Figure 26 Subsidence above LW514 under Cataract Reservoir

More details are given in Seedsman and Kerr (op cit) which presents a summary of the monitoring of microseismic emissions and microstrain within the rock mass, far-field movements, and the development of pillar subsidence and panel sag.

5 SUBSIDENCE PREDICTIONS

5.1 CONVENTIONAL AND NON-CONVENTIONAL SUBSIDENCE

Conventional subsidence has been defined by Southern Coalfields Inquiry[6] (SCI) as:

> *The conventional or general model of surface subsidence, which finds worldwide acceptance, is based on assuming the following site conditions:*

[6] Southern Coalfields Inquiry (2008). NSW Department of Planning.

- the surface topography is relatively flat;
- the seam is level;
- the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities;
- the surrounding rock mass does not contain any extremely strong or extremely weak strata; and
- the mine workings are laid out on a regular pattern.

The behaviour of a single, or isolated, excavation provides the basis for the conventional model of subsidence behaviour."

By default, all other subsidence must be defined as non-conventional. The SCI recognised that 'nonconventional subsidence' term was somewhat of a misnomer but decided to maintain the term for the sake of simplicity.

On the basis of the SCI definition, subsidence above the proposed Wongawilli longwalls will be non-conventional. This is because the conditions that are being considered include:

- Multiple seams are to be extracted,
- The panels in the previously mined seams are not isolated
- The proposed panels are not isolated,
- The chain pillars are designed to yield or fail,
- An irregular topographic surface is present,
- The Bulgo Sandstone is known to be an extremely strong/spanning unit,
- The mine workings in the Wongawilli East area are not on a regular pattern.

The Bulgo Sandstone is known to be a spanning unit over Bulli Seam longwall panels with widths of at least 200m to 250m. This can be readily seen in the Holla and Barclay curves and has also been shown from microseismic studies. In addition, upsidence of plateau ground (not valleys) associated with massive units has been recorded on the NRE lease adjacent to Cordeaux Colliery.

Almost all longwall layouts in the Southern Coalfield have employed pillar designs whereby the chain pillars are designed to yield or fail. The consequence of this is a subsidence pattern whereby the majority of the subsidence develops above the chain pillars and there is lesser additional subsidence above the longwall voids.

The Southern Coalfield is characterised by a rugged or undulating topography. Down-hill movement in steep topography is the same phenomenon as valley closure. The dominant mechanism is likely to be simple shear translation along flat-lying bedding surfaces that daylight in the sides of any low points in the topography. Uplift (upsidence) can develop if the translation is along a surface that is just below the base of the surface relief.

5.2 PREDICTING THE SHAPE OF A SUBSIDENCE BOWL FOR A SINGLE SEAM

In all methods, the prediction process starts with an estimate of vertical subsidence – either as a few discrete points or as profiles or surfaces. For profiles and surfaces, differentiation gives tilts and curvatures. Empirical relationships are then used to give strains.

Vertical subsidence for single seams can be predicted by a number of methods:

- Upper-bound values from a data base – The various reports by Holla provide some of the details of the database and a transparent presentation of the recommended design lines. The design lines are drawn towards predicting the maximum deformations.
- Incremental profile method – This is a proprietary method developed by MSEC. The database has not been published and there is no publication of any details of the design lines or its application to multiple seams. The incremental profile method can only be used by MSEC and is not subject to peer review.
- Application of geotechnical engineering principles to the estimation of subsidence above pillars and sag between pillars[7].
- Direct application of precedent practice from nearby identical layouts.

5.2.1 Predicting the shape of the bowl

The prediction of the shape of the subsidence bowl is more complex. In the Holla method, a number of estimates of key shape parameters are available and a smooth line is then drawn:

- Location of the inflexion point
- Maximum tilt – K3 values
- Maximum strain – K1 and K2 values
- Vertical subsidence at the goaf edge,
- Extent of subsidence bowl

It is not known how the shape of the subsidence bowls is determined in the incremental profile method.

In the influence function method, international experience in many coal fields has shown that a Gaussian function fits the subsidence well and this has been confirmed in Australian coalfields[8]. As implemented in SDPS[9], determining the shape of the subsidence bowl with the influence function method requires:

- Location of the inflexion point (as presented in the Holla methods)
- Maximum tilt via the influence angle (tangent of the influence angle B is equivalent to K3 in the Holla methods)

For multiple seams, there is no database of inflexion point locations, K3 values or strain coefficients. The approach adopted in this report has been to determine appropriate values from a back analysis of the Balgownie subsidence results.

5.2.2 Predicting strains

The recent Bulli Seam PAC discussed the theoretical problems in the way subsidence strain is calculated, and there is reference to the well-acknowledged problem of assuming continuum behaviour for jointed rock. The academic validity of these comments is accepted, but this does not negate the need for the practical application of the engineering concepts.

[7] Seedsman, R.W. A review of methods to determine panel and pillar dimensions that limit subsidence to a specified impact. Coal 2004. 5th Australasian Coal Operator's Conference, Wollongong, 2004.
[8] Byrnes, R. Case studies in the application of influence functions to visualising surface subsidence. Coal 2003 4th Australasian Coal Operator's Conference, Wollongong, 2003.
[9] www.carlsonsw.com

One of the major problems with predicting strains is related to the fact that much of the data is at magnitudes approaching the resolution of the survey tools. This means there is a large degree of "noise" in the data (the cloud of points near the origin in Figure 27). A statistical line of best fit is close to meaningless in the low strain range – but this is not material as any associated impacts or consequences are non-existent. At higher strain values, the spread in the data is somewhat similar to that seen with other subsidence parameters. .

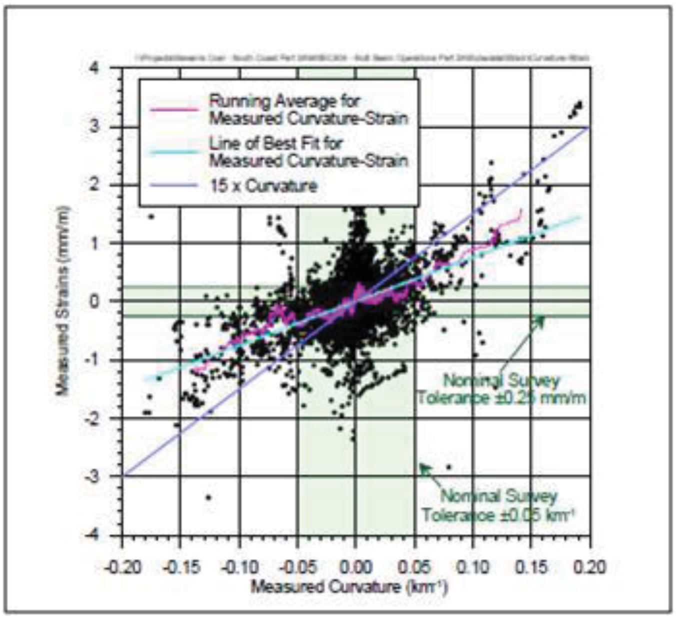


Figure 27 Cross plot of curvatures and strains measured along survey lines

It is noted that USA workers[10] have found that a better empirical relationship between strain and curvatures requires consideration of depth and the K3 factor. As implemented in SDPS, strain/curvature = B *depth/tanB where B has an empirically derived value of 0.35 in USA (imperial system - applies to curvatures measured in feet), equivalent to 0.1 for the metric system[11]. In our work with SDPS in Australia, we have found values between 0.1 and 0.2 apply.

5.3 ACCURACY, UNCERTAINTY AND PREDICTION

In interactions with the various government agencies over the last four years, it has become apparent there is a serious disconnect between their expectation of "accuracy" and the practice of geotechnical engineering in general and specifically subsidence engineering. As cited by Galvin[12] and discussed by Beder[13], the Institution of Engineer Australia recommends that '*……….engineers present the community with options, honestly communicating the limitations and uncertainties associated with each and allowing the community to choose.".* Morgenstern makes similar observations and stresses

[10] Karmis, M., A. Jarosz, P. Schilizzi and Z. Agioutantis. 1987. *Surface Deformation Characteristics Above Undermined Areas: Experiences from the Eastern United States.* Civil Engineering Transactions, The Institute of Engineers, Australia.
[11] Pers com – Prof Z Agioustantis – August 2012.
[12] Galvin, J.M. 2008. Geotechnical Engineering in Underground Coal Mining. Principles, Practices and Risk Management. Workshop Notes. ACARP Project C14014. UNSW School of Mining Engineering.
[13] http://www.uow.edu.au/~sharonb/fallible.html

that managing uncertainties is a feature of geotechnical engineering ventures and highlights the need to separate predictions from acceptable performance[14].

"Performance requires consideration of safety, serviceability, and affordability. Serviceability criteria apply to such considerations as limited deformations, limited leakage, and consistency with environmental constraints. … the value of prediction in performance assurance has been over-estimated…… Risk analysis is essential to provide assurance of performance."

In their correct application, the term "accuracy" relates to a measurement – how close is the measurement to the actual dimension, and "precision" relates to the reproducibility of the measurement.

In all geotechnical engineering, including subsidence engineering, the process is to achieve an acceptable outcome. Achieving a forecast deformation makes the venture easier, but most geotechnical engineers realise that this is not always achievable and that risk management is always required. Risk management can include the strategies outlined earlier or can be as simple as assuming a worst case forecast or a percentage of the forecast.

By definition, a worst-case prediction cannot be considered absolutely reliable or "accurate" as there will be any circumstances where the prediction is in excess of what is subsequently measured. Importantly, there must be concern if a worst-case prediction is relied on but is subsequently found to be lower than what is measured. Both the Holla and Barclay and MSEC methods claim to be biased towards "worst case" but there are now several examples where they have significantly under-predicted. Pells (op cit) refers to cases of under-prediction in the order of 200%.

The current uncertainties with subsidence predictions are for single seam operations where there is a large experience base. There is a very small experience base with multiple seams so precedent practice cannot be used.

The approach adopted in this report is to consider the engineering mechanics and to apply that knowledge with our broad rock mechanics experience to produce a set of estimates for the various deformations. We will keep the concepts as simple as possible so the uncertainties can be readily identified. This will allow appropriate "uncertainty factors" to be applied when conducting risk assessments on the impact to features which are to be undermined. Adaptive management based on monitoring deformations above the early longwalls will then be incorporated as soon as possible.

5.4 VERTICAL SUBSIDENCE ABOVE MULTIPLE SEAM EXTRACTION

Li et al[15] has begun the important task of collating information on the subsidence developed above multiple seam longwalls. The paper presents a much abbreviated database of five studies of mostly shallow cases of longwall mining under previous longwalls. No information is provided on tilts and strains, or on the geological conditions in the overburdens. Only one of the case studies is from a depth comparable to those under consideration. Two are from mines where the panels were stacked, and two are from situations where there is no survey data provided for the upper walls.

[14] Morgenstern, N.R. 2000. Performance in geotechnical practice. The Inaugural Lumb Lecture. May 10, Hong Kong. http://www.hku.hk/civil/lumb_lecture/morgenstern-paper.pdf

[15] Li , G., Steuart, P., Paquet, R., and Ramage, R. 2010. A case study on mine subsidence due to multi-seam longwall extraction. 2nd Australasian Ground Control in Mining Conference, Sydney. 23-24 November.

Researchers are possibly not giving appropriate attention to the influence of the thickness of the interburden as discussed as early as 1987[16]. The majority of the bulking that occurs in a longwall goaf develops in the caving zone (Figure 28). If this caved zone from the lower seam intersects the overlying seam the thickness of the caved zone and hence the amount of bulking will be reduced. On this basis, if the interburden is very thin the amount of bulking supplied by the interburden is small and the total subsidence for the lower extraction will approach 100% of the extracted thickness. If the interburden is thick (in excess of the normal thickness of the caved zone - say 10 times the seam thickness), the lower seam bulking will fully develop and the total subsidence for the lower seam extraction will tend towards the value for a single seam (say 65%).

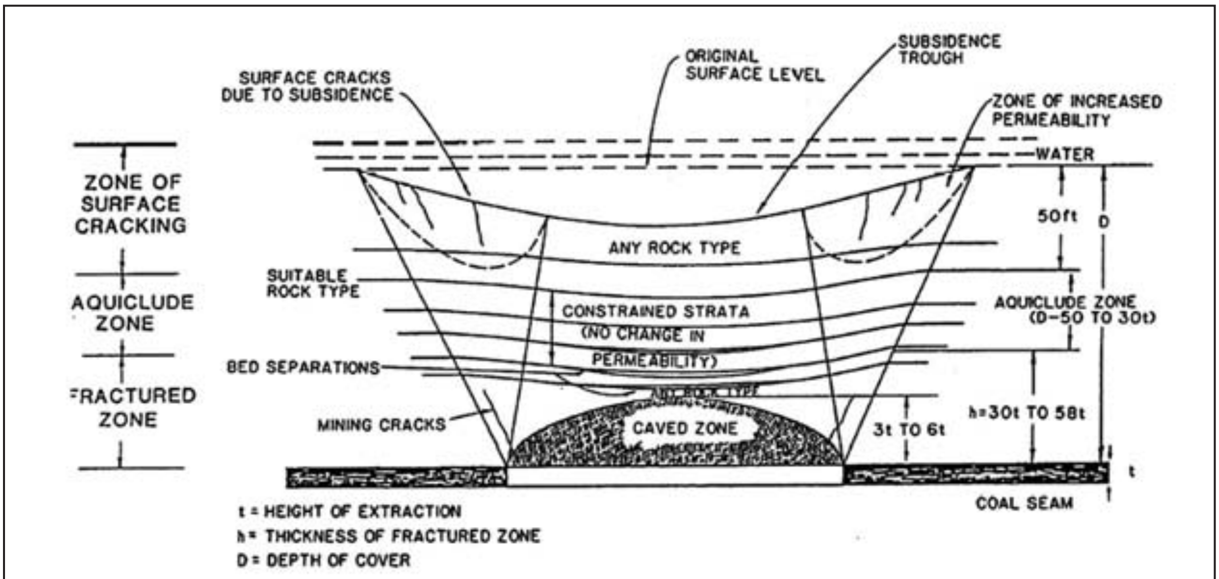


Figure 28 A model for fracturing above a longwall panel[17]

Given our alternative analyses, the apparent availability of other information which is not consistent with the Li et al model and the lack of guidelines for the selection of shape parameters, there is no rigorous basis for using the Li et al recommendations at this time.

The approach adopted in this report is to assume that the vertical subsidence will be the sum of the subsidence associated with the Wongawilli Seam plus any residual subsidence that may develop in the upper seam.

For Wongawilli East this means:

- A nominal 300mm for the narrow Wongawilli longwall panels with no goafs above.
- Plus the impact of the collapse of small Bulli Seam pillars that may be still standing after Balgownie retreat.
- Plus two options for how to deal with the extraction goafs of the Balgownie and Bulli Seams.

For Wongawilli West this means:

[16] Van der Merwe, J.N. 1987. A study of the effects of mining relatively shallow overlying longwall panels with staggered inter-panel pillars at Sigma Colliery, South Africa. *In* Engineering geology of underground movements, Proceedings of the 23rd Annual conference of the Engineering Group of the Geological Society, Nottingham.

[17] Bai, M and Kendorski F.S. 1995. Chinese and North American High Extraction Underground Coal Mining Strata behaviour and Water Protection Experience and Guidelines. 14th Conference on Ground Control in Mining. 209-217.

- 65% of Wongawilli extraction.
- Plus collapse of the overburden above Bulli Seam longwall panels so that the residual of 65% develops for that seam.

As will be discussed later, these estimates provide the base case for risk assessments. As required in the earlier SMP process, the estimates can be increased by nominated percentages to address prediction uncertainty.

5.5 PREDICTIONS OF VERTICAL SUBSIDENCE FOR WONGAWILLI EAST AND WONGAWILLI WEST

5.5.1 Wonga East

The basic geometric parameters for Wonga East area are:

- Depths – 280m to 340m
- Extraction – 2.7m to 3.2m
- Panel width – 150.5m rib to rib
- Pillar width – 59.5m rib to rib

The Wonga East area is complex with a variety of overburden conditions including:

- First working Bulli Seam workings with pillars greater than 15m in width with no Balgownie Seam longwall panels
- First working Bulli Seam workings with pillars greater than 15m in width with Balgownie Seam longwall panels
- Bulli Seam pillar extraction goafs with no Balgownie Seam longwall panels
- Bulli Seam pillar extraction goafs with Balgownie Seam longwall panels
- Bulli Seam pillars with widths less than 15m with no Balgownie Seam longwall panels
- Bulli Seam pillars with widths less than 15m with Balgownie Seam longwall panels

Subsidence in the Southern Coalfield is controlled in part by the spanning capability of very thick to massive units within the Bulgo Sandstone. This capability may be destroyed by wide extraction panels formed by:

- wide pillar extraction panels in the Bulli Seam
- Balgownie longwalls inducing wider spans by undermining Bulli Seam barriers.
- Wongawilli panels inducing wider spans by undermining Balgownie Seam chain pillars.

There is only the Balgownie longwall empirical database and the initial retreat of LW4 in the Wongawilli Seam on which to determine maximum vertical subsidence, and no information for multiple seams involving the Wongawilli Seam. A large degree of judgement has been used to decide on maximum vertical subsidence outcomes for the various layouts that are proposed.

In areas where there has been no Balgownie extraction and only Bulli first workings, the proposed narrow longwalls with wide pillars, as used in the Cataract 500 series area, will result in subsidence similar to that developed under Cataract Reservoir. The sag subsidence will be very low as the Bulgo Sandstone will be spanning. A value of 300mm has been assumed (Table 4) – this is greater than that recorded above the Cataract 500 series panels.

For areas of Bulli goaf, it is assumed that there is a reduction in spanning capacity and the maximum vertical subsidence will be 1.2m (based on what has been measured above LW4).

For areas of "small" Bulli pillars, it is assumed that the Wongawilli longwalls will collapse the Bulli pillars and a maximum vertical subsidence of 1.2m will result

Two cases are considered for subsidence above the Balgownie longwalls and large Bulli pillars. The likely (base) case that the overburden will still have spanning capacity and subsidence will be limited to 300mm. An upper case assumes the spanning capacity has been disrupted by the Balgownie longwalls so that a 1.2mm maximum subsidence could develop.

Table 4 Model for subsidence in the Wongawilli East area

LW	SDPS	Balgownie goaf	Bulli goaf	Bulli pillars	Expected case Smax (mm)	Upper bound Smax (mm)
1	1			Large	300	300
	2		Yes		1200	1200
	3			Large	300	300
2	4			Large	300	300
	5	Yes		Large	300	1200
	6			Large	300	300
	7	Yes		Large	300	1200
	8			Large	300	300
3	9	Yes		Large	300	1200
	10	Yes	Yes		1200	1200
4	11	Yes	Yes		1200	1200
5	12			Large	300	300
	13	Yes		Large	300	1200
	14		Yes		1200	1200
6	15	Yes	Yes		1200	1200
	16	Yes	Yes		1200	1200
	17	Yes		Large	300	1200
	18			Large	300	300
	19		Yes		1200	1200
7	20	Yes		Large	300	1200
	21		Yes		1200	1200
	22			Small	1200	1200
	23		Yes		1200	1200
8	24		Yes		1200	1200
	25			Large	300	300
	26	Yes	Yes		1200	1200
	27		Yes		1200	1200
9	28			Large	300	300
	29			Small	1200	1200
	30			Large	300	300
	31		Yes		1200	1200
10	32			Large	300	300
	33		Yes		1200	1200
	34			Large	300	300
	35		Yes		1200	1200
	36			Small	1200	1200
11	37		Yes		1200	1200

The other input parameters for the influence function visualisation of subsidence are:

- The inflexion point is located 40m in from the goaf edge.
- Influence angle of 80^{o} (tanB=5.80).
- Strain coefficient of 0.15.

5.5.2 Wongawilli West

The basic geometric parameters for Wonga West area are:

- Depths – 440m to 500m
- Extraction – 2.7m to 3.2m – assume 3.2m average
- Panel width – 388m rib to rib
- Pillar width – 59.5m rib to rib

For the Wongawilli West area, the geometric situation is simpler with only the Bulli Seam already extracted. Referring back to Figures 23 and 24, it can be appreciated that the maximum vertical subsidence recorded to date is about 1.0m which is less than the 1.6m (65% of 2.5 implied by Holla and Barclay) interpreted to be the maximum possible in conventional subsidence theory. It is proposed the difference is related to the spanning capacity of the Bulgo Sandstone across the panels which are less than 188m wide, and that this spanning capability may be reduced with wider panels.

Referring to Figure 29, Table 5 outlines the possible subsidence history of various points.

A. Above Bulli extraction panel, and above Wongawilli pillar. Subsidence of about 1.0m already developed due to compression of Bulli pillar system and sag of the Bulgo Sandstone. Additional subsidence related to the compression of the Wongawilli pillar system and "collapse" of the Bulgo Sandstone.
B. Above Bulli Seam pillar and above Wongawilli panel. Subsidence of about 0.8m already developed due to compression of Bulli pillar system. Wide Wongawilli panel leads to subsidence of 65% of 3.0m extraction thickness or 1.95m.
C. Above Bulli and Wongawilli goafs. Subsidence of about 1.0m already and possibly an additional 2.55m during Wongawilli extraction.

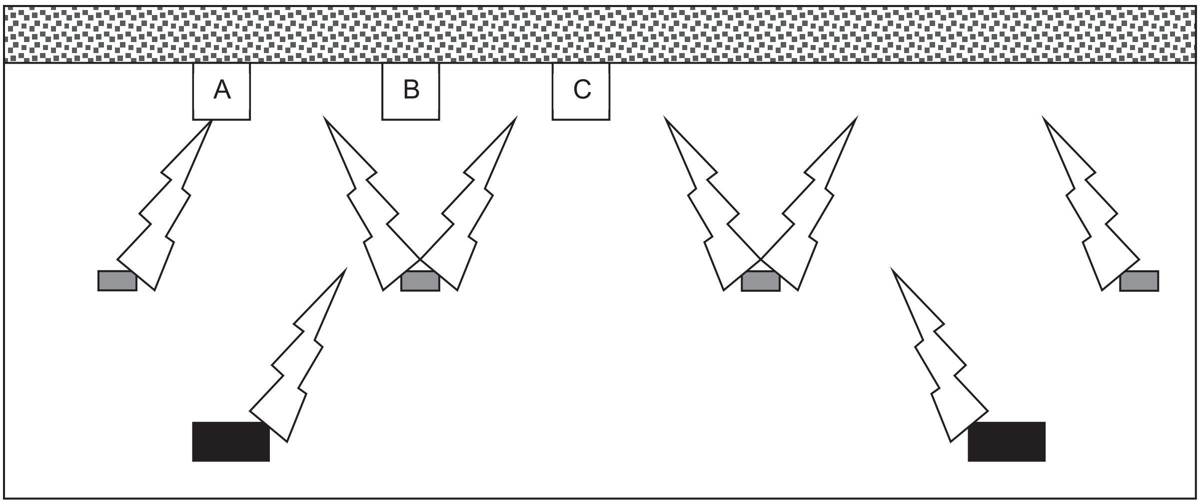


Figure 29 Cartoon showing relative location of 3 surface points above Bulli and Wongawilli Seam longwall panels

Table 5 Summary of possible maximum subsidence values for Wongawilli West

	Previous Bulli Seam	Bulli residual potential	Wongawilli Seam only	Mining proposal	Combined
A	1.0 m	0.6 m	0.8 m	1.4 m	2.4 m
B	0.8 m	0.0	1.95 m	1.95 m	2.75 m
C	1.0 m	0.6 m	1.95 m	2.55 m	3.55 m

5.6 THE LATERAL EXTENT OF SUBSIDENCE

Recognising the uncertainties in subsidence prediction and the need to apply risk management strategies, one of the key parameters is the lateral extent of subsidence deformations above unmined coal.

Holla and Barclay (op cit) state that for single seam operations in the Southern Coalfield the average angle of draw to a vertical subsidence of 20mm is 29^{o}, with 70% of the survey less than 35^{o}. There are vertical movements outside the angle of draw but they are assessed to be related to survey precision. In this definition, there is no judgment made as to whether the 20mm threshold represents the onset of unacceptable deformation.

There is no data base for the angle of draw for multiple seams. From a consideration of the mechanics of broken overburden, the angle of draw in multiple seams should tend to be lower

Over the last 15-20 years, much focus has been applied to horizontal movements, and particularly those that have been measured outside the 35^{o} angle of draw for vertical subsidence. The studies have not adequately acknowledged the precision of the surveys (20mm[18]). Once this is included, the available data (Figure 33) indicate no movements at 1900m from the goaf edge (10 sites, 28 data sets, range of topographic and geological conditions). The Kay et al (2007) paper also notes that “the magnitude of far-field movement reduces as the subsidence produced by the longwall reduces, which is expected.”. There is no database of horizontal movements associated with multiple seam extraction.

5.7 THE PILLAR RUN HAZARD IN WONGAWILLI EAST

5.7.1 Background

Government agencies have raised concerns about the potential for a pillar run. The term “pillar run” is often used but is not formally defined. Current usage seems to be for any unexpected failure of a large number of pillars. In the following, the term “pillar run” will be used to describe the rapid collapse of a large number of pillars. This distinguishes a run from another poorly defined term – a “pillar creep” – which is a slow convergence of roadways over a large area.

[18] Kay, D.J., DeBono, P.L., & Pinkster, H. 2007. Probabilistic approach to predicting far field horizontal movements during mining. Proceedings 7th Triennial Conference on Mine Subsidence: A Community Issue.

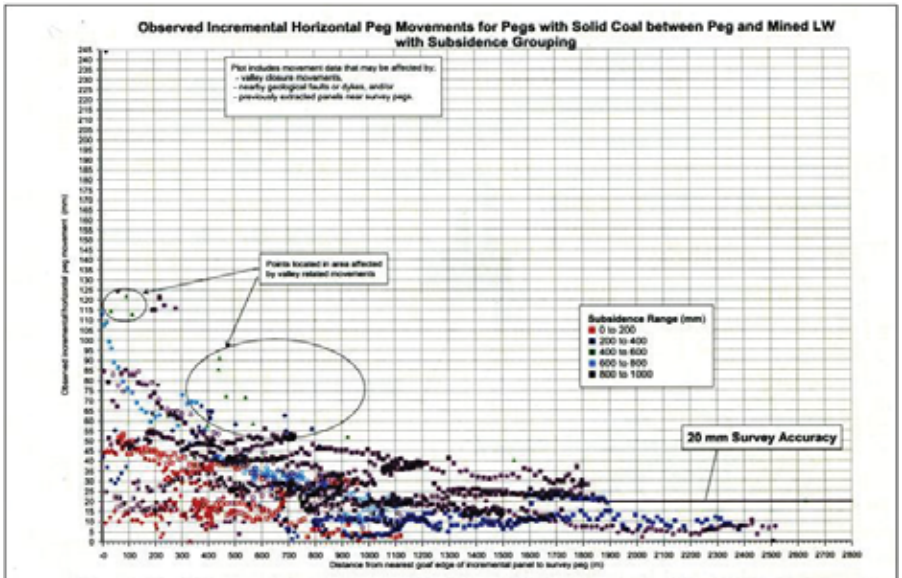


Figure 10 – Observed Incremental Horizontal Movements for Pegs with Solid coal between Peg and Panel vs Distance from Nearest Goaf Edge of Incremental Panel – Grouped by Subsidence

Figure 30 Horizontal movements above solid coal (reproduced from Kay el al. 2007)

There is no record of the Balgownie longwalls inducing a pillar run when extracted 6-8m below the Bulli seam. Given the imagined severity of such an event it is unlikely that it went unreported. In fact, inspection of the subsidence data shows the Balgownie panel edges deform in the same way as isolated Bulli Seam longwall panels which indicates that the Bulli Seam pillars immediately adjacent to the Balgownie goaf edges did not fail. If they did not fail here, there could not be a subsequent failure further away from the abutment stress peaks.

In the international technical literature, there is no record of a pillar run induced by mining in a lower seam. Stable Strata (op cit) reports that there have been no subsidence induced pillar runs in South Africa.

It can be argued pillar runs did occur prior to the 1960 collapse of Coalbrook in South Africa in 1960 that initiated detailed research into pillars. There have been examples of isolated pillar failures since the introduction of the pillar design methods, but SGPL is not aware of a pillar run. In South Africa, the more recent failures have been at shallow depth, with slender pillars, and the incorrect use of their guidelines. In Australia, the pillar failures that were included in the UniNSW database were either formed prior to the introduction of the pillar design methodology or can be tracked to inappropriate implementation of the design methodology. There has been no pillar run in Australia that has been discussed in the engineering literature. Recent Newstan longwalls extracted directly under standing pillars in Awaba Colliery and did not induce a pillar run. There was extensive monitoring to examine this perceived hazard.

To generate a pillar run, a wide area of undersized pillars are required such that loads can be transferred to adjacent undersized pillars which then subsequently fail. At Wongawilli East, we would be dealing with a different mechanism of pillar failure compared to a standard “pillar run”. What is apparently being invoked is that by withdrawing the foundation to pillars, load is transferred to other pillars that have not been undermined and these then subsequently fail. The only way pillar loads can be increased in this geometry is for the overburden to arch from the undermined location. If the

previous mining caused full subsidence and "broke' the overburden sequence, arching is not possible and hence loads cannot be transferred.

5.7.2 What is an undersized pillar?

"Undersized" implies a pillar that fails to perform to requirements. The coal pillar failure database does not provide a definition of "failure" – it is assessed that failure relates to underground operational issues, particularly workplace safety, and was originally designed to include cases involving the failure of a large number of pillars in a panel and to specifically exclude cases where the floor fails.

The interpretation of the database is purely empirical/statistical: there has been no attempt to establish the engineering mechanisms. There were only 61 failed pillars in the Australian/South African database used in the UNSW method (16 Australian cases) and this limited number means care is needed when quoting probabilities of failure. The probabilities quoted (up to 1:1000000) relate to an assumed normal distribution and particularly an assumption that there is no error in the estimate of the pillar load. There is little value in pursuing statistical stability in the Mount Ousley case because there is a very high level of uncertainty in the estimate of pillar loads.

A major problem in the statistical analysis is the lack of any valid recorded case for failure of pillars with width/height greater than 4.3. A 2006 review of South African data[19] made a number of key observations:

- The database excludes floor failure,
- The were 27 failures in the 1967 database and there is now 75 in the 2006 database,
- Most of the failures have occurred at less than 100m depth,
- There are none with w/h greater than 4.3.

A recent paper by Galvin[20] includes a discussion of the only two cases of "failed" pillars where the w/h ratio is greater than 5.0. One of these cases is Crandal Canyon, and the other is an unpublished "confidential" case study. The detailed nature of the Crandal Canyon pillar deformations are not known – the fatalities could have been due to rib spall/failure while the pillars were still load-bearing. The unpublished case study has recently been reported to likely be from the Great Northern Seam with a very weak tuffaceous unit in the floor - a coal seam where floor failures are very common. Until the uncertainty with the unpublished case study is resolved, the valid empirical data indicates a truncated distribution with no failures with width/height ratios of more than 4.3.

An alternative approach is to seek to understand the kinematics of pillar behaviour. The published pillar database has no failed pillar with a width to height ratio of greater than 4.3 and this value is equivalent to a 13° friction angle if the failure mode is considered to be shear through the pillar (Figure 31). It is possible that failed pillars are ultimately controlled by shear.

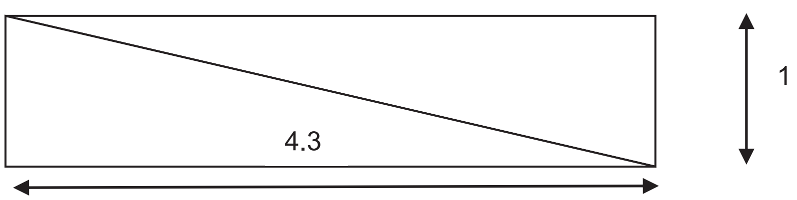


Figure 31 A 4.3:1 W/H ratio is equivalent to an included angle of 13°

[19] Van der Merwe, 2006. South African coal pillar database. J South African Institute of Mining and Metallurgy, 106, 116-127.
[20] Galvin, J.M. 2010. ICGCM Pillar design workshop.

The roof and floor of the Bulli and Balgownie Seams in this area of the mine are of rock-like strengths (30 MPa - 50 MPa) and there is no hazard associated with low strength roof and floor materials such as would negate the use of the coal pillar strength approach.

Given the failure database, the presumed floor strengths, and the considerations of aspect ratios, it is assessed that a pillar with a w/h ratio of 6 (indicating an internal friction angle of 10^{o}) represents an appropriately conservative definition of a barrier to the progress of pillar failure. It is stressed that this does not mean that squatter pillars do not deform. They certainly will deform, and the level of deformation may or may not be interpreted as failure depending on the allowable deformations that have been defined. The possible deformations are implicitly discussed later in this report.

5.7.3 Analysis of layout

Recognising the way loads are redistributed between pillars of different stiffness, there is no value in determining the stability of small pillars because it is not possible to determine their loading. A more appropriate approach is to assess the stability of the large pillars and determine if they can carry the loads without failing. As discussed above, we have chosen a w/h ratio of 6:1 as the aspect ratio where the pillar has a very high strength and can be considered to be a barrier to progressive failure. On this basis, pillars in the Bulli Seam (2.4m seam height) more than 15m wide and in the Balgownie Seam (1.3m seam height) more than 8m wide will act as blocks to the progression of subsidence.

In addition, caving and hence subsidence deformation cannot extend through existing goafs. On this basis, the presence of goafs will also represent a block to subsidence progression.

Accepting that a pillar run - a rapid progression - is not credible, there remains a concern about a creep. It is SGPL's view this is not possible as there is no way by which pillar stresses can increase on the pillars under Mount Ousley Road as they are surrounded by goaf material or too far distant along the line of pillars.

Acting under the direction from government regulators to assume a pillar run is initiated, the pillar run risk assessment[21] examined the residual risk ranking for identified impacts on a range of surface features. The review concluded that there is no hazard for Picton Road, Mount Ousley/Picton Road interchange, stored waters of Cataract Dam, various microwave/radio transmitters, Cataract River, Illawarra Escarpment. For other consequences, the likelihood factor was selected to be "E" – rare: practically impossible considering present controls in the absence of available lower likelihood factor.

5.8 UPSIDENCE AND VALLEY CLOSURE

There is inadequate understanding on how to relate the extent of horizontal movement above un mined coal to the vertical subsidence recorded above the extraction panel. Conventional subsidence theory would propose that the horizontal movements will decrease with distance from the edge of extraction. A corollary of this is that the surface would be under tension and that topographic features would tend to expand. This overall trend is apparent in Figure 32, but is contradicted by the measurements of valley closure and upsidence (both of which indicate compressive stresses).

Valley closure relates to the convergence of the two sides of a valley, upsidence is the amount by which the local subsidence is less than the wider trend. Figure 32 indicates that valley closure has

[21] Knl consultants March 2012. Pillar run in the Bulli Seam associated with Wongawilli Seam LW4 &LW5 extraction. Report to NRE

been measured[22] within about 700m in-line of extraction or about a 45° draw angle to the side. At the position of presumed negligible vertical subsidence the range of horizontal movement is less than 20mm to 150mm (at 35° draw angle) or 70mm (at 300m offset from extraction edge).

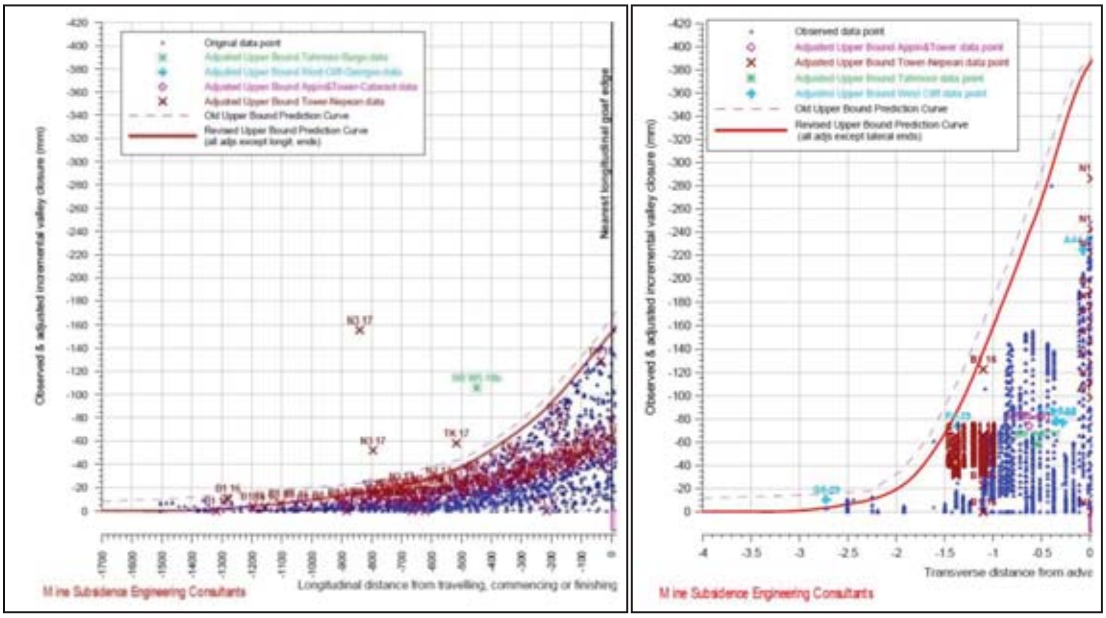


Figure 32 Closure data (reproduced from MSEC, 2008)

For upsidence, the range of values at the negligible vertical subsidence limit are less than 20mm to a maximum of 60mm (Figure 33).

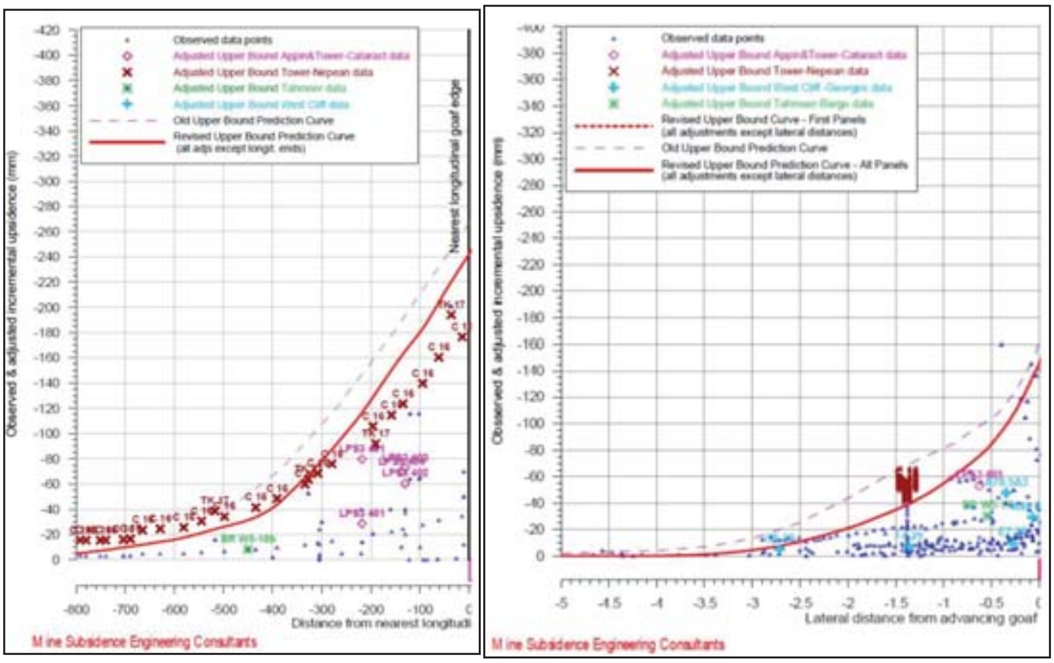


Figure 33 Upsidence data (reproduced from MSEC, 2008)

22 MSEC (Mining Subsidence Engineering Consultants), 2008. The prediction of subsidence parameters and the assessment of mine subsidence impacts on natural features and surface infrastructure resulting from the proposed extraction of Longwalls 20 to 44 at Metropolitan Colliery in support of a Part 3A Application. Report Number MSEC285 to Helensburgh Coal Pty Ltd.

The mechanisms for valley closure and upsidence are not fully understood and are hence not amenable to an analytical engineering prediction. The raw data is not available in the public domain and only modified incremental data is presented. Extrapolation to multiple seams is fraught with problems.

5.9 PREDICTION OF SUBSURFACE SUBSIDENCE EFFECTS

Any aquifers located within or intersected by mining-induced fracturing will undergo a change in permeability and the potential for localised drainage into the mine workings. If the fractured zone extends to the surface, there is a possibility for a interconnection between the surface and the mined seam.

5.9.1 Geometric models

The standard hydrogeological model (Figure 28) proposes caving and fracturing zones with their dimensions, which are derived empirically, related to the seam thickness. This normalisation process is anomalous in the context of the conventional model for subsidence whereby panel width is an important parameter. The ratios quoted in Figure 28 may be applicable only for the panel widths in the data base – and this parameter is not provided in the literature. An alternative approach is to consider the fracturing height in the context of the collapsing rock mass encountering a bridging or spanning unit.

It has been established from microseismic studies that the Bulgo Sandstone contains a bridging unit. Further evidence of spanning can be derived from an interpretation of the subsidence data for isolated panels which has subsidence of less than 10% of seam thickness (say 250mm) for width/depth ratios of 0.44 (say 205m panel at 470m depth).

5.9.2 Geotechnical models

Analyses of spanning units can be conducted using well-established concepts that are widely applied to mining (and civil engineering) designs. An important aspect of the analysis is the deflection that is associated with the onset of failure. The following paragraphs speculate on an implication to fracturing and transmissivity.

The original voussoir beam work by Evans in 1941 was published in the Transactions of the Institution of Mining and Metallurgy, as was the update by Beer and Meek in 1982. From the 1985 first edition of the standard text "Rock Mechanics for Underground Mining" by Brady and Brown has included a full chapter dedicated to the approach. The more recent improvements have been published in the International Journal of Rock Mechanics and Mining Sciences.

There is a need to consider the failure state of beams where the deflection is limited to a set amount. There may be situations where a stress-based analysis indicates a beam may fail, but such failure is prevented by the restraint offered by the bulking zone. There are major implications of this in the context of fracturing – if the beam fails it can be assumed to be fractured and have high vertical transmissivity, whereas if the beam is thick enough, the required deflection is prevented, the unit may become constrained with no change in transmissivity (in fact transmissivity may be decreased due to increased stresses compressing the pore space).

As outlined in the FMEA report, there was no conclusive outcome of the considerations about potential water loss to the mine. The SGPL position is based on the mechanics of beam deflection and failure such that there is inadequate room for the Bulgo Sandstone beams to have deflected enough to cause through-going failure. Without such failure, there would be no transmissive fractures and hence no significant change in vertical transmissivity.

Figure 34 outlines a conceptual model for rock breakage and spanning in the Bulgo Sandstone above longwalls. An important aspect of this model is that a voussoir beam may “sit down” on top of the goaf material before it reaches the deflection that is associated with fracturing. This means that a voussoir beam analysis needs to consider both the stability (onset of compressive failure) and the available deflection when assessing the possibility onset of collapse.

Figure 35 presents an analysis of the stability and deflection of various thickness of Bulgo Sandstone. For a 300m wide panel, a 50m thick units is required and compressive failure of the beam can only develop if the deflections are in excess of 1800mm. One aspect of this model is that it incorporates both seam thickness (bulking reduces the available deflections) and panel width.

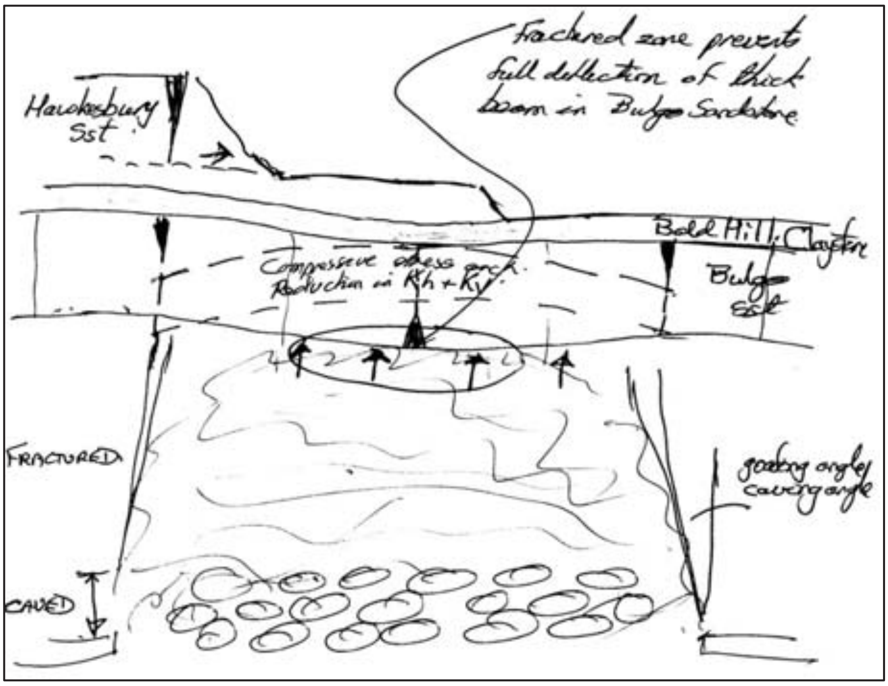


Figure 34 Collapse of a voussoir beam in the Bulgo Sandstone is prevented by bulking in the underlying goaf.

The model may be considered too simplistic until reference is made to the recent ACARP research conducted by CSIRO[23]. Their extensometry data from Westcliff colliery reveals a 56m thick unit at the top of the Bulgo Sandstone (G5) that has deflected approximately 700mm (Figure 36), which is reasonably consistent with Figure 35.

[23] Shen, B., Alehossien, H., Poulsen,B, and Waddington,A. 2010.Subsidence control using coal washery waste. ACARP C 16023.

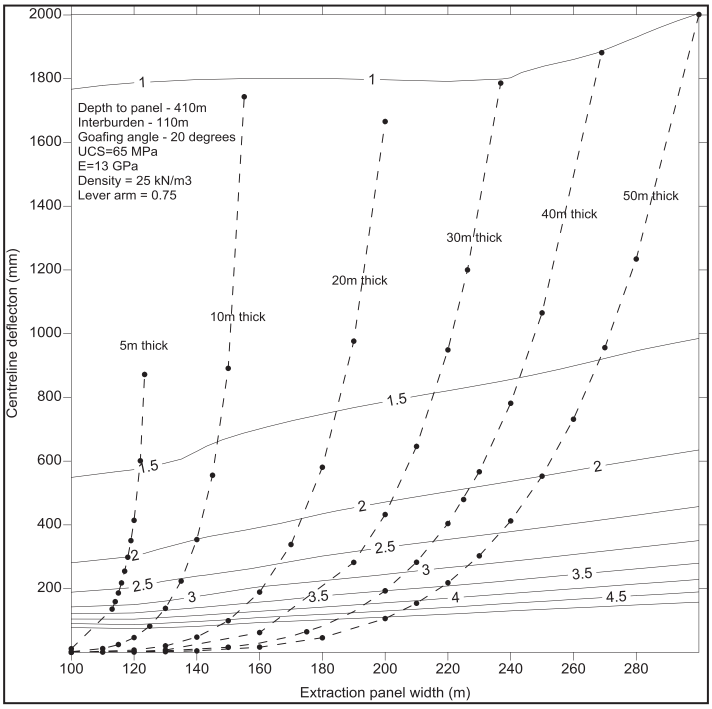


Figure 35 Stability(lines) and deflection (dashes) for voussoir beams developed within the Bulgo Sandstone

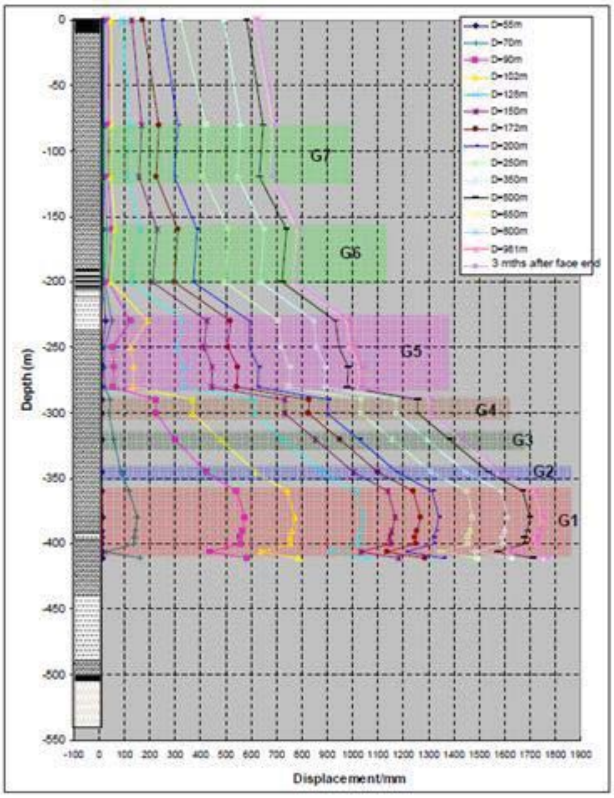


Figure 36 Westcliff extensometer data

In summary, there is a body of rock mechanics theory, supported by monitoring data, which suggests that cracking to the surface will not develop and hence no connective cracking.

5.9.3 Other approaches

An alternative approach to assessing water inflow has been investigated using numerical models calibrated to empirical relationships from the British Coalfield[24]. For the postulated maximum vertical subsidence of 2.4-3.5m at 500m depth, Figure 37 indicates no water inflow into the mine workings.

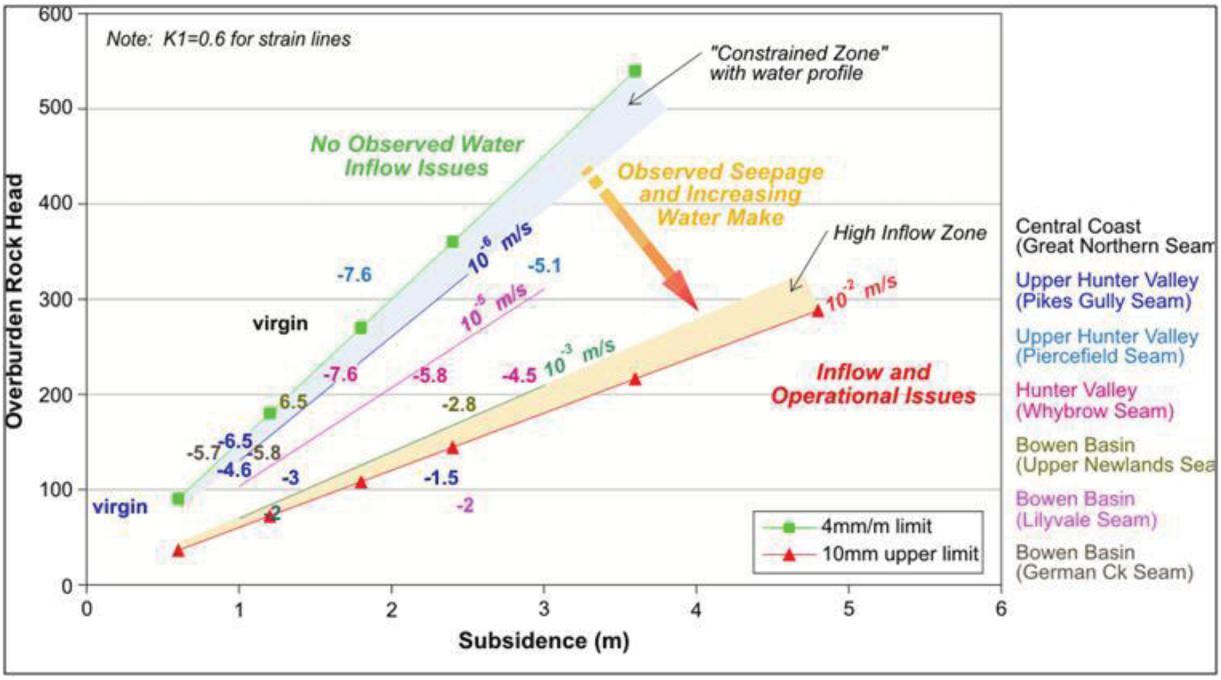


Figure 37 Average overburden conductivity characteristics relative to subsidence and depth criteria (reproduced from Gale, 2008)

6 SUBSIDENCE RISK MANAGEMENT

Subsidence risks exist because the reliability of the predictions is uncertain and because the consequences of under-predictions may be unacceptable. Section 4 and Appendix B highlight the uncertainties in subsidence prediction. An appropriate approach to manage the range of risks is to apply the standard hierarchy of risk controls of elimination, substitution, engineering and administration.

On a local scale, prediction uncertainties can be eliminated by not extracting under or near the surface feature. The prediction uncertainties can be reduced by either substituting a mine layout with narrow panels and wide pillars such that there is confidence that the Bulgo Sandstone remains intact, or to have very wide panels so that the Bulgo Sandstone is definitely broken. The latter reduces the prediction uncertainties but could introduce a wide range of consequences that are deemed unacceptable.

[24] Gale, W. 2008. ACARP Report C13013: Aquifer Inflow Prediction and Water Barrier Design for Longwall Panels

6.1 ELIMINATION AS A CONTROL

6.1.1 Mount Ousley Road

Mount Ousley Road is the major road access between Wollongong and the South Coast and Sydney. In the some parts of the area of interest, Mount Ousley Road lies directly above a chain pillar in the Balgownie Seam (Figure 38). In terms of the Bulli Seam, the road lies partly above a wide extraction area and partly above first working pillars.

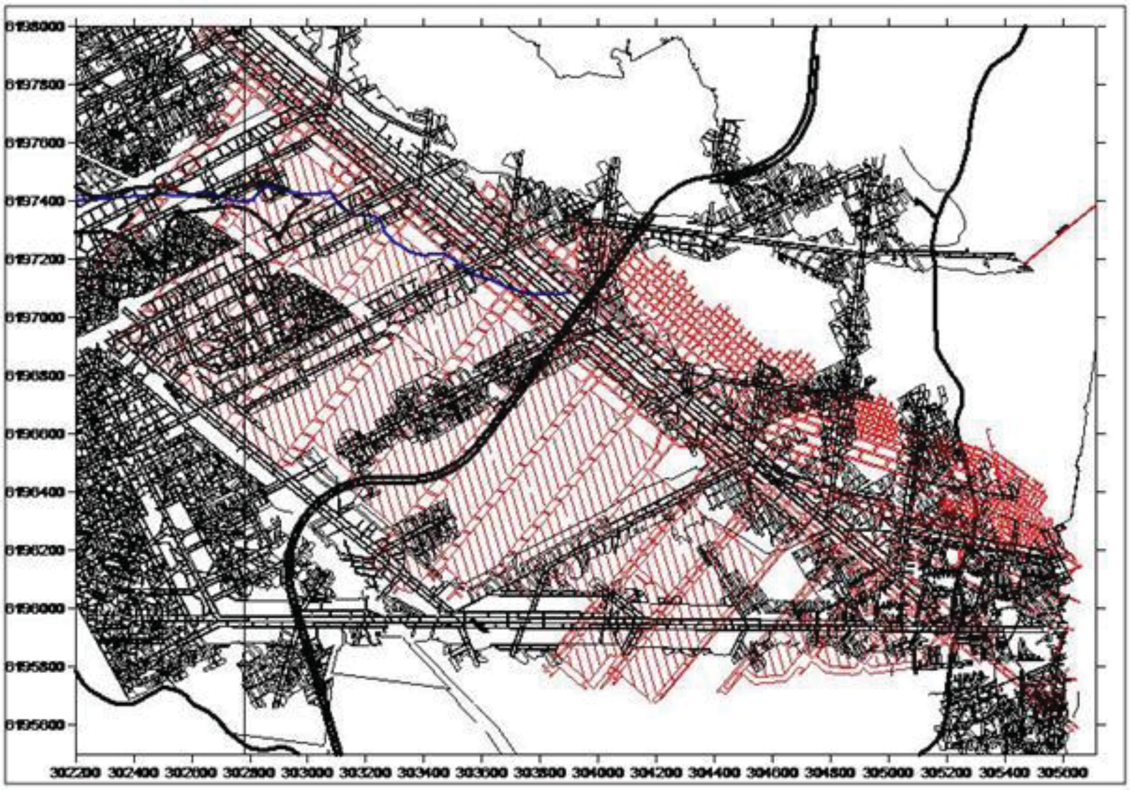


Figure 38 Mount Ousley Road and existing Bulli and Balgownie Seam workings

The Bulli and Balgownie extraction will have caused the maximum sag of the Bulgo Sandstone and it assessed that there is no subsidence potential left in these 2 seams. This is particularly the case for Faces 6 and 7 adjacent to the road (see later). This means that should subsidence develop some distance from the road, it cannot run through the subsided ground. Because of the pre-broken nature of the overburden, any Wongawilli longwall extraction directly under the road (even at comparatively narrow widths) will produce large vertical subsidence, and high localised tilts and strains. One rejected mining layout considered longwall extraction under the road (see Appendix A).

A longwall elimination zone under and within 100m of the road is recommended where the road is above Bulli Seam extraction (Figure 39). For areas where the standing pillars in the Bulli Seam are indicated, engineering controls based on monitoring should be used to locate the finish line of the longwall panels.

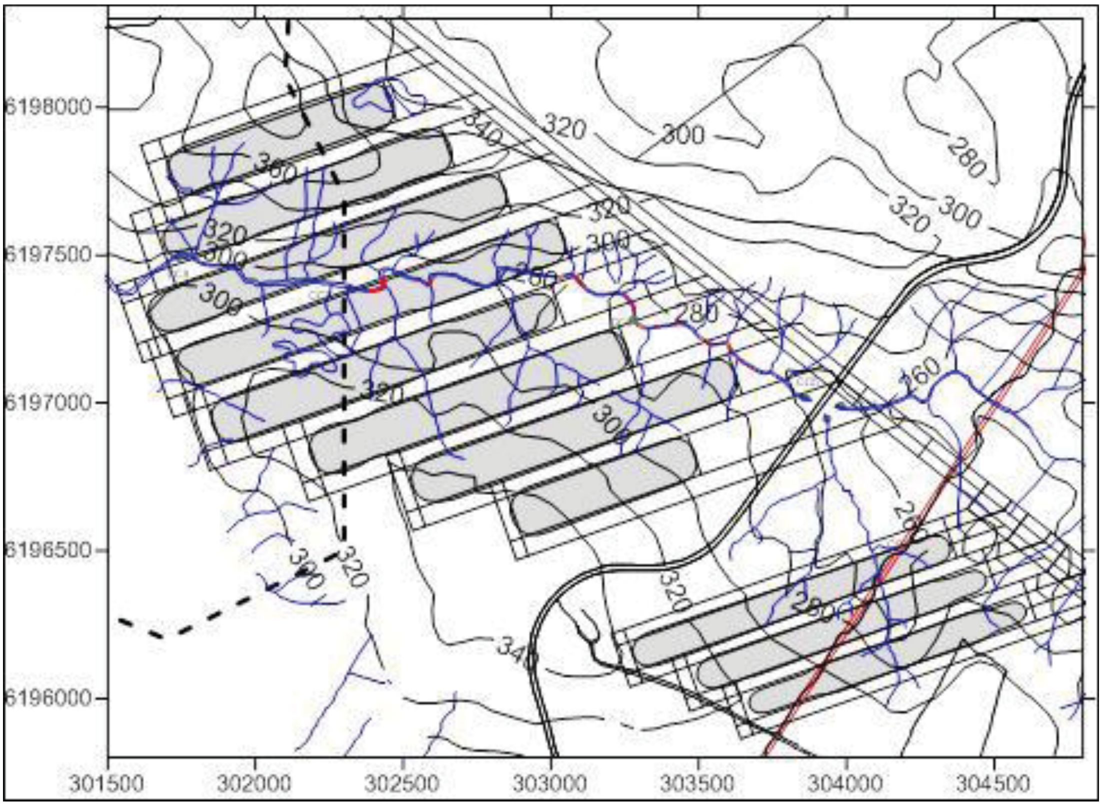


Figure 39 Extent of vertical subsidence (20mm) for Wongawilli East panels with respect to Mount Ousley Road & Cataract Creek and depth of cover

6.1.2 Illawarra Escarpment

Based on the understanding of coal quality, the eastern end of the proposed extraction footprint is located 500m from the crest of the Illawarra Escarpment as defined as 340m ASL (Figure 40). The depth of cover to the Wongawilli Seam at this location is 260m, such that the angle of draw is 70°.

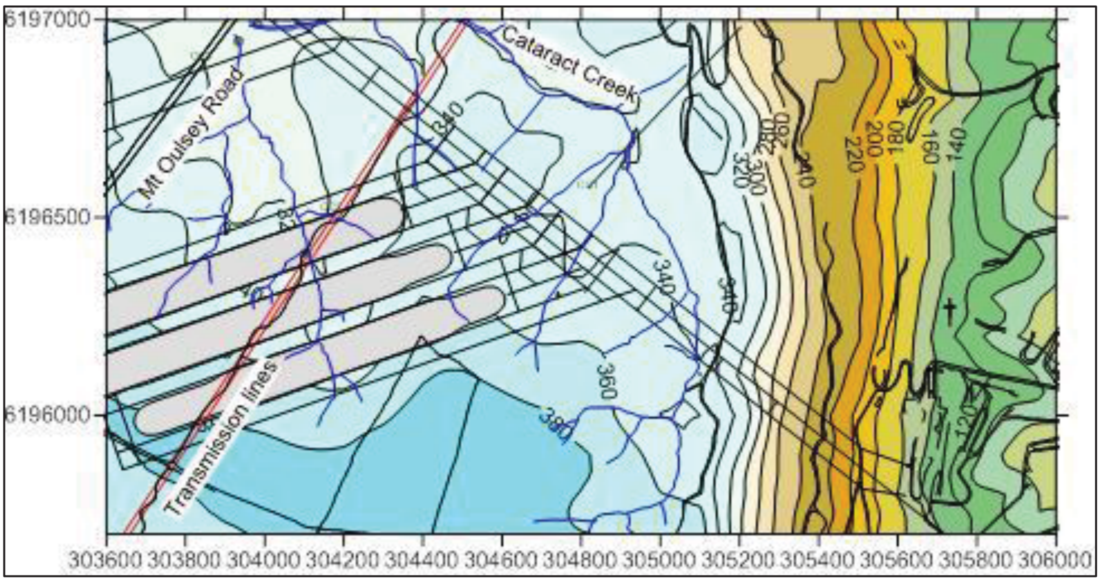


Figure 40 Extent of vertical subsidence (20mm) in relation to escarpment

By reference to Figure 32, and anticipating the vertical subsidence predictions (see Section 6.3) the maximum expected horizontal movement at the crest of the escarpment would be in the order of 35mm. Better information is available from the monitoring of the 500 series panels where the maximum vertical subsidence was in the order of 250mm. In this case, at 700m distance, the horizontal movements were measured to be 20mm, and strains were less than 0.2 millistrain (Figure 41). Figure 41 highlights the difference between the horizontal movements with nominally 250mm subsidence (500 series and Station Y) and 1000mm (304 panel).

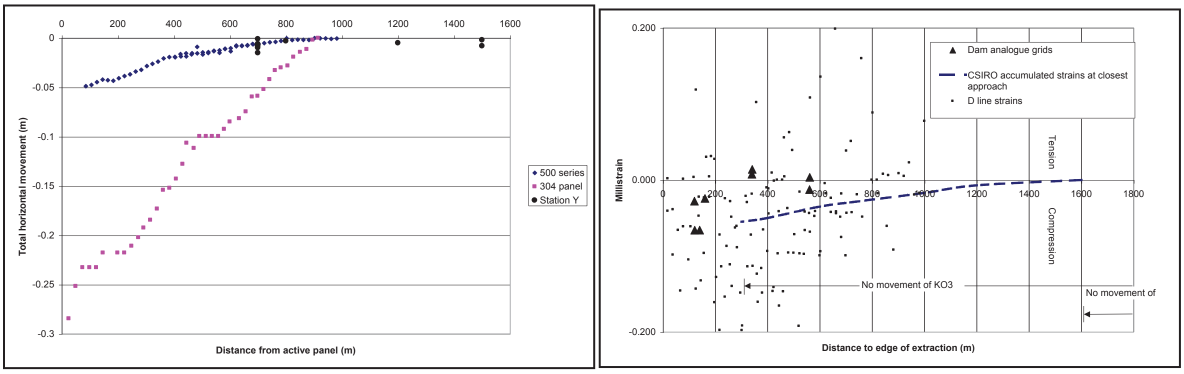


Figure 41 Horizontal movements associated with low levels of vertical subsidence in the 500 series panels

6.1.3 Cataract Reservoir

For the western area, the longwall extraction of Wongawilli Seam coal under the 500 series longwalls directly under the stored waters would result in subsidence levels well beyond the current precedents. No such extraction is proposed for the western area.

Based on earlier dealings with the NSW Dams Safety Committee during the mining of the 500 series longwalls, a 1km distance from the spillway was set as a threshold for more detailed studies. Recently, this has been extended to 1.5km. The sequencing of the longwalls in the western area may not allow progressive collection of information so it is possible that the mine plan will need to be altered in this area (Figure 42).

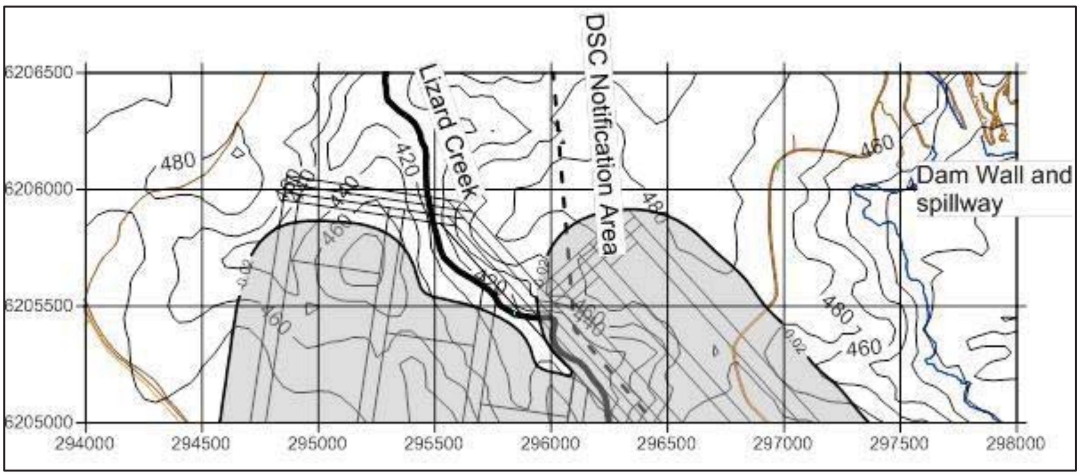


Figure 42 Extent of vertical subsidence (200mm) for Wongawilli West area

6.1.4 Fourth order Lizard Creek

Reflecting community concerns about mining near and under rivers, at the planning stage wide longwall extraction should be eliminated from within a 200m offset from the centreline of each longwall panel to the centreline of the Lizard Creek. As will be outlined below, substitution with narrow layouts would be an alternative strategy. The suitability of the 200m offset should be assessed as monitoring data from Wongawilli East is examined. The information can then be used to refine the layout and adjust the mine plan.

6.2 SUBSTITUTION AS A CONTROL

The key to a substitution strategy is to reduce vertical subsidence. The current “state of the art” of the prediction of deformations requires a prediction of the vertical movements. Tilt is the first derivative of the vertical deformations and curvature is the second derivative. Strain can be predicted by manipulating the curvature information.

Longwalls in the Southern Coalfield have gradually increased in width such that the longwall face widths at Appin, Westcliff and Dendrobium are currently in the order of 300m. Metropolitan Colliery utilises narrower panels (maximum of 163m). The maximum subsidence above these layouts is in the order of 1.2m to 1.4m, mainly reflecting the decision to have yielding chain pillars in order to maximise coal recovery.

The longwalling under Cataract Reservoir (Seedsman and Ker, op cit) substituted yielding pillars with large, very stable pillars and also used relatively narrow longwall panels. For the longwall panels closer the dam wall (LW514 onwards), the layout was based on 150m wide panels and 65m wide pillars. The maximum subsidence was 240mm and this involved 180mm above the chain pillars and 60mm of sag above the extraction. A comparison with Metropolitan, where the panel widths are similar, highlights the impact wide pillars can have on surface subsidence.

The use of a layout with comparatively wide chain pillars provides a way of managing some of the subsidence risks at Wongawilli East. The elimination of the option of longwalling under Mount Ousley Road, together with operational considerations about panel alignment, requires a south-westerly orientation of the panels. With this orientation, the economic demands for longer panels require extraction within the DSC Notification Area and under the full supply level of Cataract Reservoir.

The DSC approved the 150m/65m panel and pillar layout and hence are familiar with the design concepts applied. The Wongawilli East area is shallower than the LW514 area and the application of the design to the deeper Wongawilli Seam is appropriate. A step-change in the geometry would require several years of monitoring data and analysis. A wide chain pillar layout also provides a way to consider extraction of coal under Cataract Creek in the Wongawilli East area.

6.3 ENGINEERING AND ADMINISTRATIVE CONTROLS

For longwalls, the principal engineering control is the ability to change the location of the start and finish lines of each panel. Administrative controls are incorporated in the various management plans required by the regulator.

As required for all longwall extraction, there will be a need to closely monitor the subsidence that develops as the walls are extracted and use this data to refine the controls.

7 SUBSIDENCE WITHIN THE WONGAWILLI EAST FOOTPRINT

This section presents a subsidence prediction and visualisation based on a large degree of judgement in the absence of adequate calibration/validation data. It is presented as an example of how subsidence management can be implemented and to provide subsidence parameters for environmental assessments to be conducted by others.

7.1 ELIMINATION AND SUBSTITUTION CONTROLS

The longwall footprint has been defined within an area more than 500m from the Illawarra Escarpment. It is assessed that the Bulli goafs and small Bulli pillars below Mount Ousley Road are fully collapsed and this means that the risk of a subsidence run under the road is eliminated. There is no longwall mining in the Wongawilli seam proposed within at least 100m of Mount Ousley Road.

Narrow longwalls are proposed for the Wongawilli Seam to allow longwall extraction within the Notification Area where there has been no secondary extraction of either the Bulli or Balgownie Seams. A consequence of this decision is that low levels of subsidence will develop in other areas where there are no Balgownie longwalls and large Bulli pillars.

7.2 LAYOUT OPTION

The layout under investigation involves 100m wide panels and 45m pillars (Area 1), and then 150m wide panels with 65m pillars inside the footprint defined by the elimination controls (Area 2).

Based on previous dealings with the NSW Dams Safety Committee, their starting position is based on the Reynolds Recommendations, which were never formally adopted by the NSW Government. These guidelines involved a panel width no more than 1/3 depth and a pillar width no less than 1/5 depth (or more than 15 times the seam thickness). At Bellambi West, and directly under the stored water, the panels were increased to 150m width and the pillars increased in width to 65m to maintain the same factor of safety (approximately 5.2). For this arrangement the minimum depth of cover was 310m to 410m.

For the Wongawilli East area, the depths to the Wongawilli Seam area are 300m to 340m, the proposed panels are 150 wide and the pillars are 60m wide. In the following calculations, the gateroad height is assumed to be 3.0m, with sensitivities determined at 3.2m or 3.5m. Table 6 shows that the factors of safety against pillar collapse are in the range of 3.3 to 5.4 – it is noted that the width /height ratios are well in excess of 6.0.

As a frame of reference, long term stability is conventionally defined as a factor of safety of 2.11 for the squat equation if the pillar stresses are known with a high level of confidence. A threshold value for chain pillars and chain pillar loading has not been established. For the Bellambi West mining directly under the stored water values of 5.2 were accepted. It is assessed that the values in Table 6 are suitable for the mining which is not under the stored water.

With regards to the pillar loadings in the overlying seams, it is not possible to accurately model the complex and possibly temporal changes in pillars stresses in the Bulli and Balgownie Seams. This is one of the reasons why we have avoided making specific detailed subsidence predictions and adopted the risk management approach of elimination in key areas.

Table 6 Pillar stability calculations

Goaf angle	21					
Loading factor	2					
Depth (m)	310			340		
Pillar stress (MPa)	20.6			23.2		
Height (m)	3.0	3.2	3.5	3.0	3.2	3.5
Width/height ratio	20	18.7	17.1	20	18.7	17.1
Squat effective (MPa)	111.4	95.3	77	111.4	95.3	77
Linear, minimum width (MPa)	48.6	45.8	42.3	48.6	45.8	42.3
Factor of safety - squat	5.4	4.6	3.7	4.8	4.1	3.3
Factor of safety - linear	2.4	2.2	2.1	2.1	2.0	1.8

7.3 SUBSIDENCE VISUALISATION

Subsidence deformations based on the predictions in Section 5.5.1 are presented below. There is a base case (Figure 43) and an upper bound (Figure 44) based on whether the Balgownie longwalls have disrupted the spanning capacity of the Bulgo Sandstone above large Bulli Seam pillars. The statistical distributions of vertical movement, tilts and strains are shown graphically in Figure 45 for the data base where the vertical subsidence is clipped to values more than 20mm. The maximum tilts are 25 mm/m and the range of strains is from -10 mm/m to 6mm/m. A crossline (Figure 46) is also presented to assist in interpretation.

7.4 OTHER DEFORMATIONS

For the 150m panel/65m pillar layout used at Bellambi West, the vertical subsidence was measured to be in the order of 200mm-250mm with no valley closure across the arms of Cataract reservoir. On this basis, no “regular” valley closure and associated upsidence has been predicted for Wongawilli East.

The prediction of closure and upsidence in Cataract Creek relies on the prediction of vertical subsidence shown in Figures 43 and 44. The 1200mm of subsidence above longwalls 5 and 6 (Figure 44) is based on the worse case assumption that the Bulli pillars will collapse. This is an extreme assumption, because the subsidence data indicates that they did not collapse when undermined by the Balgownie longwalls.

Given the distance from Cataract Creek and the low levels of subsidence, a value of 50mm of closure is an appropriate value to use to identify any hazards applying to this creek.

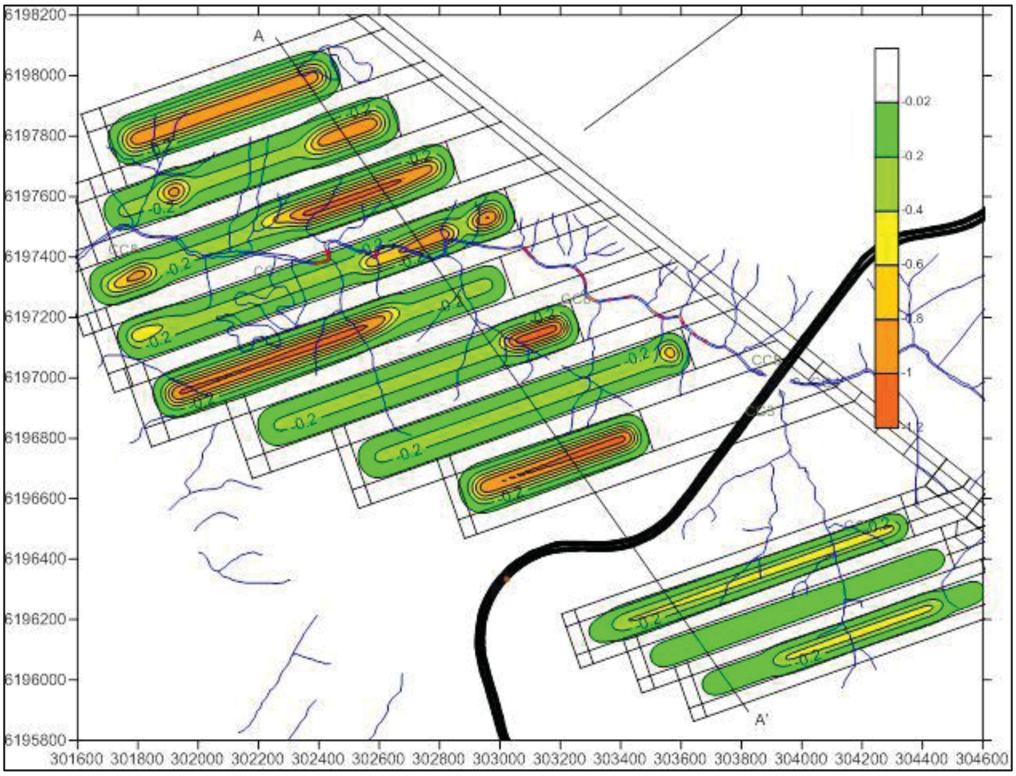


Figure 43 Predicted vertical subsidence above Wongawilli East option (base case)

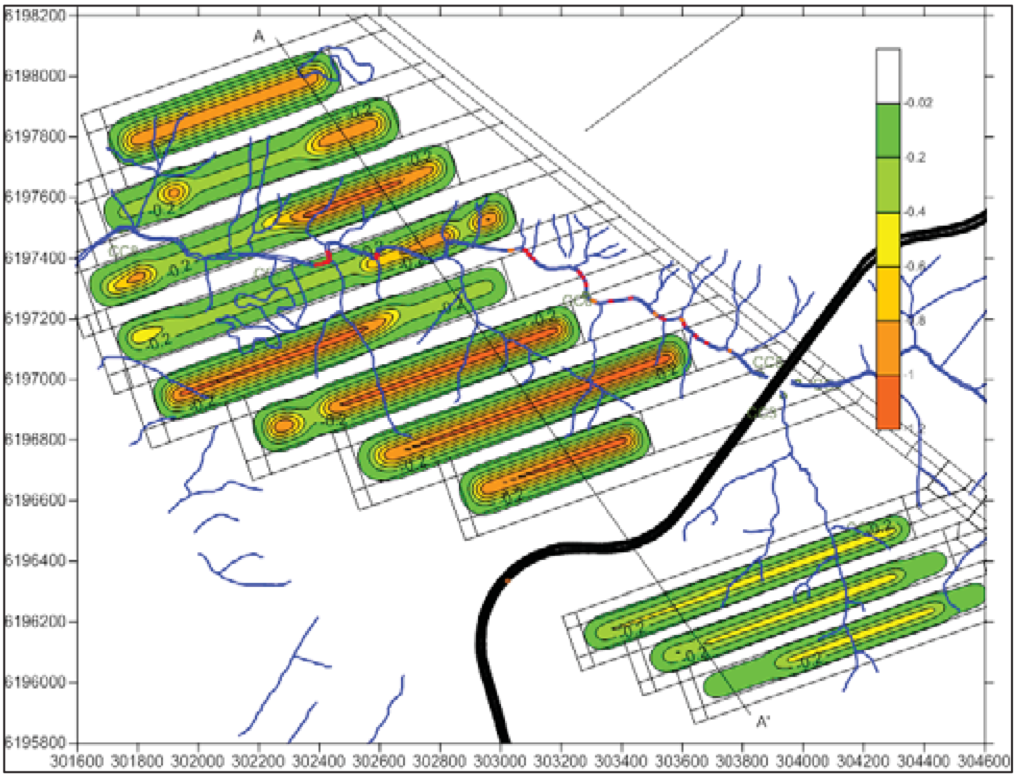


Figure 44 Predicted vertical subsidence above Wongawilli East option (upper bound)

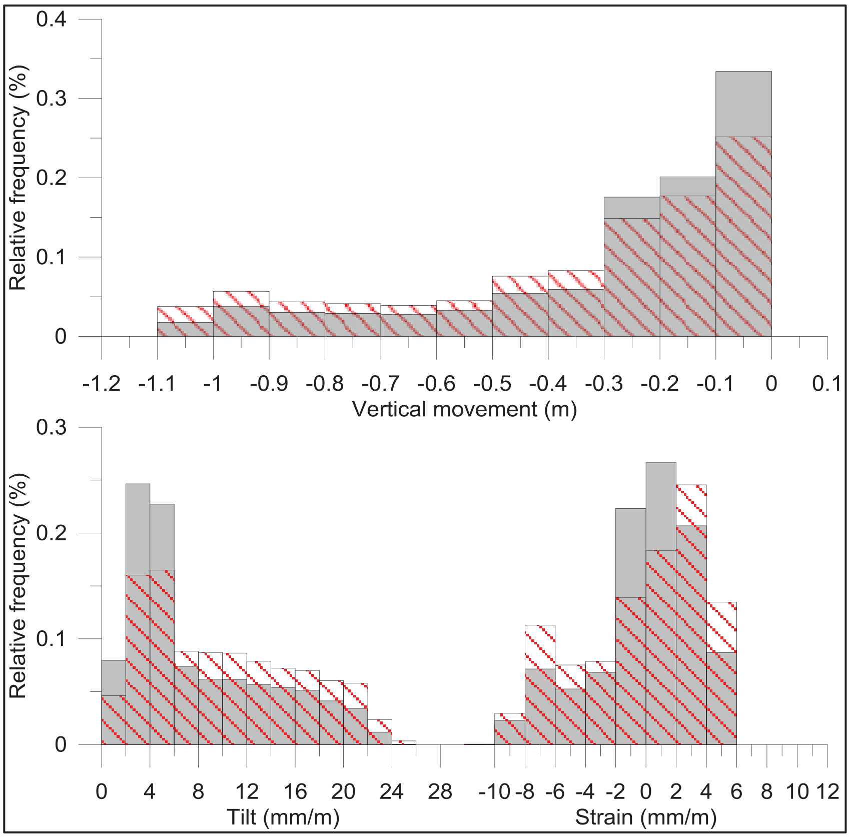


Figure 45 Histogram of subsidence parameters when vertical subsidence is greater than 20mm for Wongawilli East (grey-base case, hatching – upper bound)

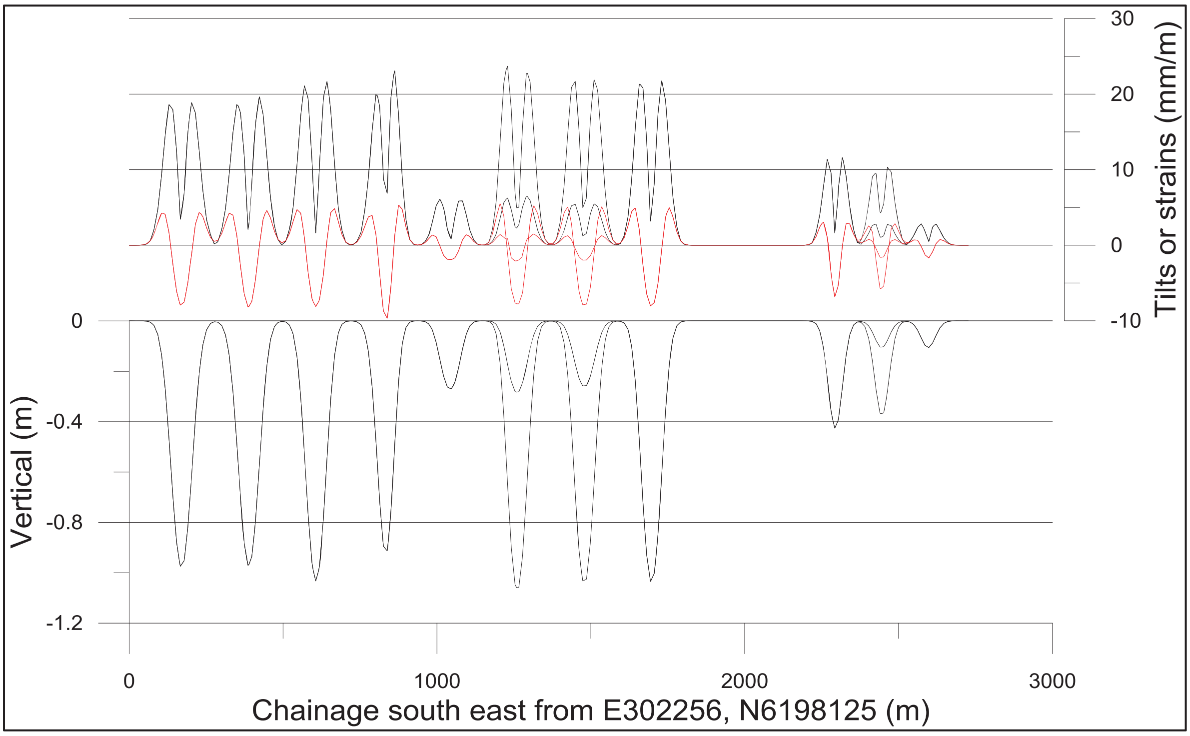


Figure 46 Subsidence developed along line AA' shown in Figure 43

7.5 SITES OF SPECIAL SIGNIFICANCE

7.5.1 Mount Ousley Road

As mentioned earlier, Mount Ousley Road is positioned on a chain pillar between two Balgownie longwall panels (Faces 6 and 7).

Both these centrelines show subsidence in excess of 3ft after the extraction of the Balgownie Seam. Given the seam thickness was in the order of 4ft, there is a very high degree of confidence that the overburden above both these faces has fully collapsed. A corollary of this is that the collapsed zone provides a "barrier" to any lateral progression of subsidence that may be induced by any mechanism in the immediate vicinity. Therefore, the prediction is that no significant deformations will be imposed on Mount Ousley Road.

Recognising the distance from the longwalls and its location, the Picton Road bridge over Mount Ousley Road is not exposed to mining-induced movements. The bridge is approximately 840m distant from the closest longwall extraction and the bridge itself is located on the southern side of a valley and does not span the valley.

7.5.2 Cataract Creek

Where Cataract Creek crosses LW8, the mine plan shows pillar extraction in the Bulli Seam and some longwall extraction in the Balgownie Seam (Figure 10). Based on monitoring recently obtained from LW4, it should be assumed that the vertical subsidence to be induced by the Wongawilli Seam extraction will be in the order of 1.2m. It may be necessary to review the risk substitution strategy currently adopted in this location (elimination or walls narrower than 150m).

Above LW9, there has been no pillar extraction of the Bulli and Balgownie Seam under the creek and in this area the proposed narrow longwalls and wide chain pillars in the Wongawilli seam should not destabilise the Bulli pillars. Subsidence at the creek above LW9 is estimated to be in the order of 200mm.

8 SUBSIDENCE WITHIN THE WONGAWILLI WEST FOOTPRINT

8.1 ELIMINATION AND SUBSTITUTION CONTROLS

No longwall extraction is planned within 1 km from the spillway and dam wall of Cataract Reservoir or directly under the primary (named) channels of 3rd creeks and all 4th order creeks. A longwall is proposed under an un-named 3rd order tributary of Lizard Creek

The possibility of narrowing the extraction under the creeks was examined. The geotechnical limitations on where to place the gateroads meant that the option resulted in panels being uneconomic.

8.2 LAYOUT OPTION

The proposed layout locates the main headings in close proximity and aligned with Lizard Creek and then to extract wide longwalls to the south with a parallel and staggered layout (Figure 47). Panels to the north are non-parallel to the Bulli Seam longwalls.

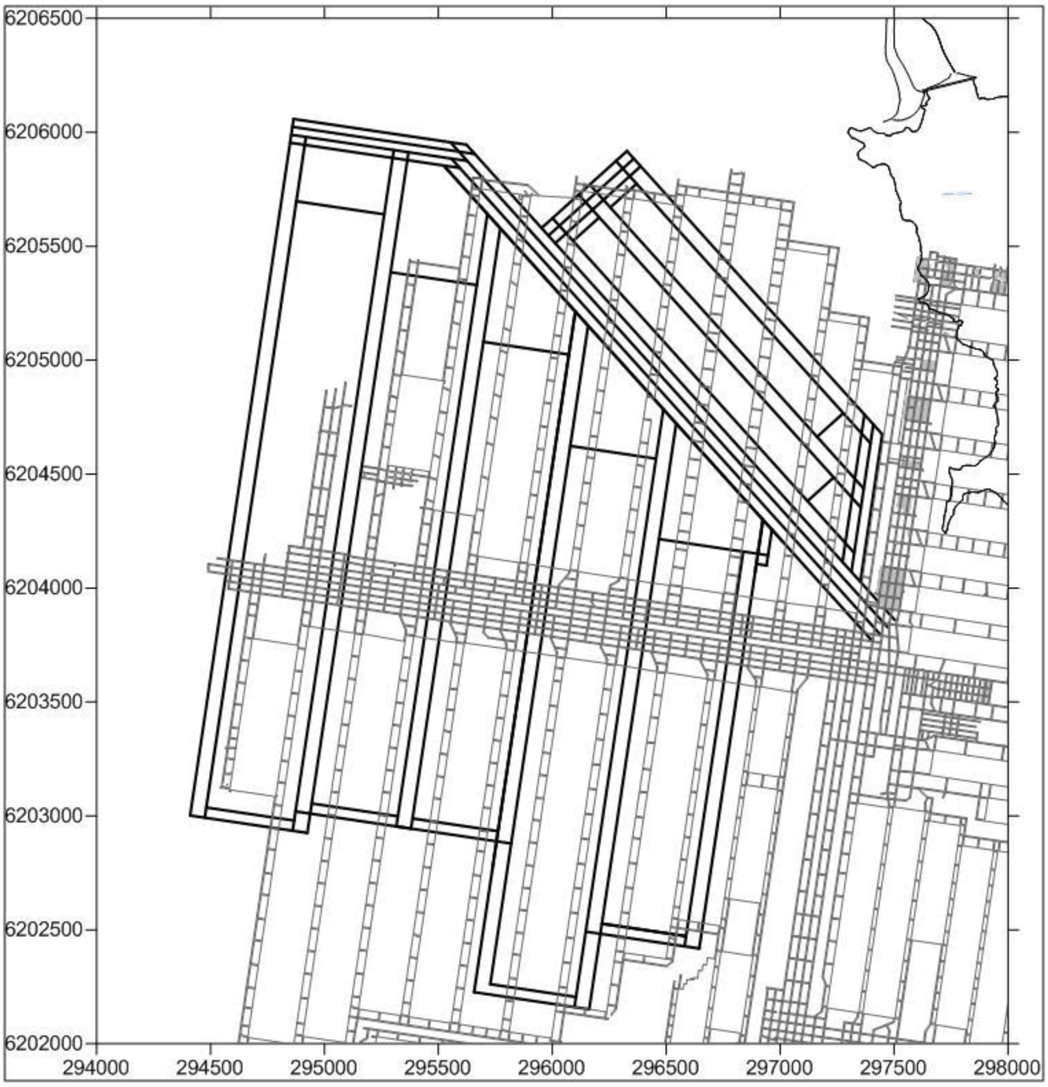


Figure 47 Bulli and Wongawilli Seam layout for Wongawilli West

8.1 SUBSIDENCE VISUALISATION

A visualisation of the subsidence bowls associated with just the Wongawilli Seam extraction is shown in Figure 48, and the combination of Bulli and Wongawilli Seams in Figure 49. Frequency histograms of vertical movement and tilts after the extraction of both seams are presented in Figure 50.

.

The input parameters for the influence function visualisation of subsidence are:

- Vertical subsidence according to Table 5.

- The inflexion point is located at the goaf edge – increases the width of the bowls.
- Influence angle of 66.6° (tanB=2.31) – wider bowls but lower maximum tilts.
- For just the Wongawilli Seam the strain coefficient was set at 0.35. Recent discussions with the authors of the SDPS program have revealed that this value is possibly too high – the result could be that the strains will be over-estimated.
- Strains were not calculated for the combined seams.
- SDPS produced an unexplained anomaly above LW5 which has been addressed.

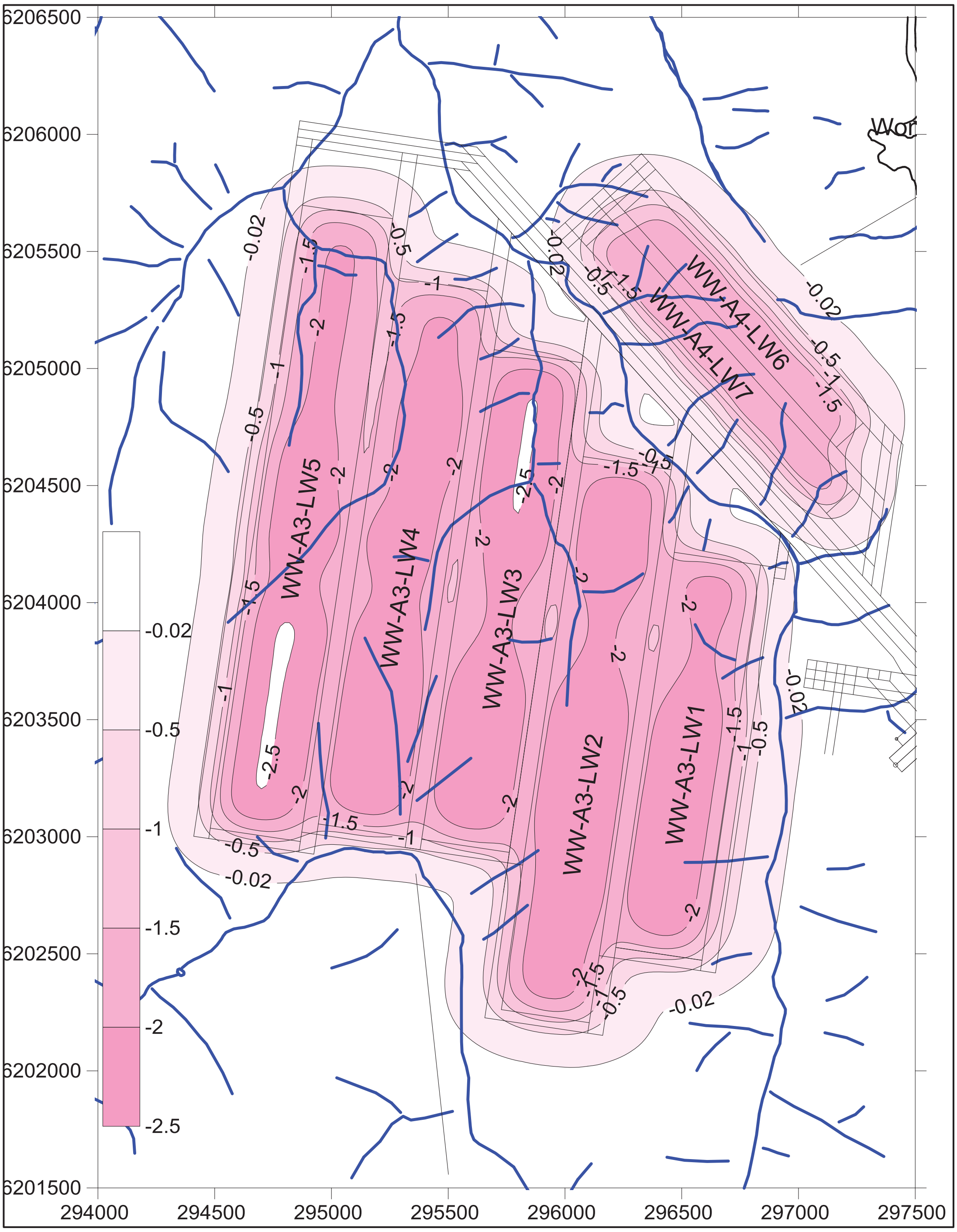


Figure 48 Predicted vertical subsidence above the base-case Wongawilli West option

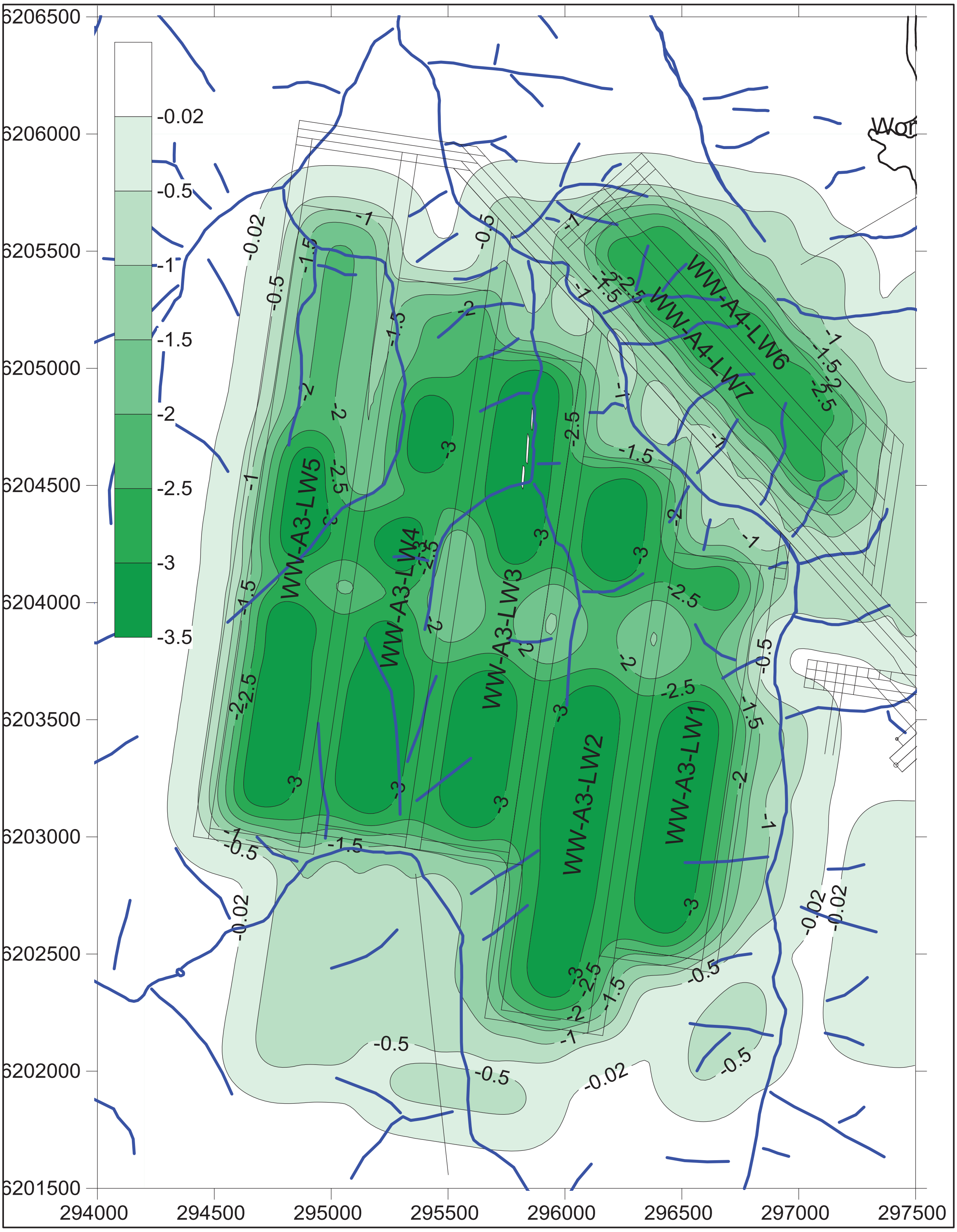


Figure 49 Combined Bulli and Wongawilli vertical subsidence for Wongawilli West

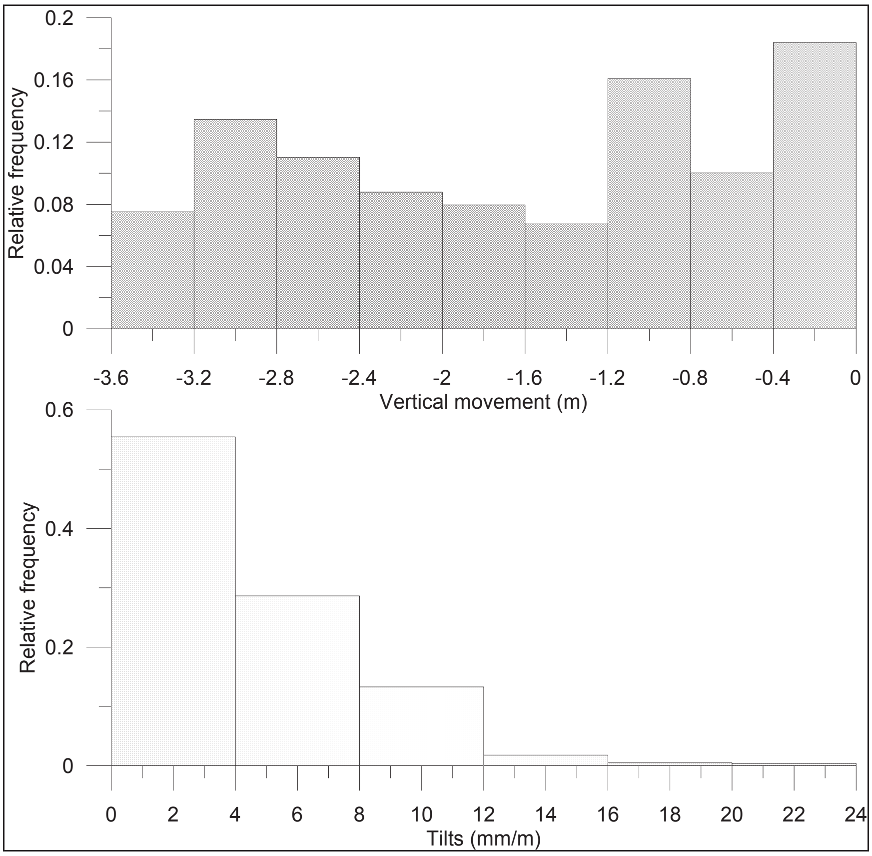


Figure 50 Statistics of vertical movements and tilts induced by both seams

8.2 OTHER DEFORMATIONS

The available prediction method for closure and upsidence is based on single seam extraction with wide panels and small pillars and does not provide a system for dealing with multiple seams – such a layout was not envisaged when the system was developed. Detailed reference to the available method would be misleading and give any prediction more credence than can be justified. It is noted that subsidence associated with the proposed mining will be less adverse than that already imposed on the Lizard Creek by the Bulli extraction.

Because of the decision to eliminate longwall extraction under the primary (named) 3rd order channels of creeks, the systematic strains in these creeks can only be tensile. Because of block rotations above the longwall extraction panels there may be some compressive strains transferred to the creeks. Valley closures of about 100mm and upsidence of about 60mm should be anticipated. The comment by the FMECA review was that it would be good practice to double these estimates in the context of an impact risk assessment.

8.3 SITES OF SPECIAL SIGNIFICANCE

Longwall extraction has been eliminated from the area of the dam wall. The two panels in the north east are within the expanded DSC Notification Area – it is noted that narrow longwalls have been proposed in response to the substitution strategy.

APPENDICES

A. REJECTED MINE LAYOUTS
B. FMECA

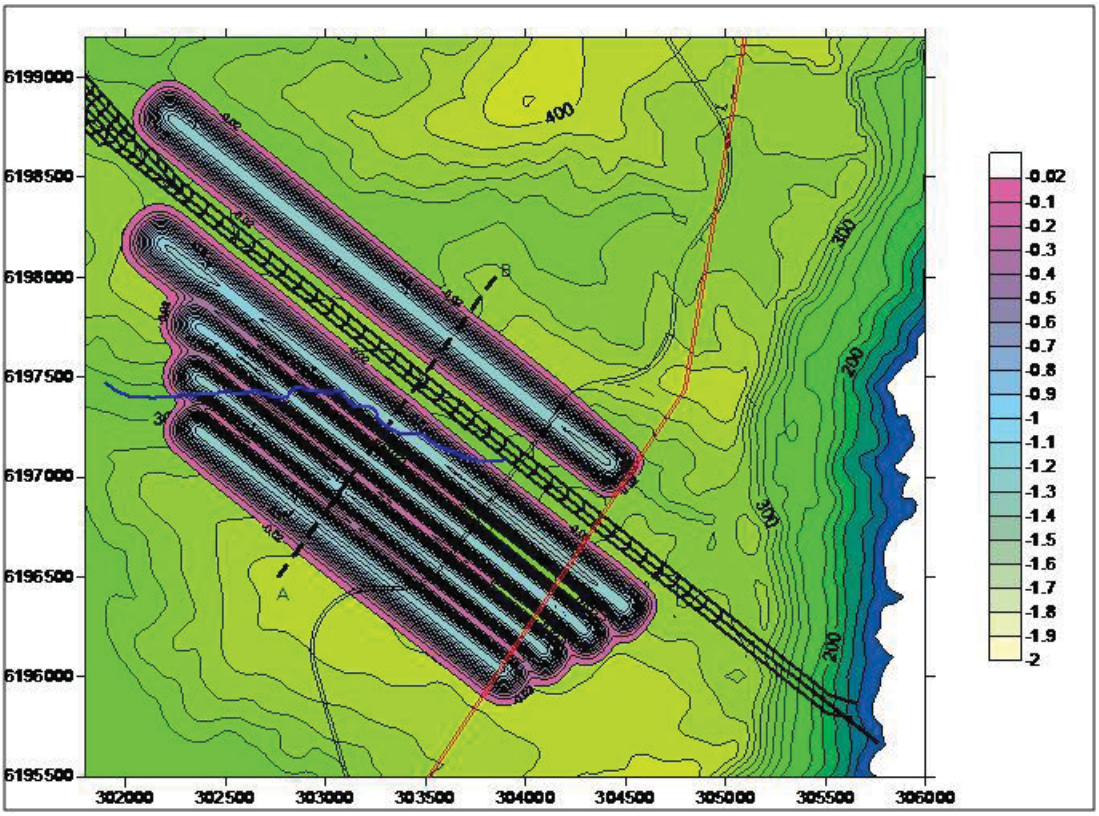
APPENDIX A

REJECTED OPTIONS

Wongawilli East

This option involved long panels aligned parallel to the Wonga Mains. Both wide (250m) and narrow (150m) options were examined. This option had high coal recoveries and high rates of investment return. Predicted strains under Mount Ousley Road were in the order of 8-10 mm/m and discussions with RTA indicate a very strong reluctance to consider this.

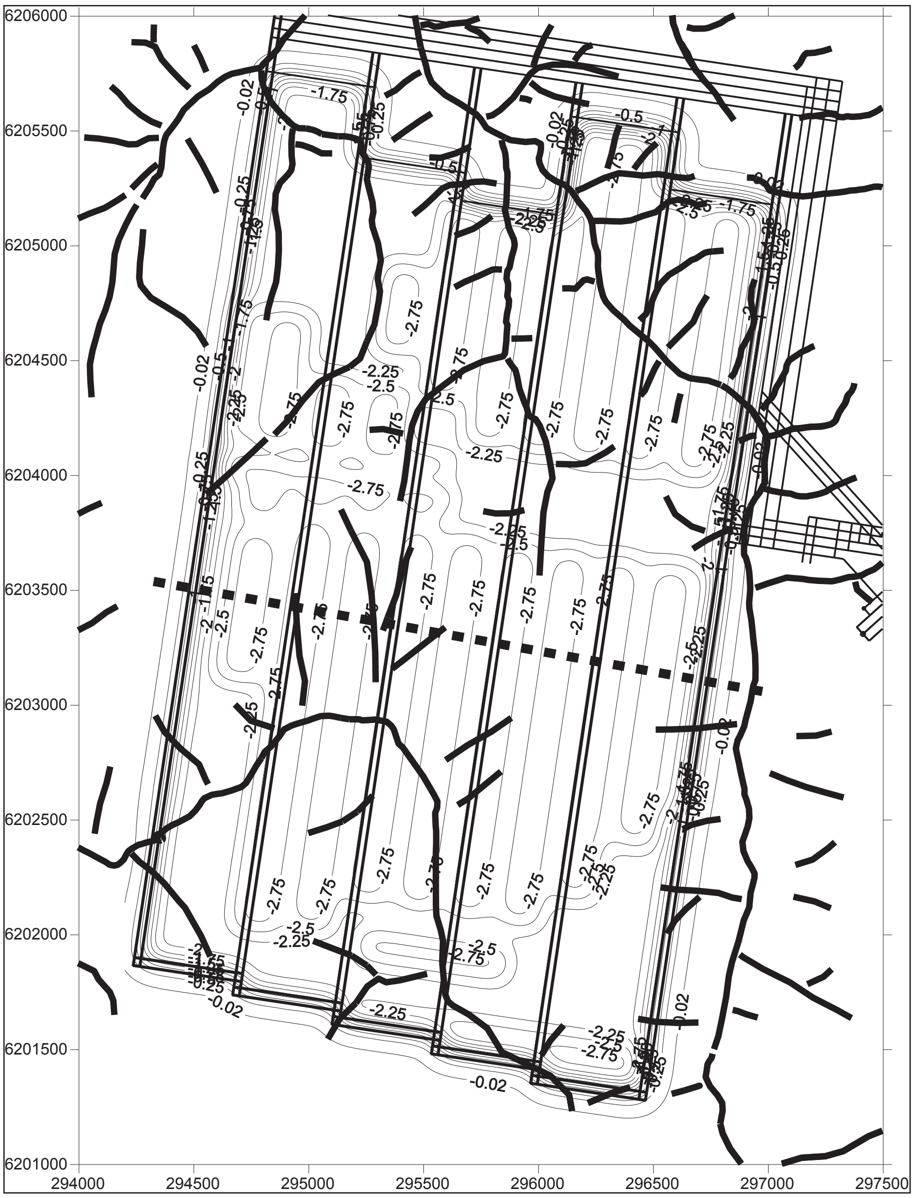
Elimination of longwall extraction under Mount Ousley Road was adopted and layouts aligned north east investigated



Vertical subsidence patterns in the Wongawilli East area for the rejected layout

Wongawilli West

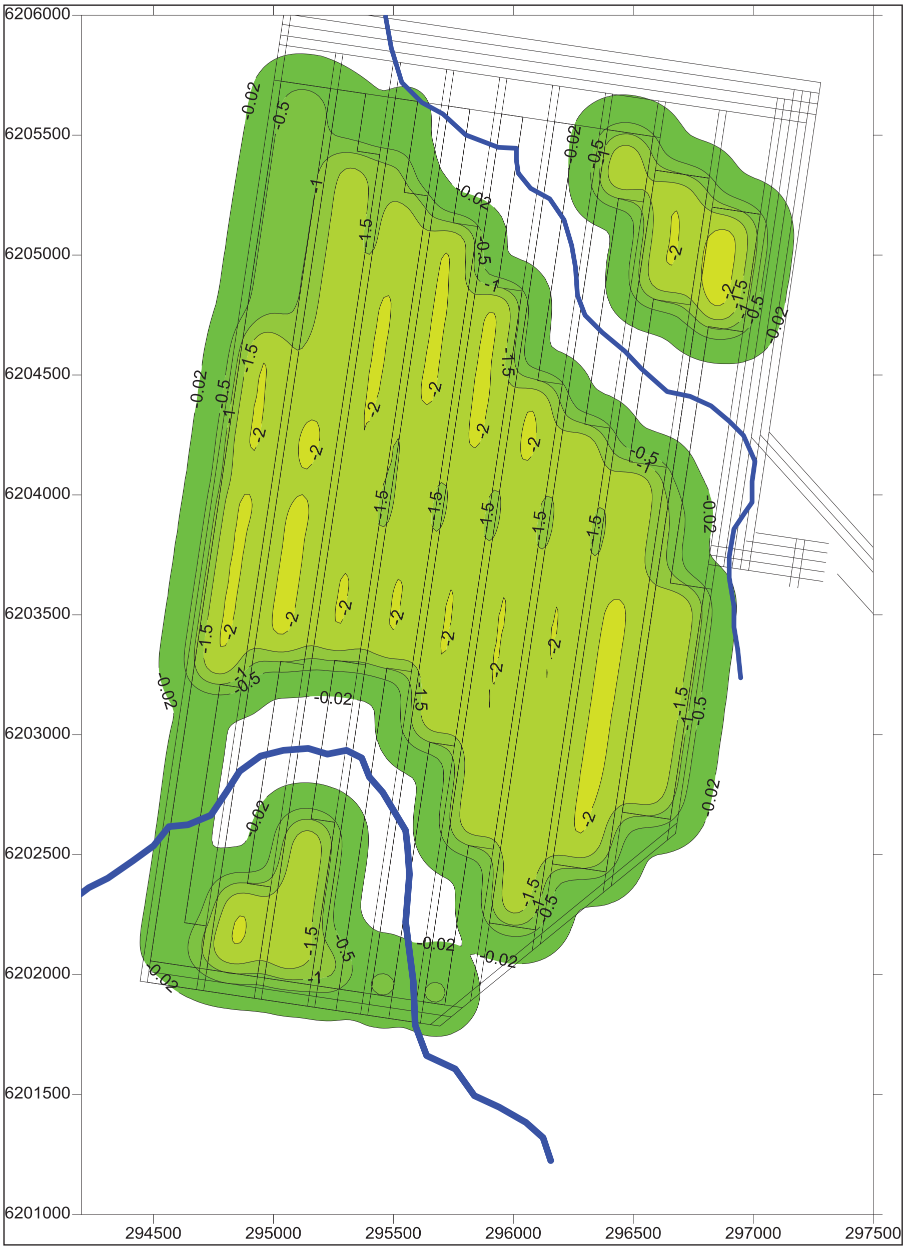
This option involved wide panels taking all of the assessable coal outside of 4th order streams. The layout was rejected due to hazards of up to 3m of subsidence under the 3rd order creeks – Lizard/Wollandoola Creeks.



Vertical subsidence patterns for the rejected wide longwall layout in Wongawilli West (subsidence after both seams)

<u>Wongawilli West</u>

This utilised a staggered layout with panel widths in the Wongawill Seam set by the Bulli Seam layout, and narrowing these even more to pass under the 3rd order creeks. The layout was assessed to be uneconomic and a number of practical mining limitations with respect to ventilation were identified.



Vertical subsidence patterns with the narrow Wongawilli layout.

APPENDIX B

OLSEN ENVIRONMENTAL CONSULTING PTY LIMITED

DRAFT

NRE No. 1 Colliery
Wongawilli Longwalls
Risk Associated With Subsidence
Prediction Methodology

Failure Mode and Effects Analysis Report

April 2010

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OEC File Reference: P84/2308

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FINAL DRAFT Failure Mode and Effects Analysis Report
NRE No 1 Colliery Wongawilli Longwalls
Risk Associated With Subsidence Prediction Methodolgy
April 2010

1. INTRODUCTION

Gujarat NRE FCGL Ltd (NRE) own and operate the NRE No 1Colliery at Russell Vale and are planning to continue to operate the colliery. NRE are required to obtain a valid development approval for the Colliery in accordance with the Environmental Planning and Assessment Act 1979 (EP&A Act). This requires the preparation of an Environmental Assessment under the provisions of Part 3A of the EP&A Act. NRE have commissioned Environmental Resources Management (ERM) to prepare an Environmental Assessment.

Part of the mining development of the continued operations of the colliery includes a proposal to mine Wongawilli coal from areas identified as:

- Wongawill East Areas 1 and 2, and
- Wongawilli West Areas 3 and 4.

The proposed mining will be undertaken in the Wongawilli Seam. The subsidence prediction methodology is described in a report prepared by Seedsman Geotechnics Pty Ltd, "Gujarat No 1 Colliery Management of Subsidence Risks Associated with Wongawilli Seam Extraction" dated March 2010.

In the areas of interest se areas the Bulli Seam and in some places, the Balgownie Seam have already been extracted either by longwall or pillar extraction techniques. As a result there are a number of constraints and assumptions that are fundamental to the subsidence predictions and these will require ongoing review and assessment to support the subsidence predictions for the proposed Wongawilli Seam extraction.

Seedsman has recommended a hierarchy of risk management strategies be applied to the mining proposals.

The hierarchy of risk management controls is:

- Elimination,
- Substitution,
- Engineering, and,
- Administration.

NRE commissioned Olsen Environmental Consulting Pty Limited (OEC) to facilitate a Failure Mode and Effects Analysis (FMEA) of the risks associated with the subsidence prediction methodology. The primary objectives of the FMEA were to:

- Confirm that the risk management approach adopted by Seedsman was robust and acceptable given the specific circumstances of the proposed activity, and,
- Identify any factors or components that were either inadequately addressed or that had not as yet been considered.

Actions determined during the FMEA would assist development of engineering and administration approaches to risk management that could be implemented to ensure appropriate management of subsidence impacts on the environment. Only some of these

controls would be able to be developed prior to mining commencing, with some being progressively developed as monitoring data is collected and prediction models refined.

2. FMEA METHODOLOGY

Failure Mode Risk and Effect Analysis (FMEA) is a recognized methodology described in the NSW Department of Primary Industries document MDG 1010, "Risk Management Handbook for the Mining Industry". It is most applicable when only one type of impact is being considered (eg environmental impact or subsidence impacts) and is therefore suitable for this exercise.

FMEA aims to identify the nature of failures which can occur in a system:

- By identifying the components or subsystems,
- Considering for each the full range of possible failure types, and,
- The effect on the system ofeach type of failure. In this FMEA, the effect on the system would be additional deformation resulting from a failure to accurately predict subsidence parameters.

Further insight into the consequence of the failure modes was achieved by determining a likely Exposure as a result of risk associated with subsidence prediction Exposue was determined by assigning a rating to both the likelihood of additional deformation and the severity of the potential outcome of any additional deformation. This enabled the risks to be ranked, and was achieved utilising the assessment matrix shown in **Table 1**.

The ranking in the Likelihood column also reflects a measure of confidence in the data available to estimate the subsidence predictions. A Low level of confidence in the data results in a High likelihood rating and a High level of confidence results in a Low likelihood rating.

It is important to appreciate that this FMEA addresses the subsidence methodology risk and not the environmental impact outcomes of that subsidence. NRE conducted an additional Failure Mode and Effects Analysis which specifically addressed the likely environmental impacts of mine subsidence. This other FMEA was undertaken by a range of appropriate environmental experts and addressed issues including flora, fauna, archaeology, surface water, groundwater and surface features. The outcomes of this other FMEA are documented in a report titled "NRE No 1 Colliery Wongawilli East and West Mining Areas Failure Mode and Effects Analysis report" dated December 2009 and prepared by Olsen Consulting Group.

Table 1. Risk Assessment Matrix.

LIKELIHOOD	SEVERITY (OF ADDITONAL DEFORMATION)		
	Low	Medium	High
High	Medium Risk	Medium-High Risk	High Risk
Medium	Low-medium Risk	Medium Risk	Medium-High Risk
Low	Low Risk	Low-medium Risk	Medium Risk

The steps in the FMEA were to:

Step 1. Define the scope of the study.

Step 2. Decide the level of analysis. In this analysis the main areas potentially subject to subsidence impacts were regarded as the elements. For each of these elements a variety of potential failure modes were identified.

The Main Elements and a list of Possible Failure Types for the FMEA were prepared by NRE, Seedsman and OEC prior to the meeting. It was not intended to be an exclusive list but was generated to provide guidance on the distinction between elements and failure types in the FMEA process. Opportunity was provided for modifications, deletions and additions during the FMEA meeting and the eventual list is as follows:

1. ***Illawarra Escarpment***

Unacceptable impact on the Illawarra Escarpment.

2. ***Mount Ousley Road***

Unacceptable subsidence effects on Mount Ousley Road as a result of mine subsidence.

3. ***Cataract Dam Wall and Spillway***

Unacceptable impacts on Cataract Dam Wall and Spillway as a result of mine subsidence.

4. ***Cataract Dam Stored Water and DSC Notification Area***

Unacceptable impacts on stored water and DSC Notification Area as a result of mining-induced subsidence.

5. ***Fourth Order Streams***

Unacceptable impacts on Lizard Creek due to mine subsidence.

Unacceptable impacts on Cataract River and Cataract Creek due to mine subsidence.

6. ***High Significance Features***

Unacceptable impacts on High Significance Features due to mine subsidence.

7. ***Groundwater System***

Unacceptable impacts on groundwater system due to mine subsidence

Step 3. For all the potential failure modes, the effect on the system as a whole and the relative importance of those effects was determined by the subsidence experts present in the FMEA meeting. The objective was to identify subsidence prediction or management risks that had been overlooked or that were still significant subsequent to ameliorative action. There was additional discussion subsequent to the meeting to clarify some matters.

Step 4. A Exposure rating was determined for each failure mode utilising the Assessment Matrix shown in Table 1.

Step 5. Agreed additional actions that would enhance the robustness of the mine subsidence assessment were developed and documented.

Part of Step 2 included discussion among the participants to identify any subsidence aspects that had not been listed for discussion during the FMEA. This was also repeated at the conclusion of the FMEA. All participants in the FMEA were satisfied that all potential predictable effects had been addressed.

Table 2 identifies the participants in the FMEA and their area of expertise.

Table 2. FEMA Participants.

Participant	Organisation	Area of Expertise
Dr Chris Harvey	NRE	Mining Engineering and Environment
Danyil Skora	NRE	Environment
Ken Mills	SCT Operations	Geotechnical Engineering and Mine Subsidence
Arthur Waddington	MSEC	Geotechnical Engineering and Mine Subsidence
David Olsen	OEC	Risk Assessment and Environment
Ross Seedsman	Seedsman Geotechnics	Geotechnical Engineering and Mine Subsidence

3. OUTCOMES, FINDINGS AND RECOMMENDATIONS

During and immediately following the FMEA meeting a worksheet was completed for each identified Possible Failure Types. A complete set of worksheets is included in **Appendix I**.

The Worksheets identify the following:

- Element,
- Possible Failure Type,
- Effect on System of that Failure Type,
- Expert Panel Comments,
- Agreed Additional Actions, and,
- Criticality Analysis.

APPENDIX

FAILURE MODE AND EFFECT ANALYSIS

MEETING WORKSHEETS

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Actions	Exposure
1.Illawarra Escarpment	**1.1 Unacceptable impact on the Illawarra Escarpment.** The eastern end of the proposed extraction footprint is located 700m from the crest of the Illawarra Escarpment (340m).	**1.1.1** Proposal to leave 700m standoff considered to be inadequate to confidently predict negligible impacts.	Standoff distance of 700m considered appropriate.	Check actual standoff distance on current plans and adjust mine plan to accommodate the correct stand off distance. Check standoff distances and associated data with Dendrobium for comparison.	Likelihood: Low Severity: Low LOW
		1.1.2 Lack of geological data limits confidence in ability to define acceptable/suitable standoff distance.	Geological data not limiting.	Nil.	Likelihood: Low Severity: Low LOW
		1.1.3 Adverse impact on escarpment face due to land instability resulting from subsidence.	Mining induced movements, if any, would be small horizontal displacements. These would not de-stabilise the escarpment.	Nil.	Likelihood: Low Severity: Low LOW
		1.1.4 Available mining history information not adequate to determine whether selected standoff distance is appropriate to avoid impacts.	Historical mining data adequate.	Nil.	Likelihood: Low Severity: Low LOW
		1.1.5 Initiation of pillar run may adversely affect subsidence predictions.	Have to assume available plans are accurate. Previous extraction close to the escarpment will also reduce risk	NRE to ensure the most accurate plans are obtained and utilised.	Likelihood: Low Severity: Medium LOW-MEDIUM

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
2. Mount Ousley Road	**2.1 Unacceptable subsidence effects on Mount Ousley Road as a result of mine subsidence.** Current relocated route of Mount Ousley Road lies directly above Balgownie Seam chain pillar and over Bulli Seam extracted areas. A longwall elimination zone under and within 100m of the road is recommended where the road is above Bulli Seam extraction. For areas where the standing pillars in the Bulli Seam are indicated, engineering controls based on monitoring should be used to locate the finish line of the longwall panels.	**2.1.1** Proposal to leave 100m standoff above areas of Bulli Seam extraction is considered inadequate to confidently predict negligible impacts.	The 100m standoff is appropriate and limits subsidence at Mt Ousley road. It was noted that NRE advised that a management plan will be implemented in consultation with RTA.	Re-assess/cross check the likely strains, tilts, angle of draw and deformation characteristics associated with Balgownie Seam extraction	Likelihood: Low Severity: Medium LOW-MEDIUM
		2.1.2 Proposal to utilise engineering controls based on monitoring in areas where standing pillars in the Bulli Seam are indicated is considered to be impractical. The controls would define the location of the finish line of the longwall panels.	Practical engineering controls are available. Engineering controls can be used to locate finish lines.	Engineering controls includes any remediation work that may become necessary as a result of mine subsidence management plan that will be implemented in consultation with RTA.	Likelihood: Low Severity: Medium LOW-MEDIUM
		2.1.3 Time between analysis of monitoring data and definition of finishing line is inadequate to implement appropriate engineering controls.	Where confirmation of finish line is pertinent, there will be time between collection of monitoring data and implementation of any variation.	Nil.	Likelihood: Low Severity: Low LOW
		2.1.4 Lack of geological data limits confidence in ability to define acceptable/suitable standoff distance.	Geological data adequate.	Nil.	Likelihood: Low Severity: Low LOW
		2.1.5 Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid impacts.	Available mining history is adequate.	Nil.	Likelihood: Low Severity: Low LOW
		2.1.6 Initiation of pillar run may adversely affect subsidence predictions.	The majority of the road is bounded by known collapsed Balgownie longwalls. In other areas given pillar shape and distribution with respect to mined and unmined areas, pillar run is unlikely to occur. It is valid to assume it will not occur.	Nil.	Likelihood: Low Severity: Low LOW
		2.1.7 Lack of knowledge of RTA road construction & tolerability criteria.	Although standoff distances are predicted to avoid significant impacts, this information will be required to fully assess likely impact on structures.	Obtain RTA data on road construction, Cataract Creek culvert details as well as any RTA impact criteria. This will also be fully addressed in the Management Plan that will be developed with RTA input.	Likelihood: Low Severity: Medium LOW-MEDIUM

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
3. Cataract Dam Wall and Spillway	**3.1 Unacceptable impacts on Cataract Dam Wall and Spillway as a result of mine subsidence.** It has been decided that the DSC 1km boundary will form a boundary to longwall extraction.	**3.1.1** Adverse effects on structuress because DSC 1km standoff not adequate to confidently predict negligible subsidence impacts.	The 1km standoff under the current mining layout is acceptable. The Expert Panel noted that it is ultimately subject to DSC approval.	Ongoing monitoring will supplement validation data.	Likelihood: Low Severity: Medium **LOW-MEDIUM**
		3.1.2 Lack of geological data limits confidence in ability to define acceptable/suitable standoff distance.	Geological data adequate.	Nil	Likelihood: Low Severity: Low **LOW**
		3.1.3 Initiation of pillar run may adversely affect subsidence predictions.	There is no precedent for a 'pillar run' in a longwall chain pillar layout. The width to height ratio of the chain pillars mitigates against a run. It is valid to assume it will not occur.	Nil	Likelihood: Low Severity: Low **LOW**
		3.1.4 Inadequate knowledge of SCA structures limits ability to determine subsidence effects.		Structures currently monitored by SCA. Management Plan will be developed with DSC before mining in general area of structures commences.	Likelihood: Low Severity: Low **LOW**

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
4. Cataract Dam Stored Water and DSC Notification Area	**4.1 Unacceptable impacts on stored water and DSC Notification Area as a result of mining-induced subsidence.** Narrow longwalls have been extracted from the Bulli Seam in Wongawilli West area. Consequently, additional longwall extraction is not proposed here. Within the DSC notification area, there has been no previous longwall extraction in the Wongawilli East area and narrow longwalls are now proposed. Proposed layouts should produce vertical subsidence similar to or less than those already experienced in the '500 series' panels.	**4.1.1** Lack of geological data limits confidence in ability to predict subsidence characteristics.	Geological data adequate (but see agreed action column). Mining in Notification Area will be subject to DSC approval.	Undertake further assessment of loading estimates for chain pillars in Bulli Seam within the DSC Notification Area in Wongawilli east area.	Likelihood: Low Severity: Medium **LOW-MEDIUM**
		4.1.2 Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid impacts.	Available mining history is adequate for current predictions.	Nil.	Likelihood: Low Severity: Low **LOW**
		4.1.3 Time between analysis of monitoring data and definition of finishing line is inadequate to implement appropriate engineering controls.	Adequate time available to respond to monitoring data.	Nil.	Likelihood: Low Severity: Low **LOW**

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
5. Fourth Order Streams	**5.1 Unacceptable impacts on Lizard Creek due to mine subsidence.** The lower reaches of Lizard Creek are indicated to constitute a 4th order stream. Wide longwall extraction will not occur within a 200m offset from the centre of Lizard Creek.	**5.1.1** Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid impacts.	• Mining history data from adjacent mines can be applied • The 200m standoff from Lizard Creek should mean any impacts are minor • Further monitoring will provide an opportunity to refine standoffs with information from earlier longwalls	• Geoterra be commissioned to define exact location of third and fourth order streams. • SCPL should review the consequences of a doubling of the upsidence and closure values given by the incremental data plots. • NRE to monitor earlier longwalls in WW west to obtain data of multiple seam extraction	Likelihood Low Severity Medium **LOW-MEDIUM**
		5.1.2 Time between analysis of monitoring data and definition of finishing line is inadequate to implement appropriate engineering controls.	Adequate timing will be available to respond to monitoring data.		Likelihood Low Severity Low **LOW**
	5.2 Unacceptable impacts on Cataract River and Cataract Creek due to mine subsidence. The lower reaches of Cataract Creek are indicated to constitute a 4th order stream.	**5.2.1** Lack of geological data limits confidence in ability to predict subsidence characteristics.	Geological data adequate for predictions.		Likelihood Low Severity Low **LOW**
		5.2.2 Available mining history information not adequate to determine whether extraction proposal is appropriate to avoid impacts.	Mining history adequate for assessment.		Likelihood Low Severity Low **LOW**
		5.2.3 Time between analysis of monitoring data and definition of finishing line is inadequate to implement appropriate engineering controls.	Adequate time available to respond to monitoring data.		Likelihood Low Severity Low **LOW**
		5.2.4 Subsidence greater than 200mm occurs beneath Cataract Creek.	This subsidence prediction is based on data obtained from the 500 series of longwall extractions.	SCPL to review predictions of "no valley closure" in light of the predictions of up to 900mm subsidence elsewhere in the mined area. This review should be supported by Geoterra assessing impact, should valley closure be predicted to occur.	Likelihood Low Severity Low **LOW**

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
6. High Significance Features	**6.1 Unacceptable impacts on High Significance Features due to mine subsidence.**	**6.1.1** Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid significant impacts.	Adequate mining history available for risk assessment purposes. High Significance Features will be subject to various Management Plans approved prior to mining. Panel noted Lizard Creek and Wallandoola Creek will not be undermined despite the presence of good coal reserves.	Nil.	Likelihood Low Severity Low **LOW**
	High Significance Features include: 1. **Third Order Streams** Cataract Creek, Lizard Creek, Wollandoola Creek and some un-named creeks have already been undermined. NRE have made the decision to not extract wide longwalls under named 3rd order creeks. 2. **Upland Swamps** Contiguous networks of intact upland swamp are present in both the Wongawilli East and Wongawilli West areas. 3. **Transitional Shale Forests** Open Blue Gum and Stringybark forests are present above area 3 in the Wongawilli West area. 4. **Heritage Sites** Some archaeological sites present 6. **Telstra Cable** There is a fibre optic cable located alongside one of the fire trails in area 3 above the Wongawilli West area. 7. **Transmission Lines and Towers** 8. **Fire Trails**	**6.1.2** Time between analysis of monitoring data and definition of finishing line is inadequate to implement appropriate engineering controls.	Adequate time available to respond to monitoring data.	Nil	Likelihood Low Severity Low **LOW**
		6.1.3 Lack of geological data limits confidence in ability to predict subsidence characteristics.	Geological data adequate for assessment purposes.	Nil	Likelihood Low Severity Low **LOW**

FAILURE MODE AND EFFECTS ANALYSIS
SUBSIDENCE PREDICTION NRE NO 1 COLLIERY

Element	Possible Failure Type	Effect on System	Expert Panel Comments	Agreed Additional Action	Exposure
7. Shallow Groundwater System	**7.1 Unacceptable impacts on groundwater systems due to mine subsidence.** Analyses indicate no signficant change in fracture flow from surface to coal seam.	**7.1.1** Inadequate knowledge of geological and groundwater related structures to determine subsidence effects.	Groundwater impacts have been addressed in a manner that is acceptable. Monitoring programs will provide data as mining progresses.	Nil.	Likelihood: Low Severity: Low **LOW**
		7.1.2 Loss of surface runoff to the mine workings.	Not likely, although wider longwall panels and multiple seams mean that large degree of interpretation of empircal database is required	Review risk assessment with external consultants as appropriate	Likelihood: Low Severity: Medium **LOW-MEDIUM**
		7.1.3 Lack of geological data limits confidence in ability to define acceptable/suitable standoff distance.	Geological data adequate.	Nil.	Likelihood: Low Severity: Low **LOW**
		7.1.4 Available mining history information not adequate to determine whether selected standoff distance or extraction proposal is appropriate to avoid impacts.	Mining history adequate.	Nil.	Likelihood: Low Severity: Low **LOW**
		7.1.5 Initiation of pillar run may adversely affect subsidence predictions.	Given pillar shape and distribution with respect to mined and unmined areas, pillar run is unlikely to occur. It is valid to assume it will not occur.	Nil.	Likelihood: Low Severity: Low **LOW**

Annex N

Peer Review - Subsidence

Gujarat NRE Coking Coal Limited

REVIEW OF SUBSIDENCE AND RELATED FACETS OF THE NRE NO 1 COLLIERY

UNDERGROUND EXPANSION PROJECT DRAFT ENVIRONMENTAL ASSESSMENT

P043.R2 (Final)
19th October 2011

Report Title	Review of subsidence and related facets of the NRE No 1 Colliery - Underground Expansion Project Draft Environmental Assessment
Authors	Philip Pells; Steven Pells
Job No.	P043
Report No.	R2
Client	Gujarat NRE Coking Coal Ltd

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1 INTRODUCTION

The Environmental Assessment report (**EA**) for NRE No 1 Colliery Stage 2 (February 2011) contains a large amount of information germane to assessment of the proposed project under the Environmental Planning and Assessment Act of 1979. Several NSW State Government departments have raised questions in respect to the sufficiency of some of the information, calculations and expert opinions given in that report. This report addresses the various questions from a viewpoint that is independent of those persons who prepared the EA.

While we have made much use of information in the various appendices to the EA we have also undertaken the following independent work:

1. Collection and interpretation of structural geological data including preparation of plans and cross-sections.
2. Review of the original, historical, mine plans of workings in the Bulli and Balgownie coal seams, and discussions with a registered surveyor regarding the accuracy of those plans.
3. Independent calculations of surface subsidence above the proposed Wonga West and Wonga East longwall panels using numerical analysis.
4. Review of calculations of the factors of safety of key pillars in the Bulli Seam workings in the Wonga East area.
5. Assessment of groundwater pressure data from standpipes installed in the areas of the Cordeaux, South Bulli and Bulli collieries since the time of the Reynolds Inquiry of 1976.
6. Inspection of underground workings and goaf area in the Wonga West area beneath Cataract Dam, with a particular view to understanding mine inflows and the mine water balance.
7. Discussions with personnel from BHPB Illawarra Coal regarding water levels in the Cordeaux and Bulli collieries that are on either side of NRE No 1.
8. Inspections of swamps in Lizard and Wallandoola creeks.
9. Discussions with RTA personnel regarding possible subsidence impacts on Mt Ousley Road, and the management plan in preparation for dealing with possible events, a plan similar to that currently in place for longwall mining beneath the Hume Highway.

While we have sought to make this review a self-contained document, relevant appendices to the EA have to be read for complete information.

Issues and questions in relation to the EA had been received, as of early July 2011, from the Sydney Catchment Authority (**SCA**), NSW Department of Resources and Energy (**DRE**) and NSW Environment, Climate Change and Water (**DECCW**) and are set out in Table A1 of Appendix A.

In order to reduce the extent to which the reader has to reference drawings in the EA, this report includes a set of drawings showing key features of the proposed Stage 2 of NRE No 1 Colliery. The drawings in Appendix D are:

P043 – 1	Overall Site Plan
P043 – 2	Wonga West Area Proposed Longwall
P043 – 3	Wonga West – Geology and Existing Bulli Seam Workings
P043 – 4	Wonga East Proposed Longwalls

P043 – 5	Wonga East Geology and Existing Bulli and Balgowie Seam Workings
P043 – 6	Wonga East – Proposed Longwalls in Wongawilli Seam Relative to Existing Workings
P043 – 7	Wonga East – Geological Cross Sections

The questions that are dealt with in this report relate to subsidence, groundwater, surface water, impacts on swamps, impacts on creeks and impacts on transmission lines. We do not have expertise in areas of flora and fauna and Aboriginal heritage.

2 SUBSIDENCE

2.1 A Note on Subsidence Predictions

The prediction of the impacts of subsidence on swamps, creeks, groundwater and infrastructure depends on the accuracy of the subsidence predictions themselves. However, it is a fact that these prediction of subsidence, and in particular tilts and ground surface strains, is fraught with uncertainty. The main reason for this is the impact of geological structures, often unknown, and, in the case of multi-seam mining is exacerbated by limited precedent.

However, even for single seam longwall mining in the Southern Coalfields, where MSEC have used a copious database to calibrate their excellent, empirical Incremental Profile Method (Waddington & Kay, 1995), there are sometimes significant limitations to the predictions. Some recent examples, in regard to vertical movements, are:

- Appin Colliery LW703 – 33% to 52% overprediction.
- Westcliff Colliery LW34 – 10% under prediction.
- Tahmoor Colliery LW24A – 290% under prediction.
- Tahmoor Colliery LW26 – 100% under prediction.

Other predictions methods are used, such as that of Holla and Barclay (2000), based on the original National Coal Board method; numerical methods, such as that used by Strata Control Technologies (Gale and Sheppard, 2011); and structural calculations based on jointed beams (Seedsman, 2004). These too have their limitations, primary because of variability in geological influences.

Matters become more complicated for multi-seam mining, as discussed by MSEC (2007) and Li *et al* (2010). For seam interburden thickness between about 30m and 50m, MSEC propose a 10% to 20% increase of subsidence factors for the second mining, depending on the single seam subsidence factor. This assumes the overlying seam pillar areas are stable. Li *et al* cover the situation of mining under existing longwall goaf, and recommend that a subsidence factor of 80% should be adopted for the underlying longwalls .

Uncertainties in predictions become greater when it comes to surface tilts and strains. This is particularly the case when the mining is at substantial depth (>300m) as is the case at NRE No 1. Typically with mining at such depths, surface tilts and strains can be accommodated by most infrastructure. However, high tilts and strains (compressive, tensile and shear) have frequently been encountered in association with faults, dykes and, also, major topographic changes (cliffs and steep sided valleys). Examples include Appin Road, The Hume Highway, Cataract River and Cataract Tunnel.

Arising out of the above discussion it is concluded that it is inappropriate to make a single prediction of subsidence contours, tilts etc, above the Wonga West and Wonga East longwalls. A predicted range is more appropriate, and this is what has been done in this report as a review of the predictions given in Annexure I of the EA.

2.2 Uncertainties In Relation To Old Bulli Seam Workings

In their letter of 26 May 2011, DRE raised the uncertainty of knowledge of the historical workings in the Bulli and Balgownie seams as a fundamental flaw in the EA. Similar concerns are expressed by the SCA in their letter of 30 May 2011.

It is agreed that verification of the accuracy of the old mine workings is crucial to assessment of future subsidence arising out of workings in the Wongawilli Seam. For that reason, we have expended substantial effort in:

- studying the original mine plans (drawing rolls) of the South Bulli / Belllambi Colliery;
- discussing the accuracy of the old mine plans with a surveyor expert in the matters of historical mine grids, tracing of mine plans and documentation in the Department of Mines;
- studying historical records in the annual reports of the Department of Mines and in local histories of the South Bulli and Corrimal mines, and;
- reviewing attempts to verify old mine plans by drilling.

Figures 1 to 3 are photographs of parts of the Bulli Seam linen plans held at the mine, dating from the 1890's to 1940's. Figure 4 is part of the formal mine tracings held at the mine, that have been carefully checked by a skilled professional surveyor.

An important portion of the Bulli Seam workings relates to the development of what were called the North West headings. These headings are on the same alignment of the headings created for the 1970-1980 Balgownie longwalls at Wonga East, which is the same alignment as the current headings to the Wongawilli headings in Wonga East and Wonga West (see Drawings P043-3 and P043-6). The particular importance of these headings in the Bulli Seam is that the pillars left in that seam are critical to the safety against pillar failure, and what is termed "pillar run", when the new Wonga East longwalls are mined.

Figure 1 shows the development of these NW headings (1892) as three parallel drives. Figure 2 shows, by means of 1903 and 1938 plans, how two parallel drives (twins) were driven either side of the initial triplet of headings, and then, in about 1938, sub-headings were driven to extract coal between the triplet headings and the twin headings. This process left behind the pillars that are shown on the formal tracing (see Figure 4), which are analysed for stability in Annexure K of the EA.

An important facet of the workings within the Bulli Seam at Wonga East is the extent and locations of areas of pillar recovery. We have examined the sequential linen tracings and note that there appears to be a meticulous record of the splitting and recovery of pillars. Figure 3 is an example of the record of recovery between 1935 and 1944.

We would record that, in our view, an exceptional effort has been made by the surveyors responsible for assessing the historical mine plans of South Bulli Colliery in establishing the limitations to the accuracy of those plans. This work, coupled with our own study of the original plans held at the mine, leads us to conclude as follows:

(i) The mine plans of the Bulli Seam bord and pillar workings in the Wonga East area, and Bulli Seam longwall mining in the Wonga West area, show the dimensions of remnant pillars, areas of pillar recovery and longwall panels with a satisfactory level in respect to geometry (shape).

(ii) There is some uncertainty as to the precise positions of the workings in respect to current MGA coordinates because of different grids used in the past, and the historical difficulty of defining the true x, y, z coordinates in underground workings.

Figure 1 - 1892 Plan, NW headings

Figure 2 - Plan from 1903 next to 1938.
These show the development of the main NW headings that are on the line of the current headings to Wonga West.

Figure 3 - Pillar recovery 1935 to 1944
Records in the area to be undermined by the new Wonga East longwalls.

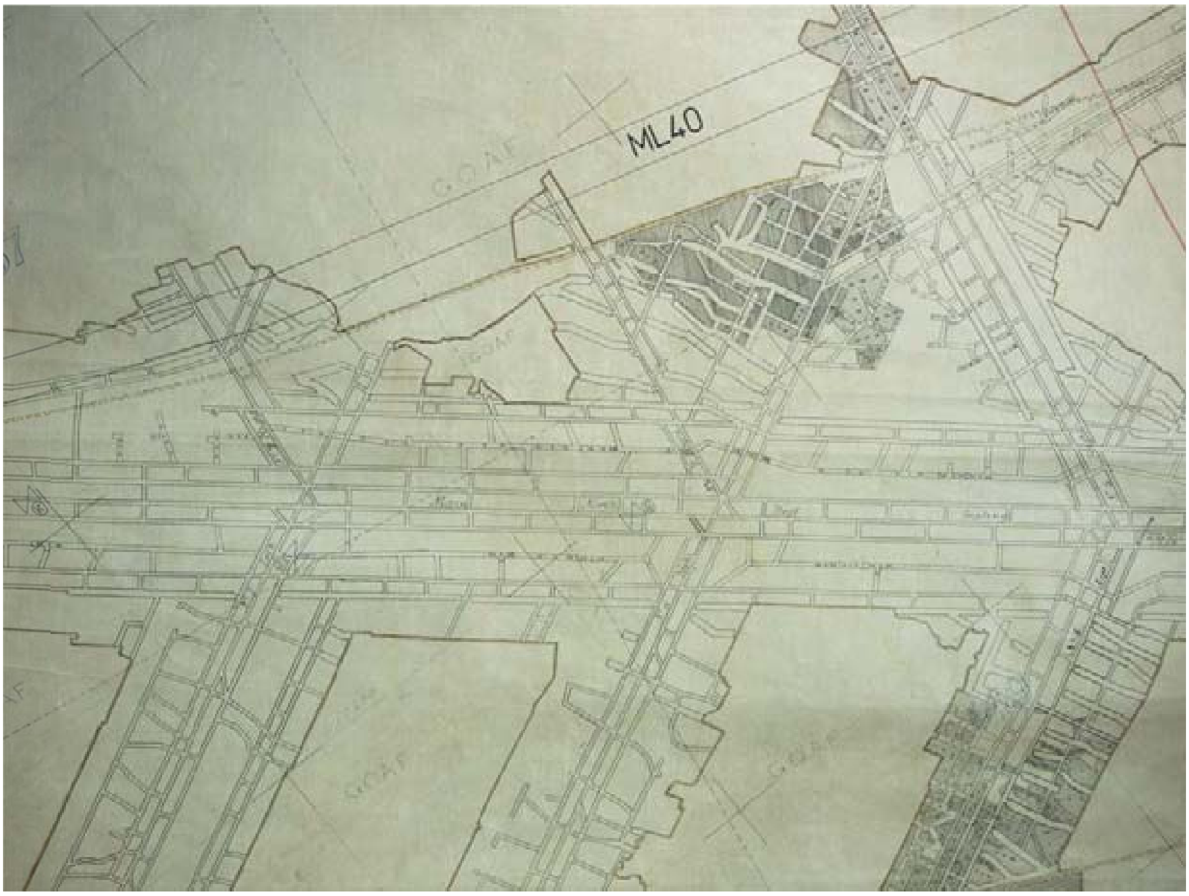

Figure 4 - Portion of Mine tracing showing main NW headings.
This was checked against the linen plans.

Figure 5 - Fault adjacent to clay dyke ˜1904

We note that in places, in the Wonga East area, where boreholes have been drilled up into the Bulli Seam workings, the boreholes have struck voids where voids were expected. We also note that in an inspection of a limited area of the Bulli pillars along the NW Headings by Dr N van der Merwe (August 2011) pillars were found as per the pre-1930 mine plan[1].

Based on our investigations, we are of the opinion that:

(i) the locations of the old Balgownie longwalls in the Wonga East area (dated from the 1970s) and the Bulli Seam longwalls in Wonga West (dated from the late 1960s) are correct in dimensions and correct in space to about ± 2m; and

(ii) the areas of pillar recovery in the Bulli Seam in the Wonga East area (dating from the 1930s) are correct in extent; and

(iii) the remnant pillars in the main roadways of the Bulli Seam workings in the Wonga East area are correct in dimension to a few metres.

The factual information available to us by way of the old mine plans, and historical records, indicate that the plans of workings shown on drawings in the EA, and reproduced herein on Drawings P043-1, 3, 4 and 6, can be used with confidence in assessment of future subsidence arising out of the proposed mining in the Wongawilli Seam. Therefore it is our view that no modifications are needed to the EA in this regard.

---

[1] Email 30/8/2011:
Philip
We did not measure any pillars, but except for one or two discrepancies, the map corresponded pretty well to what we found underground. The discrepancies were drivages that did not go all the way through, a skin of about a metre having been left in place. We also missed one or two entries but I think that was due to stonewalls having been built and also there was a lot of material (spillage, spalling material, etc) stowed in the entries so it was easy to miss some of them. The purpose of the visit was to observe the condition of the pillars and the amount of spalling that had taken place.
Prof Neilen van der Merwe

2.3 Assessment of Subsidence and Associated Tilts and Strains

The assessment of subsidence and the philosophy for addressing major subsidence issues is set out in detail in Annexures H and I of the EA.

In essence, the process has been to design the layouts and widths of longwall panels to control subsidence impacts. The proposed Wongawilli longwalls are all beneath previous workings, namely:

- Wonga West – beneath the 200 and 300 Series longwalls of the South Bulli – Bellambi Colliery (1990s) in the Bulli Seam.
- Wonga East – beneath first workings and pillar recovery areas in the Bulli Seam (~ 1910-1935) and later longwalls in the Balgownie Seam (early 1980s).

The magnitudes of subsidence, tilts and strains have been computed using principles of rock mechanic coupled with shape functions to provide contours of surface settlement. Subsidence calculations provided in the EA are summarised in Table 1.

Table 1 –Calculated Subsidence As Presented in the EA

Region	**Seam**	**Subsidence** (m)	**Tilt** (mm/m)	**Strain** (mm/m)	**Upsidence** (mm)	**Valley Closure** (mm)
Wonga East, Area 1	Overall	0.88	9	10.5	-	-
Wonga East, Area 2	Overall	1.2	18	-14 to +16	-	-
Cataract Creek 3rd order or higher channel	Overall	0.25	8.2	5	120	200
Wonga West, Area 3	Wongawilli + Bulli	3.5	23	n/a	n/a	n/a
	Wongawilli	2.5	17.5	-12 to 14	-	-
Wonga West, Area 4	Wongawilli + Bulli	2.5	n/a	n/a	n/a	n/a
	Wongawilli	1.5	12.5	-10.5 to 6.5	-	-

Pells Consulting undertook independent computations of vertical subsidence, tilts and strains using numerical methods similar in concept to those published by Winton Gale in various papers (see Gale and Shepard, 2011).[2]

[2] One of the main differences is that Gale uses the dynamic relaxation program FLAC, with proprietary routines that have not been published, while our analyses use finite elements, with joint elements for bedding planes, joints and faults. Gale uses Hoek-Brown failure criteria for the rock, we use Hoek-Brown and Mohr–Coulomb, so as to give an understanding of the sensitivity to these failure criteria. Parameters used in our analyses are given in Appendix B so that our calculations can easily be repeated by persons with programs such as Abaqus, Phases or Plaxis.

We have also noted the recommendations in the paper by Li et al (2010) and compare our calculations with those recommendations. Details of the calculated subsidence profiles, tilts and strains are given in Appendix B.

These calculations have been made for the two sections as shown in Drawing P043-5. We consider that these section lines would encompass the maximum settlements associated with the historical workings, and the proposed Wongawilli longwalls.[3]

1. A north-south section through Wonga East (303200 m E) was chosen to pass through a major area of pillar recovery in the Bulli Seam, diagonally through three of the Balgownie longwalls, and slightly on the diagonal through proposed longwalls LW4 to LW6.
2. A west-east section through Wonga West (6204000m N), was chosen to pass beneath Bulli Seam first workings and longwalls (300 Series), and slightly on the diagonal through the proposed longwalls LW1 to LW5.

The computed settlements are summarised in Table 2, with a range of values given (as discussed in Section 2.1 above).

Table 2 – Independent Subsidence Computations Undertaken by Pells Consulting

Region	Seam	Range	**Settlement** (m)	**Tilt** (mm/m)	**Strain** (mm/m)
Wonga West – WE Section 6203000 mN	BULLI	Lower	0.9	-	<2
		Upper	1.05	-	<2
		Measured	1	4.5	1.5
	WONGAWILLI	Lower	2.2	-	20*
		Upper	2.4	12	18*
		Measured	-	-	-
Wonga East – NS Section	BALGOWNIE	Lower	1.5 m	-	11*
		Upper	1.55 m	-	14*
		Measured	1.4	10	3
	WONGAWILLI	Lower	0.9	-	13
		Upper	1.6	8	14
		Measured	-	-	-

* These are localised values associated with particular joints in the model

It can be seen from Table 2 that there is reasonable agreement between our calculations and previously measured subsidence above Bulli Seam and Balgownie seam longwalls.

The data in Table 2 indicate that at Wonga West, where mining is beneath the Bulli longwalls, the calculated maximum (upper) settlement arising from the proposed Wongawilli longwalls amounts to 80% of the extracted thickness of the Wongawilli seam, and about 45% of the total extracted thickness. This is less than the value of 80% of total extracted thickness put forward by Li *et al* (2010). The difficulty that we have with the Li *et al* recommendations, in this case, is that with a measured extraction factor (a_1) of 0.4 for the Bulli seam longwalls, there would have to be an extraction factor of 1.2 (ie 120% of extracted thickness) for the Wongawilli longwalls (Equation 5 from Li *et al*). This does not seem reasonable, and is certainly not shown by our numerical analyses.

[3] We note that different section lines would generate different predicted profiles and that we would have to analyse many such section lines to generate contour plans of settlement, tilt and strain. We consider such work to be beyond that required of a review, given that the intent of this review is to give an assessment of the validity of the subsidence predictions given in the EA.

At Wonga East where mining is beneath both Bulli and Balgownie extractions, the computed maximum incremental subsidence due to the Wongawilli longwalls is calculated as 53% of the extracted thickness.

It must be noted that the maximum surface strains are a function of the locations where joints and faults are included in the model, and how these interact with bedding planes. These calculated strains are only considered to be indicative of the strains that may be associated with particular rock mass defects in the real world, defects whose specific locations and properties are unknown and unknowable.

2.4 Valley Closure and Upsidence

While the mechanisms causing valley closure and 'upsidence' are reasonably well understood, there are no theoretical methods that can predict these movements. This is because the movements arise from perturbations to the horizontal stress field, localised block movements, and brittle failure, that are specific to particular geological structures (bedding planes, joints, dykes and faults), and particular localised changes in topography.

Rather than attempt theoretical predictions, MSEC have collated available data on valley closure and upsidence, and presented these data in relation to distances from longwall panels (see Figures 23 and 24 in Annexure I of the EA). Based on this information, and records from subsidence monitoring above the Wonga East Balgownie longwalls and the Wonga West Bulli longwalls, the EA[4] concludes as follows:

Regarding Wongawilli West

> *"Because of the decision to eliminate longwall extract under named 3rd order creeks, the systematic strains in these creeks can only be tensile. Because of block rotations above the longwall extraction panels there may be some compressive strains transferred to the creeks. Valley closures of about 100mm and upsidence of about 60mm should be anticipated. The comment by the FMECA review was that it would be good practice to double these estimates in the context of an impact risk assessment."*

Regarding Wongawilli East

> *"A value of 50mm of closure is an appropriate value to use to identify any hazards in this (Cataract) creek."*

It is noted that a closure of 50mm is being used in evaluating possible impacts on Mount Ousley Road, where it crosses Cataract Creek some 350m beyond the eastern end of LW5 (see Drawing P043-5). This value of 50mm closure is double the value predicted using the upper bound of the data collated by MSEC.

The writer is a member of the Technical Committee set up by the RTA to assess the possible impacts of the Wonga East longwalls on RTA infrastructure, and notes that the Technical Committee has accepted that a closure of 50mm is a reasonably conservative value for assessment of Mount Ousley Road at Cataract Creek.

The writer is of the opinion that adopting double the predicted values at Wonga West is equally conservative."

[4] Annexure I, Addendum to the Subsidence Report.

2.5 Impact on Mt Ousley Road

The RTA has set up a Technical Committee to evaluate and manage impacts the proposed Wonga East mining may have on Mt Ousley Road. This committee has been in operation for about 12 months and mirrors a similar committee that successfully continues to manage mining beneath the Hume Highway from Appin Colliery. The NRE No 1 committee had met twelve times by July 2011. The writer is a member of the Technical Committee.

It would be inappropriate, and unnecessary, to express views in this review report that are pseudo-independent of the committee. Suffice it to say that, through the process of the twelve meetings to date, and future meetings, procedures are being established to safeguard the RTA's infrastructure, and to sustain the RTA's obligations to the public in respect to Mt Ousley Road.

3 STRUCTURAL GEOLOGY

An understanding of geological structures is key to proper interpretation of subsidence impacts on the surface and on the groundwater regime. To this end, we collected and collated information from the following sources:

1. Structures shown at seam levels in the South Bulli Colliery maps of old workings in the Bulli and Balgownie seams.
2. NERDDC Project 1239, ACARP report, "*Sydney Basin – Geological Structure and Mining Conditions Assessment for Mine Planning*" (1992).
3. 1912 geological map of the Bulli – Mount Kembla District.
4. 1985 1:100,000 geological map of Wollongong – Port Hacking.
5. "*Syn-sedimentary normal fault in the South eastern Sydney Basin*" by Memarian and Fergusson (1995).
6. "*Impacts of igneous intrusions, roof and floor irregularities and injection features on longwall mining*" by B. Agrali (1996): dealing with the Wonga West area.

The outcrop stratigraphy in the area of NRE No 1 (old South Bulli) Colliery, together with faults recorded on the 1:100,000 geological map, is shown in Figure 6. Outcrop in the Wonga West area is entirely Hawkesbury Sandstone, with some Quaternary deposits in swamp areas. The position of the Corrimal Fault shown on the 1985 1:100,000 map was taken directly from the 1912 map "Bulli – Mount Kembla District".

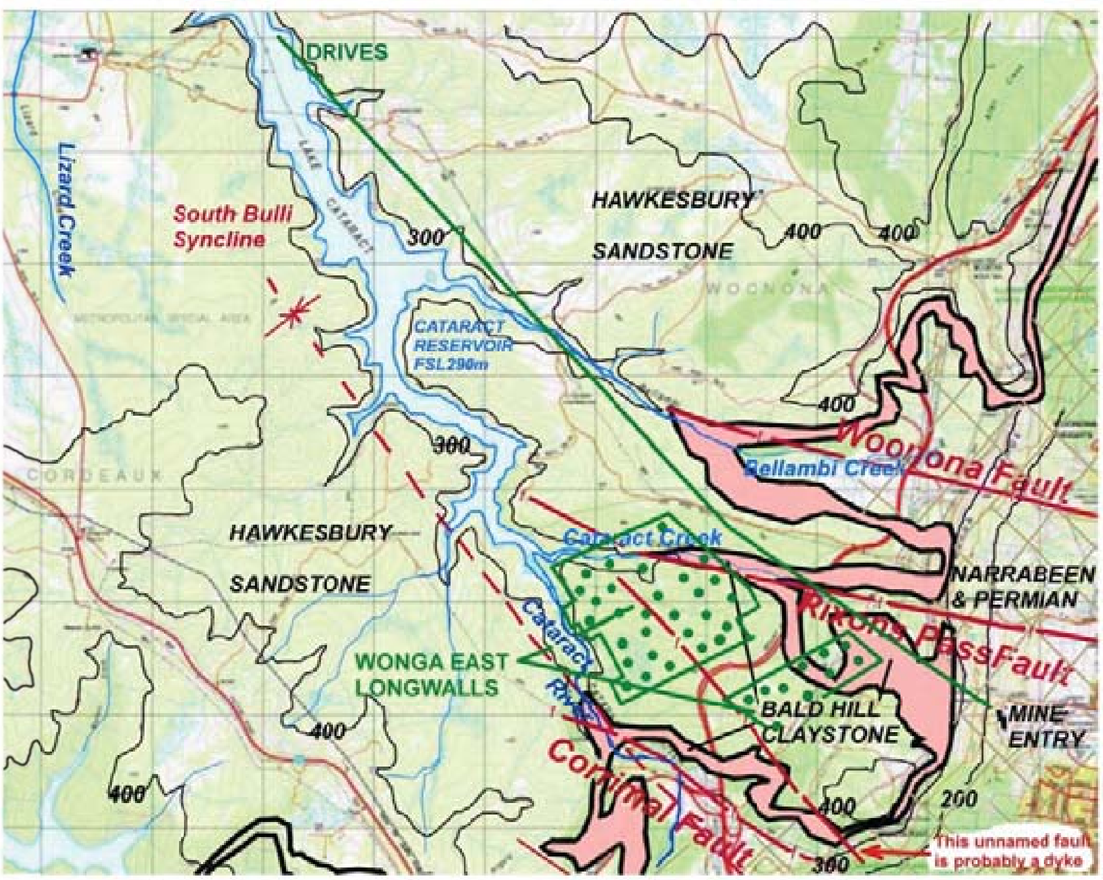

Figure 6 – Outcrop Triassic Stratigraphy Over the Study Area

North-South and West-East cross-sections showing stratigraphy and surface features in Wonga East are given on Drawing P043-7. The typical features of two of the major stratigraphic units, the Bulgo Sandstone and the Scarborough Sandstone and shown in Photographs 1 and 2.

Photograph 1 – Example of Scarborough Sandstone
Massive Scarborough Sandstone, underlain by Wombarra Shale, just above the old road of Lawrence Hargrave Drive.

Photograph 2 – Example of Bulgo Sandstone
Upper (Bulgo) and lower (Scarborough) sandstones above Lawrence Hargraves Drive. The sandstones are separated by the Stanwell Park shales.

Figure 7 shows the relevant portion of Sheet 3 from the 1992 NERDDC report which gives a good summary of many of the more significant structures recorded from coal seam mapping.

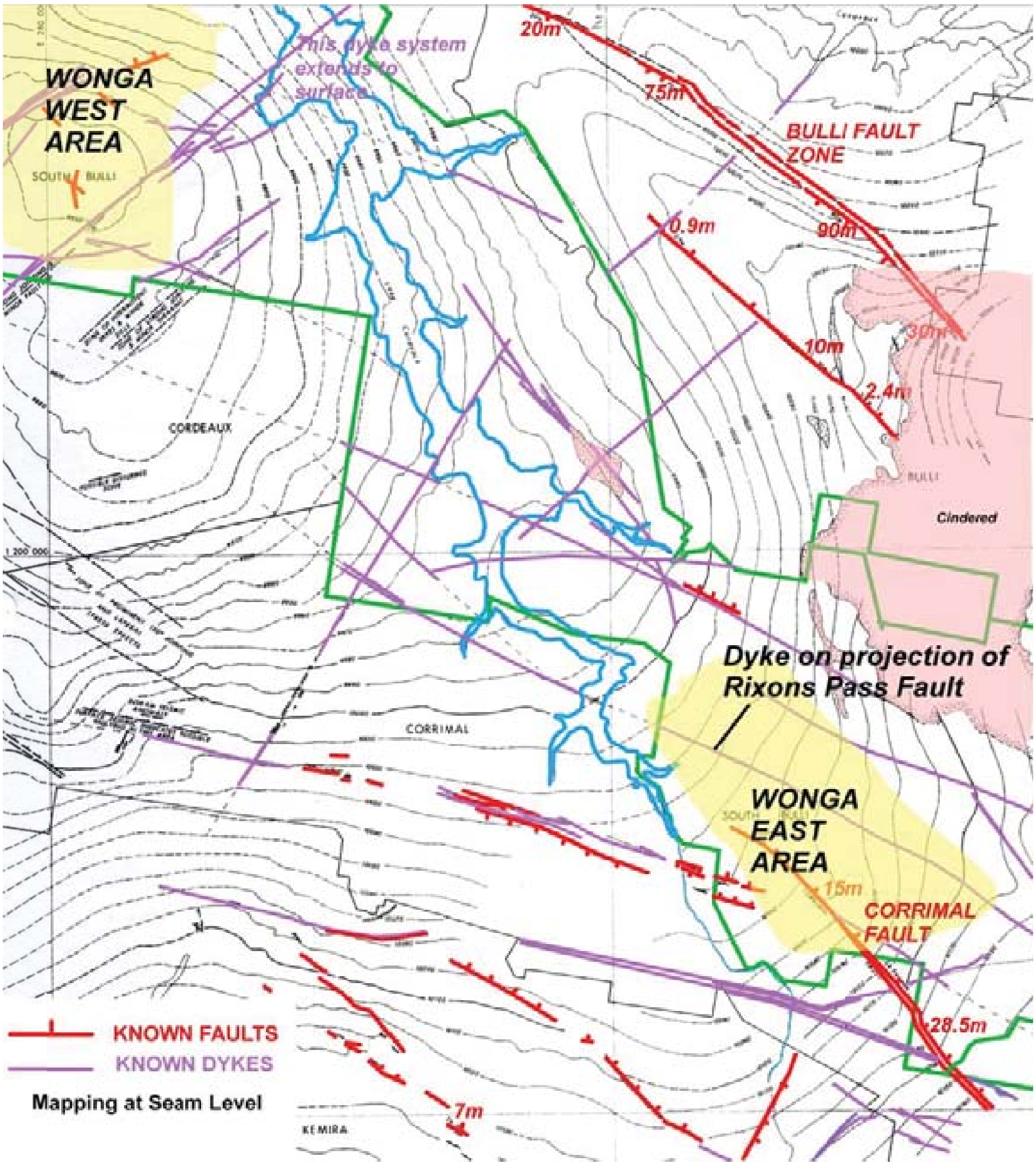

Figure 7 - Portion of Sheet 3 from the 1992 NERDDC report.

The information shown in Figure 7 has been checked against mine seam mapping on the plans held at NRE No 1 Colliery. These plans show additional detail (examples shown in Figures 8 and 9), and this has been collated with data given in Figure 9, on Drawings P043-3 (Wonga West) and P043-4 (Wonga East).

It is important to note that, in the area of Wonga East, the Rixons Pass fault aligns with an unfaulted dyke. It has been confirmed by a study of in-seam geological records in the Bulli and South Bulli collieries, where Rixons Pass fault dies out to the west, there commences a dyke on a very similar alignment.

Figure 8 – Corrimal Fault
Corrimal Fault encountered in Corrimal Colliery drives from lower left.

Figure 9 – Whin Dyke

Our analysis of the known geological structures indicates that there are three structures that will have a significant impact on surface movements, particularly strains, and, possibly, on groundwater and surface water impacts. These are shown on Drawing P043-3 and are:

1. a NS fault to the immediate west of the proposed Wonga West longwalls[5];
2. a major NE trending dyke swarm that passes the south east corner of the Wonga West longwalls[6], and;
3. the Corrimal Fault at Wonga East, which dips at about 30° to the north east.

The dyke swarm (No. 2, above) is part of a structural zone, described in the 1992 ACARP report as follows:

> *"A series of three northeast-trending zones of a significant number of northeast oriented dykes, strong jointing, and minor faulting is located in the western central section of the South Bulli area (Figure 5.3). These zones are generally between 200 and 400m in width, and are between 0.5 and 1.0km apart. The zones are up to 4km in strike length, and extend in a southwesterly direction into the Cordeaux Colliery area. It is notable that these northeasterly trending zones essentially straddle the "bullseye" structure-contour pattern at the northern end of the South Bulli Syncline, and may represent structures and intrusions controlled by the northeast oriented basement structures postulated to cross the Bulli and South Bulli areas at the northwestern terminations of the Bulli Anticline and the South Bulli Syncline."*

This dyke was noted on aerial magnetic work (Agrali, 1996).

The Corrimal Fault was first encountered in 1906 in what was then the main entry of the Corrimal Colliery. It was said to have a 91ft (27.7m) throw (down to the north east) at this point. As a result, a new entry to that colliery was created, about 1.6km to the south. The fault was encountered in the Bulli seam workings of South Bulli Colliery as shown in Figure 10, where it was recorded as having a throw of 15m.

The Corrimal Fault is shown in detail on the South Bulli linen plans dating from the early 1900's and on the mine plans of the Corrimal Colliery (digitized plan from old mine workings) (see Figures 8 and 11).

The Corrimal Fault appears to be of the syn-sedimentary type described by Memarian and Fergusson (1995), and, like the Jetty Fault near Coalcliff, it appears to die out quite rapidly to the north west (inland). It was not noted in the Balgownie Seam workings (see Drawing P043-4).

The geological structures, described above, are used in this report in addressing the issues raised by the regulators in respect to subsidence and surface strains and impacts on swamps, creeks and the groundwater regime.

[5] This fault was associated with three fatalities from a gas outburst in the Bulli Seam longwall.
[6] There is strong evidence that dykes associated with this swarm extend to the surface.

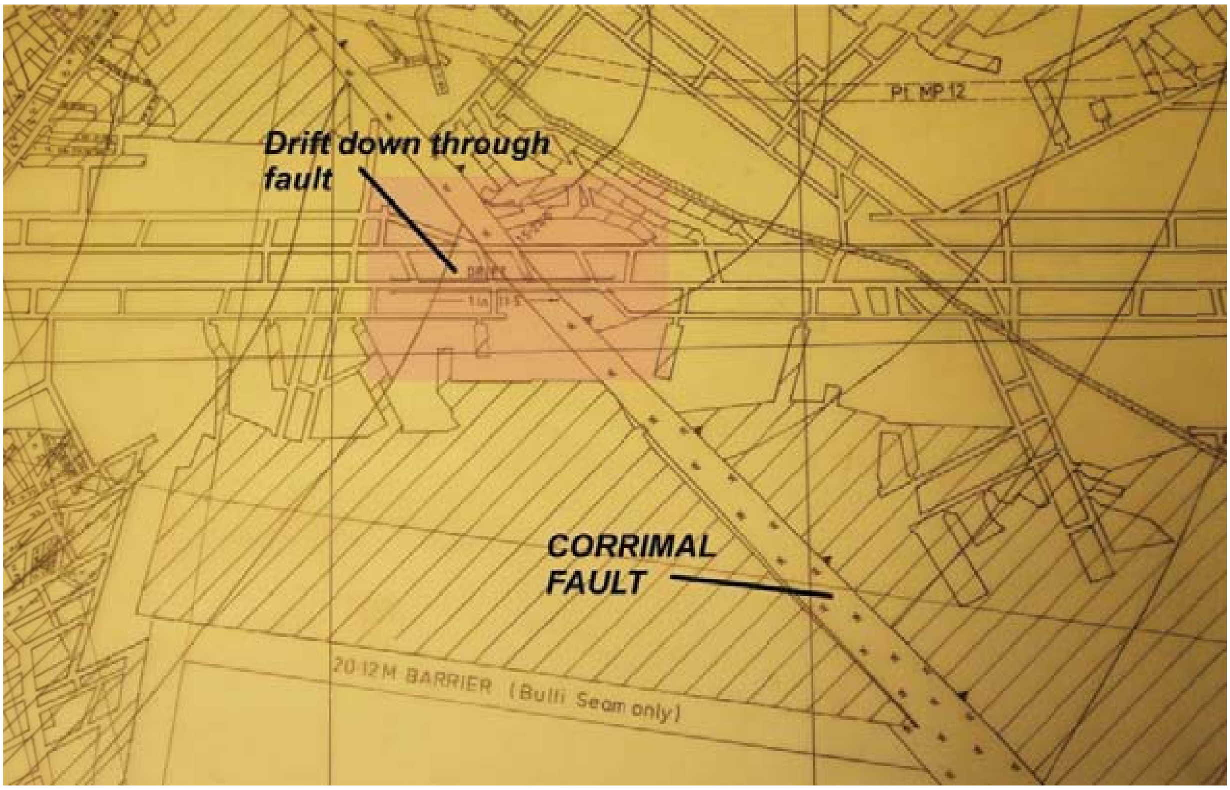

Figure 10 - Fault encountered in the Bulli Seam workings of South Bulli Colliery.

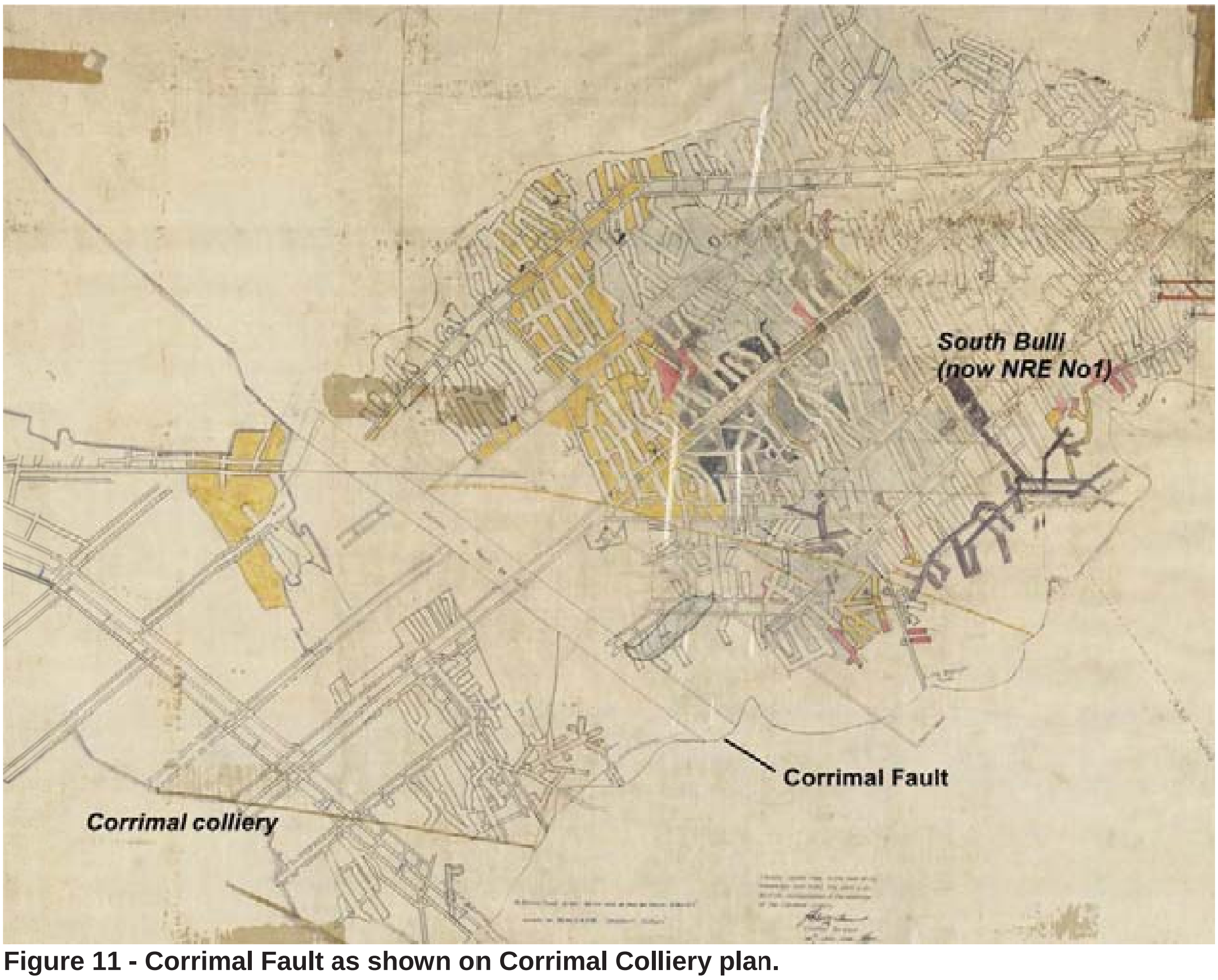

Figure 11 - Corrimal Fault as shown on Corrimal Colliery plan.

The SCA letter of 30 May 2011 raises the issue of faults and dykes in the Wonga East area not being taken into account in the subsidence predictions. The possible impacts of fault structures, in particular the Rixons Pass fault, is also raised in the DECCW letter of 24 June 2011.

The EA, and its various appendices, give due consideration to the stratigraphy of the near horizontal Triassic strata above the Permian coal seams. However, documentation of important geological structures such as faults, joint swarms and igneous intrusions is very limited, and consideration of the impacts of such structures on surface deformations, groundwater flow, and impacts on creeks and swamps, is not adequate.

One example, is that while presentation of the 3D groundwater model includes a figure showing geological structures, no such structures are actually included in the model.

It is also noted that the near surface stratigraphy set out in the flora and fauna report (Appendix J), postulating the presence of Wianamatta shales to the west of Lizard Creek, and beneath the Wallandoola swamp cluster, does not accord with the 1:100,000 geological map of the same area.

Our experience in respect to subsidence impacts in the Southern and Western Coalfields, covering areas such as Cataract Tunnel, the Hume Highway, Appin Road, Cataract River and Tahmoor Colliery, is that unexpected impacts on creeks, swamps and surface infrastructure are either related to geological structures, sometimes known beforehand (eg. Cataract Tunnel), sometimes unknown (eg. Appin Road), or rapid change in topography.

We have sought, in this regard, to correct this perceived deficiency in the presented EA, by collecting and collating geological structural information presented above.

4 PILLAR RUN

The term pillar run refers to the rapid, sequential, failure of coal pillars over a significant area of bord and pillar workings. Possibly the most infamous pillar run was at Colebrook colliery where, on 21 January 1960, 435 miners were killed as a result of the explosive collapse of some 900 coal pillars over an area of about $3km^2$. This tragedy lead to a series of major studies in South Africa (ref 2. and 7.) of the strength of coal pillars, including full scale testing (see Figure 12). Many other 'pillar runs' have occurred throughout the world (see Figure 13 for example from Brazil) and the factors relevant to such failures are now well understood.

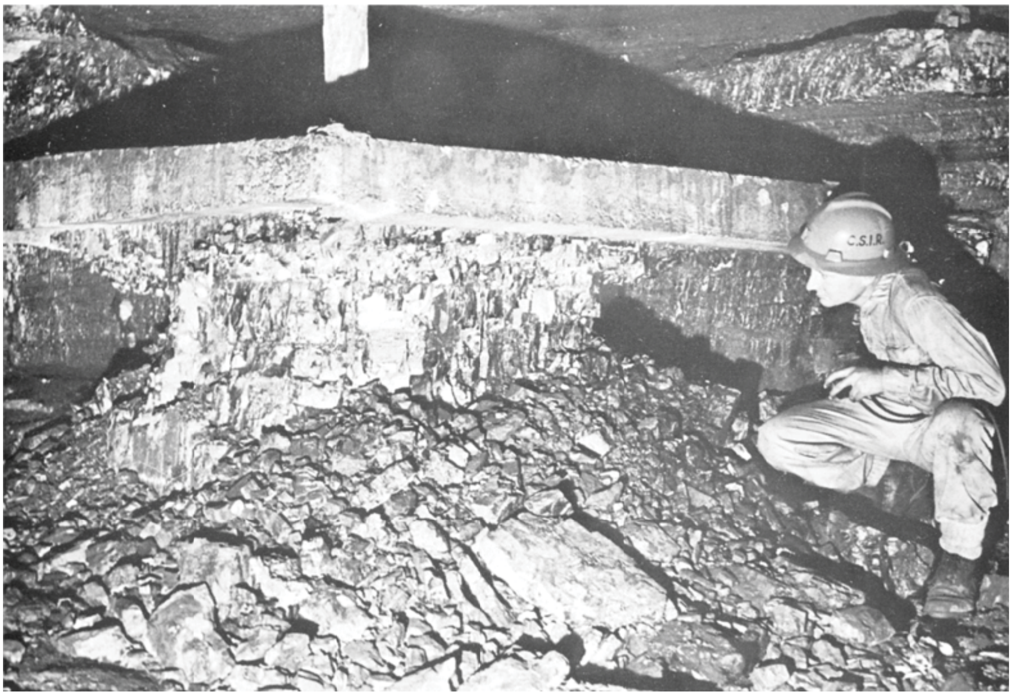

Figure 12 - Field testing of coal pillars, Witbank Colliery, South Africa

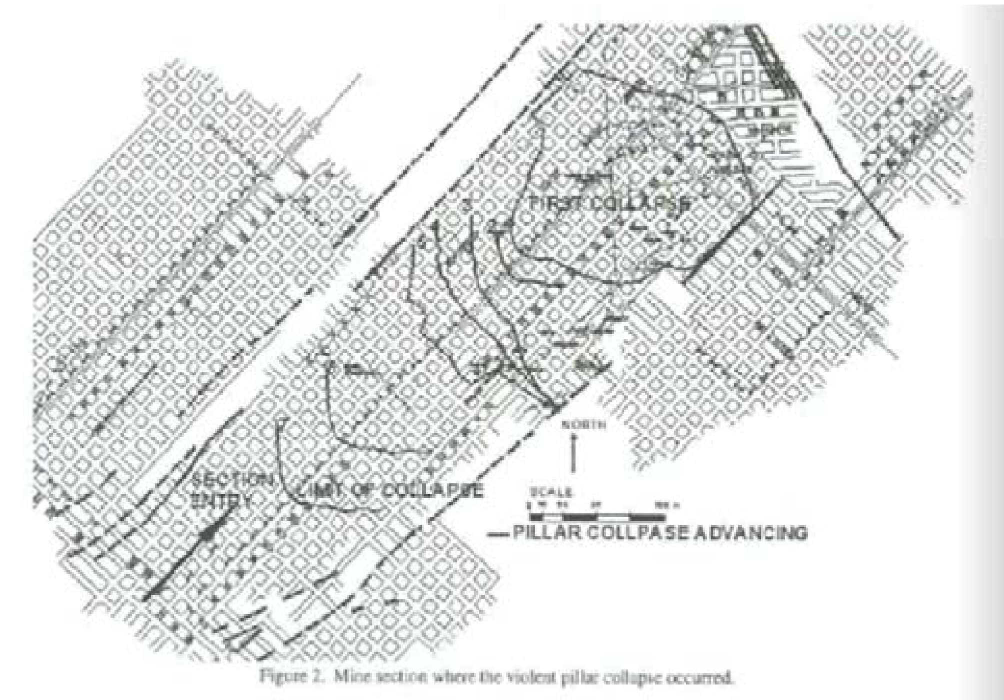

Figure 13 - Pillar run; Santa Catarina State Mine, Bonito Seam, Brazil

Annexure J of the EA provides the calculations relevant to determining the probability of pillar run occurring away from the proposed area of longwall mining in Wonga East. These calculations have considered pillars in both the overlying Balgownie and Bulli seam workings. They have assessed the probability of sequential failure, away from the new and existing goaf area, both to the south west (ie. towards Corrimal Colliery) and to the north east (ie. towards Mount Ousley Road).

The calculations given in Annexure K are based on the proper premise that overburden load will be concentrated on existing pillars around the perimeter of the goaf area. If these pillars can be shown to have an appropriate factor of safety against failure, particularly brittle failure, then propagation of failure, in either the Bulli or Balgownie seam, would be improbable.

We have reviewed the calculations in Annexure K and consider that they are appropriate in respect to calculation of pillar strengths. We are also satisfied, by virtue of the work reported in Section 2.2 above, that the pillar geometries, used in Annexure K, are appropriate.

Figures 14 and 15 are extracts from Figures 11 and 12 of Annexure K of the EA respectively. They show the computed factors of safety and width-to-height ratios of relevant pillars in the Balgownie and Bulli seam workings at Wonga East.

However, we consider that the calculations possibly underestimate the loadings on pillars to the north east of the goaf above the proposed Wongawilli longwalls[7]. Based on the numerical analysis of subsidence, discussed in Section 2 above, we consider that pillars to the north east of the goaf area may be subject to additional load from down drag within the goaf. This may lead to loads averaging about 20% greater than those calculated by tributary area theory. It is our opinion that the issue of pillar run in the Bulli Seam workings is more important than in the Balgownie Seam, primarily because the Bulli Seam workings are very extensive, extending to below Mount Ousley Road. Given our view that average pillar loadings may be about 1.2 times those adopted in the Annexure K calculations, it is considered appropriate to reduce the calculated factors of safety shown in Figure 14 (below) by that same ratio.

It was found that this does not negate the validity of the conclusion reached in Annexure K to the effect that there is a negligible probability of pillar run to the north east (towards Mt Ousley Road). There is also a very low probability of failure to the south west, not just because of the adequate factors of safety but also because of the presence of the Corrimal Fault that dips to the NE (see Drawing P043-6).

The computed factors of safety in the Balgownie Seam workings, as shown in Figure 15, indicate that there is an insignificant probability of pillar run into the relatively small area of bord and pillar workings to the north east.

The writer notes that the Technical Committee of the RTA, which is addressing possible impacts of the Wonga East mining, has also reviewed the pillar run assessment given in Annexure K and has accepted that there is an insignificant probability of such pillar run creating unexpected subsidence impacts on Mt Ousley Road.

[7] Annexure K assumes loadings to be in accordance with tributary area theory.

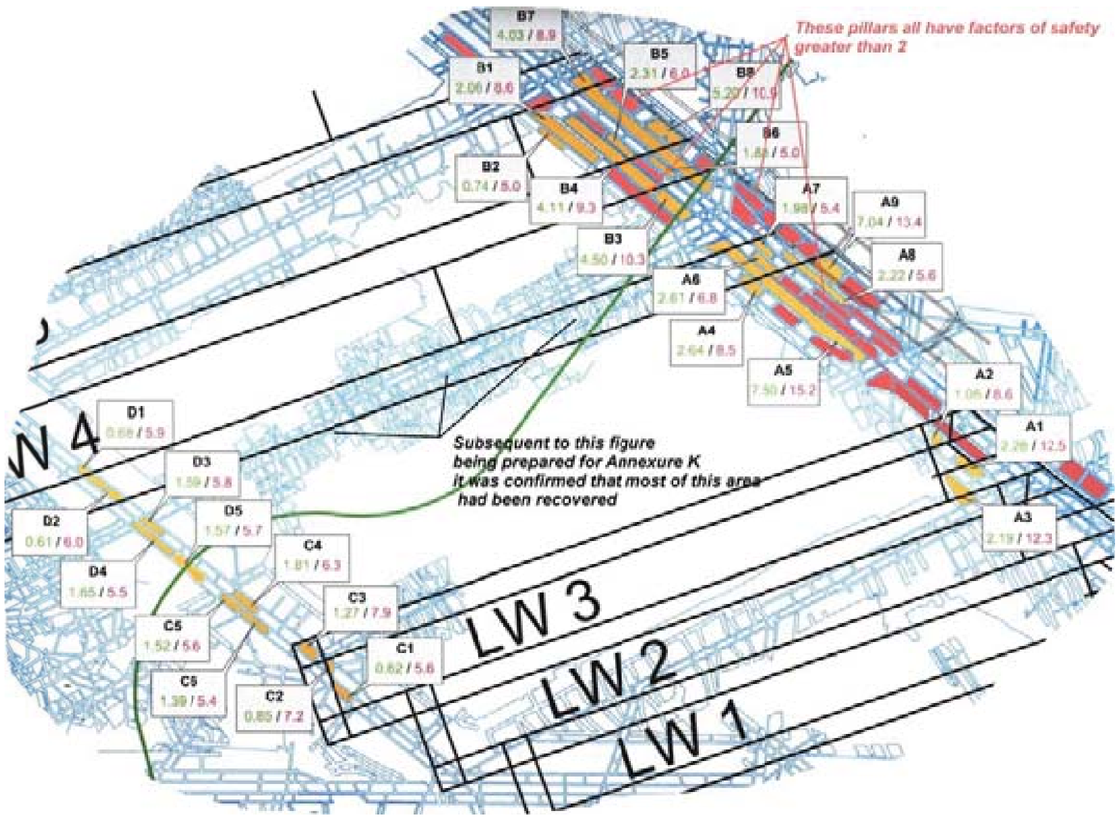

Figure 14 - Extract from Figure 11 of Annexure K of EA
Shows computed safety factors (green) and width-to-height ratios (red) ain Bulli seam.

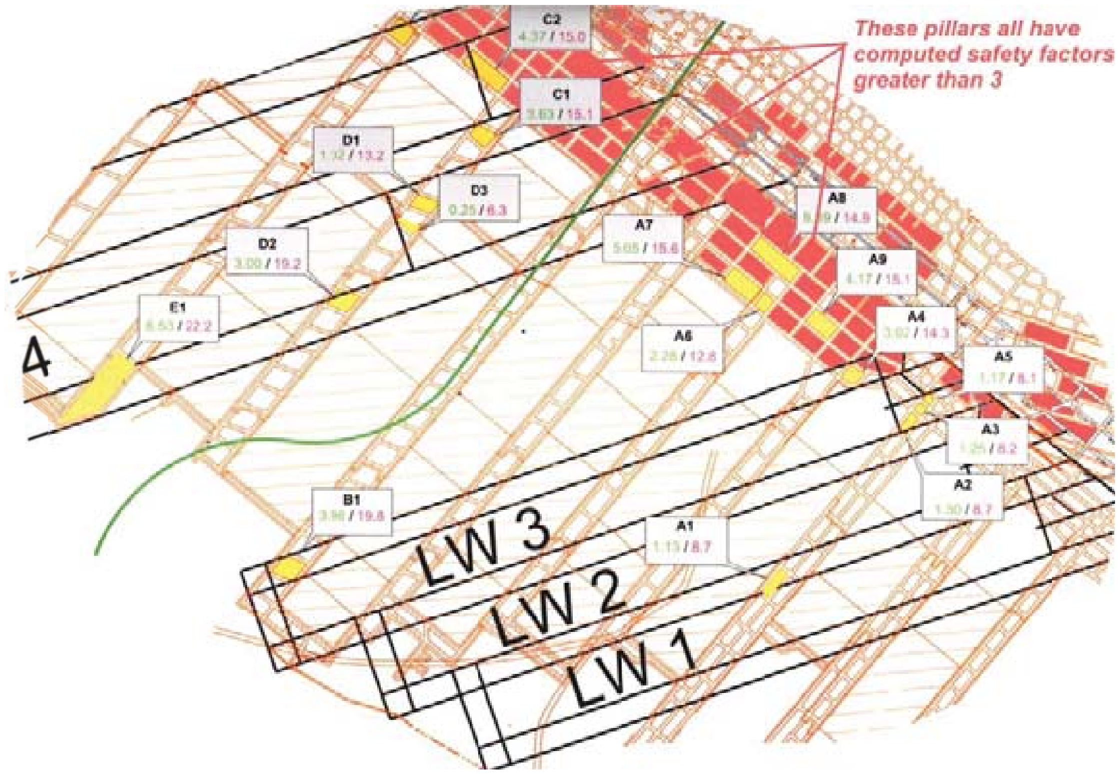

Figure 15 - Extract from Figure 12 of Annexure K of EA
Shows computed safety factors (green) and width-to-height ratios (red) in Balgownie Seam.

5 GROUNDWATER ISSUES

Commentary in the review letter SCA 14/4 stated that: "significant deficiencies exist in the EA", and questioned the adequacy of groundwater monitoring and groundwater modelling presented in the EA (see Appendix A for further details).

The groundwater monitoring and groundwater modelling undertaken for the EA are summarised in Sections 5.2 and 5.3 below, respectively. Independent comments on their adequacy is presented in Section 5.4. Additional efforts were made to in this report to resolve historical measurements from two deep piezometers, P501 and P502 by obtaining original installation reports not made available during preparation of the EA. This provides additional data for the EA, and these data are considered in our review

Prior to this discussion, it is considered important to establish a common basis for consideration of the effects of underground works on groundwater systems. In Section 5.1, a brief discussion presenting the considered viewpoint of the authors on this matter is given.

5.1 The Effects of Underground Works on Groundwater

Where underground mining activities encounter groundwater, the ensuing seepage is normally removed from the mine to maintain suitable working conditions. From a water balance perspective, seepage patterns must develop to replace the extracted groundwater. This must include a vertical seepage component from aquifers above the mine. The rate of seepage is a function on the hydraulic properties (hydraulic conductivity and storage characteristics) of the geological units[8].

By way of illustration, vertical flow through a saturated homogenous column of rock into a depressurised cavern will adopt a hydraulic gradient of unity. From Darcy's law, it follows that this seepage velocity becomes equivalent to the vertical hydraulic conductivity. With consideration to the typical wide range of hydraulic conductivities of geologic units, it follows that the rate of vertical seepage into mines varies widely. For undisturbed rock units typical in this study area vertical seepage rates in the order of 1×10^{-8} to 1×10^{-11} m/s may be expected. This is equivalent to rates of 0.3 to 300mm per annum, 0.00005 to 0.05mm per hour, or discharges of 1×10^{-8} to 1×10^{-6} litres per second per square metre of mine. Such seepage rates would be imperceptible to the observer. Nonetheless, over time and a large mining area, this amounts to accumulation of 0.025 to 2.5 ML/month per square kilometre of mine.

Hence, underground works initiate an ongoing process of depressurisation of the aquifers above the works, although the rate can be very slow, being controlled by the hydraulic properties of the geological units which vary widely. For many mines, including those in the southern coalfields, the slow process of depressurisation remains ongoing during the operation of the mine. In such cases, transient groundwater analyses are required to track the likely effects applicable during the period of the mine operations.

A vertical flow field creates a head distribution below hydrostatic conditions. This manifests as a reduction in standing water levels that would be recorded in bores. For example, bores in a saturated but vertical flow field, with downward hydraulic gradient of unity, would exhibit no standing water level at all. A mining effect of an

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[8] Given enough time, and depending on the nature of the geology, the quantity of vertical seepage may become limited by the available recharge.

otherwise negligible quantity of seepage (to the observer) but associated with a change in flow direction can have profound impacts on the groundwater regime. An example of this situation is shown in Figure 16, from Metropolitan Colliery.

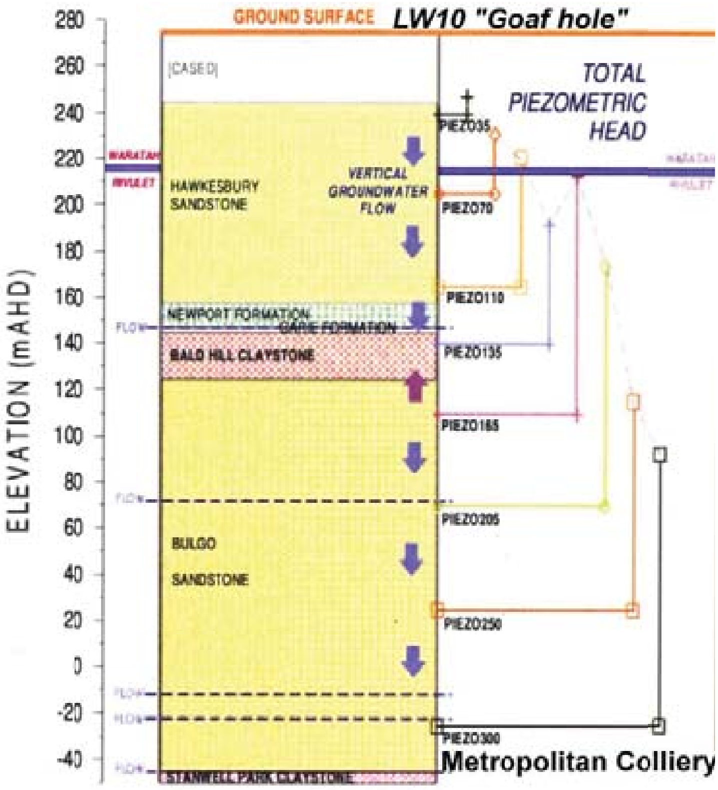


Figure 16 - LW10 goaf borehole, Metropolitan Colliery (Merrick, 2009)

Horizontal layers of low conductivity material in the geological strata will introduce impedance to vertical flow and the development of perched water tables. This does not indicate the cessation of vertical seepage, simply the reduction of the vertical seepage and rate of depressurisation in accordance with the hydraulic properties of the material. While the terms 'aquifers' and 'aquitards' are accepted (but non-standardised) terms to demarcate strata of differing characteristics, the writers reject the notion of the existence of 'aquicludes', which are understood to comprise geological layers that are completely impermeable. For example, aquitards, where present, are associated with smaller of groundwater flow rates *but not cessation of flow.* They are similarly associated with delayed rates of depressurisation *but not a removal of the effects of depressurisation* – it just takes a longer period of time.

Longwall mining also introduces a further issue of subsidence and associated fracturing:

- An increase of hydraulic conductivity through fracturing can impact substantially on the quantity of vertical seepage. Such impacts are contingent on the continuity of fractures, which varies. In some cases, discontinuous fracturing may result in little net change to the vertical flow regime.
- Increases to aquifer storativity through fracturing may be associated with large and rapid drawdowns of regional water tables. However, without

introduction of new flow paths through fracturing to drain the aquifer, this effect will be temporary.

- Fracturing at the surface can intercept streams or surface runoff, and redirect surface water flows to new locations, impacting on stream ecology. However, flow rates through cracks are slow compared to typical surface discharges during runoff events[9]. The quantum of surface water lost to cracking from intermittent or ephemeral streams will therefore be low.
- Increased drainage of the aquifer toward the mine (post fracturing) may lower regional standing water levels relative to creek bed levels. This would be associated with a reduction in creek baseflows.

5.2 Summary of Groundwater Monitoring Data Used in the EA

A summary of the groundwater bores used in the EA is given in Table 3 below. A plan and cross section of the NRE No 1 mining site is shown in Figure 17.

Deep bores at locations NRE-A to NRE-D were installed around the periphery of the proposed Wonga East workings. Deep bores at locations NRE-E, NRE-G and NE-3 were installed on the southern and northern periphery of the proposed Wonga West workings. These seven bores were installed by GeoTerra for the currently considered mining stages.

Existing deep bore P514 (1998) provided additional information at the periphery to Wonga West. Existing deep bores at locations P502 and P501 (Coffey Partners, 1992) provided information between the two locations, and adjacent to the proposed central Wonga workings. To the west of the mine lease, two deep exploration bores (BHP DDH120 and DDH 124) provided detailed stratigraphic logging. Piezometric data from vibrating wire piezometers and standing water level records from these bores are depicted in Figure 17.

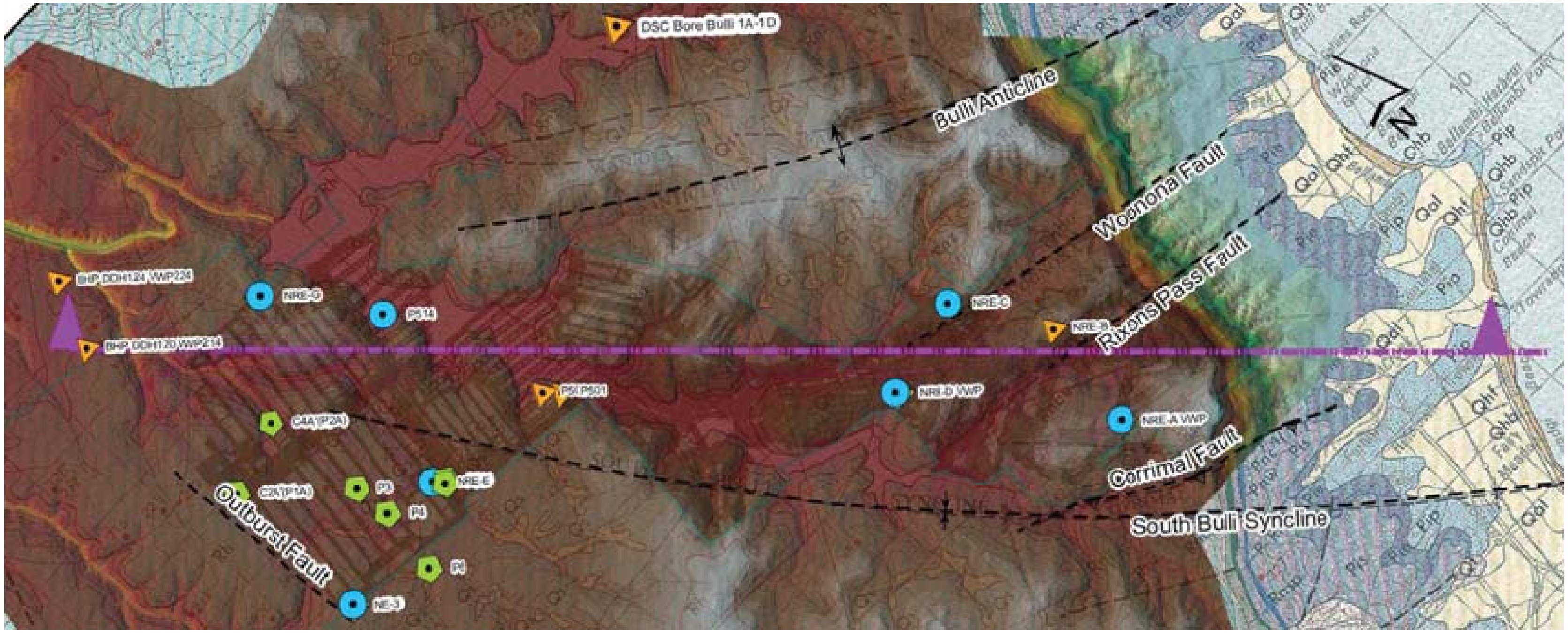
Shallow “swamp piezometers” at locations P1 to P6 at West Wonga were installed to monitor groundwater levels “within the perched valley fill and headwater swamps ... since July 2006” (EA, Annex M, pg 39). These six bores were installed by GeoTerra for the currently considered mining stages.

Packer tests were undertaken at various intervals within 6 bores to support the groundwater studies. Constant rate pumping tests were also undertaken at each of the bores to estimate hydraulic conductivity. Note that aquifer storage parameters were not estimated from bores during any aquifer pumping tests.

[9] With the exception of very large cracks.

Table 3 – Summary of Groundwater Investigation Bores Referenced in the EA

Name	Type	mE	mN	Date Installed	Depth (m)
NRE-A VWP	Vibrating Wire Piezometer	303680	6196034	Dec-09	153
NRE-B	Vibrating Wire Piezometer	303939	6197567	Dec-09	170
NRE-D VWP	Vibrating Wire Piezometer	301875	6198493	Dec-09	176
NE-3	Vibrating Wire Piezometer	294794	6201945	Dec-09	281
P501	Vibrating Wire Piezometer	298771	6201855	Dec-92	335
P502	Vibrating Wire Piezometer	298598	6202049	Aug-93	167
NRE-A	Standpipe Piezometer	303692	6196033	Nov-09	47
NRE-C	Standpipe Piezometer	303233	6198797	Dec-09	24
NRE-D	Standpipe Piezometer	201870	6198509	Nov-09	52
NRE-E	Standpipe Piezometer	296727	6202286	Oct-09	29
NRE-G	Standpipe Piezometer	296949	6205679	Oct-09	53
NE-3	Standpipe Piezometer	294804	6201954	Dec-09	60
P514	Standpipe Piezometer	297917	6204280	Nov-98	191
C2 (P1)	Swamp Piezometer	294808	6204141	Jul-06	1.72
C2A (P1A)	Swamp Piezometer	294795	6204130	Oct-09	2
C4 (P2)	Swamp Piezometer	295806	6204436	Jul-06	0.77
C4A (P2A)	Swamp Piezometer	295813	6204440	Oct-09	1.45
P3	Swamp Piezometer	295961	6202990	Jul-09	1.69
P4	Swamp Piezometer	296014	6202447	Jul-09	1.38
P5	Swamp Piezometer	296860	6202187	Jul-09	1.09
P5U	Swamp Piezometer	296820	6202161	Jul-09	1.47
P6	Swamp Piezometer	295854	6201546	Jul-09	1.79
BHP DDH120 VWP214	Vibrating Wire Piezometer	294825	6206962	Dec-05	516
BHP DDH124 VWP224	Vibrating Wire Piezometer	295215	6207858	Dec-05	554



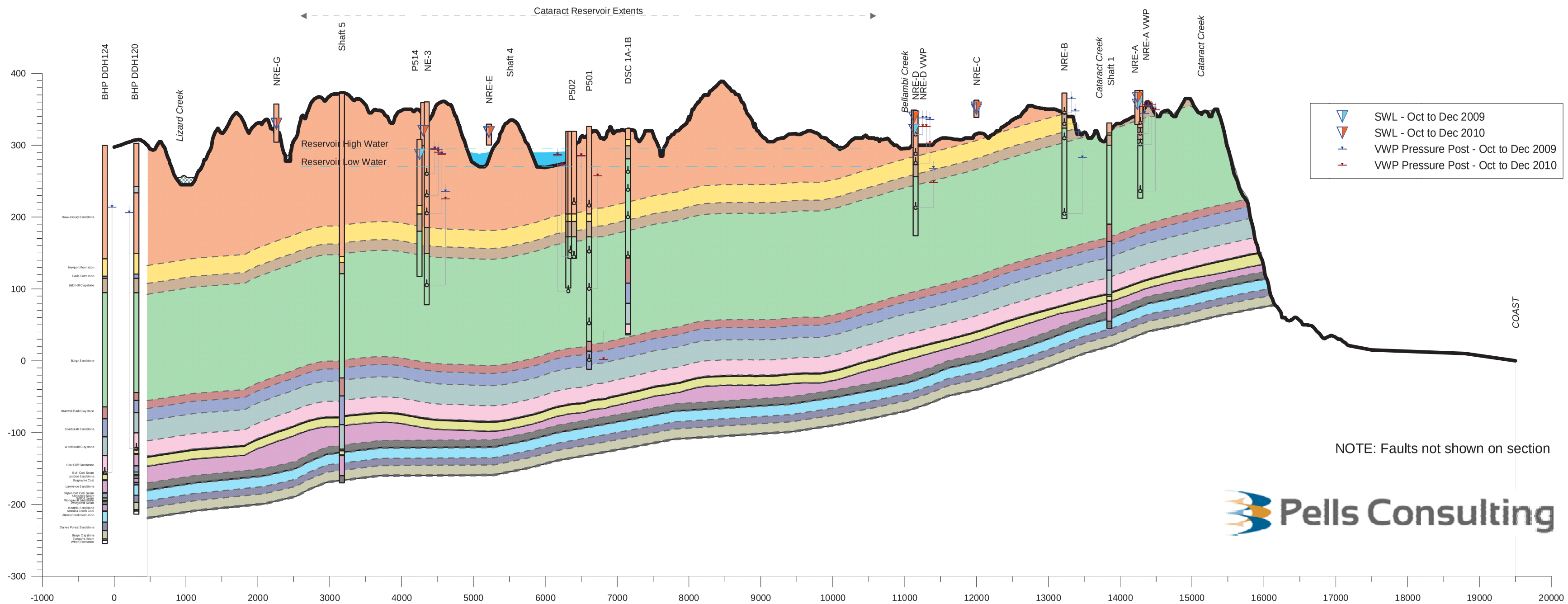


Figure 17 - Plan and Section Showing Bore Locations

5.3 Summary of Groundwater Modelling Presented in the EA

The numerical groundwater model undertaken for the EA comprised a 3D finite-element model simulating saturated transient groundwater flow using the code FEFLOW. The stated objectives of the model were:

- "*to assess the relative changes in the groundwater regime and recharge to surface water bodies due to the proposed mining*" (pg 1, Appendix A, Annex M of the EA), and;
- "*one of the main aims of the study has been to assess whether the main low hydraulic conductivity layers in the system, the Bald Hill Claystone, is sufficient to limit the effects of depressurisation on the Cataract Dam*" (ibid, pg 20).

The model represented the geology in 22 layers (similar to Figure 17 above). Structural geological features (such as faults and dykes) were not included in the model. The periphery of the model (including its base), it is understood, was defined by no-flow boundaries, and an assumed recharge of 2% of annual rainfall was applied to the model surface (ie. ranging between 20 to 35 mm/year). Hydraulic conductivities were increased in regions of the model to represent subsidence induced fracturing, relying on the EA's subsidence predictions as guide.

Applying these conditions, the model was used to simulate mine inflow discharges and aquifer desaturation for four periods:

1. Presented conditions [10];
2. 6.5 years from the present, corresponding with the planned end of mining at Wonga East ("Stage 1");
3. 14.5 years from present, corresponding with the planned end of mining at Wonga West ("Stage 2"), and;
4. 24.5 years from present, corresponding with a 10 year period of recovery after cessation of mining ("Stage 3").

A single alternative model conceptualisation was also run using alternative hydraulic conductivity parameters. This was undertaken as a cursory examination of the sensitivity of the model results to chosen parameters.

The predicted drawdowns (or depressurisation) at each stage was presented for selected geological sequences in figures in the EA. A summary of key values (approximated) was compiled and in presented in Table 4.

The model was also used to interpret potential changes on stream flow. A range of figures were presented in the EA showing the horizontal flow components (in plan) in upper formations for each of the mining stages.

Based on the modelling, the following key conclusions were presented in the EA:

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[10] The EA states that the present condition was represented with a 'quasi-steady state model', although the details of this are not presented in the EA.

Regarding the extent of depressurisation:

1. "*In Wonga West … with the Bald Hill Claystone intact the model indicated that near-surface depressurisation and effects … are estimated to be negligible*" (pg 24, Appendix A, Annex M of the EA)
2. "*In Wonga East area … the proposed workings … indicate depressurisation (of the order of 10 – 20 m near surface)*" (pg 24, Appendix A, Annex M of the EA).
3. "*The Bald Hill Claystone, where currently considered intact, was assumed to remain unaffected by subsidence above the proposed workings. As a result, the model indicated negligible drawdown in overlying strata*" … "*However, if subsidence develops in this area .. this may cause changes*" (pg 24, Appendix A, Annex M of the EA).
4. "*The Bulli and Wongawilli Coal Seams show significant recovery after 10 years, in both the Wonga West and Wonga East areas*" (pg 22, Appendix A, Annex M of the EA).

Regarding impacts to streams and reservoirs:

5. "*The modelled changes*" [to streamflow in the Cataract Creek catchment] "*are relatively minor (0.5 -0.6%) compared to the average flow in the creek to the Cataract Reservoir*" (pg 74, Annex M of the EA)
6. " *There is anticipated to be negligible change in stream flow or groundwater seepage in the Cataract River (upstream of Cataract Reservoir) and Bellambi Creek catchments due to the very low proportion of the two catchments that may be partially depressurised*" (pg 74, Annex M of the EA)
7. "*At Wonga West, no surface to seam free drainage is predicted through the Bald Hill Claystone*" (pg 77, Annex M of the EA)
8. "*It is not anticipated there will be any observable effects on Lizard Creek or Wallandoola Creek stream flow due to the limited depressurisation predicted by the groundwater model in the Upper Hawkesbury Sandstone aquifers*" (pg 77, Annex M of the EA)
9. "*Based on modelling, the potential effects of the proposed mine workings on Cataract reservoir are considered to be negligible*" (pg 22, Appendix A, Annex M of the EA)
10. "*Geoterra (2010) and other studies carried out for swamps indicate that they have perched water tables which are separated from the deeper regional water table by 10-20 m, and thus are not anticipated to be affected by the proposed workings*" (pg 22, Appendix A, Annex M of the EA)
11. "*In Wonga West … we expect negligible impact on flows in the overlying streams … in Wonga East … in the area of Bellambi Creek and the Cataract River upstream of the Cataract reservoir, the model indicated negligible drawdown in the Hawkesbury Sandstone … and therefore we expect a negligible impact on flows in these creeks*" (pg 22, Appendix A, Annex M of the EA)

It is noted here that the statements given under Points 1 and 2 above do not accord with the results as summarised in Table 4.

Table 4 – Summary of Predicted Drawdowns from EA Groundwater Model

Model Layer	Geological Sequence	Thick-ness (m)	Depth (mBGL)	Predicted Drawdowns[1] (m)			
				Stage 1		Stage 2	
				Wonga East	Wonga West	Wonga East	Wonga West
1	Hawkesbury Sandstone (Upper)	20	20				
2		17	37	4 (20)	4 (3)	2	12
3	Hawkesbury Sandstone (Lower)	43	80				
4		77	157	5	4	4	12
5	Newport and Garie Formation	12.2	169.2				
6	Bald Hill Claystone	20.1	189.3				
7	Bulgo Sandstone (Upper)	51	240.3				
8		20	260.3	8	6	5 (10)	100 (80)
9	Bulgo Sandstone (Lower)	48	308.3				
10		23	331.3	30	40	10	180
11	Stanwell Park Claystone	17.1	348.4				
12	Scarborough Sandstone	19.5	367.9	40	110	10	140
13	Coalcliff Sandstone (Upper)	49	416.9				
14	Coalcliff Sandstone (Lower)	27.7	444.6				
15	Bulli Coal Seam	2.3	446.9	50	130	20	120
16	Loddon Sandstone	9.5	456.4				
17	Balgownie Coal Seam	1.2	457.6				
18	Lawrence Sandstone	17	474.6				
19	Eckersley Formation	7.6	482.2				
20	Wongawilli Coal Seam	9.7	491.9	55	60	40	90
21	Kembla Sandstone	9	500.9				
22	Generalised Sedimentary Unit	50	550.9				

[1] As presented in the EA. Bracketed values indicate results from alternative (sensitivity) model scenario

5.4 Review

5.4.1 Monitoring Data

Data from piezometers P501 and P502 were reviewed by Pells Consulting with reference to original installation reports[11]. Plots showing the vertical pressure distribution in P501 and P502 are presented in Figure 18, with the piezometric head at each measurement location presented on 'stick plots'.

These plots indicate that a hydrostatic profile was observed at P501 at the point of installation (10th December 1992), with the standing water table at all levels corresponding with typical levels in Cataract Reservoir. Shortly after installation (15th January 1993), a vertical downwards pressure profile began developing with depressurisation of the lower piezometers, in response to first workings adjacent to P501. Almost-hydrostatic conditions were observed at the shallower locations of P502 when it was first installed (12th August 1993), but ongoing depressurisation was evident. Complete depressurisation of lower formations at-and-below the Scarborough Sandstone are currently maintained, as recorded by ongoing measurements from P1 and P2. It is the writer's view that this depressurisation front is expected to keep moving upwards and will progressively impact on the shallower piezometer locations. However, the rate of depressurisation in determined by the hydraulic properties of the strata, which are not known with confidence.

Presentations of piezometric data from other vibrating wire piezometers and standpipes have also been included in Figure 17, using a similar 'stick plots'. This data shows the presence of a vertical downwards pressure gradient across the site.

The groundwater monitoring program provides valuable data to assist with characterisation of the groundwater systems. This characterisation can always be improved with additional field investigations. It is not possible to comment on the adequacy of the groundwater monitoring program to satisfy statutory guidelines, as no such statutory guidelines exist.

The available monitoring data does not provide a confident assessment of the water tables in the Upper Hawkesbury Sandstones across the site, and hence does not provide quantifiable insights into the groundwater dependency of streams. Similarly, there is no stream gauging data. The available data does not support a confident assessment on impacts to surface water systems, and it will be difficult for the monitoring to perceive and quantify impacts to surface water features from mining.

[11] The complete findings are presented in a letter to Gujarat NRE (Pells Consulting, 2011).

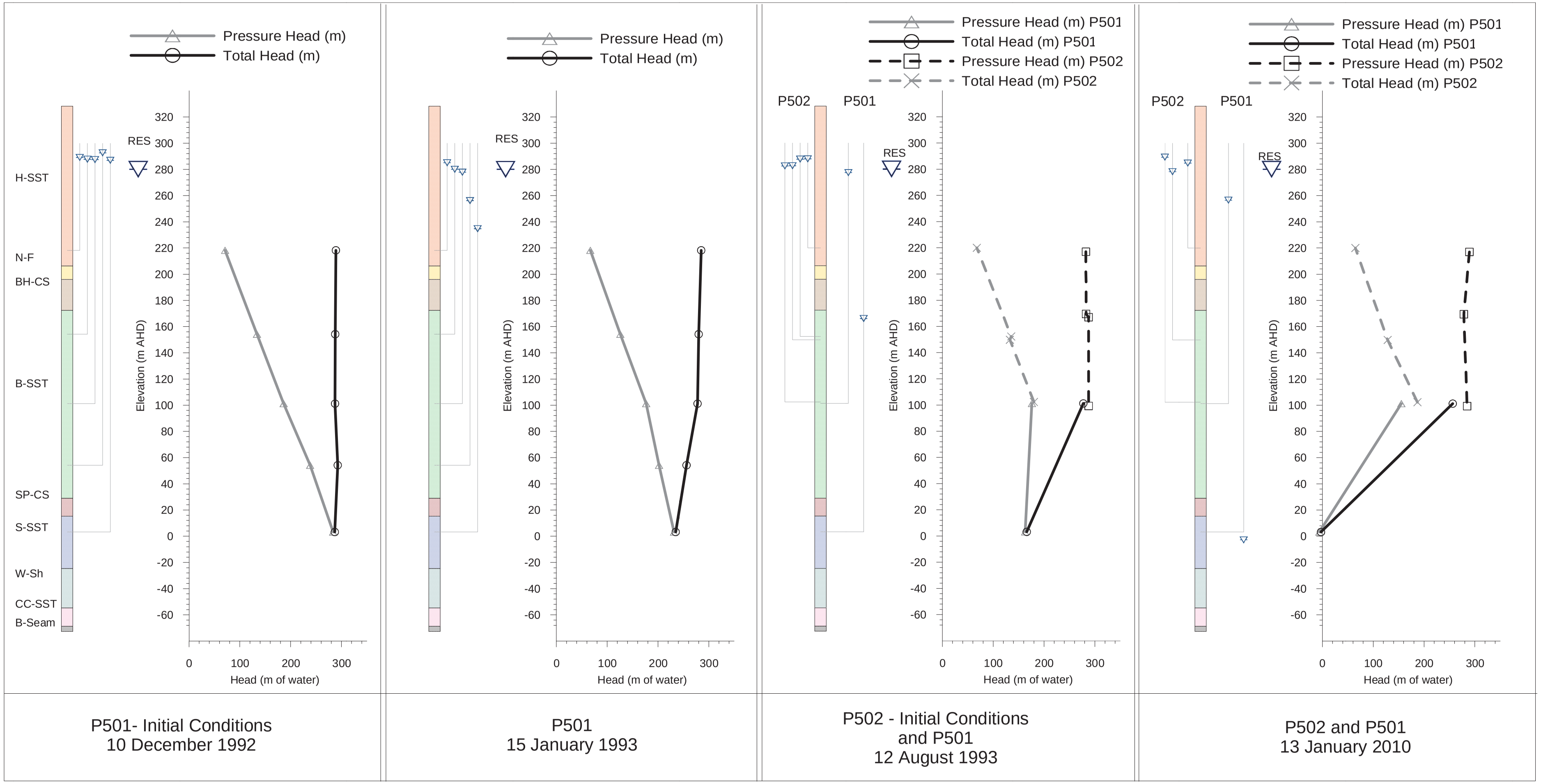

Figure 18 - Profiles of Readings from P501 and P502

5.4.2 The Bald Hill Claystone as a Confining Layer

Commentary in the review letter SCA 30/3 noted that "the groundwater modelling predictions have been based on … an assumption that the Bald Hill Claystone aquitard will remain intact and unaffected". It is agreed that this assumption is evident in both qualitative descriptions and in the numerical representation of the groundwater systems in the EA. For example:

- in the Executive Summary in Annexure F, it is stated:

  "The Bald Hill Claystone hydraulically separates the Hawkesbury Sandstone and Quaternary units from the underlying Bulgo Sandstone and deeper lithologies, except where it has been eroded away in the mid valley of Cataract Creek at Wonga East."

- The groundwater model (p19 Golder Associates, in Annexure F) adopts a very low vertical permeability for the Bald Hill Claystone[12] and assumes no change to this permeability in any of the relevant mining scenarios, namely triple seam mining at Wonga East, and double seam mining at Wonga West.

The writers conclude that the role of the Bald Hill claystone in reducing mining impacts has been overstated in the EA for the following five reasons:

1. The Bald Hill Claystone is not continuous across the site

   With reference to Figure 6, it is noted that the Bald Hill Claystone 'daylights' in the eastern region of the site. The Bald Hill Claystone does not form a complete 'blanket' over the site. This was noted by the SCA and was also acknowledged and incorporated in the numerical model, but it may not have been given due recognition in the text of the EA.

2. The monitoring data does not support the statement that the Bald Hill Claystone is creating a hydraulically disconnected system.

   The piezometric monitoring data presented in Figures 17 and 18 and discussed in Section 5.4.1 show that a vertical pressure distribution exists, including in and above the Bald Hill Claystone. The evidence from the Coffey's data for P501 and P502 suggests that such a distribution developed in response to mining. This has significant implications in respect to borehole water levels and creek recharge and infers that the Bald Hill Claystone does not hydraulically separate shallower groundwater systems from mining effects

3. The values used to model the Bald Hill Claystone are not congruent with the measured properties

   The Bald Hill Claystone is an approximately 20m thick layer of interbedded, kaolinite and haematite, siltstone, claystone and fine sandstone. It contains as many as eight soil profiles[13] (ie. eight superimposed palaeosols), is fissured and jointed, and is transgressed (in places) by faults and igneous intrusions (see Photographs 3 to 5).

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[12] In the Golder Associates report (p16) the permeability data are said to be derived from work at Metropolitan Mine and BHPB Bulli Seam Environmental Assessments. The data is not given, nor are the references given despite Metropolitan Mine being indicated as Reference 5.
[13] Herbert (1980) Chapter 2 *A Guide to The Sydney Basin.*

Permeability data from packer tests in the Bald Hill Claystone were compiled, including packer tests undertaken by GeoTerra for the EA, and also from other relevant locations, including at Kemira (presented in a MWS & DB report to the Reynolds Inquiry, 1974), and at numerous locations in the Sydney Basin (presented in Pells, 1993). These data are presented in Figures 19 and 20. The values for vertical and horizontal conductivity used in the numerical model are also presented in Figure 20.

With reference to these figures, there is a substantial range in measured (packer-test) hydraulic conductivity values – 4 to 5 <u>orders of magnitude</u>. The available data does not show the Bald Hill Claystone having a distinguishably lower hydraulic conductivity than adjacent formations.

It is accepted that lower permeability values may be selected for the Bald Hill Claystone based on its known constitution of fine clay and silt materials. However, the values of hydraulic conductivity for the Bald Hill claystone used in the model may be too low, and are not congruent with the available data.

4. The assumption that the Bald Hill Claystone will not be impacted by subsidence needs to be tested.

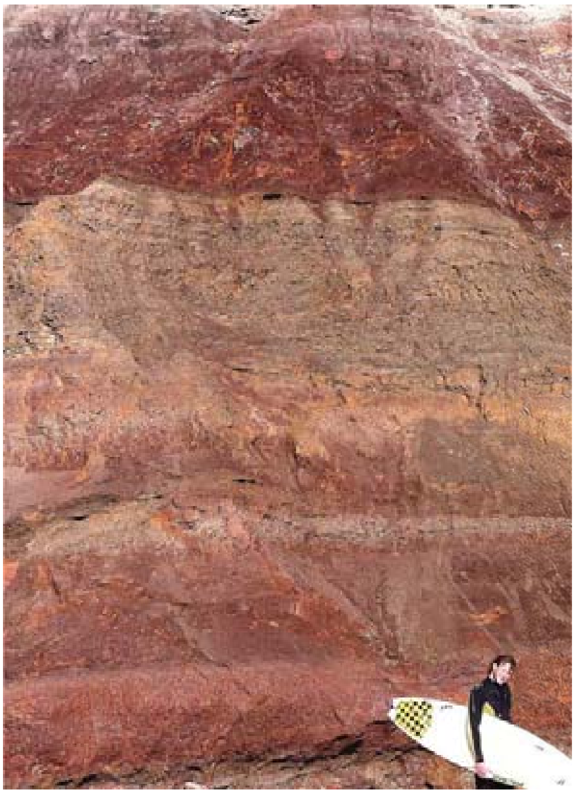
   The subsidence modelling suggests that connective fractures will not extent up to and beyond the Bald Hill Claystone. However, it is possible that the Bald Hill Claystone characteristics may be changed under the vertical translations predicted, and this uncertainty should be considered in the groundwater assessments.

   In our opinion, given the key role that the Bald Hill Claystone allegedly has in protecting surface features, and the uncertainty in subsidence assessments, it is inappropriate to base conclusions on a single, very low, permeability value for the Bald Hill Claystone, and to determine that this will not be affected by mining.

5. The philosophy of 'hydraulic separation' requires clarification

   The philosophy that a geological feature such as the Bald Hill Claystone could create a 'hydraulic separation' needs clarification. Clarification is required between *quantity* of groundwater flow, and *direction* of groundwater flow (and the orientations of groundwater equipotentials). Clarification is also required regarding the transient effects - i.e. the time taken for depressurisation to occur. The timing of depressurisation is important, given the finite time of the mine. This rate is very sensitive to the values of hydraulic conductivity and storage values chosen, which are not known with confidence.

   The presence of a low permeability horizon will reduce the quantity of vertical flow, but the development of a vertical flow direction, albeit slower, will still (eventually) occur and will still be associated with significant depressurisation and its effects.



Photograph 3 – Bald Hill Claystone at Long Reef

Photograph 4 – Joints in Bald Hill Claystone at Bald Hill

Photograph 5 – Through going joint type section, Bald Hill

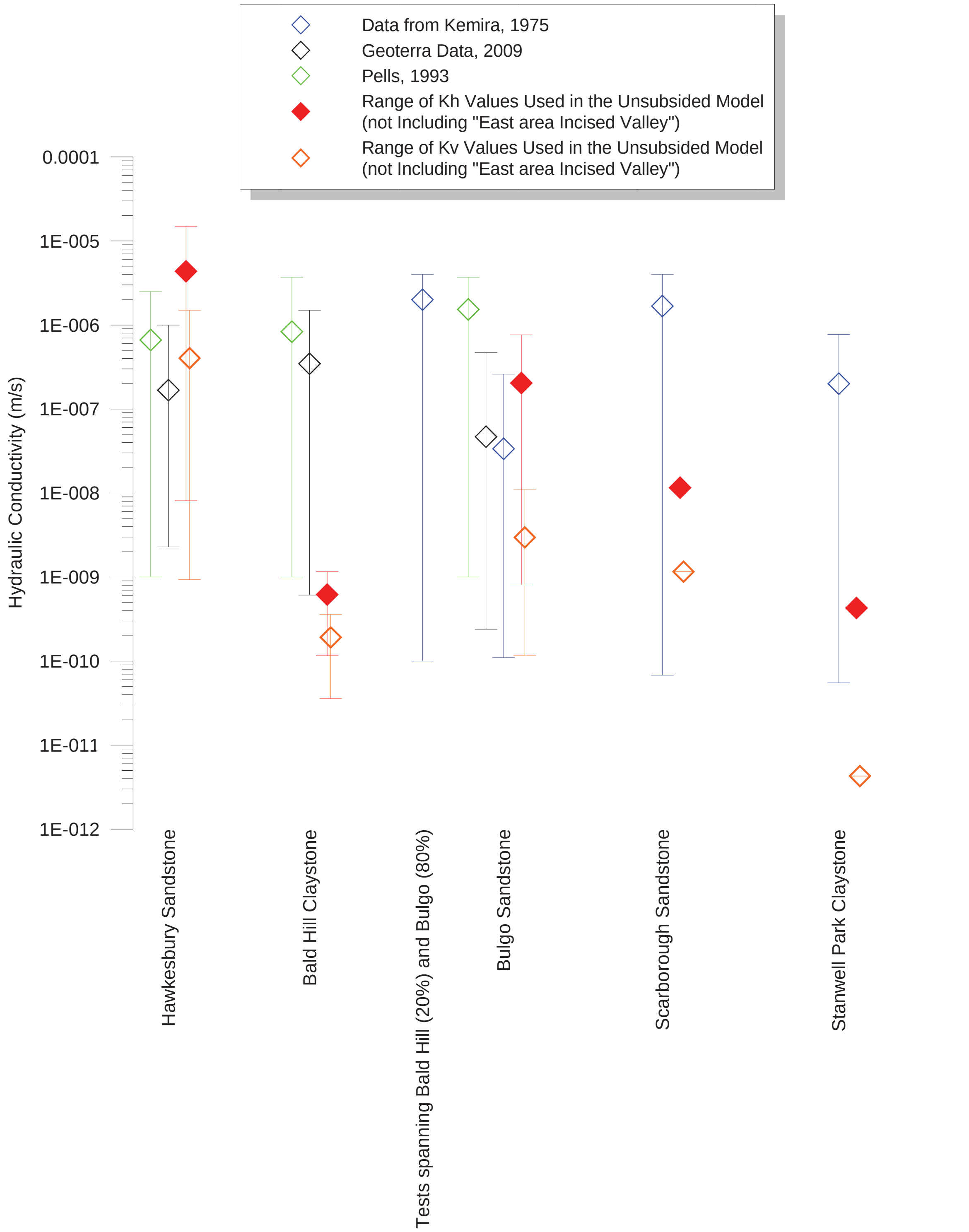


Figure 19 - Permeability data for the stratigraphic units above the Bulli Seam

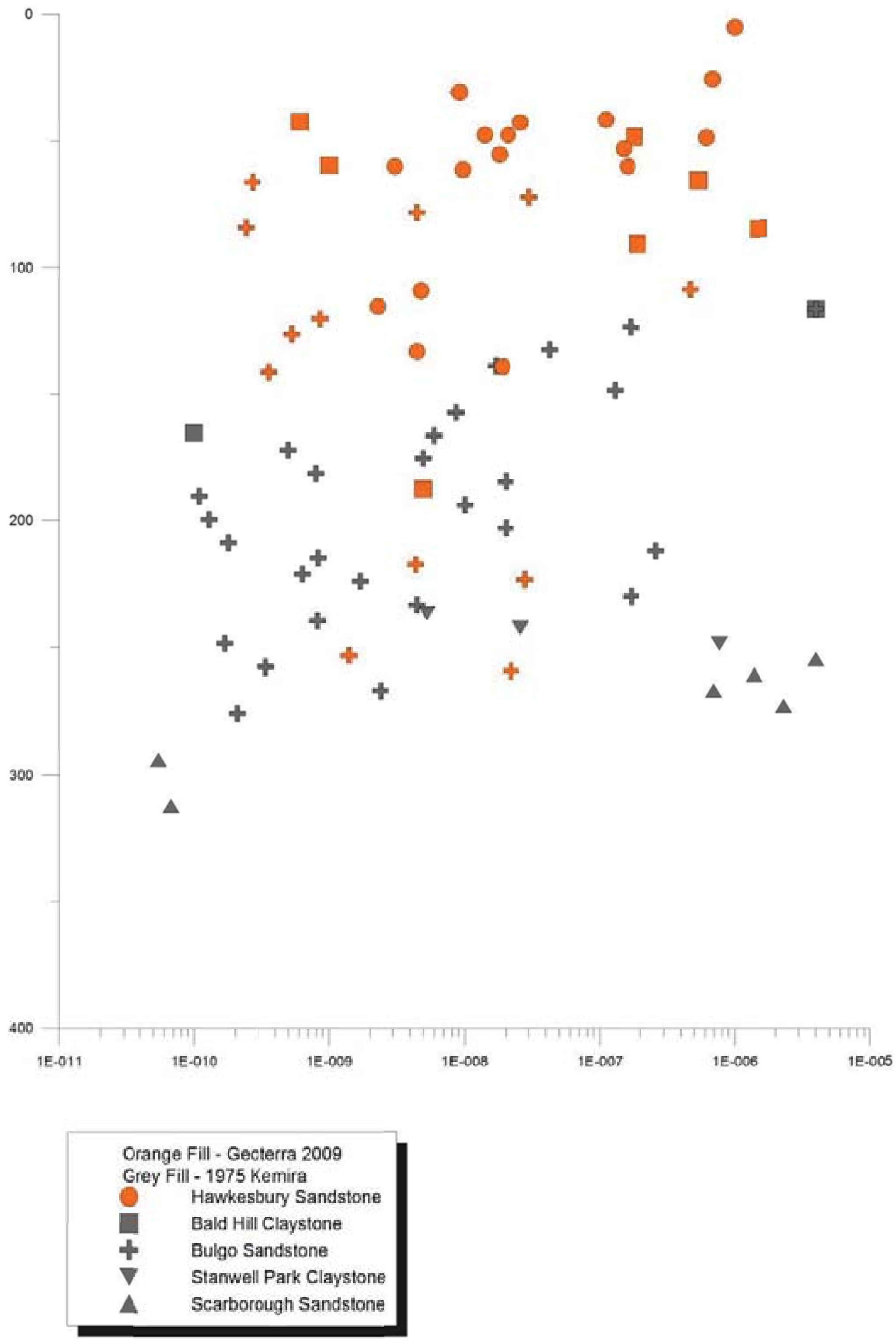


Figure 20 - Permeability data plotted versus depth

5.4.3 Connection to Cataract Dam

In 1975 and 1976 the Australian Atomic Energy Commission carried out studies of tritium levels in water seeping into the Bulli Colliery near Cataract dam.

Sampling at the Bulli Colliery was from the major fault that passes through this colliery (see Figure 21), and from dyke intersections.

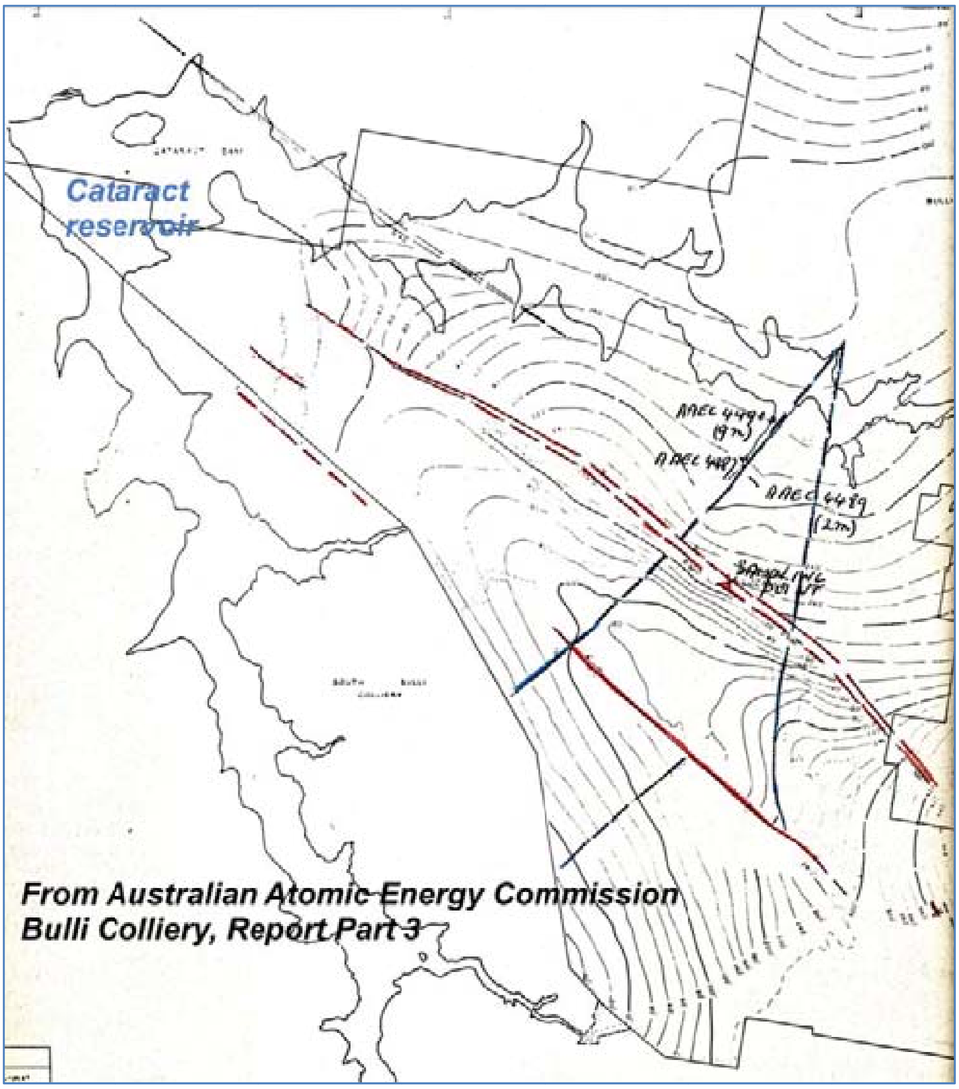


Figure 21 - Diagram showing major fault that passes through the Bulli Colliery

The results of this testing indicated that, if any water was seeping from Cataract reservoir to the sampling point, it was taking a very long time for the flow passage. The tritium levels in the colliery seepage were very low.

Our investigations indicate that there are very small seepage inflows into the existing Bulli Seam workings at Wonga West, directly beneath Cataract reservoir.

The records submitted by NRE No 1 Colliery to the Dams Safety Committee show that between October 2005 and April 2011 the net inflow into the whole mine (Wonga West and Wonga East) was about 20 megalitres/month (~ 7.7 lit/sec) between 2005 and 2008 and less than 10 megalitres/month in 2010 and 2011 (to April 2011). This

includes water seeping into the colliery from the old Corrimal Colliery and the Cordeaux Colliery. The Cordeaux Colliery is closed and is being allowed to fill with water. As of July 2011 the water level in the colliery was about -80m AHD.

Given the seepage of between 4 and 8 litres per second is from an area of at least 60 square kilometres it can be calculated that this equates to an average vertical permeability, of the overlying strata, of about 5×10^{-8}m/sec, to 1×10^{-7}m/sec. It is accepted that some water is lost through evaporation underground, but it is also noted that the 60 square kilometres may be an underestimate. The point is that the computed permeability is consistent with values derived from borehole measurements.

In addition to the considerations set out above, we have read the findings of the Reynolds Inquiry, and have read the submissions by the MWS&DB to that inquiry[14].

It is our conclusion that there is an insignificant probability of seepage flows of greater than 1 lit/sec from Cataract reservoir to the proposed Wongawilli longwalls in the Wonga West area, longwalls that are not beneath the reservoir.

5.4.4 Impacts to Streams

The conclusions drawn in the EA regarding impacts to streams (see Section 5.3 above) generally indicated minor to negligible impacts, based on the anticipated small seepage quantities and the properties of the Bald Hill Claystone.

Our review concurs that there is insignificant seepage quantity down into the existing Bulli Seam and Balgownie Seam workings, whether from the natural groundwater table, streams, swamps or Cataract Dam. However, the following factors have not been adequately addressed in the consideration of impacts to streams and surface water resources:

1. Consideration of geological structures;
2. Consideration of uncertainty in the properties of the Bald Hill Claystone, before and after mining, and;
3. Following review of the Bald Hill Claystone, consideration of the impacts of changes in pressure (not just flow quantities) to baseflows to creeks, swamps and existing water bores (if any).

[14] We have a set of the original MWS&DB files in our possession.

5.4.5 Adequacy of Groundwater Modelling

In a letter from the SCA (30.3), concern was raised of the statement in the EA that "model results should be considered as indicative only".

It is the writer's view that this is the correct understanding of the role of the numerical model – as an indicative tool - and we support the statement made in the EA. Mining in the area pre-dates the monitoring data. This rules out the possibility of establishing a calibrated pre-mining model. As such, the model does not provide confident assessments of the absolute condition of groundwater but only provides insights into the relative changes to the groundwater regime from mining effects.

This is not to say that the model is inadequate. Based on review of the EA, the model appears to be constructed to industry standards, and presents many useful findings. The reviewer argues that the model is more complex than warranted by the available data, but this does not negate its function.

It is not considered necessary to re-state shortcomings which are well known and common to all numerical groundwater models. However, the following items are considered by the reviewer to warrant further investigation for this study:

1. Sensitivity

As a transient simulation, the model attempts to predict the extent of desaturation at various periods in the future of the mine. The development of desaturation over time is highly sensitive to the values chosen to represent hydraulic conductivity and storage. These values are not known with confidence, and there is additional uncertainty introduced by the subsidence effects.

It is concluded that the examination of sensitivity (the range of possible predictions that can occur under the current level of uncertainty) has not been adequately addressed in the EA. The sensitivity studies presented in the EA also do not address the range set out in the PAC report for the "Bulli Seam Operations" (2010)

2. Geological Structures

While the layout of structural geological features is plotted with the groundwater results, it is understood that no such features were included in the model. As already stated, these features exert a significant influence on groundwater flow, particularly after subsidence effects.

6 STREAMS AND SWAMPS

6.1 Introduction

In our view, it would be very difficult to write a better description of the potential impacts on swamps and streams of mining induced groundwater changes, than that given in the Bulli Seam Operations, Planning Assessment Commission (**PAC**) report of 2010. Appendix B includes extracted important parts of that report that are relevant to our assessment of likely impacts of the proposed NRE No 1 longwalls.

6.2 Wonga West Streams Classification

There are two named creeks (Lizard and Wallandoola), and two tributaries of Lizard Creek, in the Wonga West area, as shown in Figure 22.

Figure 22 - Creeks and swamps, Wonga West

Lizard and Wallandoola are designated Category 3 streams. The northern part of the central tributary of Lizard Creek also classifies as Category 3 according to the streams shown on the 1:25 000 map (see Figure 23). This is by virtue of a very short stream drawn under the '0' of Wallandoola.

While it is accepted that streams shown on 1:25 000 topographic maps are the basis for categorization, we note that the short stream, that leads to a Category 3 classification of the tributary, cannot be seen in the contour map or stereo aerial photographs of various vintages (see Figure 24). An inspection of the area was made during which the small stream could not be found.

In our opinion the tributary of Lizard Creek should be classified as Category 2, as per Figure 25. However, even if this formality is not accepted, it appears inappropriate to evaluate the tributary as being equivalent to Wallandoola and Lizard Creeks.

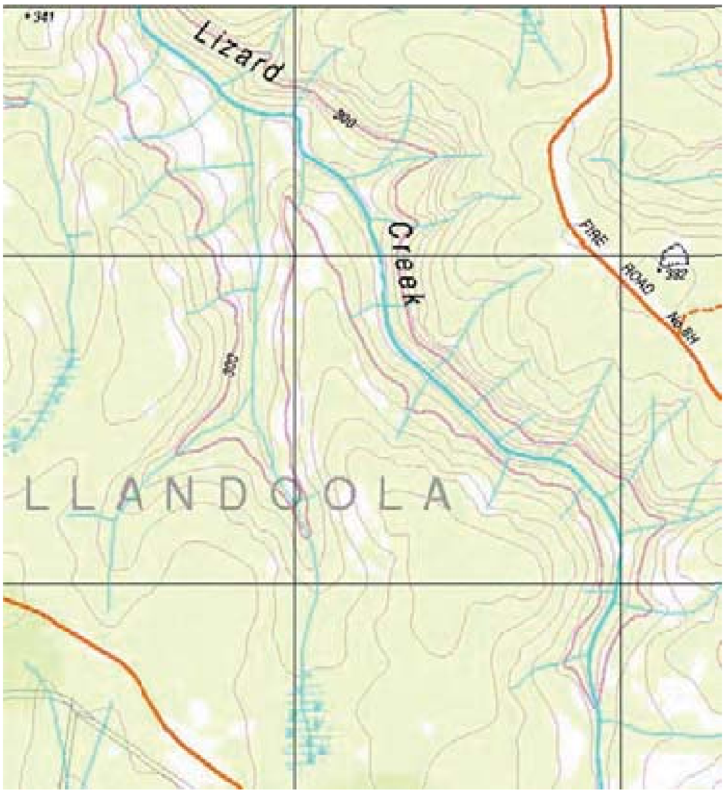


Figure 23 – Lizard Creek

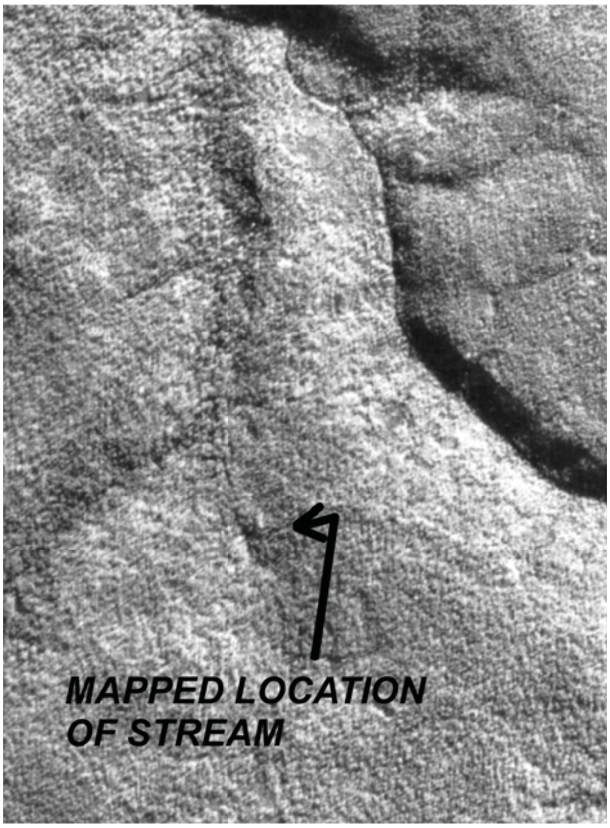


Figure 24 - Mapped location of stream

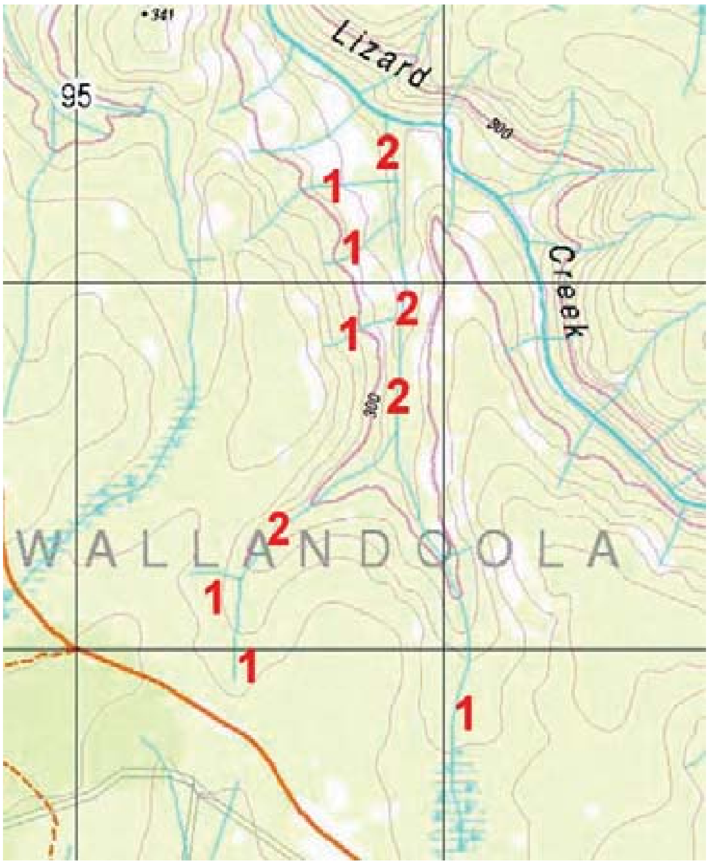


Figure 25 – Lizard Tributary, suggested classification

6.3 Impacts on Wonga West Streams from previous mining

Impacts on the streams discussed above from the Bulli longwall mining are set out in detail in Annexures D, F and M of the EA. These findings are shown in Figure 26 and may be summarized as set out below.

1. There are clear signs of negative impacts from the previous Bulli longwalls on Lizard Creek downstream from the point that has been termed the "Cracked Peat Hole".
2. There are clear signs of negative impacts on Wallandoola Creek downstream of the observation point WC4.

There is no need for us to repeat here the details of the damage to Lizard and Wallandoola Creeks that can reasonably be ascribed to subsidence impacts from the previous Bulli Seam longwall mining. The one point we would note is that the reported stream collapse at the 'cracked peat hole' corresponds to the point where a major dyke system crosses Lizard Creek. We think this dyke has contributed to what appears to be a collapse of the bed of the creek.

Specific questions in relation to Lizard and Wallandoola Creeks, raised by the regulators, are addressed in Appendix A.

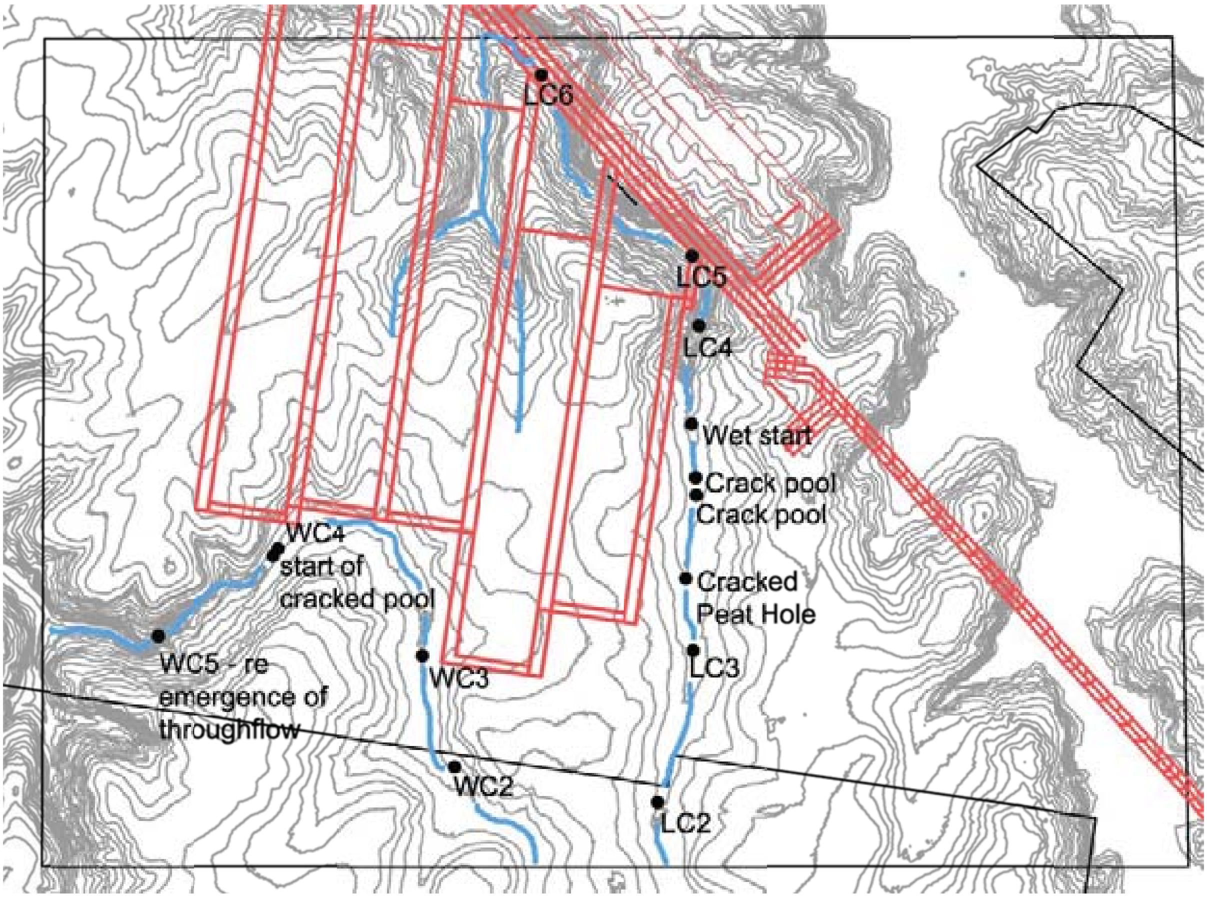


Figure 26 - Crack sites, from EA

6.4 Wonga West Swamps

Figure 22 shows swamps, detailed in Annexures D, F and M of the EA, that are above or close to the proposed Wonga West longwalls.

We have not independently evaluated all these swamps. We have inspected two of the valley fill (vfs) swamps that are south of the existing Bulli Seam longwalls and proposed Wongawilli Seam longwalls. These are wcvfs1 and lcvfs1 (Lizard Creek Valley Fill Swamp 1). At the time of our inspection (July 2011) both these swamps had water at or above the surface, were spongy, and densely vegetated (see Photographs 6 and 7).

Annexure D (Flora and Fauna) reports (p67) that, in 2009, the Lizard Creek and Wallandoola swamps were observed "to be in good condition". Annexure F (Colliery Stream Assessment) records as follows:

"10.7.2 Headwater Swamps

No adverse effects on swamp water flow, water quality or ecosystem health have been observed in headwater swamps over the Wonga East and Wonga West Study Areas resulting from subsidence over the Bulli or Balgownie Seam workings.

10.7.2 Valley Fill Swamps

No valley fill swamps are presented in the Wonga East area.

Valley fill swamp Lcvfs2 shows headward erosion of the downstream periphery of the organic swamp sediments near the confluence with headwater swamp Lchs2."

Photograph 6 – Swamp lcvfs1, July 2011

Photograph 7 – Swamp wcvfs1, July 2011

6.5 Wonga East Streams

The relevant streams in the Wonga East area are Cataract Creek and Cataract River (see Drawing P043-4). We have inspected Cataract Creek at the point where it passes through two culverts beneath Mt Ousley Road. We have not inspected Cataract River.

Annexure F, p63, records that:

"No evidence of stream bed cracking, flow loss or adverse effects on pool levels has been observed in Cataract Creek in the areas undermined by the Bulli Seam or Balgownie Seam workings."

No evaluation is given of Cataract River.

We note that a 1973 report, by the MWS&DB, records significant surface cracking on the NE side of the Cataract River valley just west of Mt Ousley Road, at 6196000m N (see Drawing P043-4). This cracking is near the edge of the Bulli Seam goaf and near the surface outcrop line of the Corrimal fault. We have found no records of cracking in, or near, the bed of Cataract Creek in the Wonga East area.

We expect that Cataract Creek would have been impacted by the previous mining of the Bulli and Balgownie Seams. However, we note that Annexure D (Flora and Fauna) notes:

"The forest habitat in Cataract Creek is in good condition and shows little sign of disturbance west of Mt Ousley Road."

However, it also notes that "heavily iron-oxidised bacteria flocculation was observed", around three observation points above mining in the Bulli and Balgownie Seams. In our view this may be indicative of subsidence impacts.

6.6 Future Impacts from proposed mining

6.6.1 Conclusions of the EA

The EA (Section 13, Annexure F) reaches the following conclusions in respect to streams.

<u>Cataract Creek and Cataract River</u>

- *The proposed mining at Wonga East is not anticipated to be a significant risk to either Cataract Creek or Cataract River (upstream of Cataract Reservoir) in regard to stream flow, stream pools, water quality or aquatic ecosystems.*

<u>Lizard Creek</u>

- *The proposed Wongawilli Seam mine layout is anticipated to avoid potential adverse effects on the main channel of Lizard Creek, including the deemed "significant" section at Waterfall L1.*
- *A low potential risk to the integrity of the Lizard Creek stream bed may be present in the area to the north of Longwall A3 LW2 and south of the northern end of Longwall A4 LW5. The stream flow and pool holding capacity in this stream reach has already been observed to be adversely affected by previous subsidence associated with the Bulli Seam longwalling.*
- *The third order tributary stream bed and banks from the LCT1/LCT2 junction to Lizard Creek is anticipated to have a lower to minor potential risk of adverse affects due to extraction of Longwall A3 LW5.*
- *The third order tributary stream bed and banks from C11 to Lizard Creek is anticipated to have a potential risk of adverse affects due to extraction of Longwall A3 LW5. The stream flow and pool holding capacity in this stream reach has already been observed to be adversely affected by previous subsidence associated with the Bulli Seam longwalling.*

- *The pool water holding capacity in Lizard Creek or its tributaries is not anticipated to be adversely affected due to the low predicted tilts and steep gradients in the incised sections of the creek catchment.*
- *The valley fill swamps in the flatter gradient section along Lizard Creek are also not anticipated to be adversely affected due to the lack of predicted subsidence in those areas.*

Wallandoola Creek

- *The proposed Wongawilli Seam mine layout is anticipated to avoid potential adverse effects on the main channel of Wallandoola Creek. A low potential risk to the integrity of the Wallandoola Creek stream flow and pool water holding capacity may be present in the area that my potentially undergo up to 6mm/m of tensile strain and up to 0.5m of subsidence to the south of Longwall A3 LW3 and A3 LW4.*
- *The pool water holding capacity in Wallandoola Creek or its tributaries is not anticipate to be adversely affected due to the low predicted tilts. The valley fill swamps along Wallandoola Creek are also not anticipate to be adversely affected due to the predicted subsidence tilts and strains.*

The following conclusions are reached in respect to swamps (Annexure M, Section 14).

- *Swamps that are anticipate to undergo extensional rib-line cracking are Crhs1 at Wonga East and Wchs1, Wchs2 and Lchs4 at Wonga West, however, none of these are interpreted to be "significant" swamps.*
- *The changes in storativity and permeability are estimated to be small and negligible and unlikely to have a measurable impact outside of water level variability due to current climatic influences.*
- *Connective cracking to deeper strata is not predicted and as such, it is not anticipated that the swamp could freely drain into the deeper sandstone strata.*
- *Of the designed "significant" swamps, only Wcvfs2 may potentially undergo tensional strains of up to 6.5mm/m which could cause cracking in the sandstone underlying or adjacent to the swamp at its northern end. However, based on observation of previously undermined swamps at NRE No.1 that have undergone similar strains due to undermining by the previous Bulli workings, no observable adverse consequences are anticipated on the water holding capacity, water quality or ecosystem health of Wcvfs2.*
- *All other designated "significant" swamps are not anticipated to undergo sufficient compressional or extensional strains to generate cracks in the underlying or adjacent sandstone, and therefore are not anticipate to undergo any adverse effects or consequences from the proposed mining.*
- *Where a swamp straddles a chain pillar or is on the edge of the subsidence bowl, it could experience temporary localized re-distribution of localized, 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.*

We note the findings of the Bulli PAC report, quoted in Section 14.2, in respect to negative impacts, at many places in the Southern Coalfields, on stream and swamp hydrology.

We are of the view that groundwater modelling cannot provide definitive answers as to impacts on creeks and swamps. We consider that the modelling completed to date for the NRE No 1 project does not properly consider the likely ranges of permeability and storativity parameters, but notwithstanding this limitation, does indicate that the existing workings, and the proposed mining will have negative impacts on the groundwater regime.

We conclude that there will be additional negative impacts on Lizard and Wallandoola Creeks, and the tributaries of Lizard Creek that are located above the proposed Wongawilli longwalls. We also conclude that there will be negative impacts to the length of Cataract Creek that has probably already been impacted by prior mining.

We consider that it is probable that there will be negative impacts on at least five swamps above the Wonga West workings, namely wchs1, wchs2, lchs3, lchs4 and wcfs2 (see Figure 22). We are unable to quantify these impacts.

7 FINDINGS AND RECOMMENDATIONS

The findings of this review are summarised below:

On subsidence:
Given the inherent uncertainty in subsidence predictions, it is recommended that a predicted range of subsidence effects, rather than a single value, is presented.

A review of the mapping of old Bulli Seam workings was undertaken, and the available data was found to be of satisfactory accuracy.

An independent analysis of subsidence was undertaken, and it was found that the settlement predictions in the EA fall within our computed range. We judge that there is about an 85% chance of settlements being greater than our "low" values and 15% chance of their being greater than our "high" values.

It was also found that the tilts and strains given in the EA were within the typical range of our calculations. However, we note that at some locations where we had included faults, or major joint systems, in our model there were anomalous high strains. This is exactly what happens in the real world, but we are unable to predict the true position of anomalous movements because the requisite knowledge of geological structures would never be available.

On structural geology
A review of geological structures relevant to the study area has been presented in Section 3 of this report. We have sought, in this regard, to correct this perceived deficiency in the presented EA, by collecting and collating geological structural information presented above.

On Pillar Run
We have reviewed the calculations in the EA and consider that they are appropriate in respect to calculation of pillar strengths. We are also satisfied that the pillar geometries used in the EA are appropriate. It is recommended to factor up the average pillar loadings by 1.2 times those adopted in the EA, and thus reduce the calculated factors of safety shown in Figure 14 (below) by that same ratio. It was found that this does not negate the validity of the conclusion reached in the EA that there is a negligible probability of pillar run to the north east (towards Mt Ousley Road). There is also a very low probability of failure to the south west, not just because of the adequate factors of safety but also because of the presence of the Corrimal Fault that dips to the NE.

On Groundwater
The groundwater monitoring undertaken for the EA provides useful information for characterisation of deep groundwater systems. Additional studies will always provide for more confident characterisation and reduction of uncertainty. No statutory guidelines stipulating the required monitoring exists, and hence the required extent of monitoring is a matter for the statutory bodies to determine.

Additional studies are nonetheless recommended for better characterisation and monitoring of shallow groundwater systems, particularly groundwater dependency of streams monitoring of mining effects on the streams. This may include some stream gauging.

The groundwater modelling undertaken for the EA is considered to conform to current standards. We concur with the EA in describing the groundwater model as 'indicative only' – this is the correct understanding of the role of numerical modelling.

The EA places high importance on the Bald Hill Claystone in controlling impacts at the site, but the uncertainty of this assumption is not tested. A review of the Bald Hill claystone presented in this report found that:

1. Statements in the EA that the Bald Hill Claystone created 'hydraulic separation' requires clarification
2. Monitoring data does not support the statement of 'hydraulic separation'
3. The values used to represented the Bald Hill Claystone in the model are low, and are not congruent with available data
4. The assumption that the Bald Hill Claystone will remain unaffected by subsidence has not been tests
5. The Bald Hill Claystone is not continuous over the study area

The writers conclude that the role of the Bald Hill claystone in reducing mining impacts has been overstated in the EA in both the interpretation of monitoring data and the implementation of the numerical model.

Sensitivity studies should be undertaken which should reflect the level of uncertainty in hydrogeological parameters (hydraulic conductivity and storage) as well as the uncertainty in subsidence predictions. Studies should also consider the uncertainty with respect to geological structures. As for subsidence predictions, it is recommended that a range of values, rather than a single number, representing the predicted depressurisation is presented.

The assessment of the impacts on stream and swamps should be reviewed after the results of these sensitivity tests.

<u>On Streams and Swamps</u>
There is evidence that the groundwater regimes have been affected by previous mining, such as:downwards flow to seam level, piezometic pressure reduction below hydrostatic, and; drawdown of the phreatic surface (water table) in the Hawkesbury Sandstone.

There is evidence of negative impacts on the hydrology of lengths of Lizard and Wallandoola Creeks above, or close to, areas of longwall extraction in the Bulli Seam.

There is no obvious evidence of degradation of the swamps above the existing mining areas of Wonga West and Wonga East.

There are historical reports of surface cracking associated with the Corrimal Fault in Wonga East, and the major, NE, dyke swarm at Wonga West.
Seepage quantities into the existing Bulli Seam workings at Wonga West, whether from groundwater or from Cataract dam, are very small, to the point of being insignificant.

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APPENDIX A

SPECIFIC ISSUES

A.1 SUMMARY OF ISSUES

Table A 1- Summary Of Primary Questions From Regulators

Questions and Issues		Document[1.]	Dealt with in this review
1	Inadequate consideration of the Bulli Seam Planning Assessment Commission (PAC). Particularly in regard to significant natural features, protection of Lizard and Wallandoola Creeks, and classification of the swamps.	DECCW 24/6	A.2.1
2	Uncertainties in respect to the layout of the old Bulli Seam workings and the dimensions of the pillars in those workings. This is considered to be "the fundamental flaw" by DRE.	SCA 14/4, SCA 30/3, DRE 26/5	2.2
3	Inadequate consideration of faults and dykes in the Wonga East area.	SCA 30/3	3
4	Inadequate assessment of probable subsidence, particularly with multi seam mining. Subsidence possibly greater than stated in the EA.	SCA 30/3, DECCW 24/6, DRE 26/5	2.3
5	Inadequate assessment of tilts associated with subsidence.	DECCW 24/6	2.3
6	Uncertainties in respect to valley closure and upsidence.	SCA 30/3	2.4
7	Uncertainty in respect to the stability of the old pillars in the Bulli seam workings, and the associated risk of "pillar run".	SCA 30/3, DECCW 24/6, DRE 26/5	4[2.]
8	Inadequate basis for groundwater assessment, modelling and available monitoring.	SCA 14/4, SCA 30/3	5.4; A2.2
9	Uncertainty in respect to the impacts of subsidence on the groundwater regime, in particular the ongoing integrity of the Bald Hill Claystones.	SCA 30/3, DECCW 24/6	5.4.2
10	Connection for seepage from Cataract Reservoir to mine workings.	SCA 14/4	5.4.3
11	Inadequate assessment of impacts of subsidence on streams and swamps.	SCA 14/4, DECCW 28/3, DECCW 24/6	6.6
12	Specific concerns in regard to Lizard, Wallandoola and Cataract Creeks, and correct categorisation of these creeks. Potential for additional damage to Cataract Creek.	SCA 14/4, SCA 30/3, DECCW 24/6, DRE 26/5	A.2.3
13	Impacts on transmissions lines	DRE 26/5	A.2.4
14	Impact on Mt Ousley Road and an overbridge over Mt Ousley Road.	DRE 26/5	2.5
15	Inconsistent statements as to the layouts of the longwalls in Wonga West and Wonga East.	SCA 14/4, DECCW 24/6	No
16	Conflicting statements in respect to offsets (setbacks) from Lizard Creek, Wallandoola Creek and Cataract Reservoir.	SCA 30/3, DRE 26/5	No
17	Inadequate survey of disused ventilation shafts (habitat for threatened bat species).	DECCW 28/3	No
18	Inadequate survey of threatened species within the project area.	DECCW 28/3	No
19	Inadequate assessment of discharge water quality into Bellambi Creek.	DECCW 28/3	No
20	Inadequate assessment of Aboriginal heritage.	DECCW 24/6	No
21	Inadequate definition of post-mining land rehabilitation.	DRE 26/5	No

[1.] The following documents are cited:

SCA 30/3: Sydney Catchment Authority 30 March 2011
SCA 14/4: Sydney Catchment Authority 14 April 2011
DRE 26/5: NSW Resources & Energy 26 May 2011
DECCW 28/3: NSW Environment, Climate Change & Water 28 March 2011
DECCW 24/6 NSW Environment, Climate Change & Water 24 June 2011

[2.] Also dealt with by Dr van der Merwe

A.2 ADDITIONAL COMMENTS

A.2.1 Consideration of Bulli Seam Planning Assessment Commission

The letter from DECCW of 24 June 2011 states (Section 2.1) "the EA has not fully taken into account the findings and recommendations of the Bulli Seam Planning and Assessment Commission" (**Bulli PAC**), apparently on the basis that the proponent "has indicated that the Bulli Seam PAC Report… had not been released at the time of the draft EA's development".

The origin of this latter statement has not been found by this writer, but it does appear that there has been a breakdown in communications. The Bulli PAC is referenced on p215 of the EA (**EA**) in regard to subsidence. Section 10.5.1 (Stream Flow and Ponding), states that the assessment has been "guided by the outcomes of the Bulli PAC". This document is listed in Section 11.2.1 as being one of four documents forming the basis of the "Director Generals' Requirements …..." in respect to groundwater.

The writer notes also that Annexure F of the EA specifically includes a Revision B termed "Incorporate relevant Bulli PAC findings ….". This Annexure quotes extensively from the Bulli PAC and includes, at p6, the same quotation that is in the DECCW letter in Section 2.1.1.

While it appears to the writer that the EA report has sought to take into account the Bulli PAC, it is noted that the specific matters of concern in the DECCW letter of 24 June 2011 relate to subsidence impacts on Lizard and Wallandoola Creeks. These specific matters are addressed under Issue 11 in Section 16 of this report.

A.2.2 Inadequate basis for groundwater assessment, modelling and available monitoring.

A.2.2.1 The Queries

Commentary in the review letter SCA 14/4 stated that: "significant deficiencies exist in the EA", and listed the following matters regarding the groundwater monitoring:

1. The groundwater monitoring was based on groundwater bores installed for previous mining stages.
2. There are no bores on the western side of Wonga east area and the western and northern side of the Wonga west area.
3. There are no monitoring points in upland swamps within the Wonga east area.
4. Monitoring of all significant features is required

In an earlier SCA letter (30/3), concern was raised over the statement in the EA that "because of the lack of available data, model results should be regarded as indicative only" (pg 25 of Appendix A to Annex M). SCA noted an apparent contradiction that the numerical model had nonetheless been used to indicate that negligible impacts would be incurred. In response to this, the SCA stated the following:

> *"Given that the groundwater modelling is based on limited data … SCA requests: A comprehensive geological investigation and groundwater monitoring, and; Updated groundwater modelling and associated impact assessment"*

A.2.2.2 The Assessment

- It is understood that the following bores installed by GeoTerra for the currently considered mining stages:
    - o deep bores at locations NRE-A, NRE-B, NRE-C, NRE-D, NRE-E, NRE-G andNE-3, and
    - o Shallow bores at locations P1 to P6.
- We agree that further field investigations would improve the confidence of groundwater assessments. In particular, we note:
    - o Groundwater levels in the Upper Hawkesbury Sandstone were presented in Drawing 8 of EA Annex M against the backdrop of all bores listed. However, it is understood from Table 3 that standing water levels were available from only a 6 of 7 bores (the swamp bores are in most instances too shallow) and that these contours are therefore indicative only. There is therefore a paucity of data characterising shallow groundwater systems. Thus the impacts of mining on baseflow cannot be predicted with confidence.
    - o Installation of further deep piezometer arrays would assist in assessing vertical flow distributions.
- Notwithstanding this, the assessment of groundwater conditions will always have a component of uncertainty regardless of the scope of monitoring undertaken.
- There are no current guidelines or standards specifying the number, location and depth of bores required to be installed to support such assessments.

With respect to the monitoring data available, and the requests of the SCA, it is recommended that further groundwater monitoring bores are installed. The location of bores should satisfy the requirements of the relevant authorities. The opportunity should also be taken to improve the assessment of standing water levels through installation of standpipe piezometers in the Hawkesbury Sandstone and to improve the conceptualisation of vertical flows through installation of additional vibrating wire piezometer arrays.

Recommendations regarding groundwater modelling include consideration of geological structures and undertaking of further sensitivity studies. The groundwater model is otherwise considered to be appropriate, but can be updated in the future to incorporate further monitoring data.

A.2.3 SPECIFIC CONCERNS IN REGARD TO LIZARD, WALLANDOOLA AND CATARACT CREEKS

A.2.3.3 The Queries

The particular concerns expressed by the government regulators are set out below.

1. “Longwall A4LW7 in the Wonga West area 4 is likely to intersect a known fault line cutting across the stored waters”. (SCA 14/4/11)
2. “Whether the existing bed cracking and iron oxide seepage into Wallandoola and Lizard Creeks have been considered in the surface water assessment”. (SCA 14/4/11)
3. “Cataract Creek has been inconsistently described in the EA”. (SCA 14/4/11 and SCA 30/3/11)

4. "The EA states there will not be any extraction under 3rd order reaches of any stream….all mine layouts show extraction under Cataract Creek in Area 2". (SCA 30/3/11)
5. "Extraction is proposed under a 3rd order reach of Lizard Creek". (SCA 30/3/11 and DECCW 24/6/11).
6. "Inconsistent information in regard to previous mining under Cataract Creek". (SCA 30/3/11)
7. The mine layouts do not show the designed setbacks to Lizard Creek. (SCA 30/3/11)
8. Longwall A2-LW5 is not set 110m from top stored water level in Cataract reservoir. (SCA 30/3/11)
9. "It is noted that the PAC 2010 report on *Bulli Seam Operations* recommended that Wallandoola and Lizard Creeks be afforded *Special Significance* ……" (SCA 30/3/11 and DECCW 24/6/11).
10. "OEH…. has concerns with the EA identifying 1st and 2nd order and sometimes 3rd order streams and swamp aquifers as 'ephemeral' …..such an assessment ignores the effect upland swamps have on baseflow delivery…..". (DECCW 24/6/11)
11. "OEH considers Cataract Creek being a 1st, 2nd, 3rd and 4th order stream in the project area, to still be a sensitive ecosystem (containing threatened species) which, once damaged, could effectively be irreparable. In this regard OEH recommends that Cataract Creek should be identified as being of special significance that warrants negligible environmental consequences criteria being applied to this stream. This is consistent with the findings of the Bulli Seam PAC." (DECCW 24/6/11)
12. "The assessment disregards the swamps as being representative of the Temperate Highland Peat Swamps on Sandstone (THPSS) endangered ecological community listed on the Commonwealth Environment Protection Biodiversity Conservation (EPBC) Act.

In this regard OEH recommends that the proponent should consult with the Commonwealth on this matter as soon as possible and whether any approval should be sought under the EPBC Act." (DECCW 24/6/11)

13. "The EA suggests potential adverse effects may occur in swamps Wcvfs2, Lchs3 and Lchs4 but only minor effects in swamps Wchs1 and Wchs2. OEH does not concur with the EA's subjective assessment of minor negligible impact to upland swamps (particularly with Wchs1 lying over the end and corner of a 380m wide panel). Based upon the current subsidence predictions for swamps, they fall within the range that the Bulli Seam PAC considered at risk of negative environmental consequences." (DECCW 24/6/11)

A.2.3.4 Responses

The thirteen questions listed above are dealt with, in turn, as set out below.

<u>Q1: Intersection of known fault by A4LW7</u>

Based on a careful study of available data (see Drawing P043-3) it is concluded that longwall A4LW7 will not intersect a known fault but may be slightly impacted by the gentle Bulli Anticline.

Q2: Existing bed cracking in Lizard and Wallandoola Creeks.

The existing bed cracking is dealt with in detail in Annexures F and M of the EA. In particular, it is noted that the Surface Water modelling report by WRM Water and Environment (in Annexure F) addresses, in detail, possible impacts of cracking of Lizard and Wallandoola Creeks on surface water flow. We have reviewed this report and consider it to be properly done, and to reach appropriate conclusions.

Q3: Inconsistent description of Cataract Creek.

It is unfortunate that there are inconsistencies in the descriptions of Cataract Creek. The categorisation is accordance with Figure A.2.2 which means that Cataract Creek is 3rd and 4th order above the proposed Wonga East longwalls.

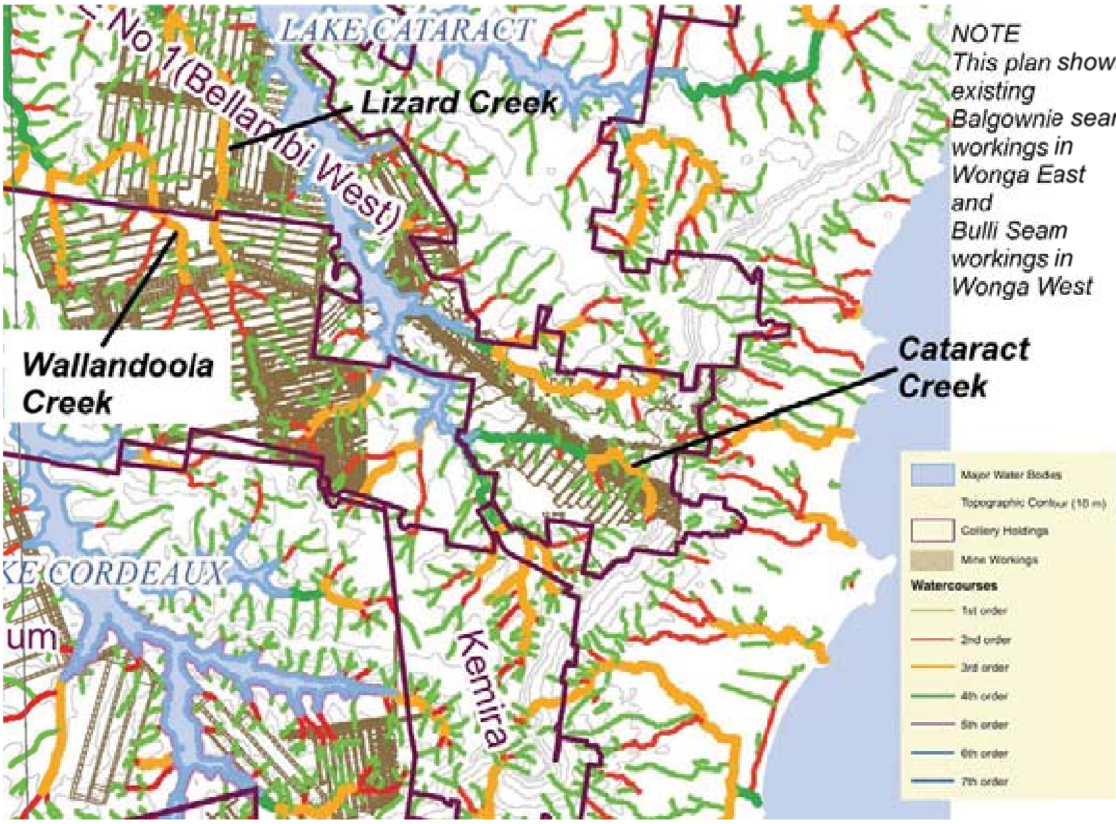

Figure A.2.2

Q4 and Q5: Extracting under 3rd order streams.

There will be extraction beneath Cataract Creek where it is 3rd and 4th order. Extraction has previously occurred under these lengths of creek in both the Bulli and Balgownie Seams.

There will be extraction in Wonga West under a tributary of Lizard Creek, part of which is currently classified as Category 3. As discussed in Section 14.3 of this report, we consider that this categorisation is inappropriate and is based on a pre-1970 error in aerial photographic interpretation.

Q6: Previous mining beneath Cataract Creek.

It is unfortunate that there is inconsistent information in the EA about previous mining beneath Cataract Creek. The factual situation is shown on Drawing

P043-4. There has been previous bord-and-pillar, and extensive pillar recovery, mining in the Bulli Seam beneath the whole length of Cataract Creek. There has been bord-and-pillar mining and a short length of longwall extraction in the Balgownie Seam beneath more than 70% of Cataract Creek.

Q7 and Q8: Setbacks not properly shown on mine layouts.

We recommend that NRE No 1 make corrections where appropriate.

Q9. Special Significance for Lizard and Wallandoola Creeks.

The Bulli Seam Operations PAC report of 2010 gives considerable discussion to the classification of “Special Significance” as given by BHP Billiton Illawarra Coal to features in the then proposed Bulli Seam Operations area. The report states “The Panel’s conclusion is that the Proponent’s assessment of ‘special significance’ is not credible and cannot be relied upon’,. The Panel therefore reached its own conclusions (page v).

The Panel provided detailed discussion of the assessment of Special Significance for swamps. It then noted that the Proponent did not assign Special Significance to “any of the rivers or creeks in the Study Area” (not even the Nepean River).

The report then states:

The Panel has addressed the question: are there other rivers and streams in the Study Area that cross the special significance threshold either for individual values or in consideration of the sum of several values? The comments in Table 11 suggest a number of possible candidates. The candidates comprise the rivers and creeks that flow in the largely undisturbed confined sandstone gorges mainly in the south and east of the Study Area.

Table 15 of the Bulli PAC report lists the streams that the Panel “assess as achieving Special Significance status”. Lizard Creek is not included as one of the creeks.

Wallandoola Creek is included on the basis of it being natural and undisturbed. Given the fact that a significant length of Wallandoola Creek in the NRE No 1 area (as opposed to the Bulli Seam Operations area) has been significantly disturbed by previous mining, it is our view that the Panel may not have intended their recommendation to cover the length of Wallandoola Creek that was outside their study area.

NRE have considered Wallandoola and Lizard Creeks as being ‘Significant’ and have adjusted their mine plans so as not to have long wall panels directly beneath these creeks.

Q10. Assessment of creeks as ‘ephemeral’

It is unfortunate if the discussion of the ephemeral flows in certain creeks and swamp areas has given the impression that such creeks or swamps warrant less consideration. We agree with DECCW that this not the case, and we also do not think that the intent of the EA is to diminish the importance of these creeks and swamps.

Q11: Special Significance for Cataract Creek

NRE consider Cataract Creek to be of special significance.

Q12: Swamps being representative of Temperate Highland Peat Swamps.

The matter as to whether particular swamps in Wonga West or Wonga East may, at some time in the future, be classified by the Commonwealth Government in a category of National Significance is clearly outside our ability to determine, or comment upon.

Q13. Minor impacts on certain swamps.

As set out in Section 14, above, we agree with the opinion expressed by DECCW that swamps Wchs1 and Wchs2 would be adversely impacted by the proposed longwall mining at Wonga West.

A.2.4 IMPACTS ON TRANSMISSION LINES

According to Section 1.4.3 of the main text of the EA, infrastructure above the proposed mining areas includes:

- Telstra fibre optic cable.
- Electrical transmission lines.
- Roads (sealed and unleased).

The fibre optic cable runs along Fire Trail No 8, about midway between Wallandoola and Lizard Creeks, and directly over longwalls A3 LW1 to A3 LW5 (see Drawing P043-2).

There are two transmission lines. The first is east of, and approximately parallel to, Mt Ousley Road. It crosses Mt Ousley Road close to where that road passes over Cataract Creek. It passes over the three narrow longwalls (A1 LW1 to A1 LW3) in Wonga East.

The second is the transmission line that services the NRE No 1 Colliery operations. It does not pass over any of the proposed workings.

Based on the calculations of likely subsidence settlements, tilts and strains given in the EA, and our check calculations given in Section 8 of this report, it is considered that there is an insignificant probability of the Mt Ousley Road transmission line being adversely impacted.

Our experience with subsidence impacts on optic fibre cables along the Hume Highway suggests that the cable across the Wonga West workings may be affected by subsidence-induced tensile ground strains. However, from this experience we know that the operators of such cables can monitor, with extraordinary precision, if, and where, a cable is being subjected to unacceptable tension, and can implement remedial measures prior to loss of signal through such a cable.

APPENDIX B

EXTRACT FROM BULLI PAC REGARDING SWAMPS

The following material is taken from Part 5 of the Bulli PAC report of 2010.

The SCI[15] identified two fundamental groundwater domains for consideration in project impact assessment:

1. The deep systems generally associated with geological strata at depths greater than 20m or so. These strata include the greater part of the Hawkesbury Sandstone down to and beneath the Bulli Seam. The system is typically confined and pressurised except for the uppermost parts which are unconfined.

2. The shallow systems associated with surface drainage lines and swamps. These are typically unconfined systems where the stream courses tend to act as 'hydraulic sinks' attracting groundwater flows from adjacent strata then draining the system via surface flows. There are also perched systems where for example, some swamps in elevated terrain provide a water store which is located above the regional water table and which may sustain downwards leakage into underlying strata.

In consideration of the deep groundwater system(s), the SCI determined that environmental impacts arising from historical mining operations were not easily characterised but were related mostly to the extent of deep strata depressurization associated with drainage of the fractured subsidence zone above extracted longwall panels.

In consideration of the shallow systems, the SCI determined that the potential impacts of mining included cracking of stream beds and rock bars as a result of tensile failure and/or bedding shear associated with normal subsidence, or with valley closure mechanisms. Tilt was also noted in relation to upland swamps. Consequences of these mechanisms on stream beds are known to include partial to complete loss of surface flows as water is redirected into underlying fractures, draining of pools upstream of cracked rock bars, erosion of swamp materials as flows are reconcentrated (from tilts), changes to the water table in swamps and associated changes to habitat, and water-rock geochemical interactions along newly exposed fracture pathways. The latter is typically associated with iron (Fe) staining along creek beds and on rock bars, bacterial matting, reduced oxygen levels and unnatural discolouration of stream waters.

The hardrock systems have been recharged by rainfall and runoff over a very long period of time. This recharge sustains a water table that commonly resides in the shallow strata at elevation equal to or higher than the beds of the creeks and rivers throughout the region. Where the water table is at shallow depths, it is observed to respond quite rapidly to rainfall but with increasing depth, it tends to respond more slowly.

Swamp lands in upland catchment areas act as water stores and baseflow contributors by virtue of their composition (unconsolidated sandy materials), fabric and location. Rainwater falling on swamps is capable of infiltrating the porous soil matrix if that matrix is unsaturated, or being retarded in its surface flow to the outlet of a swamp system by the presence of dense hydrophidic vegetation.

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[15] NSW Department of Planning. *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield*. Strategic Review. July 2008

The porous matrix of swamp soils is comprised of unconsolidated sands derived from weathering of the Hawkesbury Sandstone, and peaty matter. These materials are limited in thickness from less than 0.5m to typically no more than about 2m above the sandstone base. They serve to retard catchment runoff by infiltration of rainwater during rain events (until runoff is initiated) and exfiltration of stored groundwater after hose events. This groundwater contributes to downstream baseflow. During dry or drought spells, exfiltration is likely to occur progressively down slope with the most elevated and peripheral parts of a swamp draining first. This process will be governed to a large extent, by the topographic grade, saturated thickness and hydraulic properties of the soils, and the prevailing floral habitat. In sustained dry spells, baseflow may fall to very low levels, especially where swamp size (aggregated within a catchment) is low and the material thickness is small.

Potentially, the headwater swamp systems, while contributing to baseflow in surface drainage systems, could also contribute significantly to the deeper regional groundwater systems when it is considered that:

1. the swamps are saturated water sources that are essentially permanent, and

2. they provide a sustained driving head for downwards migration of water into the underlying sandstones which are semi-perveous, and

3. downwards seepage may be very significant where swamp lands occupy large areas, especially within North Cliff Area and eastern parts of Area 2. This contribution would logically support regional groundwater flows within the Hawkesbury Sandstone.

It is possible that a number of upland headwater swamps are also directly connected to the underlying hardrock groundwater system (rather than being perched) since they occupy very large areas of the Woronora Plateau.

The valley fill swamp systems probably exhibit slightly greater sediment thickness than headwater swamps simply because they occupy more incised parts of the stream systems. They are also more likely to be connected to the groundwater systems. The Panel regards the hydrology of swamps to be especially vulnerable in view of their thin plate-like structure extending typically over areas of 1ha or more.

For swamps to experience adverse environmental consequences, changes to swamp hydrology would have to occur that were large enough and of sufficient duration to create conditions that were favourable for drying, erosion, fire, or changes in species composition. In the case of species compositional change, there may be a substantial biological lag (up to decades) before any impact is apparent.

Mechanisms by which subsidence could cause changes in swamp hydrology can be summarized in terms of impact pathways as follows:

1. The bedrock below the swamp cracks as a consequence of tensile or compressive strains and water drains into the fracture zone. Here the fracture zone provides enhanced storage and the water loss impact may be temporary until the storage is filled.

2. The bedrock below the swamp cracks as a consequence of tensile or compressive strains induced by conventional and non conventional subsidence processes and water drains into the fracture zone. If the

fracture zone is connected to a source of escape (e.g. a deeper aquifer or bedding shear pathway to an open hillside) then it is possible for sufficient water to drain to alter the hydrologic balance of the swamp. This pathway is considered to be similar to re-directed flows encountered beneath stream channels in the region.

3. Some parts of the swamp subside more than others (e.g. a longwall only impacts part of a large swamp or a series of longwalls have different impacts on parts of a swamp), causing the elevation of the water table to drop in the subsided area relative to surrounding areas, so leading to localized redistribution of groundwater. This could result in the favouring of some existing and/or new vegetation associations over others, both within the subsided section of the swamp and around the flanks of the subsidence area.

4. Tilting of sufficient magnitude occurs to either re-concentrated runoff leading to scour and erosion, potentially allowing water to escape from the swamp margins (possibly affecting the whole swamp) or to alter water distribution in parts of the swamp, thus favouring some vegetation associations over others.

Consequences of these impacts depend upon a wide variety of factors such as how much water is lost, over what period, whether ‘self-healing’ occurs and to what degree, and whether there are severe rainfall events or fire events. Depending on these factors and their interactions, a swamp could show no evidence of change, or be severely damaged over a relatively short space of time.

This Panel and previous Panels have sought examples of desiccated swamps that have not been undermined but none have been forthcoming to date. The limited monitoring data that is available is not adequate to preclude mining induced subsidence as the root cause of changes in the hydrology of at least some, if not all, of the swamps noted above. At this point in time, neither conventional nor unconventional subsidence effects, singly or in unison, can be eliminated as the source of changes in swamp hydrology.

There are compounding problems in the current lack of ability to detect and quantify all but the most obvious change and the possibility that vegetation compositional changes will take time (possibly decades). However, the bottom line appears to be if mine subsidence has the potential to impact on near surface formations to an extent that could cause changes in the hydrology of a swamp, then the swamp is at risk of serious negative environmental consequences in whole or in part.

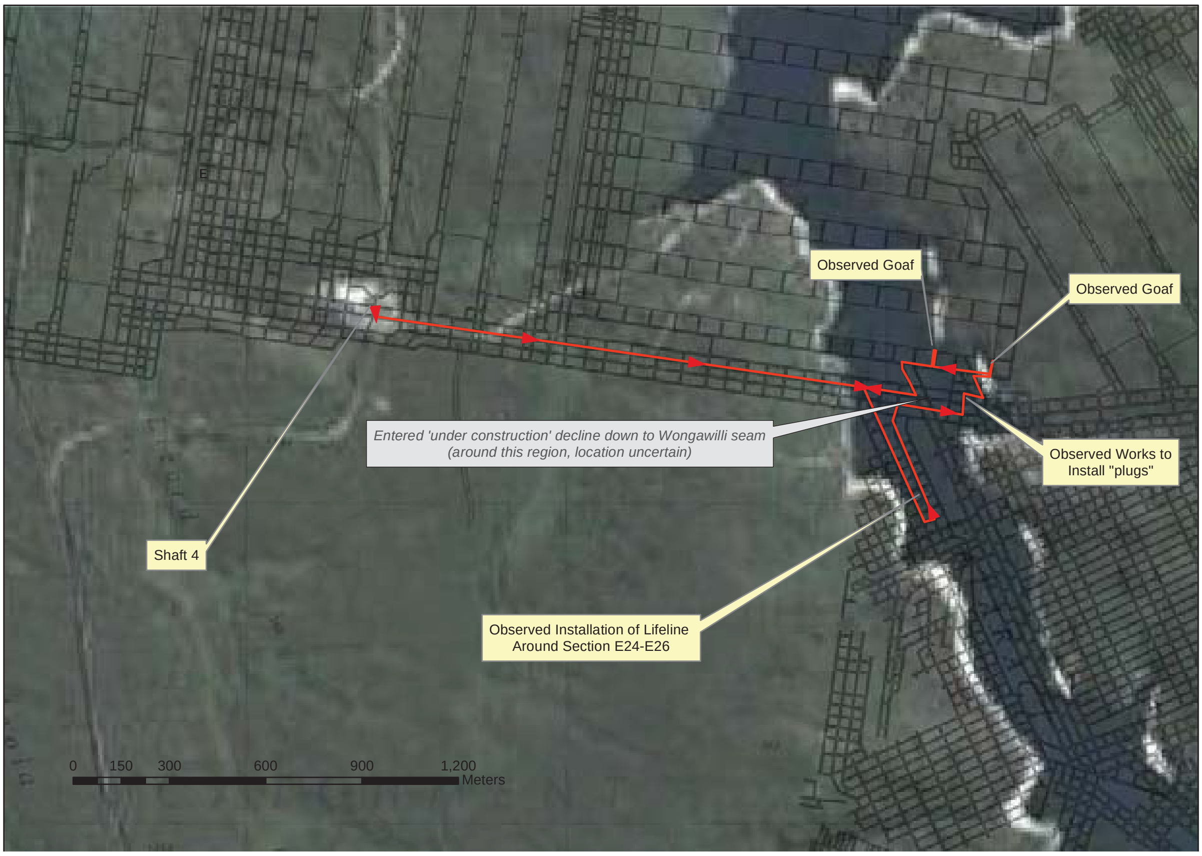
APPENDIX C

SITE INSPECTION

Steven Pells visited Gujarat NRE 1 coal mine on the 27th July 2011 to observe some of the underground workings and some selected surface features. The features observed are shown in the Figure below. Each region is discussed in turn.

Underground

The underground workings were accessed from Shaft 4, and I travelled along the existing Bulli Seam. There was no mining being done in this area – the works being done there related to: maintenance; installing 'plugs' in the worked Bulli seam in the locations underneath Cataract reservoir (as per the requirements of the SCA), and; construction of a decline down to the Wongawilli seam for proposed mining of the Wongawilli seam. Few staff were available in this western portion of the mine – it was stated that all staff were over at the eastern side, preparing for the proposed mining of the Wongawilli seam at that location (Wonga East).



Initially I assisted with installation of a lifeline in the Bulli seam in the excavated regions near "E24" and "E26" (the grid is named in a letter – number fashion). The following observations were made:

- The seam was about 2.2 – 2.4 metres thick
- Excellent quality coal remained in the walls.
- At the perimeter of the excavations, the roof was supported with old timber post, many of which were bent or broken due to forces of roof settlement or floor uplift.
- The coal walls were cracked and loose – one could easy excavate lumps of coal by hand, causing sequential collapse.
- The roof was supported with rockbolts which held up a steel mesh of about 150mm x 150 mm, pinning fractured and delaminated roof material up. The roof material appeared to be a very strong, brittle grey shale or siltstone.
- Tunnels in the one direction displayed significant cracking and delamination in the roof – these tunnels had an irregular roof. Tunnels in the perpendicular direction were primarily intact with a smooth and defined roof structure. I'm not sure but I think

it was the E-W tunnels that were intact and the N-S ones that were fractured. This observation is well recognised by the workers.

- The mine is referred to by workers and a 'dry mine'. There is almost no sign of water in the regions I visited – the floor was dry and dust kicked up as one walked. The coal walls were very dry and brittle, the coal was light and dry. I saw no locations of seepage drips from the roof. It felt dry.
- The only exceptions were in one location near where plugs were being placed under cataract dam and in the decline to Wongawilli seam, where he floor was ponded, although it was not possible to differentiate insitu water from water being added by work activities. In both locations, my supervisor said that a little water was present, but acknowledged that the significant bulk came from water added to the machinery.
- The 'plugging' activities require:
    - Re-support of walls and roof in a designated region (guessing about 200 m upstream and downstream of plug location).
    - Cleaning and removal of all timber props and al fallen or fractured material
    - Shotcreting walls and ceiling on the upstream side of the plug
    - Installation of a solid plug filling the tunnel – the specification for such a plug was unclear to the person in charge.
- I observed the goaf of the old 500 series panels in this region. They were clearly visible and demarcated – you could just walk up to them. They featured a random crumbled assortment of fallen delaminated roof panels. Fallen panels were generally 400 mm to 900 mm thickness, with voids ranging from 100mm to 500 mm clearly visible. There was no visible water at all, it appeared completely dry.
- My supervisor advised that over at 'x-main' there has been a roof collapse following saturation and rotting of the timber posts. He had excavated the fallen goaf material following this collapse and he observed a 'beautiful' intact domed roof above the goaf.
    - It was stated that water does flow in at the x-main location, discussed below.
- The tunnels are generally well ventilated. The tunnels are cold where effectively ventilated and warm and stifling where not. The fans could blow you over and run constantly. I would have thought that they were pretty effective in evaporation of any water.
- I entered the decline to Wongawilli seam.
    - It was not possible to view the strata as all the walls are coated with limestone dust.
    - There were some locations of floor seeps in the decline, it generally felt a little 'danker'
    - At the base, workers were drilling to remove methane from the Wonga seam. There was a lot of it, apparently.
    - They were using heaps of water for drilling, it was ankle deep everywhere.

<u>Water at x-main:</u>
I was told the following, I did not visit it …

- Water is present at x-main – the western and lowest point in the Bulli seam workings.
- There is a large underground reservoir there. It neighbours the Cordeaux colliery which, next door, is supposed to be filling at 17 L/s. Some workers postulate that water is seeping through.

- The reservoir is used as a balancing storage, they pump water from this reservoir to use in the mine, but they also pump excess water back there. The net inflow it is unclear.
- A short bore exists in the floor here with a sump pump which is in regular operation, and transfers water up the shaft to the surface dam. If the surface dam is ful, excess is pumped over to Russel Vale in the east. It the surface dam is really full, water is pumped back underground to x-main.
- I'm told they use all available water on the mine. There is no excess, but there is enough to use in the workings.
- Workers say that the Wonga East mine is not as dry.

Cataract Dam

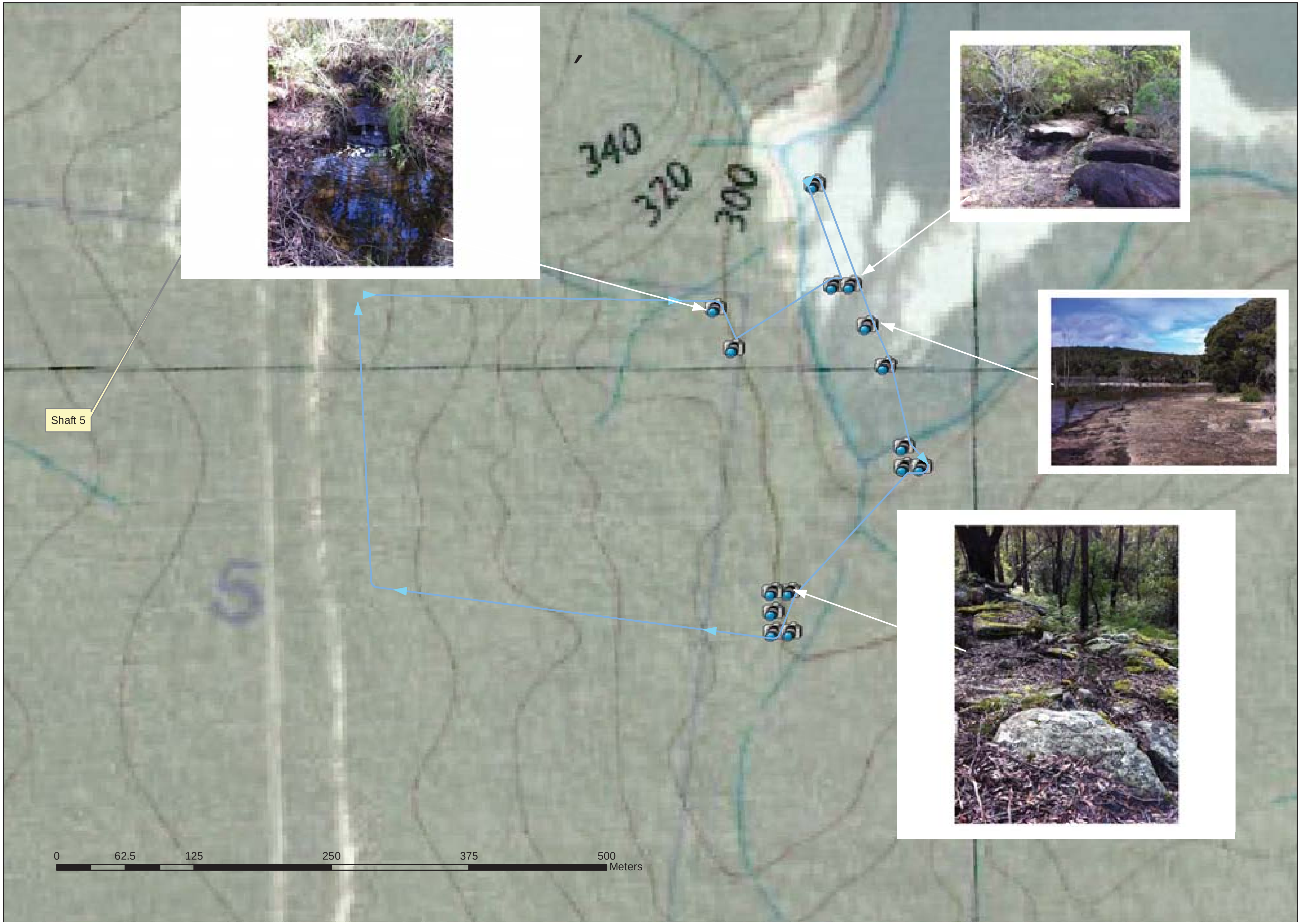
The shores of cataract dam (at location shown) was visited to look for signs of a postulated dyke

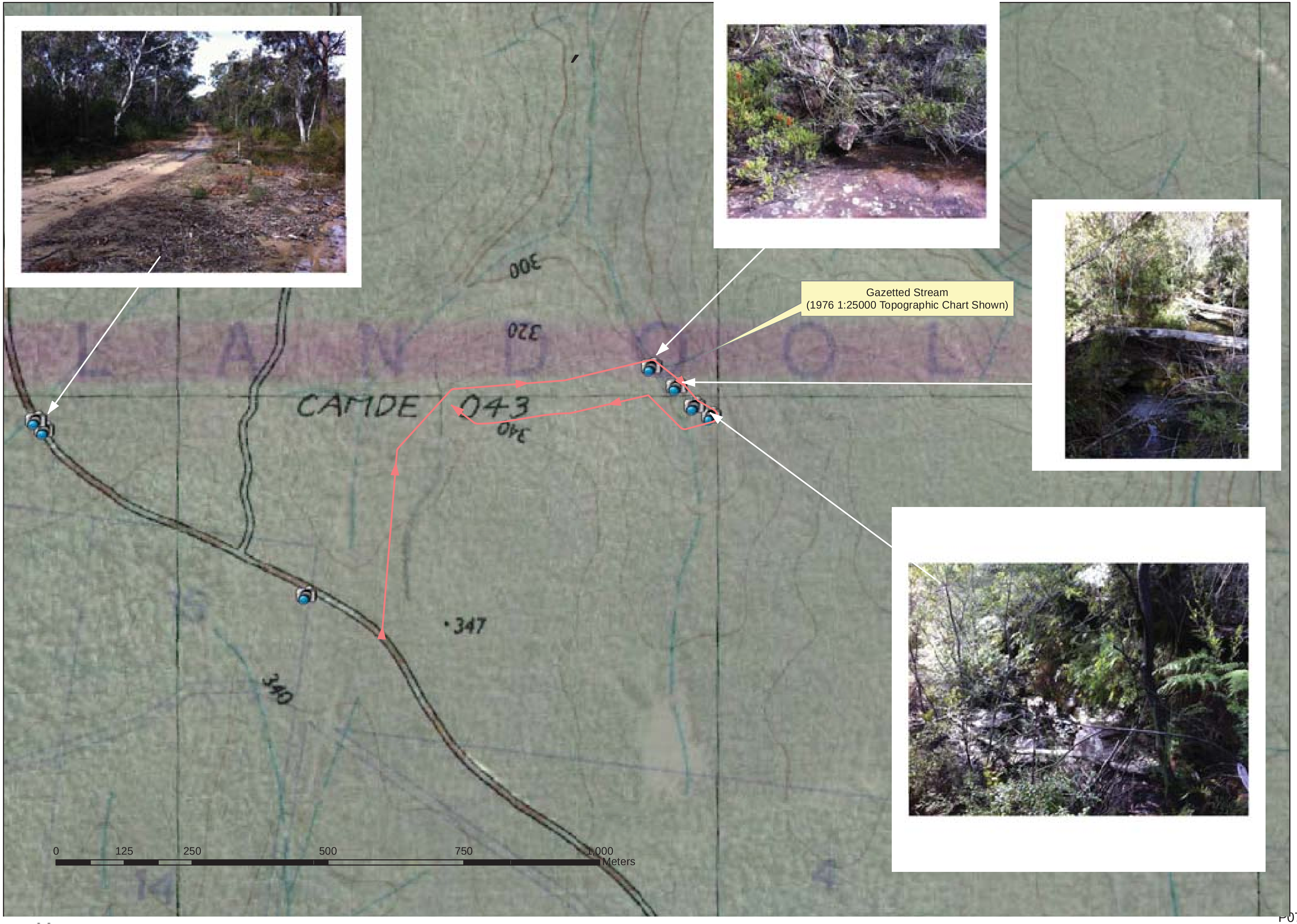
- At the shore, it was sandy. You could not see the basement rock.
- However, at one location a small, linear outcrop of sandstone rocks was noted. It appeared in a series of separated rounded boulders. I wondered if they had been 'cooked'
- I followed the valley up towards the south west from the shores, again I encountered a similar outcrop of sandstone boulders. Water was flowing amongst the boulders (you could hear it)
- There was a line of small steel posts installed – perhaps a subsidence survey line?

Lizard Creek Tributary

I walked down to Lizard Creek to observe the gazetted confluence of two first order creeks.

- Lizard Creek was flowing at this location – perhaps at 20 L/s.
- It was difficult to find a confluence as the creek was very small and there was a lot of vegetation covering it.
- I could not clearly find the confluence. At a location just upstream of the gazetted confluence I observed a small inflow channel from the eastern side, but I could not trace it upstream. There were numerous wet patches.
- If there is a confluence, it is clear that the incoming stream is smaller than the main Creek channel.

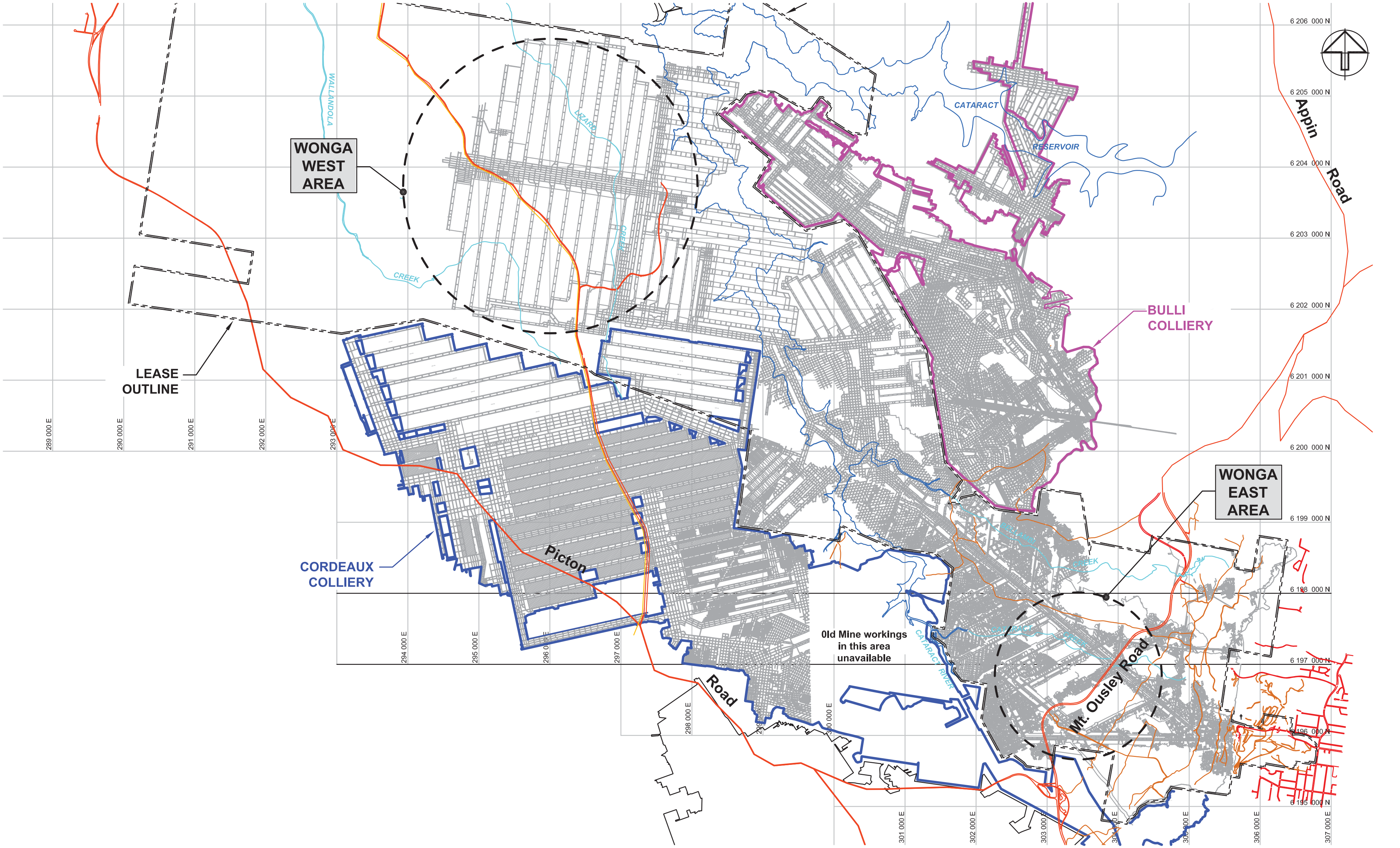

340
320
300
5
Shaft 5
0
62.5
125
250
375
500
Meters



Gazetted Stream
(1976 1:25000 Topographic Chart Shown)
CAMDE
043
300
320
340
347
0
125
250
500
750
1000
Meters

APPENDIX D

SITE DRAWINGS



Scale 1 : 5,000 @ A3

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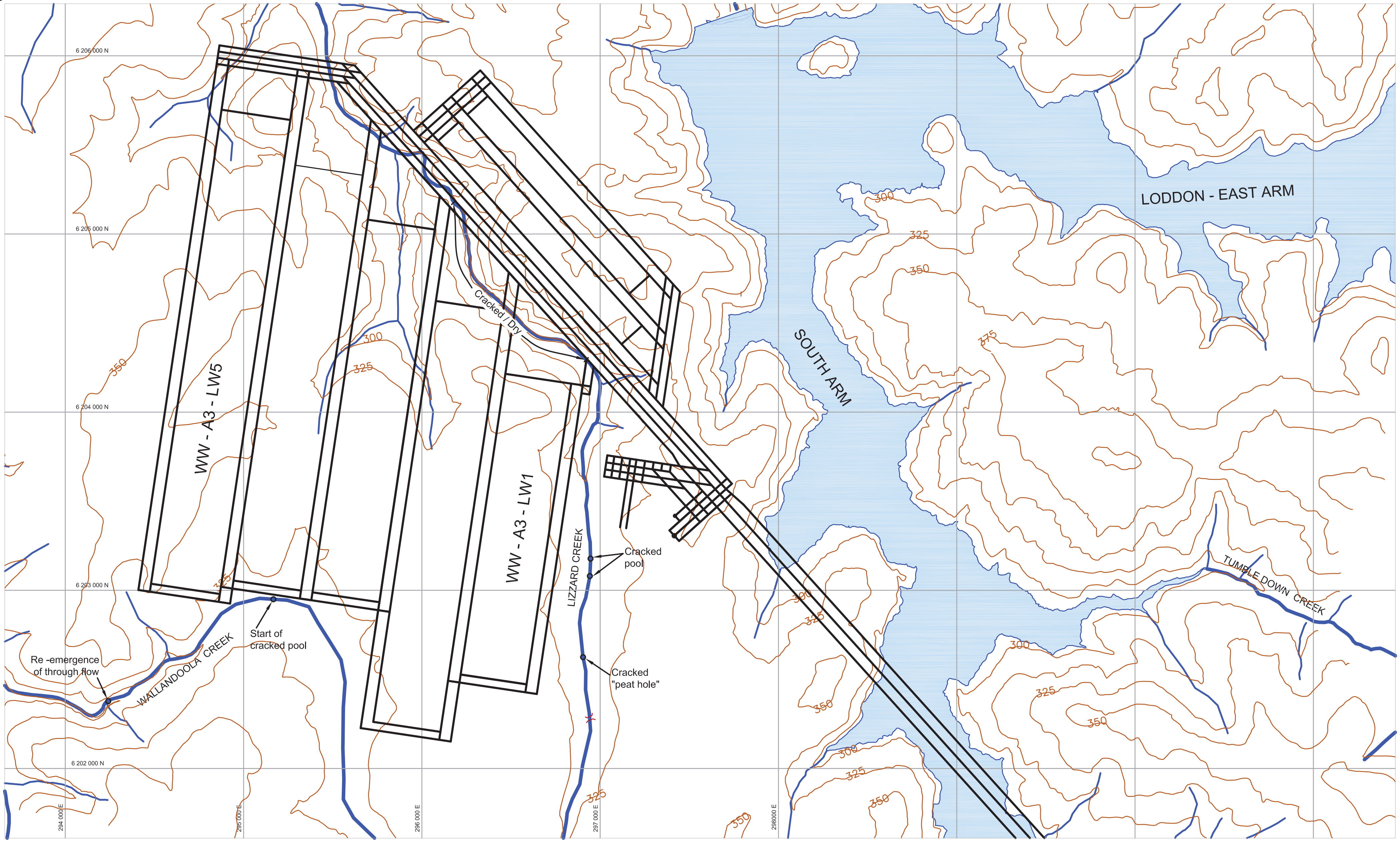
Gujarat NRE No.1 Colliery Stage 2
Review of Environmental Assessment

OVERALL SITE PLAN

DRAWING NO: PO43-1

REV: 0

A3



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Gujarat NRE No.1 Colliery Stage 2

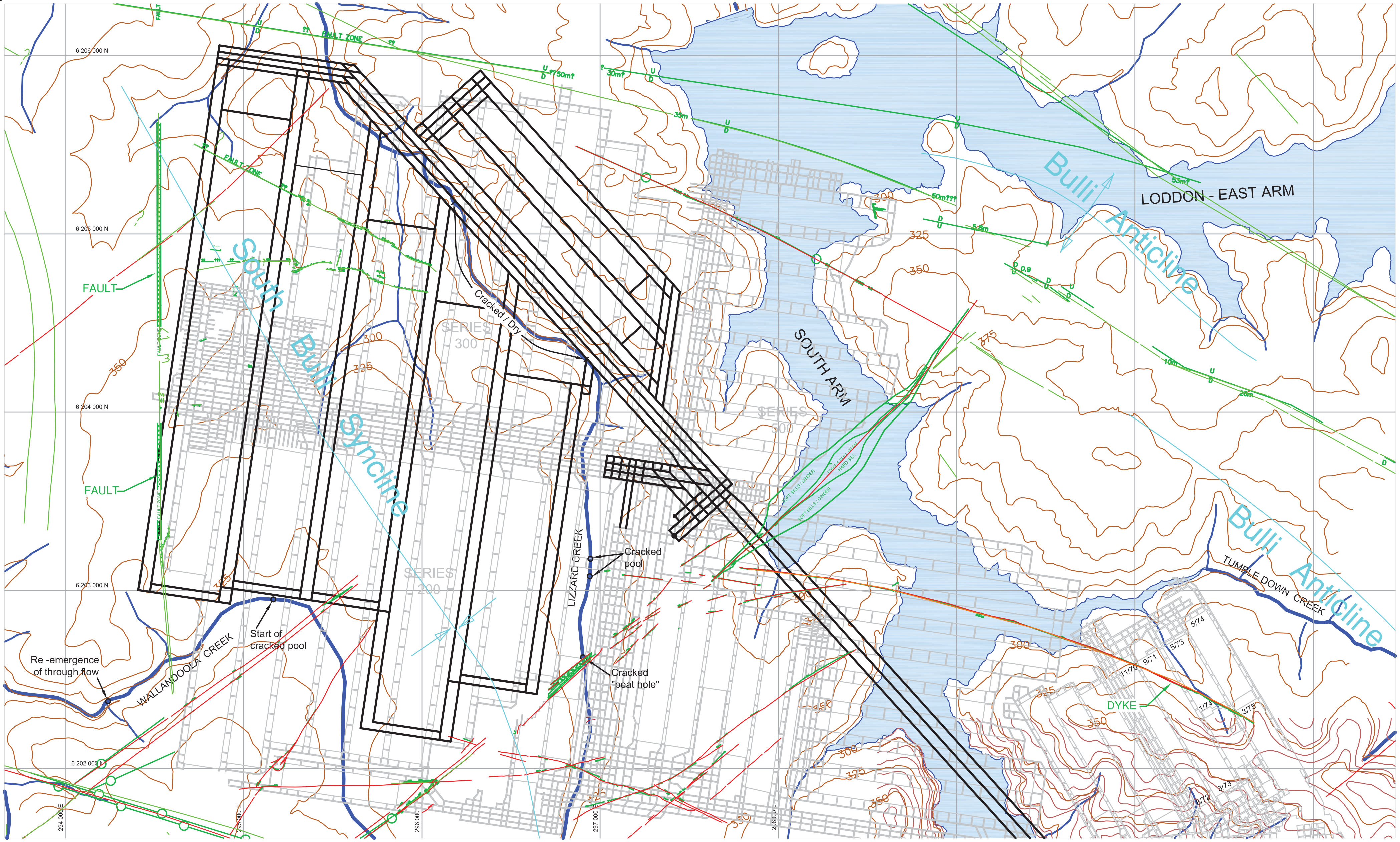
Review of Environmental Assessment

WONGA WEST AREA

PROPOSED LONGWALLS

DRAWING NO: PO43-2

REV: 0



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Note:
Geological structures taken from two source maps.
Green lines are data used in Environmental Assessment Report.
Red lines are additional data from NRE No.1 records.

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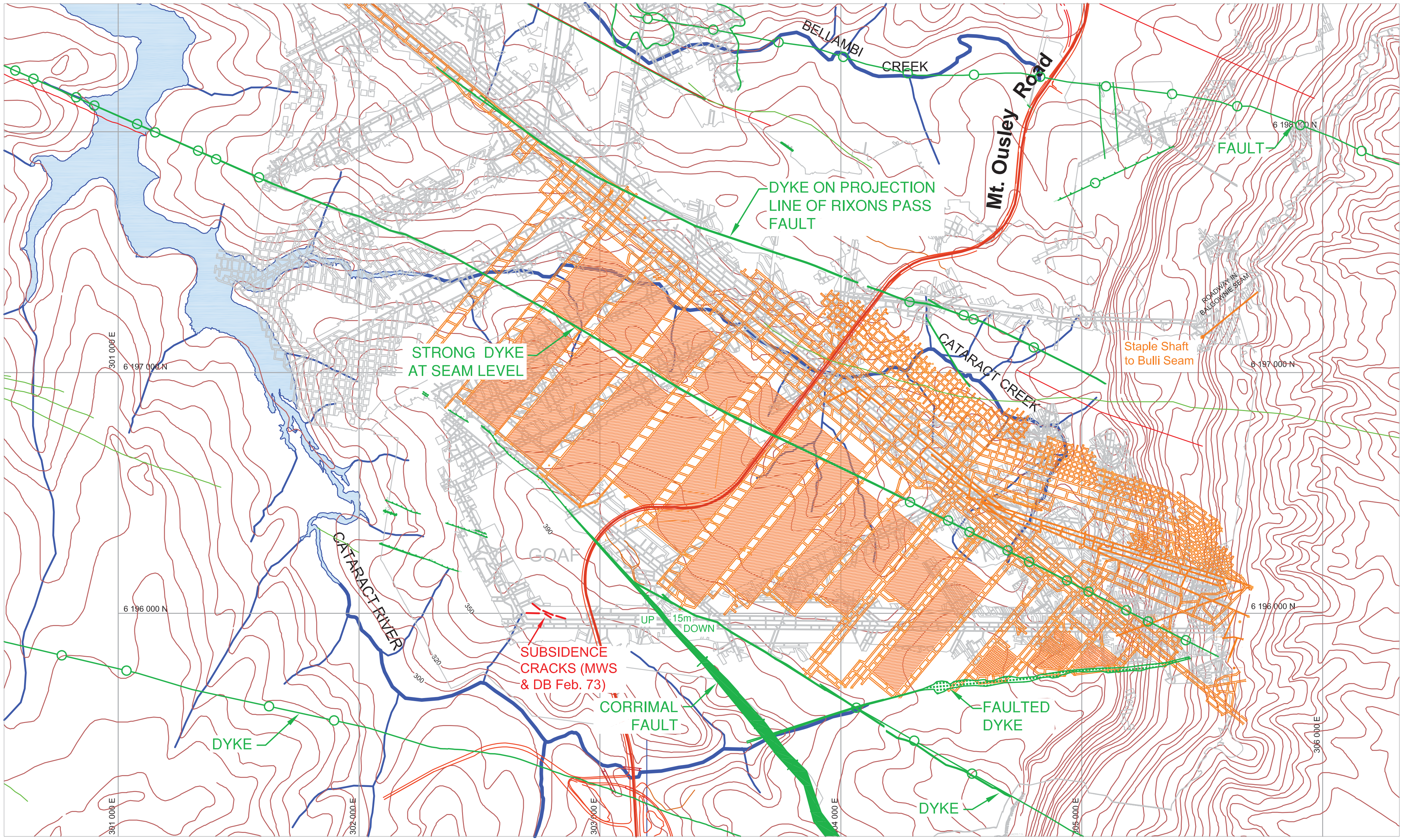
Gujarat NRE No.1 Colliery Stage 2
Review of Environmental Assessment

WONGA WEST - GEOLOGY
AND EXISTING BULLI SEAM WORKINGS

DRAWING NO: PO43-3

REV: 0

A3



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Gujarat NRE No.1 Colliery Stage 2

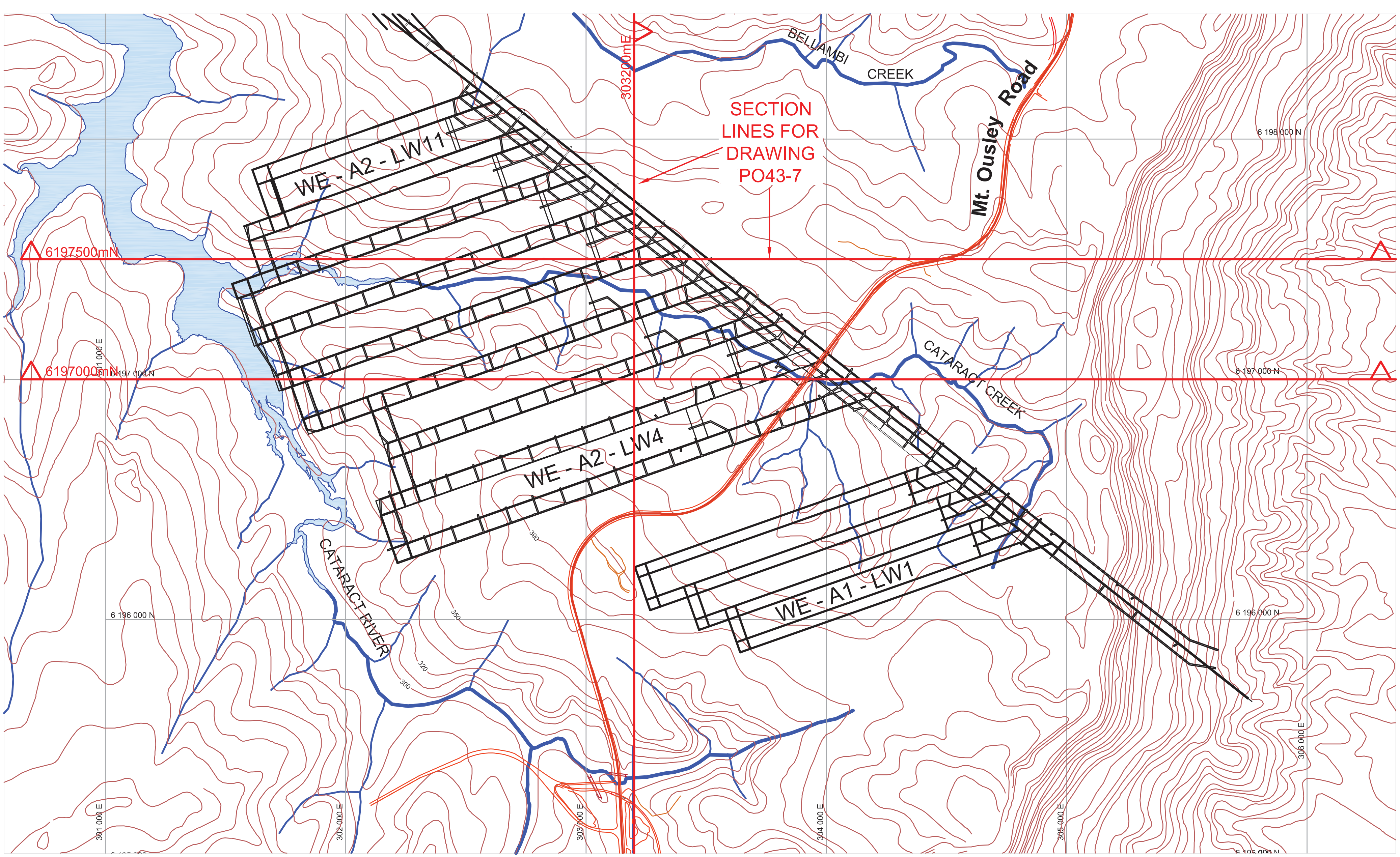
Review of Environmental Assessment

WONGA EAST - GEOLOGY AND EXISTING BULLI AND BALGOWRIE SEAM WORKINGS

DRAWING NO: PO43-4

REV: 0

A3



Scale 1 : 15,000 @ A3

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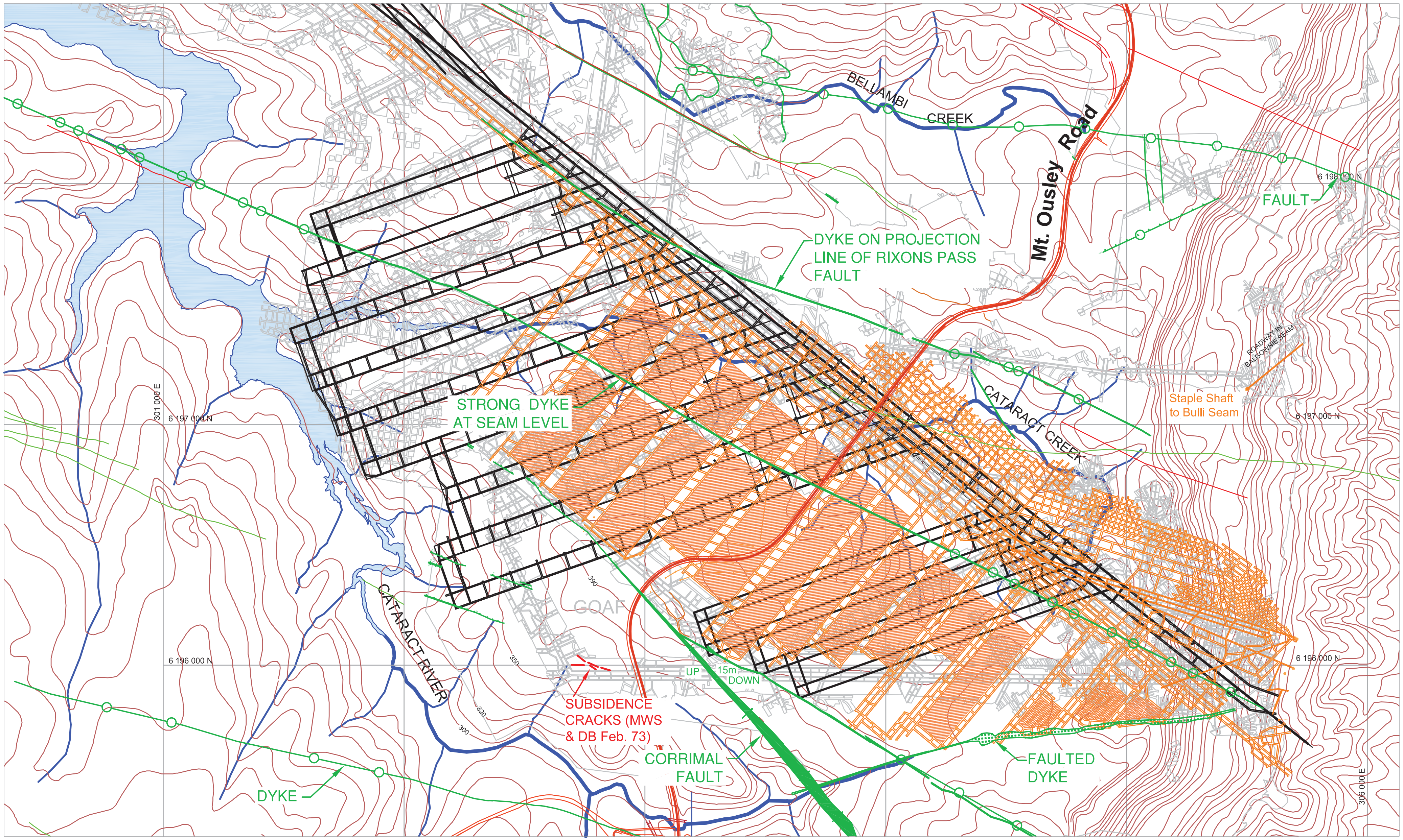
Gujarat NRE No.1 Colliery Stage 2

Review of Environmental Assessment

WONGA EAST

DRAWING NO: PO43-5

REV: 0



Scale 1 : 15,000 @ A3

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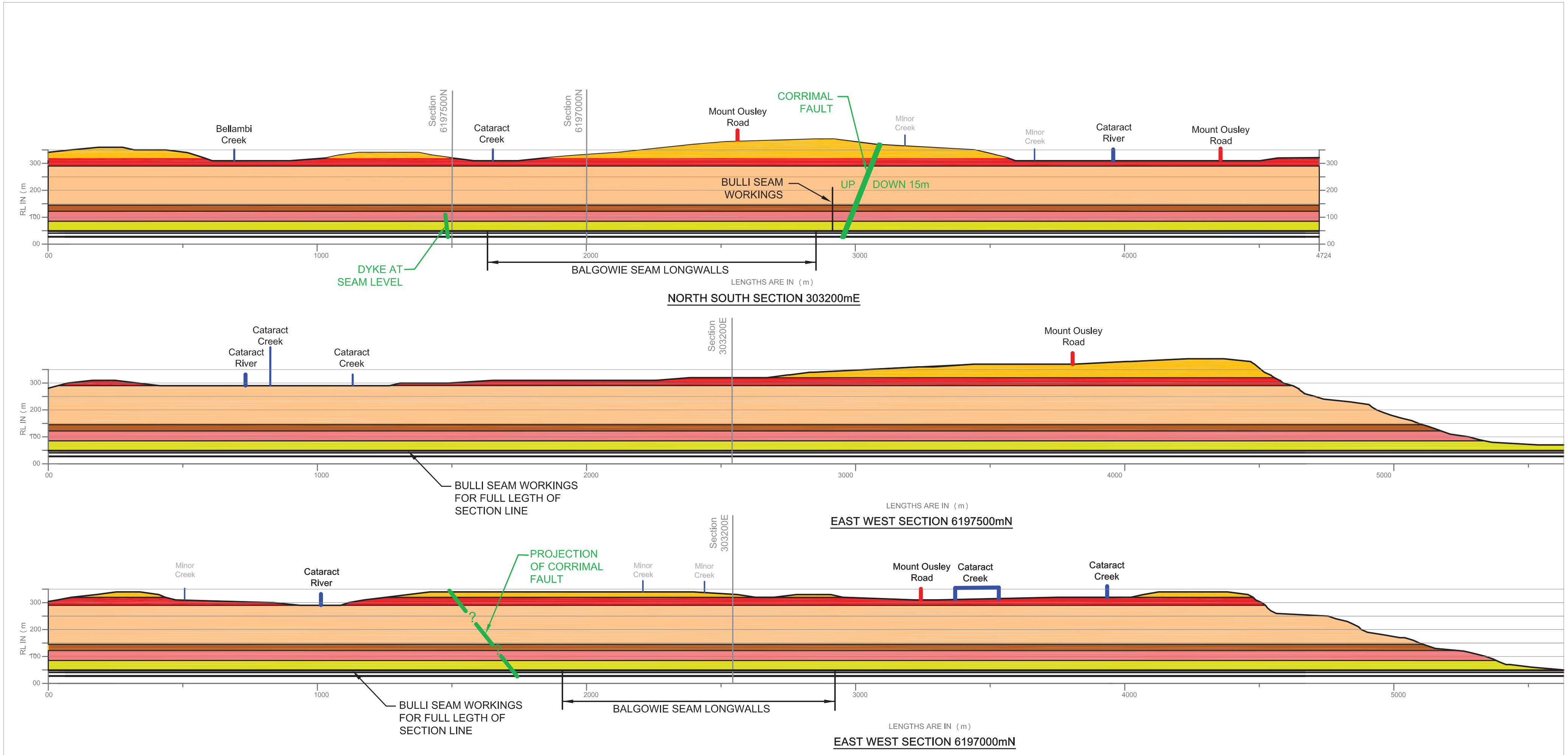
Gujarat NRE No.1 Colliery Stage 2
Review of Environmental Assessment

WONGA EAST - PROSED LONGWALLS IN WONGAWILLI SEAM
RELATIVE TO EXISTING WORKINGS

DRAWING NO: PO43-6

REV: 0



LEGEND
Hawkesbury Sandstone
Bald Hill Claystone
Bulgo Sandstone
Stanwell Park Claystone
Scarborough Sandstone
Wombarra Shale and Coalcliff Sandstone

Note:
Strata dip at about 1 in 70 to NW.
This dip is not shown on these sections.

Scale 1 : 15,000 @ A3

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Gujarat NRE No.1 Colliery Stage 2
Review of Environmental Assessment

CROSS SECTIONS

DRAWING NO: PO43-7

REV: 0

Annex O

Stream Assessment

GeoTerra

GUJARAT NRE COKING COAL LTD

NRE No.1 COLLIERY
MAJOR EXPANSION
STREAM ASSESSMENT

Bellambi, NSW

GUJ1-SWR1D

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

GUJ1-SWR1D (27 NOVEMBER, 2012)

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

Attention: Dr C Harvey

Chris,

RE: Wonga East and Wonga West Stream Assessment

Please find enclosed a copy of the above mentioned report.

Yours faithfully

GeoTerra Pty Ltd

Andrew Dawkins (AuSIMM CP-Env)

Managing Geoscientist

Distribution:	Original	GeoTerra Pty Ltd
	1 electronic copy	Gujarat NRE Coking Coal Ltd
	1 electronic copy	ERM Australia Pty Ltd

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GeoTerra

Authorised on behalf of GeoTerra Pty Ltd:	
Name:	Andrew Dawkins
Signature:	
Position:	Managing Geoscientist

Date	Rev	Comments
11.08.2010		Draft
15.10.2010	A	Incorporate reviewer comments and add additional commentary
31.01.2011	B	Incorporate relevant Bulli PAC findings and review comments
05.11.2012	C	Incorporate adequacy review comments
27.11.2012	D	Incorporate review comments

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Appendix B	Stream Significance Assessment
Appendix C	Stream Photographs and Mapping

EXECUTIVE SUMMARY

Gujarat NRE Coking Coal (Gujarat) propose to extract the Wongawilli Seam via 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.

The proposed workings are located approximately 13km north west of Wollongong in NSW.

The Study Area has previously been mined by bord and pillar workings to the east and west, as well as pillar extraction to the east of the reservoir in the Bulli Seam within the Gujarat lease since the turn of the century.

Bord and pillar mining in the Bulli Seam was also conducted in the same time period to the north and south by BHP Billiton Illawarra Coal (BHPBIC).

Longwall mining has been conducted in the Bulli Seam to the south in the BHPBIC Cordeaux mining area, in the Wonga West area by Gujarat, along with longwall mining in the Balgownie Seam and in longwall WE-A2-LW4 of the Wongawilli Seam at Wonga East in the Gujarat lease area.

The Study Area is defined as being within 600m of the edge of secondary longwall extraction.

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.

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

The proposed Wonga West panels are subdivided into Area 3, to the west of Lizard Creek, and Area 4, to the north east of Lizard Creek. The proposed five Area 3 panels terminate to the north of Wallandoola Creek and do not undermine Lizard Creek.

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

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

The main channels of Lizard Creek and Wallandoola Creek are predicted to undergo a maximum of 0.5m subsidence and 120mm uplift, whilst Cataract Creek is predicted to undergo 1.2m subsidence and 60mm uplift.

Surface water features within 600m of the proposed secondary workings consist of:

- 1st to 3rd order streams of Wallandoola Creek which drain into the Cataract River, downstream of the Cataract Dam wall at Wonga West;
- 1st to 4th order streams of Lizard Creek which drain into the Cataract River, downstream of the Cataract Dam wall at Wonga West;
- 1st to 4th order streams of Cataract Creek and Cataract River which flow into Cataract reservoir,

- 1st and 2nd order tributaries of Cataract River and Bellambi Creek (upstream of the reservoir) which will not be undermined by the Wonga East workings;
- Cataract Reservoir, which will not be undermined by the Wonga East workings, although the western end of longwall WE-A2-LW10 extends into the reservoir high water mark in Cataract Creek;
- thirty nine swamps at Wonga East within 600m of the proposed workings that meet the definition of the Coastal Upland Swamp Endangered Ecological Community, fourteen of which lie within the predicted 20mm subsidence zone. Of those fourteen, seven are 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
- forty five swamps at Wonga West within 600m of the proposed workings that meet the definition of the Coastal Upland Swamp Endangered Ecological Community. Of these, thirty six lie within the predicted 20mm subsidence zone. Of those thirty six, eight are 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

Note that a detailed discussion of upland swamps is contained in (Biosis, 2012).

Lizard, Wallandoola, Bellambi and Cataract creeks, as well as Cataract River and Cataract Reservoir are all contained within the Sydney Catchment Authority controlled Metropolitan Special Area.

The 3rd order or higher creek channels are interpreted to be “losing” streams in the upper catchments and “gaining” streams in the incised, sandstone based gorge reaches of Lizard Creek and Wallandoola Creek in Wonga West (Areas 3 and 4) as well as in the Cataract Creek, Cataract River and Bellambi Creek catchments at Wonga East (Areas 1 and 2).

No extraction is proposed under the 3rd order or higher channel of Lizard and Wallandoola Creeks, with the panel layout being designed to avoid subsidence impacts on the bed of the creeks and Cataract reservoir.

Extraction is proposed, however, under 3rd order tributaries of Lizard Creek at Wonga West in tributaries LCT1 and LCT2.

No extraction is proposed under the 3rd order or higher channels of Cataract River (upstream of the reservoir) or Bellambi Creek at Wonga East.

Cataract Creek is proposed to be undermined by longwalls in Wonga East (Area 2), with a predicted maximum subsidence of 0.8m, along with up to 10mm/m compressive and 5mm/m tensile strains over WE-A2-LW8 (Seedsman Geotechnics, 2012).

Within the overall catchment, Cataract Creek has the potential to subside by up to 1.2m (Seedsman Geotechnics, 2012) as a worst case scenario.

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250mm and the creek experiences greater than negligible impact.

The upper reaches of Lizard Creek and Wallandoola Creek are predominantly underlain by humic, clayey to sandy valley fill swamp sediments with interspersed shallow alluvium covered pools and shallow exposed Hawkesbury Sandstone substrate.

Downstream of the alluvium / shallow pool dominated reach, 20 - 25m high waterfalls are present in Wallandoola Creek (Waterfall W1) and Lizard Creek (Waterfall L1), with the creek bed containing increasingly exposed Hawkesbury Sandstone above and downstream of the waterfalls.

The lower reach of Cataract Creek at Wonga East contains the exposed Newport / Garie Formation shales and the Bald Hill Claystone, along with the Bulgo Sandstone with a thin alluvium, whilst the upper flanks of the valley and upper headwaters contains predominantly thin alluvium over Hawkesbury Sandstone.

The plateaus in both areas are covered in a thin or absent Hawkesbury Sandstone derived sandy colluvium, whilst up to 1.9m thick humic, clayey to sandy colluvial / alluvial sediments are located within the headwater swamps in the first order tributaries.

One regional scale SW / NE trending fault / dyke is located in the Bulli Seam workings, at seam level, over the proposed Wonga West workings, along with some thinner dykes, whilst a north / south trending fault is located to the west of the proposed Wonga West workings. .

The Rixons Pass Fault is interpreted to be sub-parallel to Cataract Creek, although it has not been mapped in the Bulli or Balgownie workings at Wonga East.

A SE / NW trending dyke has been identified in both the Bulli and Balgownie workings, whilst the Corrimal Fault has been mapped in the proposed Wonga East Area 2 workings footprint (GeoTerra, 2012).

Stream flow in Wallandoola Creek is permanent in the valley fill swamp and downstream reach to the upper section of Waterfall W1, where cracks in exposed sandstone enable overland flow to cease during extended dry periods. Permanent stream flow resumes downstream of Waterfall W1.

Flow in Lizard Creek is permanent in the valley fill swamps and downstream reach to Site LC3. Site LC3 can stop flowing, although remains ponded, during low flows. Between LC3 and LC4, where cracks are present in exposed sandstone, the creek bed can dry out during extended dry periods, with permanent flow or standing pools, resuming approximately 200m upstream of Waterfall L1, downstream to Site LC5.

Between LC5 and LC6, stream flow can cease after extended dry periods, with either standing pools or permanent flow resuming downstream of LC6 down to the confluence with Cataract River.

Flow in Cataract Creek has been observed to be perennial, with no evidence of stream bed cracking or adverse effects on pool water retention due to previous multi seam extraction in the Bulli bord and pillar, Bulli pillar extraction, Balgownie longwall and Wongawilli (longwall WE-A2-LW4) workings.

The high water mark of Cataract Reservoir depends on draw down from the dam and rainfall in the catchment, with a maximum high water extent in Cataract Creek near Site CC9 of 289.87mAHD.

Based on a comparison between rainfall and underground water management reports, no evidence of connective cracking from Cataract Creek to the multi-seam mined Wonga East workings is indicated.

No evidence of connective cracking is noted for the existing (deeper) western Bulli Seam workings (S Wilson, pers. Comm.).

As a result of logistical limitations due to unconstrained flow in valley fill swamp reaches, as well as both natural bedding plane / jointing and previous subsidence induced sub-surface diversions through cracks in the stream beds, limited volumetric flow monitoring locations have been installed. Measurement of pool depth is however measured at numerous locations in Lizard, Wallandoola and Cataract creeks as well as Cataract River.

Stream channel reaches have been defined as “significant” between CC5 and CC9 in Cataract Creek due to the presence of Macquarie Perch.

Lizard Creek is defined as “significant”, due to the unique nature and unaffected flow status at Waterfall L1.

Since regular water quality monitoring started in July 2007, Lizard Creek has had a pH range from 2.50 – 7.07 and electrical conductivity (EC) from 19 – 290µS/cm, whilst Wallandoola Creek ranges from pH 3.35 – 6.83 and EC from 56 – 199µS/cm.

Cataract Creek ranges from pH 4.39 – 6.91 and 101 - 190µS/cm EC, whilst Cataract River ranges from pH 5.1 – 6.5 and 52 - 147µS/cm EC.

All four streams and their tributaries exhibit ferruginous precipitation at seepage outflows along the valley, from upland swamps as well as above and below the waterfall reaches.

Swamp water levels and outflow seepage are highly variable, and have a direct relationship to rainfall recharge in the catchments. The headwater swamps have pH ranging from 3.64 – 7.48 and EC from 64 - 1121µS/cm, whilst the valley fill swamps range from 5.25 – 7.24 and EC from 83 - 358µS/cm.

No adverse effects have been observed in any of the swamps due to previous mining induced subsidence in the Gujarat lease area.

The potential effects, impacts and consequences of the proposed longwall mining in the Wongawilli Seam on the streams as well as Cataract Reservoir are summarised in the following tables.

Potential Lizard Creek Effect, Impact and Consequence Summary

REACH	EFFECT*	IMPACT	CONSEQUENCE
LC1 - 3	<0.02m S_{max}, <1mm/m strain, <1mm/m tilt <200mm valley closure <120mm uplift	No change to fabric or structure of the stream bed or water quality	Negligible potential impact on flow diversion, no connective cracking, pool drainage, iron staining, water quality or gas releases
LC3 - 4	0.02m S_{max} , <2mm/m strain, <1mm/m tilt <200mm valley closure <120mm uplift	No change to fabric or structure of the stream bed or water quality	Negligible potential impact on flow diversion, no connective cracking, pool drainage, iron staining, water quality or gas releases
LC4 - 5	<0.02m S_{max}, <1mm/m strain, <1mm/m tilt <200mm valley closure <120mm uplift	No change to fabric or structure of the stream bed or water quality	Negligible potential impact on flow diversion, no connective cracking, pool drainage, iron staining, water quality or gas releases
LC5 - 6	0.25m $S_{max,}$ <7mm/m (extension) strain <4mm/m tilt, <200mm valley closure, <120mm uplift	Potential cracking of creek bed due to the proximity of the northern end of Longwall A3 LW2 to creek bed	No connective cracking. Low potential impact on stream flow (with downstream flow re-emergence), as well as pool holding capacity, iron hydroxide seepage or gas release due to stream bed cracking. All of these aspects are currently adversely affected by existing Bulli workings subsidence
LC6 - 7	0.25m $S_{max,}$ <6mm/m (extension) strain <1mm/m tilt, <200mm valley closure <120mm uplift	Potential cracking of creek bed due to the proximity of the northern end of Longwall A4 LW7 to the creek bed	No connective cracking. Low potential impact on stream flow (with downstream flow re-emergence), as well as pool holding capacity, iron hydroxide seepage or gas release due to stream bed cracking. All of these aspects are currently adversely affected by existing Bulli workings subsidence
LCT1	2.25m $S_{max,}$ -7mm/m (compression) to <7mm/m (extension) strain <6mm/m tilt <200mm valley closure <120mm uplift	Potential cracking of 3rd order tributary bed due to undermining by Longwall A3 LW3	No potential for connective cracking. Potential impact on stream flow, pool holding capacity, iron hydroxide seepage or gas release. All of these aspects are currently adversely affected by existing Bulli workings subsidence.
LCT2	0.25m $S_{max,}$ <4mm/m (extension) strain <1mm/m tilt <200mm valley closure <120mm uplift	Limited potential for cracking of 3rd order tributary due to the proximity of the northern end of Longwall A3 LW5 to the creek bed	No connective cracking. Limited potential impact on the upper headwaters of the stream reach flow (with downstream flow re-emergence), as well as pool holding capacity, iron hydroxide seepage or gas release due to stream bed cracking
All reaches	Regional Groundwater Depressurisation	Up to 12m groundwater level reduction in upper Hawkesbury Sandstone	Negligible (0.02ML/day gain to 0.10ML/day reduction, or 0.012 gain to 0.0058ML/km^2/day reduction, or 0.2% gain to 0.8%reduction) of 17ML/day av. flow in Lizard Creek (GeoTerra, 2012)

NOTE: S_{max} = maximum subsidence (from Seedsman 2012)

Potential Wallandoola Creek Effect, Impact and Consequence Summary

REACH	EFFECT*	IMPACT	CONSEQUENCE
WC1 - 3	<0.02m S_{max}, <2mm/m strain, <1mm/m tilt <200mm valley closure <120mm uplift	No change to fabric or structure of the stream bed or water quality	No connective cracking. Minimal to no potential for flow diversion, change in pool drainage, iron staining, water quality or gas releases
WC3 - 4	<0.5m S_{max}, <6mm/m (extension) strain <4mm/m tilt <200mm valley closure <120mm uplift	Potential cracking of 3rd order stream bed due to the proximity of the southern end of Longwall WW-A3-LW3 and WW-A3LW4 to the stream. WW-A3-LW5 has limited potential to generate stream bed cracking	No connective cracking. Potential impact on stream flow (with down stream flow re-emergence), pool holding capacity, iron hydroxide seepage or gas release. Iron hydroxide seepage is currently present
WC4 - 5	<0.02m S_{max}, <2mm/m (extension) strain <1mm/m tilt <200mm valley closure <120mm uplift	No change to fabric or structure of the stream bed or water quality	No connective cracking. Minimal to no potential for flow diversion, change in pool drainage, iron staining, water quality or gas releases
All reaches	Regional Groundwater Depressurisation	Up to 12m reduction of groundwater level in upper Hawkesbury Sandstone	Negligible predicted 0.06 – 0.25ML/day, or 0.0018 – 0.0075ML/km^2/day, or 0.1 - 0.6% reduction in 33.0ML/day average flow in Wallandoola Creek

NOTE: S_{max} = maximum subsidence (from Seedsman 2012)

Potential Waterfall Effect, Impact and Consequence Summary

REACH	EFFECT*	IMPACT	CONSEQUENCE
Waterfall L1	<0.12m S_{max}, <3.5mm/m (extension) strain <2.9mm/m tilt <200mm valley closure <120mm uplift	Limited to no change to structural integrity of the waterfall	Limited to no potential for flow diversion through waterfall, iron staining or water quality
Waterfall W1	<0.02m S_{max}, <1mm/m strain <1mm/m tilt <200mm valley closure <120mm uplift	No change to structural integrity of the waterfall	Minimal to no potential for flow diversion through waterfall, iron staining or water quality

NOTE: S_{max} = maximum subsidence (from Seedsman 2012)

Potential Cataract Creek Effect, Impact and Consequence Summary

REACH	EFFECT*	IMPACT	CONSEQUENCE
CC1 – 4	<0.02m S_{max}, <-1 to 1mm/m strain <1mm/m tilt <200mm valley closure <120mm uplift	No change to fabric or structure of the stream bed or water quality	Negligible potential for connective cracking, flow diversion, negligible change in pool drainage, iron staining, water quality or gas releases
CC2 – 3	<0.16m S_{max} < -2 to 1 mm/m strain <3mm/m tilt <200mm valley closure <120mm uplift	Potential cracking of 1st and 2nd order tributary bed due to undermining by Longwalls A1 LW1, 2 and 3	Potential impact on 1st and 2nd order stream flow with downstream flow re-emergence. There are no 3rd order pools or stream reaches in this section. Potential effect on iron hydroxide seepage, although iron hydroxide seepage is currently present in the 1st and 2nd order stream reaches
CC5 - 9	<0.8m S_{max}, <-9.5 to 5 mm/m strain <4mm/m tilt <200mm valley closure <120mm uplift	Potential cracking of up to 4th order stream bed due to subsidence near / over WE-A2-LW7, LW8, LW9 and LW10	Potential impact on stream flow, with downstream flow re-emergence. Potential effect on pool holding capacity of rock bars CCRB10- 15. Potential iron hydroxide seepage, although iron hydroxide seepage is currently occurring.
All reaches	Regional Groundwater Depressurisation	Up to 4m groundwater level reduction in eroded Hawkesbury / upper Bulgo Sandstone	Predicted 0.06 – 0.07ML/day (0.0115 – 0.0135ML/km^2/day) or (0.5 – 0.6%) reduction of 11.73ML/day average flow in Cataract Creek. The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250mm and the creek experiences greater than negligible impact

Potential Cataract Reservoir, Cataract River and Bellambi Creek Effect, Impact and Consequence Summary

STREAM	EFFECT	IMPACT	CONSEQUENCE
Cataract Reservoir	<0.02m S_{max}, <1mm/m strain <1mm/m tilt no valley closure or uplift	No change to the fabric or structure of the reservoir or dam wall	Negligible reduction in the quality and quantity of water resources reaching Cataract Reservoir. No connective cracking between the reservoir surface and the mine. Negligible leakage from Cataract Reservoir to the mine
Cataract River	<0.02m S_{max}, <1mm/m strain <1mm/m tilt no valley closure or uplift	No change to fabric or structure of the stream bed or water quality	Negligible potential for connective cracking, flow diversion, change in pool drainage, iron staining, water quality or gas releases
Bellambi Creek	<0.02m S_{max}, <1mm/m strain <1mm/m tilt no valley closure or uplift	No change to fabric or structure of the stream bed or water quality	Negligible potential for connective cracking, flow diversion, change in pool drainage, iron staining, water quality or gas releases

NOTE: S_{max} = maximum subsidence (from Seedsman 2012)

1. INTRODUCTION

This study assesses the potential mining impact on streams, as well as providing an indicative management and monitoring strategy to manage potential adverse effects on streams that may be caused by subsidence.

The Study Area is located approximately 13km northwest of Wollongong and is defined as being within a 600m distance from the edge of secondary extraction for the proposed workings (NSW Planning Assessment Commission, 2009).

Gujarat NRE Coking Coal Ltd (Gujarat) proposes to extract coal from the Wongawilli Seam by longwall extraction from eleven panels at Wonga East and seven panels in the Wonga West area. The proposed workings are contained within the NRE No. 1 Colliery in Consolidated Coal Lease 745 (CCL745) and Mining Lease 1575 (ML1575) as shown in **Drawing 1**.

The two main extractions 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**.

This study provides a baseline assessment of the current status of streams within the proposal area, and has been conducted to satisfy the Environmental Assessment approvals process as administered by the Department of Planning and Infrastructure.

Office studies, field monitoring, laboratory analysis and computer modelling studies have been used to prepare a baseline and potential post subsidence assessment of stream flow and standing pool water depths, as well as stream water quality and stream geomorphology.

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

The mine plan has been designed so that the 3rd order or higher main channels of Wallandoola, Lizard and Bellambi creeks will not be directly undermined by the proposed workings.

The 3rd order tributary (LCT1) of Lizard Creek and a short section of the 3rd order reach of LCT2 are proposed to be undermined by Longwall 2 in Area 3 of the Wonga West workings, whilst Cataract Creek will be undermined by the Wonga East Area 2 workings.

Although Cataract Creek is proposed to be undermined, narrow longwalls with wide pillars have been planned to reduce the total subsidence to generally less than 250mm under the creek bed, except for WE-A2-LW8, which may subside by up to 0.8m.

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250 mm and the creek experiences greater than minimal impact

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

Surface water related features within the Study Area include;

- 1st to 3rd order streams of Wallandoola Creek which drain into the Cataract River, downstream of the Cataract Dam wall at Wonga West;
- 1st to 4th order streams of Lizard Creek which drain into the Cataract River,

downstream of the Cataract Dam wall at Wonga West;

- 1st and 2nd order tributaries of Cataract River and Bellambi Creek (upstream of the reservoir) which will not be undermined by the Wonga East workings;
- Cataract Reservoir, which will not be undermined by the Wonga East workings, although the western end of longwall WE-A2-LW10 extends into the reservoir high water mark in Cataract Creek;
- thirty nine swamps at Wonga East within 600m of the proposed workings that meet the definition of the Coastal Upland Swamp Endangered Ecological Community, fourteen of which lie within the predicted 20mm subsidence zone. Of those fourteen, seven are 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
- forty five swamps at Wonga West within 600m of the proposed workings that meet the definition of the Coastal Upland Swamp Endangered Ecological Community. Of these, thirty six lie within the predicted 20mm subsidence zone. Of those thirty six, eight are 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

Note that a detailed discussion of upland swamps is contained in (Biosis 2012).

The Study Area contains ephemeral 1st and intermittent 2nd order tributaries which drain into 3rd order Schedule 2 streams in the Wallandoola and Lizard Creek catchments over the proposed Wonga West workings.

Lizard Creek becomes 4th order where tributary LCT1 joins the main channel, and 5th order, downstream of the 4th order reach of the LCT2 confluence, whilst Wallandoola Creek is 4th order approximately 1.7km downstream of the proposed workings and beyond the study area boundary.

Cataract Creek contains 1st and 2nd order tributaries draining into 3rd order channels, upstream of the freeway, which becomes 4th order downstream of the freeway.

In addition, only ephemeral, first order tributaries of Cataract River and Bellambi Creek overlie the proposed Wonga East (Area 2) workings.

Cataract Creek, Cataract River and Bellambi Creek drain directly into Cataract reservoir, whilst Lizard Creek and Wallandoola Creek drain into Cataract River, downstream of the Cataract Dam wall.

The Cataract River subsequently flows to the Macarthur Water Treatment offtake at Broughton's Pass Weir.

As discussed in (GeoTerra, 2012) the valley fill and headwater upland swamps are located upstream of the waterfalls and Hawkesbury Sandstone incised reaches at Wonga West, as well as on the more steeply sloping flanks of Cataract River, Cataract Creek and Bellambi Creek at Wonga East.

No valley fill swamps are present within Wonga East.

Although the streams and swamps are hydraulically interconnected, the reader is directed to the assessment of upland swamps detailed in the groundwater report (GeoTerra, 2012)

and swamp assessment (Biosis, 2012) for the proposal.

The Study Area also contains increasingly incised valleys in the central and northern (downstream) reaches of Wallandoola and Lizard creeks, downstream of waterfalls L1 and W1. Less incised, although steeper gradient, streams and hills are present in the Wonga East Area.

Cataract River is regulated by Cataract Dam, which is upstream of the Lizard Creek / Wallandoola Creek confluences, as well as by Broughton's Pass Weir, which is approximately 6.25km downstream of the junction with Lizard Creek, and 1.2km downstream of Wallandoola Creek. The Cataract River is partially diverted through Cataract Tunnel or the Macarthur Water Treatment Plant for the metropolitan water supply at Broughtons Pass Weir.

The proposed Wonga East workings underlie the Cataract Creek, Bellambi Creek and Cataract River catchments in essentially undeveloped bushland, apart from limited fire access and power transmission access trails, whilst the Wonga West catchments of Lizard and Wallandoola creeks also contain mine surface infrastructure and access road associated with the Gujarat NRE No. 1 Colliery No. 4 and No. 5 shafts.

Risk Management Zones (RMZ) have been defined according to the Southern Coalfield inquiry (NSW Department of Planning, 2008) and Bulli Seam PAC (NSW Planning Assessment Commission, 2010) which laterally extends to either side of Wallandoola, Lizard, Cataract and Bellambi creeks, as well as Cataract River (upstream of the reservoir) for 400m from the creek centre line.

A 600m wide "potentially significant feature" zone has also been defined as shown in **Drawing 4**.

No private farm or domestic dams are present within the Study Area.

Previous underground mining in and adjacent to the proposed workings has been conducted through longwalling the Bulli Seam to the west, east and beneath Cataract reservoir, by Gujarat as well as in the BHPBIC Cordeaux lease area to the west / south of the Study Area.

Multi seam mining has been conducted where the Bulli Seam was extracted by bord and pillar as well as pillar extraction methods.

In addition, longwalls have been extracted in the underlying Balgownie Seam, whilst one longwall has been mined in the Wongawilli Seam (WE-A2-LW4) at Wonga East.

Predominantly bord and pillar mining, and to a lesser degree, longwall extraction, has also been conducted in the old BHPBIC Bulli Colliery workings to the north of the Wonga East Area.

The previous Bulli Seam mining has caused both conventional and non-conventional subsidence consequences on stream flow and / or water quality in Lizard Creek and Wallandoola Creek at Wonga West as detailed later in this document, with the streams no longer providing a continuum of stream flow or connected pools after extended dry periods.

No adverse consequences have been observed on stream flow or water quality in Cataract Creek, Bellambi Creek or Cataract River, upstream of the reservoir.

2. SCOPE OF WORK

This study is intended to provide a baseline, pre-mining and post mining assessment of the potentially affected surface water systems within the proposed Wonga East and Wonga West catchments in accordance with the Environmental Assessment approvals process as administered by the Department of Planning.

This document does not discuss surface water aspects of the Gujarat NRE1 colliery pit top and infrastructure areas, which is covered by separate authors.

In accordance with the Director Generals Requirements for Application No. 09_0013, (20/3/2009), the requirements for the surface water 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 surface water resources in the project area, paying particular attention to the Upper Nepean River sub-catchment (Metropolitan Special Area), the discharge of mine water and surface runoff into Bellambi Gully Creek and Bellambi Lagoon* (Note this second part is dealt with in an associated water management report prepared by Beca (2010).

GeoTerra Pty Ltd were commissioned by Gujarat NRE Coking Coal Ltd to assess the existing baseline status and to address any potential surface water impacts relating to the proposed extraction and associated subsidence of the Wongawilli Seam extraction in the Wonga East and Wonga West areas.

The stream and swamp monitoring was conducted to assess the;

- functional nature of flow in streams over the panels;
- creek bed and bank erosion and channel bedload;
- stream and upland swamp water quality;
- stream bed and bank vegetation;
- sediment bedload;
- presence and appearance of pools;
- the presence or absence of bedrock, stream bed or bank cracking;
- any observed or inferred groundwater discharge zones, and the;
- presence of hydrocarbon gas.

3. GUIDELINES AND LEGISLATION

3.1 Guidelines and Policies

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

- National Water Quality Management Strategy: Australian Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000a).
- National Water Quality Management Strategy: Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ARMCANZ, 2000b).
- Using the ANZECC Guideline and Water Quality Objectives in NSW (Department of Environment and Climate Change [DECC], 2006a).
- State Water Management Outcomes Plan.
- NSW Government Water Quality and River Flow Environmental Objectives (DECC, 2006b).
- Managing Urban Stormwater: Soils & Construction (Landcom, 2004).
- Managing Urban Stormwater: Treatment Techniques (NSW Environment Protection Authority [EPA], 1997).
- Managing Urban Stormwater: Source Control (EPA, 1998).
- Floodplain Management Manual (Department of Natural Resources [DNR], 2005).
- Floodplain Risk Management Guideline (DECC, 2007).
- Technical Guidelines: Bunding and Spill Management (DECC).
- National Water Quality Management Strategy: Guidelines for Sewerage Systems - Effluent Management (ANZECC/ARMCANZ, 1997).
- National Water Quality Management Strategy: Guidelines for Sewerage Systems - Use of Reclaimed Water (ANZECC/ARMCANZ, 2000c).
- Environmental Guidelines: Use of Effluent by Irrigation (DEC, 2004).
- Approved Methods for the Sampling and Analysis of Water Pollutants in NSW (Department of Environment and Conservation [DEC], 2004), and;
- A Rehabilitation Manual for Australian Streams (Land and Water Resources Research and Development Corporation and Cooperative Research Centre for Catchment Hydrology [LWRRDC and CRCCH, 2000).

3.2 NSW Water Management Act, 2000

The *NSW Water Management Act, 2000* (WMA, 2000) replaced the *Water Act, 1912* in the Study Area on July1, 2011 following gazettal on the 25th of February, 2011 of the;

- Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011, and the;
- Water Sharing Plan for the Greater Metropolitan Region Groundwater Water Sources 2011;

The statutory requirements of the WMA, 2000 include for it to:

" provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations and, in particular:

(a) to apply the principles of ecologically sustainable development, and

(b) protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality, and

(c) recognise and foster the significant social and economic benefits to the State that

result from the sustainable and efficient use of water, including:

> *(i) benefits to the environment, and*
>
> *(ii) benefits to urban communities, agriculture, fisheries, industry and recreation, and*
>
> *(iii) benefits to culture and heritage, and*
>
> *(iv) benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water,*

(d) recognise the role of the community, as a partner with government, in resolving issues relating to the management of water sources,

(e) provide for the orderly, efficient and equitable sharing of water from water sources,

(f) integrate the management of water sources with the management of other aspects of the environment, including the land, its soil, its native vegetation and its native fauna,

(g) encourage the sharing of responsibility for the sustainable and efficient use of water between the Government and water users, and to;

(h) encourage best practice in the management and use of water.

The provisions of the WMA 2000 apply to regulation of access to available waters in all rivers, wetlands and groundwater sources in New South Wales.

Any extraction, interception or diversion from either surface and/or groundwater requires access licences under the provisions of the WMA 2000, including the take of water by means of redistributing or diverting water from a water source, as provided in the definition of take of water in the *Water Management Amendment Act, 2010*.

Lizard, Wallandoola and Cataract Creeks are located within the Upper Nepean River Tributaries Headwaters Management Zone (UNRTHMZ) of the Upper Nepean Water Source. The creeks provide water for environmental requirements and enhancement of flows augmenting regulated releases in the Cataract River to the Broughton's Pass Weir off take, and downstream to the Nepean River.

The NSW Office of Water (NOW) considers the diversion of water from surface water sources to sub-surface fracture zones, or redistribution within groundwater sources as a "take" under the WMA 2000, and as a result, licences must be obtained to account for the take of water from the respective water source.

Specific access and protection rules that may apply to water sources within the assessment area of the proposal are outlined in the following sections.

Protection to surface and associated groundwater sources is a critical to be achieved through a rigorous assessment of the values, risks and environmental consequences resulting from mining-induced subsidence and strains to features within water sources, which will lead to quantifiable, rigorously assessed, achievable outcomes in project approvals.

Such outcomes are required to ensure that equitable sharing of water to all users, including environmental water requirements, is, not diminished by mining developments.

3.2.1 Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011

Under the UNRTHMZ access rules for the environmental flow protection rule, pumping is not permitted when there is no visible flow at a pump site.

Trading rules indicate that trading;

- into the management zone is not permitted;
- within the management zone is permitted, subject to assessment, with no trade allowed from below to above the SCA dams, or vice versa, and;
- conversion to a high flow access licence is not permitted

3.2.2 NSW Aquifer Interference Policy

For a description of the surface water related issues in this policy refer to (GeoTerra, 2012).

3.3 Sydney Water Catchment Management Act, 1998

The proposed mining is within the SCA managed Metropolitan Special Area.

The SCA roles, objectives and functions as detailed in the Sydney Water Catchment Management Act 1998 (SWCM Act) can be summarised as to;

- manage and protect catchment areas and catchment infrastructure works (such as dams and water storages)
- protect the water quality of stored waters; and
- maintain the ecological integrity of the land.

3.4 State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011

SEPP (Sydney Drinking Water Catchment) 2011 applies to land within the hydrological catchments that contribute to Sydney's drinking water supply. The aims of this Policy are:

- *to provide for healthy water catchments that will deliver high quality water while permitting development that is compatible with that goal;*
- *to provide that a consent authority must not grant consent to a proposed development unless it is satisfied that the proposed development will have a neutral or beneficial effect on water quality; and*
- *to support the maintenance or achievement of the water quality objectives for the Sydney drinking water catchment.*

The WMP area is designated as a *Schedule 1 Restricted Access Area (Metropolitan Special Area)* under the *Sydney Water Catchment Management Act 1998* and is managed by the Sydney Catchment Authority (SCA). Consequently this SEPP applies.

In deciding whether or not to approve the Project under Part 3A, the Minister may take into account Clause 9 and 10 of the SEPP. Clause 9 states that:

1) *"any development or activity proposed to be carried out on land to which this Policy applies should incorporate the Authority's current recommended practices and (*performance*) standards*;

2) If any development or activity does not incorporate the Authority's current recommended practices and (performance) *standards, the development or activity should demonstrate to the satisfaction of the consent authority or determining authority how the practices and performance standards proposed to be adopted will achieve outcomes not less than those achieved by the Authority's current recommended practices and standards."*

Clause 10 states that:

1) "*A consent authority must not grant consent to the carrying out of development under Part 4 of the Act on land in the Sydney drinking water catchment unless it is satisfied that the carrying out of the proposed development would have a neutral or beneficial effect on water quality;*

2) *For the purposes of determining whether the carrying out of the proposed development on land in the Sydney drinking water catchment would have a neutral or beneficial effect on water quality, the consent authority must, if the proposed development is one to which the NorBE Tool applies, undertake an assessment using that Tool."*

The *Neutral or Beneficial Effect Tool* (NorBE Tool) identified in Clause 10 of SEPP (Sydney Drinking Water Catchment) 2011 describes how to assess a neutral or beneficial effect (NorBE) on water quality for development applications made to consent authorities for land in the Sydney drinking water catchment, as defined in the SEPP.

The NorBE Tool is detailed in Appendix 1 of the *Neutral or Beneficial Effect of Water Quality Assessment Guidelines 2011* (NorBE Guidelines).

The NorBE Guidelines supports the implementation of the SEPP by providing clear direction on what a neutral or beneficial effect means, how to demonstrate it, and how to assess an application against the neutral or beneficial effect on water quality test using the NorBE Tool.

Although not specified in the SEPP, the NorBE Guideline may provide a framework to consider major infrastructure and other projects under Part 3A of the EP&A Act. The Minister for Planning and Infrastructure determines these projects and which water quality test will be applied.

Monitoring to date indicates that the proposed works will not have significant impact on water quality within lands to which the Sydney Drinking Water Catchment SEPP applies.

4. SOUTHERN COALFIELDS INQUIRY AND PLANNING ASSESSMENT COMMISSION STUDIES

In addition to the policies and guidelines outlined in Section 2.0, the three following reports have guided the NRE No.1 surface water assessment;

- NSW Department 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;
- NSW Planning Assessment Commission, 2010 Bulli Seam Operations PAC Report

The above mentioned reports, hereafter referred to as the Southern Coalfield Strategic Review (SCSR), the Metropolitan PAC and the Bulli PAC, indicate that surface water monitoring regimes and impact assessments should be based on the following

(paraphrased) issues that were expanded upon in the Metropolitan and Bulli PAC reports.

As a general conclusion, the PAC reports indicated a proposed project should achieve "negligible environmental consequences", which includes;

- no diversion of flow,
- no change in the natural drainage behavior of pools,
- minimal iron staining,
- minimal gas releases, and
- continued maintenance of water quality at its pre-mining standard.

Where the predicted subsidence impacts could lead to unacceptable environmental consequences for significant natural features, the PAC adopted a strategy of specifying outcomes to be achieved for a significant feature, rather than prescribing limits for subsidence effects and/or impacts, or setting arbitrary mining setbacks. The Proponent is responsible for satisfying the Consent Authority and regulators that the proposed strategies will achieve these outcomes.

The SCSR and PAC reports defined *subsidence impact, subsidence effect* and *environmental consequence* as outlined below;

effect describes the subsidence itself

impact any physical change to the fabric or structure of the ground or its surface

consequence any change in the amenity or function of a feature that arises from an impact. Some consequences may give rise to *secondary consequences.* Consequences related to natural features are referred to as *environmental consequences.*

As an example, tensile strain due to the ground surface being `stretched' as a result of undermining is an *effect,* a crack resulting from the tensile strain is an *impact,* loss of water down the crack is *a consequence,* and the drying of a water dependent ecosystem as a result of this loss of water is *a secondary consequence.*

The key surface water related issues within the predicted 20mm subsidence zone highlighted in the above reports that were recommended to be addressed are outlined in the following sections.

Further detailed discussion on the relevant surface water issues is contained within this report.

4.1 Catchment Yield

The PAC assessments have determined that a proponent should derive and calibrate a rainfall runoff model for the relevant streams and storages from dam water level and flow records and compare the data with rainfall runoff modeling to ascertain if there is a departure between the modeled and observed data that indicates an existing loss of water from the catchment.

The possibility that the quality of water reaching Cataract reservoir or Broughton's Pass Weir may be reduced as a consequence of subsidence induced cracking in the

waterways and catchment should be assessed.

It should be ascertained if there will be any measurable reduction in runoff to the water supply system operated by the Sydney Catchment Authority or to otherwise represent a threat to the water supply of Sydney or the Illawarra region, as well as any reduction in runoff, including downwards leakage to mining operations, especially where a shallow depth of cover prevails or a structural feature provides a conduit for flow.

4.2 Stream Health

The potential for cracking of stream beds and the underlying strata should be assessed which can lead to:

- loss or redirection of surface water flows;
- changes in water quality, particularly ferruginous springs and/or development of iron bacterial mats that can form flocs, discolouration of water in pools or staining of rock surfaces, as well as generation of elevated levels of manganese and aluminium;
- loss of ecosystem functionality, such as loss of pool integrity, pool connectivity, changes in water quality or loss of visual amenity.

The proponent should conduct mapping and logging of the density and spatial variability of existing subsidence impacts correlated with characteristics of the rock strata in the bed to allow extrapolation of the likely nature and extent of future impacts.

4.3 Stream Flow Reduction

The proponent should compare flow data from gauging stations and, by observation of the shape of recessions and persistence of low flows over a 12 month period, discern if there is any evidence of flow reduction resulting from existing longwall mining under the streams through;

- comparison of daily flows between stations;
- comparison of 5 day moving averages of flow at the stations;
- derivation of rainfall runoff coefficients for the stations

4.4 Risk Management Zones

The SCSR outlined that Risk Management Zones (RMZs) should be identified to focus assessment and management of potential impacts and to manage subsidence effects on significant natural features. The SCSR considered RMZs are particularly appropriate for non conventional subsidence effects.

RMZs should be identified for all significant environmental features which are sensitive to valley closure and upsidence, including rivers, significant streams and valley fill swamps.

Risk Management Zones should be applied to all streams of 3rd order or above in the Strahler stream classification and be defined from the outside extremity of the surface feature, either by a 40° angle from the vertical down to the coal seam which is proposed to be extracted, or by a surface lateral distance of 400m, whichever is the greater.

The Metropolitan PAC report pointed out that defining a RMZ was not, of itself, a determination of `significance', nor does it suggest a need to exclude mining, although it does mean that careful assessment may lead to management consequences.

The Metropolitan PAC report recommended that RMZs be incorporated into a broader risk framework along with assessment of a set of values to assist in determining the nature and level of any protection that might be required.

5. PREVIOUS RELATED STUDIES

Stream flow and stream water quality status of Wallandoola Creek has been assessed in:

- September 2001 (Seedsman Geotechnics Pty Ltd, 2001) at two sites within Wallandoola Creek, approximately 500m downstream of the V Mains Project Area;
- November to December 2001 (GeoTerra Pty Ltd, 2002) at three sites within the main channel and a tributary of Wallandoola Creek, downstream of V Mains. This was in preparation for a proposed expansion of longwall mining to the west of the existing Bulli Seam workings, which, in the end, did not proceed; and
- Between July 2007 and the present within Wallandoola Creek in the vicinity of the proposed Bulli Seam V Mains extraction area.

The stream flow and water quality of Lizard Creek has also previously been assessed in:

- March 2001 (Australian Water Technologies, 2001) at two sites (LC2 and LC8);
- September 2001 (Seedsman Geotechnics Pty Ltd, 2001) at numerous sites within Lizard Creek and its tributaries downstream of V Mains;
- November to December 2001 (GeoTerra Pty Ltd, 2002) at numerous sites within the main channel and tributaries of Lizard Creek, adjacent to and downstream of V Mains in preparation for a potential expansion of longwall mining to the west of the existing Bulli Seam workings (which did not proceed);
- Between July 2006 and the present (Ecoengineers Pty Ltd, 2008) in two unnamed tributaries of Lizard Creek over the current extraction area at T and W Mains, and;
- Between July 2007 and the present in the vicinity of the proposed Bulli Seam V Mains extraction area.

6. PREVIOUS MINING AND SUBSIDENCE

The following discussion on previous mining and subsidence is generated from Seedsman Geotechnics (2012).

6.1 Wonga East

Longwall mining in the Balgownie Seam as well as bord and pillar extraction of the Bulli Seam under Cataract Creek, Bellambi Creek and the Cataract River (upstream of the reservoir) has previously been conducted, with no record of adverse impacts on the stream bed or banks or upland swamps.

At Wonga East, the Bulli Seam overlies the Balgownie Seam by approximately 6 - 8m, whilst the Balgownie Seam overlies the Wongawilli Seam by approximately 10 - 15m.

6.1.1 Bulli Seam Bord and Pillar, Pillar Extraction

As shown in **Drawing 5**, the Bulli Seam has been mined in adjoining workings by BHP Billiton (and its predecessors) at the;

- Cordeaux Colliery to the immediate south and west of the Gujarat lease using longwall extraction, and;
- Bulli Colliery to the immediate north and east of the Gujarat lease area by predominantly bord and pillar methods, with pillar extraction.

The Bulli Seam was initially mined within the NRE No. lease area up to 125 years ago in a relatively disordered bord and pillar pattern with roadways driven approximately 5m wide with approximately 25m wide pillars, which in some cases were split diagonally as shown in **Drawing 5**.

Subsequent pillar extraction of up to 490m wide occurred, with the actual extent being as accurate as historical survey records permit.

It was noted during subsequent extraction of the Balgownie longwalls that the ground conditions matched the recorded mine workings in the Bulli Seam.

As the Cordeaux and Bulli mine workings have the potential to directly influence the groundwater system within the Study Area, the adjacent underground Bulli workings are summarised in **Table 1**.

Table 1 Adjacent Mining Operations

MINE	Operator	Extraction Method	Max Depth (mbg)	Max Mine Inflow (ML/yr)	Status
Cordeaux (d)	BHP	Longwall	455	n/a	flooded
Bulli (d)	BHP	Bord and pillar	405	n/a	flooded

NOTES: LW longwall d decommissioned mbg m below ground n/a not available

The Bulli Seam was mined by BHP Billiton (and its predecessors) at the Cordeaux Colliery to the immediate south of the Gujarat lease using longwall extraction from 1979, with the mine currently being closed on a care and maintenance basis.

BHPBIC also mined the Bulli Seam via bord and pillar extraction between the Cordeaux longwalls and the Bulli Seam workings in the Wonga East area.

The Bulli bord and pillar workings to the east of the NRE1 500 series longwalls and north of the Wonga East area were extracted as shown in **Drawing 5**, with the workings extending to the east, with and a number of portals through to the Illawarra Escarpment.

Longwall extraction in the Bulli Seam has been, and is currently occurring at least 2.6km to the north of the Gujarat lease on the northern, opposite side of the Cataract River in the BHP Billiton Illawarra Coal Westcliff, Northcliff and Appin workings as well as in the Helensburgh Coal Metropolitan mine. These workings are far enough to the north to be of no influence on the Gujarat lease area.

6.1.2 Balgownie Longwalls

The Balgownie longwalls were extracted after and beneath the Bulli Seam in the 1970s and 1980s. The Balgownie Seam was approximately 1.35m thick, although the mining height may have been slightly greater. Panel widths ranged from 144 - 186m and pillars were 25 - 40m as shown in **Drawing 6** for a 280 - 290m depth of cover, with the mining face being relocated around a north-west trending dyke.

Monitoring over the 150 - 190m wide longwalls indicated subsidence of approximately 0.55m above the chain pillars and sag over the panels of up to 0.8m, for a maximum of 1.4m. Strains up to 3mm/m were measured above large Bulli pillars and up to 6mm/m above Bulli Seam extraction areas, with tilts up to 10mm/m.

Following extraction of the Balgownie Seam, subsidence between 0.6 – 0.8m developed where large pillars and barriers were left in the Bulli Seam, with sag between the pillars and above the Balgownie longwalls of approximately 0.2m.

Vertical subsidence above the pillars averaged about 0.55m.

6.1.3 Wongawilli Seam Longwall WE-A2-LW4

The Wongawilli Seam longwall WE-A2-LW4 at Wonga East was mined between 19/04/2012 and 18/09/2012.

The panel was located at 310 – 340m below surface, with a 150m width and an extraction height of 3.1m.

No streams and one swamp (Ccus6) overly the predicted 20mm subsidence zone.

Maximum subsidence of 1.3m, along with maximum strain of 4.3mm/m (tensile) and 3.4mm (compressive) and a maximum tilt of 26.8mm/m were observed over the panel, whilst tensile cracking was observed near the longwall centreline, parallel to the longwall face, and in the pavement of Mt Ousley Road.

It was observed that subsidence was constrained within the panel footprint, with the Bulli and Balgownie seams being mined immediately above WE-A2-LW4. This implies that the previous mining has reduced the bridging characteristics of the overburden to make it more compliant and less able to span the single panel.

Total cumulative subsidence is estimated to be;

- 1m from the Bulli Seam
- 0.5 – 1.3m from the Balgownie Seam (depending on the actual location), and;
- 1.3m from WE-A2-LW4, for a total of up to 3.6 m.

No evidence of pillar run is present for the Bulli Seam, whilst the pillar extraction areas in the Bulli Seam are fully subsided (SCT Operations, 2012).

The observed cracking is consistent with general experience of mining in steep terrain and is likely to be associated with an equal amount of compression across Cataract Creek, with movement likely to have been taken up on a horizontal shear plane at or near the base of the valley.

An inspection of Cataract Creek, in October 2012 did not reveal evidence of stream bed cracking, loss of pool holding capacity, development of ferruginous springs or changes in stream water quality.

No adverse effect on tributary stream outflow, groundwater levels or stream / groundwater quality was observed on swamp Ccus6 or tributary CT1 due to the subsidence or cracking

over WE-A2-LW4.

The groundwater related aspects of WE-A2-LW4 are discussed in (GeoTerra, 2012).

The observations from mining WE-A2-LW4 were incorporated into an updated subsidence prediction assessment for the Wonga East longwalls (Seedsman, 2012).

6.2 Wonga West

The Bulli Seam was extracted using 142 -188m wide longwalls in the north/south aligned 200 and 300 series panels.

The 200 series longwalls were extracted between July 1979 (LW202) and October 1993 (LW212), whilst the 300 series were extracted between November 1981 (LW301) and March 1993 (LW309). Longwall 310 was completed in January 2002.

Pillar widths ranged from 19 - 35m, with some experiments at 51m for a depth of cover between 400 - 450m and a 2.5m seam thickness.

The panels underlie both Lizard and Wallandoola Creeks.

The 500 series were extracted between July 1993 (LW501) and September 2000 (LW518) under Cataract Reservoir, between the proposed Wonga East and Wonga West areas.

The longwalls utilised large, stable pillars with narrow panels, whilst workings closer to the dam wall (LW514 onwards) were based on 150m wide panels with 65m wide pillars, which generated a maximum subsidence of 240mm.

Monitoring of the first four longwalls in the 300 series indicates greater deformation above the chain pillars and subsidence of approximately 1m, tilts up to 4.5 mm/m and strains up to 1.5mm/m.

The available subsidence data has been utilised to give an indicative contour plan of the vertical subsidence across the first 4 panels and was processed to visualise the likely subsidence across the full western area.

6.3 Proposed Adjacent Mining

The Environmental Assessment for the BHP Billiton Bulli Seam Operations initially contained longwall workings in the Appin Area 2 Extended and Appin Area 3 Extended areas, which were located at least 1100m north of the Gujarat Lease (BHPB, 2009).

In a subsequent revision, these workings were removed from the Bulli Seam Operations Preferred Project Report (BHPB, 2010).

No other mining is currently proposed in the vicinity of NRE No.1.

7. PROPOSED NRE NO.1 MINING

7.1 WONGA EAST

The proposed north east / south west trending Wonga East panels are subdivided into Area 1 to the east and Area 2 to the west of Mount Ousley Road, with the gap designed to avoid subsiding the freeway.

Based on the current understanding of coal quality, the proposed eastern mining edge is approximately 560m from the crest of the Illawarra Escarpment (defined as 320m ASL).

As summarised in **Table 2**, Area 1 comprises three, 105m wide panels with 40m wide pillars that underlie steeply sloping, northerly draining, 1st and 2nd order intermittent tributaries of Cataract Creek, with a depth of cover to the Wongawilli Seam of approximately 237 - 255m. The tributaries join at Mt Ousley Road into the 4th order, steeply sloping, easterly draining channel of Cataract Creek.

Area 2 comprises eight, 145 - 150m wide panels with 60m wide pillars that underly the 4th order channel as well as 1st and 2nd order tributaries of Cataract Creek with approximately 267m to 320m depth of cover.

The western end of Panel 10 in Area 2 also underlies the 289.87m AHD high water mark of Cataract Creek in the upper backwaters of Cataract Reservoir, which may marginally overlie the panel edge during high water periods as shown in **Drawing 2**.

Fourteen upland swamps that meet the definition of the Coastal Upland Swamp Endangered Ecological Community lie within the predicted 20mm subsidence zone. Of those, 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 longwalls are positioned so that vertical subsidence under 3rd or higher order streams will be restricted to generally less than 250mm, except over WE-A2-LW8, where subsidence may extend up to 1.0m in Cataract Creek.

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250 mm and the creek experiences greater than minimal impact.

All panels will be extracted down dip from south to north.

A plan of the proposed workings in relation to previous workings is shown in **Drawings 5** and **6**.

Table 2 Wonga East Panel Dimensions and Wongawilli Seam Depth of Cover

Panel	Width (rib to rib) (m)	Pillar Width (m)	Length (m)	Depth of Cover (m)
Area1 LW1	105	40	1040	237 - 242
Area1 LW2	105	40	1080	243 - 247
Area1 LW3	105	40	1150	247 - 253
Area2 LW4	150	60	1325	267 - 284
Area2 LW5	150	60	1435	272 - 288
Area2 LW6	150	60	1120	277 - 293
Area2 LW7	150	60	1230	282 - 304
Area2 LW8	150	60	1375	283 - 310
Area2 LW9	150	60	1280	287 - 316
Area2 LW10	150	60	1020	287 - 318
Area2 LW11	150	60	780	288 - 321

NOTE: Shading indicates previously extracted longwall

The proportion of catchment areas to be undermined is shown in **Table 3**.

Table 3 Wonga East Proportion of Catchment Within Potential Subsidence Areas Compared to Total Catchment Area

Stream	Total Catchment (km^2)	Within 20mm Subsidence Zone (km^2)	% of Catchment
Cataract Creek	5.2	2.5	48.1
Bellambi Creek	9.3	0.05	0.5
Cataract River	11.6	0.4	3.4

Source: WRM Water and Environment (2012) in Appendix A

7.2 WONGA WEST

The Wonga West panels are subdivided into Area 3, to the west of Lizard Creek, and Area 4, to the east of Lizard Creek, with the panel layout designed to avoid subsidence related cracks developing in the main channels of Lizard or Wallandoola Creeks.

No extraction is proposed under the main channels of Lizard Creek or Wallandoola Creek, and no extraction is proposed at Wonga West under the Cataract Reservoir.

The proposed Area 4 panels are at least 1km from the Cataract Dam wall, and are positioned to avoid generating a hydraulic connection between the 20mm subsidence zone and Cataract Reservoir.

Five 374 – 390m wide, up to 2690m long, north-south panels with 65m wide chain pillars are proposed in Area 3, along with two 155m wide and up to 1738m long panels

separated by 65m wide pillars in Area 4 as summarised in **Table 4**.

Table 4 Wonga West Panel Dimensions and Depth of Cover

Panel	Width (rib to rib) (m)	Pillar Width (m)	Length (m)	Depth of Cover (m)
Area3 LW1	374	65	1626	480 - 512
Area3 LW2	381	65	2186	482 - 510
Area3 LW3	379	65	214	472 - 510
Area3 LW4	383	65	2357	457 - 497
Area3 LW5	390	65	2690	457 - 488
Area4 LW6	155	65	1652	457 - 490
Area4 LW7	155	65	1738	465 - 485

The proposed Wonga West main headings will be aligned with and located in close proximity to, or underneath, Lizard Creek as shown in **Drawing 3**.

The proposed panels, underlie ephemeral 1st to intermittent 2nd order tributaries of Lizard Creek and Wallandoola Creek. In addition, the 3rd order reach of the Lizard Creek tributary (LCT1) overlies WW-A3-LW3, along with a short reach of 3rd order channel in LCT2 over WW-A3-LW5.

The depth of cover to the Wongawilli Seam ranges from approximately 455 - 510m in Area 3, with 460 - 495m in Area 4.

Thirty six swamps that meet the definition of the Coastal Upland Swamp Endangered Ecological Community lie within the predicted 20mm subsidence zone. Of those, eight were assessed to be of "special significance" according to the NSW Office of Environment and Heritage criteria (OEH, 2012), as shown in **Drawing 3**, 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

Figure 1 indicates the relationship between the previous Bulli Seam and the proposed Wongawilli Seam workings, which will all be extracted down dip from south to north.

Figure 1 Proposed Wonga West Longwalls and Old Bulli Seam Workings

The proportion of catchment areas to be undermined is shown in **Table 5**.

Table 5 Wonga West Proportion of Catchment Area Within Potential Subsidence Areas Compared to Total Catchment Area

Stream	Total Catchment (km^2)	Catchment Within 20mm Subsidence Zone (km^2)	% of Catchment
Lizard Creek	17.1	6.3	36.8
Wallandoola Creek	33.2	2.0	6.0

Source: WRM Water and Environment (**Appendix A)**

7.3 Anticipated Mining Schedule

Intital development of access and ventilation drifts as well as water drainage of the workings has been conducted at Wonga East, and will be required for access to and development of the remaining workings in Wonga East and Wonga West.

It is currently planned that Longwall 5 in Area 2 will be mined, followed by Longwalls 6 to 11 in Wonga East, then the workings in Wonga West.

Table 6 Proposed Underground Mining Schdule

MINING AREA	Estimated Duration of Drift Installation, Pre Drainage and Longwall Mining (Years)
Wonga East Area 1	2.0
Wonga East Area 2	4.5
Wonga West Area 3	7.0
Wonga West Area 4	1.25

8. PREDICTED SUBSIDENCE

8.1 Wonga East

The Cataract Creek, Cataract River and Bellambi Creek catchments have previously been undermined by multi-seam extraction, comprising the Bulli Seam bord and pillar, as well as pillar extraction workings, the Balgownie Seam longwalls and Wongawilli Seam longwall WE-A2-LW4.

The possible subsidence effects at Wonga East shown in **Drawings 7** to **9** were determined using Surface Deformation Prediction System (SDPS) software and default parameters, with the prediction taking into account the subsidence over WE-A2-LW4 (Seedsman Geotechnics, 2012).

Subsidence under the main channel of Cataract Creek is predicted to be generally less than 250mm, along with valley closure of up to 100mm and upsidence of up to 60mm. However, subsidence of up to 0.8m may occur over Longwall WE-A2-LW8 in the bed of Cataract Creek.

Following the Failure Mode and Effects Analysis (FMEA) review (Olsen Environmental Consulting, 2010), it was considered good practice to double these estimates in the context of an impact risk assessment (Seedsman Geotechnics, 2012).

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250mm and the creek experiences greater than negligible impact

A summary of predicted maximum subsidence, strain and tilt is shown in **Table 7**. Subsidence predictions for sub-sections of the creeks are shown in **Appendix B**.

Table 7 Maximum Predicted Wongawilli Workings Subsidence (Wonga East)

	Subsidence (m)	Tilt (mm/m)	Strain (mm/m)	Upsidence (mm)	Valley Closure (mm)
Overall Wonga East Area 1 Mining Domain	1.10	17.0	-13 to 11	120	200
Overall Wonga East Area 2 Mining Domain	1.10	17.0	-14 to 15	120	200
Cataract Creek Main Channel	0.25	4.0	-2 to 8	120	200
Cataract River Main Channel	0	0	0	<60	<100
Bellambi Creek Main Channel	0	0	0	0	0

NOTES: compressive strain = -ve values, tensile strains = +values (Seedsman Geotechnics, 2012)

8.2 Wonga West

The predicted subsidence due to extraction of the Wongawilli Seam (only) is shown in **Drawings 10 to 12,** whilst the combined subsidence of the Bulli Seam and Wongawilli Seam mining is shown in **Figure 2**.

A summary of predicted maximum subsidence, strain and tilt is shown in **Table 8**. Subsidence predictions for sub-sections of the creeks are shown in **Appendix B**.

It should be noted that the Wonga West area has been back analysed to have undergone up to 1m of subsidence following extraction of the 200 and 300 series longwalls, and that both Wallandoola Creek and Lizard Creek, their associated tributaries, as well as upland and valley fill swamps have been previously undermined by the Bulli Seam workings.

Both Wallandoola Creek and Lizard Creek have also been previously undermined by the SW-NE oriented longwall panels of the BHPBIC Cordeaux workings to the south of the Gujarat lease.

Valley closures of up to 100mm and upsidence of about 60mm are predicted. However, following the FMEA review, it was considered good practice to double these estimates in the context of an impact risk assessment (Seedsman Geotechnics, 2012).

No published studies have been conducted on the subsidence effects at Cordeaux on stream flow, water quality or upland swamps. As a result of the lack of pre or post mining data, it is not possible to indicate whether, or not, subsidence has had an adverse effect on the surface water system over the Cordeaux panels.

Table 8 Maximum Subsidence (Wonga West)

	Subsidence (m)	Tilt (mm/m)	Strain (mm/m)	Upsidence (mm)	Valley Closure (mm)
Overall Wonga West Area 3 Mining Domain					
Wongawilli Seam + Bulli Seam	3.5	23	n/a	n/a	n/a
Wongawilli Seam only	2.5	17.5	-12 to 14	-	-
Overall Wonga West Area 4 Mining Domain					
Wongawilli Seam + Bulli Seam	2.5	n/a	n/a	n/a	n/a
Wongawilli Seam only	1.5	12.5	-10.5 to 6.5	-	-
Lizard Creek Main Channel					
Wongawilli Seam + Bulli Seam	1.5	n/a	n/a	n/a	n/a
Wongawilli Seam only	0.5	4.0	7.0	120	200
Wallandoola Creek Main Channel					
Wongawilli Seam + Bulli Seam	1.5	n/a	n/a	n/a	n/a
Wongawilli Seam only	0.5	4.0	6.0	120	200

SOURCE: Seedsman Geotechnics, 2012 n/a not available

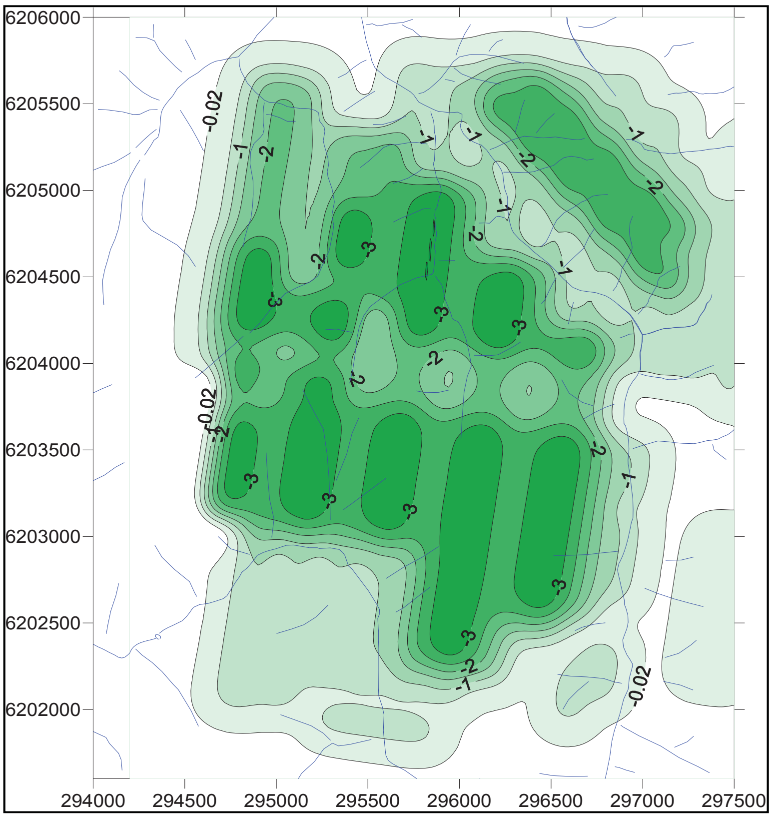


Figure 2 Combined Potential Wongawilli and Bulli Seam Subsidence at Wonga West

9. GENERAL STUDY AREA DESCRIPTION

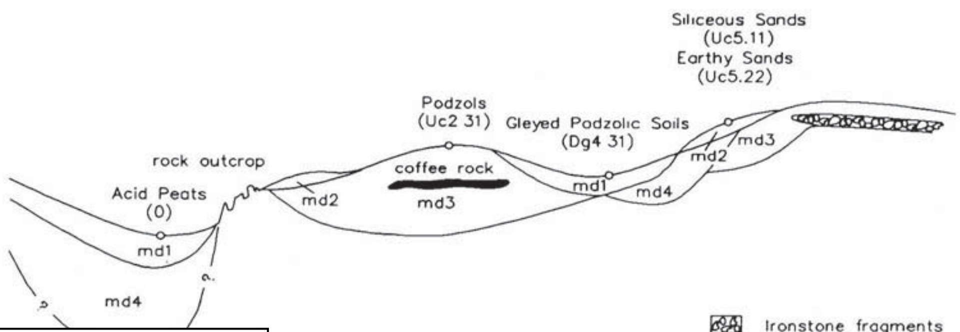
9.1 Land Use

The Study Area is located within the Sydney Catchment Authority restricted access Metropolitan Special Area, which is principally an undeveloped bushland. The region features a limited number of fire and mine site access trails, current and decommissioned mine ventilation shafts as well as men and materials access shaft and infrastructure sites.

9.2 Soil Landscapes

The area comprises three main soil landscapes (Hazelton, 1990) as shown in **Figures 3** to **5**. In general, the upper watershed portions of the catchment are within the Maddens Plains landscape, which migrates into the Lucas Heights landscape, whilst the Hawkesbury landscape is located in the lower, downstream incised valleys as described below.

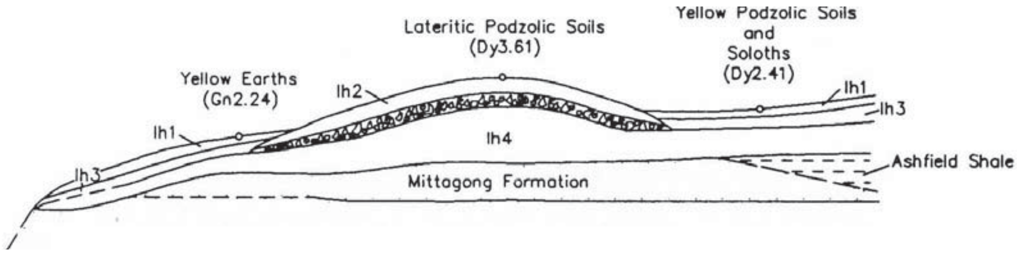
- **Maddens Plains:** moderately to gently undulating rises on plateau surfaces with widespread upland swamps / wetlands. Local relief ranges up to 1-10m with valley slope gradients of 1-10%. The dominant landform elements are broad, usually waterlogged drainage depressions with scattered rock outcrop. The landscape is present within the study area along the channels of Wallandoola and Lizard Creeks.



Source: Hazelton. P.A. Tille. P.J. 1990

Figure 3 Maddens Plains Soil Landscape

- **Lucas Heights:** gently undulating plateau surfaces and ridges 200-1000m wide, with level to gently inclined slope gradients of <10%. Local relief is less than 30m and rock outcrops are absent. Lateritic podzolic soils can be present within the Lucas Heights profile, which would be a source of dissolved iron into stream waters. The landscape is present on the plateau areas.



Source: Hazelton. P.A. Tille. P.J. 1990

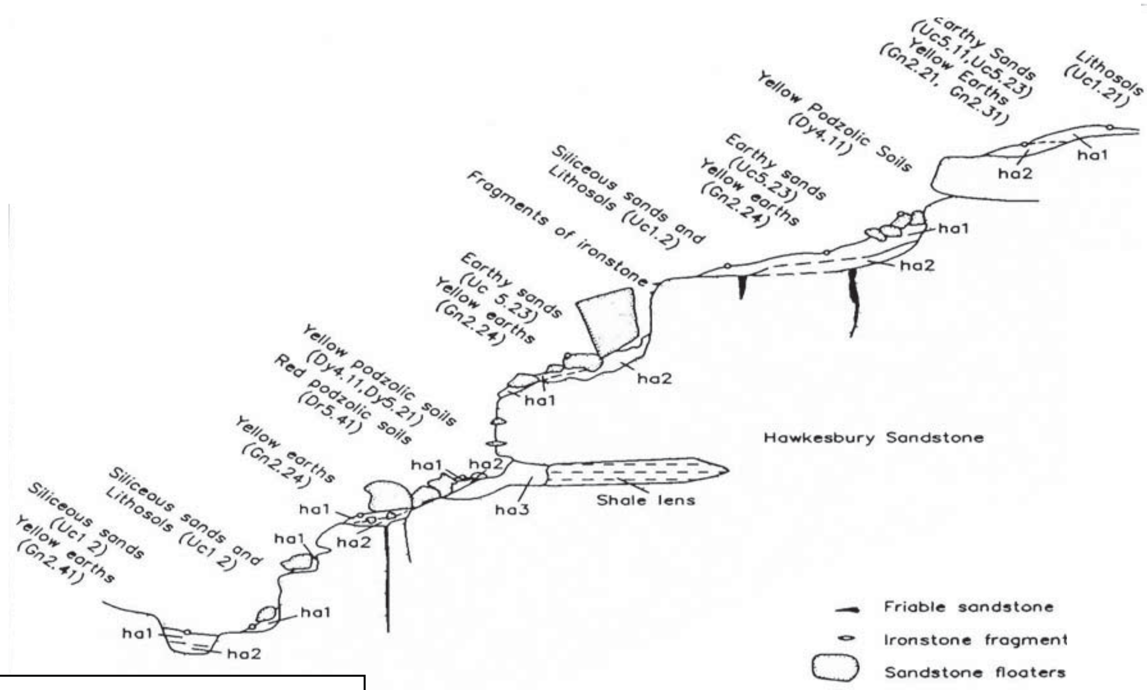
Figure 4 Lucas Heights Soil Landscape

Hawkesbury: Rolling to very steep hills. Local relief of 100 - 200m with slope gradients of 20-70%. Crests and ridges are convex and narrow and <100m wide. Slopes are moderately inclined to precipitous. Valleys are narrow (20-100m) and incised. Rock outcrop is common and occurs as horizontal benches and broken scarps up to 10m high. Rock outcrops and surface boulders and cobbles up to 50% of the ground surface.

Ironstone fragments are present in the profile, which would be a source of dissolved iron into receiving streams.

Cliffs associated with the Hawkesbury landscape have been mapped and discussed in a separate report (SCT Operations, 2012).

The Hawkesbury landscape is present within the steeper, incised sections of Lizard and Wallandoola Creeks.



Source: Hazelton. P.A. Tille. P.J. 1990

Figure 5 Hawkesbury Soil Landscape

9.3 Surficial Geology

For details refer to (GeoTerra, 2012).

9.4 Local Hydrogeology

For details refer to (GeoTerra, 2012).

9.5 Climate

The study area is in a warm temperate region however, it has significant variation in temperature and precipitation due to topographic effects and its proximity to the Illawarra Escarpment and the coast.

Rainfall varies from a maximum of 1800mm/year in the east to 1000mm/year in the west of the Study Area, with maximum rainfall in the Autumn to Winter period.

A plot of rainfall recorded at Cordeaux Colliery since January 2002, which is located to the immediate north of the NRE No. 1 lease area is shown in **Figure 6**.

The plateau generally experiences cooler temperatures than the coast, below the escarpment. Average diurnal temperature ranges from 21.5°C in January to 12.5°C in Winter.

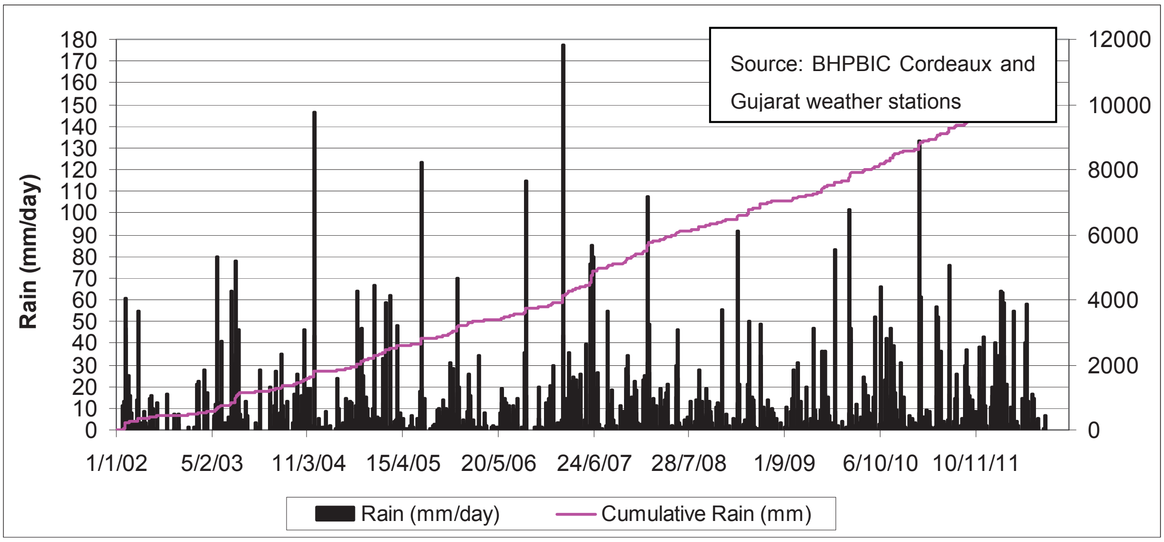


Figure 6 Local Daily Rainfall

10. STREAM CATCHMENTS

The regulated Wonga East Cataract Creek, Cataract River and Bellambi Creek catchments are located upstream of Cataract Reservoir, whilst the Wonga West Lizard and Wallandoola Creeks are unregulated and drain to the Cataract River downstream of the Cataract Dam wall.

Downstream of the junction with the two creeks, the Cataract River flows to a regulated section of the river at Broughtons Pass Weir.

10.1 Wonga West Streams

Lizard Creek and Wallandoola Creek vary along their reach from being "losing-disconnected streams" in the southern headwaters where the shallow groundwater system is recharged from stream flow seeping vertically from the base of the creek, to "gaining" streams in the middle and northern portions of the NRE No.1 lease where the creeks are incised into Hawkesbury Sandstone.

Although it has not directly been observed, variable rates of seepage from the Hawkesbury Sandstone is interpreted to enter the creeks, downstream of waterfalls L1 and W1, and can maintain a low volume baseflow, depending on the interaction between rainfall runoff / recharge and groundwater level applying at any one time.

Differentiation between the distribution of "losing" and "gaining" streams also varies depending on the amount of rainfall recharge into the sandstone plateau and the resultant standing water levels within the regional groundwater system.

Upstream of the incised stream sections and waterfalls, the two catchments are separated by a 15 - 25m high watershed, with the watershed height increasing significantly downstream of the waterfalls, where 55 – 85m deep valleys are located in the northern, downstream section of the lease.

Four channel types are present:

- valley fill upland swamps with an indistinct channel;
- narrow indistinct overgrown channels associated with a low sedge / heath and a relatively thick sandy riparian soil with a streambed consisting of weathered bedrock and/or sandy material;
- rock platforms of variable width which are usually smooth except for minor depressions on joint planes and occasional potholes. These platforms normally grade into a thinly vegetated sandy soil on either bank and can exhibit deposition of hydrated iron oxide observed as orange to black discolouration of the rock surface, or;
- incised channels in sandstone which exhibit rough riffle like surfaces, usually with accumulations of boulders and other sediments. These channels are usually bound by solid rock outcrop.

Four pool types can also be present:

- shallow, linear, small pools located in depressions formed by joint systems or cross-bedding and sometimes associated with potholes. Accumulated water is usually less saline than in surrounding pools and have minor to no interaction with the local groundwater system;
- linear pools associated with narrow erosion channels in sandy soil. The soil is usually vegetated with heath like species, whilst the downstream end is constrained by a rockbar or outcrop;
- larger pools constrained by a downstream rockbar which can be undercut by

erosion and exhibit signs of chemical weathering, or;

- larger pools constrained downstream by sediments. The sediments may extend for a considerable distance downstream.

10.1.1 Wallandoola Creek

Wallandoola Creek flows in a northerly, then westerly direction at Area 3.

The creek has previously been undermined by longwalling in the Bulli Seam by both the BHPBIC Cordeaux and Gujarat NRE No.1 workings as shown in **Drawing 5**. It does not overlie the proposed Wongawilli Seam panels, although is contained within the predicted 20mm subsidence envelope to the south of Area 3, longwalls 3 and 4, as shown in **Drawing 9**.

The main channel of Wallandoola Creek within the Wonga West 20mm subsidence zone is a Schedule 2, 3rd order stream (DIPNR, 2005) with ephemeral 1st and intermittent 2nd order tributaries, and becomes increasingly incised into Hawkesbury Sandstone at and downstream of Waterfall W1.

Wallandoola Creek joins the Cataract River approximately 8km (or 11km along the stream reach) to the north northwest of the Study Area, downstream of the Cataract Dam wall, whilst its headwaters are located south of the Gujarat lease over the previously longwalled BHPBIC Cordeaux Colliery workings.

The creek is not regulated by any dams or weirs within the Study Area. Wallandoola Creek stream monitoring site location details are shown in **Table 9** and **Drawing 3**.

Table 9 Wallandoola Creek Stream Monitoring Sites

SITE	E (MGA)	N (MGA)	DESCRIPTION
WC1	296155	6200724	Upstream of the proposed Wonga West workings and overlying the BHPB Cordeaux workings.
WC2	295854	6201546	Over the proposed V Mains workings on southern NRE No.1 lease boundary
WC3	295560	6202488	Located in a long linear pool to the south west of the proposed panel A3 LW2
WC4	294830	6202802	Upstream of waterfall W1 to the south of the proposed panel A3 LW5
WC5	294792	6202671	In a plunge pool downstream of waterfall W1, downstream of the Wonga West panels
WCT1	295038	6201404	Generally dry tributary which discharges into Wallandoola Creek between WC2 and WC3

NOTE: WC6 was monitored from Sept 2007 to June 2008, whilst WC7 and 8 were irregularly monitored in 2001, but are not discussed in detail in this report as they are significantly downstream of the Wonga West subsidence area Co-ordinates supplied from GPS

Outside of the "spot" monitoring conducted in 2001, regular stream water quality and water level monitoring commenced at each location as shown in **Table 10**.

Table 10 Wallandoola Creek Monitoring History

Location	Monitoring Start Date
WC1	July 2007
WC2	November 2008
WC3	July 2007
WC4	November 2009
WC5	November 2009

The stream gradient generally increases with distance downstream in the Wonga West (Area 3) as shown in **Table 11** and **Figure 7**.

Table 11 Wallandoola Creek Gradient

Stream Reach	Vertical Fall (m)	Distance (m)	Gradient
WC1 - WC2	7	1115	0.006
WC2 - WC3	5	650	0.008
WC3 - WC4	6	1190	0.005
WC4 - WC5	34	780	0.044

As shown in **Appendix C**, Wallandoola Creek at Wonga West is characterised by a long linear pool and rock bar at WC1 and a downstream valley fill swamp which overlies the BHPBIC Cordeaux longwall subsidence area, upstream of the Gujarat lease boundary.

WC2 is located within a valley fill swamp with no discernible stream channel in the sedge dominated channel to the immediate south, and outside of, the NRE No.1 lease boundary.

WC3 is located within an approximately 1.25km long linear pool, whose water level is maintained by a rock bar at the downstream end.

Downstream of WC3, Wallandoola Creek reverts back to an approximately 110m long valley fill swamp, then transposes into an approximately 300m long linear pool followed by a restricted channel flowing over exposed sandstone, at the downstream end of which is a distinctly iron hydroxide orange coloured pool. The coloured pool terminates at a rock bar with a less than 3m high shallow "step", with a "clear" approximately 1.7km long pool situated immediately upstream of the less than 5m drop into a plunge pool at WC4.

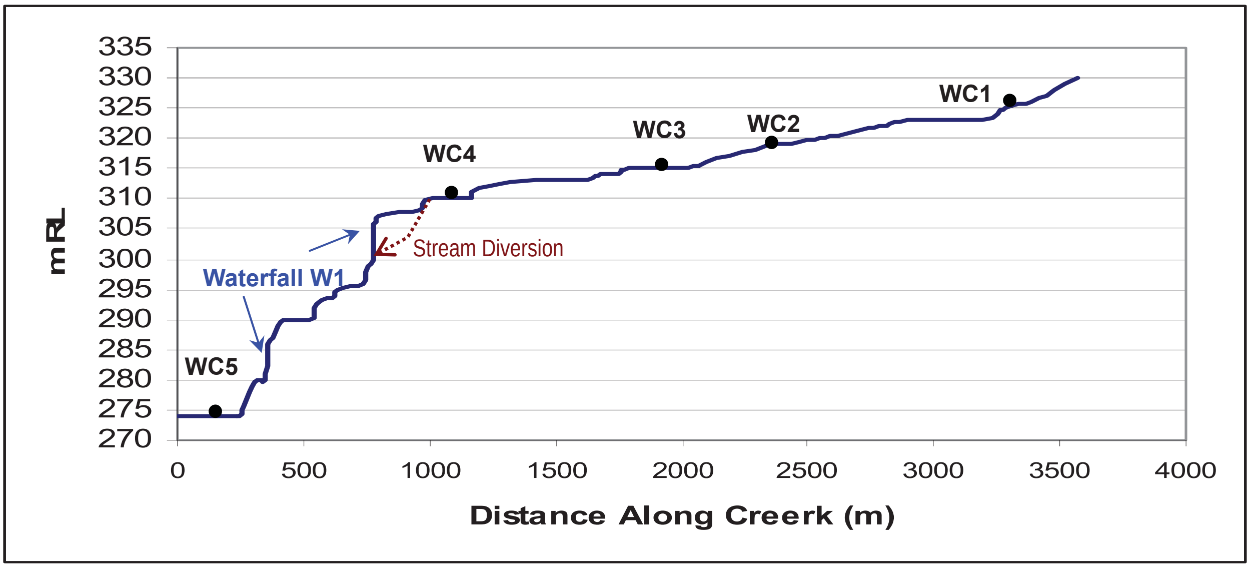


Figure 7 Wallandoola Creek Stream Reach

No evidence of stream bed cracking or enhanced pool drainage is observed between Sites WC1 and WC4.

The WC4 pool water level is constrained by a rock bar with evident cracking located approximately 100m upstream of Waterfall W1, where the pool level and extent is affected by enhanced drainage of the pool through the downstream cracked sandstone streambed.

Waterfall W1 has two major “steps” of 11m and 16m, for a total drop of approximately 30m over a 1.1km stream reach. Downstream of the waterfalls, and outside of the 20mm subsidence zone, the stream gradient flattens out to a series of extended pools constrained by rock bars.

The waterfall is also affected by cracking in the sandstone, as the stream has not been observed to flow over the falls during “dry” periods.

The sandstone streambed located approximately 100m upstream of Waterfall W1 is situated over the western edge of the old Bulli Seam workings subsidence area, and it is assessed that the stream bed cracks are due to mine subsidence.

Downstream of the waterfall, the plunge pool containing Site WC5 maintains a consistent pool, with a distinctly orange ferruginous colour.

The valley fill swamps dissipate out approximately 200m upstream of the WC4 pool, with shrubs, grasses and trees dominating along the creek banks at and downstream of WC4.

The stream bed and banks of the plateau streams are well vegetated, and do not show significant erosion or bank instability.

PLATE 1 Wallandoola Creek Monitoring Sites

10.1.2 Lizard Creek

Lizard Creek flows to the north to north west between the proposed Wonga West Area 3 and Area 4. The creek has previously been undermined by Bulli Seam longwalls in both the BHP Cordeaux and Gujarat NRE No.1 leases.

Lizard Creek does not overlie the proposed Wongawilli longwalls, although it is contained within the 20mm subsidence envelope as shown in **Drawing 10**.

The main channel of Lizard Creek is a Schedule 2, 3rd order stream (DIPNR, 2005) with ephemeral 1st to intermittent 2nd order tributaries, which becomes increasingly incised into Hawkesbury Sandstone as it drains downstream of Waterfall L1.

Lizard Creek joins the Cataract River approximately 6km (or 7km along the stream reach) to the north of the Study Area, downstream of the Cataract Dam wall, whilst its headwaters are located to the south over the BHPBIC Cordeaux longwalls.

The creek is not regulated by any dams or weirs.

Lizard Creek stream monitoring site details are shown in **Table 12**.

Table 12 Lizard Creek Monitoring Sites

SITE	E (MGA)	N (MGA)	DESCRIPTION
C10	295475	6204030	In a 1st order tributary of Lizard Creek tributary LCT1
C11	295800	6204475	Downstream of C10 in a 2nd order tributary
LC1	296982	6200704	In valley fill swamp over Cordeaux workings, south of Project Application Area
LC2	296773	6201510	Upstream of Wonga West 20mm subsidence zone, north of lease boundary, downstream of main road access bridge
LC3	296947	6202290	Upstream of Wonga West 20mm subsidence zone, southeast of A3 LW1, upstream of Fire Road 8 creek crossing
LC4	296972	6203921	Southeast of A3 LW1, downstream of Waterfall L1
LC5	296918	6204276	Between proposed panels A3 LW1 and A4 LW7, over first workings driveage
LC6	296174	6205204	Between proposed panels A3 LW3 and A4 LW7
LC7	295293	6206428	Downstream of Wonga West 20mm subsidence area, upstream of LCT2 tributary
LC8	295408	6206686	At Gujarat lease northern boundary, downstream of 20mm subsidence zone
LC9	295534	6207794	Downstream of Gujarat lease, downstream of 20mm subsidence zone, upstream of Lizard Creek Waterfall 2
LCT2A	294836	6204153	Within Swamp Lcus25, over panels A3 LW4 and A3 LW5, on Fire Road 8
LCT2B	294280	6205173	To the west of A3 LW5, on Fire Road 8
LCT2	295185	6206397	Downstream of LCT1 and LCT2 tributaries and enters Lizard Creek immediately downstream of LC7

NOTE: LC1 was monitored irregularly up to June 2008 and LC9 was discontinued after March 2010 as it is outside the Gujarat lease Co-ordinates supplied from GPS

Outside of the “spot” monitoring conducted in 2001, regular stream water quality and water level monitoring commenced at each location as shown in **Table 13**.

Table 13 Lizard Creek Monitoring History

Location	Monitoring Start Date
C10	July 2006
C11	July 2006
LC1	July 2007
LC2	July 2007
LC3	July 2007
LC4	November 2008
LC5	November 2009
LC6	November 2009
LC7	August 2008
LC8	March 2010
LC9	August 2008
LCT2A	August 2008
LCT2B	August 2008
LCT2	August 2008

The stream gradient varies with distance downstream and the presence of extended pools, rock bars, boulder fields or a 26m high waterfall / stepped zone to the west of No. 5 shaft as shown in **Table 14** and **Figure 8**.

Table 14 Lizard Creek Gradient

Stream Reach	Vertical Fall (m)	Distance (m)	Gradient
LC1 - LC2	7	675	0.010
LC2 - LC3	6	795	0.008
LC3 - Waterfall	18	1350	0.013
Waterfall - LC4	20	300	0.067
LC4 - LC5	25	375	0.013
LC5 - LC6	5	1270	0.004
LC6 - LC7	15	1580	0.009
LC7 - LC8	32	1475	0.022

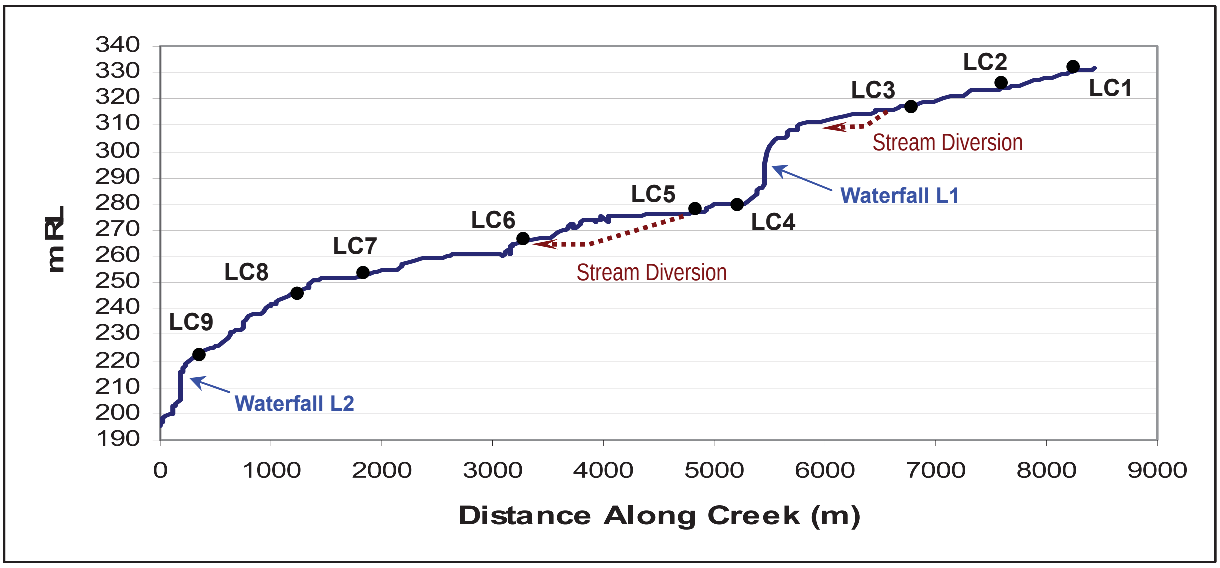


Figure 8 Lizard Creek Stream Reach

As shown in **Appendix C**, Lizard Creek in the Wonga West area is characterised by a series of valley fill upland swamps and pools between LC1 and approximately 50m downstream of LC3. The pool levels are supported behind exposed sandstone rock bars, often with less than a 0.5m drop between pools which range up to approximately 500m long.

The pool at Site LC3 is predominantly full and overflowing, however on one occasion for a few weeks, the stream flow temporarily ceased after an extended lack of rainfall / runoff in the catchment.

The upland swamp fringed stream banks can be up to 0.5 to 1.0m high within a reasonably well defined channel in the upstream section, which becomes more defined toward LC3. The creek can have up to approximately 50m of flanking riparian sedge / upland swamp vegetation along each bank, with the sedge / swamp areas grading upslope, out of the channel into either headwater swamps or Scribbly Gum Woodland.

The valley fill swamp Lcus4 terminates in an area of headward erosion near the junction with headwater swamp Lcus6.

Shrubs, grasses and trees dominate along the creek banks downstream of LC3 where the stream becomes increasingly more incised into sandstone.

The stream bed can be dry for a stream reach of approximately 750m between the downstream termination of valley fill swamp Lcus4 and the approximately 200m long, orange discoloured permanent pool upstream of Waterfall L1.

A 26m high waterfall / stepped zone (Waterfall L1) is located between LC3 and LC4.

Downstream of the waterfall, the stream flows through a sequence of elongated pools, rock bars, boulder fields and rock shelves to LC4 and onto LC5.

The creek has been observed to dry out after extended low rainfall periods between LC5 and LC6 over approximately 1.3km of stream reach in an area of sequential pools, rock bars, boulder fields and sandy sediment based pools.

Permanent stream flow and pool depth is re-instated at LC6, where the water is highly orange iron hydroxide affected.

Between LC6 and downstream of LC7, the stream gradient flattens out where permanent elongated pools held behind rock bars are prevalent.

The northern boundary of the Gujarat lease is located at LC8, which is located in a permanent elongated pool held back by a sandstone rock shelf.

From the lease boundary to LC9, the creek gradient steepens, with a series of pools held behind rock bars and elongated sandstone shelves, ending in a 20m high step / waterfall zone, approximately 30m downstream of LC9. Downstream of the waterfall, Lizard Creek subsequently flows into Cataract Creek.

The stream bed and banks of the plateau streams are well vegetated, and do not show significant erosion or bank instability.

PLATE 2A Lizard Creek Monitoring Sites

PLATE 2B Lizard Creek Monitoring Sites

10.1.3 Lizard Creek 3^{rd} Order Tributaries

Two 3^{rd} order tributaries flow into Lizard Creek in the vicinity of the proposed Wonga West longwalls.

Tributary LCT1 has its headwaters over proposed Area 3 longwalls LW2 and LW3, with the 3^{rd} order reach overlying the northern end of Longwall 3, downstream of monitoring point C11. Swamp Lcus18 is located in its headwaters.

All of the 1^{st}, 2^{nd} and 3^{rd} order components of Tributary LCT1 have previously been subsided by the Bulli Seam longwalls, with stream bed cracking, subsurface transfer of stream flow and ferruginous seeps present in the channel. During extended dry periods, the 3^{rd} order reach of the tributary is dry.

Tributary LCT2 headwater's originate in swamp Lcus25, which overlies the proposed Area 3 longwalls LW4 and LW5, as well as swamp Lcus26, which lies to the west of the proposed longwalls. The 1^{st} and 2^{nd} order tributaries flow over Area 3 Longwalls LW4 and LW5, joining as a 3^{rd} order stream in the northwest corner of the proposed LW5, which then becomes 4^{th} order over the proposed first workings.

Tributary LCT2A and swamp Lcus25 have predominantly been undermined by first workings in the Bulli Seam, although the downstream end of Lcus25 has also been partially undermined by longwall 310.

Tributary LCT2B and swamp Lcus26 have not been undermined.

The 3rd and 4th order reach of tributary LCT2 generally contains flowing or ponded water and does not have significant ferruginous precipitates, although it tends to be ponded during extended dry periods.

PLATE 3 LIZARD CREEK TRIBUTARIES

10.2 Wonga West Waterfalls

10.2.1 Waterfall L1

Waterfall L1 has one major drop off with an upper stepped zone of up to 26m high, and is located to the west of No. 5 Shaft.

Downstream of the waterfall the stream gradient flattens out to a series of extended sand based pools constrained by sandstone rock bars.

The waterfall is not observably affected by previous subsidence related cracking as it is located over an area of low subsidence Bulli Seam first workings, however significant underflow / throughflow is observed to exit the face of the waterfall through bedding planes and joints.

The waterfall exhibited ferruginous overland flow in the channel bed as well as a more substantive ferruginous seepage from bedding discontinuities on the western flank of the waterfall as shown in **Plate 4**.

Downstream of the waterfall, the plunge pool maintains a consistent pool, with no distinctive water discolouration.

PLATE 4 Waterfall L1

10.2.2 Waterfall W1

Waterfall W1 has two major “steps” of 11m and 16m, for a total drop of approximately 30m over a 1.1km stream reach. Downstream of the waterfalls, and outside of the 20mm subsidence zone, the stream gradient flattens out to a series of extended pools constrained by rock bars.

The waterfall is also affected by cracking in the sandstone, as the stream has not been observed to flow over the falls during “dry” periods.

The sandstone streambed located approximately 100m upstream of Waterfall W1 is situated over the western edge of the old Bulli Seam workings subsidence area, and it is assessed that the stream bed cracks are due to mine subsidence.

Downstream of the waterfall, the plunge pool containing Site WC5 maintains a consistent pool, with a distinct orange colour as shown in **Plate 5**.

PLATE 5 Waterfall W1

10.3 Wonga East Streams

10.3.1 Cataract Creek

A LIDAR survey was flown with an accuracy of 0.55m and contored at 1m intervals to determine the current surface topography in the study area as shown in **Figure 9.**

Cataract Creek flows to the west into Cataract Reservoir at Wonga East Area 2.

The Schedule 2, 4th order (DIPNR, 2005) Cataract Creek channel does not overlie the secondary extraction areas of longwalls WE-A2-LW4 or LW5 as shown in **Figure 9**.

The main channel and tributaries have been undermined by longwalls in the Balgownie Seam as well as bord and pillar and pillar extraction in the overlying Bulli Seam.

The main channel of Cataract Creek has eroded sequentially into the Hawkesbury Sandstone, Newport and Garie Formations and Bald Hill Claystone, with the Bald Hill Claystone and Bulgo Sandstone being exposed in the lower reach of the creek, upstream of the reservoir.

Cataract Creek flows directly into Cataract Reservoir over the western section of Wonga East, Area 2, whilst its headwaters are located immediately to the west of the Illawarra Escarpment.

The creek is not regulated by any dams or weirs.

The creek is relatively steep, particularly in its headwaters, with a reducing gradient with distance downstream, and flows through a series of short pools, sandy reaches, rock bars and boulder fields as shown in **Table 15** and **Figure 10**.

Table 15 Cataract Creek Gradient

Stream Reach	Vertical Fall (m)	Distance (m)	Gradient
Headwater to CC2	87	865	0.101
CC2 to CC3	8	535	0.015
CC3 to CC5	1	110	0.009
CC5 to CC6	4	635	0.006
CC6 to CC9	5	1250	0.004
CC9 to CC10	4	435	0.009
CC10 to Cataract Dam	1	375	0.003

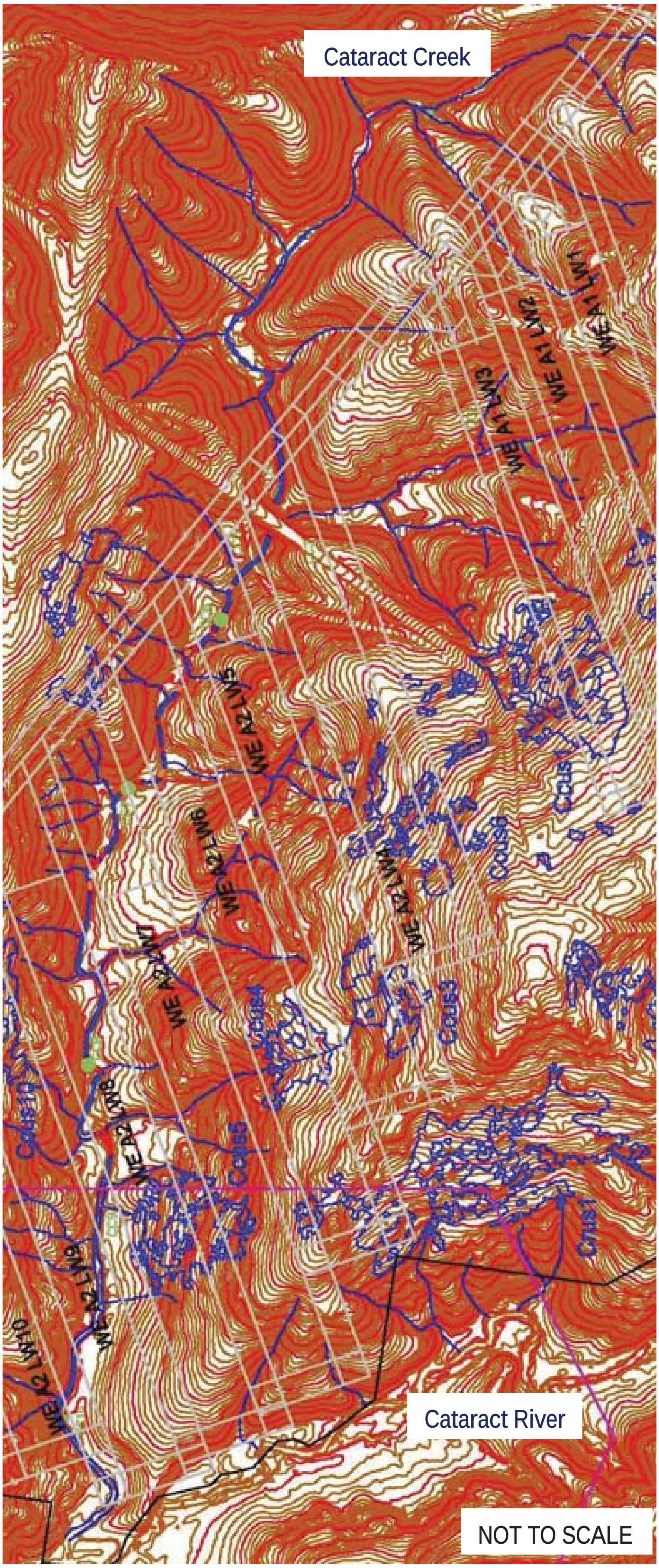


Figure 9 Wonga East 1m Contour Topography

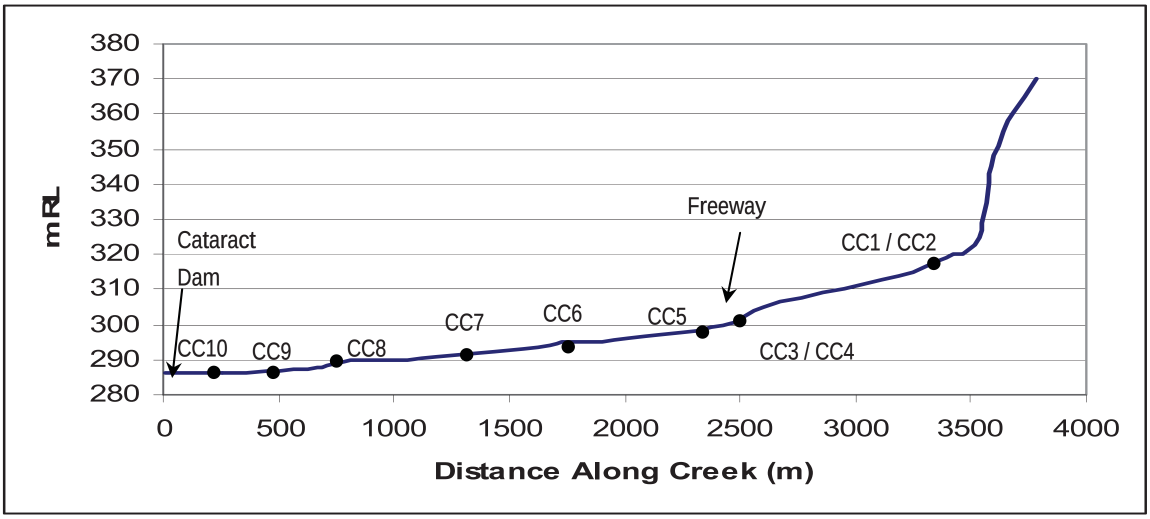


Figure 10 Cataract Creek Stream Reach

Cataract Creek is characterised by two steeply sloping headwater valleys monitored by Sites CC1 and CC2, which flow to sites CC3 and CC4 before joining as a single stream at Site CC5.

The headwater tributaries have eroded through the Hawkesbury Sandstone and, in the deeper eroded areas, through to the Bald Hill Claystone and the underlying Bulgo Sandstone.

Detailed stream bed mapping between CC5 and CC9 identified a series of long elongated pools that are constrained by low (<0.5m high) shallow rock bars, which predominate in the upper to mid section, along with occasional, gravel sized riffle sections that also predominate in the upper to mid section of the study reach.

Significant reaches of sandy based substrate dominate between CC7 and CC9, which has developed in an eroded, interspersed shale and sandstone sequence compared to the Hawkesbury Sandstone.

A limited number of rock bar constrained pools are present between CC7 and CC9, although two moderate sized, <1-2m deep pools have developed at significant bends at rock bars CcRB13 and CcRB14 as shown in **Figure 11**.

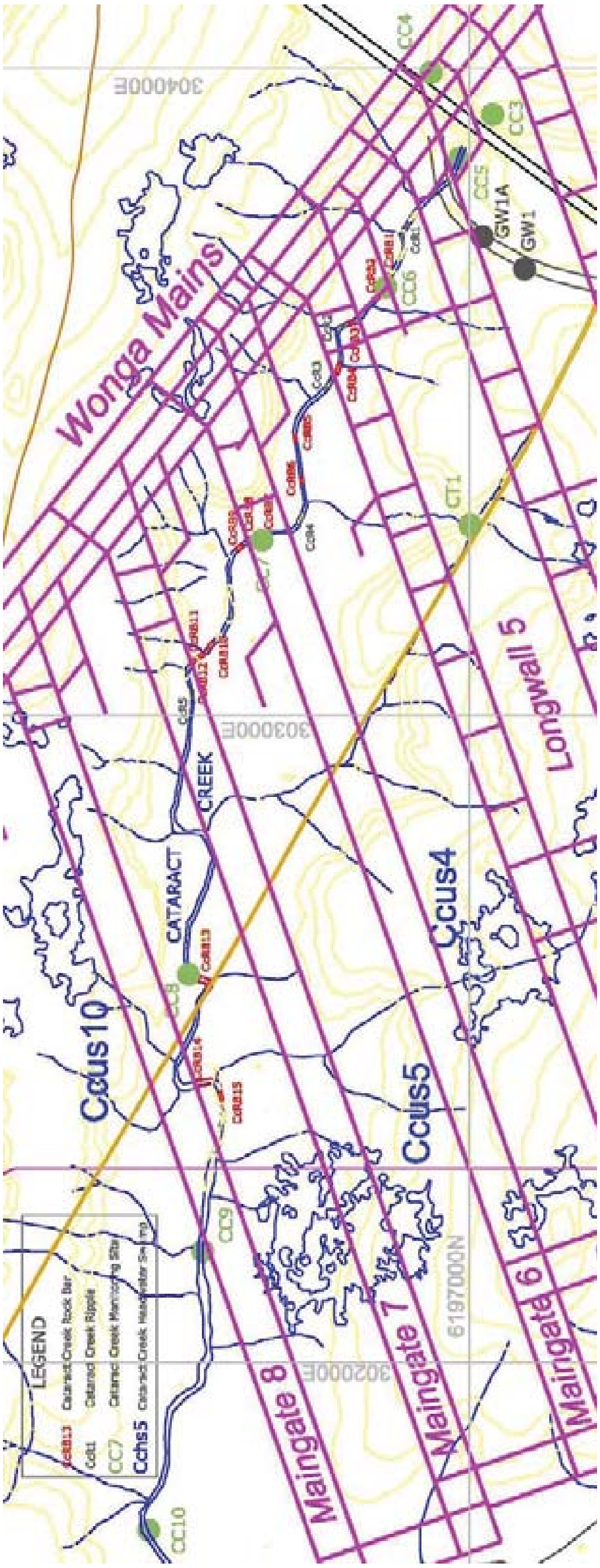


Figure 11 **Cataract Creek Wonga East Area 2 Stream Monitoring Sites**

Well developed, primarily rainforest based shrubs, grasses and trees dominate along the creek banks.

No waterfalls or highly stepped zones are present in the creek.

The stream bed and banks of the plateau streams are well vegetated and do not show significant erosion or bank instability. Heavily vegetated rainforest is developed from the edge of the escarpment to downstream of the freeway, which transgresses into heavily wooded forest between the freeway and the dam.

The photographs shown in **Plate 6** indicate the typical nature of the rock bars and riffles and pools in the reach between CC5 and CC9.

PLATE 6 Typical Cataract Creek Rock Bars, Riffles and Stream Reach

Details of the regular stream water quality and water level monitoring locations in Cataract Creek are shown in **Table 16**, with photographs shown in **Plate 7**.

Table 16 Cataract Creek Stream Monitoring Sites

SITE	E (MGA)	N (MGA)	DESCRIPTION
CC1	304893	6196615	Tributary draining east of the escarpment to the east of proposed Panel A1 LW2
CC2	304107	6196418	Tributary draining east of the escarpment over proposed Panel A1 LW3
CC3	303937	6196961	Nthn tributary junction east of freeway, between proposed Panels A1 LW3 and A2 LW4
CC4	303964	6196992	Sthn tributary junction east of freeway, between proposed Panels A1 LW3 and A2 LW4
CC5	303852	6197005	Start of main Cataract Ck channel west of freeway upstream of proposed panel A2 LW5
CC6	303645	6197145	Adjacent to proposed Longwall 5
CC7	303299	6196994	Adjacent to proposed Longwall 6, downstream of tributary CT1
CC8	302595	6197425	Over Longwall 8
CC9	302175	6197415	Upstream of dam high water level over proposed panel A2 LW9
CC10	301740	6197495	Creek site within creek high water level on western edge of proposed panel A2 LW9
Crus1c	302195	6196635	Surface water discharge from swamp Ccus1
Ccus3c	302860	6196935	Surface water discharge from swamp Ccus3
Ccus4c	302560	6197015	Surface water discharge from swamp Ccus4
SP1c	303275	6196995	Surface water runoff down slope of shallow piezometers SP1
CD1	301257	6198280	Cataract Reservoir to north of Cataract Creek, outside of the Application Area

NOTE: Co-ordinates supplied from GPS

PLATE 7A Cataract Creek Monitoring Sites

PLATE 7B Cataract Creek Monitoring Sites

The CC1 – CC5, CC9, CC10 and CD1 monitoring sites were installed by GeoTerra Pty Ltd (GeoTerra) in August 2008, and were regularly monitored on a bi-monthly basis up until Gujarat NRE Coking Coal Pty Ltd (Gujarat) took over continued monitoring, management and implementation of the NRE1 project field work in July 2010.

CT1 was installed in a 2nd order tributary by Gujarat in April 2012.

Stream water level, flow and water quality stations are in the process of being installed by Gujarat between CC6 and CC8.

Monitoring at CC10 was initially installed in 2008 and then discontinued shortly thereafter when it was assessed the site was within the high water mark of the dam.

The Ccus2, 3, 4, 5, 6, Crus1 and Bcus4 swamp and 1st order creek monitoring sites were installed by GeoTerra in March 2012, with ongoing management of field work and laboratory analysis being conducted by Gujarat.

10.3.2 Cataract River

Stream flow, height and water quality monitoring installations were installed by Gujarat on 12 April 2012 at locations shown in **Drawing 2**, and as summarised in **Table 17** with photographs shown in **Plate 8**.

Table 17 Cataract River Stream Monitoring Sites

SITE	E (MGA)	N (MGA)	DESCRIPTION
CR1	303905	6195540	Upstream of Freeway
CR2	302175	6195745	At SCA weir flow monitoring site, downstream of Freeway
CR3	301915	6196130	Upstream of Swamp Crhs1
CR4**	301780	6196770	Within high water section of Cataract Reservoir

NOTE: Co-ordinates supplied from GPS CR4 is currently not monitored as it is currently in the dam

The Cataract River catchment has not been fully inspected to date as the proposed longwalls are not predicted to undermine or impact on the creek bed, and therefore a detailed assessment has not yet been conducted on the geomorphology of the reach between the freeway and the reservoir.

Plate 8 Cataract River Stream Monitoring Sites

10.4 Stream Flow and Pool Depths

10.4.1 Lizard Creek

Volumetric stream flow monitoring has been conducted in Lizard Creek since mid September 2009 at LC3 near the southern boundary of the Gujarat lease.

Limited volumetric stream flow monitoring was conducted for dry flow periods at site LC7 near the northern lease boundary until it was established a natural diversion through a washed out bedding plane in the sandstone enabled approximately 30% of the stream flow to divert around the flow monitoring site. As a result, flow monitoring was discontinued, although stream pool height monitoring has continued.

Accurate stream flow monitoring for use in comparing upstream and downstream catchment volumetric flows is logistically difficult to achieve in Lizard Creek for the following reasons;

- lack of sites where all stream flow is present as overland flow due to;
    - natural diversions through fissures, joints and washed out bedding planes in the sandstone, or
    - diversion underneath the stream bed through subsidence cracks that developed over the Bulli Seam longwalls
- lack of constriction points where stream flow is constrained into a single channel, rather than being split in a number of sub – flow paths, such as in boulder fields or exposed sandstone shelves, or flow through / out of fissures and washed out bedding planes

As shown in **Drawing 5**, Site LC3 is located over essentially unsubsided main headings within the Bulli 200 series workings. Site LC5 is located over the subsided Bulli panel LW303, whilst Site LC6 is located over the subsided LW307. Site LC7 is located in an unsubsided stream reach to the north and approximately 750m downstream of LW309 and Site LC8 is located in unsubsided ground near the northern lease boundary.

Stream pool height monitoring has been conducted as shown in **Figure 12**.

Volumetric stream flow monitoring has also commenced using the manual cross section / flow velocity method at the LC3, 4, 5, LC7, LCT1 and LCT2 rock bar constrictions during field logger download events under the field data management of Gujarat. Extrapolation of the future and historic pool height transducer data to volumetric flow will be conducted when flow / duration curves over a sufficient range of flow events have been developed.

The effect of enhanced pool drainage is apparent at, and between, Sites LC5 and LC6 over the Bulli 300 series longwalls.

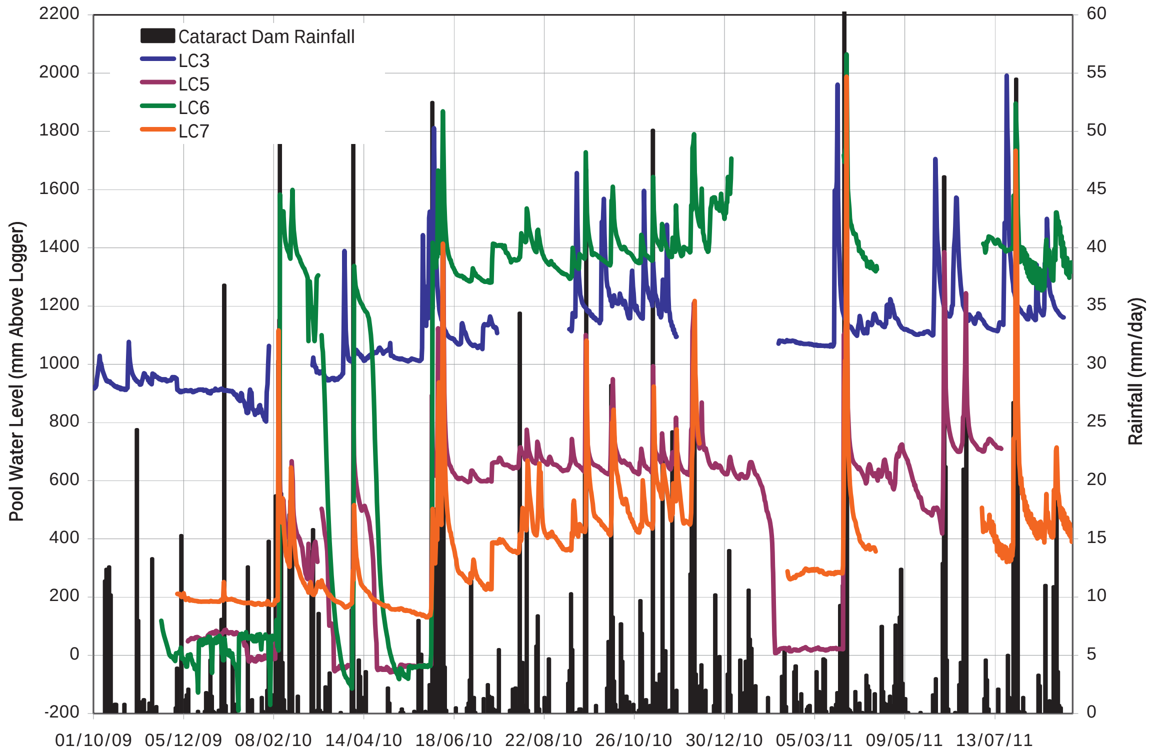


Figure 12 Lizard Creek Pool Depths

10.4.2 Wallandoola Creek

Pool height water level monitoring has been conducted at sites WC1, WC3 and WC4 as shown in **Figure 13**.

Volumetric stream flow monitoring has also commenced using the manual cross section / flow velocity method at the WC1 and WC4 rock bar constrictions during field logger download events under the field data management of Gujarat. Extrapolation of the future and historic pool height transducer data to volumetric flow will be conducted when flow / duration curves over a sufficient range of flow events have been developed.

As shown in **Drawing 5**, Site WC1 overlies the Cordeaux Colliery Bulli longwall subsidence area, WC3 is within an elongated pool between valley fill swamps Wcus1 and Wcus4 over Longwalls 206 and 207, whilst WC4 overlies the western periphery of the NRE No.1 Bulli longwall 20mm subsidence zone.

Sites WC1 and WC3 do not show an enhanced pool drainage rate, whereas WC4 has enhanced pool level reduction as it is in a pool that is hydraulically connected to the subsidence cracked Waterfall W1.

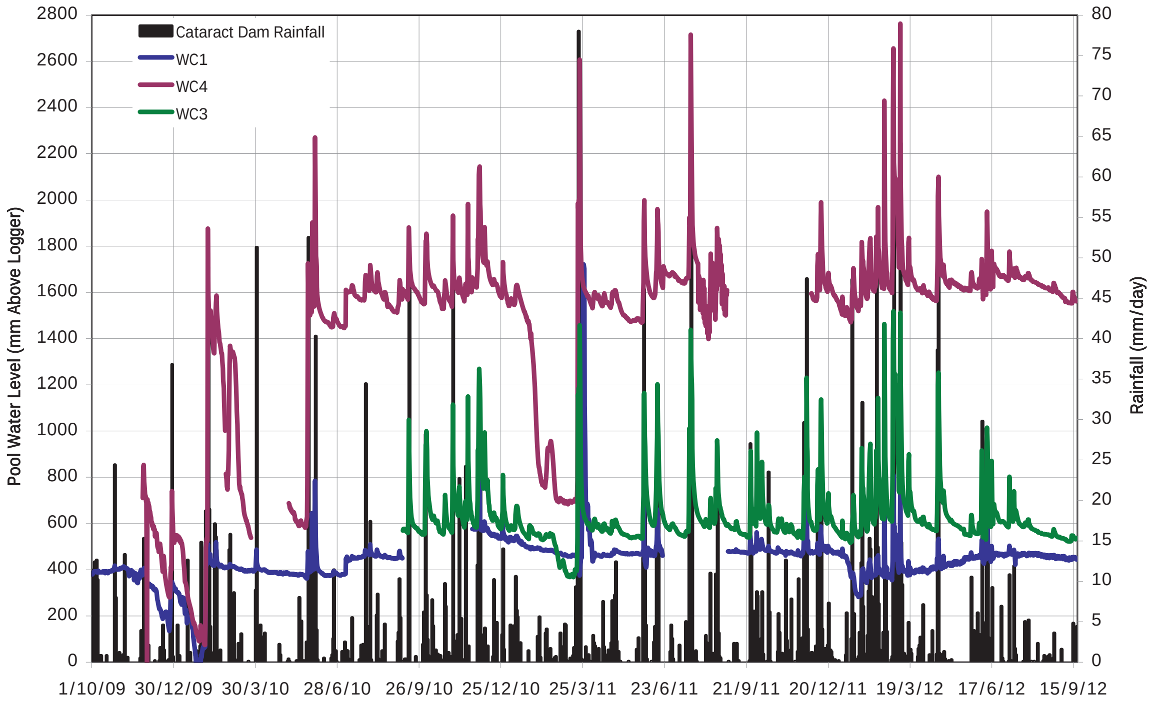


Figure 13 Wallandoola Creek Pool Depths

10.4.3 Cataract Creek

The 2nd order tributaries between Sites CC1 - CC4 and CC2 - CC3 have not been observed to dry out since monitoring began in July 2008, although they usually contain ferruginous precipitates.

The fourth order stream channel between CC5 and CC9 has also been continuously flowing.

Downstream of CC5 the creek water becomes sequentially clearer, although ferruginous precipitation can be observed along the entire reach down to the headwaters of the dam.

Tributary CT1 has a notable development of ferruginous sandy sediment and discoloured runoff, and has often been observed to raise the ferruginous discolouration downstream of its confluence with Cataract Creek, upstream of site CC7.

No adverse effects on stream flow continuity or stream ponding have been observed in Cataract Creek.

No obvious mining induced cracking of rock bars and loss of pool holding capacity has been observed between CC5 and CC9.

Pool height water level monitoring, which commenced in November 2010 under the management of Gujarat, is conducted at sites CC3, CC4 and CC7, whilst CT1 was initiated in April 2012 as shown in **Figure 14**.

Volumetric stream flow monitoring using either the cross sectional / flow velocity or temporary box notch weirs was initiated at CC3 and CC4 by Gujarat during April 2012. Additional sites are currently being installed by Gujarat at CC6, 7 and 8. The future and historic pool level data will be converted to volumetric flow once flow / duration curves have been sufficiently developed.

Sites CC3 and CC4 overly the Bulli seam pillar extraction and the Balgownie longwalls, whilst CT1 overlies Bulli seam bord and pillar workings.

All pools between Sites CC1 and CC9 do not show an enhanced pool drainage rate, and have not dried up during the monitoring period.

The tributary monitored by CT1, which drains off the Longwall 4 and 5 catchment area has been observed to dry out after extended lack of runoff, however the pools still generally hold low pond levels and do not show total drainage due to subsurface cracking.

Recently, Cataract Reservoir has inundated Cataract Creek to approximately 100m upstream of CC9, although it has extended to approximately 75m downstream of CC9 since regular monitoring began in July 2008. As a result, flow monitoring at CC9 was temporarily discontinued until the dam level fell below the monitoring site.

Since July 2008, CC10 has been permanently inundated by the dam and has not been regularly monitored.

The dam spill height is at 289.87m AHD (T Schultz, pers comm.)

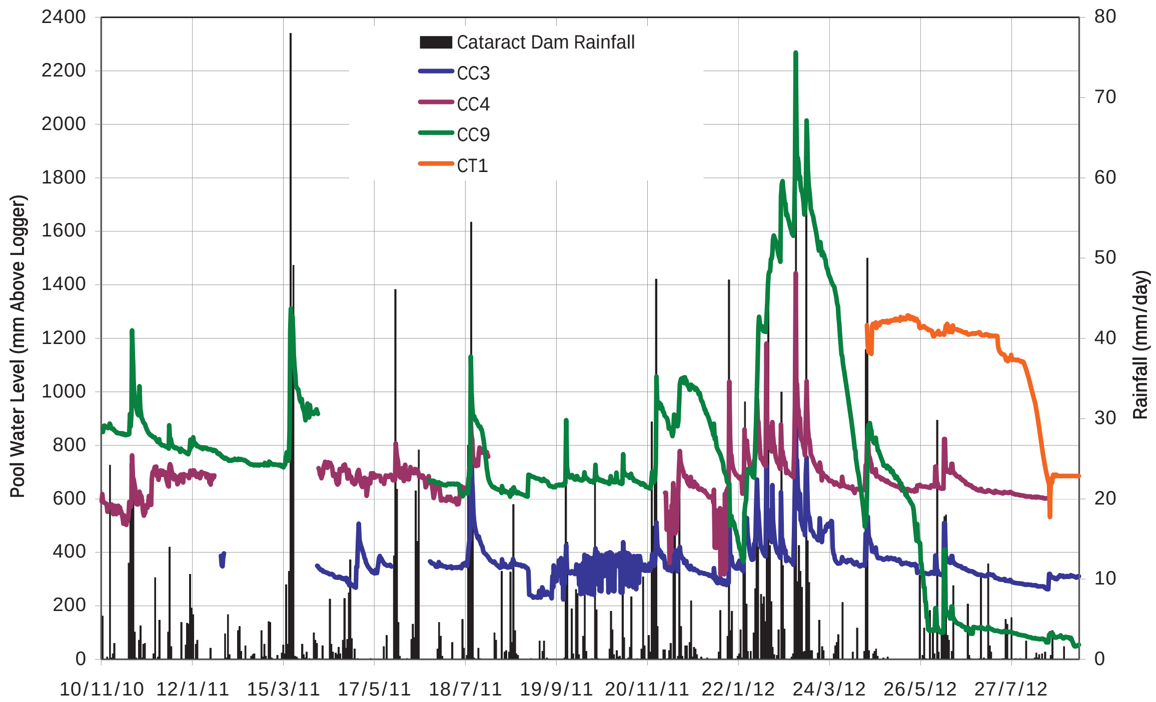


Figure 14 Cataract Creek and Tributary Pool Depths

10.4.4 Cataract River

The Cataract River between sites CR1 and CR4 has been continuously flowing during the monitoring period, and usually contains ferruginous precipitates.

No adverse effects on stream flow continuity or stream ponding have been observed in Cataract Creek.

No obvious mining induced cracking of rock bars and loss of pool holding capacity has been observed in the river.

Pool height water level monitoring, which commenced in April 2012 under the management of Gujarat, and is currently conducted at sites CR1, 2 and CR3 as shown in **Figure 15**.

Volumetric stream flow monitoring using the cross sectional / flow velocity method at sites CR1 and CR3 as well as an SCA weir at CR2 was initiated by Gujarat during April 2012. The pool level data will be converted to volumetric flow once flow / duration curves have been sufficiently developed.

Site CR4 was installed, but has not yet been used as it is currently under the high water mark of Cataract Reservoir.

Site CR1 lies within the Gujarat lease area and does not overly any previous mining. Sites CR2, 3 and 4 overly the old BHP Cordeaux Colliery Bulli seam bord and pillar workings.

All pools between Sites CR1 and CR3 do not show an enhanced pool drainage rate, and have not dried up during the monitoring period.

The dam spill height is at 289.87m AHD (T Schultz, pers comm.)

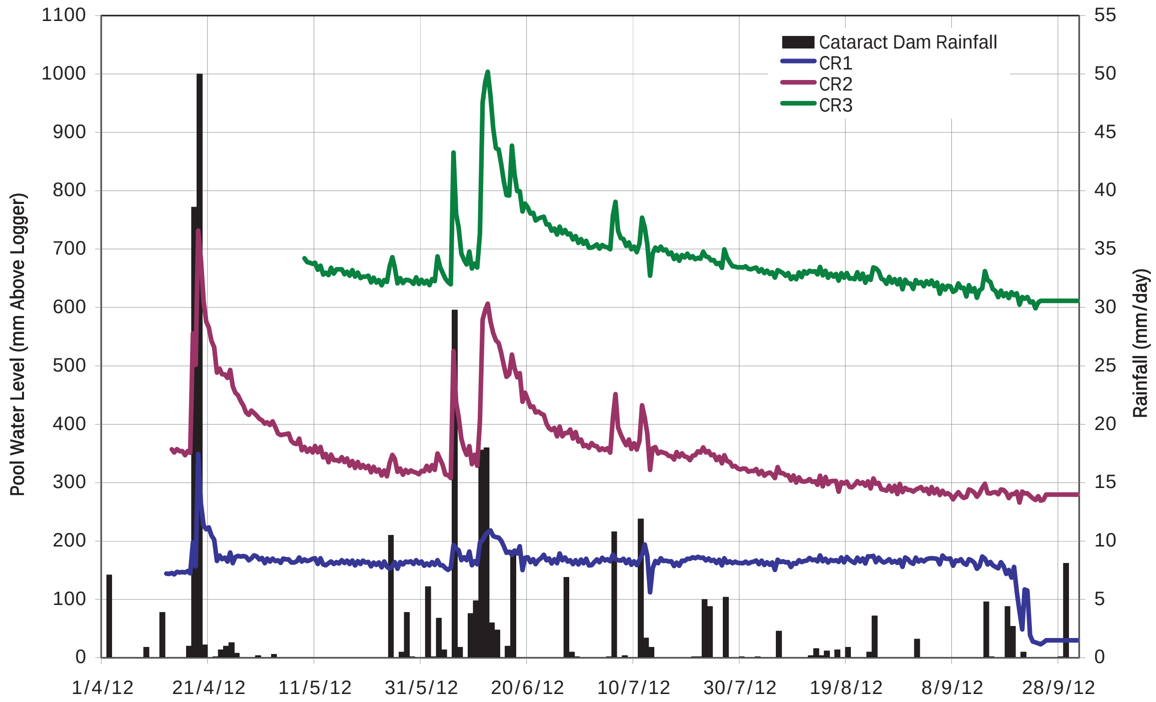


Figure 15 Cataract River Pool Depths

10.5 Stream Water Quality

10.5.1 Lizard Creek

In general, enhanced rainfall in the catchment has the effect of reducing salinity, marginally raising pH (i.e. increasing alkalinity) with flow downstream, increasing dissolved oxygen, diluting ferruginous discolouring (or deposition), diluting major metals and generally increasing nutrients, with the change relating to the degree and duration of rainfall runoff dilution in the stream.

Lizard Creek's overall pH ranges from 2.50 to 7.1, with a median range from 4.6 – 6.5 as shown in **Figures 16** and **17**.

It shows a trend to less acidity (increasing alkalinity) downstream, except between LC5 and LC6 during low flow periods, where the stream has a subterranean flow and downstream upwelling component.

Lizard Creek's pH is outside the ANZECC 2000 South Eastern Australia Upland Stream criteria, and, since July 2007, has had an overall reduction in acidity by approximately pH 0.5 to1.0 units.

It is generally the case that the stream pH is more acidic as it discharges out of the humic and fulvic acid dominated swamp areas, then becomes more alkaline as it flows down the main stream, with no significant acidification downstream of upwelling seepage re-entry locations in the streams.

The creek's overall salinity ranges from 19 - 290µS/cm and generally rises by approximately 60µS/cm between LC2 and LC8, outside of the LC5 to LC6 reach.

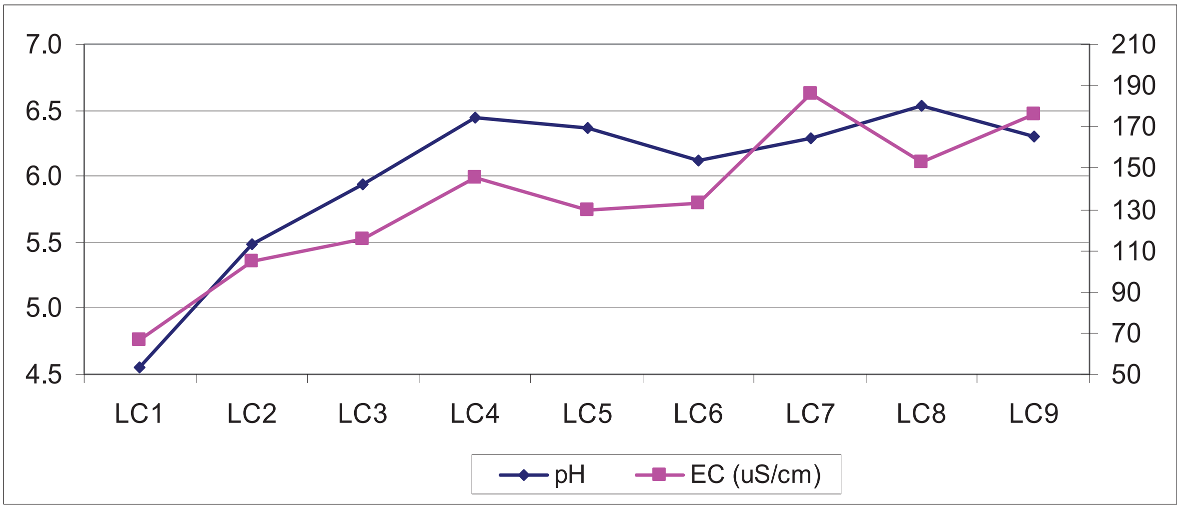


Figure 16 Lizard Creek Median pH and Salinity

The main channel of Lizard Creek has a predominantly perennial flow, although the WC4 pool to the base of Waterfall WL1 can temporarily dry up.

The first and second order tributaries are ephemeral to intermittent and generally dry or ponded, with short term flow after sufficient rain.

Since regular monitoring began in July 2007, the stream's salinity generally rises with distance downstream by approximately 90µS/cm as shown in **Figure 17**.

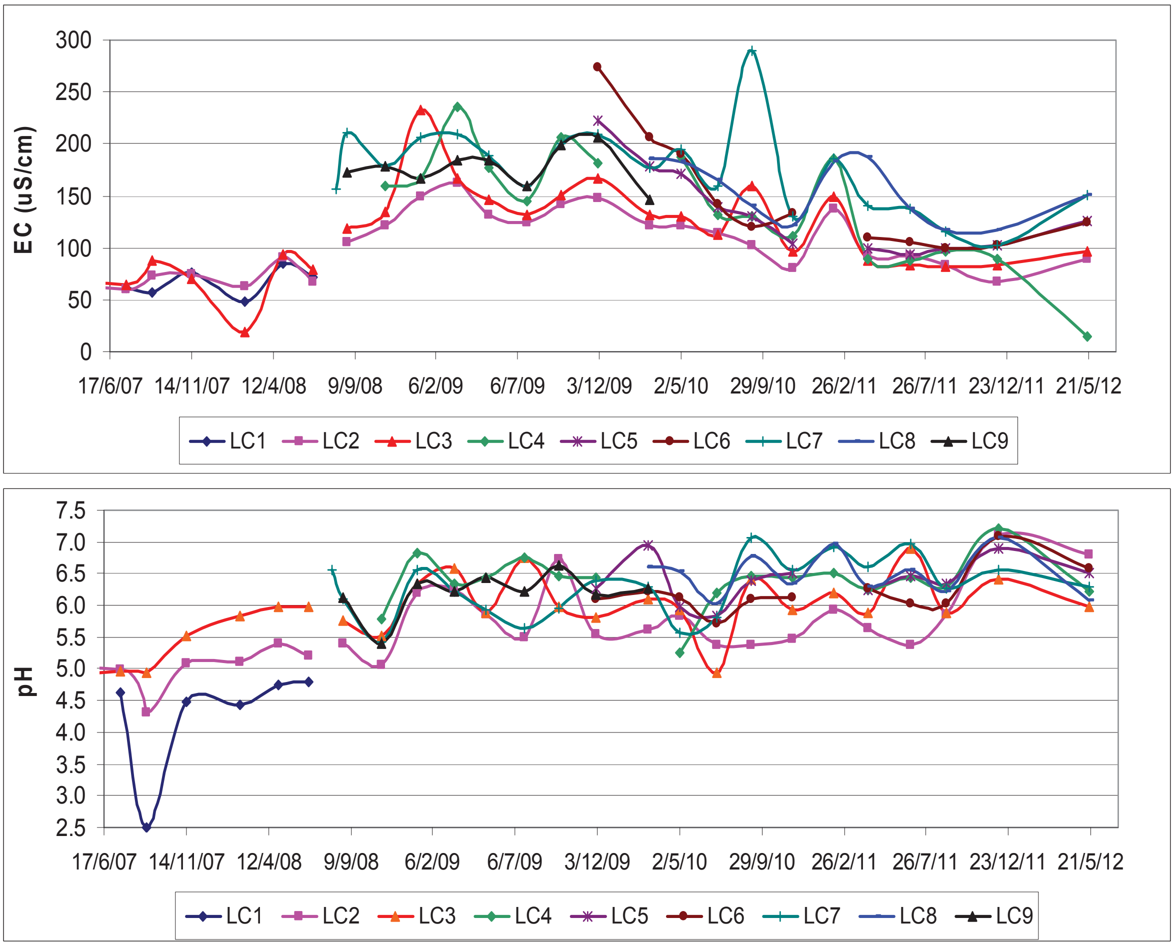


Figure 17 Lizard Creek Field Water Chemistry

Figure 18 indicates the median filtered iron has a relatively flat profile with distance downstream, although total iron peaks at LC6, where the underflow seeps back into the creek.

The median total and filtered iron discharging into the Cataract River at, and downstream of LC8, are 0.64mg/L and 0.17mg/L respectively.

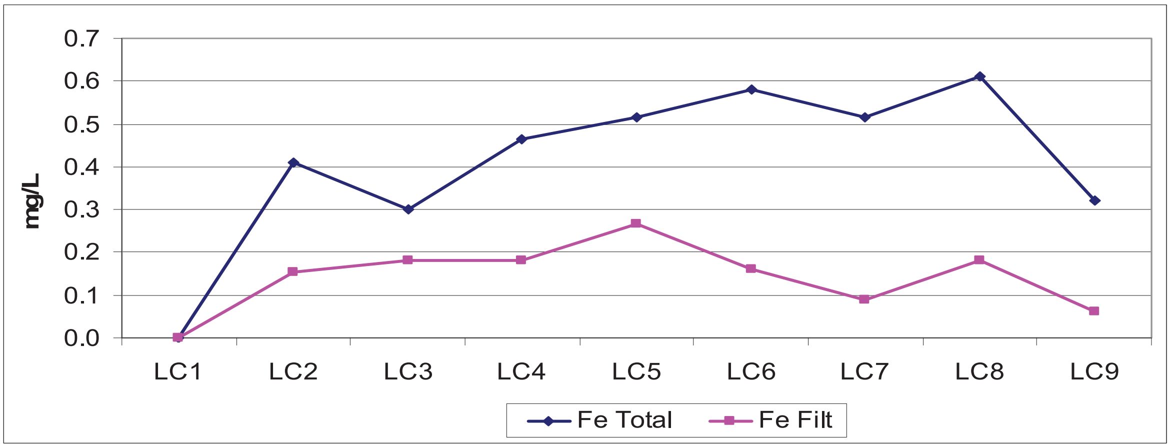


Figure 18 Lizard Creek Median Iron Levels

Figure 19 indicates the median manganese in the creek shows a relatively flat profile, although with a peak of up to 0.13mg/L at LC8.

Total and filtered median manganese levels discharging into the Cataract River (at and downstream of LC8) are 0.13mg/L and 0.12mg/L respectively, compared to the ANZECC 2000 criteria of 1.9mg/L, although at LC9, upstream of the Cataract River, the levels fall to 0.01mg/L.

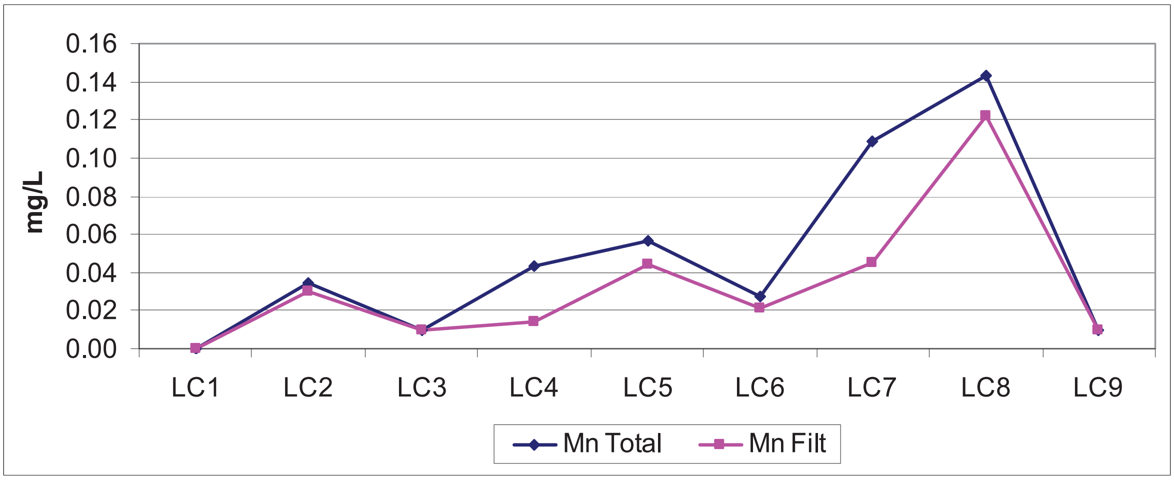


Figure 19 Lizard Creek Median Manganese Levels

A peak in sulfate is generally identified at LC4 and LC5, downstream of Waterfall L1 as shown in **Figure 20**, after which, sulfate falls at LC6, then gradually rises downstream.

The rise in sulfate would relate to a marginal rise in sulfuric acid generation through iron sulfide weathering as a result of enhanced subsurface flow through the cracked Hawkesbury Sandstone over, and downstream of, the subsided Bulli longwalls.

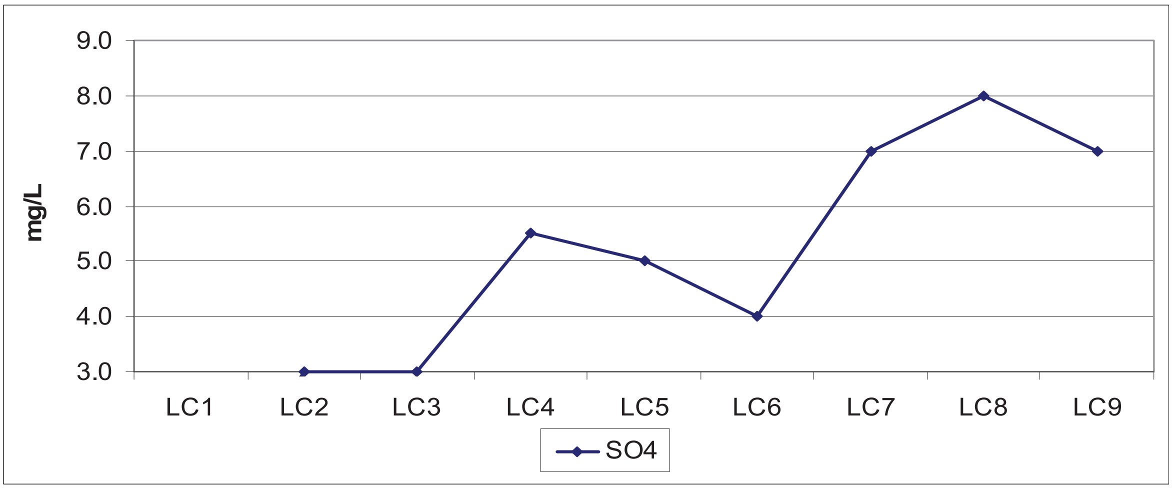


Figure 20 Lizard Creek Median Sulfate Levels

Monitoring indicates the creek is within the acceptable range for potable water, however it is generally outside the ANZECC 2000 South Eastern Australia Upland Stream criteria for pH. The creek can also be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines, depending on the flow conditions at the time of sampling for;

- filtered zinc occasionally at all sites, with a high variability
- total nitrogen and total phosphorous at all sites, infrequently;
- occasionally, filtered copper, nickel, and;
- aluminium, very infrequently, where it exceeds both the criteria of 55μg/L and pH 6.5.

In the reach between LC3 and LC4, where the headward erosion of valley fill component of swamp Lcus4 is observed as well as desiccation of the sandstone based stream bed can occur, ferruginous deposits are observed in the permanent pool immediately upstream of Waterfall L1, as well as on the waterfall face, but not in the waterfall plunge pool and downstream to LC4.

In the LC3 to LC4 reach, the median water quality of above ANZECC 2000 criteria parameters is as discussed below, where the median;

- filtered zinc reduces from 0.006 – 0.003mg/L,
- filtered aluminium reduces from 0.03 – 0.02mg/L, and
- total phosphorous rises from 0.01 – 0.02mg/L
- whilst pH rises from 5.88 – 6.42 and salinity rises from 130 - 172μS/cm

Between LC4 and LC5 no adverse effects on stream flow, ponding or water quality is observed.

Between LC5 and LC6, where the creek has an enhanced drying out rate in the pools, the above criteria parameter changes observed are where the median;

- filtered zinc reduces from 0.005 – 0.004mg/L,
- total nitrogen reduces from 0.3 – 0.015mg/L, and
- total phosphorous remains static around 0.02mg/L
- whilst pH acidity remains static around 6.12 and salinity rises from 175 - 198μS/cm

From LC6, where there is a distinctive ferruginous precipitation at the point of upwelling and a continuum of flow with no adverse effects on pool water levels, to where the stream bed is not underlain by Bulli workings and has no associated subsidence effects at LC7, LC8 and LC9 (which is upstream of Waterfall L2), the median

- filtered zinc reduces from 0.004mg/L at LC6 to 0.002mg/L at LC9,
- total nitrogen reduces from 0.15mg/L at LC6 to 0.1mg/L at LC9
- total phosphorous reduces from 0.02mg/L at LC6 to 0.01mg/L at LC9
- whilst pH rises from 6.11 – 6.31 and salinity reduces from 198 - 176μS/cm

Where Lizard Creek discharges out of the Study Area at LC8, the above (or outside) criteria parameters can be;

- pH, which is occasionally below pH 6.5;
- filtered zinc (<0.036mg/L), occasionally, and;
- total nitrogen (<0.4mg/L) and total phosphorous (<0.16mg/L), rarely.

10.5.2 Wallandoola Creek

Water quality monitoring initially commenced during September 2001, with regular data monitoring initiated in July 2007.

The pH in Wallandoola Creek ranges from 3.35 to 6.83, with the median pH ranging from 5.49 – 6.19 as shown in **Figures 21** and **22**, with the pH being outside the ANZECC 2000 South Eastern Australia Upland Stream criteria.

It is generally the case that the stream pH is more acidic as it discharges out of the humic / fulvic acid dominated swamp areas, then becomes more alkaline as it flows down the main stream, with no significant acidification downstream of upwelling seepage re-entry locations in the streams.

The creek's salinity ranges from 53 - 199µS/cm and generally rises by approximately 70µS/cm between WC1 and WC6.

Since regular monitoring began in July 2007, the stream's median salinity generally rises with distance downstream, then becomes less saline downstream of Site WC5, as shown in **Figures 21** and **22**, which is downstream of Waterfall W1.

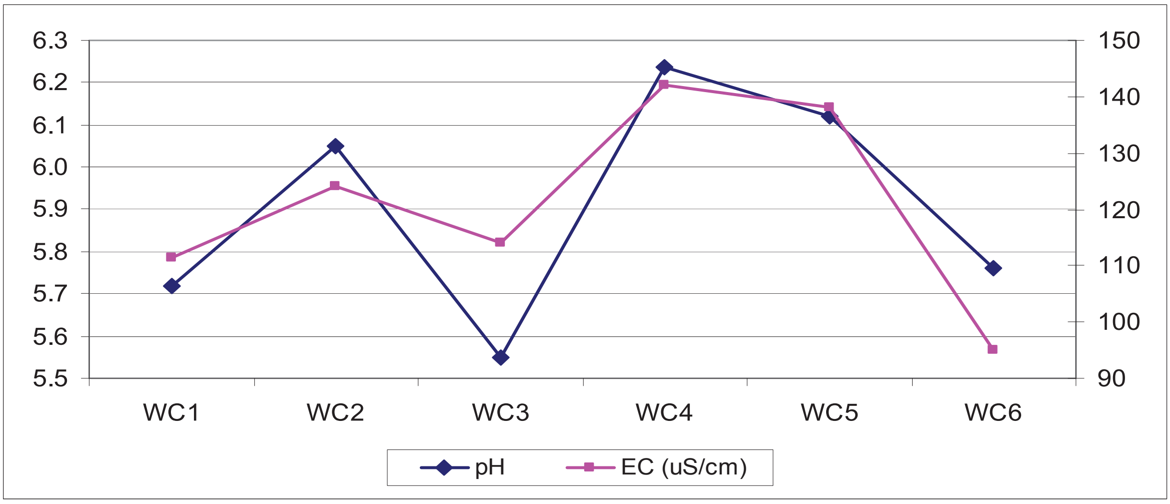


Figure 21 Wallandoola Creek Median Field pH and Salinity

The main channel has an intermittently ponded to perennial flow, whilst the first and second order tributaries are generally dry or are pooled, with short term flow after sufficient rain.

Plots of the field water quality parameter trends are shown in **Figure 22**.

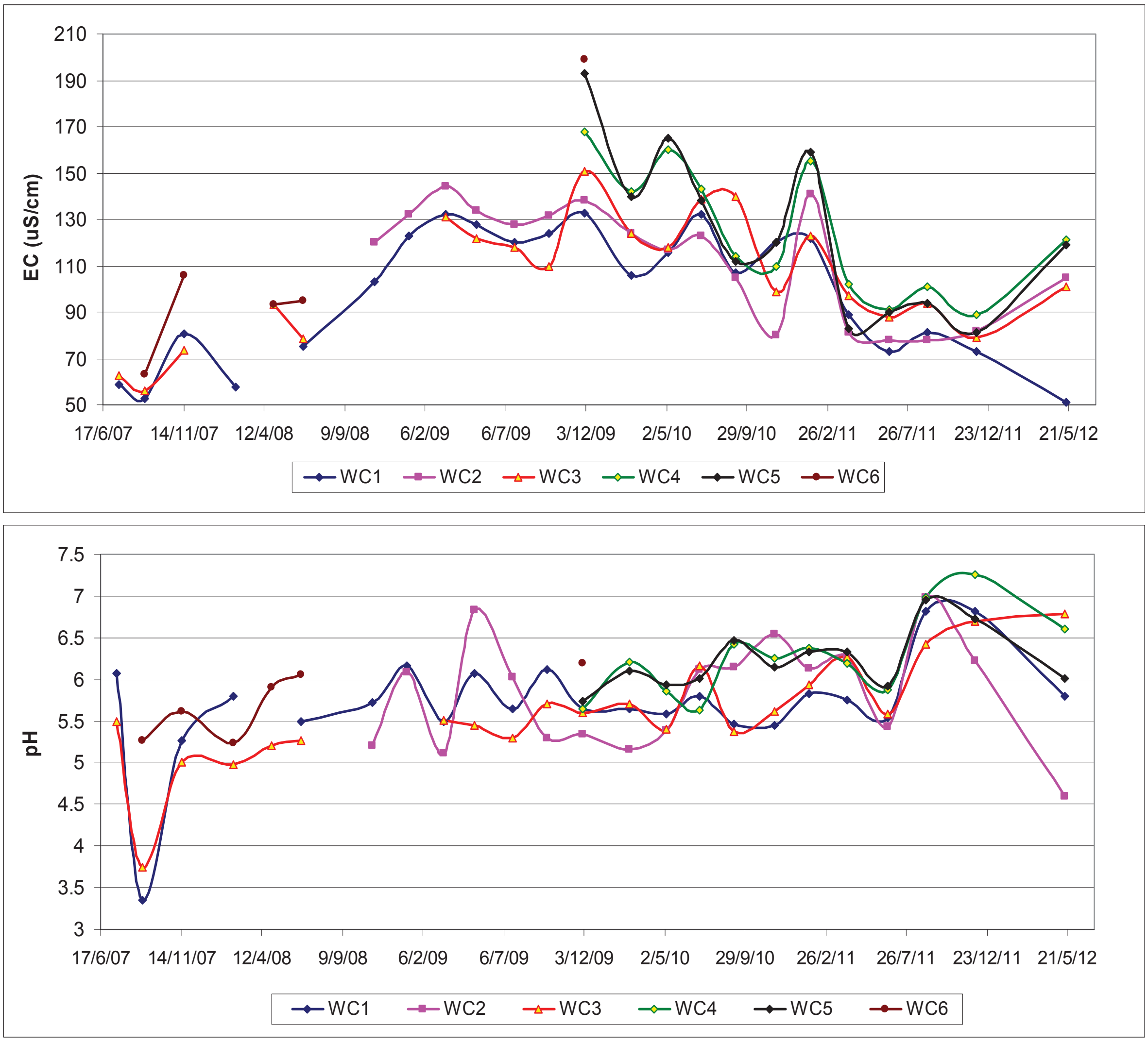


Figure 22 Wallandoola Creek Field Water Chemistry

As shown in **Figure 23**, total iron levels in the creek do not show any significant recurring trend with distance downstream apart from a peak in total iron through oxy-hydroxide precipitation at WC5 over Longwalls 209 and 210 near the major bend in the creek. A slight rising trend can be seen in filtered iron with distance downstream.

Total and filtered median iron discharging from downstream of the subsided Bulli workings in Wallandoola creek is 0.50mg/L and 0.19mg/L respectively.

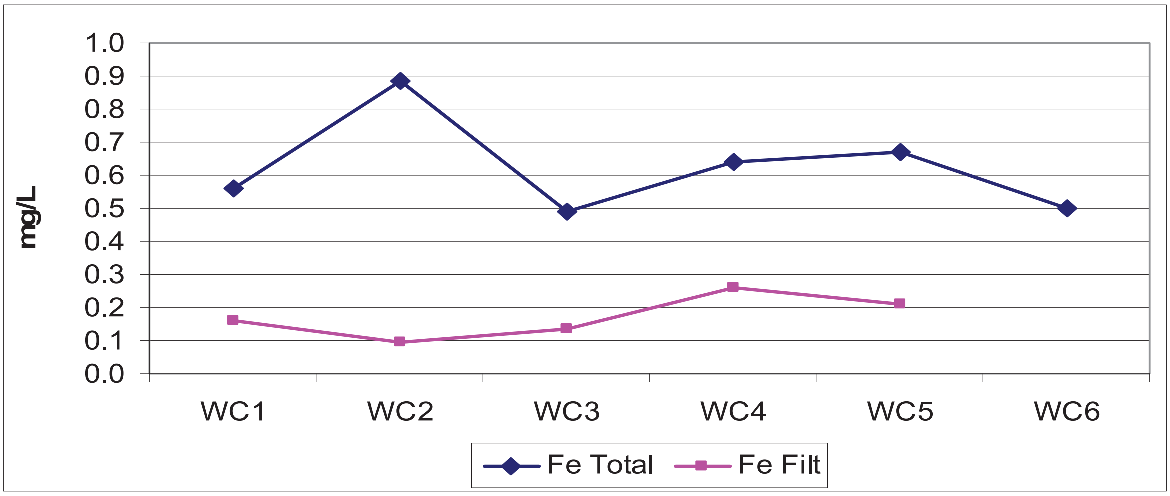


Figure 23 Wallandoola Creek Median Iron Levels

Figure 24 illustrates that manganese decreases from WC1 to WC3, then rises downstream of WC3 over Longwalls 209 and 210 near the major bend in the creek.

Total and filtered manganese levels discharging downstream of the Bulli workings are 0.07mg/L and 0.06mg/L respectively, which is well below the ANZECC 2000 criteria of 1.9mg/L.

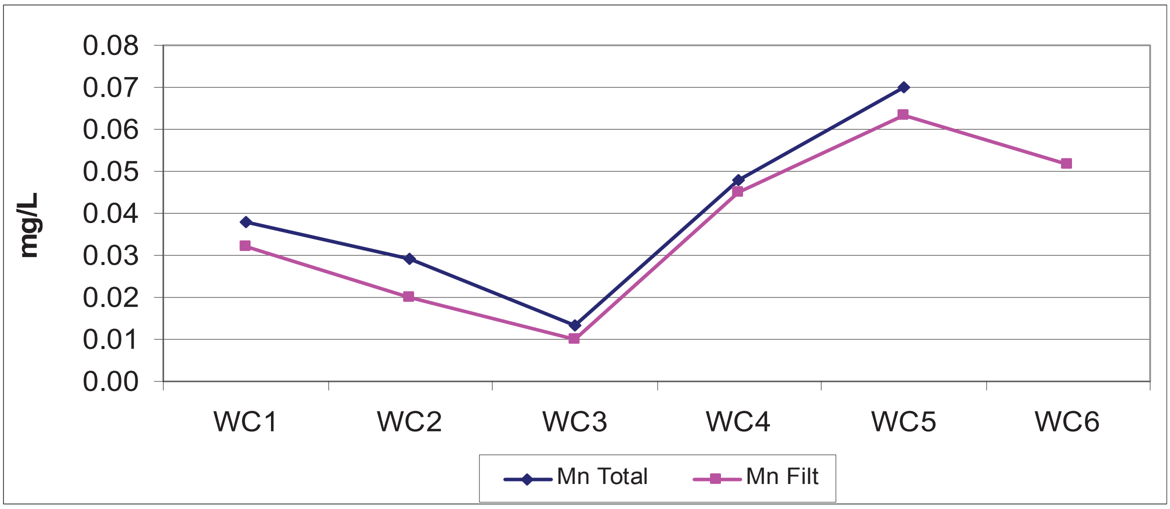


Figure 24 Wallandoola Creek Median Manganese Levels

Figure 25 indicates that the median sulfate levels marginally from WC2 to WC4, then rises again downstream of WC5.

The rise in sulfate would relate to a marginal rise in sulfuric acid generation through iron sulfide weathering as a result of enhanced subsurface flow through the cracked Hawkesbury Sandstone over, and downstream of, the subsided Bulli longwalls.

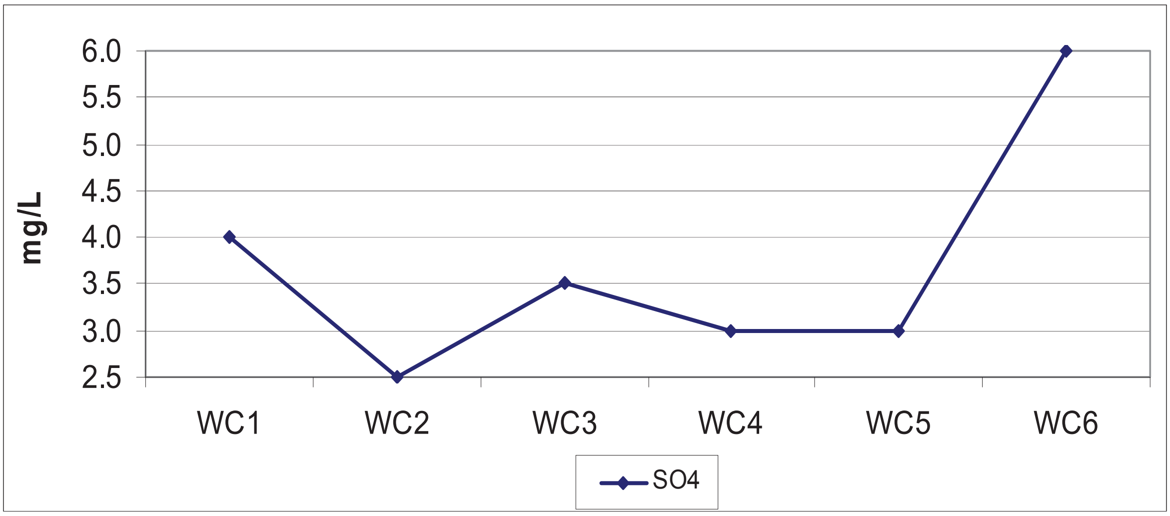


Figure 25 Wallandoola Creek Median Sulfate Levels

Monitoring indicates the creek is within the acceptable range for potable water, however it can exceed the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines for the following parameters, depending on the flow conditions at the time of sampling;

- filtered zinc at all sites for the majority of the time,
- total nitrogen at some sites for part of the time with no regular pattern,
- total phosphorous occasionally at each site, with no regular pattern and
- filtered copper, occasionally

In the reach between WC3 and WC4, where ferruginous deposits are generally observed, the median filtered zinc and total nitrogen, which are the only above criteria parameters in this stretch, generally improve with flow downstream as shown below, where the median;

- filtered zinc reduces from 0.014 – 0.005mg/L, and
- total nitrogen increases from 0.2 – 0.25mg/L, whilst
- pH becomes more alkaline, rising from 5.43 – 5.76 and salinity rises from 118 - 151µS/cm

Between WC4 and WC5, where subsidence related cracking is evident around Waterfall W1, the above criteria parameter changes are where the median;

- filtered zinc rises from 0.005 – 0.013mg/L, and
- total phosphorous reduces from 0.24 – 0.08mg/L, whilst
- pH rises from 5.76 – 5.97 and salinity is relatively constant

Where Wallandoola Creek discharges out of the Study Area at WC5, the above criteria parameters can be;

- pH, which is generally below pH 6.5;
- filtered copper (<0.004mg/L), very rarely;
- filtered zinc (<0.03mg/L), occasionally;
- total nitrogen (<0.7mg/L), rarely, and;
- total phosphorous (<0.19mg/L) occasionally.

10.5.3 Cataract Creek

The CC1 – CC5 and CD1 monitoring sites were installed by GeoTerra in August 2008, and were regularly monitored on a bi-monthly basis up until Gujarat took over ongoing management and implementation of the NRE1 project field work, monitoring and laboratory analyses in July 2010. Since Gujarat took over the field monitoring, additional sites have been sequentially added, with the suite now containing Sites CC1 to CC10 and CT1.

Monitoring of field and laboratory water quality and general observation of the stream flow commenced in March 2012 and is conducted by Gujarat in the first order gully drainage sites Crus1c, Ccus3c and Ccus4c, which are downstream of upland swamps Crus1, Ccus3 and Ccus4, as well as in the SP1c swamp outflow.

Monitoring at these sites is conducted when there is flowing or ponded water in the ephemeral drainage gullies.

In addition to the current bi-monthly stream water depth, stream flow and stream water quality monitoring, photographic records of each monitoring site are taken during each field trip.

In general, enhanced rainfall in the catchment has the effect of reducing salinity, marginally raising pH, increasing dissolved oxygen, diluting ferruginous discolouring (or deposition), diluting major metals and generally increasing nutrients, with the degree of change relating to the degree and duration of rainfall runoff dilution in the stream.

Cataract Creek's overall pH ranges from 4.39 to 6.91, with a median of 5.56 upstream at CC1, along with a relatively "flat" trend at all other sites of from 6.1 to 6.3 as shown in **Figures 26** and **27**.

It is generally the case that the stream pH is more acidic as it discharges out of the humic / fulvic acid dominated swamp areas, then becomes more alkaline as it flows down the main stream, with no significant acidification downstream of upwelling seepage re-entry locations in the stream.

The stream's pH is outside the ANZECC 2000 South Eastern Australia Upland Stream criteria, which is not uncommon in natural catchments draining off Hawkesbury Sandstone in the Southern Coalfields.

The median creek salinity ranges from 130 - 145µS/cm, with a minor decrease with distance downstream as shown in **Figures 26** and **27**.

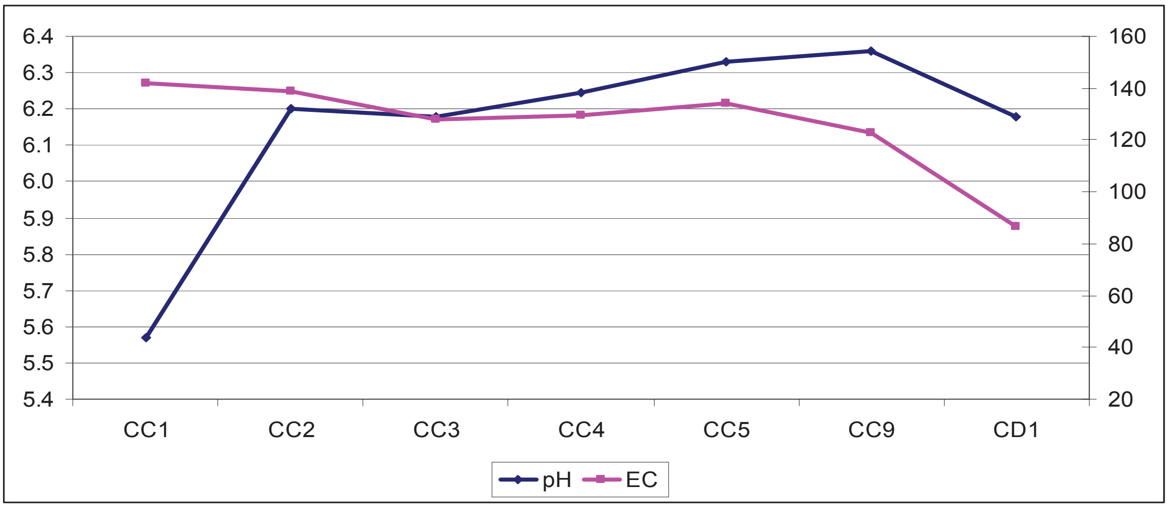
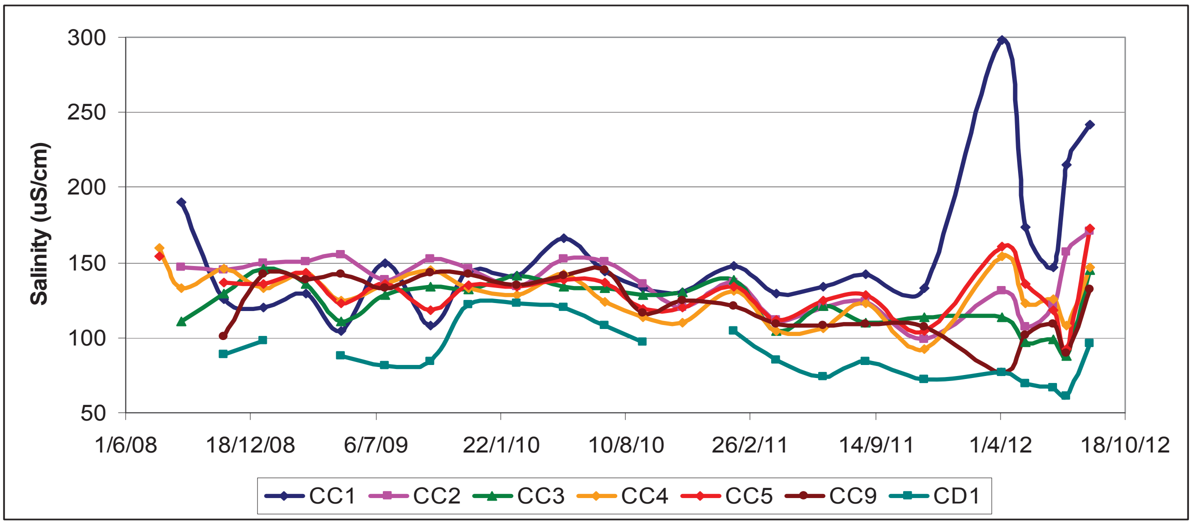


Figure 26 Cataract Creek Median pH and Salinity

All 2nd order or higher tributaries and the main channel of Cataract Creek have been observed to have intermittent to perennial flow.



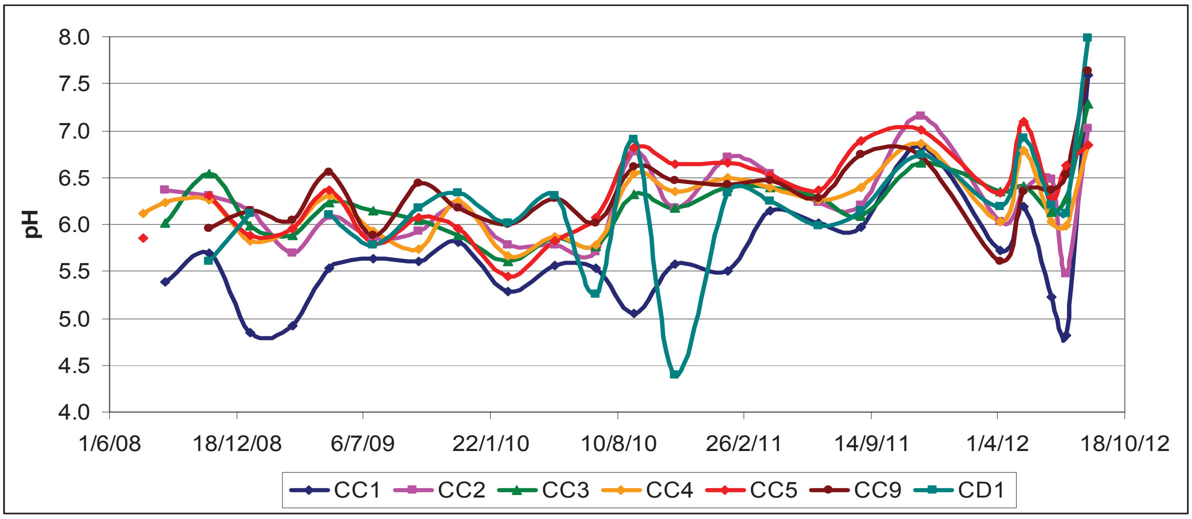


Figure 27 Cataract Creek Field Water Chemistry

As shown in **Figure 28**, filtered iron levels are generally unchanged with flow downstream.

Hydrous ferruginous seeps are relatively common in Cataract Creek, although their exact inflow location has not yet been identified as ferruginous precipitation is relatively ubiquitous in the creek both upstream and downstream of the freeway.

Due to the lack of pre mining data, it is not possible to ascertain whether the ferruginous seeps are caused by, or related to, historic mine subsidence.

Total and filtered median iron discharges into Cataract Reservoir at LC9 are 0.96mg/L and 0.26mg/L respectively.

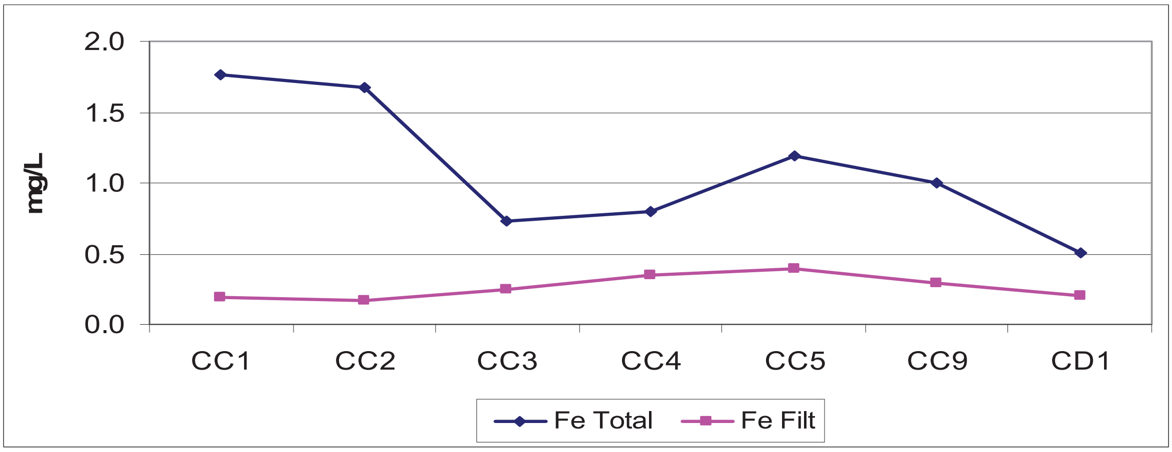


Figure 28 Cataract Creek Median Iron Levels

Figure 29 illustrates that median total manganese peaks at CC2, whilst filtered manganese has a general reduction with flow downstream.

Total and filtered median manganese discharge at CC9 into Cataract reservoir is 0.08g/L and 0.01mg/L respectively, compared to the ANZECC 2000 criteria of 1.9mg/L.

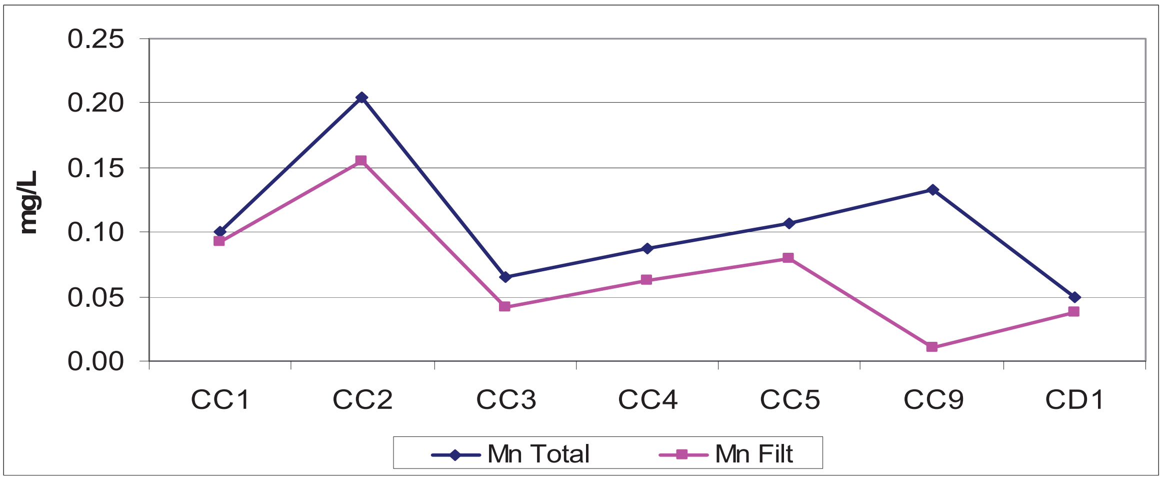


Figure 29 Cataract Creek Median Manganese Levels

A peak in sulfate is present in the CC2 / CC3 tributary as shown in **Figure 30** which could represent the dissolution of sulfuric acid following iron sulfide weathering as a result of shallow subsurface flow through cracks in the subsided and cracked basement strata, and / or weathering of the exposed Bald Hill Claystone and overlying shale / claystone dominated units.

A peak is also present at CC5 where the (CC1 - CC4 and CC2 - CC3) tributaries join.

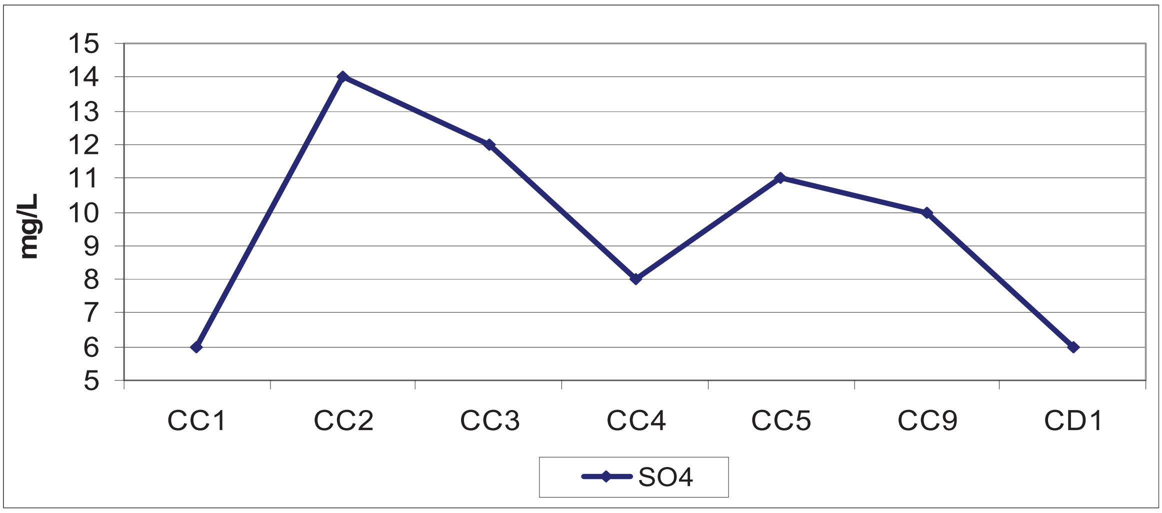


Figure 30 Cataract Creek Median Sulfate Levels

In summary, monitoring to date indicates the creek is within the acceptable range for potable water, however is generally outside the ANZECC 2000 South Eastern Australia Upland Stream Criteria for pH. It is generally the case that the stream pH is more acidic as it discharges out of the humic / fulvic acid dominated swamp areas, then becomes more alkaline as it flows down the main stream, with no significant acidification downstream of upwelling seepage re-entry locations in the streams. The Creek can also be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines depending on the flow conditions at the time of sampling for;

- filtered zinc at CC1, CC4 and CD1, with a high variability
- total phosphorous at all sites, generally;
- total nitrogen, at all sites, infrequently;
- occasionally filtered copper, and;
- aluminium on only one occasion (CC1 on 2/12/11), as although some values exceed 55µg/L, they do not exceed the ANZECC 200 criteria as they are below pH 6.5.

No adverse effects on stream flow continuity or stream ponding have been observed in Cataract Creek, however, where the ferruginous deposits occur, the stream water quality can exceed ANZECC 2000 criteria between CC1 and CC5 for;

- filtered copper up to 0.004mg/L, very infrequently
- filtered zinc up to 0.12mg/L, infrequently
- filtered aluminium up to 0.1, very infrequently
- total nitrogen up to 1.9mg/L, very occasionally, and
- total phosphorous up to 0.27 mg/L, occasionally
- with a gradually rising pH with distance downstream from 5.54 – 6.1 and a relatively static salinity of 141µS/cm

Where Cataract Creek discharges into Cataract Reservoir at CC9, the above criteria parameters can be;

- pH, which is generally below pH 6.5;
- filtered copper (<0.004mg/L) and filtered lead (<0.0014mg/L), very rarely;
- filtered zinc (<0.029mg/L), occasionally, and;
- total nitrogen (<1.2mg/L) and total phosphorous (<0.11mg/L) occasionally.

10.5.4 Cataract River

The CR1 – CR4 monitoring sites were installed by Gujarat May 2012, when bi-monthly monitoring of field and laboratory water quality and general observation of the stream flow commenced.

In addition to the current bi-monthly stream water depth, stream flow and stream water quality monitoring, photographic records of each monitoring site are taken during each field trip.

In general, enhanced rainfall in the catchment has the effect of reducing salinity, marginally raising pH, increasing dissolved oxygen, diluting ferruginous discolouring (or deposition), diluting major metals and generally increasing nutrients, with the degree of change relating to the degree and duration of rainfall runoff dilution in the stream.

Cataract River's pH ranges from 5.1 – 6.4, whilst salinity ranges from 52 - 117µS/cm as shown in **Figure 31**.

The stream's pH is outside the ANZECC 2000 South Eastern Australia Upland Stream criteria, which is not uncommon in natural catchments draining off Hawkesbury Sandstone in the Southern Coalfields.

All sites have been observed to have perennial flow.

Insufficient data has been collected to date to discuss longer term trends for iron, manganese and sulfate.

Monitoring to date indicates the creek is within the acceptable range for potable water, however 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 depending on the flow conditions at the time of sampling for;

- filtered zinc, total phosphorous and total nitrogen.

Where Cataract River discharges out of the Study Area, and subsequently into Cataract Reservoir at CR3, the above criteria parameters can be;

- pH, which is below 6.5;
- filtered copper (<0.002mg/L), very rarely;
- filtered zinc (<0.388mg/L), generally, and;
- total nitrogen (<1.2mg/L) and total phosphorous (<1.32mg/L) generally.

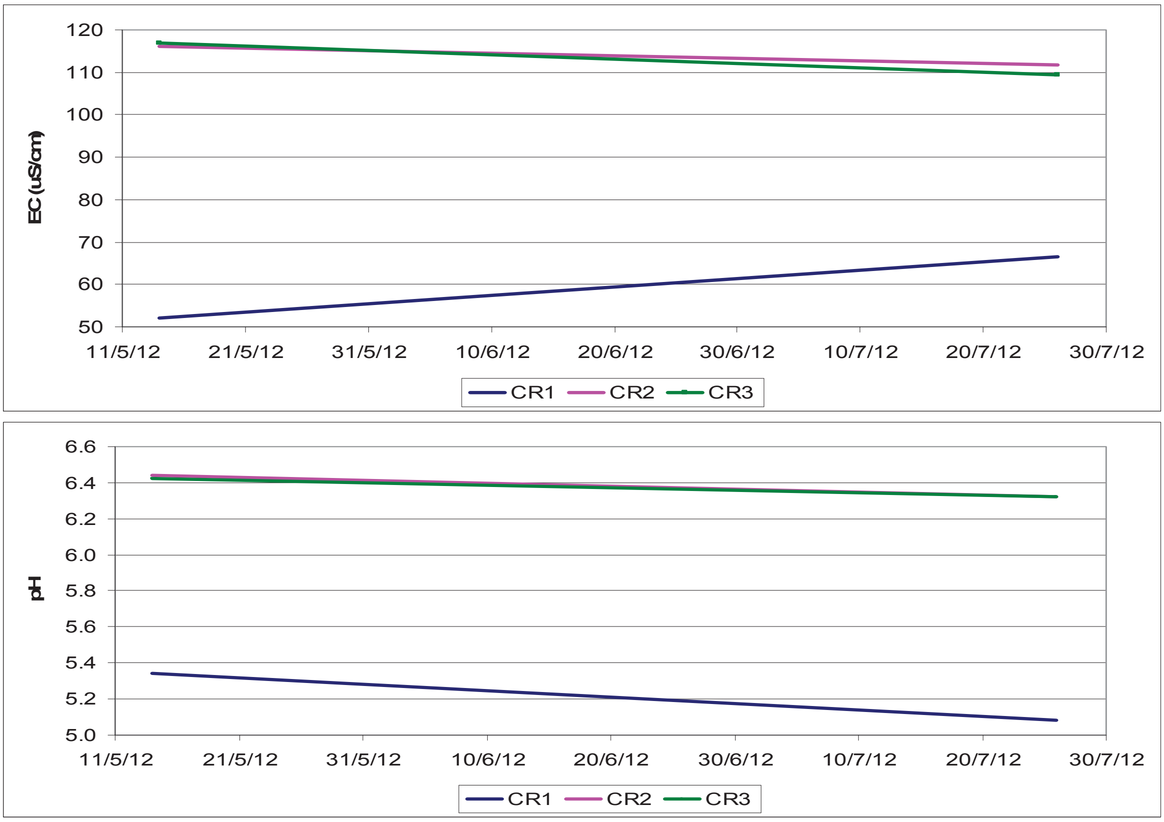


Figure 31 Cataract River Field Water Chemistry

11. PREVIOUS SUBSIDENCE EFFECTS ON STREAMS

The previous operators of NRE No.1, as well as Cordeaux Colliery, have extracted Bulli Seam longwalls under both Lizard and Wallandoola Creeks at Wonga West.

Cataract Creek was undermined by bord and pillar and pillar extraction in the Bulli seam as well as narrow longwalls in the Balgownie workings at Wonga East.

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

Bord and pillar, as well as 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 5**.

In the 200 series longwalls, no subsidence was measured with 190m wide panels and 35m wide chain pillars, whilst the same layout to the north in the 300 series, 0.9m of subsidence was recorded.

Longwall mining generated a maximum subsidence of 1.1m for the 155m wide longwalls with 30m wide pillars to the east of Cataract reservoir, whilst the 205m wide panels at Cordeaux Colliery, with 30m wide chain pillars, generated up to 1.3m of subsidence (Seedsman Geotechnics Pty Ltd, 2012).

Microseismic monitoring at Bellambi West indicated rock fracturing extended to approximately 100m above the Bulli Seam, whilst vibrating wire piezometer monitoring between longwalls 501 and 502 indicates that the hydraulic integrity of the Bulli Seam and Hawkesbury Sandstone was not adversely affected (Seedsman Geotechnics Pty Ltd, 2011).

No publicly available pre and post mining surveys of the creek flow and water quality are known to be available over the BHPB Cordeaux longwalls.

The following sections outlined the observed effects of subsidence due to the previous extraction of the Bulli Seam at Wonga East and Wonga West, as well as the underlying Balgownie longwalls and the Wongawilli longwall WE-A2-LW4 at Wonga East.

11.1 Lizard Creek

As shown in **Drawing 5**, from south to north within the Gujarat lease, Lizard Creek overlies the north south oriented access drives (to the east of the longwall 202A) and directly overlies the subsidence goaf of longwalls 202B and 202.

Between the southern lease boundary and downstream of LC3, Lizard Creek has been observed to be continuously ponded and predominantly flowing. At the southern end of valley fill swamp Lcus4, downstream of LC3 where a 2m to 3m deep rock bar constrained pool is present, the creek is continuously ponded and generally flowing, with low ferruginous precipitation.

The downstream end of Lcus4 has headward eroded valley fill swamp sediments as well as a rock bar constrained pool as shown in **Plate 9** that can dry out after extended lack of rainfall and runoff.

PLATE 9 Downstream end of Swamp Lcus4

Two sandstone based pools, overlying an un-subsided area between the previously mined Longwalls 202B and 202, are observed to have a single north south oriented crack along the eastern side of the creek in each pool.

The pools can be dry in the immediate vicinity of each crack after extended lack of rainfall, but predominantly contain shallow ponds on the eastern side of the channel in each pool where it is not cracked.

Downstream of the cracked pools, the creek over the southern two thirds of Longwall 202, to the north of Longwall 202B, can be dry and stained with ferruginous deposits after extended dry periods, although no cracks were observed in the exposed sandstone creek bed as shown in **Plate 10**.

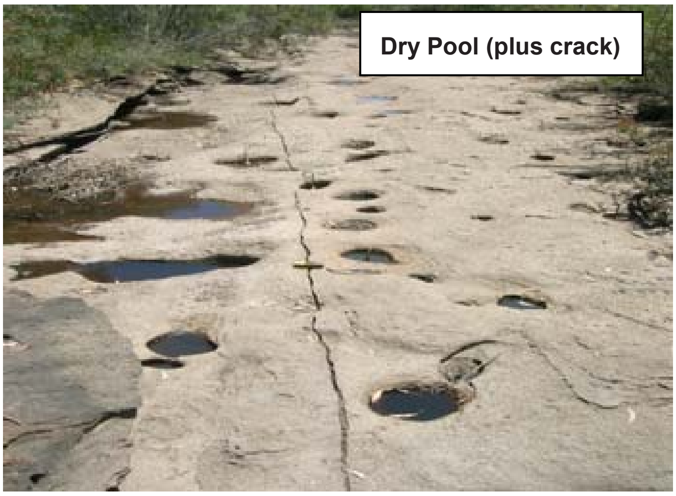


PLATE 10 Downstream of Lcus4 and Upstream of Waterfall L1

The northern third of Lizard Creek over Longwall 202 and over the east west oriented access drives between the 200 series and the 300 series contain a ferruginous predominantly ponded and generally flowing pool, which subsequently cascades with a predominantly permanent flow over Waterfall L1.

The waterfall exhibited ferruginous overland flow in the channel bed as well as a more substantive ferruginous seepage from bedding discontinuities on the western flank of the waterfall as shown in **Plate 11**.

PLATE 11 Pond Upstream of Waterfall L1 and Waterfall L1

Downstream of Waterfall L1, over the access drives between the Series 200 and 300 Bulli Seam workings, the plunge pool and extended pool that contains LC4 is generally flowing, although not significantly ferruginous, although can contain pooled, flowing relatively clear water downstream to LC5, which overlies the southern goaf of Longwall 303.

After extended dry periods, water can be observed flowing into a cracked sandstone substrate immediately downstream of LC5 as shown in **Plate 12**.

PLATE 12 Monitoring Site LC5

The creek bed between LC5 and LC6 can dry out after extended lack of rainfall where the creek bed overlies Longwalls 303 to 307. This reach has both sandy and exposed sandstone sections as shown in **Plate 13**.

This reach contains observable stream bed cracks and uplifted sandstone plates, however the majority of the reach does not have obvious cracking.

The reach between LC5 and LC6 has been observed to be completely dry on three occasions since December 2009 as shown in **Figure 12**, with the dry spells lasting for;

- 6 days between 21/3/10 – 27/3/2010.
- 37 days between 19/4/2010 – 26/5/2010, and;
- 45 days between 2/2/2011 – 19/3/2011

PLATE 13 LC5 to LC6 Stream Reach

The creek water is highly ferruginous where it seeps back into the stream at LC6 as shown in **Plate 14**, then becomes sequentially clearer with flow downstream.

Between LC6 and LC7, over Longwalls 308 and 309 and downstream from LC7 to LC9, Lizard Creek is continuously ponded and generally perennial.

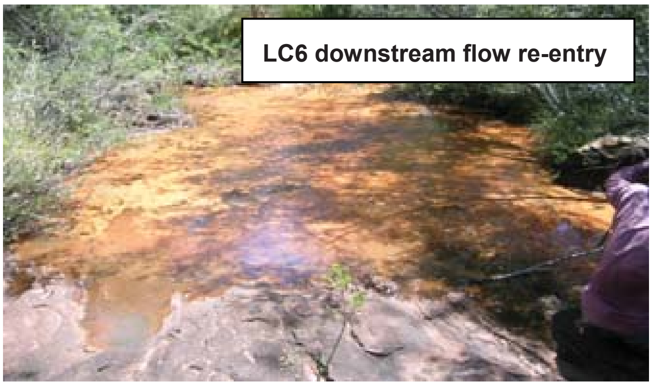


PLATE 14 Site LC6

11.2 Lizard Creek Tributaries

11.2.1 LCT1

Monitoring conducted since August 2006 over T and W Mains in the Bulli Seam, which are located in the headwaters of tributary LCT1 between the 200 and 300 series longwalls, has not observed any adverse geomorphological, hydrological or water chemistry changes due to subsidence (Ecoengineers, 2011).

The intermittent C10 - C11 tributary that overlies T and W Mains has been observed to have dry weather groundwater baseflow seeping from a sandstone headwall (Ecoengineers, 2009).

The ephemeral to intermittent tributary containing headwater swamp Lcus18 has not been observed to have adverse effects from subsidence on stream flow or stream water quality.

The 3rd Order reach downstream of site C11 lies over the western end of the Bulli Seam longwall 308 and 309 has been observed to have unaffected stream flow and water quality to approximately 350m upstream of the Lizard Creek junction.

Downstream of that point over the mid panel section of Bulli Seam longwall 307 as shown in **Drawing 5**, which was mined during 1990, the stream can contains ponded ferruginous water with intermittent flow after extended dry periods (ERM, pers comm.), although without any observable stream bed cracking as shown in **Plate 15.**

In closer proximity to Lizard Creek, also over the mid panel section of the Bulli Seam Longwall 307, contains ponded ferruginous water with an enhanced desiccation rate, although no distinctive stream bed cracking is evident.

PLATE 15 350m upstream of Lizard Creek in Tributary LCT1

11.2.2 LCT2

The ephemeral to intermittent first order tributary LCT2A that contains swamp Lcus25 in its headwaters has had no adverse subsidence effects observed on stream flow or stream water quality.

Tributary LCT2B is also ephemeral to intermittent, and only flows for a short period of hours to days after significant storms, although a sandstone based shallow pond used for water sampling 30m north of the fire road holds and maintains ponded water for weeks, and only dries out due to evaporation. No evidence of subsidence cracks in the sandstone have been observed in this tributary.

The LCT2B 3rd order tributary does not overlie any old Bulli Seam workings and does not show any adverse stream flow or water quality effects.

11.3 Wallandoola Creek

As shown in **Drawing 5**, from south to north within the Gujarat lease, Wallandoola Creek sequentially overlies the Bulli Seam east west oriented longwall panel "P", and subsequently the north south oriented Bulli Seam Longwalls 208 to 211.

Between the southern lease boundary and downstream to site WC4, Wallandoola Creek has been observed to be at least continuously ponded and generally flowing between WC1 and WC4 since 2001.

The creek is primarily clear up to the major bend in the creek to the south of proposed longwalls 3 and 4 in Area 3, then becomes ferruginous over and downstream of the Bulli Seam longwall 209, downstream of WC3.

The southern end of the WC4 pool can be dry, or have low water levels after extended low rainfall, with the pond draining into a crack in the sandstone creek bed as shown in **Plate 16**.

PLATE 16 Pools Upstream and Downstream of Site WC4

The sandstone stream bed overlying the western edge of Longwall 211 can be dry down to an upper "step" of Waterfall W1 after extended dry periods, where the water re-emerges as a ferruginous overland flow combined with numerous ferruginous seeps from sandstone bedding planes and at the base of the waterfall as shown in **Plate 17**.

PLATE 17 Upstream of Waterfall W1

Downstream of Waterfall W1, over the unmined area to the west of the previously mined Longwall 211, the plunge pool and at WC5 is usually flowing, although contains significant ferruginous precipitation as shown in **Plate 18.**

Immediately downstream of Waterfall W1, Wallandoola Creek is perennial, although is always ferruginous.

The creek water becomes sequentially clearer with flow downstream from WC5.


Cracked mid section Waterfall W1


Looking downstream to WC5 pool

PLATE 18 Downstream of Waterfall W1

11.4 Cataract Creek

As shown in **Drawing 5** Cataract Creek overlies the north west / south east and south west / north east oriented Bulli Seam bord and pillar workings as well as the south west / north east oriented longwalls in the underlying Balgownie Seam and longwall WE-A2-LW4 in the Wongawilli Seam.

The 1st and 2nd order tributaries between Sites CC1 - CC4 and CC2 – CC3 have been continuously flowing during all site visits and have not been observed to dry out, and usually contain ferruginous precipitates.

The fourth order stream channel between CC5 and CC9 has also been continuously flowing, although ferruginous precipitation is generally observed at site CC5 and downstream of tributary CT1.

No evidence of stream bed cracking, flow loss or adverse effects on pool levels has been observed in Cataract Creek in the areas undermined by the Bulli, Balgownie or Wongawilli workings.

11.5 Stream Water Quality Above ANZECC 2000 Criteria

In general, where adverse subsidence effects are noted on stream flow and ponding, there is an associated precipitation of an orange brown coloured iron hydroxide floc, which raises the total and filtered iron content of the stream water.

Although higher concentrations of associated metals and sulfate can occur in the iron floc areas, it is generally not significant, as discussed in **Section 10**.

11.6 Stream Bed and Bank Erosion

No enhanced stream bed or bank erosion has been observed within Lizard, Wallandoola or Cataract Creeks, apart from the headward erosion at the downstream end of the valley fill swamp section of swamp Lcus4 in Lizard Creek.

11.7 Upland Swamps

Refer to (GeoTerra, 2012) for further details.

12. STREAM SIGNIFICANCE

The PAC recommended the proponent should assess the waterway/s condition through describing the:

- natural features likely to be at risk of negative environmental consequences from subsidence impacts;
- permanence of stream flow;
- regional significance of the stream to the catchment water supply and scale of the watercourse;
- stream water quality;
- ecological importance of key aquatic communities;
- connectivity with swamp complexes;
- riparian vegetation environmental quality;
- stream physical form;
- stream visual amenity;
- community value of the stream;
- potential risk to those features from the mining proposal;

as well as

- identifying options for dealing with significant risk;
- determining which of these options will form part of the management plan;
- monitoring the subsidence impacts and consequences for the feature and outcomes from the management strategies;
- outlining if there are techniques available to prevent consequences or to remediate them effectively;
- deriving contingency options and planning to deal with exceedances, and where appropriate, and;
- auditing the risk management process.

The assessment should indicate the qualities of a waterway that characterise its environmental and aesthetic value. Application of one of the standard assessment approaches could provide a consistent basis for comparing the condition of the waterway before and after the impacts of mining.

The Metropolitan PAC report noted that assessment of the significance of individual watercourses in the context of acceptability of the risk of subsidence impacts and consequences is difficult, and also noted the absence of objective measures of significance and the lack of policy guidance on this issue.

The following steps were suggested by the Metropolitan PAC report to ensure adequate relevant information is available to the decision maker and to focus attention on key issues:

Step 1 Identify the mine characteristics (depth, geology, mining method, mining height, mine layout, percentage extraction) and types of subsidence impacts likely to be experienced

Step 2 Identify and describe significant natural features that might be at risk from subsidence impacts. In terms of surface water it should include at least rivers and significant streams, upland swamps, endangered ecological communities and threatened species habitat.

Step 3 Assess any features identified in Step 2 that warrant special significance status in any proposed risk management plan.

Steps 1 to 3 should be completed as part of the preparation of the initial Project Application to inform the early mine planning work and also assist in discussions between the Proponent, regulators and stakeholders.

Steps 4 and 5 provide a more refined analysis based on the possible mining parameters and depend on detailed predictions of subsidence impacts for features in question and where possible, an assessment of the potential consequences of those impacts. These steps form the core of the risk assessments and management options required in an Environmental Assessment.

Step 4 Using the criteria set out in the SCI Report for deriving RMZ boundaries, draw a RMZ around those features from Step 2 and Step 3 and assess the risk to the feature or relevant part of the feature, and

Step 5 Proposed risk management plans will be required for those features of special significance identified in Step 3 where a risk of impact is a real possibility or for features identified in Step 2 where a risk of *significant* impact is a real possibility.

The following stream significance assessment has been conducted in accordance with the procedures outlined in the Bulli Seam Operations environmental assessment and Planning Assessment Commission reports.

Only stream reaches within the predicted 20mm subsidence zone were considered in this assessment.

Due to the effects of previous mine subsidence in sections of Lizard and Wallandoola Creeks, and to relate to separate operational areas of the proposed workings, the significance of the streams has been assessed both in sections, and as an overall connected linear network.

A discussion of the stream significance is outlined in the following sections, and summarised in **Appendix B.**

12.1 Lizard Creek

Lizard Creek, between LC3 and LC7 (over the proposed subsidence reach), conforms to some of the “special significance” criteria in that it;

- has potential regional significance to water supply at Broughtons Pass Weir, downstream of Cataract Reservoir;
- has Endangered Ecological Community (Coastal Upland Swamp) within its channel and tributaries;
- provides potential habitat for the Giant Burrowing Frog and the Red Crowned Toadlet;
- provides potential habitat for Adams Emerald Dragonfly, although the dragonfly has not been identified in the stream, and;
- has a stream discharge out of the predicted subsidence area, and subsequently into Cataract Creek (downstream of the reservoir) generally within the ANZECC 2000 criteria, except for;

- o pH, which is occasionally below pH 6.5;
- o filtered zinc (<0.036mg/L), occasionally, and;
- o total nitrogen (<0.4mg/L) and total phosphorous (<0.16mg/L), rarely.

However, it does not conform to other criteria, in that;

- the connected linear network of the stream is disrupted as it does not have perennial flow between the LC3 to Waterfall L1, and the LC4 to LC6 reaches (excluding the actual waterfall) due to previous subsidence effects between 1979 and 1992 (i.e. 31 to 18 years ago) and can be totally dry in this reaches after extended lack of rainfall;
- the stream is ferruginous where the through flow from the upstream reaches discharges back into Lizard Creek, downstream of LC6, and;
- it does not have a high degree of "naturalness" in the affected reaches.

On the basis that the connected linear network of Lizard Creek and its "naturalness" is "*diminished by the effects of previous mining*", the Bulli PAC did not consider Lizard Creek to qualify for "special significance" (NSW Planning Assessment Commission, 2010).

As a result, the third order or higher reach of the main channel of Lizard Creek within the Study Area is not deemed to have special significance.

12.1.1 Waterfall L1

Waterfall L1 is located on the downstream end of the potential Wonga West 20mm subsidence zone between LC3 and the waterfall.

The waterfall has not been observed to be adversely affected by loss of stream flow or water level reduction in the downstream plunge pool.

It has an absence of adverse effects due to a lack of subsidence as it overlies an area of only first workings in the Bulli seam, although it does have elevated ferruginous precipitates in its vertical seepage face.

As a result, Waterfall L1 is considered to qualify for "special significance". (SCT, 2012)

12.1.2 Lizard Creek Tributary 1

Lizard Creek Tributary 1 conforms to some of the "special significance" criteria in that it;

- has potential regional significance to water supply at Broughtons Pass Weir, downstream of Cataract Reservoir;
- has Endangered Ecological Community (Coastal Upland Swamp) within its channel and tributaries;
- provides potential habitat for Adams Emerald Dragonfly, although the dragonfly has not been identified in the stream, and;
- has a stream discharge into Lizard Creek which is generally within the ANZECC 2000 criteria, except for;
    - o pH, which is generally below pH 6.5;
    - o filtered zinc (<0.046mg/L) and;
    - o total nitrogen (<2.08mg/L) and total phosphorous (<0.24mg/L), occasionally.

However, it does not conform to other criteria, in that;

- the connected linear network of the stream is disrupted as it does not have perennial flow between the C11 and LCT1 due to previous subsidence effects between 1979 and 1992 (i.e. 31 to 18 years ago) and can be totally dry in this reach after extended lack of rainfall;
- the stream is ferruginous, and;
- it does not have a high degree of "naturalness" in the affected reaches.

On the basis that the connected linear network of Lizard Creek Tributary 1 and its "naturalness" is "*diminished by the effects of previous mining*", the Bulli PAC did not consider Lizard Creek to qualify for "special significance" (NSW Planning Assessment Commission, 2010).

As a result, the third order reach of Lizard Creek Tributary 1 is not deemed to have special significance.

12.1.3 Lizard Creek Tributary 2

Lizard Creek Tributary 2 conforms to some of the "special significance" criteria in that it;

- has potential regional significance to water supply at Broughtons Pass Weir, downstream of Cataract Reservoir;
- has Endangered Ecological Community (Coastal Upland Swamp) within its channel and tributaries;
- provides potential habitat for Adams Emerald Dragonfly, although the dragonfly has not been identified in the stream, and;
- has a stream discharge into Lizard Creek which is generally within the ANZECC 2000 criteria, except for;
  - o pH, which is generally below pH 6.5;
  - o filtered zinc (<0.048mg/L) and;
  - o total nitrogen (<3.4mg/L) and total phosphorous (<0.13mg/L), occasionally.
- it has a high degree of "naturalness".

However, it does not conform to other criteria, in that;

- the stream has ferruginous reaches.

As a result, the third order reach of Lizard Creek Tributary 2 is deemed to have special significance.

12.2 Wallandoola Creek

Wallandoola Creek, between WC3 and WC7 (over the proposed subsidence reach), conforms to some of the "special significance" criteria in that it;

- has potential regional significance to water supply at Broughtons Pass Weir, downstream of Cataract Reservoir;
- has Endangered Ecological Community (Coastal Upland Swamp) within its channel and tributaries;
- provides potential habitat for the Giant Burrowing Frog, the Heath Frog and the Adams Emerald Dragonfly, although they have not been identified in the stream,

and;

- has a stream discharge out of the predicted subsidence area, and subsequently into Cataract Creek (downstream of the reservoir) generally within the ANZECC 2000 criteria, except for;
  - o pH, which is generally below pH 6.5;
  - o filtered copper (<0.004mg/L), very rarely;
  - o filtered zinc (<0.03mg/L), occasionally;
  - o total nitrogen (<0.7mg/L), rarely, and;
  - o total phosphorous (<0.19mg/L) occasionally.

However, it does not conform to other criteria, in that;

- the connected linear network of the stream is disrupted as it does not have perennial flow between the WC4 and WC5, including Waterfall W1 due to previous subsidence effects between 1988 and 1992 (i.e. 22 to 18 years ago) and can be totally dry in this reaches after extended lack of rainfall;
- the stream is ferruginous where the through flow from the upstream reach discharges back into Wallandoola Creek, downstream of Waterfall W1, and;
- it does not have a high degree of “naturalness” in the affected reach;

The Bulli PAC considered Wallandoola Creek, downstream of the Study Area, to be both important and rare, and based on its “naturalness” was considered a candidate for “special significance” status. However, it is not apparent whether the WC4 – WC5 reach was considered in the Bulli PAC assessment.

On the basis that the of Wallandoola Creek and its “naturalness” is diminished by the effects of previous mining in the WC4 to WC5 reach, that reach is not considered to have special significance.

However, although the stream has been impacted by previous mining subsidence which has diminished the naturalness of the creek in the WC4 to WC5 reach, the catchment is essentially undisturbed and has a high level of naturalness, except where mining subsidence is present.

12.2.1 Waterfall W1

The WC4 to WC5 reach is adversely affected by previous subsidence through dessication of the creek bed and Waterfall W1 after extended dry periods, and through ferruginous seepage into the creek at and downstream of the waterfall.

As a result, Waterfall W1 is not considered to qualify for “special significance” in terms of its interrupted connected linear network between WC4 and WC5.

It is noted, however, that Waterfall W1 is considered to be of ‘special significance’ as a cliff structure (SCT 2012).

12.3 Cataract Creek

Cataract Creek, upstream of Cataract reservoir, is considered to have special significance because;

- of the presence of Endangered Ecological Community (Coastal Upland Swamp) within tributaries;
- it provides habitat for Macquarie Perch, Silver Perch and an unidentified freshwater cod (potentially the threatened Murray Cod, Trout Cod or a hybrid of these species (Cardno Ecology Lab 2012);
- provides potential habitat for Adams Emerald Dragonfly and potential breeding habitat for the Stuttering Barred Frog, although neither species has been identified in the stream;
- has perennial flow in the lower reaches and provides a regionally significant water supply function to Cataract reservoir;
- has a high degree of “naturalness”;
- has a stream discharge into Cataract Reservoir that generally is within the ANZECC 2000 criteria, except for;
  - pH (generally below pH 6.5),
  - filtered copper (<0.004mg/L) and filtered lead (<0.0014mg/L), very rarely;
  - filtered zinc (<0.029mg/L), occasionally, and;
  - total nitrogen (<1.2mg/L) and total phosphorous (<0.11mg/L) occasionally.

12.4 Cataract River

Cataract River, upstream of Cataract reservoir, is considered to have special significance because;

- of the presence of Endangered Ecological Community (Coastal Upland Swamp) within tributaries;
- it provides habitat for Macquarie Perch, Silver Perch and an unidentified freshwater cod (potentially the threatened Murray Cod, Trout Cod or a hybrid of these species (Cardno Ecology Lab 2012);
- it provides breeding habitat for Giant Burrowing Frog (confirmed) and Heath/Littlejohn’s Tree Frog in tributaries;
- provides potential habitat for Adams Emerald Dragonfly and the Stuttering Barred Frog although neither species has been identified in the stream;
- has perennial flow in the lower reaches and provides a regionally significant water supply function to Cataract reservoir;
- has a high degree of “naturalness”;
- has a water quality discharge into Cataract Reservoir that generally is within the ANZECC 2000 criteria, except for;
  - pH, which is below 6.5;
  - filtered copper (<0.002mg/L), very rarely;
  - filtered zinc (<0.388mg/L), generally, and;
  - total nitrogen (<1.2mg/L) and total phosphorous (<1.32mg/L) generally.

13. RISK ASSESSMENT, POTENTIAL STREAM EFFECTS, IMPACTS AND CONSEQUENCES

In accordance with the Bulli Seam PAC findings, a stream risk and an associated potential stream effects, impacts and consequences assessment was conducted through comparing findings and predictions summarised in previous sections, along with observations from field inspections and monitoring.

13.1 Stream Flow and Pool Levels (General)

Stream flow and pool levels are maintained in a stream when there is sufficient runoff in a subject catchment, as well as through contribution groundwater baseflow and upland swamp seepage.

Stream flow is separated into ‘baseflow’ from delayed groundwater, swamp seepage and release from stream bank storage, as well as ‘quickflow’, which is a direct and short term response to rainfall that includes overland flow, rapid lateral movement in the soil (interflow) and direct precipitation onto the stream surface.

The relative contribution of baseflow and quickflow changes through a streams hydrographic record.

Potential geomechanical effects and impacts on streams generated in areas with exposed Hawkesbury Sandstone, Bald Hill Claystone or Bulgo Sandstone due to subsidence can include:

- bending, delamination or lifting of discrete surface sheets of rock into an inverted V due to compression at right angles to the axis of the V, particularly above and immediately behind an active extraction area;
- horizontal stress concentration or mobilisation of natural horizontal stress, mainly in areas of localised topographic highs such as rock bars, with surface shearing, usually along bedding planes or sliding of one sheet above the other with measurable horizontal and relative vertical displacement of the sheets;
- horizontal and low angle shearing, particularly in cross-bedded sandstone;
- isolated thin sheet shear and failure;
- tensile failure of upper beds, mainly perpendicular to the direction of compression, and;
- vertical hairline fracturing perpendicular to the axis of horizontal shearing, usually with significant horizontal opening up to several centimetres, but usually with short vertical penetration into the strata. The fracturing can be characterised by iron rich seeps that oxidise on exposure to the air which are a visible precursor to progressive fracturing in creeks close to mining activity.

Based on experience gained during longwall mining in other Southern Coalfield operations, mining under a creek or river can result in horizontal separation of strata in the base of the valley and redistribution of existing horizontal stresses in the walls and base of the valleys.

If the redistributed stress exceeds the bulk shear strength of the strata, then relative horizontal shear can produce uplift of the valley floor.

Localised weathering patterns may significantly influence the geometry of deformation.

In general terms, the range of possible consequences due to subsidence are:

- loss of water from pools due to rockbar fracturing where surface water is temporarily diverted through near surface fractures;
- full or partial re-emergence of diverted stream flow further downstream;
- loss of surface water inflow to pools due to upstream diversion into the shallow substrate beneath a stream;
- reduced water retention in isolated pools, or sequential pools;
- modification of surface water quality through geochemical and biochemical interactive changes with exposed fresh mineral surfaces following fracturing;
- increased salinity and / or alteration of water quality following slumping, erosion and modified sediment transport;
- adverse impacts on ecosystems by changes in surface water flow, pool water retention and / or changes in water quality, or;
- changes to aquatic habitats due to lower pool water levels, drying of riffle zones, sedimentation etc.

Subsidence and valley uplift is usually associated with shallow horizontal fracturing and diversion of surface water to the shallow substrate beneath a stream bed, which may or may not be hydraulically connected to the underlying regional groundwater system.

Although horizontal stress redistribution can result in localised instability within steep valley slopes, minimal influence on geomorphic features on the plateau or slopes is expected.

The majority of adverse effects or consequences on stream flow and pool water holding capacity in stream beds is due to non-conventional subsidence.

It is noted that the mine layout as proposed has been developed to reduce and limit the potential for these impacts to develop on and within the primary channels of the major creeks within the study area.

With respect to the Catratct Creek, the proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250mm and the creek experiences greater than negligible impact.

The Bulli PAC assessed that it is well established that, the vertical and lateral extent of upsidence fracture networks increases with the level of upsidence, which in turn increases with the level of closure. However, impact categories have yet to be assigned to measured closure or upsidence effects because:

- upsidence does not correlate well with closure due to difficulties in measuring upsidence accurately and different amounts of upsidence can be induced by the same amount of closure, depending on rock type;
- different levels of impact can be associated with the same level of upsidence, depending primarily on local rock type, rock fabric and structure (massive, laminated, cross bedded, jointed etc) and the orientation of the structure relative to the direction of valley closure, and;
- in the case of some features, some high consequence impacts occur at very low levels of movement. Further increases in the magnitude of the effect (movement) do not always result in an incremental increase in the magnitude of the impact and its consequences, albeit that they might increase other impacts and consequences. Field observations reveal that this is the case in particular for watercourses controlled by rock bars.

The Bulli Seam EA assessed that no pool impacts had been observed where valley closure was less than 200mm.

Total valley closure is critical for features in the base of a valley where most of the displacement occurs, along with the high compressive strains in the valley floor, which is observed as upsidence.

The Bulli PAC determined it is more appropriate if valley closure movements were assessed in terms of compressive strains that could be correlated with subsidence impacts.

The Bulli PAC also noted that although impacts at rockbars in previous studies were based on predicted valley closure, this approach was illogical and unsatisfactory as it is based on correlation between predicted closure (an estimate) and observed impact (a fact) and that there is generally a poor correlation between measured closure and observed impact.

The Bulli PAC concurred with using closure strain as a risk criterion, where closure is a measure of the absolute amount of horizontal displacement across a valley and the impact of the movement is determined by its distribution between the valley sides, that is, by the strain arising from this movement. The Bulli PAC noted that strain distribution changes across the closure profile, with peak strain occurring in the centre of a valley.

Based on the Bulli PAC's findings, total diversion of surface flow into a subsidence induced subsurface fracture system requires higher total compressive strains that are dependent on geological factors such as strata composition, thickness and bedding laminations. Limited measurements indicate a threshold total compressive strain for diversion of flow in sandstone environments of 7mm/m (NSW Planning Assessment Commission, 2010), where conventional compressive strain can make a significant contribution to total compressive strain.

Due to the variable manner in which upsidence can develop and is measured, the Bulli PAC had concerns using upsidence as a risk criterion as its measurement is susceptible to the manner in which the rock surface fails and the location of survey stations.

As a result of the Bulli PAC findings, this assessment of potential effects on stream flow and pool water holding capacity of the subject streams places the emphasis on predicted strains in creek valleys, rather than predicted valley closure.

These aspects are discussed further in the following sections.

13.2 Stream Water Quality (General)

Previous observations in similar geomorphological, hydrological and mining environments within the Southern Coalfields, have assessed that water quality can be adversely affected through:

- increased groundwater discharge to a stream following direct undermining and subsidence;
- lowered dissolved oxygen, lowered pH, elevated dissolved Fe / Ni / Zn / Mn / Al as well as elevated sulfate and salinity from flow through fresh cracks in cliff and stream bed sandstone following subsidence which manifests as orange-brown, low dissolved oxygen plumes in receiving waters, and;

- pool depth reduction and enhanced stagnation and evaporative concentration which enhances low dissolved oxygen and elevated salinity.

The main observable change in streams results from dissolution of freshly exposed diffused iron sulfide and carbonate minerals (such as marcasite, pyrite or siderite) from cracked sandstone which subsequently precipitates on discharge to a receiving water body as an orange-brown iron hydroxide floc, along with the generation of sulfuric acid and increased levels of dissolved iron, manganese, aluminium, nickel and zinc species.

Mine subsidence can delaminate erosion surfaces and bedding planes within and between strata which occurs preferentially along the interface between materials with different elastic properties. Delamination, dilation and interfacial permeability enhancement is likely along the sub-horizontal interface between sub-cropping sandstone and outcropping shales.

The effects of ferruginous springs is generally aesthetic and does not pose an adverse risk to stream ecology due to the relatively short length and high gradients of the streams in the Study Area as well as the substantial dilution and dispersion that would occur at the confluence with the Cataract River (downstream of the dam) or in Cataract reservoir itself.

Where a seep discharges into a stream, the stream can be slightly more acidic and brackish downstream of a subsidence affected area, which, with in-stream diffusion and mixing, subsequently reduces with flow downstream.

An increase in dissolved aluminium may be due to dissolution from kaolinite in the fractured bedrock or, being remobilised from precipitated hydrous iron, manganese or aluminium oxides due to dissolution by humic and fulvic acids in organic rich upland swamps.

In addition, enhanced armouring of stream bed substrate with precipitated iron hydroxide has been observed at discharge areas, however this effect has also be observed in natural, non mining affected streams in the NRE1 lease area.

The generation of ferruginous seeps into a stream decreases over a time frame of years due to armouring of marcasite and siderite with iron oxyhydroxide precipitates (Nicholson et al, 1990).

The diversity and abundance of aquatic species within the Study Area may be affected by the comparitively acidic pH (which is often natural in Hawkesbury Sandstone streams), as well as dissolved aluminium and zinc. Sulfate and dissolved humic and fulvic acids may also be insufficient concentration to form complexes with dissolved aluminium and reduce the stream water ecotoxicity.

If additional adverse seepage to a stream occurs, it is usually diluted in a short distance, with a reduction of pollutant concentration downstream from the point of emergence. This assumes, however, the discharge occurs at an isolated location, whereas it is often observed that the seepage is disseminated along a stream, depending on the subsidence induced flow regime, with the resultant dilution, precipitation and adsorption effects as described above.

Studies at Elouera Colliery (currently operated as the Gujarat NRE Wonga Pty Ltd Wongawilli Colliery) in a similar geomorphological and hydrological environment to the Study Area, indicate there are no residual ecotoxic effects (as opposed to physical subsidence effects on flow) from acidic pH, aluminium, nickel or zinc, with the effects of undermining at Eloura requiring less than 10 years to be ameliorated (Comur Consulting,

2007).

It has also been observed in stream over the Elouera workings that natural attenuation of an affected stream reach can occur up to 750m downstream of the seepage location (BHP Billiton, 2009).

The effect of acidity is reduced mainly through dilution with receiving waters as well as buffering from alkaline solutes such as bicarbonate ($HCO3^-$) and, to a lesser degree, hydroxide species (OH^-).

The increased acidity and lower dissolved oxygen in receiving waters is generally only observed close to the discharge point, and depends on the flow rate and volume at the discharge point.

Dilution of the discharge as well as precipitation of iron and manganese hydroxides, adsorption of dissolved Ni and Zn onto the iron hydroxides, as well as binding or adsorption onto dissolved / total organic carbon can significantly improve water quality downstream from the emergence point.

Further downstream from the seepage point, a stream can be affected by moderately elevated salinity, however this also quickly diminishes with mixing downstream.

Monitoring in the Study Area has identified numerous ferruginous seeps within both the main channel and tributaries of all three creeks.

The potential effects, impacts and consequences are discussed in the following sections, with reference to the predicted subsidence as outlined in **Table 18**.

Table 18 Stream Reach Maximum Subsidence

	Subsidence (m)	Tilt (mm/m)	Strain (mm/m)
Wonga East (Cataract Creek)			
CC1 - CC4 tributary (nth catchment)	<0.02	<1.0	<1.0 to -1.0
CC2 - CC3 tributary (sth catchment)	0.16	3.0	<1.0 to <-1.0
CC5 – CC9	0.8	<1.0	5.0 to -9.5
Wonga East (Cataract River and Bellambi Creek)			
Cataract River and Bellambi Creek	<0.02	<0.1	<1.0 to <-1.0
Wonga West (Lizard Creek and Tributaries)			
LC1 – LC3	<0.02	<1.0	<1.0 to <-1.0
LC3 – Waterfall L1	0.2	3.0	2.0 to -1.0
Waterfall L1	0.12	2.9	+3.5
Waterfall L1 – LC4	0.2	<1.0	<1.0 to <-1.0
LC4 – LC5	<0.02	<1.0	<1.0 to <-1.0
LC5 – LC6	0.25	3.0	5.0 to <-1.0
LC6 – LC7	0.25	<1.0	3.0 to <-1.0
LCT1 (3rd order reach)	2.5	13.0	-7.0 to 7.0
LCT2 (3rd order reach)	1.9	9.0	4 to -6
Wonga West (Wallandoola Creek)			
WC2 – WC3	0.02	<1.0	2.0 to <-1.0
WC3 – WC4	0.5	3.0	6.0 to <-1.0
WC4 – Waterfall W1	<0.02	<1.0	<1.0 to <-1.0
Waterfal W1	<0.02	<1.0	<+1.0
Waterfall W1 – WC5	<0.02	<1.0	<1.0 to <-1.0

NOTES: source: Seedsman Geotechnics, 2012 -ve strain = compression +ve strain = extension

13.3 Lizard Creek

13.3.1 Stream Flow

Due to the designed set back of the longwalls from the main channel of Lizard Creek (and the associated lack of subsidence and uplift), the proposed Wongawilli Seam layout is designed to avoid potential adverse effects on the main channel of Lizard Creek.

A low potential risk to the integrity of stream flow and connectivity in Lizard Creek could be present in the area that may potentially undergo 6 - 7mm/m of tensile strain to the north of WW-A3-LW2 and south of the northern end of WW-A4-LW5.

It should be noted however that stream flow in this reach is already adversely affected by subsidence over the Bulli longwalls, with the quantum, duration and connectivity of flow in Lizard Creek being dependent upon rainfall and runoff in the catchment, as the main creek bed can dry up in two areas, including a:

- 950m reach upstream of Waterfall L1, and;
- 1300m reach between LC5 and LC6.

It is assessed there will be no adverse impacts, effects or consequences in the Lcus1 or Lcus4 valley fill swamps as well as in the sandstone based and rock bar constrained pools due to the predicted 20mm to 0.25m of subsidence (Seedsman Geotechnics, 2012) along the length of Lizard Creek at Wonga West Areas 3 and 4.

Between LC1 and LC5, the predicted strains along Lizard Creek are predominantly less than 3mm/m, which is also not expected to generate any adverse effects impacts or consequences on stream flow.

To the north of WW-A3-LW2, mid way between LC5 and LC6, maximum strains of between 3 - 7mm/m are predicted over a stream reach of approximately 300m (Seedsman Geotechnics, 2012), which could generate cracking in the Hawkesbury Sandstone creek bed.

The LC5 – 6 reach has shown through monitoring to completely dry up for periods of between 6 to 45 days since December 2009. Lizard Creek at this location was undermined by Bulli Seam longwalls 304 to 306 between 1986 and 1989 (i.e. up to 24 years ago).

If subsidence consequences do occur on the bed of Lizard Creek in this reach, it could manifest through additional rock bar leakage, enhanced transfer of stream flow to the underlying sandstone substrate or by an enhanced pool drainage rate.

The degree and extent of predicted cracking can not be determined with accuracy, however, as the predicted strains are not large, and as the stream flow and pool holding capacity has been adversely impacted by previous subsidence, it is not anticipated that any significant change will be observed in the creek.

Valley closures of up to 200mm and upsidence up to 120mm may occur. Notwithstanding this, no significant, observable uplift or valley closure is anticipated within the channel of Lizard Creek. Because of the decision to eliminate longwall extraction under named 3rd order creeks, the systematic strains in these creeks can only be tensile. Because of block rotations above the longwall extraction panels there may be some compressive strains transferred to the creeks.

As is observed with current stream flow conditions in this reach, it is expected that if any subterranean flow transfer occurs due to subsidence or uplift cracking in the stream bed from the proposed workings, stream flow will re-emerge downstream, without loss of total stream discharge from the subsided catchment.

Groundwater modelling indicates a potential 12m reduction in groundwater level, and an associated 0.02 ML/day baseflow reduction after the end of Stage 1 (V Mains and Area 1 and 2) and 0.10ML/day at the end of Area 4 mining to Lizard Creek (GeoTerra, 2012). It is assessed that this would generate negligible environmental consequences except potentially during extended dry periods due to depressurisation in the upper Hawkesbury Sandstone aquifer in the gaining portions of the stream, downstream of Waterfall L1.

No reduction in stream flow is anticipated in the hydraulically separated reach of the creek upstream of the waterfall.

As there is no predicted change, based on the subsidence predictions, to the semi-confining properties of the Bald Hill Claystone following extraction of the proposed Wonga West panels, it is assessed that the modelled stream flow reduction of 0.02 – 0.1ML/day would be accommodated within the secondary porosity generated through bedding plane separation and fracturing after subsidence of the mid to upper Hawkesbury Sandstone.

The additional stored connate water would flow under the regional gravity profile, and, with a delay, discharge either to a downstream reach of Lizard Creek or to an adjoining downgradient catchment, such as the Cataract River as baseflow recharge to the streams.

Based on the modelled outcome that no additional significant water passes through the Bald Hill Claystone into the underlying Narrabeen Group or Illawarra Coal Measures following extraction of the Wongawilli West longwalls, as well as at Wonga East where the claystone is not eroded away in the valley of Cataract Creek, it is assessed there would be no net loss to the water volume flowing into the Cataract River.

Stream flow modelling (WRM Water & Environment, 2012) indicates the average daily flow from Lizard Creek to the Cataract River is 17.0ML/day. Therefore, a 0.02 – 0.1ML/day flow reduction represents approximately 0.1 – 0.6% of the Lizard Creek flow into Cataract River.

13.3.2 Waterfall L1

Waterfall L1 is predicted to undergo less than 0.12m of subsidence and less than 3.5mm/m of extensional strain.

No adverse subsidence effects, impacts or consequences are anticipated at Waterfall L1 and as such, it is predicted to have a low risk of subsidence related cracking and a low risk of enhanced stream bed throughflow.

13.3.3 Rock Bars

A low potential risk to the integrity of rock bar constrained pools could be present in the area that may potentially undergo 6 - 7mm/m of tensile strain to the north of WW-A3-LW2 and south of the northern end of WW-A4-LW5.

It should be noted however that the pool holding capacity in this reach is already adversely affected by subsidence over the Bulli longwalls, with the pool depths and duration being dependent upon rainfall and runoff in the catchment, as pools in the following two areas have been observed to dry out in low flow periods between the:

- 950m reach upstream of Waterfall L1, and;
- 1300m reach between LC5 and LC6.

Monitoring of the LC5 – 6 reach has shown it to be completely dry up for periods of between 6 to 45 days since December 2009.

13.3.4 Tributaries

The first, second and third order tributaries which overly the proposed 20mm subsidence zone are at risk of subsidence related stream bed cracking, enhancement of stream bed underflow, discharge of ferruginous springs and reduced stream water quality at their confluence with Lizard Creek.

It is not anticipated, however, that the total volume of water entering Lizard Creek will be adversely affected.

Adverse impacts, effects or consequences are possible on the sandstone based pools due to the predicted 2.5m of subsidence (Seedsman Geotechnics, 2012) in the 3rd order reach of LCT1 and up to 1.9m of subsidence along the 3rd order reach of LCT2 at Wonga West Area 3. The 3rd order reach of LCT1 was undermined by Bulli longwalls 306 to 308 between 1989 and 1991 (i.e. up to 20 years ago), whilst the 3rd order reach of LCT2 was not undermined by the Bulli longwalls.

The predicted strains in the 3rd order reach of LCT1 may range up to 7mm/m (tensile) to -7mm/m (compressive), whilst the 3rd order reach of LCT2 may experience up to 4mm/m to -6mm/m, which could generate stream bed cracking. The degree and extent of cracking can not be determined with accuracy, however, as the stream flow and pool holding capacity has already been adversely impacted by the pre-existing effects of previous subsidence in the 3rd order reach of LCT1, it is not anticipated that any significant change will be observed in that tributary. Adverse effects may occur, however, in LCT2.

If subsidence consequences do occur on the tributaries, it could manifest in the tributaries through additional rock bar leakage, enhanced transfer of stream flow to the underlying sandstone substrate, by an enhanced pool drainage rate or through enhanced discharge of ferruginous seepage.

It is expected that if any subterranean flow transfer occurs due to subsidence or uplift cracking in the stream bed from the proposed Wongawilli Panels, the flow will re-emerge downstream in Lizard Creek, without loss of total stream discharge from the subsidence area.

13.3.5 Upland Swamp Outflow

A detailed significance and risk assessment of the Lizard Creek swamps is contained in (Biosis, 2012).

The predominantly headwater swamps overlying the proposed Wonga West subsidence area have the potential to undergo subsidence related bedrock cracking. The Lcus8 swamp overlying WW-A3-LW1 is anticipated to be at low risk of adverse subsidence related effects (Biosis 2012) while Lcus1, Lcus6 and Lcus27 anticipated to be at a negligible risk of adverse subsidence related effects (Biosis 2012).

However it is considered that the risk of swamp drainage, reduction of discharge to downstream gullies and adverse effects on water quality are low, and that the total volume of water entering Lizard Creek will not be observably affected.

The valley fill swamps along Lizard Creek, to the south of the proposed subsidence zone, are not anticipated to be at significant risk of adverse effects

13.3.6 Stream Water Quality

The main stream reach to the north of the proposed longwalls 1 in Area 3 is currently affected by ferruginous precipitates, as well as reduced stream flow and pool holding capacity due to pre-existing effects from the Bulli Seam longwall subsidence.

If additional stream bed cracks form to the north of the proposed panel, along with enhanced diversion of stream flow through the underlying sandstone substrate, ferruginous orange discolouration of the water and elevated total / filtered iron, along with zinc and possibly copper and aluminium could occur, along with increased opacity of the

water and reduced dissolved oxygen. However, it is unlikely that any observable, adverse effect on stream water quality will occur in addition to the existing water quality in that stream reach.

Due to the minimal predicted subsidence and strain in the main channel of Lizard Creek, and therefore the associated lack of potential for generation of additional stream bed cracking and substrate through-flow, no observable adverse effect on stream water quality is anticipated, outside of the longwall 1 and 2 stream reach.

13.3.7 Tributary Water Quality

Tributary LCT1 is currently affected by ferruginous precipitates, as well as reduced stream flow and pool holding capacity due to pre-existing effects from the Bulli Seam longwall subsidence.

The 3rd and 4th order reach of LCT2 has not been undermined, and is not affected by subsidence, although the LCT2A 1st and 2nd order headwaters, as well as swamp Lcus25 have been undermined by the 300 series longwalls.

If stream bed cracks form in the LCT1 or LCT2 3rd order or higher channels, along with enhanced diversion of stream flow through the underlying sandstone substrate, orange discolouration of the water and elevated total / filtered iron, along with zinc and possibly copper and aluminium could occur in LCT1 or be generated in LCT2 and potentially discharged into Lizard Creek, along with increased opacity of the water and reduced dissolved oxygen.

As a result, observable, adverse effects on stream water quality in the 3rd order or higher channels of LCT1 and LCT2, as well as the receiving waters of Lizard Creek, could occur.

13.4 Wallandoola Creek

13.4.1 Stream Flow

Due to the designed set back of the longwalls from the main channel of Wallandoola Creek (and the associated lack of subsidence and uplift), the proposed Wongawilli Seam layout is designed to avoid potential adverse effects on the main channel of Wallandoola Creek.

A potential risk to the integrity of stream flow and connectivity in Wallandoola Creek could be present in the area that may potentially undergo up to 0.5m of subsidence and 6mm/m of tensile strain to the south of WW-A3-LW3 and LW4

It should be noted however that stream flow in this reach is already adversely affected by subsidence over the Bulli longwalls, with the quantum, duration and connectivity of flow in Wallandoola Creek between WC4 and WC5 being dependent upon rainfall and runoff in the catchment, as the main creek bed can dry up in this reach.

Based on the less than 20mm of predicted subsidence and associated low strains, it is assessed that there will be no adverse consequences in the Wcus1 and Wcus4 valley fill swamps and associated sandstone based / rock bar constrained elongated pools up to the main bend in Wallandoola Creek, downstream of WC3 at Wonga West Area 3.

The predicted strains of up to 6mm/m in the reach up to midway between WC3 and WC4 is not expected to generate adverse effects on stream flow as the channel is dominated by either sandy based sediments or thick valley fill swamp vegetation, which can absorb low

strain levels without generating connected stream bed cracking and the associated loss of stream flow or enhanced pool drainage.

At the northern extent of the main bend in Wallandoola Creek, to the south of proposed longwalls WW-A3_LW3 and LW4, upstream of WC4, the predicted stream bed subsidence ranges from 0.25 – 0.5m (Seedsman Geotechnics, 2012). Although it could cause adverse consequences, is not anticipated to occur based on similar, previous subsidence effects observed over the Bulli 200 series longwalls, with similar previous subsidence and strains.

The predicted strains of up to 6mm/m in the stream bed directly south of proposed WW-A3-LW3 and LW4 longwalls could generate cracking in the exposed Hawkesbury Sandstone. The degree and extent of cracking is difficult to determine, however it could potentially enable enhanced drainage of the approximately 100m long pool upstream of the rock shelf.

If subsidence effects do occur, it could manifest through rock bar leakage or transfer to the underlying sandstone substrate through the pool base.

Cracks generally form in the base of a stream and are generally prevalent in more incised reaches where sandstone bedding planes lift and "dilate". Based on observations in similar topography to Wallandoola Creek, the cracked zone can extend up to 10m below surface. Studies into the depth of dilation of a river bed due to upsidence and closure of Waratah Rivulet at Metropolitan Colliery indicate that cracking occurred to 9m within a zone monitored to 27m below surface in a 60m wide valley which subsided by up to 1.3m, with 140mm of vertical dilation of the strata due to uplift (Mills and Huuskes 2004).

If cracking occurs directly beneath the subject reach of the stream, and as the creek bed upstream of Waterfall W1 is not anticipated to be hydraulically connected to the underlying regional groundwater system based on extrapolation of drilling observations, it is assessed that any through flow into the cracks will re-surface downstream.

Due to the sequential and migratory development of uplift as mining progresses due to panel by panel extraction, the development of stream bed cracking may also migrate downstream as mining advances from WW_A3-LW2 to LW4. If cracks develop, water flow to the new voids may occur as the strain sequentially develops along the creek bed, with the rate of inflow controlled or modified by the;

- time frame of uplift
- location of uplift
- depth and width of cracking in the bedrock, and
- degree of filling in cracks with sediment

Modification of stream flow can affect the function and integrity of ecological systems, whilst enhanced recharge from streams to shallow temporary aquifers can raise the groundwater table and potentially dry up restricted portions of a stream if a hydraulic connection between the two systems is present.

It is possible, although not anticipated to be likely, that cracking could occur in the creek bed to the south of WW-A3-LW3 and LW4, which could lead to loss of flow into the underlying dilated strata or enhanced drainage of pools, however, if it did occur, the cracking is not anticipated to generate a net loss of water volume discharge from subsidence affected creek systems since the subterranean flow, if it occurred, would re-emerge under gravity drainage further downstream in the catchment.

After heavy rain, the majority of runoff would flow along the creek bed, with a lesser proportion flowing through the dilated, subsided strata, whilst during low flows, a greater proportion of water would move as underflow through the shallow stream bed substrate.

It is not anticipated that the predicted strains of between 1 - 3mm/m and subsidence of 0.02 – 0.25m at the rock shelf constrained pool immediately upstream of WC4, to the south of WW-A3-LW5 will be sufficient to adversely affect the stream flow or water holding capacity of the subject pool.

Based on the subsidence assessment, valley closures of up to 200mm and upsidence of up to 120mm could occur, which are double the predicted closure and upsidence values predicted by Seedsman Geotechnics (2012) in accordance with the FMEA assessment.

No adverse subsidence effects, impacts or consequences are anticipated at or downstream of Waterfall W1 due to minimal predicted levels of subsidence and strains at that location.

Groundwater modelling indicates a potential 12m reduction in groundwater levels, and an associated 0.06ML/day baseflow reduction after the end of Stage 1 (V Mains and Area 1 and 2 and 0.25ML/day (at the end of Area 4) to Wallandoola Creek.

It is assessed that this would generate negligible environmental consequences, except potentially during extended dry periods due to depressurisation in the upper Hawkesbury Sandstone in the gaining portions of the stream, downstream of Waterfall W1.

No reduction in stream flow is anticipated in the reach upstream of the waterfall.

As there is no predicted change in the semi-confining properties of the Bald Hill Claystone, based on the subsidence predictions, following extraction of the proposed panels, then it is assessed that the modelled stream flow reduction of 0.06 – 0.25ML/day would be accommodated within the secondary porosity generated through bedding plane separation and fracturing after subsidence of the mid to upper Hawkesbury Sandstone.

The additional stored water would flow under gravity, and with a delay, discharge either to a downstream reach of Wallandoola Creek or to an adjoining downgradient catchment, such as the Cataract River.

Based on the modelled outcome that no additional significant water flow passes through the Bald Hill Claystone into the underlying Narrabeen Group or Illawarra Coal Measures following extraction of the Wongawilli West longwalls, it is assessed there would be no net loss to the water volume flowing into the Cataract River.

Stream flow modelling (WRM Water & Environment, 2012) indicates the average daily flow from Wallandoola Creek to the Cataract River is 33.0ML/day. Therefore, a 0.06 – 0.25ML/day flow reduction represents approximately 0.2 – 0.8% of the Wallandoola Creek stream flow into Cataract River.

13.4.2 Waterfall W1

Waterfall W1 is predicted to undergo less than 0.02m of subsidence and less than 1mm/m of extensional strain.

As such it is predicted to have a low risk of subsidence related cracking and a low risk of enhanced stream bed throughflow.

13.4.3 Rock Bars

A low potential risk to the integrity of rock bar constrained pools could be present in the area that may potentially undergo 6mm/m of tensile strain to the south of WW-A3-LW3 and LW4.

It should be noted however that the pool holding capacity in this reach is adversely affected by previous subsidence associated with the Bulli seam longwalls, with the pool depths and duration being dependent upon rainfall and runoff in the catchment, as the WC4 pool has been observed to dry out in low flow periods.

13.4.4 Tributaries

The first and second order tributaries which overly the proposed 20mm subsidence zone are at risk of subsidence related stream bed cracking, enhancement of stream bed underflow, discharge of ferruginous springs and reduced stream water quality at their confluence with Wallandoola Creek.

It is not anticipated, however, that the total volume of water entering Wallandoola Creek will be adversely affected.

13.4.5 Upland Swamp Outflow

A detailed significance and impact assessment of the Wallandoola Creek swamps is contained in (Biosis 2012).

The headwater swamps overlying the proposed Wonga West subsidence area have the potential to undergo subsidence related bedrock cracking. In particular, the headwater swamp of the Wcus4 complex, which overlies WW-A3-LW2, is anticipated to be at moderate risk of adverse subsidence related effects, while Wcus11 also over WW-A3-LW2 is anticipated to be at a low risk of environmental consequences (Biosis 2012).

The valley fill swamp along Wallandoola Creek (Wcus7), to the south of WW-A3-LW3 and LW4 is anticipated to be at risk of adverse subsidence related effects (Biosis 2012). The valley fill swamp along Wallandoola Creek of the Wcus4 complex, to the south of WW-A3-LW2 is anticipated to be at negligible risk of adverse effects.

However it is considered that the risk of swamp drainage, reduction of discharge to downstream gullies and adverse effects on water quality are low, and that the total volume of water entering Wallandoola Creek from the headwater swamps, or from the valley fill swamps will not be observably affected.

13.4.6 Stream Water Quality

The stream reach to the south of the proposed longwalls WW-A3-LW3 and LW4 is currently affected by ferruginous precipitates.

If stream bed cracks form to the south of the proposed panels, along with diversion of stream flow through the underlying sandstone substrate, orange discolouration of the water, generation of bacterial mats along with elevation of total / filtered iron, zinc and possibly copper and aluminium could occur, along with increased opacity of the water and reduced dissolved oxygen.

Due to the minimal or lack of predicted subsidence and strains, and therefore the associated low potential for stream bed cracking and substrate through-flow, no adverse effect on stream water quality is anticipated outside of the longwall 3 and 4 stream reach.

13.5 Cataract Creek

13.5.1 Stream Flow

As a worst case scenario, the potential risk to the integrity of stream flow and connectivity in Cataract Creek could be present in the area:

- to the west of longwalls WE-A2-LW5, 6, and LW7, that may potentially undergo <0.02m of subsidence and <1mm/m of tensile strain;
- over LW8, where the creek may potentially undergo up to 0.8m of subsidence and up to 5mm/m tensile and 9.5mm/m compressive strain;
- over LW9, where the creek may potentially undergo up to 0.26m of subsidence and up to 1.3mm/m of tensile and 2 mm/m of compressive strain, and;
- over LW10, where the creek may potentially undergo up to 0.04m of subsidence and up to 1.1mm/m of tensile strain.

Valley closure of up to 100mm and upsidence of up to 60mm may occur at Wonga East (Seedsman Geotechnics, 2012).

The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements are predicted to exceed 250 mm and the creek experiences greater than negligible impact

In addition, monitoring following prolonged rain in early 2012 observed that Cataract reservoir backed up in Cataract Creek to just upstream of site CC9, which means that an approximately 100m long reach over WE-A2-LW10 and up to 300m over WE-A2-LW9 could lie underneath Cataract reservoir.

Cataract Creek has eroded into the Bald Hill Claystone above the proposed longwalls WE-A2-LW9 and WE-A2-LW10. During periods of high water, this could potentially generate recharge from the reservoir to the exposed Bulgo Sandstone, which could occur both before any mining occurred in the area, and afterwards. During lower dam water levels, recharge would still occur as baseflow recharge from Cataract Creek.

Stream reaches flowing over the Newport and Garie Formations, as well as the Bald Hill Claystone, may not experience the same degree of surface cracking as observed over the sandstone reaches, due to the enhanced ductility of the clay based lithologies.

Beneath the plateau area of the multi seam mined Bulli and Balgownie workings, between Cataract Creek and Bellambi Creek, extraction of the proposed workings is modelled to generate up to 4m of depressurisation in the upper Hawkesbury Sandstone at the end of mining Area 2 and V Mains (GeoTerra, 2012). The modelled, localised reduction is anticipated to reduce the regional phreatic surface gradient from the plateau to the creek, as well as toward Cataract reservoir, thereby potentially reducing baseline seepage volumes to the creek and dam. It is also possible that, if they exist, the location of seepage points in the stream bed may be relocated up to 4m lower in elevation in the catchment.

Based on interpreted local groundwater contours (GeoTerra, 2012) the 4m modelled reduction in the phreatic surface over the proposed workings represents a change in gradient toward Cataract reservoir from 0.0212 to 0.0196.

On the basis that there is no direct free drainage flow path to the workings, which is supported by water balance investigations and assessment of the post subsidence response in the pressure head and packer test data from GW1 and GW1A bores adjacent to the mined panel WE-A2-LW4 (GeoTerra, 2012), the water level decline is anticipated to be temporary, as the water table is anticipated to recover once the mining at Wonga East

has been completed.

Groundwater modelling predicts a 0.06ML/day reduction in stream flow in Cataract Creek at the end of mining Area 2 / V Mains, rising to 0.07ML/day after Area 4 is completed.

As there is no predicted vertical drainage connection from the stream bed to the proposed workings (Seedsman Geotechnics, 2012), and where the Bald Hill Claystone is not eroded into, or through, and with no change in its semi-confining properties following extraction of the proposed panels, it is assessed that the modelled stream flow reduction of 0.06 – 0.07ML/day would be accommodated within the secondary porosity generated through bedding plane separation and fracturing of the Hawkesbury Sandstone and upper Bulgo Sandstone.

The additional stored connate water would flow under gravity, and with a delay, discharge either to a downstream reach of Cataract Creek, Cataract River or Bellambi Creek and subsequently into Cataract Reservoir as baseflow recharge to the streams.

Based on the assessment that no free drainage to the workings is generated following extraction of the Wongawilli East longwalls, it is assessed there would be no net loss to the water volume flowing into the SCA water storage at Cataract Reservoir.

Stream flow modelling (WRM Water & Environment, 2012) indicates the average daily flow from Cataract Creek to Cataract reservoir is 11.73ML/day. Therefore, a 0.06 – 0.07ML/day flow reduction represents approximately 0.5 – 0.6% of the Cataract Creek flow into Cataract Reservoir.

13.5.2 Rock Bars

Low potential risk to the integrity of rock bar constrained pools could be present in the area adjacent to longwalls WE-A2-LW5, 6, 7 and LW10.

A potential risk to the integrity of rock bar constrained pools is present in the area overlying WE-A2-LW8 that may potentially undergo up to 5mm/m tensile and 9.5mm/m compressive strain. However, based upon the proponent’s commitment to limit subsidence impacts on the Cataract Creek, the potential for cracking can be minimised.

No rock bar constrained pools are present over WE-A2-LW9.

13.5.3 Tributaries

The first and second order tributaries which overly the proposed 20mm subsidence zone are at risk of subsidence related stream bed cracking, enhancement of stream bed underflow, discharge of ferruginous springs and reduced stream water quality at their confluence with Cataract Creek.

It is not anticipated, however, that the total volume of water entering Cataract Creek will be adversely affected.

13.5.4 Upland Swamp Outflow

A detailed significance and impact assessment of the Cataract Creek swamps is contained in (Biosis, 2012).

The headwater swamps overlying the proposed Wonga East subsidence area have the potential to undergo subsidence related bedrock cracking. In particular, Ccus1 over WE-A1-LW3 and Ccus5 over WE-A2-LW5 are identified as being at risk of negative environmental consequences; while Ccus5 and Ccus10 are identified as being at low risk of negative environmental consequences (Biosis 2012).

However, it is considered that the risk of swamp drainage, reduction of discharge to downstream gullies and adverse effects on water quality are low, and that the total volume of water entering Cataract Creek from the headwater swamps will not be observably affected.

13.5.5 Stream Water Quality

The Cataract Creek catchment upstream of CC5 is currently affected by ferruginous precipitates, however, no significant adverse effects on stream flow, pool holding capacity, water opacity or reduced dissolved oxygen are apparent from monitoring conducted to date after the previous multi seam mining.

Due to the predicted lack of stream bed cracking, no observable adverse effects on stream water quality are anticipated in Cataract Creek, upstream of Cataract Reservoir.

The Cataract Creek catchment flows over Hawkesbury Sandstone in its upper flanks, then subsequently over the clay dominated Newport and Garie Formations, Bald Hill Claystone and the upper Bulgo Sandstone in the more eroded reaches of the catchment as it drains to Cataract Reservoir as shown in **Figure 7**.

As a result, the ferruginous seeps in the upper catchment could represent the effects of enhanced interface drainage between the layered lithological sequence.

13.6 Cataract River and Bellambi Creek

13.6.1 Stream Flow

No potential risk to the integrity of stream flow and connectivity in Cataract River and Bellambi Creek is present. In particular, Crus1 over WE-A1-LW5 is identified as being at low risk of negative environmental consequences; while Crus2 and Crus3 are identified as being at negligible risk of negative environmental consequences (Biosis 2012).

Negligible stream flow effects, impacts or consequences are anticipated to occur in Cataract River or Bellambi Creek, upstream of Cataract Reservoir, due to the low to absent levels of predicted strains and subsidence.

Due to the Cataract River or Bellambi Creek not being undermined, or mined in near proximity to the streams, valley closures of less than 100mm and upsidence of less than 60mm are anticipated (Seedsman Geotechnics, 2012).

Groundwater modelling indicates there is negligible anticipated potential reduction in recharge or stream flow to the overall Cataract River and Bellambi Creek catchments as a result of the proposed Wonga East mining (Golder Associates, 2012).

13.6.2 Rock Bars

No potential risk to the integrity of rock bar constrained pools in Cataract River and Bellambi Creek is present.

13.6.3 Tributaries

The first order tributaries which overly the proposed 20mm subsidence zone are at low risk of subsidence related stream bed cracking, enhancement of stream bed underflow, discharge of ferruginous springs and reduced stream water quality at their confluence with Cataract River or Bellambi Creek.

As a result, it is anticipated that the total volume of water entering Cataract River or Bellambi Creek will be negligibly affected.

13.6.4 Upland Swamp Outflow

A detailed significance and risk assessment of the Cataract River and Bellambi Creek swamps is contained in (Biosis 2012).

The headwater swamps overlying the proposed Wonga East subsidence area have the potential to undergo subsidence related bedrock cracking.

However it is considered that the risk of swamp drainage, reduction of discharge to downstream gullies and adverse effects on water quality are low, and that the total volume of water entering Cataract River or Bellambi Creek from the headwater swamps will not be observably affected.

13.6.5 Stream Water Quality

The headwaters of the first and second order streams draining off the proposed Wonga East subsidence area have the potential to undergo subsidence related bedrock cracking.

However, it is considered that the risk of adverse steam water quality changes are low, and that the quality of water entering Cataract River or Bellambi Creek from the headwater streams will not be observably affected.

13.7 Stream Bed and Bank Stability

13.7.1 Wonga West

Due to the lack of significant predicted subsidence in Wallandoola Creek (<0.25 - 0.5m) and Lizard Creek (<0.5m), along with the highly vegetated swamps and the exposed sandstone dominated stream beds, no adverse effects on stream bed or bank stability is anticipated in the 3rd order or higher main channels.

Up to 2.5m of subsidence in the 3rd order or higher tributary of LCT1 is predicted, which could cause a reduction in stream bed and bank stability, however this reach is currently significantly affected by previous subsidence over the Bulli longwalls, and it is not anticipated there will be additional, adverse effects from extraction of the proposed Wongawilli Seam longwalls

Up to 1.9m of subsidence in the 3rd order or higher tributary of LCT2 is predicted, which could cause a reduction in stream bed and bank stability in the 3rd order reach, but not in the 4th order reach, which does not overlie the proposed workings.

13.7.2 Wonga East

Due to the lack of significant subsidence in Cataract River and Bellambi Creek (no subsidence), along with the highly vegetated swamps and the exposed sandstone dominated stream beds, no adverse effects on stream bed or bank stability is anticipated in the 3rd order or higher main channels.

As a worst case scenario, subsidence of up to 0.8m may occur in Cataract Creek over longwall WE-A2-LW8, which may make it potentially prone to stream bed and bank instability, whereas the stream bed over or adjacent to the other panels at Wonga East are not anticipated to be at risk of stream bed or bank instability. However, based on the proponent’s commitment to limit subsidence impacts through adaptive management of the mine workings, the potential for cracking in Cataract Creek can be minimised.

13.8 Gas Emissions

Dilation in the strata immediately beneath the base of a stream due to valley bulging is restricted to the shallow strata, up to 20m below the surface, and does not provide a direct conduit for the release of gases from underlying, deeper strata.

Due to the pre-existing subsidence and crack development in the overburden over Wonga East and Wonga West, emission of gases at the surface is not anticipated to be an issue of concern.

13.9 Cataract Reservoir Water Storage and Quality

No reduction to the surface water or groundwater quality contribution to Cataract Reservoir is anticipated from the Cataract Creek, Cataract River or Bellambi Creek catchments.

A 0.06 – 0.07ML/day (or 5 - 6%) reduction of flow from the Cataract Creek to Cataract Reservoir is predicted at the end of Mining Wonga East Area 2. However, this quantum is insignificant when compared to the average daily evaporation from the reservoir, and taking into account the numerical difficulties involved in using the surface water and groundwater models to estimate creek flows, groundwater seepage and inflow to the workings.

Based on the variability of input parameters used in the modelling assessments and the high degree of interpretation required, it is assessed there is a low risk of reduced water yield to Cataract Reservoir.

Surface water modelling **(Appendix A)** and groundwater modelling (GeoTerra, 2012) indicate there is a low risk for potential loss of water or change to the water holding capacity of Cataract Reservoir.

It is worth noting that the Planning Assessment Commission report for the Metropolitan Coal project indicated that;

"analyses based on standard flow measurement techniques at discrete points are not capable of providing a definitive position on the likelihood or otherwise of water loss from a catchment (ie, Woronora Reservoir at Metropolitan), nor is a definitive position provided by hydrologic modeling. However, the local and regional groundwater conditions coupled with the mine parameters would suggest that the likelihood of water being lost from the surface water system as a consequence of mining, and then by passing (Woronora Reservoir) is very low."

As the issue was not beyond reasonable doubt, the PAC recommended that a program of monitoring should be developed between the proponent and the SCA to further investigate the existence or otherwise of catchment yield impacts.

The proposed workings have been positioned at sufficient distance from the Cataract Reservoir and there are no known geological structures which could cause a mining induced hydraulic connection between the workings and the base of the reservoir.

14. POTENTIAL CUMULATIVE IMPACTS

14.1 Lizard and Wallandoola Creeks

The description of potential subsidence effects on Lizard and Wallandoola Creeks due to extraction of the Wongawilli Seam as outlined in **Section 13** includes a discussion of the potential cumulative effects on those creeks, and the reader is referred to this section for further detail.

14.1.1 Creek Bed and Bank Stability and Pool Levels

The Bulli Seam underlying both Lizard and Wallandoola creeks has been mined in the Gujarat and Cordeaux leases by longwall extraction, with up to 1.5m of subsidence.

The proposed Wongawilli Seam extraction at Wonga West will generate up to 2.5m of predicted additional subsidence in the catchments of Lizard and Wallandoola Creeks at Wonga West.

The main channel of Lizard Creek is predicted to undergo up to an additional 0.25m of subsidence, whilst the main channel of Wallandoola Creek is predicted to undergo up to an additional 0.5m of subsidence.

Outside of the cumulative effect of previous Bulli workings subsidence, combined with the potential predicted subsidence within the overall catchments, no site specific, cumulative effect on the creek bed and bank stability or pool levels is anticipated due to the additional subsidence (at each particular feature).

14.1.2 Tributary, Upland Swamp and Main Channel Stream Flow Connectivity

A potential cumulative effect of subsidence on the stream flow from first and second order streams, which may or may not also contain upland swamps is possible if the subsurface transfer of the tributary / swamp water outflows does not report back into the lower reach of the tributary, before it discharges into the main third order channel of Lizard or Wallandoola Creek.

In our experience, although the upper tributaries / swamps can transfer overland flow to subsurface throughflow in subsided areas, they discharge the stream flow back into the third order flow system of the main creeks at or near their confluence with the main stream, so negligible volumes of tributary / swamp outflow is “lost” to the system.

Significant ferruginous precipitates have been observed in tributaries LCT1 and LCT2 over previously mined areas, which discharge into the main stream of Lizard Creek, however no definitive assessment can be made as to whether they are due to subsidence, or not, as no pre-mining surveys are available.

14.1.3 Stream Water Quality

Where the re-emergent tributary / swamp outflow over subsidence areas re-enters the main stream, ferruginous precipitates, along with lower dissolved oxygen, localised and marginally more acidic pH and slightly elevated salinity seeps can be observed at the point of entry.

However, monitoring conducted in the NRE1 lease area indicates the adverse effects only last for a few tens of metres and that the water quality downstream of the “mixing” zone is only negligibly affected, if at all.

14.2 Cataract Creek

The description of potential subsidence effects on Cataract Creek due to extraction of the Wongawilli Seam as outlined in **Section 13** includes a discussion of the potential cumulative effects on those creeks, and the reader is referred to this section for further detail.

14.2.1 Creek Bed and Bank Stability and Pool Levels

The Bulli, Balgownie and Wongawilli workings, which underly the Cataract Creek catchment have been mined in the Gujarat and Cordeaux leases by longwall extraction with up to 1.4m of subsidence.

The proposed Wongawilli Seam extraction at Wonga East will generate up to 1.2m of predicted additional subsidence in the Cataract Creek catchment.

As a worst case scenario, the main channel of Cataract Creek is predicted to undergo up to an additional 0.8m of subsidence over longwall WE-A2-LW8 (Seedsman Geotechnics, 2012).

Outside of the cumulative effect of previous Bulli, Balgownie and Wongawilli workings subsidence, combined with the potential predicted subsidence within the overall catchments, no site specific, cumulative effect on the creek bed and bank stability or pool levels is anticipated due to the additional subsidence (at each particular feature).

To date, with three seams being mined in the Cataract Creek catchment, there has been no observable adverse effects on stream bed and bank stability or pool levels.

14.2.2 Tributary, Upland Swamp and Main Channel Stream Flow Connectivity

A potential cumulative effect of subsidence on the stream flow from first and second order streams, which may or may not also contain upland swamps is possible if the subsurface transfer of the tributary / swamp water outflows does not report back into the lower reach of the tributary, before it discharges into the main third order channel of Cataract Creek.

In our experience, although the upper tributaries / swamps can transfer overland flow to subsurface throughflow in subsided areas, they discharge the stream flow back into the third order flow system of the main creeks at or near their confluence with the main stream, so negligible volumes of tributary / swamp outflow is “lost” to the system.

To date, with three seams being mined in the Cataract Creek catchment, there has been no observable adverse effects on tributary, upland swamp and the main channel stream flow connectivity.

14.2.3 Stream Water Quality

Where the re-emergent tributary / swamp outflow over subsidence areas re-enters the main stream, ferruginous precipitates, along with lower dissolved oxygen, slightly more acidic pH and slightly more saline seeps can be observed at the point of entry.

However, monitoring conducted in the NRE1 lease area indicate that the adverse effects only last for a few tens of metres and that the water quality downstream of the “mixing” zone is only negligibly affected, if at all.

Significant ferruginous precipitates have been observed in tributary CT1 over previously mined areas, which discharge into the main stream of Cataract Creek, however no definitive assessment can be made as to whether they are due to subsidence, or not, as no pre mining surveys are available.

14.3 Wonga West Interaction with the BHPB Cordeaux Workings

14.3.1 Stream Flow and Connectivity

Due to a lack of pre and post extraction data, the impacts, effects and consequences to stream flow and stream connectivity from the Cordeaux workings, located upstream of the proposed Area 3 and Area 4 mining domains in both the Lizard and Wallandoola Creek catchments, cannot be quantified.

However, observations for this study indicate that the stream flow discharging from the Cordeaux lease area is essentially perennial and contains ferruginous seepages.

No additional workings are currently proposed in the Cordeaux lease or in the BHPBIC lease between the proposed Gujarat workings and the Cataract River, and therefore there are no anticipated additional cumulative effects on stream flow or stream connectivity.

14.3.2 Pool Heights

The Cordeaux lease area located upstream of the Gujarat lease in the Lizard and Wallandoola Creek catchments at Wonga West is predominantly composed of valley fill upland swamps, and as such, any pools which are present are predominantly shallow and of limited extent.

The proposed mining at Wonga West Area 3 and 4 is not anticipated to generate sufficient subsidence, strains or tilts to adversely affect the pools in the Cordeaux lease.

No mining is currently proposed between the Gujarat lease and the Cataract River junction at Wonga West.

14.3.3 Stream Water Quality

The water quality discharging from the Cordeaux lease has a median pH of 6.02 and EC of 124µS/cm in Wallandoola Creek and median pH and EC of 5.44 and 110µS/cm respectively.

Parameters which exceed the ANZECC 2000 water quality criteria discharging from the Cordeaux lease, as monitored at Sites LC2 and WC2, can include:

- copper (up to 0.004mg/L in Lizard and Wallandoola Creeks);
- zinc (up to 0.054mg/L in Lizard & 0.026mg/L in Wallandoola Ck);
- aluminium (up to 0.25mg/L in Lizard & 0.05mg/L in Wallandoola Ck);
- total nitrogen (up to 2.60mg/L in Lizard and 2.5mg/L in Wallandoola Ck);
- total phosphorous (up to 4.2mg/L in Lizard and 0.2mg/L in Wallandoola Ck).

As there is no new mining planned in the Cordeaux lease, and as the Cordeaux catchments are interpreted to have attained a "steady state" (GeoTerra, 2012), there are no new anticipated cumulative impacts on the water quality within and discharging as a result of the proposed Wongawilli Seam extraction.

14.4 Wonga East Interaction with BHPBIC Bulli and Cordeaux Workings

14.4.1 Bellambi Creek

The Bulli Seam underlying Bellambi Creek has been mined by the BHPBIC Bulli mine workings by bord and pillar as well as pillar extraction methods.

14.4.2 Cataract River

The Cordeaux mine has extracted the Bulli Seam with both bord and pillar, as well as longwall mining methods in the Cataract River catchment.

Outside of the pre-existing regional cumulative groundwater depressurisation of the overburden, there are no anticipated cumulative impacts within Bellambi Creek due to the interaction of the BHPBIC Bulli mine workings and the proposed Wongawilli Seam extraction, as the predicted subsidence effects are predominantly contained within the Cataract Creek catchment.

Outside of the pre-existing regional cumulative groundwater depressurisation of the overburden, there are no anticipated cumulative impacts within Cataract River due to the interaction of the BHPBIC Cordeaux workings and the proposed Wongawilli Seam extraction, as the predicted subsidence effects are predominantly contained within the Cataract Creek catchment.

14.5 Potential Vertical and Horizontal Connective Fracturing

The potential cumulative effects of vertical and horizontal, connective fracturing and overburden depressurisation is discussed in (GeoTerra, 2012).

15. MONITORING AND MANAGEMENT

A catchment based Water Management Plan incorporating detailed provisions for surface water and groundwater, monitoring, analysis, data collection, interpretation, reporting, management and rehabilitation should be prepared once approval for the project is achieved.

The monitoring and data interpretation should be best practice for the detection of surface water and groundwater impacts of subsidence within stream beds and the broader sub-catchments, as well as in the shallow and deeper (regional) groundwater systems.

A key aspect of the Plan should deal with the early detection and assessment of subsidence (or uplift) effects within the subject streams and groundwater systems using appropriately sampled and analysed geochemical and physical data to provide early indication of any subsidence related surface water or groundwater effects.

Measurement and/or monitoring of compliance with performance measures and performance indicators will be undertaken using generally accepted methods that are appropriate to the environment and circumstances in which the feature or characteristic is located. These methods will be fully described in the relevant management plans.

15.1 Management Plans and Trigger Action Response Plans

As subsidence could potentially affect the Study Area streams, the following components within monitoring, management and Trigger Action Response Plans (TARP) should be prepared to manage the risks that cover the following issues;

- stream and tributary flow;
- rock bar constrained and pool water holding capacity;
- stream water quality
- waterfalls, and;
- upland swamps.

15.2 Stream Pools and Flow

Daily automated monitoring of selected pool water depths upstream, within and downstream of the Study Area should be conducted and compared to rainfall in the local area. The monitoring sites would be sited upstream, within and downstream of the proposed 20mm subsidence area, at locations that are permanently wet.

Where the stream bed status, current flow diversions and site logistics allow, the stream monitoring locations should also be monitored for volumetric flow.

Monitoring should assess the inputs from catchment runoff and any flow variations within the Study Area before, during and after the extraction period, particularly for low flows.

The collected data should review any observable changes that develop, and, subsequently develop a plan to manage any adverse issues, if appropriate.

The chemical characteristics and concentrations of stream water quality parameters such as pH, temperature, dissolved oxygen, salinity (EC) and major ions can also be used to assess the flow mechanisms within a major stream.

Use of portable / dismountable flow gauging equipment that does not adversely affect the stream ecology may be required to obtain quantitative flow data for hydrologic

assessment.

Baseflow separation analysis is not a suitable method in the Study Area as the method can only be used;

- in ‘gaining’ streams (the upper tributaries and main channels of the Study Area streams are ‘losing’ streams);
- as the swamps also contribute to delayed discharge to the main streams from their storages, and it can only be used to;
- characterise the groundwater discharge regime at the stream gauging site,which provides information on the temporal changes but not the spatial distribution of groundwater inputs along a stream.

15.3 Stream Water Quality

Water quality monitoring should be conducted in Wallandoola, Lizard and Cataract Creeks as well as the Cataract River, upstream of Cataract reservoir, upstream, within and downstream of the Study Area before, during and after the period of extraction.

Water quality related field studies should concentrate on regular visits to main channel sites that would be monitored for identifiable inputs from catchment runoff and all key water quality parameter variations for the duration of mining and for an appropriate period following mining.

Monitoring should be conducted for the following parameters:

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

Stream water level, or spot flow monitoring and sampling should be conducted, where logistically feasible, at all locations on the same day. All samples should be collected in appropriately cleaned and prepared equipment, stored in appropriately cleaned and rinsed sample containers, then transported and analysed according to ANZECC 2000 standards, with 0.45μm filtering and nitric acid preservation to less than pH2 for metals samples.

Trigger values for selected pollutants of concern should be set within the context of a Trigger Action Response Plan (TARP), and where the values are exceeded, the cause and effect of the exceedance should be investigated and a management plan developed if the cause is directly related to mining.

The TARP system provides a simple and transparent snapshot of the monitoring of environmental performance and where required the implementation of management and/or contingency measures.

These should be reviewed following collection of additional baseline data, and additional water quality monitoring sites may need to be established as the monitoring program progresses.

The TARP should illustrate how the various predicted subsidence impacts, monitoring components, performance measures and responsibilities are structured to achieve compliance with the relevant statutory requirements and the framework for management and contingency actions.

15.4 Stream Erosion and Destabilisation

Subsidence may induce minor bed or bank erosion over the proposed panels, particularly in the headward and downstream sections of any subsidence troughs, as well as over the chain pillars.

As the creek banks are well vegetated, no significant change is anticipated and it is not envisaged that stream bank remediation will be required.

Any changes to the current state will be visually monitored after significant stream flow events, and if adverse subsidence / uplift effects occur, a specific management and rehabilitation plan should be developed for the affected areas.

15.4.1 Bedload Movement

If erosion occurs in a stream, it may cause a minor increase in potential bedload movement in and downstream of the subsidence area, which will be visually monitored during and after significant flow events.

Significant bedload movement is not anticipated and therefore stream bed or bank management and rehabilitation is not anticipated to be required.

15.4.2 Stream Gradient

It is not anticipated that significant observable change will occur due to subsidence and that stream gradient rehabilitation measures will not be required in the main stream channels.

15.4.3 Riparian Vegetation

Vegetation in the stream and banks will be visually monitored over the proposed mining area before and after any stream is undermined, particularly after significant flow events.

As no adverse effect on the riparian vegetation is anticipated, no vegetation rehabilitation measures are anticipated.

15.4.4 Waterfalls

The integrity and overland flow of the waterfalls should be monitored, along with specific subsidence measurements to indicate if any adverse effects on the waterfalls may have the potential to more than “negligibly” affect them, and necessitate “adaptive” management” of the planned mining.

15.4.5 Rock Bars

The integrity and pool holding capacity of rockbars in the potential subsidence zone should be monitored, along with specific subsidence measurements to indicate if any adverse effects may have the potential to more than “negligibly” affect them, and necessitate “adaptive” management” of the planned mining.

15.5 Mine Inflows

Mine inflows should be monitored through measurement of all water pumped into and out of the NRE No. 1 workings where underground logistics are suitable.

15.6 Rainfall

Rainfall should be monitored daily at the mine’s and the nearest Bureau of Meteorology weather station, as well as a dedicated rain station within the catchment for the duration of mining.

The quantity and variability of stream flow in Wallandoola, Lizard and Cataract Creeks will be monitored by data loggers to assess the rainfall / runoff relationship, with photography used to monitor flow conditions in both creeks as well as their unnamed tributaries.

15.7 Reporting

An end of panel report should be prepared for the mined panel, which should summarise all monitoring conducted over the period. The report will outline any changes in the surface water or groundwater system over the mined out areas.

If required, a meeting will be convened with the OEH and / or NOW and the SCA at the mine office to discuss requirements for remediation and ongoing monitoring.

All monitoring and management activities will be reported in the Annual Environmental Management Report (AEMR) in subsequent years.

15.8 Ongoing Monitoring

All results should be reviewed one year after each panel has been completed and an updated ongoing monitoring and remediation program will be developed in association with the OEH, NOW and the SCA.

15.9 Quality Assurance and Control

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

Field sample collection, storage, despatch, laboratory analysis, interpretation and reporting will be conducted according to ANZECC 2000 requirements.

15.10 Potential Subsidence Impact Contingency Measures

If monitoring indicates there has been significant hydrologic or aquatic ecotoxic effect then management and mitigation measures may be required.

Management measures may involve alterations to the area of extraction or modification to the orientation and/or disposition of future mining.

In the event a subsidence impact water resource or watercourse performance measure is considered to have been exceeded or is likely to be exceeded, Gujarat should implement the following Contingency Plan:

- the likely exceedance of the water resource or watercourse performance measure will be reported to the Technical Services Manager and/or the Environment and Community Manager within 24 hours of assessment completion;
- the Technical Services Manager or the Environment and Community Manager will report the likely exceedance to the General Manager as soon as practicable after becoming aware of the exceedance, and;
- the mine will report the likely exceedance of the water resource or watercourse performance measure to the DoP, SCA and DECCW as soon as practicable after they become aware of the exceedance.

The mine should identify an appropriate course of action with respect to the identified impact(s) in consultation with specialists and relevant agencies, as necessary. For example:

- proposed contingency measures;
- a program to review the effectiveness of the contingency measures; and
- consideration of adaptive management under circumstances where a water resource or watercourse performance measure has been exceeded.

Contingency measures should be developed in consideration of the specific circumstances of the exceedance and the assessment of environmental consequences.

Gujarat should submit the proposed course of action and a program to review the effectiveness of the contingency measures to the DoP for approval and should implement the approved course of action to the satisfaction of the DoP. Potential contingency measures for an exceedance of the water resource or watercourse performance measures could include:

- additional monitoring that increases the monitoring frequency or additional sampling to inform the proposed contingency measures;
- implementation of stream remediation measures to reduce the extent of fracturing;
- implementation of revegetation measures to remediate impacts of gas releases on riparian vegetation;
- provision of a suitable offset(s) to compensate for the reduction in the quantity of water resources reaching Cataract Reservoir or Cataract River, and;
- implementation of adaptive management measures, such as reducing the thickness of the coal seam extracted, narrowing of the longwall panels and/or increasing the setback of the longwalls from the affected area.

Ongoing monitoring should be required to assess whether any subsidence related physical and / or chemical changes to stream flows, stream or swamp water quality and stream or swamp integrity occur, as well as to validate predicted impacts on swamp groundwater levels, mine seepage and swamp groundwater water quality.

All relevant rehabilitation actions will be derived in association with the DoP, OEH, NOW and SCA and will be acted upon as appropriate.

At the end of the subject mining, assessment of the field and laboratory data will be completed to determine whether any unanticipated trends are occurring, and a review of measures will be required to address the issue if a subsidence / uplift related trend is apparent.

15.11 Adaptive Management

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

The adaptive management process is based on the premise that avoidance of adverse impacts is preferential to rehabilitation of adverse consequences to a stream.

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

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

Longwall WE-A2-LW5 is proposed to be mined under a separate approval application (MP 10_0046-MOD 1) which is currently with the DoPI. Longwall WE-A2-LW5 does not overlie the main channel or significant tributaries of Cataract Creek. As such, it will provide a good "baseline" monitoring opportunity to assess the effect of subsidence on fracture propogation and development through the overburden, as well as the;

- height of fracturing,
- development of cracking at surface,
- changes to an upland swamp perched water system in Crus1 and Ccus4, and;
- water quality in Cataract Creek and any mine inflow changes.

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

Adaptive management measures that could be used include;

- monitoring of the predicted and observed subsidence impacts, effects and consequences over the Wonga East workings. Using the data base, update subsidence predictions for the Wonga West panels and if required, modify the mining geometry for Wonga West;
- reducing the thickness of coal seam extracted if subsidence monitoring indicates a change is required;
- narrowing the longwall panels if subsidence monitoring indicates a change is required, or;
- increasing the longwall setback from a stream to limit the subsidence effects, impacts and consequences, or
- changing the start / finish lines of subsequent longwalls in order to manage subsidence impacts

In adaptive management the goal to be achieved is set so there is certainty of the outcome and the conditions requiring adaptive management do not lack certainty. The measures should establish a regime which would permit changes within defined parameters, to indicate how the outcome is to be achieved.

The Bulli PAC outlined that adaptive management measures may be required if the "Precautionary Principle" is triggered when two pre conditions exist. The conditions are that;

- a threat of serious or irreversible environmental damage is present which can be direct or indirect and where incremental or cumulative impacts are included, and;
- if there is scientific uncertainty as to the potential environmental damage

The proposed adaptive management measures will need to assess the:

- existence of the threat of serious or irreversible harm;
- degree of scientific certainty;
- spatial scale of the threat;
- magnitude of possible impacts;
- seriousness or irreversibility of environmental damage
- perceived value of the threatened environment;
- temporal scale, including persistence;
- complexity and connectivity of the possible impacts;
- manageability of impacts, through the availability and acceptability of the proposed measures (assess what is possible in principle, economically and within a reasonable timeframe);
- level of public concern and the basis for that concern;
- scientific or other evidentiary basis for that concern;
- reversibility of the impacts including management or rehabilitation feasibility
- level of precaution required;
- cost of prevention, and the;

- proportionality of the solution

The key elements of an adaptive managemnet plan should include:

- monitoring of impacts based on agreed indicators;
- conducting research to reduce key uncertainties;
- adjustment of the activity based on the results and;
- an efficient and effective compliance system.

A step-wise adaptive management approach to managing the threat should involve an iterative approach involving testing of achievement of defined goals. Through feedback to the management process, the management procedures should be changed in steps until monitoring shows the desired outcome is obtained and that there is statistical confidence in the outcome.

16. POTENTIAL REHABILITATION

If any adverse impacts occur as a result of subsidence on the streams over the proposed Wonga East and Wonga West mining domains, Gujarat should undertake appropriate remediation as agreed to by the SCA, OEH and NOW.

A Stream Rehabilitation Management Plan and Remediation Register should be used to manage implementation of remediation measures in accordance with approval from the SCA, OEH and NOW.

A potential subsidence impact performance criteria could be that negligible environmental consequences, including negligible;

- diversion of flow,
- change in the natural pool drainage behaviour,
- iron staining,
- gas release and;
- increase in water cloudiness

will occur over at least 80% of the length of the main channel of Lizard, Wallandoola and Cataract Creeks that are subject to greater than 20mm of subsidence.

Stream remediation activities should be conducted where monitoring results indicate the subsidence impact performance measure where surface flow and / or pool holding capacity of a pool has been adversely affected due to subsidence, except where the change is due to climatic conditions, has been exceeded. Exceedance of the subsidence impact performance measure will be assessed as a component of the overall Water Management Plan for the proposed longwalls.

Remediation should commence when the rate of valley closure (as measured monthly by ridge to ridge survey points) is less than 20 mm/month following mining of the subsequent longwall.

More than one remedial effort may be required at a pool or rock bar as ongoing incremental impacts may result in association with successive longwalls. In addition, the timing of remediation activities will also be influenced by practical considerations, as entry to the creek bed will require surface flow over a particular rock bar to be absent.

Fracture characterisation should be conducted to measure the depth and lateral extent of the sub-surface fracture network at each location requiring remediation. These could

include the drilling of cored holes to a depth of approximately 20m to:

- determine the depth of fracturing;
- measure the relative volume of fine versus large void spaces;
- determine the horizontal connectivity between fractures; and
- use of a borehole calliper to identify the location of individual fractures.

The principal management measure that could be used to restore surface flow and pool holding capacity is polyurethane (PUR) grout injection into the fracture network which should reduce the permeability of the rock by filling voids and reducing subsurface flow diversion paths.

Grouting products that could be used include CarboPur (WFA and WF grades), which are products used for consolidation, stabilisation and/or sealing of strata. A grout curtain could be constructed across a rock bar by drilling a line of holes at regular intervals (approximately 2m) and progressively injecting grout down to 20m below surface.

The design of any remediation and rehabilitation strategy must be cognisent of the overall environmental impacts and as such be developed on a case specific basis.

Direct access to a particular section of a stream will determine the remediation necessary and the extent to which it is implemented.

Other potential remediation techniques include:

- Hand grouting - sealing cracks exposed at surface using hand applicators;
- Shallow pattern grouting - drilling shallow holes with small hand held equipment and low pressure grout injection with a portable pump;
- Deep pattern or curtain grouting - drilling deeper holes with air hammer or reverse circulation drilling rigs and higher pressure grouting techniques, and;
- Deep angle hole cement grouting - remote directional drilling used to access inaccessible sites using the same grouting methods as deep pattern/curtain grouting methods.

The range of techniques will be considered in the design of any stream remediation program. Any technique used will need to be approved by the SCA, OEH, NOW, NSW I&I (Fisheries) and the DoP.

Where remediation activities involve drilling and grout injection into sub-surface fractures, associated activities should involve procedures for the mobilisation, placement and operation of equipment as well as implementation of a necessary environmental management measures. Drilling equipment could include a drill rig and rods, geofabric straw bale filters, tape barriers at access points, air compressors, hoses, compressed air pumps, a Dingo and a drill rig 'A' frame to enable assembly/disassembly for heli lifting.

Injection equipment could include a pneumatic PUR injection pump, diesel-operated compressor, high capacity pressure delivery hoses, static mixing unit/injection gun assembly, injection tubes and packers and a temporary shelter for personnel and equipment.

A range of environmental management measures should be described in the Stream Rehabilitation Management Plan and should be implemented during remediation works. Measures could include:

- management of soil and vegetation disturbance;
- erosion and sediment controls to minimise the potential for downstream effects;
- stream flow diversion and reduction of sub-surface flows during application of grout;
- drill cuttings containment and disposal;
- fuel management;
- management of grouting products and injection operations;
- waste management; and
- transport and handling of equipment and materials.

16.1 Baseflow Offsets

If the agreed performance measures are exceeded and the DRE Director-General determines that it is not reasonable or feasible to remediate the impact or environmental consequence, or remediation measures implemented by Gujarat have failed to satisfactorily remediate the impact or environmental consequence, then Gujarat will provide a suitable baseflow offset to compensate for the impact or environmental consequence, to the satisfaction of the Director-General.

Any baseflow offset will be proportional with the significance of the impact or environmental consequence.

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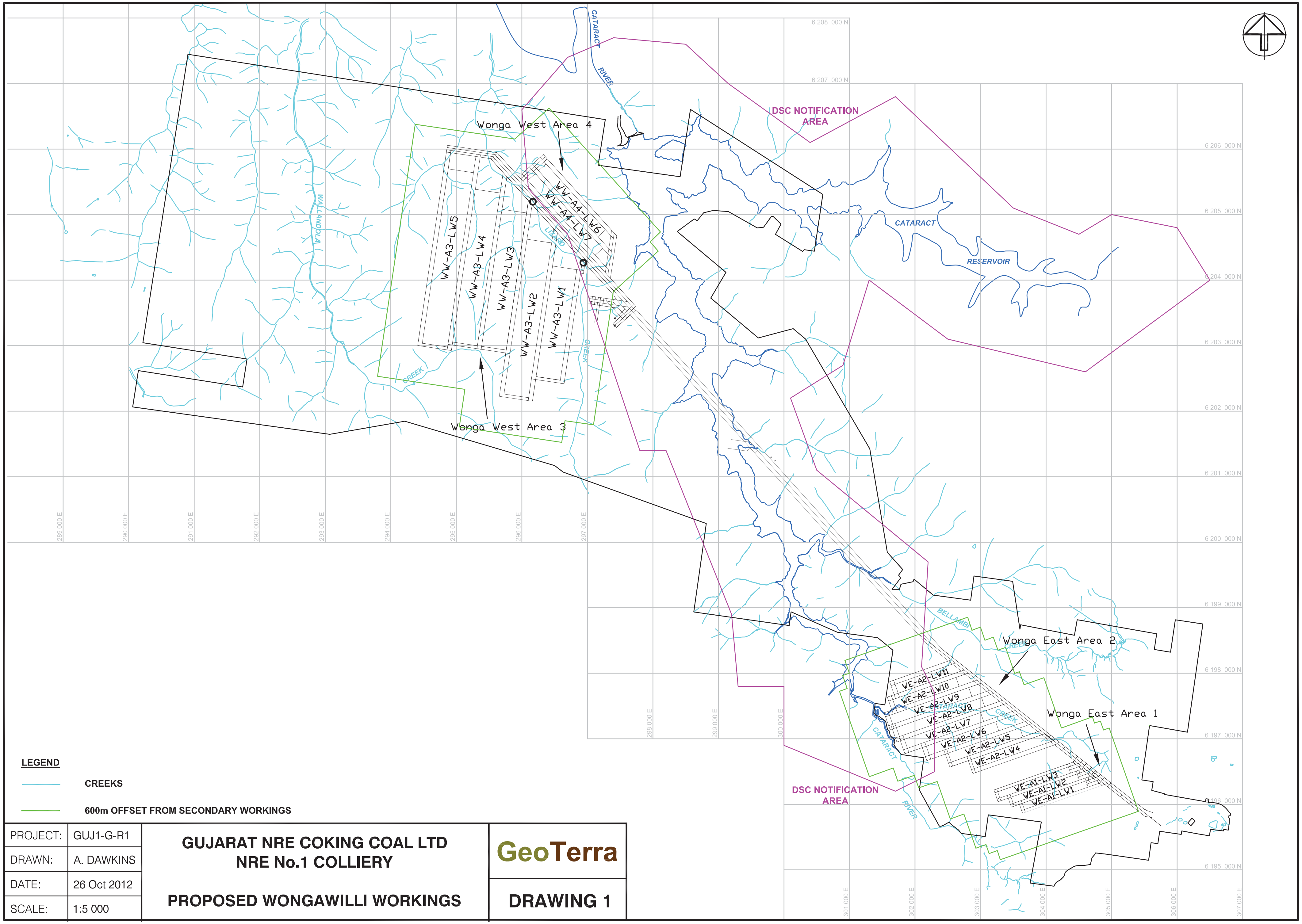

LEGEND

CREEKS

600m OFFSET FROM SECONDARY WORKINGS

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DATE:	26 Oct 2012			
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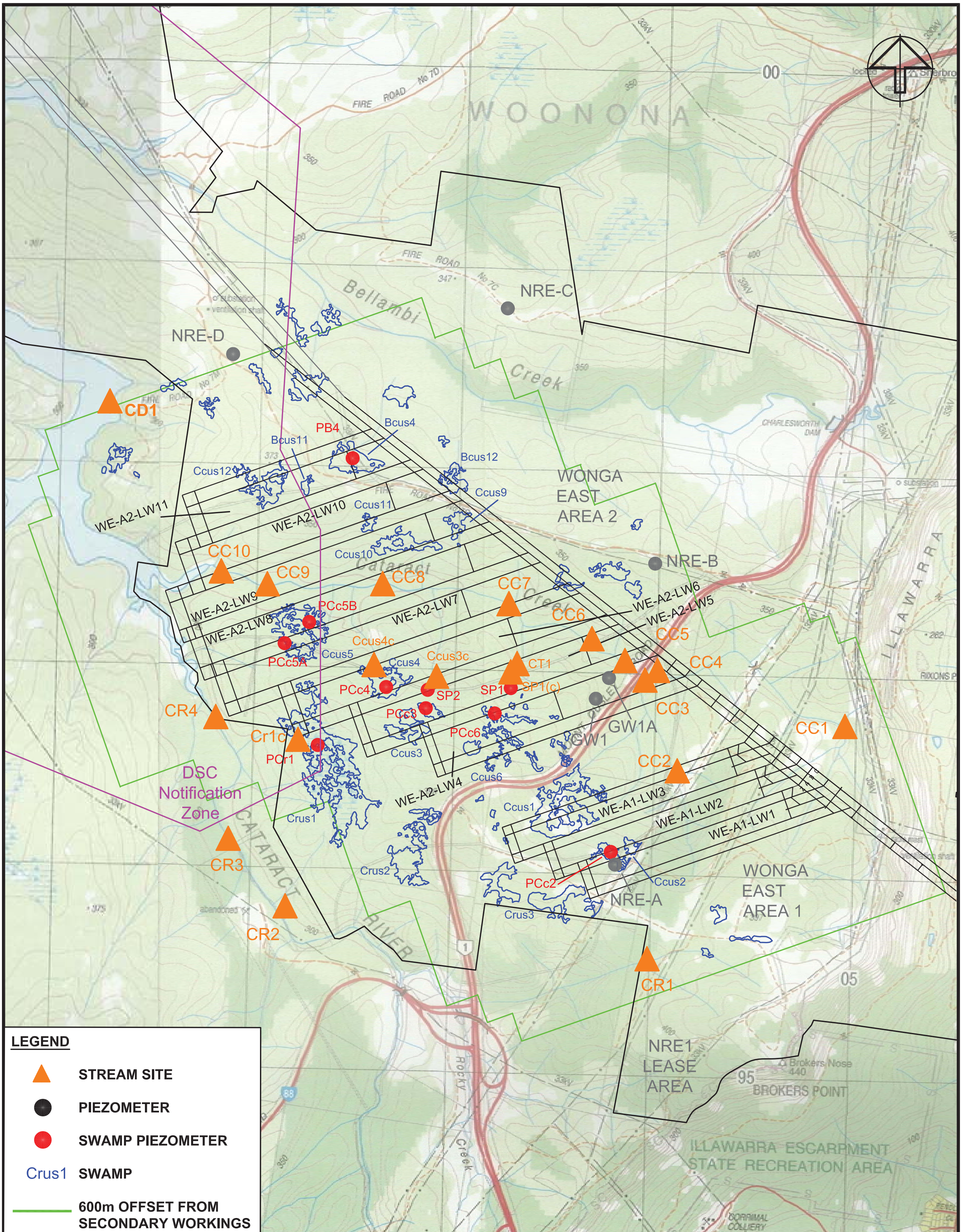

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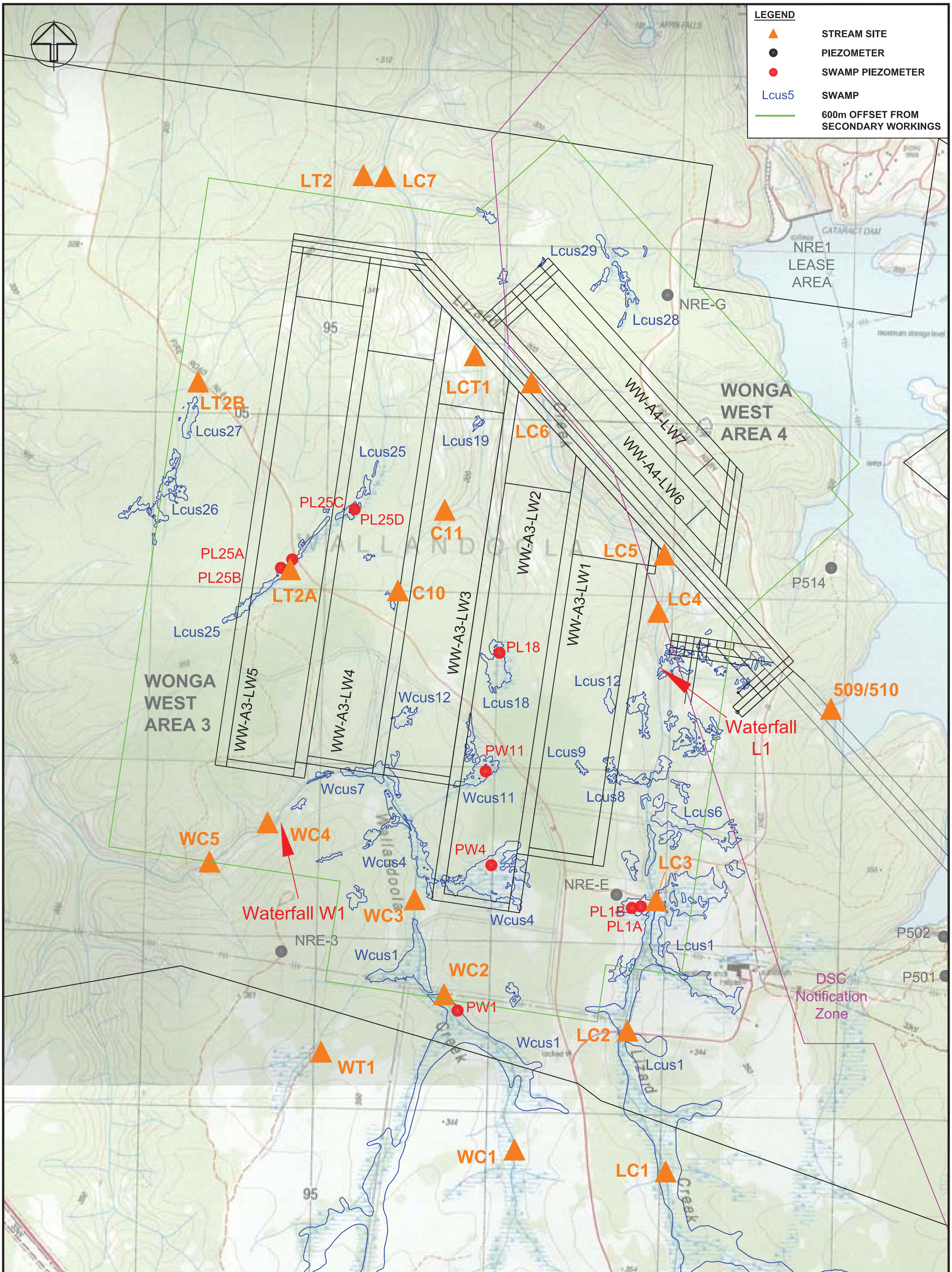
DRAWN:	A. DAWKINS	
DATE:	26 Oct 2012	**Proposed Wonga East Workings and Monitoring Locations**
SCALE:	1:250	

GeoTerra

DRAWING 2



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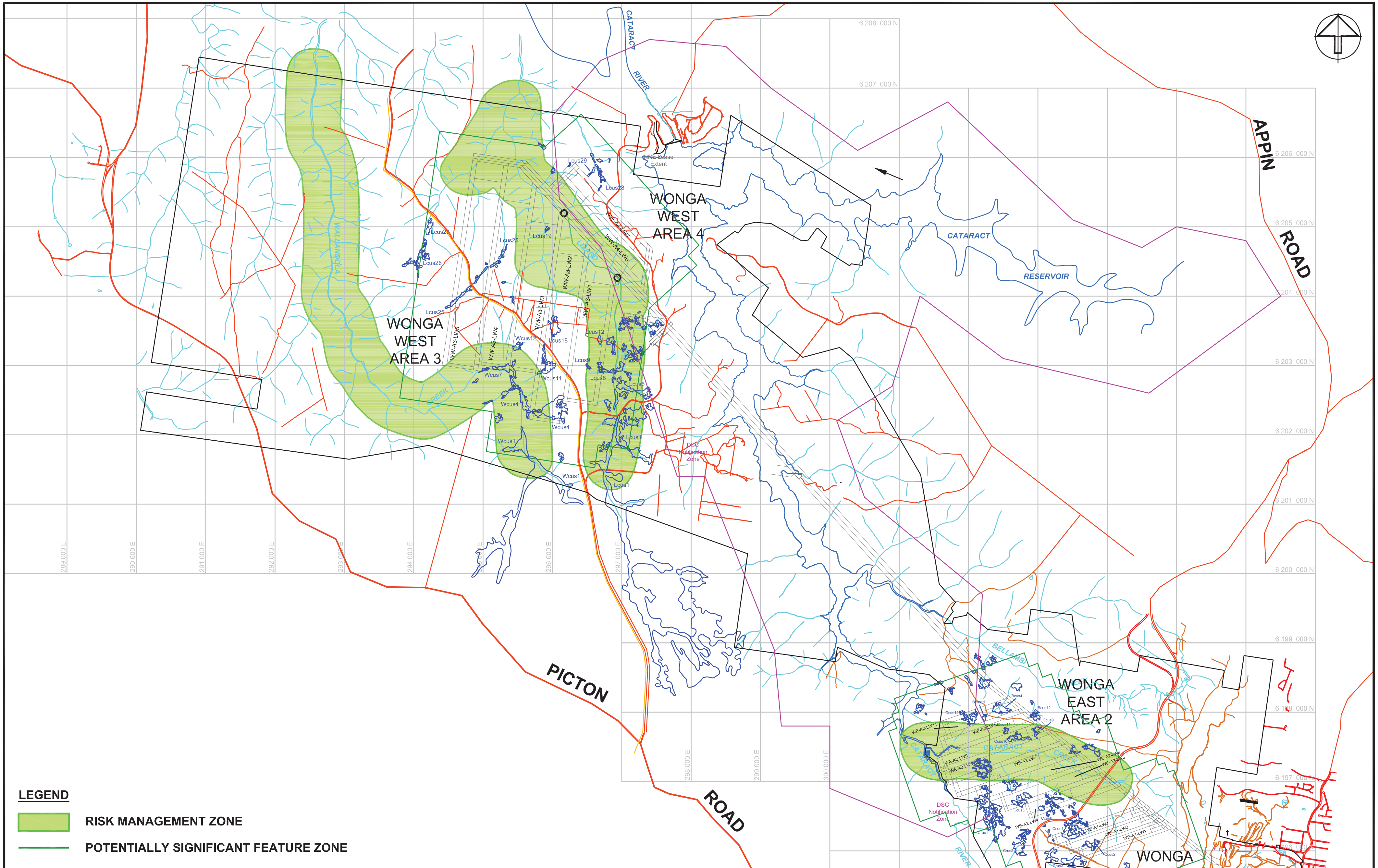


LEGEND

RISK MANAGEMENT ZONE

POTENTIALLY SIGNIFICANT FEATURE ZONE

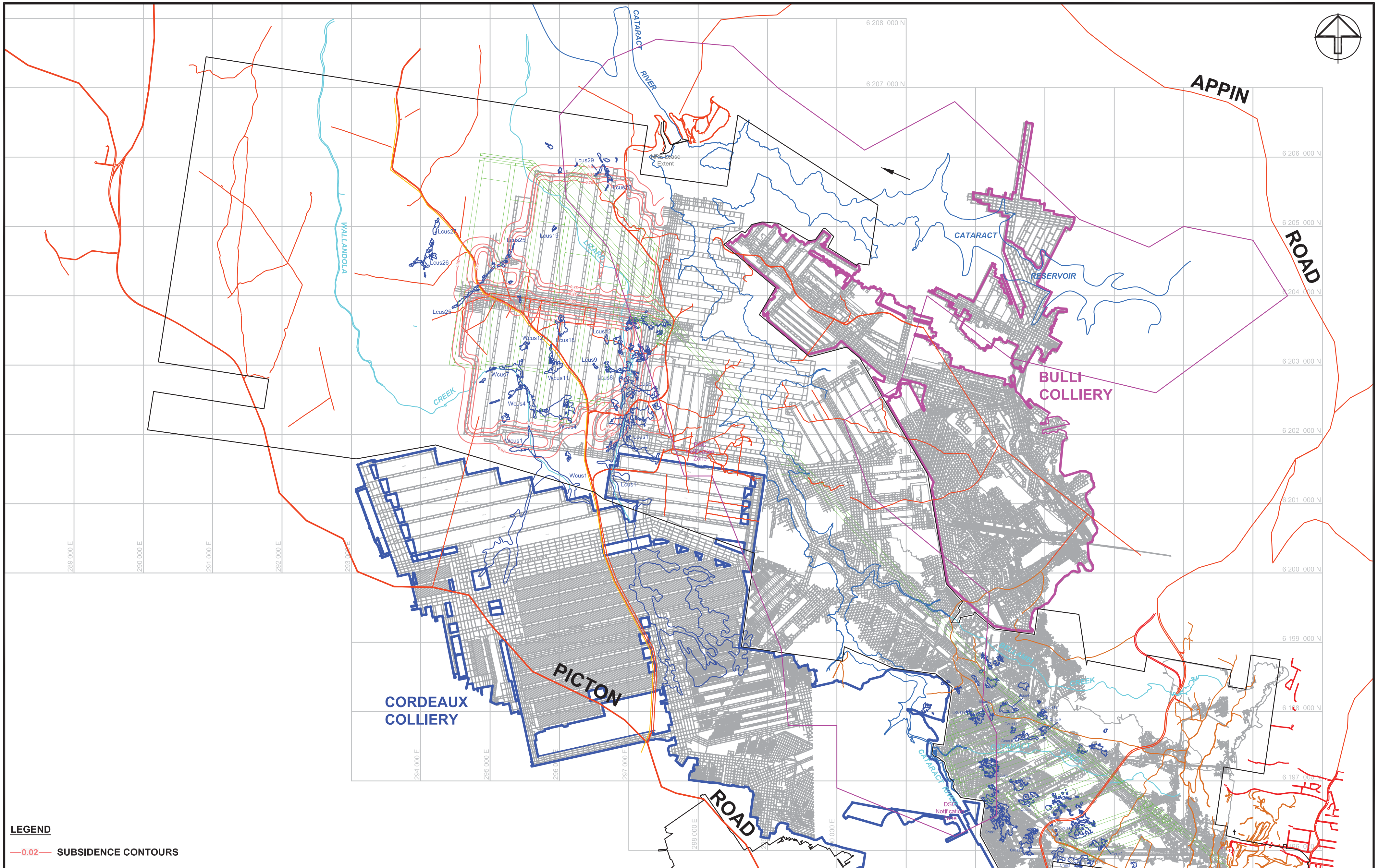
PROJECT:	GUJ1-S-R1
DRAWN:	A. DAWKINS
DATE:	23 NOV 2012
SCALE:	1:5 000

GUJARAT NRE COKING COAL LTD
NRE No.1 COLLIERY

RISK MANAGEMENT AND POTENTIALLY SIGNIFICANT FEATURE ZONES

GeoTerra

DRAWING 4



LEGEND

—0.02— SUBSIDENCE CONTOURS

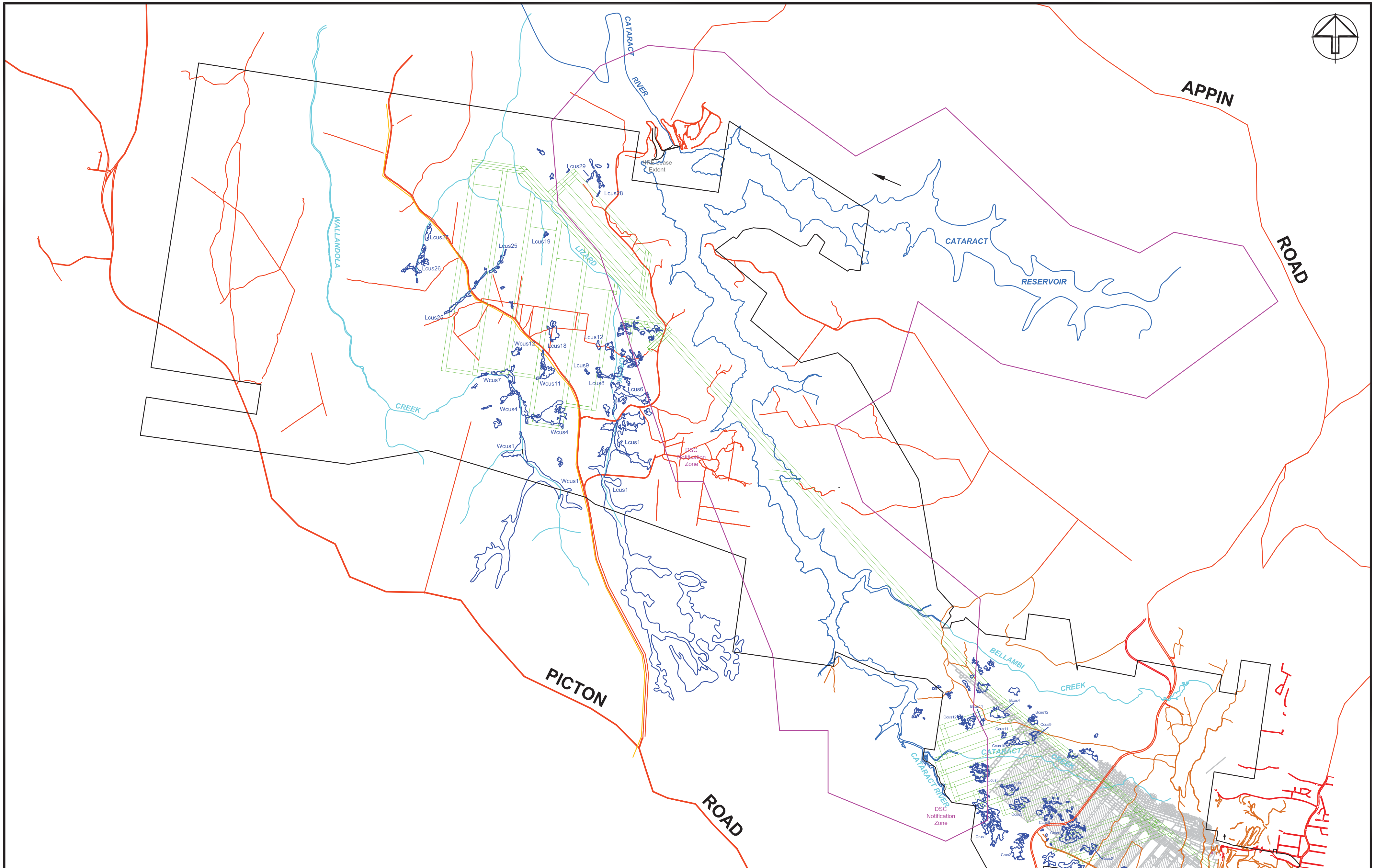
PROJECT:	GUJ1-S-R1
DRAWN:	A. DAWKINS
DATE:	19 Nov 2010
SCALE:	1:5 000

GUJARAT NRE COKING COAL LTD
NRE No.1 COLLIERY

OLD BULLI SEAM WORKINGS
AND SUBSIDENCE CONTOURS

GeoTerra

DRAWING 5



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DRAWN:	A. DAWKINS		
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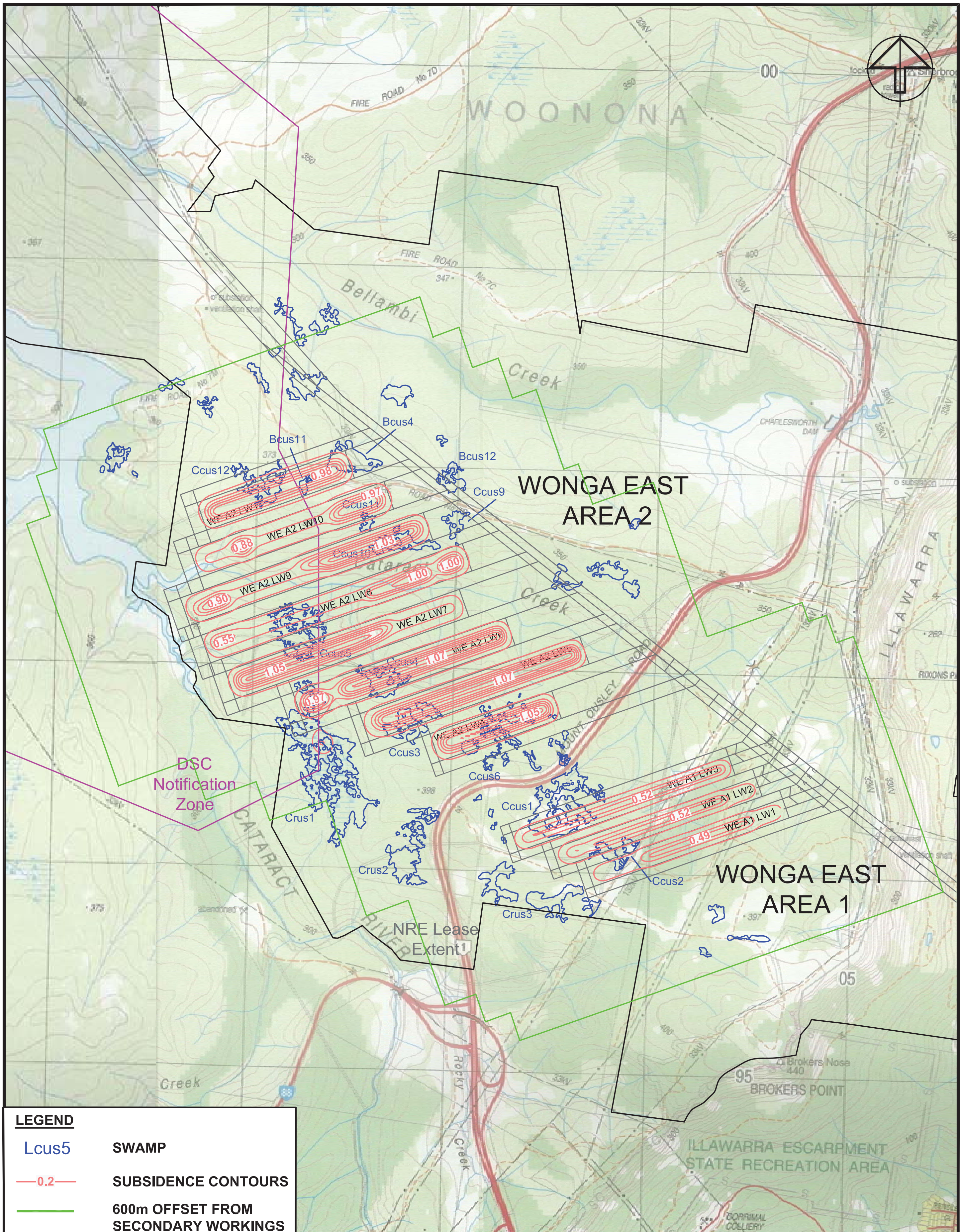

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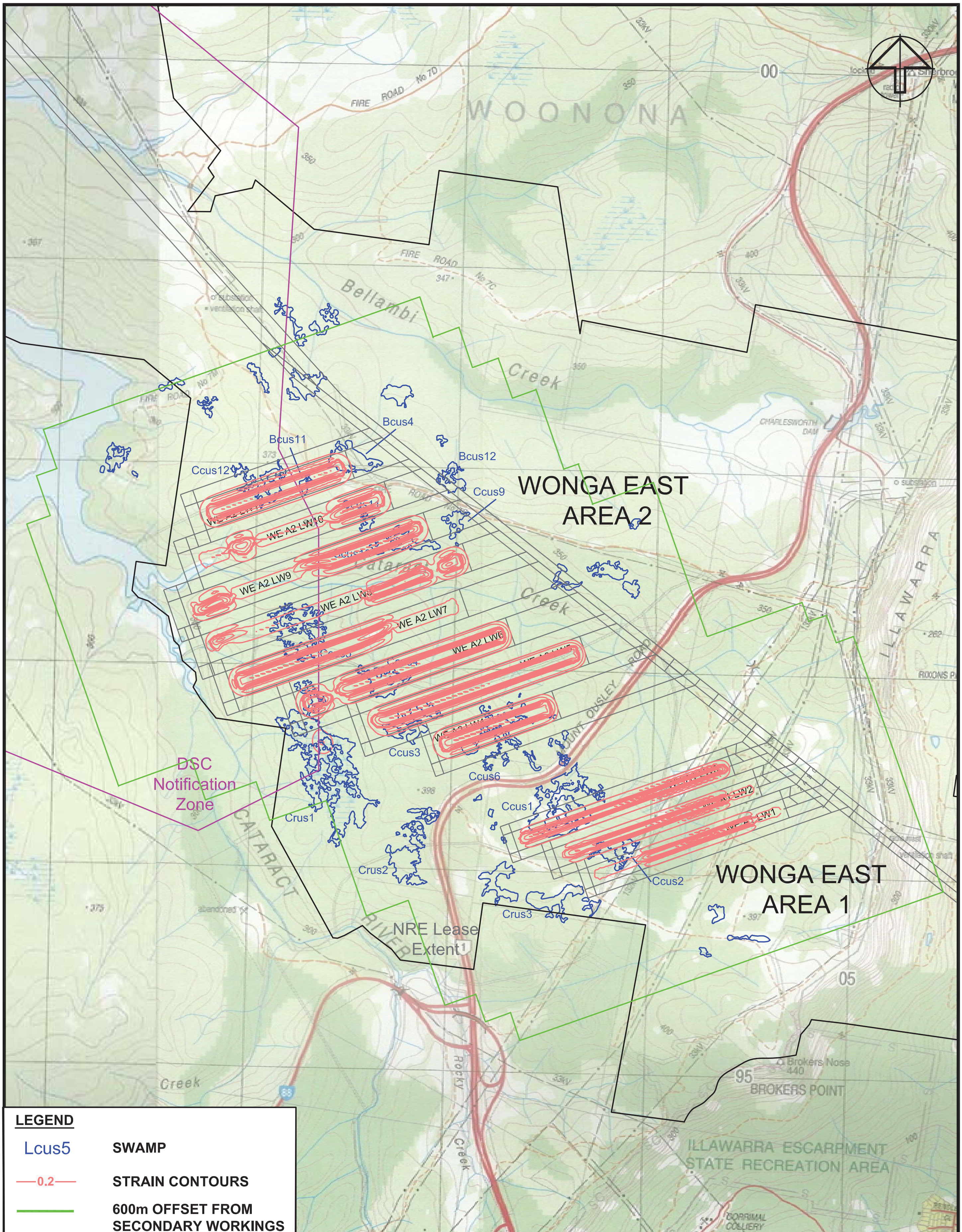
DATE:	26 OCT 2012
SCALE:	1:250

GUJARAT NRE COKING COAL LTD
NRE No. 1 COLLIERY

Proposed Wonga East Subsidence

GeoTerra

DRAWING 7



PROJECT:	GUJ1-R1
DRAWN:	A. DAWKINS
DATE:	26 OCT 2012
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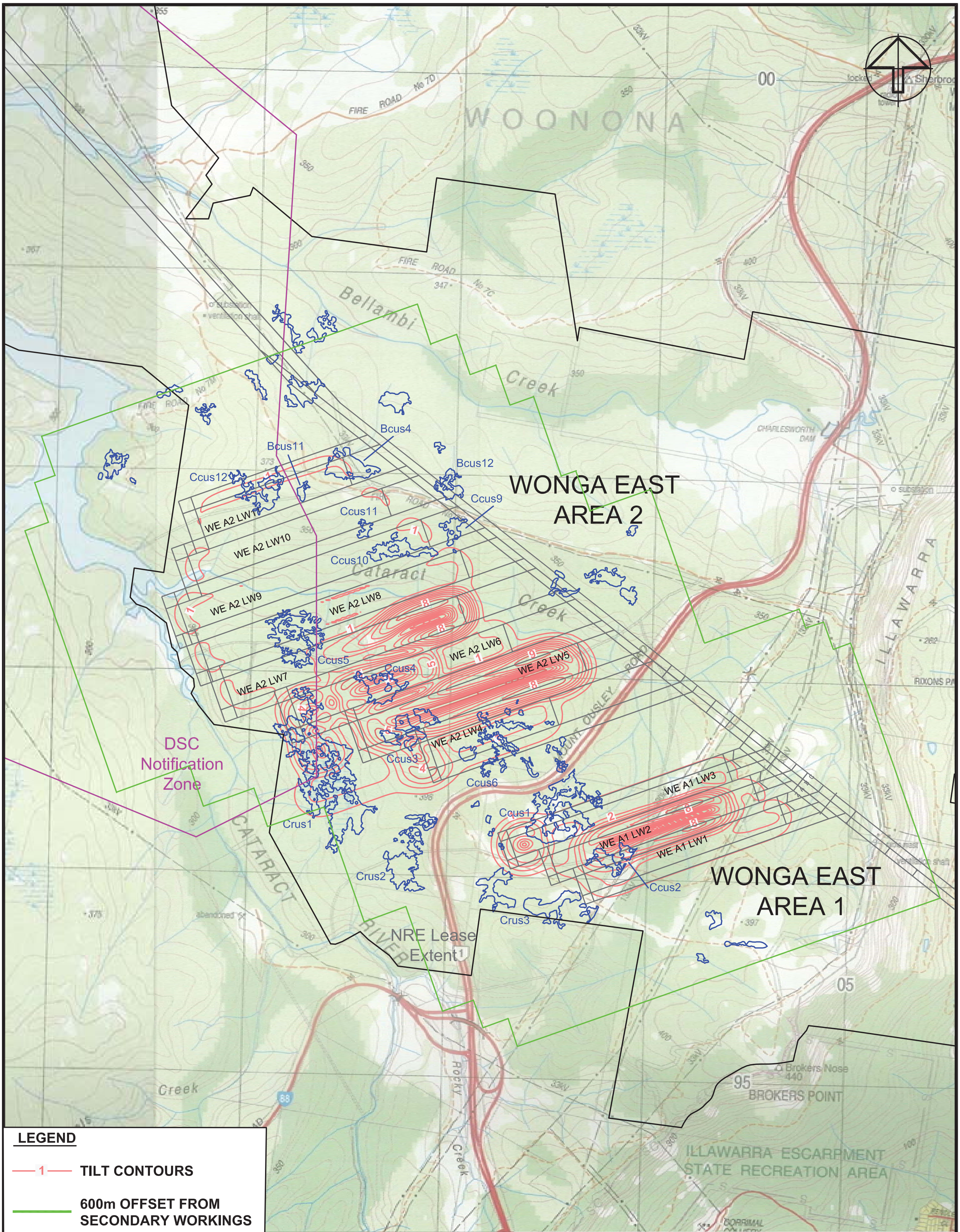
GUJARAT NRE COKING COAL LTD
NRE No. 1 COLLIERY

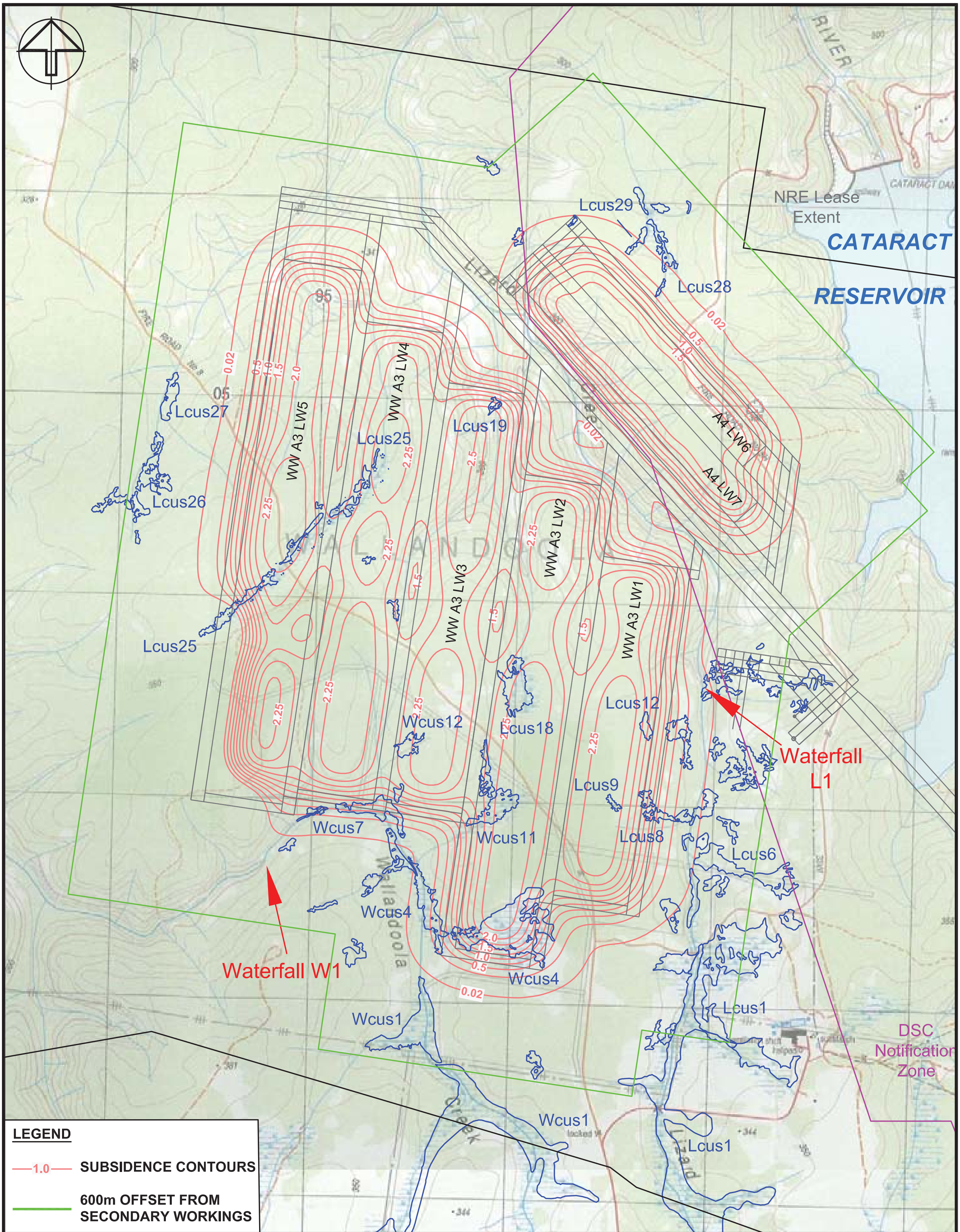
Predicted Wonga East Strains

GeoTerra

DRAWING 8



PROJECT:	GUJ1-S-R1	**GUJARAT NRE COKING COAL LTD** **NRE No. 1 COLLIERY**	**GeoTerra**
DRAWN:	A. DAWKINS		
DATE:	26 OCT 2012	**Proposed Wonga East Workings and Tilt Contours**	**DRAWING 9**
SCALE:	1:250		



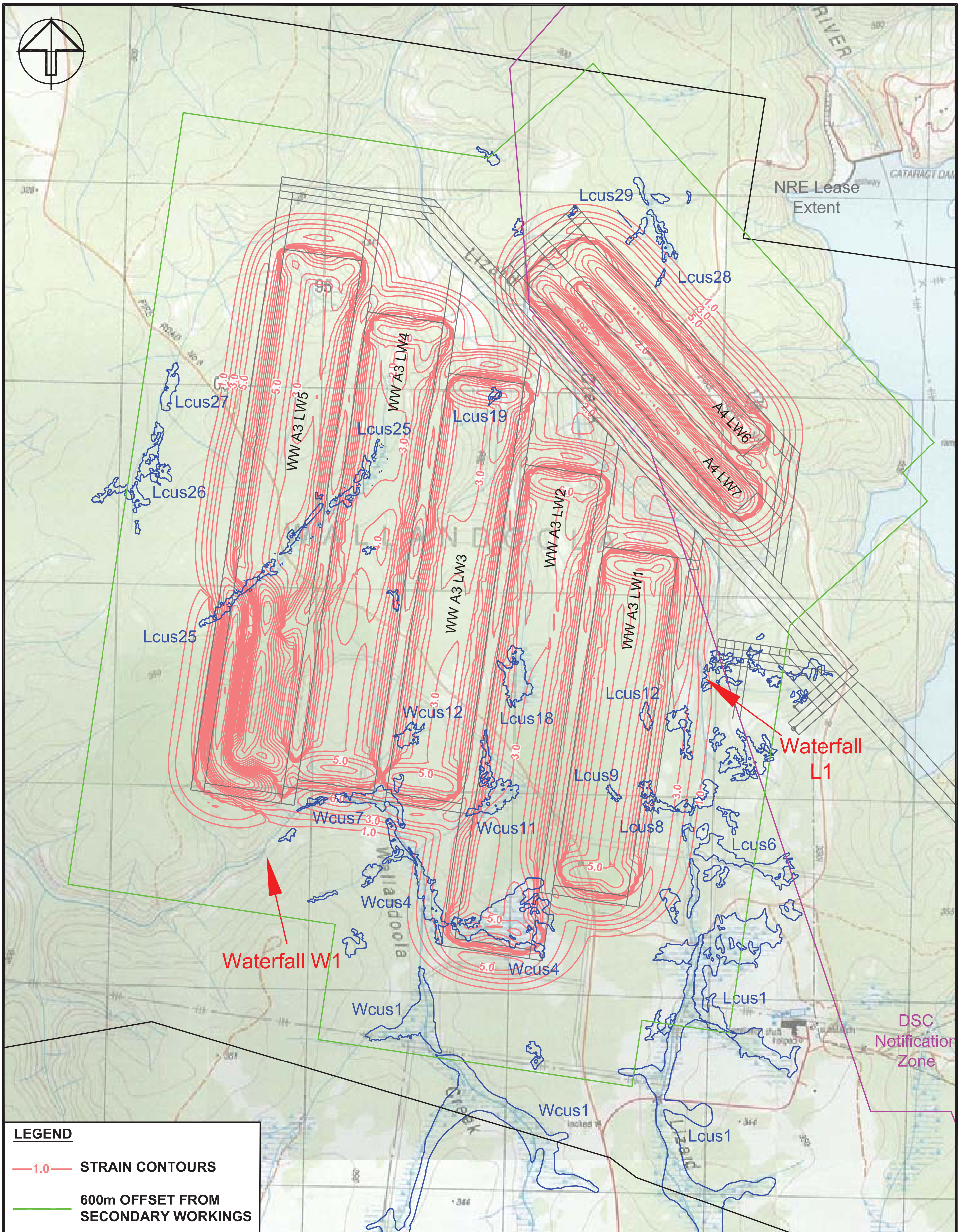
PROJECT:	GUJ1-S-R1	
DRAWN:	A. DAWKINS	
DATE:	26 OCT 2012	
SCALE:	1:250	

GUJARAT NRE COKING COAL LTD
NRE No. 1 COLLIERY

Proposed Wonga West Workings and Subsidence Contours

GeoTerra

DRAWING 10



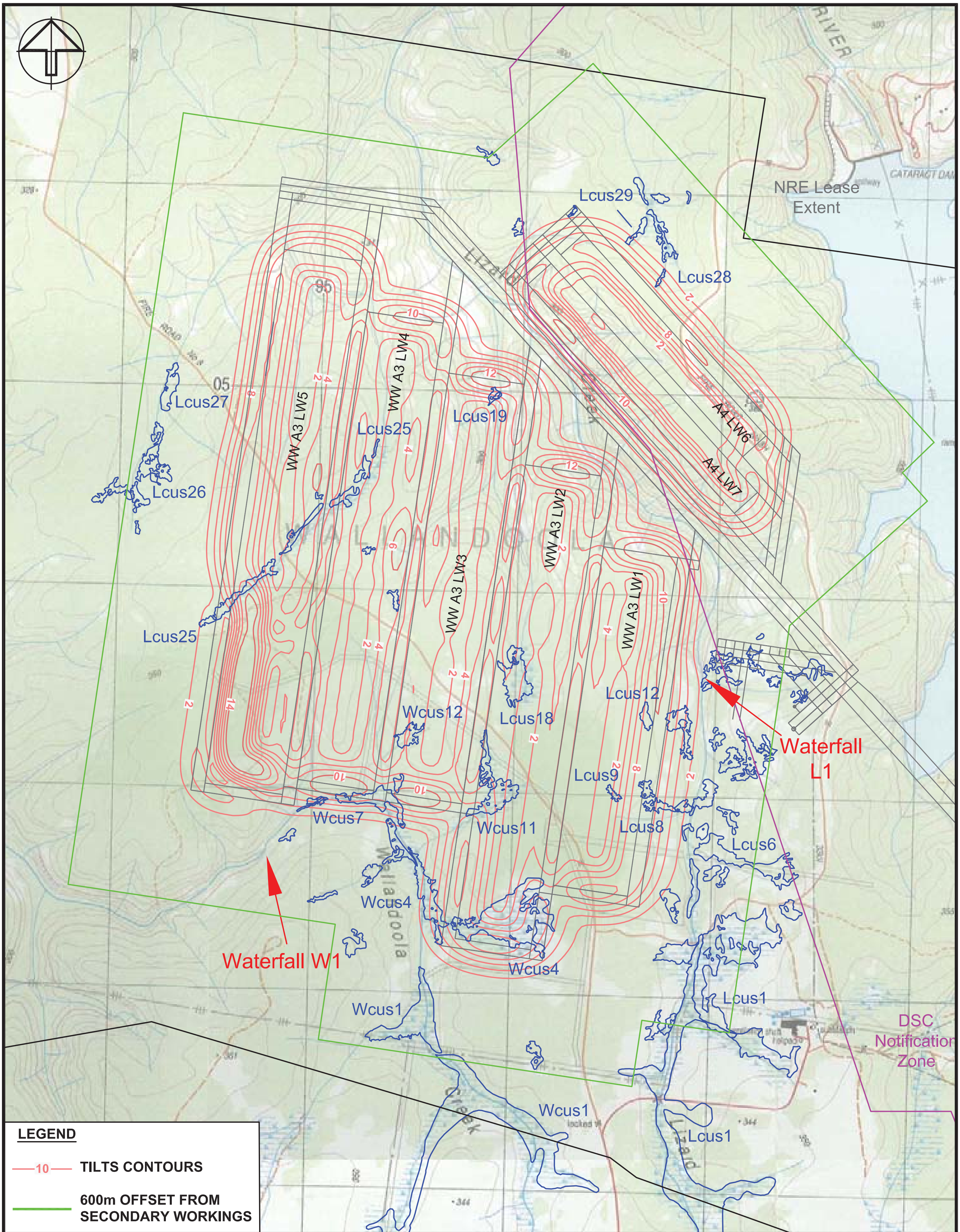
PROJECT:	GUJ1-S-R1
DRAWN:	A. DAWKINS
DATE:	26 OCT 2012
SCALE:	1:250

GUJARAT NRE COKING COAL LTD
NRE No. 1 COLLIERY

Proposed Wonga West Workings and Strain Contours

GeoTerra

DRAWING 11



PROJECT:	GUJ1-S-R1	GUJARAT NRE COKING COAL LTD NRE No. 1 COLLIERY	GeoTerra
DRAWN:	A. DAWKINS		
DATE:	26 OCT 2012	Proposed Wonga West Workings and Tilt Contours	DRAWING 12
SCALE:	1:250		

APPENDIX A

WRM WATER AND ENVIRONMENT PTY LTD
SURFACE WATER MODELLING

NRE NO.1 COLLIERY SURFACE WATER MODELLING

Gujarat NRE Coking Coal Limited
November 2012

www.wrmwater.com.au

wrm
water + environment

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REPORT TITLE: NRE No. 1 Colliery Surface Water Modelling
CLIENT: Gujarat NRE Coking Coal Limited
REPORT NUMBER: 0637-01-B [Rev 7]

Revision Number	Report Date	Report Author	Reviewer
0	16 March 2010	MB	GR
1	13 April 2010	MB	GR
2	7 May 2010	MB	GR
3	12 May 2010	MB	GR
4	6 September 2010	MB	GR
5	21 January 2011	MB	GR
6	16 November 2011	CW	MB
7	26 November 2012	CW	MB

For and on behalf of
WRM Water & Environment Pty Ltd

Michael Batchelor
Principal Civil Engineer

EXECUTIVE SUMMARY

This report describes the geometry of the catchments and streams potentially impacted by mining subsidence induced by the proposed Gujarat NRE No. 1 Colliery longwall mining project. It also outlines hydrological modelling undertaken to determine the relative contribution of the potentially affected catchments to runoff in the receiving waters.

The catchments of Lizard and Wallandoola Creeks will potentially be affected by the proposed Wonga West workings, and the catchments of the Cataract River and Cataract Creek will potentially be affected by the Wonga East workings. The western end of Panel 10 in the Wonga East workings extends under the high water extent of the northern bank of the Lake Cataract backwater in Cataract Creek.

Catchment geometry and stream longitudinal profiles were extracted from an airborne laser scanning survey acquired over the Study Area on 20th October 2009, and are described below:

1. Lizard Creek is approximately 10km long from its headwaters to the confluence with the Cataract River. It is a 3rd order stream for most of its length – with the downstream reaches being 4th order for 1.2km and 5th order for a 1.7km length. Approximately 3.6km of the stream reach is located upstream, 3.5km within and 3.2km downstream of the 20mm subsidence zone. Channel invert elevations fall from approximately 360m AHD to 200m AHD, including a 30m high waterfall located approximately half way along its length, and another 20m waterfall upstream of the Cataract River confluence. Of the total Lizard Creek catchment area of 17.1km^2, 5.2km^2 is located upstream of the potential subsidence zone, 6.3km^2 is within and 3.3km^2 is downstream of the 20mm subsidence zone overlying the proposed workings.

2. Wallandoola Creek is approximately 15.5km long from its headwaters to the confluence with the Cataract River. It is a 4th order stream for most of its length. Approximately 4.0km of the stream reach is located upstream, 1.4km within and 10.2km downstream of the 20mm subsidence zone. Channel invert elevations fall from approximately 370m AHD to 140m AHD including series of waterfalls with a total drop of 50m along a 2.5km reach approximately half way along its length. Of the total Wallandoola Creek catchment area of 33.2km^2, 8.3km^2 is located upstream of the potential subsidence zone, 2.0km^2 is within and 22.5km^2 is downstream of the 20mm subsidence zone overlying the proposed workings.

3. Cataract Creek is approximately 5.5km long from its headwaters to the upstream reaches of Lake Cataract. It is a 4th order stream for most of its length. The proposed Wonga East workings are located between Chainage 1,600m and Chainage 4,700m. Approximately 2.1km of the stream reach is located upstream, 2.0km within and 0.8km downstream of the 20mm subsidence zone. Channel invert elevations fall from approximately 340m AHD to 285m AHD. Of the total Cataract Creek catchment area of 5.2km^2, 2.1km^2 is located upstream of the potential subsidence zone, and 2.5km^2 has been identified as potentially subsided by the proposed workings.

4. Cataract River is approximately 6.7km long from its headwaters to the upstream reaches of the Lake Cataract storage. The proposed Wonga East workings and its associated 20mm subsidence zone do not underlie the Cataract River. The predicted 20mm subsidence zone runs adjacent to the Lake Cataract backwater for a distance of about 600m. It is a 3rd order stream upstream of the Link Road crossing and 4th order from the confluence just downstream of the crossing to the Lake Cataract backwater. Channel invert elevations fall from approximately 430m AHD to 285m AHD. Of the total Cataract River catchment area of 11.6km^2, 0.4km^2 has been identified as potentially subsided by the proposed workings with 11.2km^2 outside of the 20mm subsidence zone.

Lake Cataract will not be undermined by the proposed Wonga West workings. The proposed Wonga East workings underlie the backwater of Lake Cataract on Cataract Creek for a distance of 730m (maximum water depth 3.9m when the water level is at spillway level). Cataract River is not underlain by the proposed workings, or the expected subsidence zone. Of the total Lake Cataract catchment area of 127.8km^2, 3.4km^2 is identified as potentially subsided (Seedsman, 2010).

Rainfall in the study area is highly variable, with mean annual rainfall ranging from less than 1,000mm/a in the west of the Study Area to over 1,800mm/a on the eastern escarpment. Historical records show significant variations in rainfall from north to south during specific events.

Long-term streamflow records are not available for the potentially affected streams. However, data is available from gauges on headwater streams flowing into Lake Cataract: Bellambi Creek at South Bulli No. 1 (<5 years) and Loddon River at Bulli Appin Road (<19 years).

The streamflow records from these two gauges show similar responses to rainfall– with persistent baseflow being a notable feature, but contributing a relatively small proportion total runoff. The streamflow records were extended by simulating catchment behaviour using the AWBM rainfall-runoff model and historical climate data. Given the limited availability of representative rainfall data, the AWBM gave a reasonable representation of catchment behaviour, though it tended to underestimate very low flows.

Daily runoff from other catchments in the upper Study Area was estimated using the AWBM model, with the model parameters transposed from the adjacent calibrated catchments. Climate data specific to each sub-catchment of interest was used to account for spatial rainfall variability.

The catchment models were validated by directing the modelled runoff to a hydrological model of the Lake Cataract system. Simulated stored water levels were compared to historical records provided by the SCA. With the exception of a small number of individual runoff events, the model gave a good representation of historical storage behaviour over the 35 year period for which complete daily records were available.

Based on a catchment yield model calibrated to historical records since 1976, losses of 1ML/d would have had very little impact on Lake Cataract water levels. The maximum reduction in stored volume occurs in mid-2007 and ranges from 940ML for a loss of 0.5ML/d to 1,385ML/d for a loss of 10ML/d. Losses of 10ML/d would not have caused the Lake Cataract Reservoir water volume to fall below 10% of capacity. Such loss rates are very large, and unlikely to eventuate given the underlying geology and proposed mining method.

Subsidence induced cracking could potentially affect streamflow in the reaches overlying and downstream of the proposed workings. Other investigations have concluded that these impacts would normally be restricted to short reaches, where flow infiltrates into cracks in the bed, then remerges further downstream. Based on the available subsidence assessments, it is not possible to directly predict the magnitude of these losses or the lengths of streams likely to be impacted.

In the absence of long-term streamflow records on Lizard and Wallandoola Creek, the impact of losses from the affected reaches due to mine subsidence on the persistence of baseflow was estimated by extracting a constant daily loss rate from a simulated streamflow record. The model parameters were transposed from AWBM models calibrated to adjacent catchment runoff records and validated against portions of the streamflow record at Broughton's Pass Weir. Flows in Lizard Creek and Wallandoola Creek at the reporting locations just downstream of the proposed 20mm subsidence zone, are similar. A loss of 0.5ML/d would reduce the frequency of flows greater than 1.0ML/d from around 38% to 32%. A loss of 1.0 ML/d would reduce the frequency of 1.0ML/d flows to 28%. A loss of 0.5ML/d would reduce the frequency of flows greater than 0.1ML/d from around 70% to 46%. A loss of 1.0 ML/d would reduce the frequency of 0.1ML/d flows to 37%.

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1 INTRODUCTION

1.1 BACKGROUND

WRM Water and Environment was engaged by Gujarat NRE Coking Coal Limited to assist in assessment of the potential surface water impacts of the proposed NRE No.1 Colliery project.

This study describes the existing surface water hydrology of the potentially affected streams, and the hydrological modelling undertaken to quantify the potential impacts. The modelling has been undertaken to address components of the Director General's Requirements (DGRs) for the project relating to the potential impacts on flows in the potentially affected watercourses and the associated reliability of water supplies from Cataract Dam.

The study draws on estimates of the extent of mine subsidence and the potential for cracking of the ground surface along watercourses. This report focuses on surface water hydrology, whilst the potential impacts on other features of the streams and upland swamps are covered by associated studies.

1.2 PROJECT DESCRIPTION

The proposed workings are contained within the NRE No. 1 Colliery in Consolidated Coal Lease 745 (CCL745) and Mining Lease 1575 (ML1575), which are located approximately 13km northwest of Wollongong.

The proposed mining is subdivided into Wonga East (Area 1 and Area 2) and Wonga West (Area 3 and Area 4). These areas are shown in Figure 1.1.

Coal will be extracted from the Wongawilli Seam by longwall extraction from eleven panels in the Wonga East area and seven panels in the Wonga West area.

1.3 STUDY AREA

The Study Area includes the catchments of potentially affected streams in the vicinity of the project. As shown in Figure 1.1, the Study Area extends approximately 20km west from the Illawarra Escarpment and comprises the catchments of Lake Cataract, and the north-flowing tributaries which join the Cataract River downstream of Cataract Dam (Lizard Creek and Wallandoola Creek).

Lake Cataract is a component of the Upper Nepean water supply scheme, and is managed by the Sydney Catchment Authority (SCA).

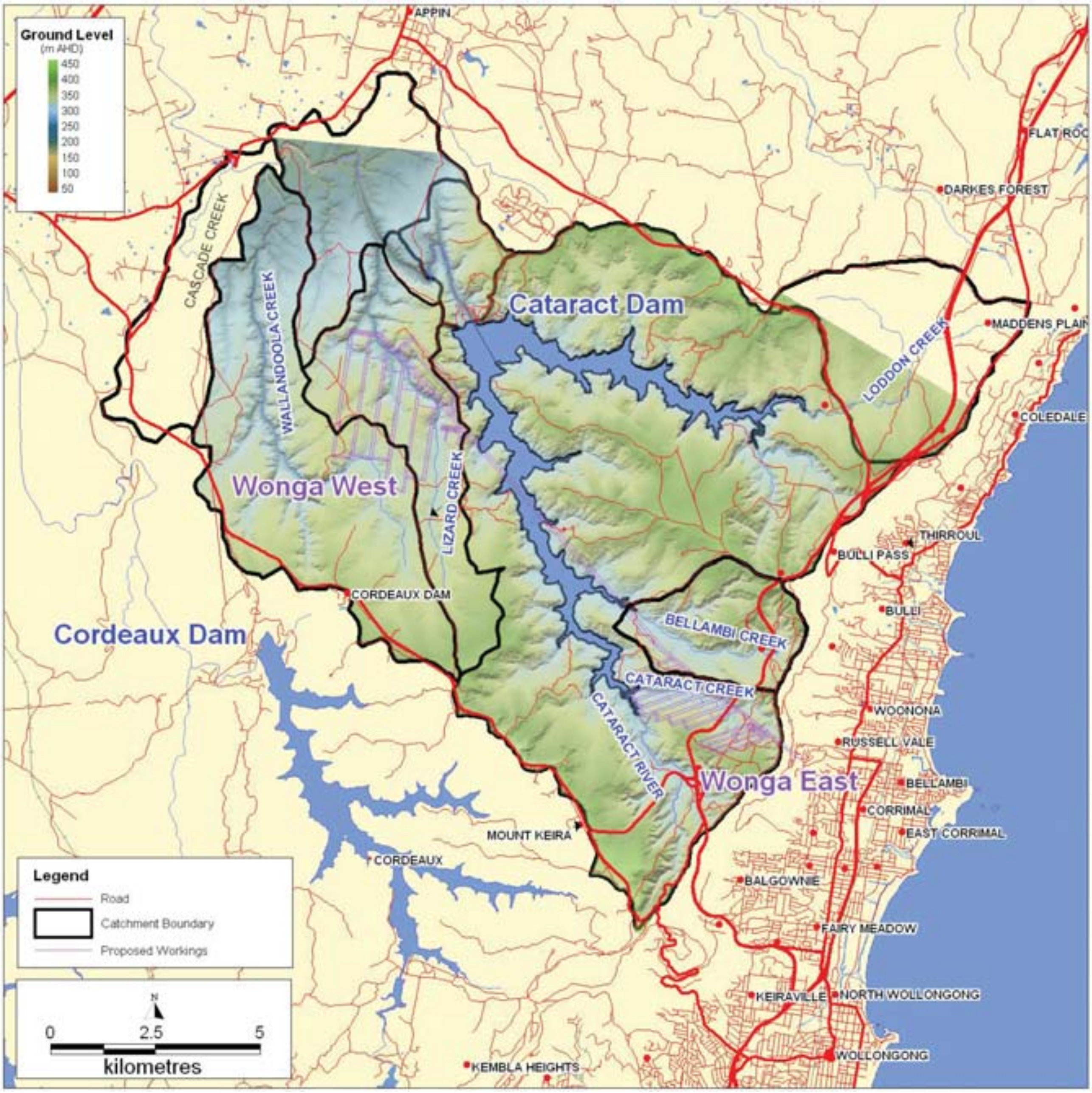


Figure 1.1 Study Area

1.4 SCOPE OF WORK

The following tasks were completed under the scope of this study:

- Delineate drainage catchments over the mine subsidence area,
- Produce longitudinal profiles over the proposed workings,
- Assess streams in terms of gradient, length, and order,
- Assess rainfall residuals for the nearest long-term rainfall gauge,
- Obtain streamflow from nearby streamflow gauges if relevant to the site catchments,
- Obtain hydrological data pertaining to Lake Cataract:
  - spill volumes,
  - stored volume,
  - water extractions, and
  - surface evaporation.
- Prepare and calibrate a rainfall-runoff model of the Lake Cataract catchment to generate a daily time series of inflows to the dam,
- Assess the contribution of the mine subsidence areas to the total runoff to Lake Cataract over a range of flow conditions,
- Assess the impact of the potential loss of flow due to subsidence-induced cracking on streamflow in the creeks crossing the proposed subsidence area.

2 CATCHMENT CHARACTERISTICS

2.1 LAKE CATARACT CATCHMENT

Ground surface elevations in the Lake Cataract catchment vary from 485m AHD near Mount Keira on the eastern escarpment to 150m AHD at the confluence of Wallandoola Creek and the Cataract River, at the downstream (western) end of the Study Area. The underlying geology predominantly comprises Hawkesbury Sandstone, however the Bald Hill Claystone and Bulgo Sandstone are exposed in the valley floor of Cataract Creek in the Wonga East Area. Steep rocky outcrops and cliffs are present in some areas, while some headwater streams drain upland valley fill and headwater swamps on the higher eastern plateau via ephemeral gullies incised into the sandstone.

Cataract Dam has significantly altered streamflow from the Cataract River since its construction in 1907. The dam has a capacity of 94,300ML and controls a catchment area of 130km^2. Flows downstream of the dam are further regulated by Broughton's Pass weir, which diverts water supplies to the Macarthur Water Treatment Plant via Cataract Tunnel.

There has been a long history of coal mining under the Upper Nepean water supply catchments. Mining activities by previous owners of NRE No.1 Colliery and the decommissioned BHP Billiton Cordeaux Colliery longwall as well as other old bord and pillar workings have caused adverse subsidence impacts in the Study Area. Longwall mining in the Appin, Westcliff and Northcliff workings approximately 2.5km to the north of the Gujarat Lease Area have also resulted in adverse impacts on surface water quality and quantity (Short, 2007).

Surface infrastructure associated with mining affects relatively small portions of the catchment, and as the SCA's Metropolitan Special Area is a restricted access area, the Study Area is otherwise largely undeveloped and in a natural condition.

2.2 WONGA WEST CATCHMENTS

As shown in Figure 2.1, the Wonga West area contains mine surface infrastructure and access roads associated with the existing Gujarat NRE No. 1, No. 4 and No. 5 shafts. It is drained by Wallandoola and Lizard Creeks, which flow north to join the Cataract River between Cataract Dam and Broughton's Pass Weir. The headwaters overlie the previously mined BHP Cordeaux Colliery to the south of the Gujarat lease. Valley infill and headwater upland swamps are also present predominantly in the southern portion of the Wonga West, and to a lesser degree, Wonga East areas.

Wallandoola Creek does not directly overly the proposed longwall workings, but as shown in Figure 2.2, a total reach of 1.3km at Wallandoola Creek, and a 4.5km reach of Lizard Creek are contained within the 20mm subsidence zone. Lake Cataract will not be undermined by the Wonga West workings.

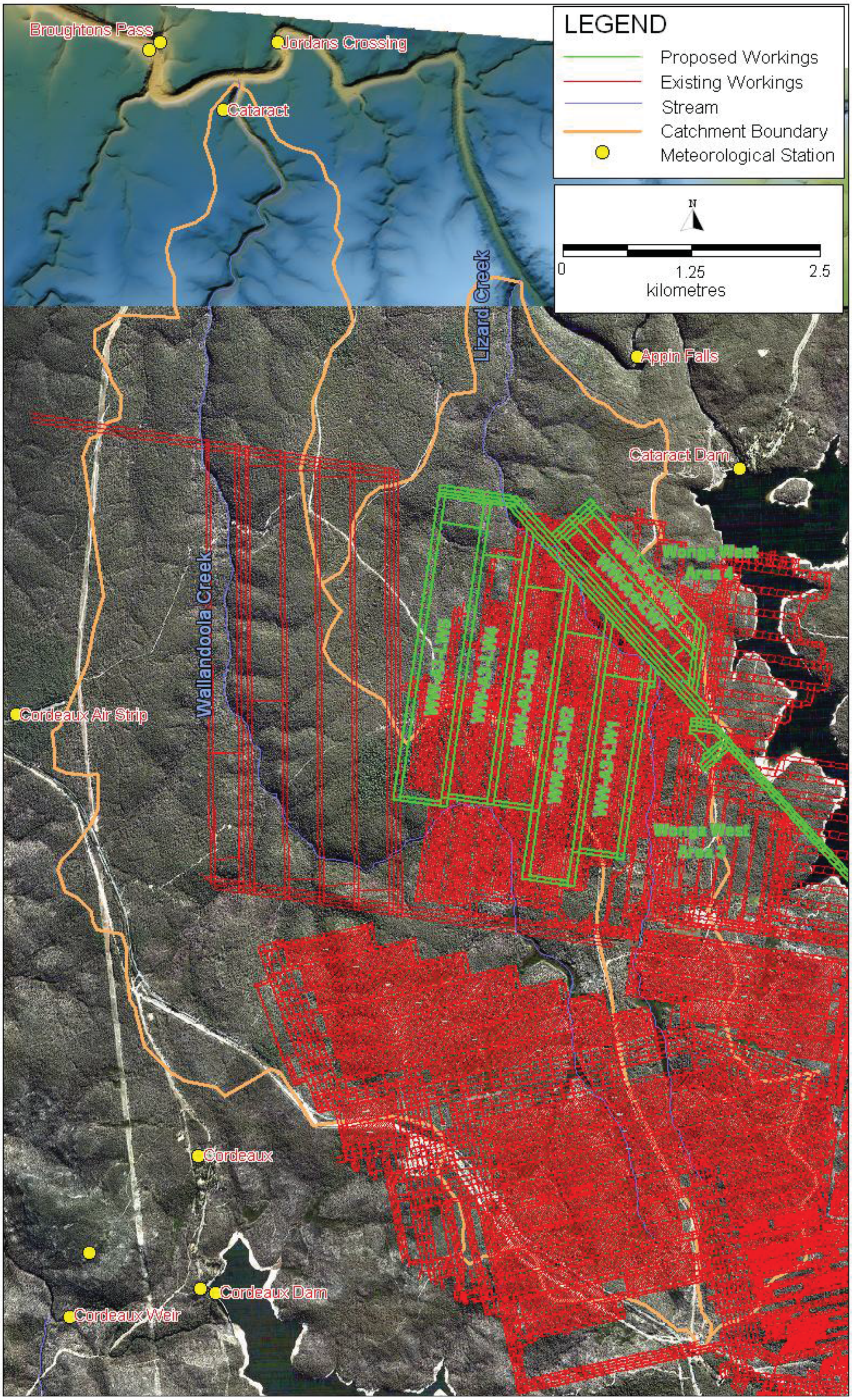


Figure 2.1 Lizard and Wallandoola Creek Catchment Areas

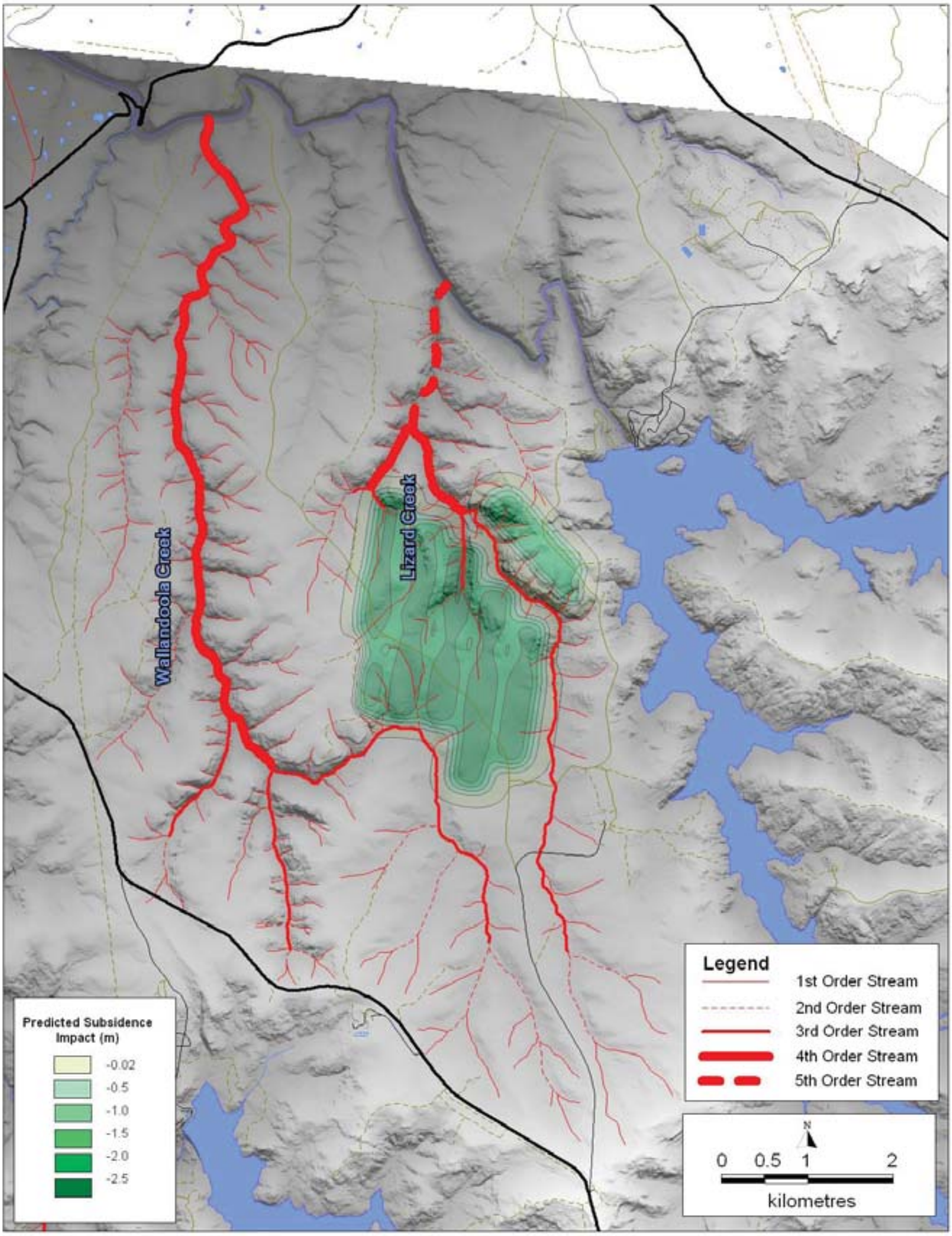


Figure 2.2 Stream Order – Wallandoola Creek and Lizard Creek

2.3 WONGA EAST CATCHMENTS

The Wonga East area is predominantly drained by Cataract Creek, and to a much lesser degree, Bellambi Creek and Cataract River. Cataract Creek joins the Cataract River within the impoundment of Lake Cataract.

As shown in Figure 2.3, parts of the upper catchments have been cleared for powerlines and access tracks. The Southern Freeway also crosses the eastern portion of these catchments. One upland swamp is present within Wonga East in the Cataract River catchment.

Longwall mining of the Balgownie Seam as well as bord and pillar extraction of the Bulli Seam has previously been conducted under Cataract Creek with no observed adverse impacts on the creek bed or banks (Geoterra, 2011).

As shown in Figure 2.3, the proposed Wonga East workings underlie Cataract Creek, but not the Cataract River. Figure 2.4 shows the western end of Panel 10 and the associated predicted 20mm subsidence zone could potentially undermine the eastern bank of the high water extent of the Lake Cataract backwater.

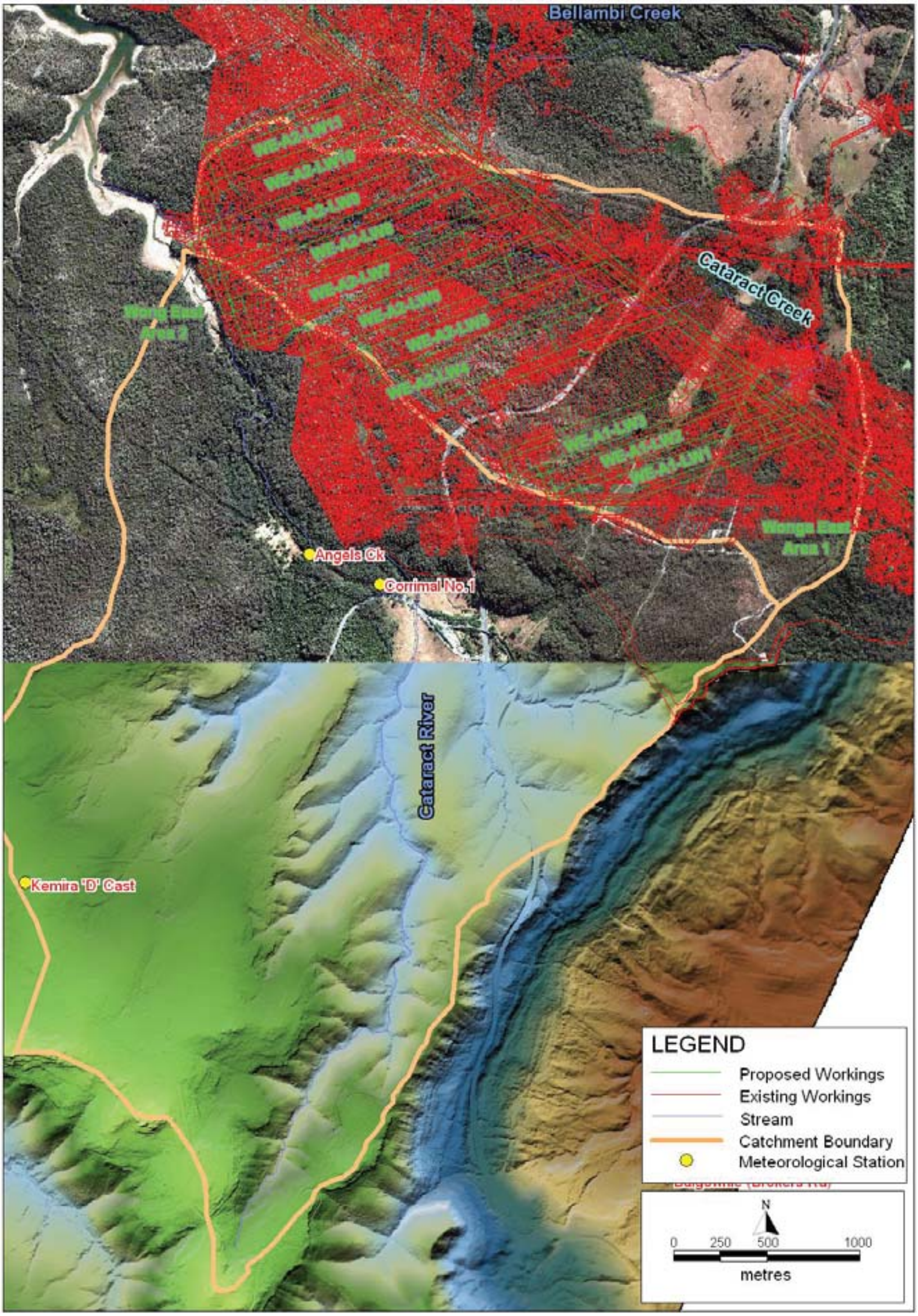


Figure 2.3 Cataract River and Cataract Creek Catchment Areas

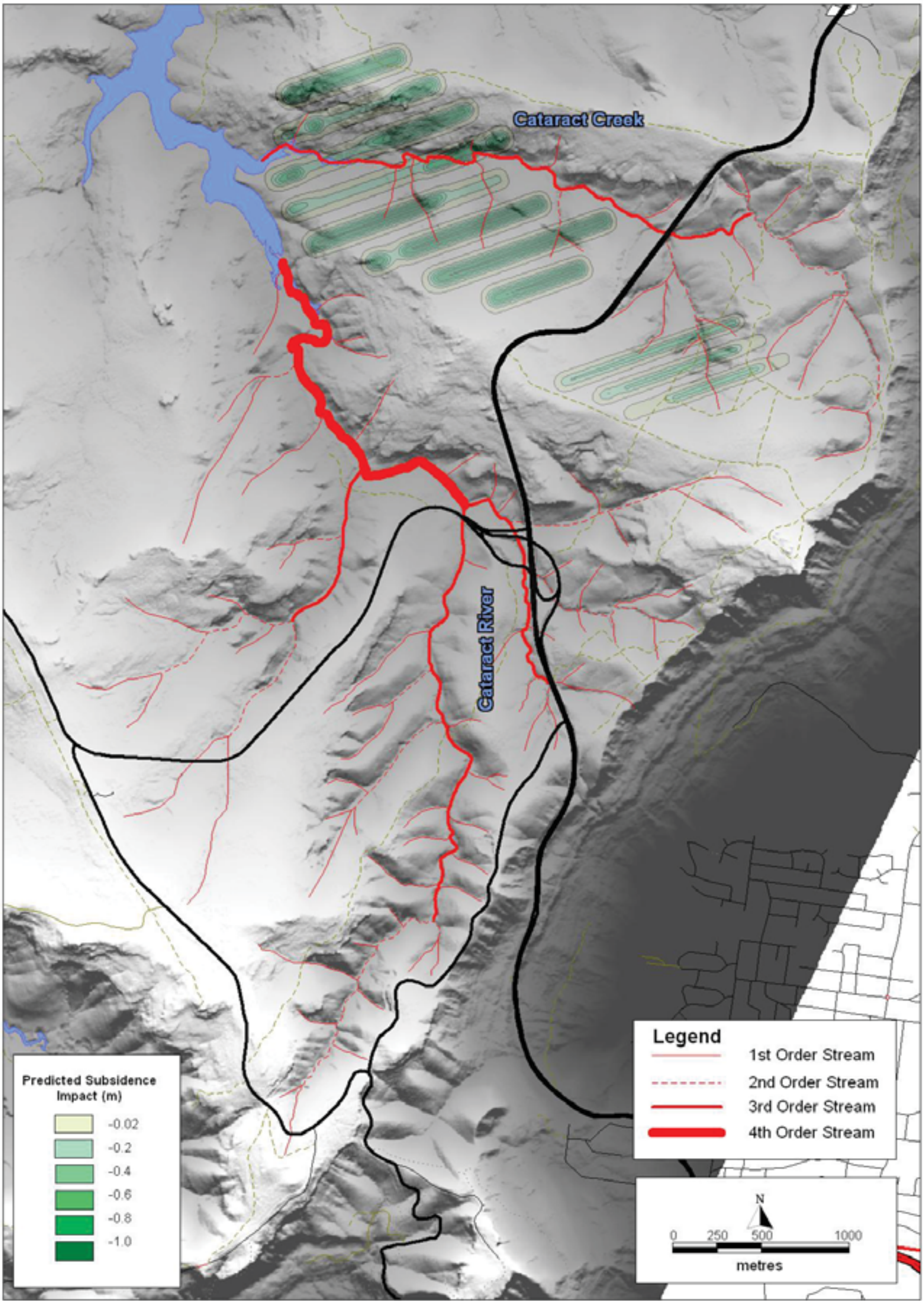


Figure 2.4 Stream Order – Cataract River and Cataract Creek

3 STREAM GEOMETRY

3.1 GENERAL

Longitudinal profiles of each of the potentially affected watercourses were produced from a digital terrain model derived using airborne laser scanning survey acquired over the Study Area on 20th October 2009. The accuracy of well defined points in the survey data is quoted as better than 100mm, based on comparison with ground survey in cleared areas (AAM Hatch, 2009).

3.2 WONGA WEST

3.2.1 Lizard Creek

As shown in Figure 2.2, Lizard Creek is a 3rd and 4th order stream that lies within the predicted 20mm subsidence zone, with a 2km stretch downstream of the subsidence zone being a 5th order stream.

A longitudinal profile of Lizard Creek is shown in Figure 3.1 (its alignment is shown in Figure 3.3). Lizard Creek is just over 10km long from its headwaters to its confluence with the Cataract River. Channel invert elevations fall from approximately 360m AHD to 200m AHD, including an almost 30m high waterfall located approximately half way along its length. A 20m waterfall just upstream of the Cataract River confluence is located downstream, and outside of, the 20mm subsidence zone. The channel gradient varies from around 0.4%, near the 5,500m chainage mark, and is steepest near the downstream end (around 3%).

The proposed Wonga West workings are located between Chainage 5,300m and Chainage 7,800m. . Approximately 3.6km of the stream reach is located upstream, 3.5km within and 3.2km downstream of the 20mm subsidence zone

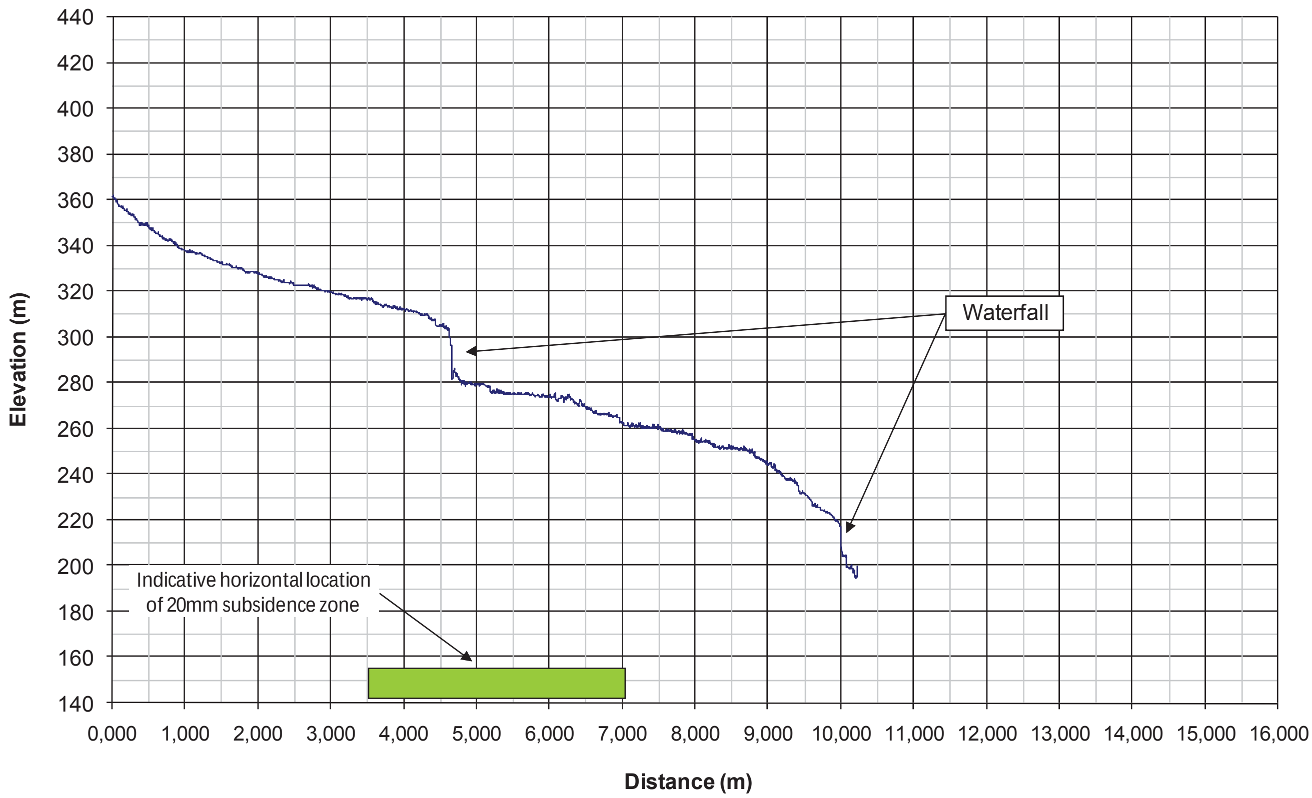


Figure 3.1 Longitudinal Profile of Lizard Creek

Channel cross-sections at three locations along Lizard Creek are shown in Figure 3.2.

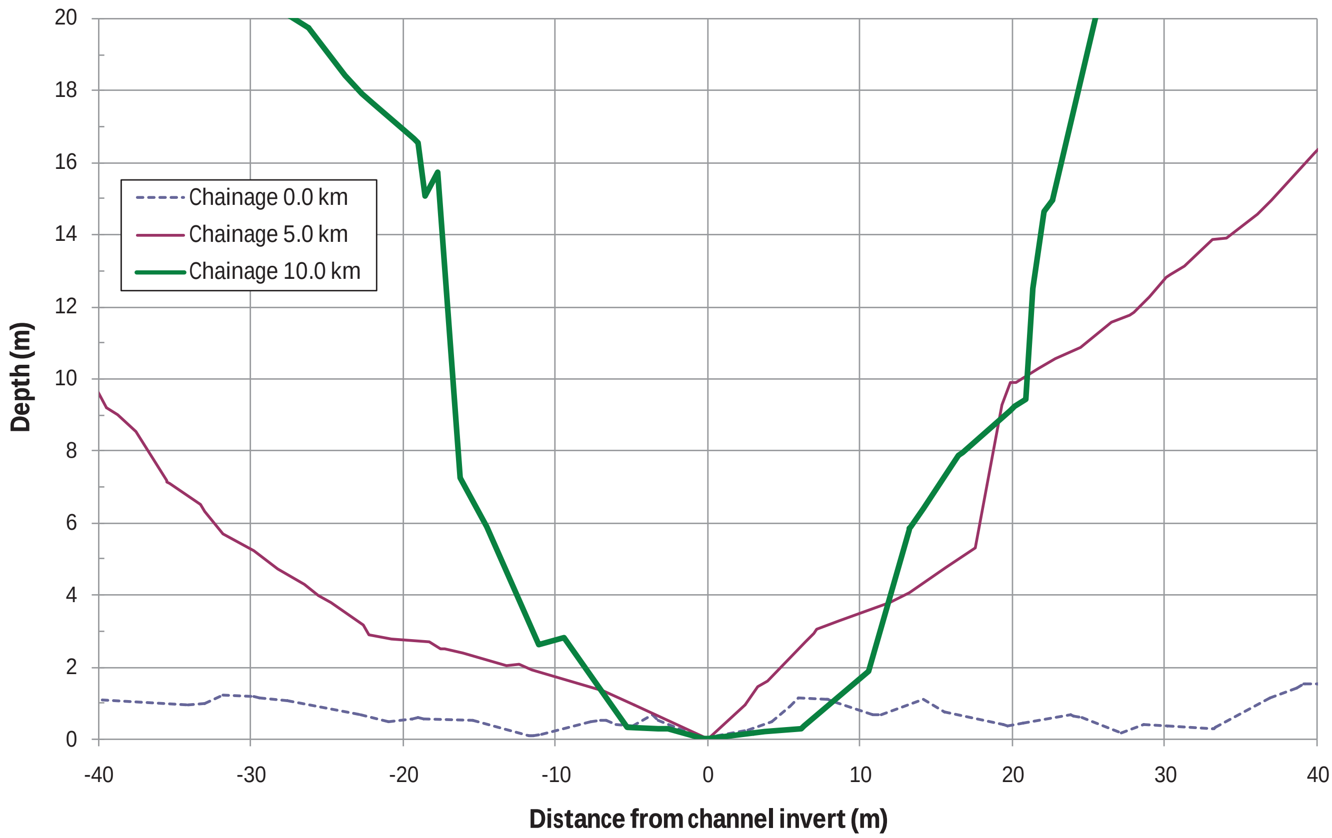


Figure 3.2 Cross-sections of Lizard Creek

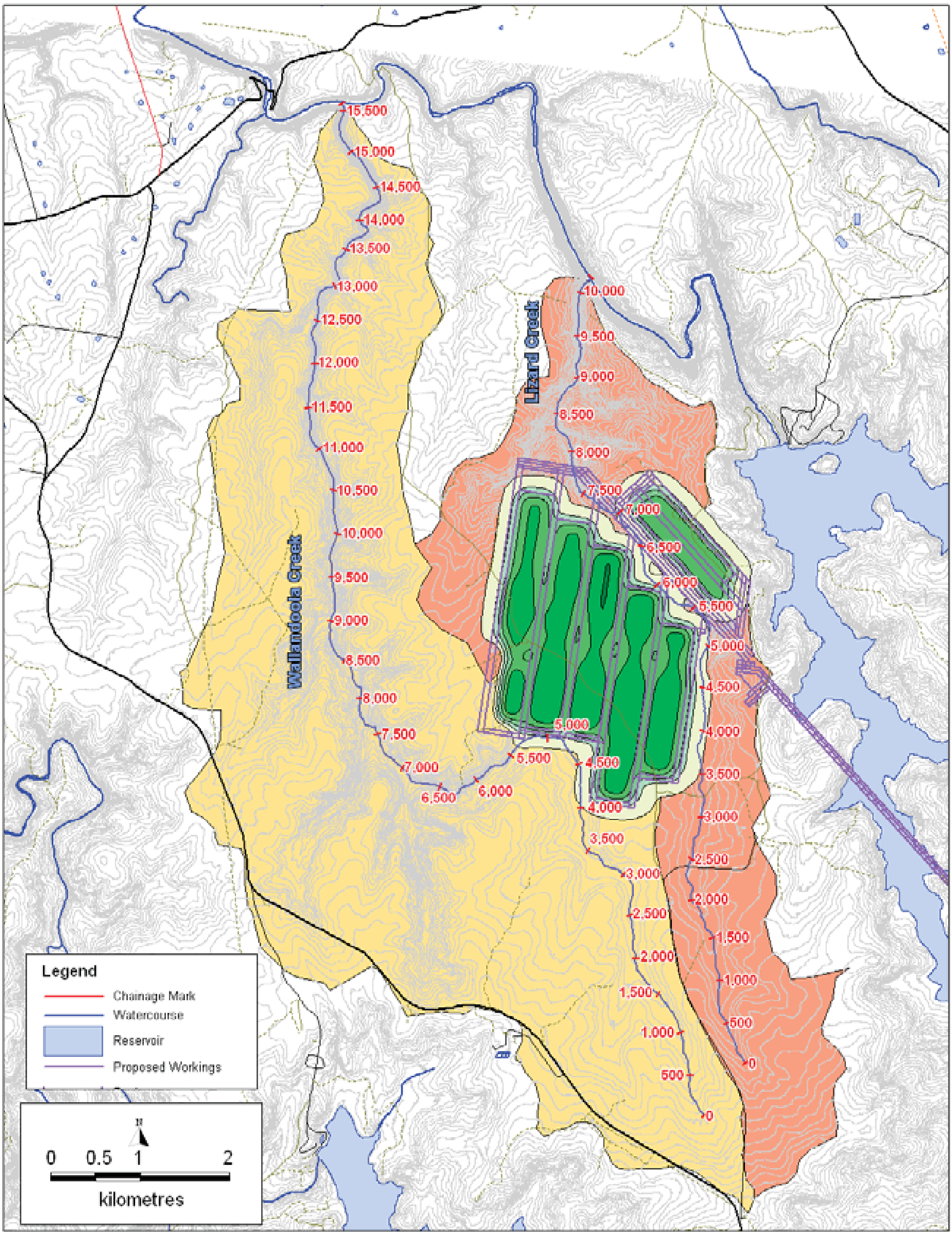


Figure 3.3 Alignments of Longitudinal Profiles of Wallandoola Creek and Lizard Creek

3.2.2 Wallandoola Creek

As shown in Figure 2.2 , Wallandoola Creek is a 4th order stream for most of its length.

A longitudinal profile of Wallandoola Creek is shown in Figure 3.4 (its alignment is shown in Figure 3.3). Wallandoola Creek is approximately 15.5km long from its headwaters to the confluence with the Cataract River. Channel invert elevations fall from approximately 370m AHD to 140m AHD, including series of stepped waterfalls totalling over 50m along a 2.5km reach approximately half way along its length. The channel gradient varies from 0.4%, near chainage 7,000m, and is steepest at the downstream end, at around 4%.

The proposed Wonga West workings are located adjacent to the channel between Chainage 3,500m and Chainage 6,000m. Approximately 4.0km of the stream reach is located upstream, 1.4km within and 10.2km downstream of the 20mm subsidence zone.

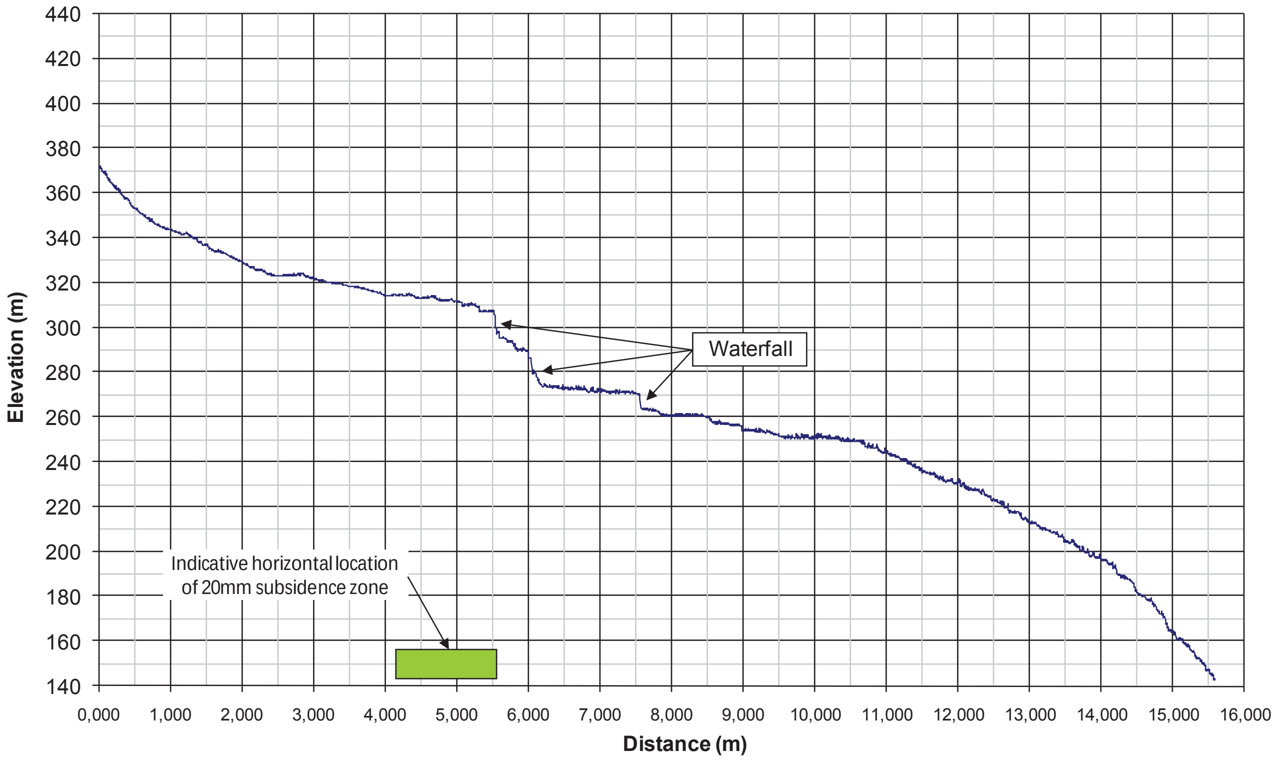


Figure 3.4 Longitudinal Profile Wallandoola Creek

Channel cross-sections at three locations along Wallandoola Creek are shown in Figure 3.5.

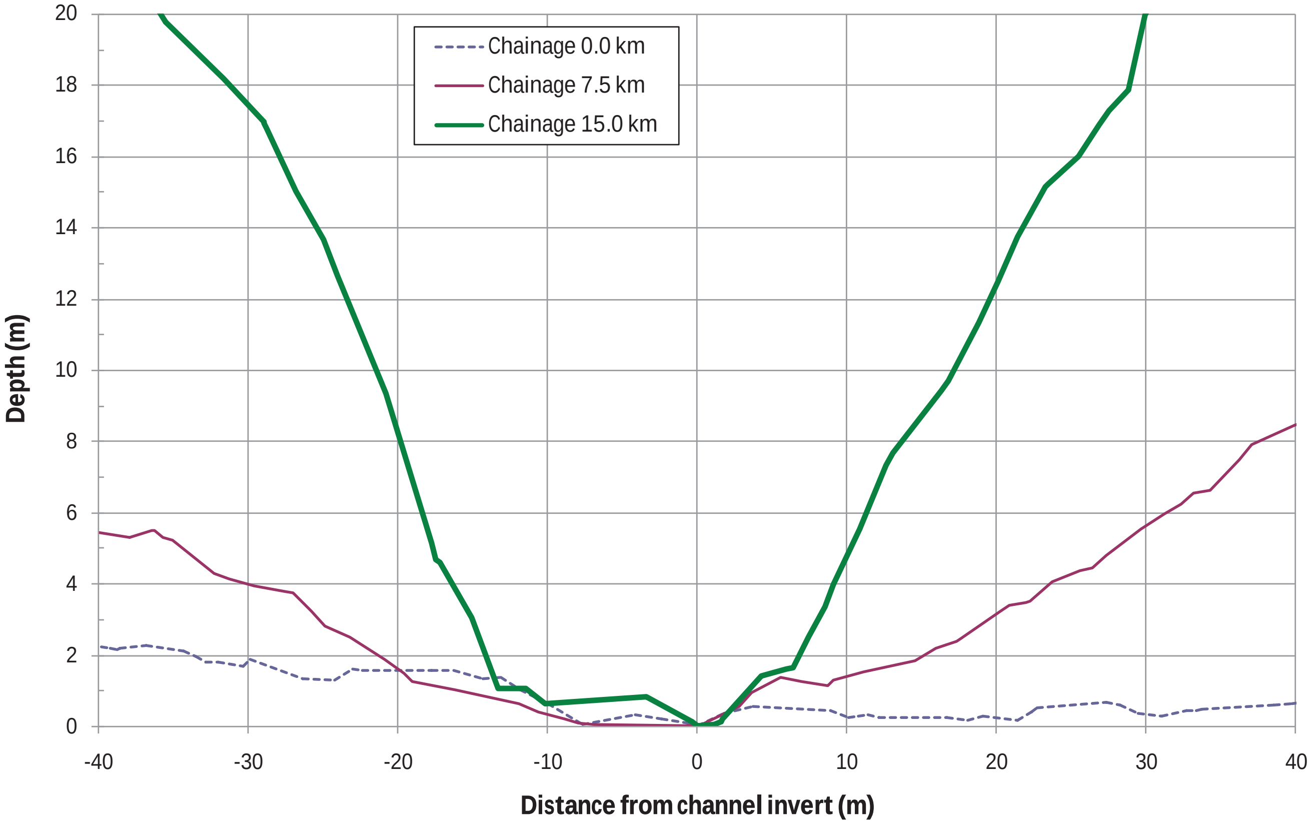


Figure 3.5 Cross-sections of Wallandoola Creek

3.3 WONGA EAST

3.3.1 Cataract Creek

As shown in Figure 2.4, Cataract Creek is a 4th order stream for most of its length.

A longitudinal profile of Cataract Creek is shown in Figure 3.6 (its alignment is shown in Figure 3.8). Cataract Creek is approximately 5.5km long from its headwaters to the upstream reaches of the Lake Cataract storage. Channel invert elevations fall from approximately 340m AHD to 285m AHD. The channel is relatively gently sloping at a gradient of 0.9%, for most of its length - the exception being the steep upstream 0.5km reach, which slopes at 4.2%

The proposed Wonga East workings are located between Chainage 3,100m and Chainage 4,200m. Approximately 3.7km of the stream reach is located upstream, 0.5km within and 0.7km downstream of the 20mm subsidence zone

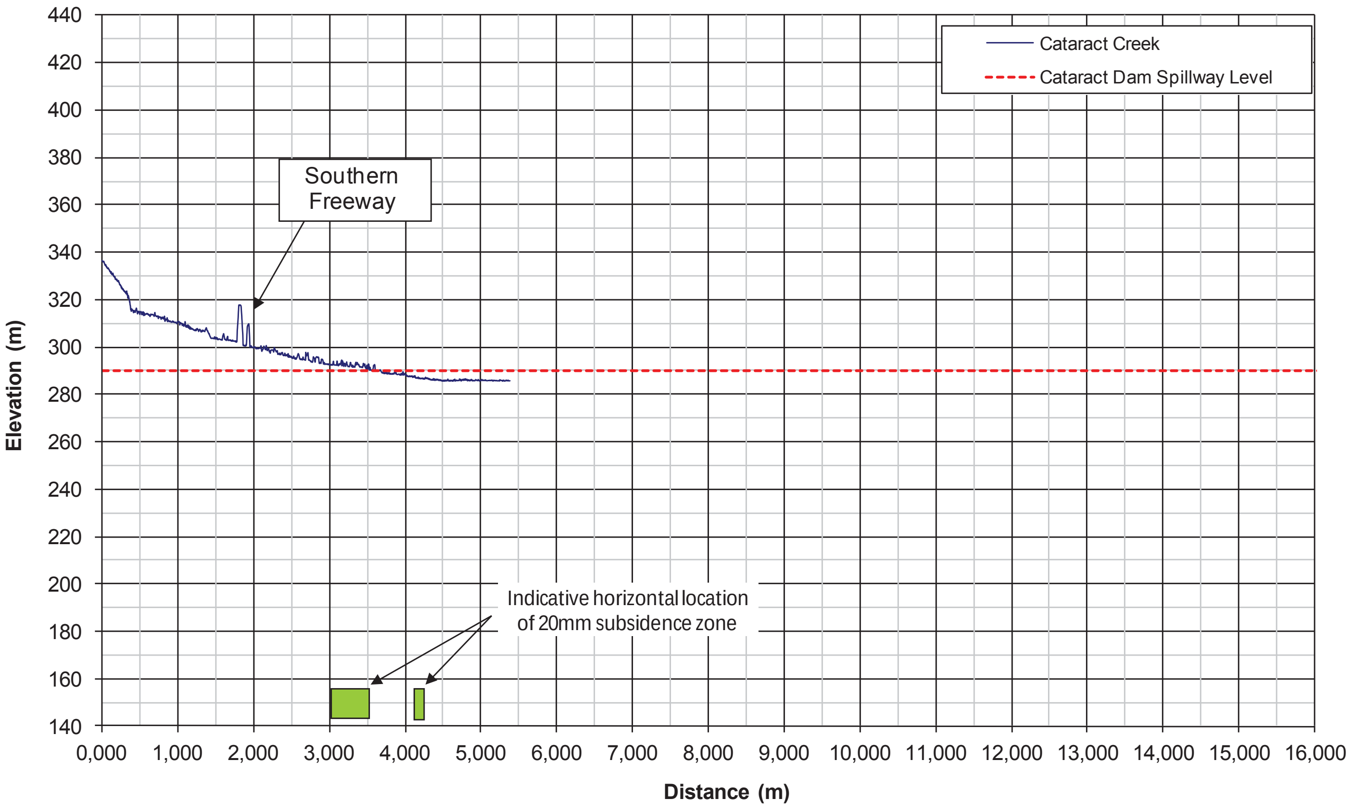


Figure 3.6 Longitudinal Profile Cataract Creek

Channel cross-sections at three locations along Cataract Creek are shown in Figure 3.7.

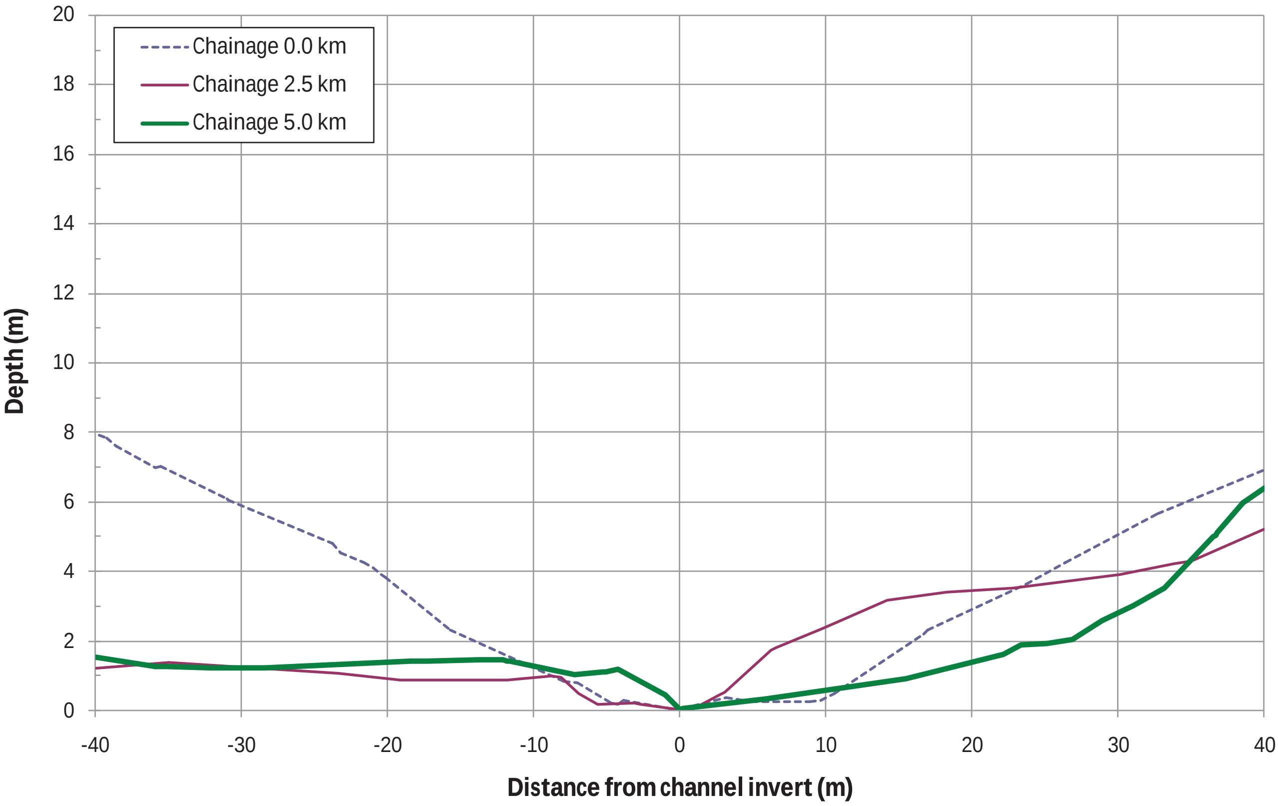


Figure 3.7 Cross-sections of Cataract Creek

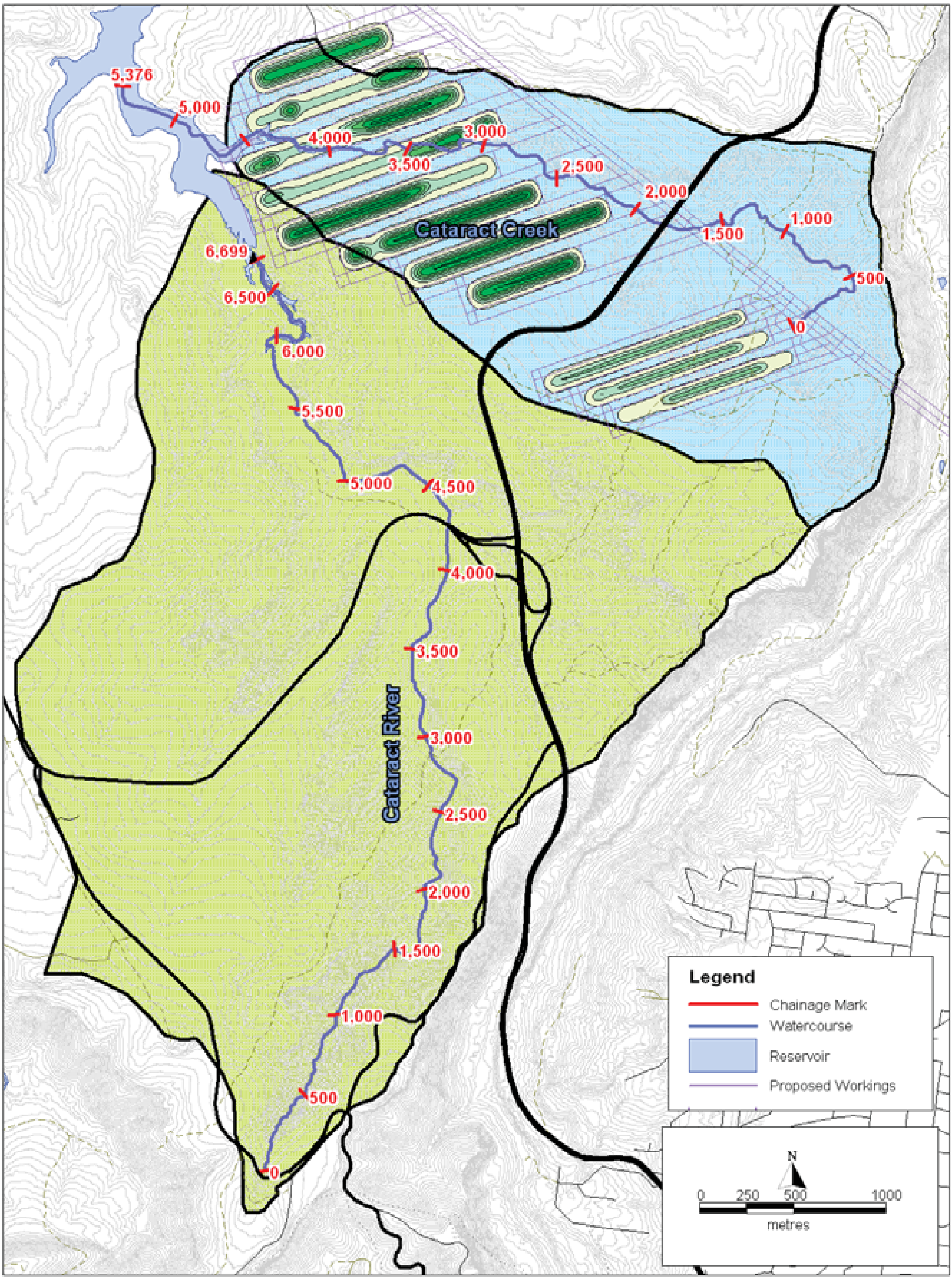


Figure 3.8 Alignments of Longitudinal Profiles of Cataract River and Cataract Creek

3.3.2 Cataract River

As shown in Figure 2.4, Cataract River is a 3rd order stream upstream of the Link Road crossing, and 4th order from the confluence near the crossing to the Lake Cataract backwater.

Cataract River is approximately 6.7km long from its headwaters to the upstream reaches of the Lake Cataract storage. Channel invert elevations fall from approximately 430m AHD to 285m AHD. The channel is relatively gently sloping at a gradient of 0.5%, for much of its length - the exception being the steep upstream 0.5km reach, which slopes at around 17%.

The proposed Wonga East workings do not underlie the Cataract River, however the predicted 20mm subsidence zone runs adjacent to the Lake Cataract backwater for a distance of about 600m.

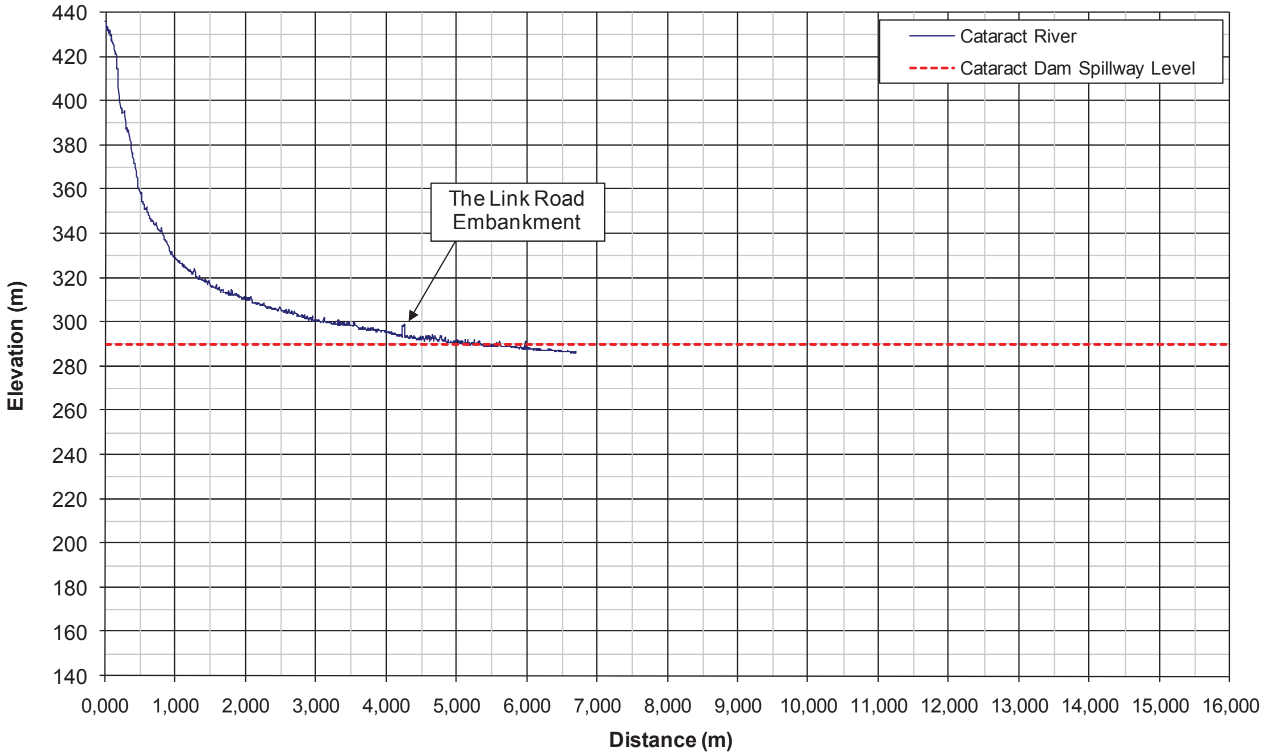


Figure 3.9 Longitudinal Profile Cataract River

Channel cross-sections at three locations along Cataract River are shown in Figure 3.10.

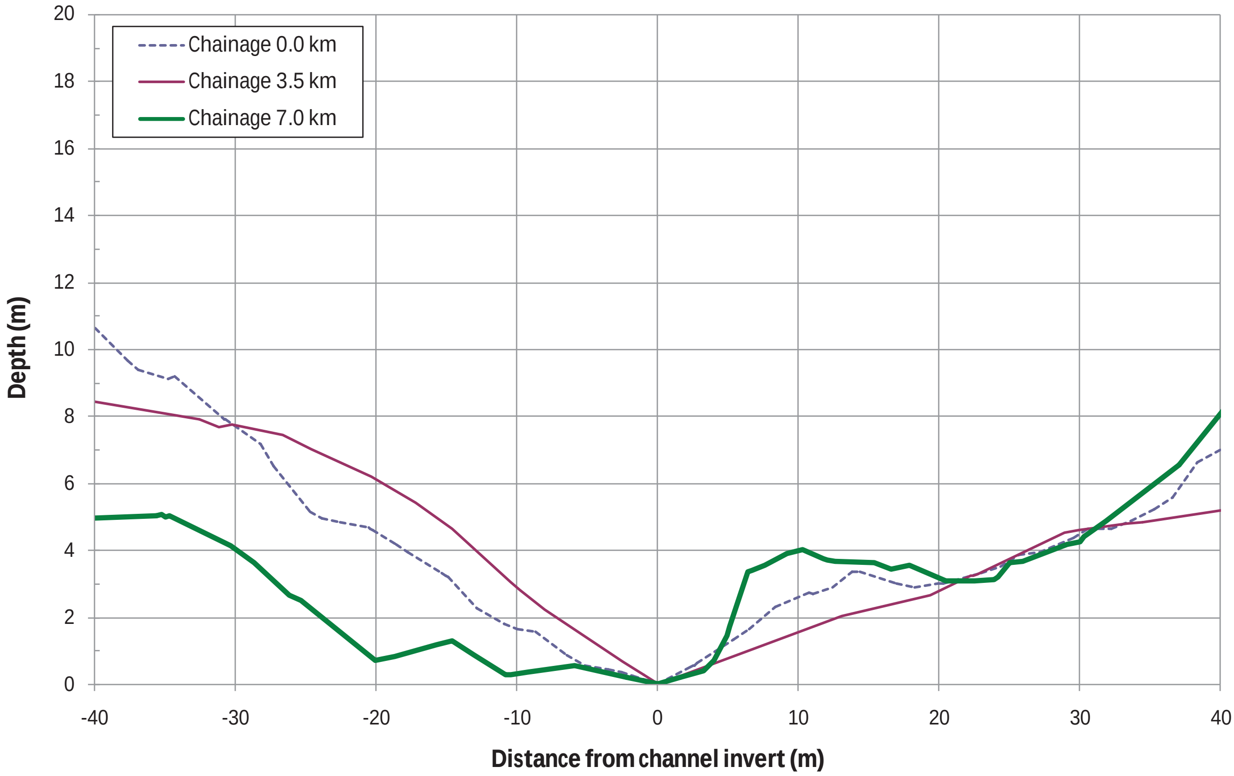


Figure 3.10 Cross-sections of Cataract River

4 CLIMATE CHARACTERISTICS

4.1 RAINFALL

4.1.1 Available Data

Daily rainfall has been recorded by the Bureau of Meteorology (BOM) and the SCA and its predecessors. The nearby rainfall stations with the longest records are located at Cataract and Cataract Dam. These stations have good quality records extending from 1883 to 1966 and 1904 to 2010 respectively.

The BOM's SILO data service has prepared Patched Point Datasets (PPDs) from the Cataract and Cataract Dam records. Gaps in the records are infilled with data interpolated from other nearby stations to provide continuous records between 1889 and the present day (Jeffrey et al., 2001).

4.1.2 Temporal Variability

As shown in Figure 4.1, annual rainfall at Cataract Dam for the period 1889 to 2011 has varied from 480mm in 1944, to 2,293 mm in 1950. Mean annual rainfall over this period was 1,080 mm/a.

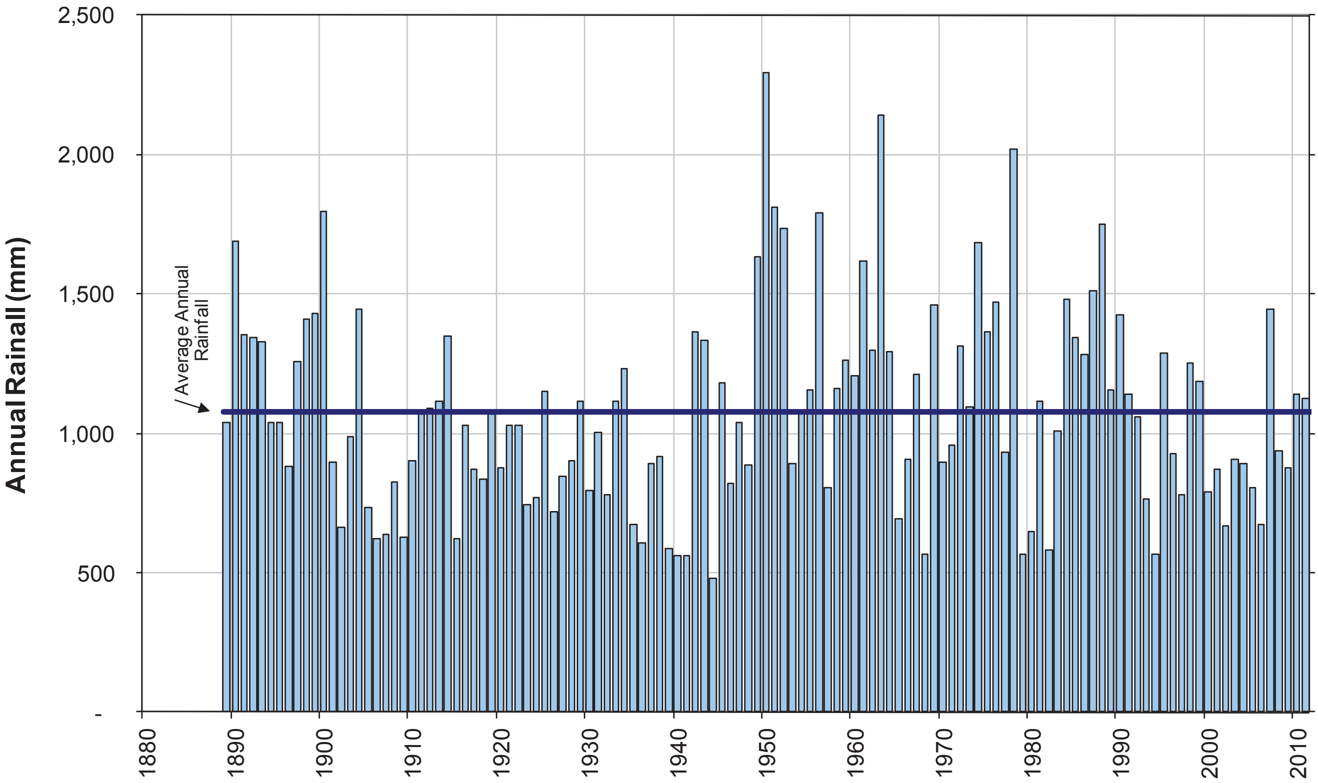


Figure 4.1 Annual Rainfall at Cataract Dam (Patched Point Dataset)

Cataract Dam rainfall is relatively consistent throughout the year. Rainfall is highest between January and June and lowest between July and December. This is illustrated in Figure 4.2, which shows mean monthly rainfall.

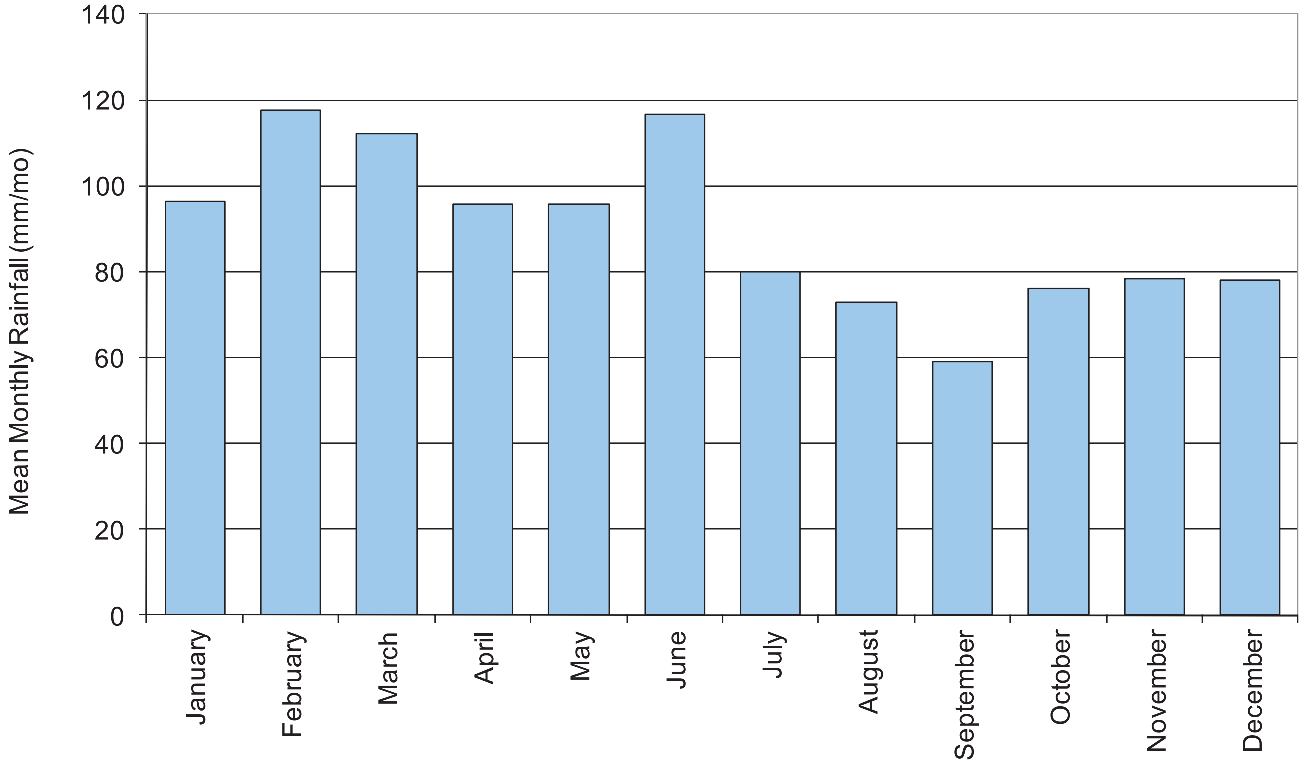


Figure 4.2 Variation in Mean Monthly Rainfall at Cataract Dam

Figure 4.3 shows a plot of rainfall residual at Cataract Dam for the period 1889 to 2010 (prepared using the PPD). The raw data for the station is overlaid on this line for comparison over the available period of record.

The rainfall residual shows departures from the long-term average (i.e. it has not been seasonally adjusted). Upward sloping lines indicate relatively wet periods, and downward sloping lines indicate relatively dry periods.

The figure shows that the period between 1905 and 1942, and the period since 1992 were relatively dry. The period from 1890 to 1900 and between 1950 and 1992 was generally relatively wet (with the exception of the late 1960s and the early 1980s). A plot of the SOI residual has been overlaid on the rainfall residual for comparison.

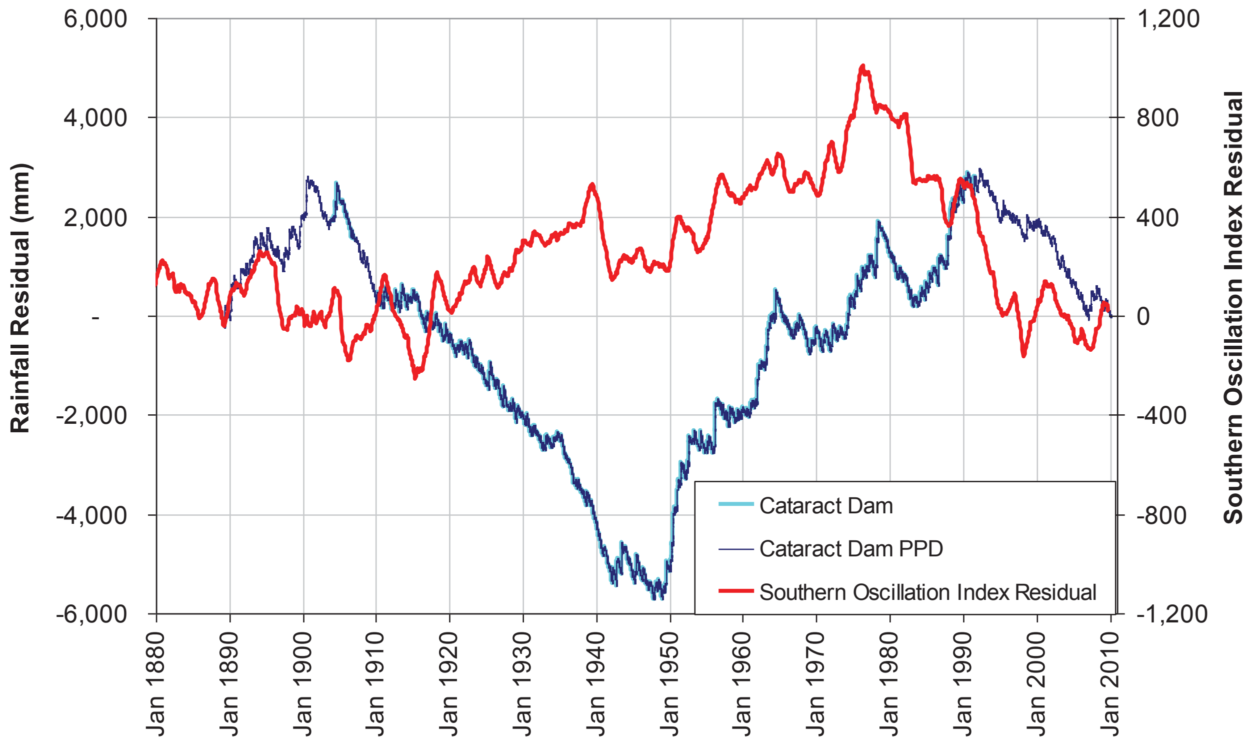


Figure 4.3 Rainfall Residual at Cataract Dam 1889-2009

4.1.3 Spatial Variability

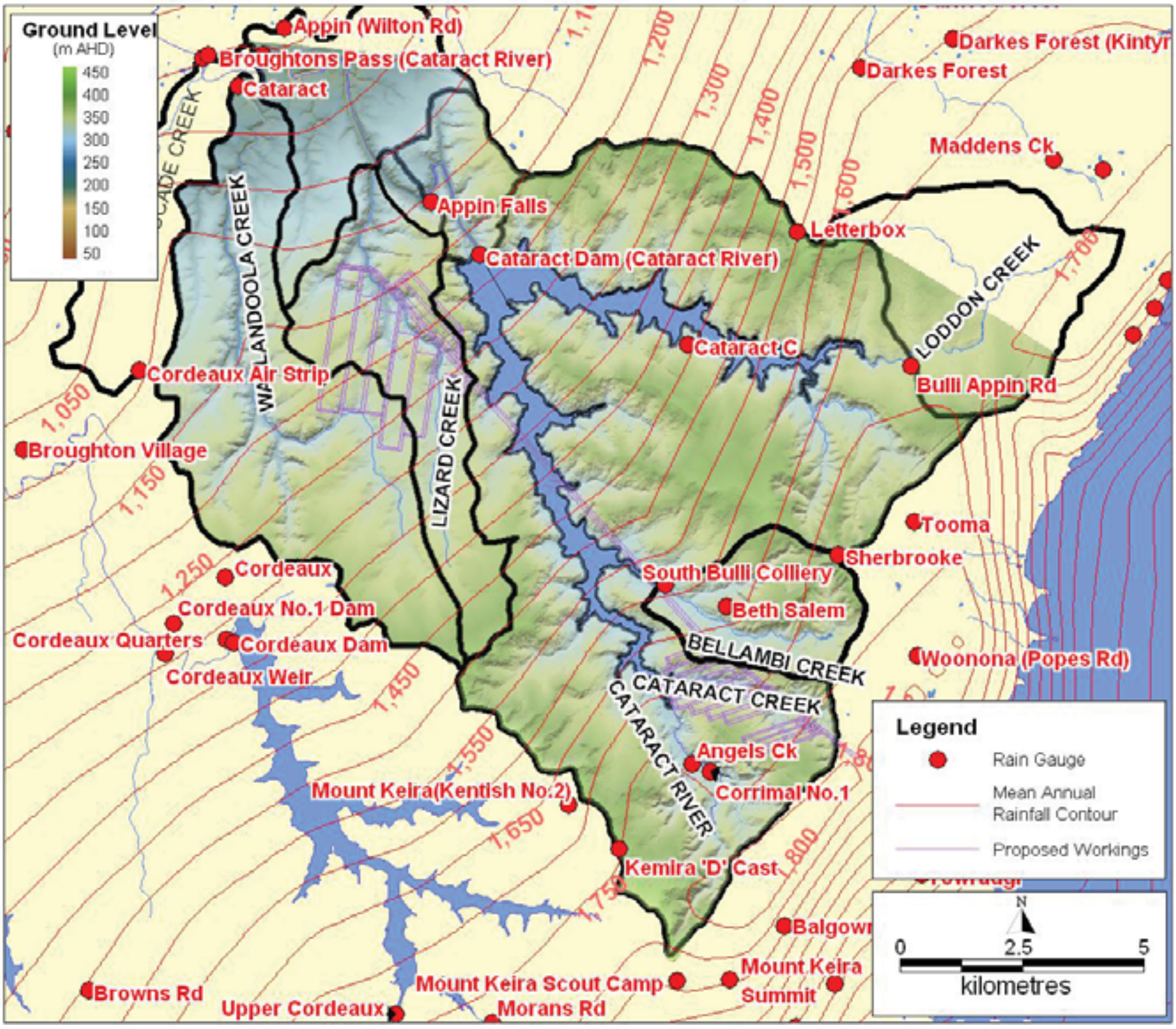
The locations of rainfall stations of interest are shown in Figure 4.4. Few stations have operated in the immediate vicinity of the proposed workings, and most are located near the Study Area boundary. Table 4.1 shows the period over which data was available from each of the gauges.

Table 4.1 Daily Rainfall Recording Stations in the Vicinity of the Study Area

Station Number	Station Name	Period of Record	
		Start	Finish
568004	Cordeaux Airstrip	08-Feb-1964	-
68020	Cordeaux Quarters	01-Jul-1945	-
68017	Cataract	30-Mar-1883	29-Dec-1966
68016	Cataract Dam	01-Jan-1904	-
568065	Letterbox Tower	06-Dec-1964	-
568067	Beth Salem	30-Aug-1966	-
68086	Mount Keira Scout Camp	30-Jan-1944	29-Jul-1992

The length and quality of records from these seven stations is variable. Continuous data from an overlapping data period is only available for the period 1984 to 1991. Figure 4.5 and Figure 4.6 compare average annual and average monthly rainfall at the gauges over this common period.

The figures show rainfall increases significantly across the study area from west to east. The eastern stations exhibit relatively high rainfall in February, March, April and June compared to the rest of the Study Area. This spatial variability of rainfall is also illustrated in Figure 4.4, which shows isohyets derived from gridded interpolated rainfall data over the Study Area prepared by BOM for the period 1969 to 1990.



(Source: BOM gridded data 1969-1990)

Figure 4.4 Mean Annual Rainfall Isohyets

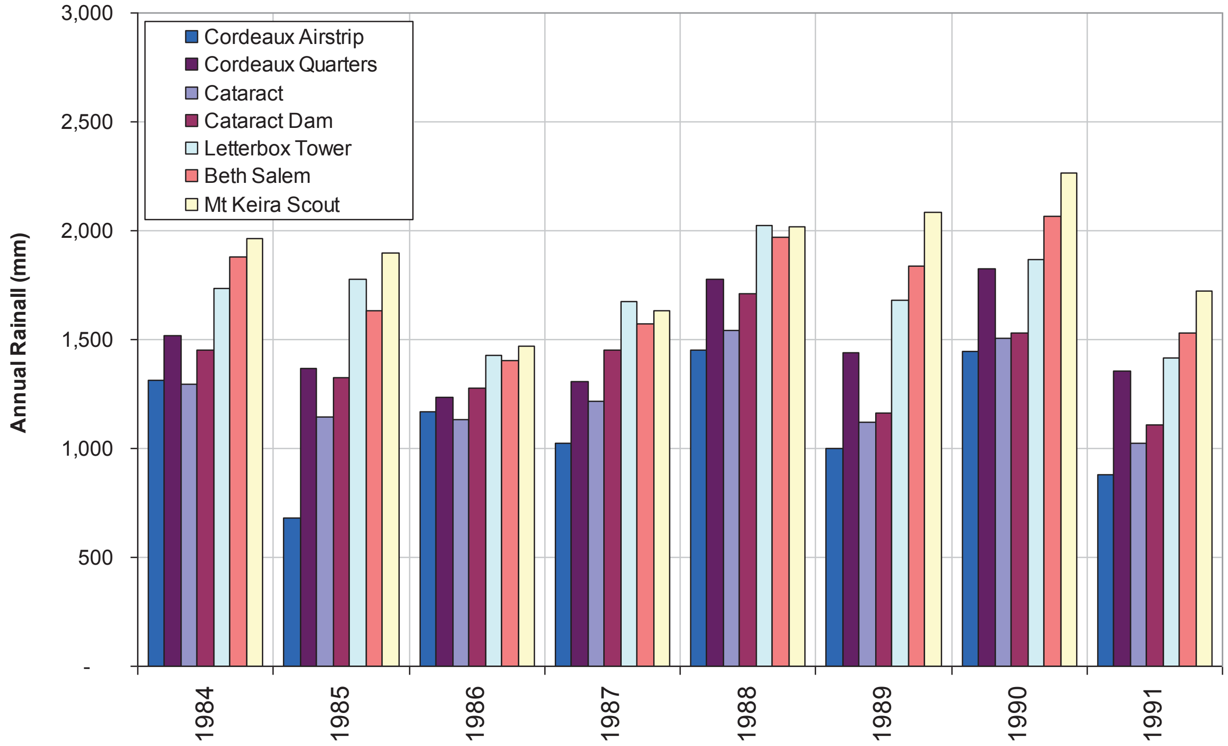


Figure 4.5 Variation in Mean Annual Rainfall across the Catchment (raw data 1984-1991)

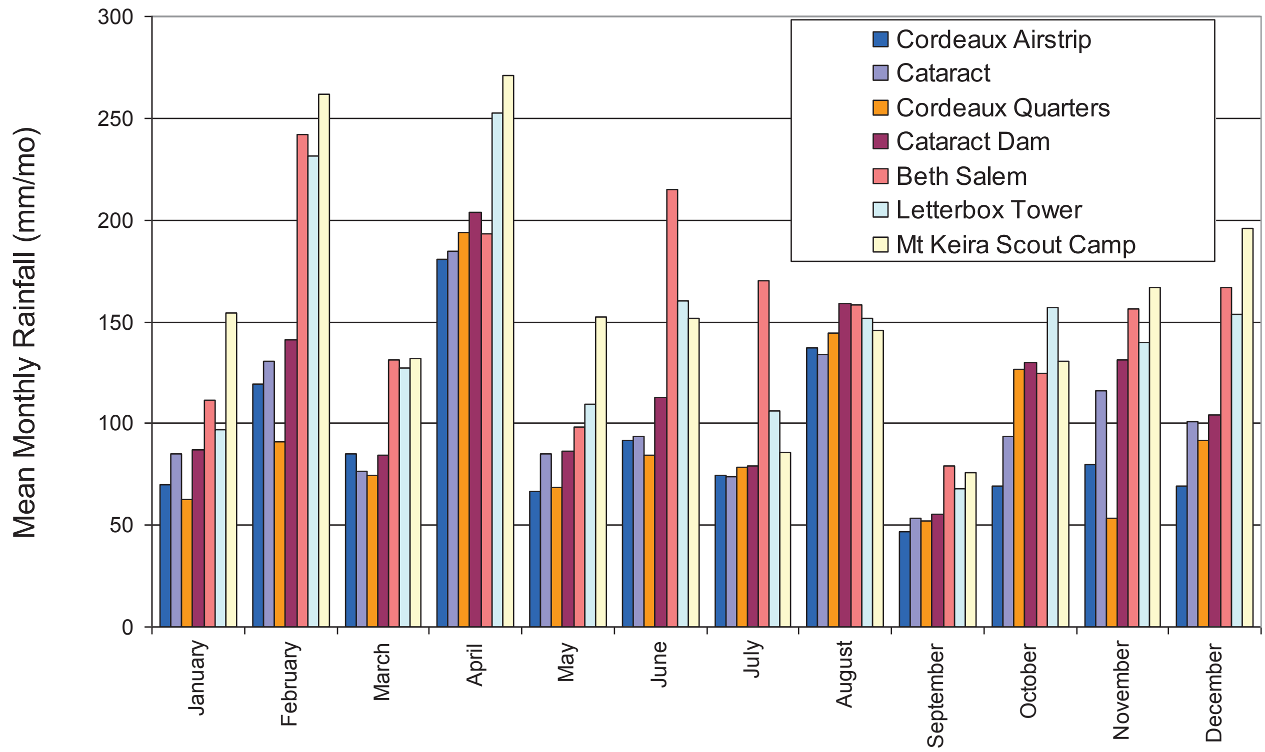


Figure 4.6 Variation in Mean Monthly Rainfall across the Catchment (raw data 1984-1991)

4.2 EVAPORATION

Daily Pan Evaporation has been recorded at the sites shown in Table 4.2 and Figure 4.7.

Table 4.2 Daily Evaporation Recording Stations in the Vicinity of the Study Area

Station	Location	Start	Finish
68017	Cataract		
668048	Cataract Dam	1908	
668049	Cordeaux Quarters	1-Jul-45	
668068	Upper Cordeaux	1973	31-Jul-96

Evaporation is relatively consistent across these gauges. Mean annual pan evaporation at Cataract Dam is approximately 1420 mm/a.

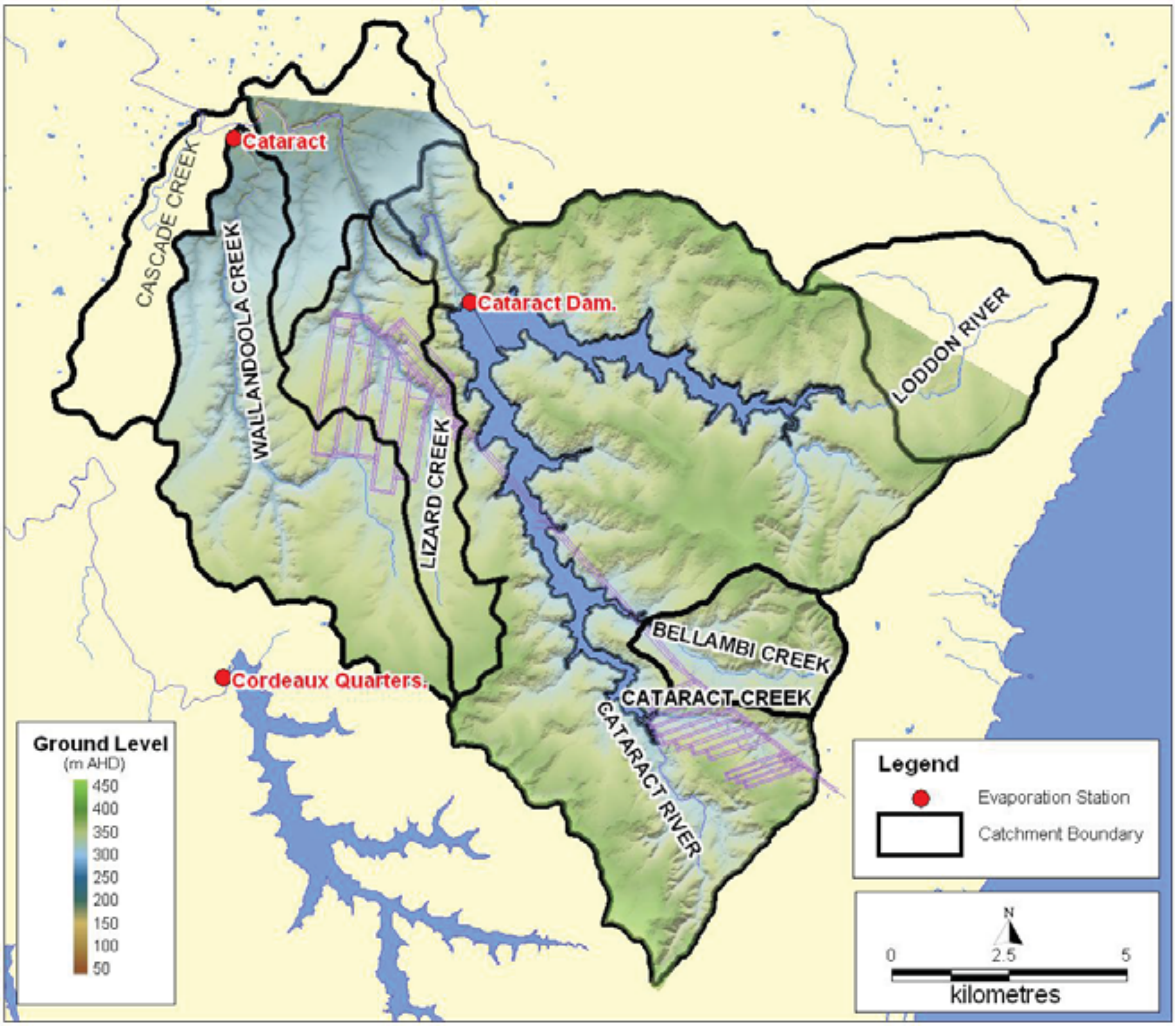


Figure 4.7 Daily Pan Evaporation Recording Stations

The monthly variation in pan evaporation at Cataract Dam is illustrated in Figure 4.8. Evaporation is highest in the summer months.

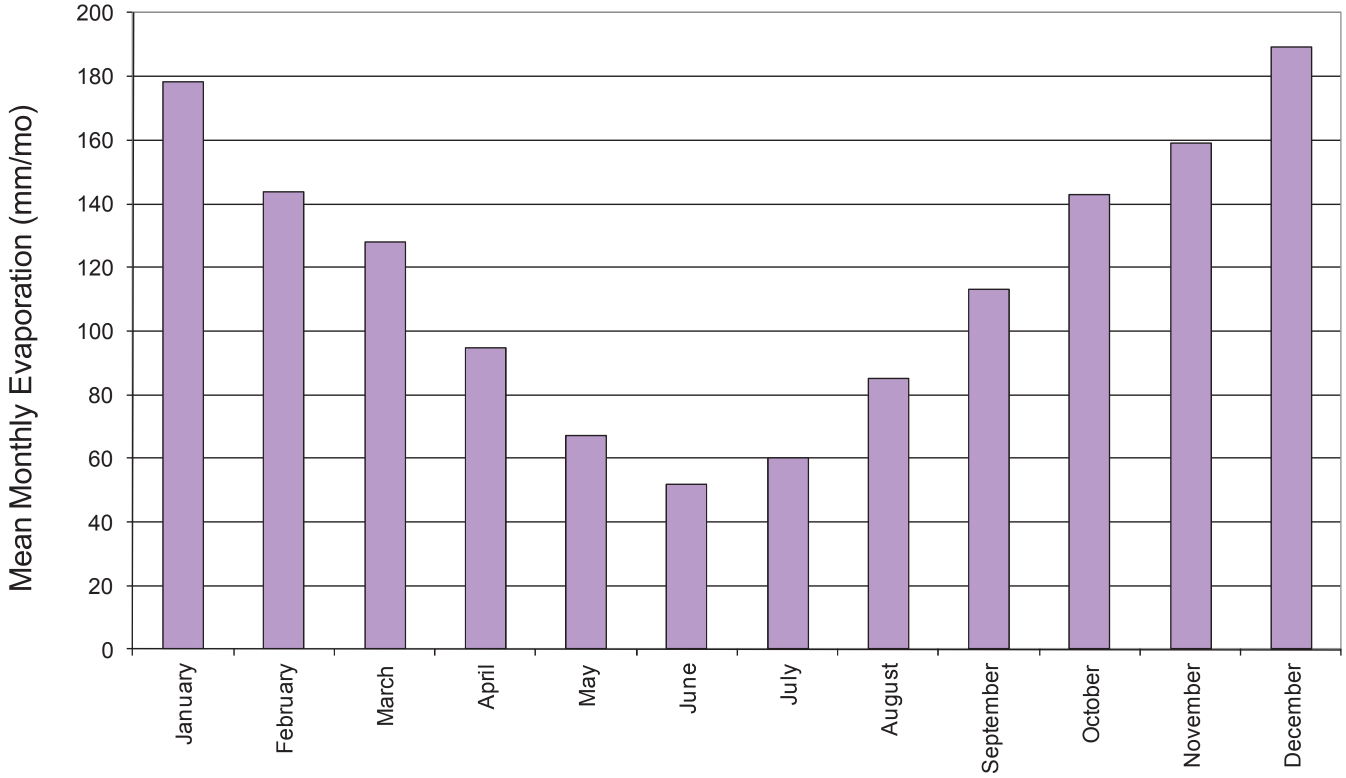


Figure 4.8 Monthly Pan Evaporation at Cataract Dam (PPD)

5 RUNOFF CHARACTERISTCS

5.1 STREAMFLOW DATA

Long term streamflow has been recorded in the Study Area at the gauges shown in Figure 5.1. Gauges in the immediate vicinity of the proposed workings used for this study are listed in Table 5.1. Both are in headwater streams flowing into Lake Cataract, and are not directly impacted by the predicted subsidence from the proposed workings.

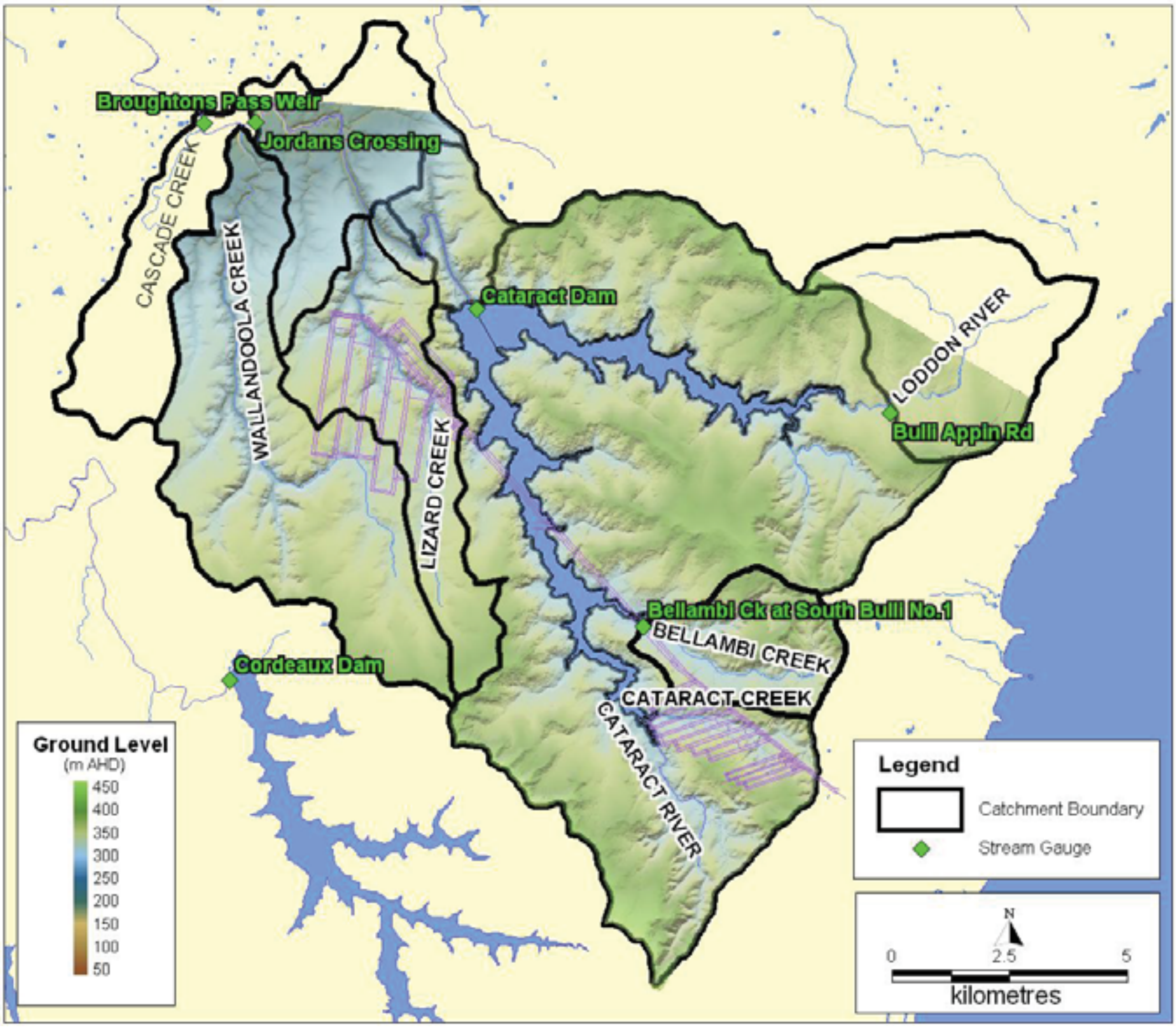


Figure 5.1 Streamflow Recording Stations in the Study Area

Table 5.1 Streamflow Recording Stations in the Study Area

Station Number	Station Name	Catchment Area (km²)	Mean Flow (ML/a)	Median Flow (ML/a)	Period of Record
2122321	Bellambi Creek at South Bulli No 1	9.3	2,608	1,194	01/01/1991-03/09/1995
2122322	Loddon River at Bulli Appin Rd	17.6	12,810	1,920	01/01/1991-08/11/2009

Streamflow is shown in Figure 5.2 for the overlapping period between 1991 and September 1995. The figure shows the catchments respond similarly, although much higher flows are generated from the Loddon River. Baseflow persists for extended periods after rainfall – and is similar in both streams, even though the Bellambi Creek catchment is much smaller. The flow frequency curves in Figure 5.3 show that flow occurs more than 90% of the time, and flows exceeding 3ML/d occur 50% of the time.

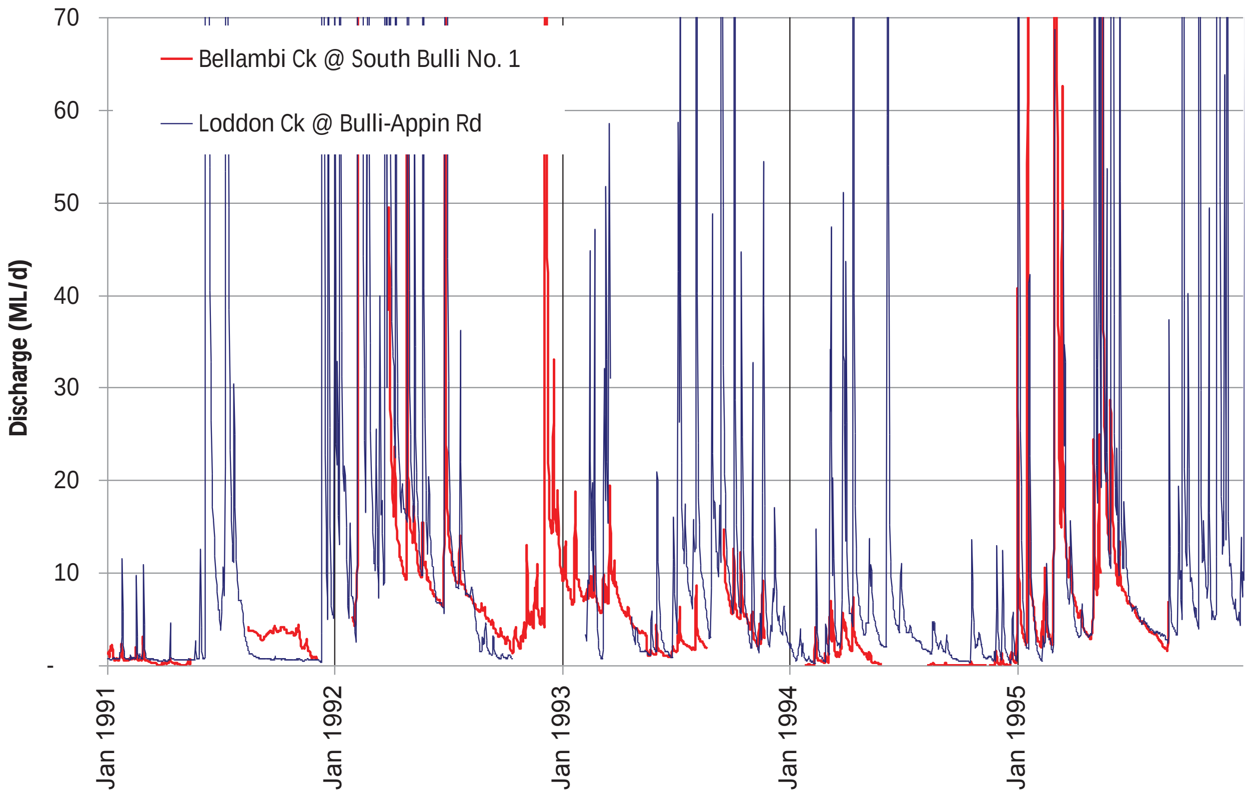


Figure 5.2 Sample Streamflow Record Bellambi Creek and Loddon River (1991-1995)

While persistent baseflow is a notable feature of the streamflow, it contributes a relatively small portion of total streamflow volume. The curves in Figure 5.4 show that over 90% of the total streamflow volume came from the largest 40% of daily flows. Flows of less than 3ML/d made up only 5% of total flow volume from both catchments.

There are however some periods when the flows are dissimilar – due probably to spatially variable rainfall. The Loddon River catchment exhibits a significantly higher runoff to rainfall ratio, as demonstrated in the table below, which compares total runoff (considering days when flow was recorded at both gauges only).

Table 5.2 Runoff Characteristics Loddon River and Bellambi Ck 1991-1995

Station Name	Mean Annual Flow (ML/a)	Runoff Depth (mm/a)
Bellambi Creek at South Bulli No 1	2,608	280
Loddon River at Bulli Appin Rd	9,239	525

Very low flows less than 1 ML/d occur less frequently in Bellambi Creek. This may be partially a result of the effect of Charlesworth Dam which is located in the upstream catchment, as shown in Figure 6.1.

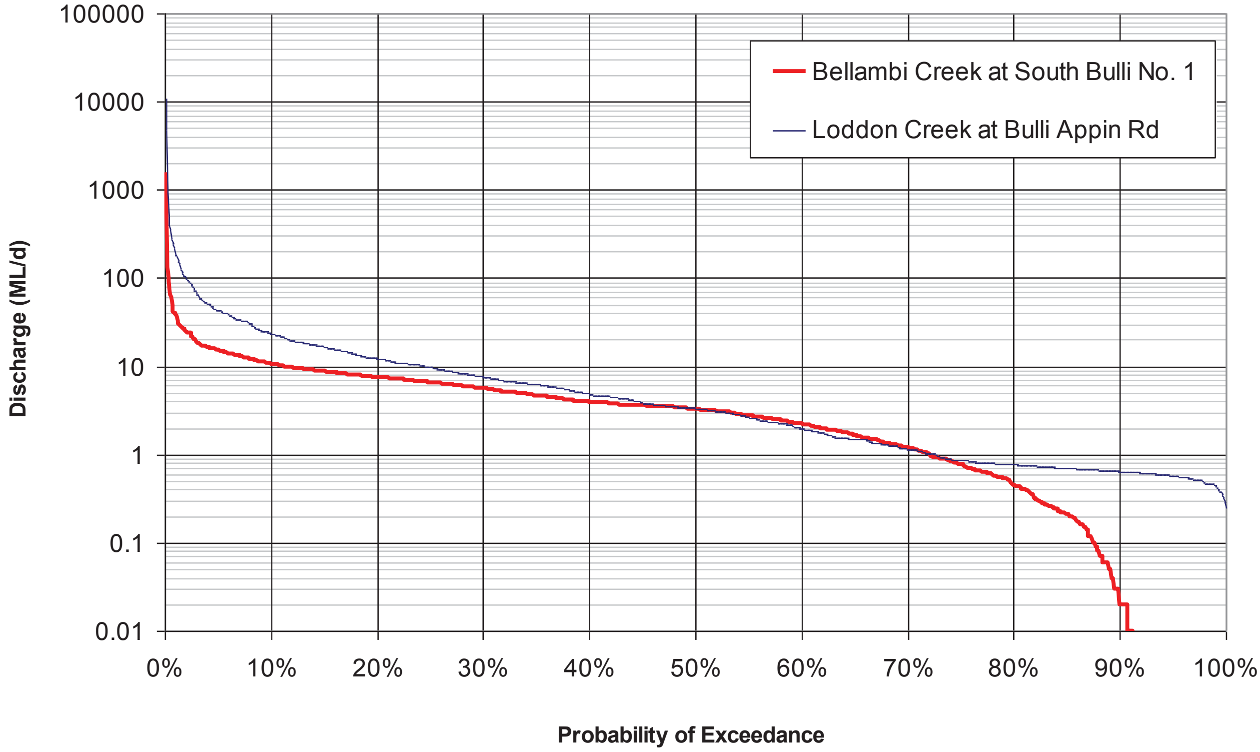


Figure 5.3 Flow Frequency Curves Bellambi Creek and Loddon River (1991-1995)

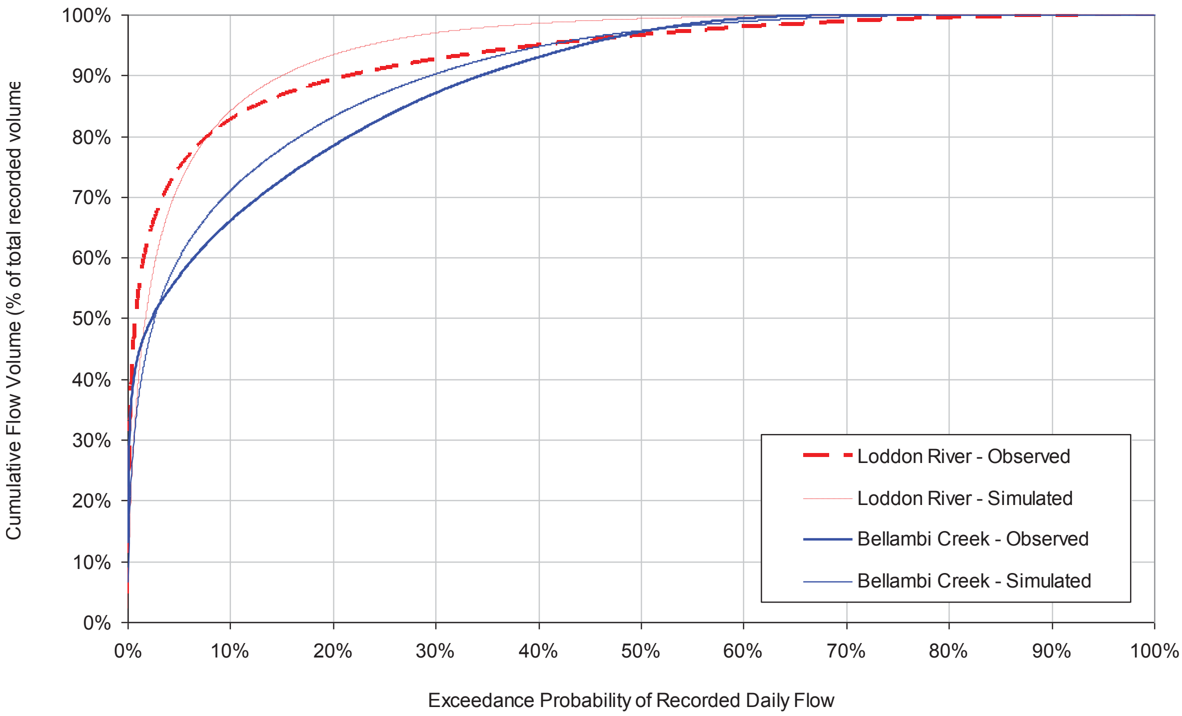


Figure 5.4 Cumulative Flow Volume Bellambi Creek and Loddon River

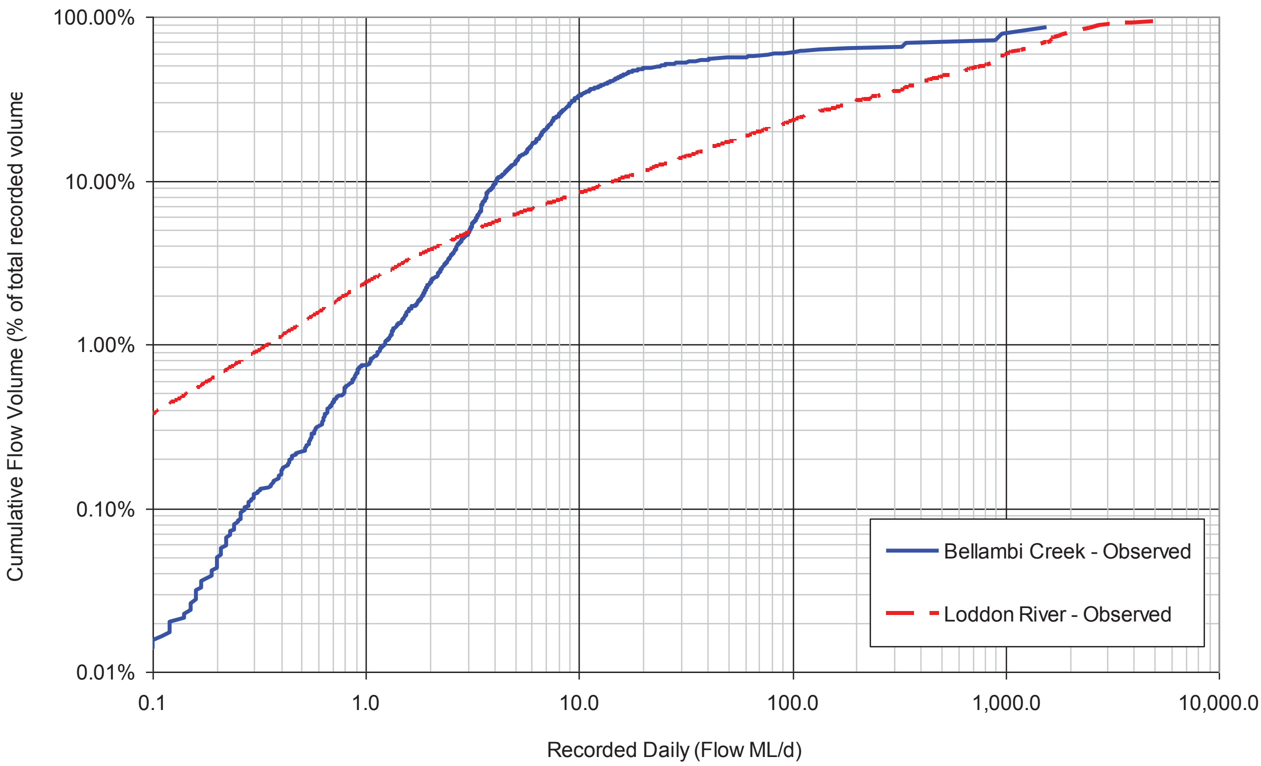


Figure 5.5 Cumulative Flow Volume Bellambi Creek and Loddon River

5.2 POOL LEVEL AND STREAM FLOW MONITORING

Pool water levels have been monitored in the study area since September 2009. Six sites are located on Lizard Creek, two on tributaries of Lizard Creek, three on Wallandoola Creek, three on Cataract Creek and two on the Cataract River as shown in Figure 5.6 and Figure 5.7 below (Geoterra, 2011). Figure 5.8 to Figure 5.12 show the recorded pool water levels in Wallandoola, Lizard and Cataract Creeks as well as the Cataract River.

Note that the logger at CC3 was found wet during the period 3/9/2011 to 2/12/2011 and therefore did not record any usable data over this period.

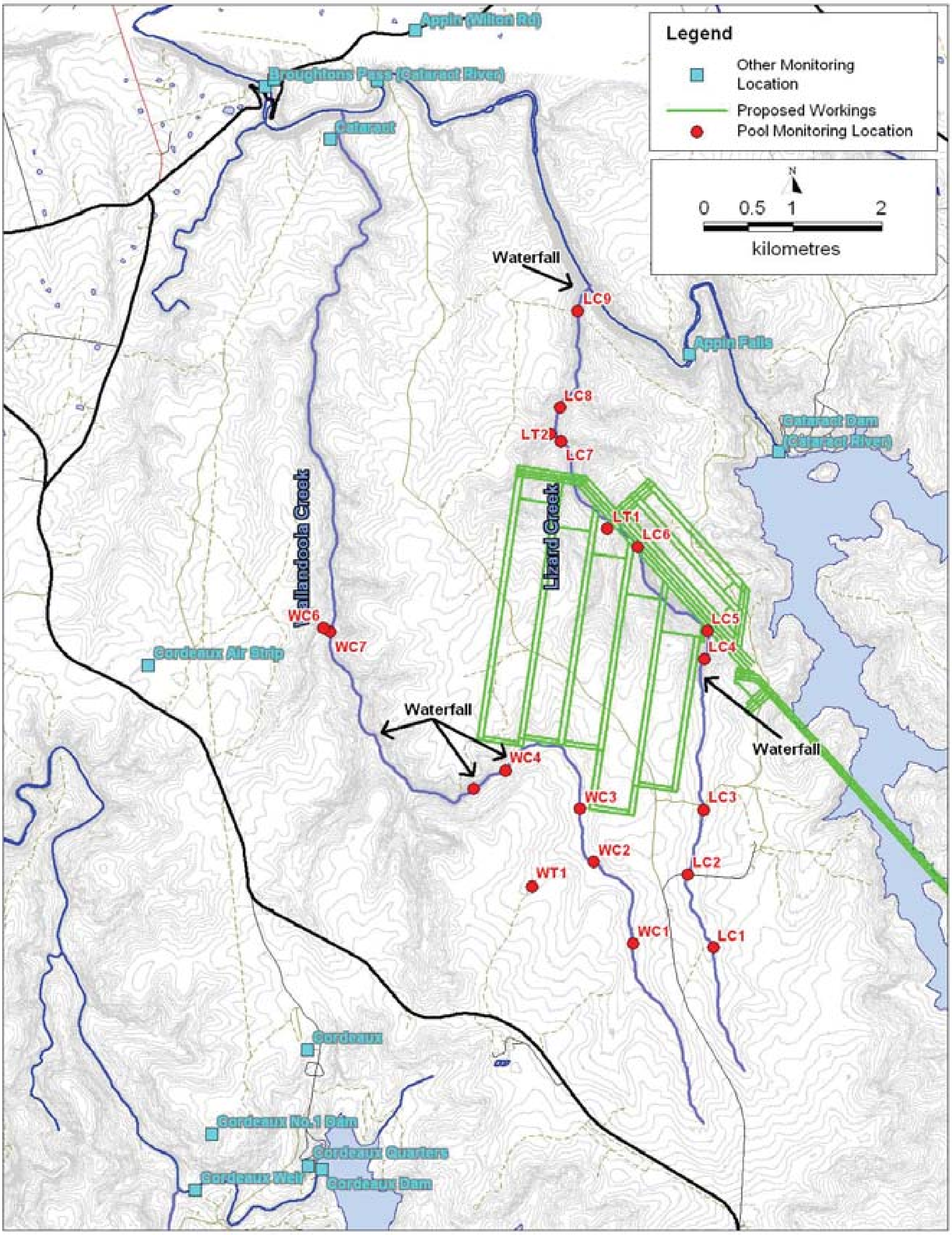


Figure 5.6 Pool Monitoring Locations, Wonga West

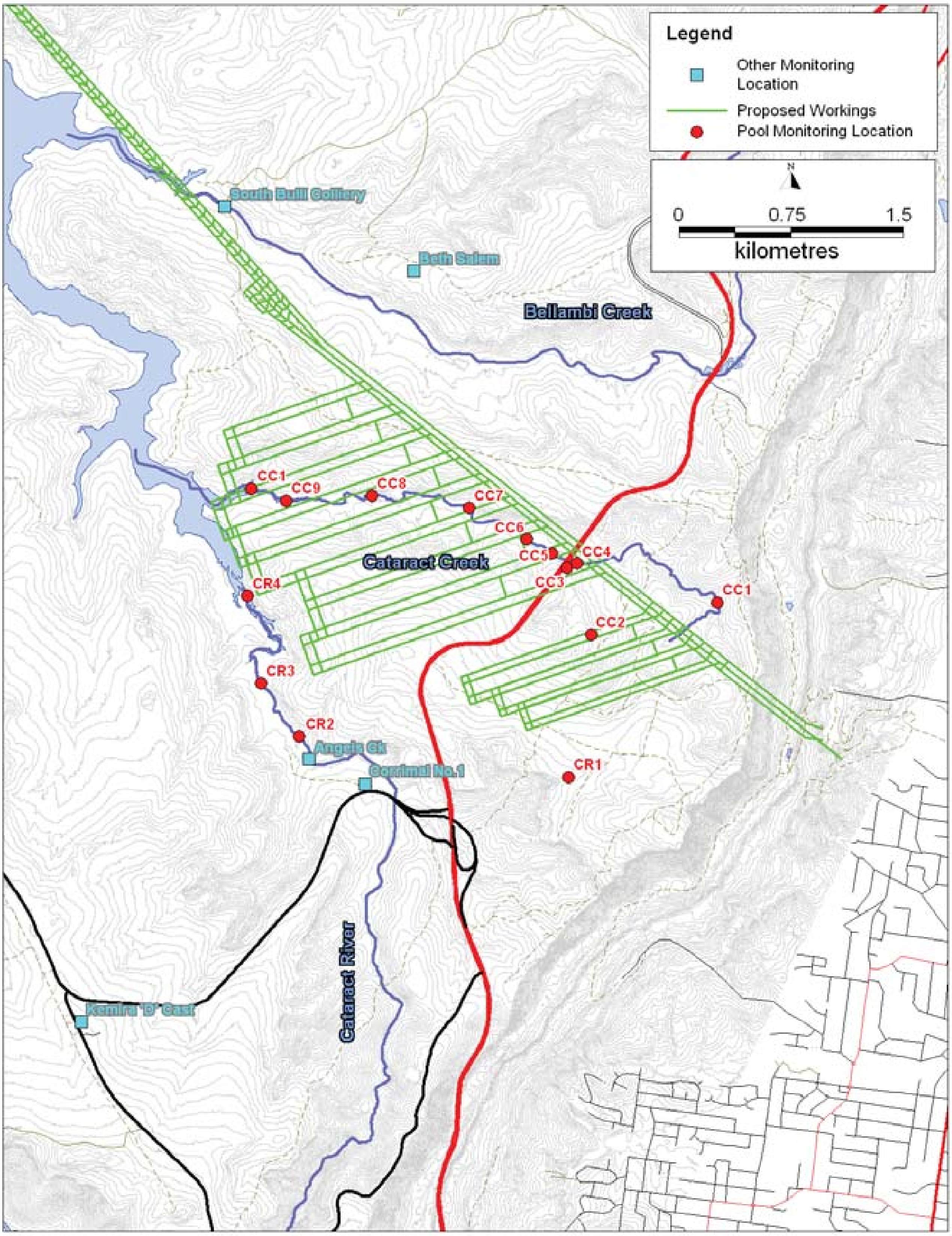


Figure 5.7 Pool Monitoring Locations, Wonga East

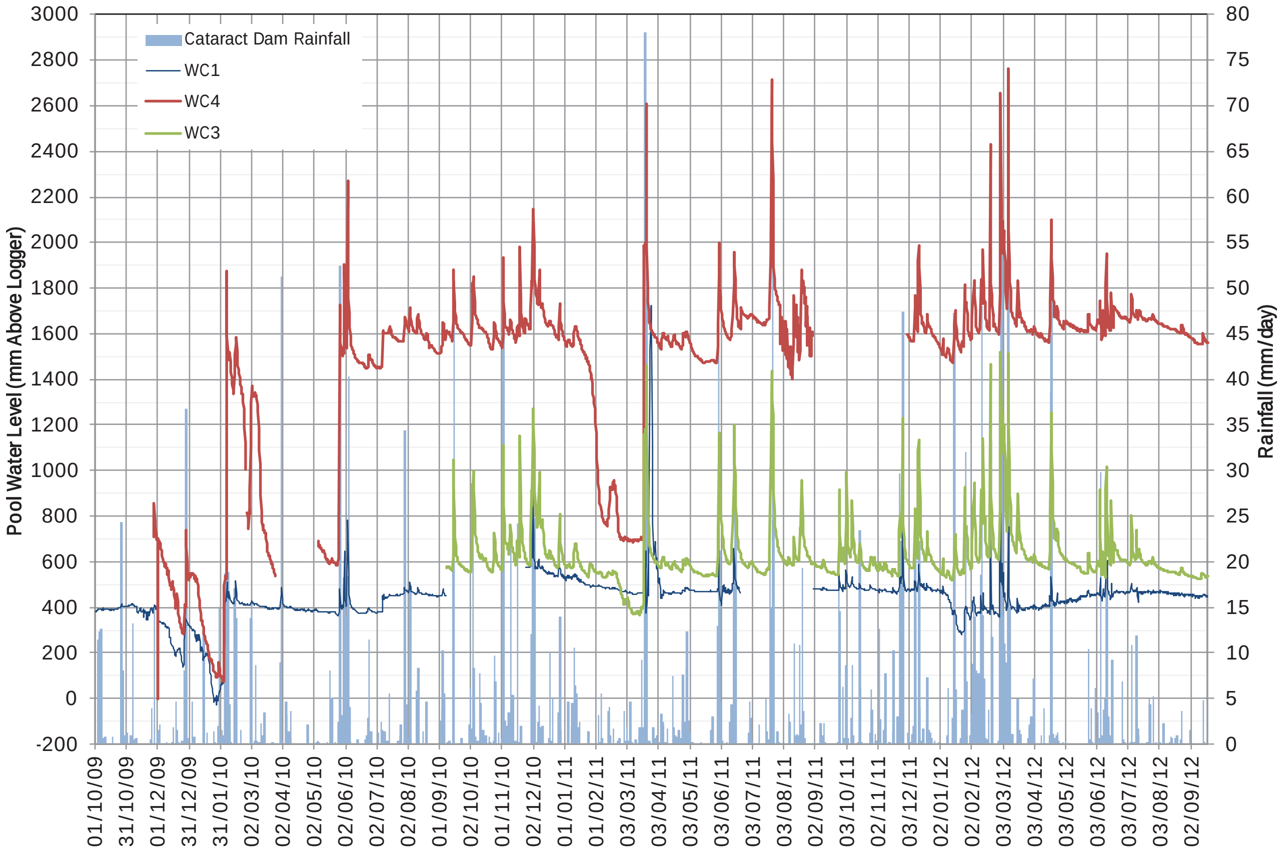


Figure 5.8 Wallandoola Creek Pool Monitoring Data

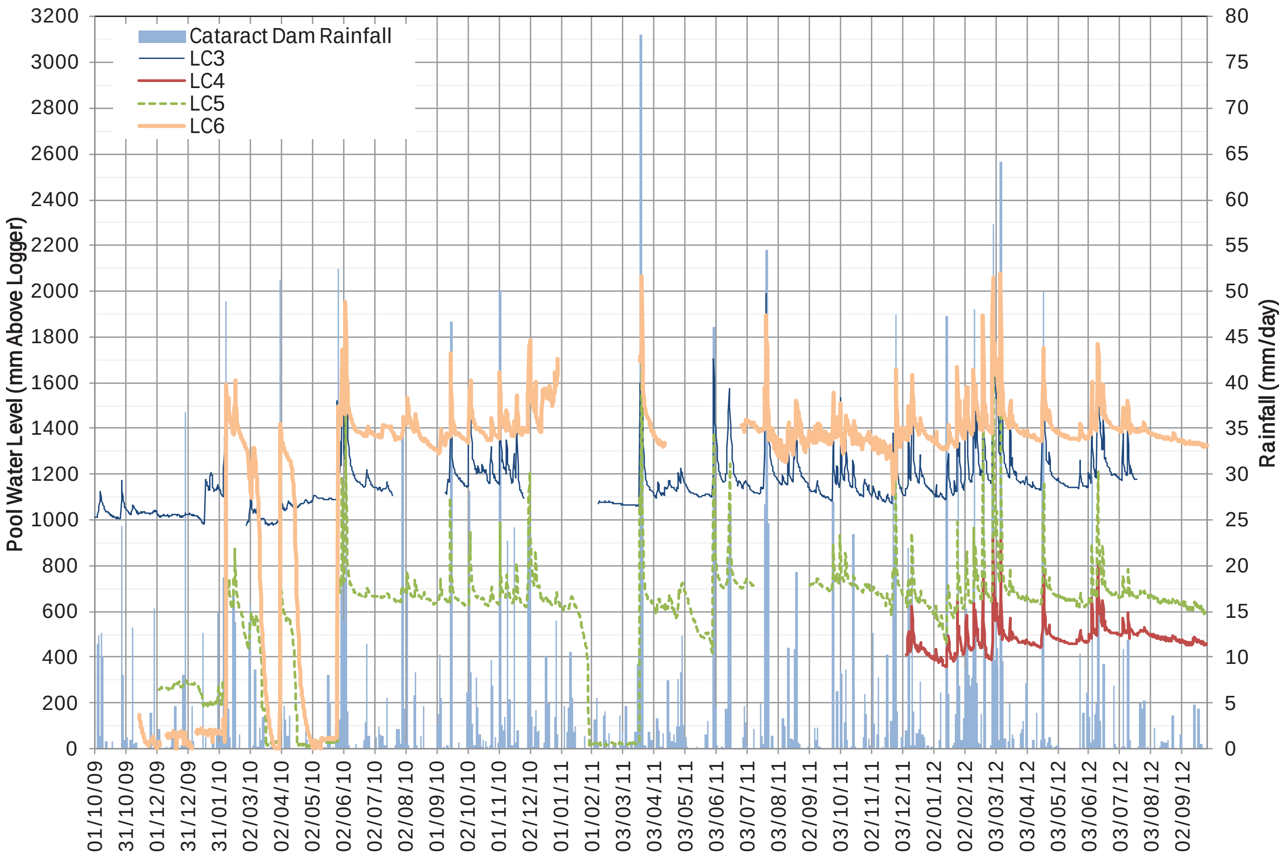


Figure 5.9 Lizard Creek Pool Monitoring Data, Sites LC3, LC4, LC5 and LC6

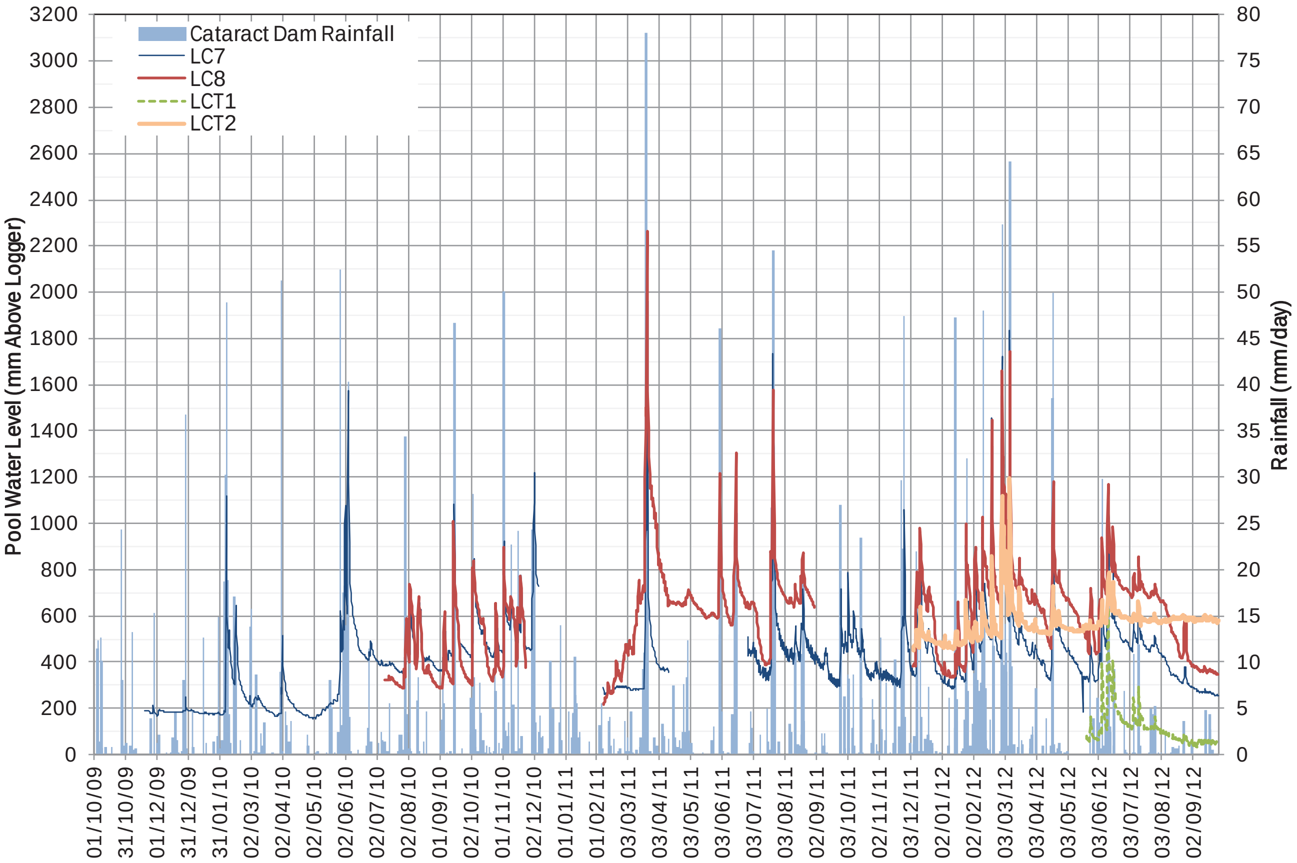


Figure 5.10 Lizard Creek Pool Monitoring Data, Sites LC7, LC8, LCT1 and LCT2

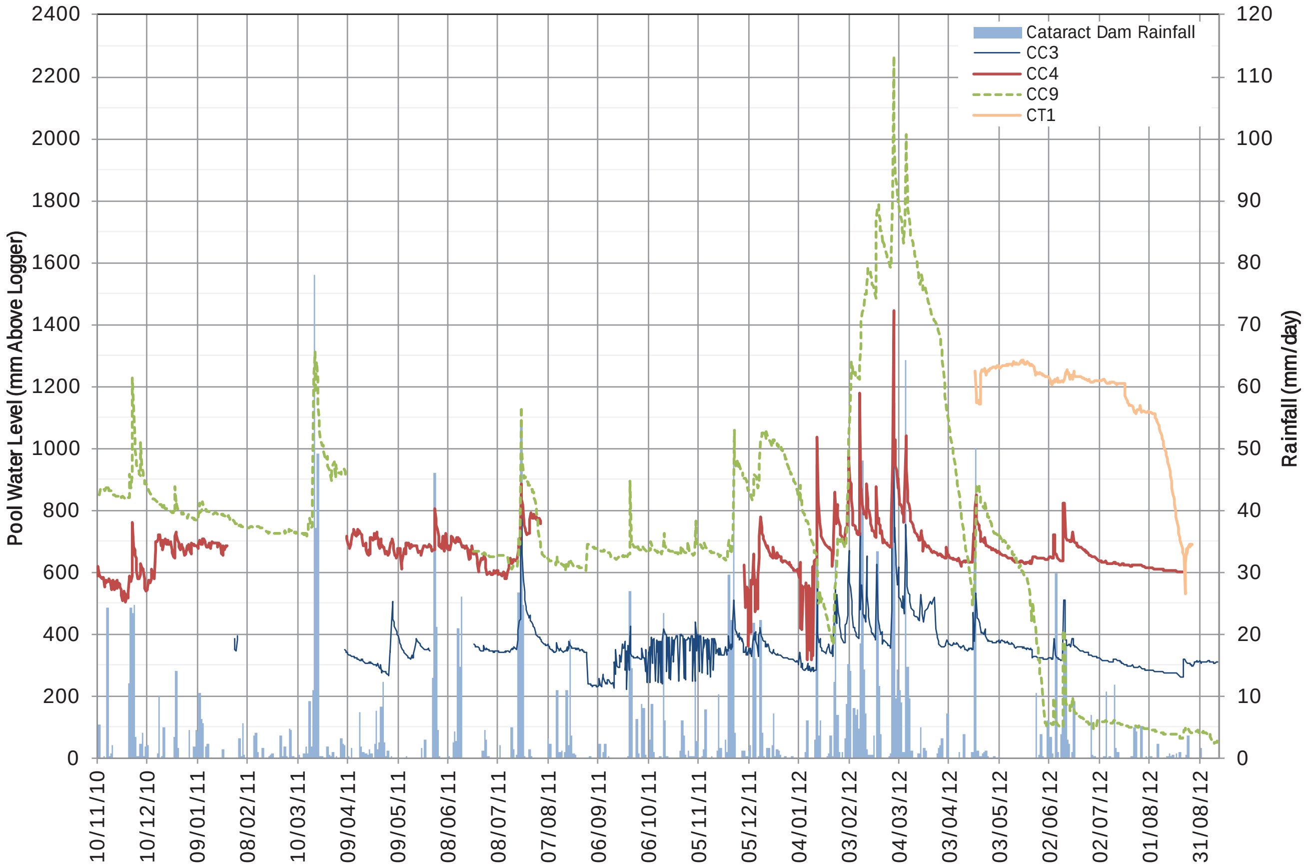


Figure 5.11 Cataract Creek Pool Monitoring Data

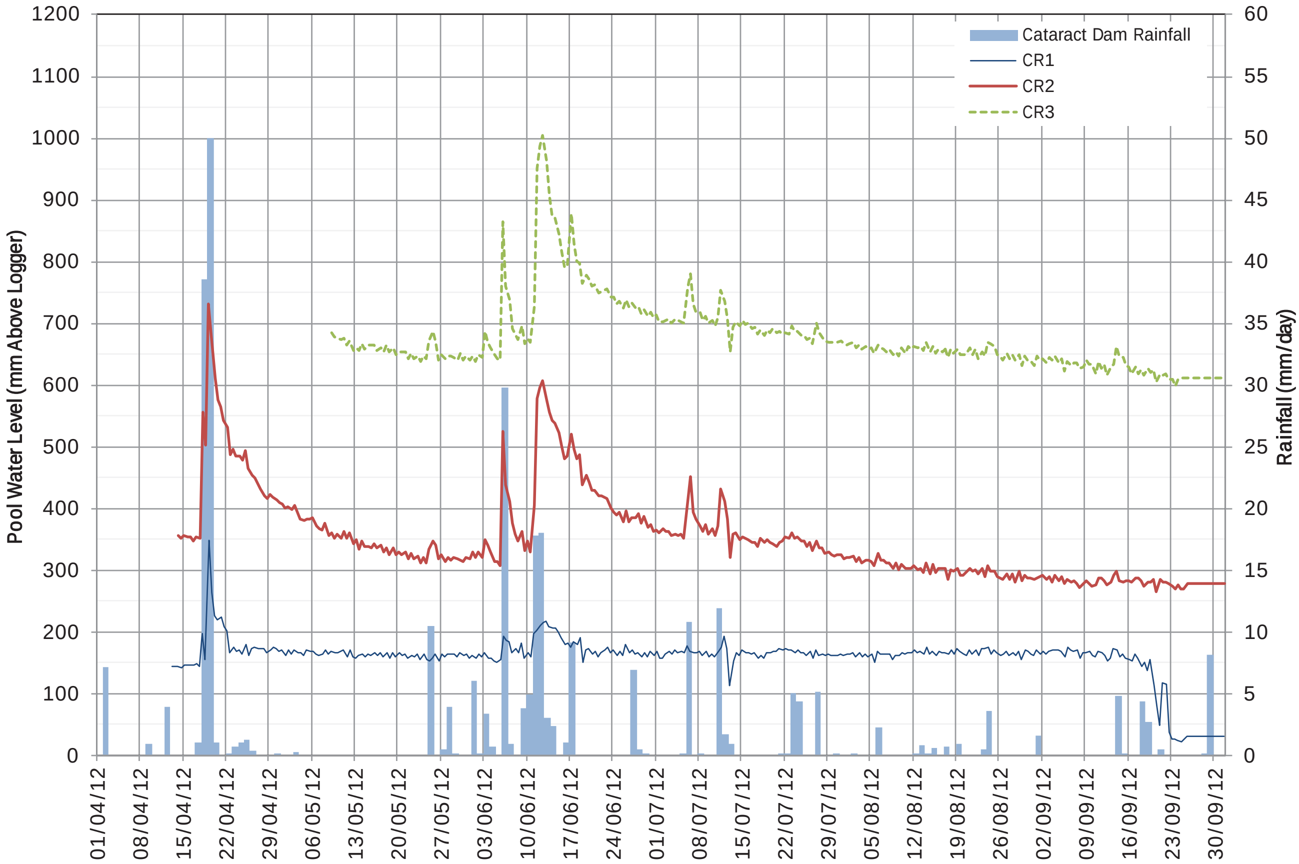


Figure 5.12 Cataract River Pool Monitoring Data

5.2.1 Lizard Creek

Volumetric stream flow monitoring has also been conducted in Lizard Creek since mid September 2009 at LC3 (see Figure 5.6). The monitoring data collected to date is shown in Figure 5.13.

Volumetric flow monitoring has not been conducted in Lizard Creek between LC3 and LC6 due to the presence of two zones of subsidence cracking in the creek bed resulting in disconnected stream flow during low flow periods due to mining subsidence over the Bulli Seam workings dating back to the 1970s.

The upstream zone extends from downstream of LC3 to approximately 200m upstream of the waterfall between LC3 and LC4. The downstream zone of cracking in Lizard Creek extends between LC5 and LC6.

The isolated cracked areas enable transfer of overland stream flow to the shallow groundwater system under the creek bed. This means that not all of the total catchment flow in this reach is present as overland flow, and therefore a surface flow based monitoring system would under report the actual volume of water flowing down the catchment and into Cataract River.

Stream flow resurfaces immediately downstream of LC6. No subsidence cracking or adverse stream flow effects are observed in Lizard Creek between LC6 and the confluence with Cataract River.

Volumetric flow monitoring was initially conducted at Site LC7 until it was observed that a variable proportion (possibly up to 30%) of the overland flow was draining through a natural bedding plane discontinuity which had been washed out. It should be noted that this diversion is natural and is not due to subsidence cracking.

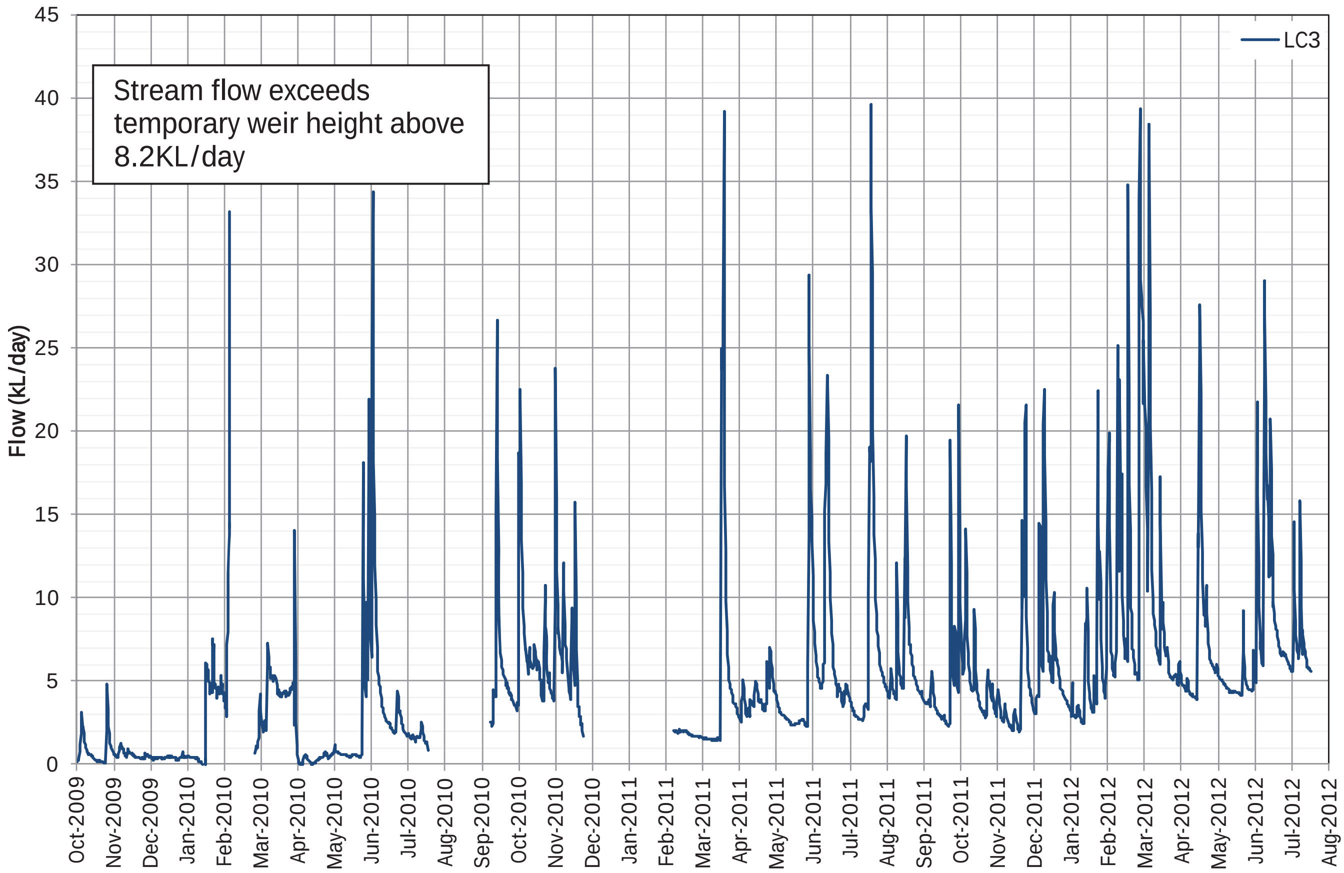


Figure 5.13 Recorded Flows in Lizard Creek at LC3

5.2.2 Wallandoola Creek

As a result of the lack of suitable sites between WC1 and WC4, no volumetric flow monitoring has been conducted to date in Wallandoola Creek. However, suitable sites are currently being searched for and installed. The limited availability of flow monitoring sites is due to the:

- valley fill swamp with no suitably defined / constrained channel between WC1 and downstream of WC2;
- elongated standing water pools between WC2 and WC4 with limited or unsuitable flow constriction points at the outflow of the pool.

In addition, no suitable overland flow monitoring sites are present in the stepped waterfall section between WC4 and WC5 due to previous subsidence cracking dating back to the 1970-80s which has caused subterranean diversion of the overland flow in that reach.

5.2.3 Cataract Creek

Volumetric stream flow monitoring has not yet been conducted in Cataract Creek, however 3 sites are being investigated for their suitability, taking into account the potential effects of:

- the presence of zones of subsidence cracking in the creek bed resulting in disconnected stream flow during low flow periods due to mining subsidence over the Bulli Seam and Balgownie Seam workings dating back to the 1970s. The isolated cracked areas can enable transfer of overland stream flow to the shallow groundwater system under the creek bed. This means that not all of the total catchment flow in this reach is present as

overland flow, and therefore a surface flow based monitoring system could under-report the actual volume of water flowing down the catchment and into Cataract Reservoir;

- overland flow diversions through natural bedding plane discontinuities which are washed out. It should be noted that this diversion is natural and is not due to subsidence cracking.

5.2.4 Cataract River

Volumetric stream flow monitoring has not yet been conducted in Cataract River, however 2 sites are being investigated for their suitability, taking into account the potential effects of:

- the presence of zones of subsidence cracking in the creek bed resulting in disconnected stream flow during low flow periods due to mining subsidence over the BHP Cordeaux workings dating back to the 1970s. The isolated cracked areas can enable transfer of overland stream flow to the shallow groundwater system under the creek bed. This means that not all of the total catchment flow in this reach is present as overland flow, and therefore a surface flow based monitoring system could under-report the actual volume of water flowing down the catchment and into Cataract Reservoir.
- overland flow diversions through natural bedding plane discontinuities which are washed out. It should be noted that this diversion is natural and is not due to subsidence cracking.

6 CATCHMENT MODELLING

6.1 MODELLING APPROACH

Rainfall-runoff models were created for the two gauged headwater catchments in the Study Area; Loddon River and Bellambi Creek. The models were calibrated to the daily streamflow records and used to extend those records to the length of available climate record.

The AWBM was selected for catchment modelling, as it has been successfully used in neighbouring catchments for similar studies. It uses a group of connected conceptual storages (three surface water storages and one ground water storage) to represent a catchment. Water in the conceptual storages is replenished by rainfall and is reduced by evaporation. Simulated surface runoff occurs when the storages fill and overflow. The model parameters define the storage depths, the proportion of the catchment draining to each of the storages, and the rate of flux between them (Boughton, 2003).

Daily runoff from other catchments in the Study Area was estimated using the AWBM, with model parameters transposed from the adjacent calibrated catchments. Climate data specific to each sub-catchment of interest was used to account for the spatial variability described in the previous sections.

The catchment models were validated by directing the modelled runoff to a daily water balance model of the Lake Cataract system. Modelled stored water levels were then compared to historical records provided by the SCA.

6.2 INPUT CLIMATE DATA

Key climate data inputs for the AWBM are daily rainfall and daily evapotranspiration (this is different to most rainfall-runoff models, which use potential evapotranspiration) (Podger, 2004).

Rainfall data for the gauged catchments was obtained from nearby recording stations. The locations of these stations are shown in Figure 6.1 and Figure 6.2 respectively.

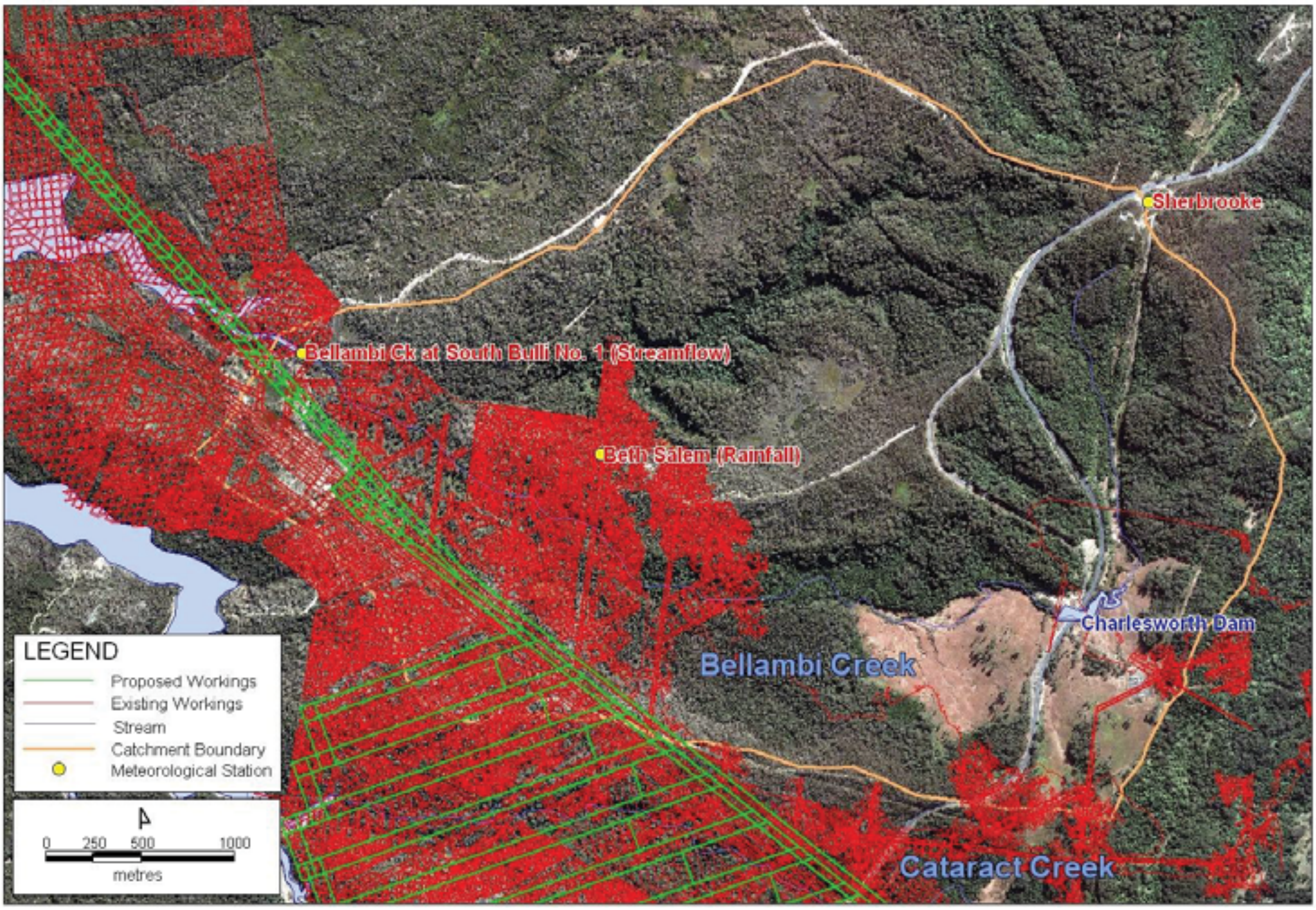


Figure 6.1 Bellambi Creek Catchment

Figure 6.2 Loddon River Catchment

As pan evaporation has not been recorded in the immediate vicinity of the streamflow gauges, the BOM's SILO Data Drill service was used to derive inputs for catchment modelling. The Data Drill *"accesses grids of data derived by interpolating the Bureau of Meteorology's station records. Interpolations are calculated by splining and kriging techniques. The data in the Data Drill are all synthetic; there are no original meteorological station data left in the calculated grid fields. However, the Data Drill does have the advantage of being available for any set of coordinates in Australia"* (Bureau of Meteorology, 2006).

Data Drill data was used to infill and extend the datasets from the nearby recording stations where required. Details of the data used are summarised in Table 6.1. Daily rainfall derived using the Datadrill are compared to rainfall observations in Appendix A for nearby rainfall gauges.

While the Datadrill data is a synthetic dataset, and therefore needs to be used with caution, it can be useful for catchment studies where insufficient site-specific data is available.

Table 6.1 Input Data Sources for Catchment Modelling

Stream Gauge	Rainfall Data Source	Evapotranspiration Data Source
Bellambi Creek at South Bulli No.1	Beth Salem (Raw Data from SCA extend and with gaps in-filled using Data Drill at Beth Salem)	Data Drill at Beth Salem
Loddon River at Bulli-Appin Rd	Letterbox Tower (Raw Data from SCA extend and with gaps in-filled using Data Drill at Beth Salem)	Data Drill at Letterbox Tower

The recorded datasets are shown in the following four figures, which also show the duration and timing of rainfall data gaps that were infilled prior to calibration and the SCA quality codes assigned to the streamflow records. Descriptions of the corresponding quality codes are given in Table 6.2.

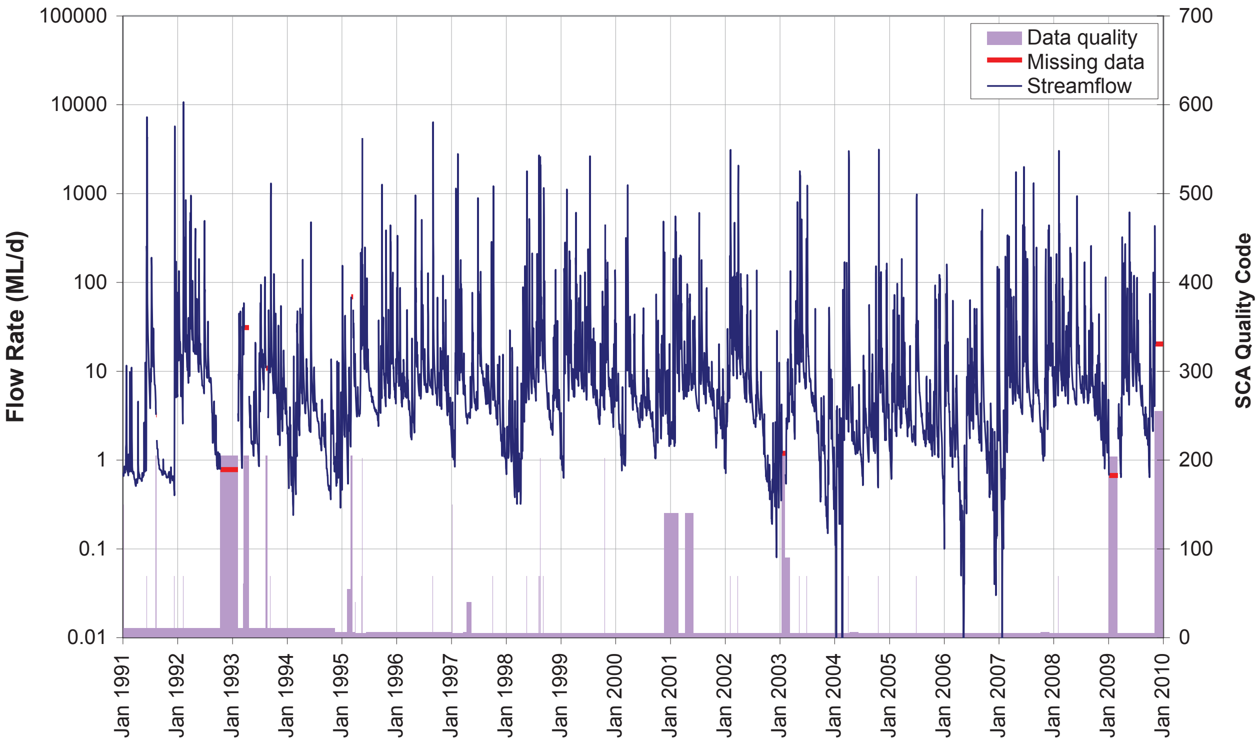


Figure 6.3 Streamflow Measured at Loddon River at Bulli Appin Road

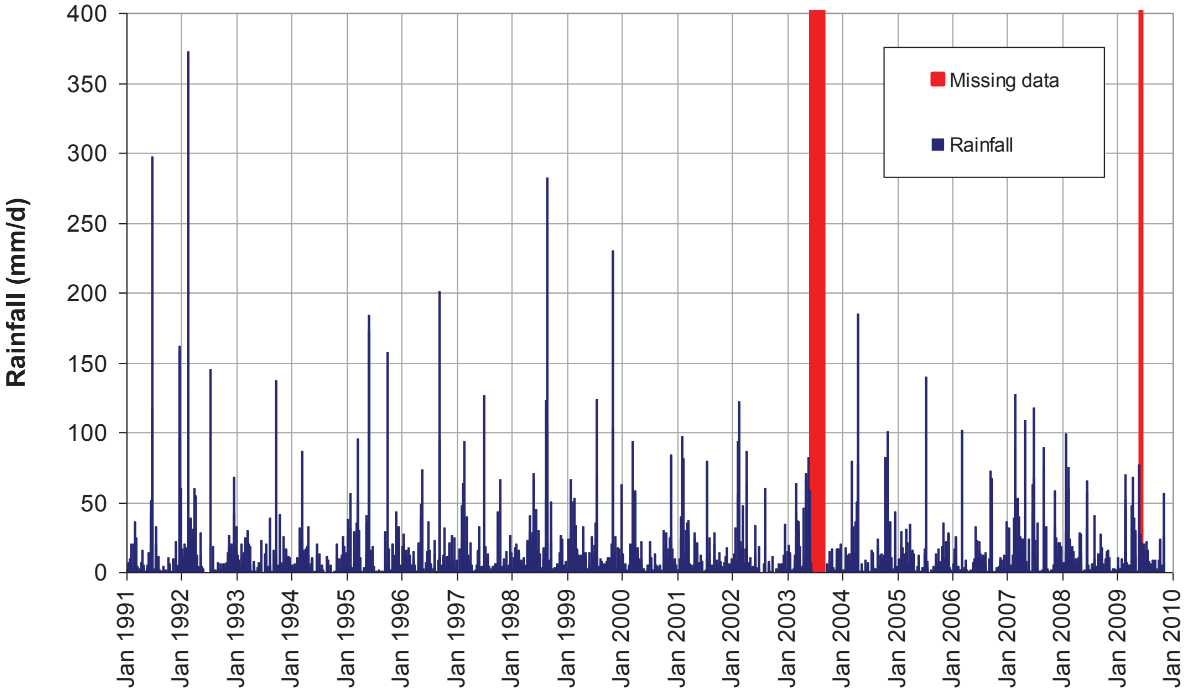


Figure 6.4 Rainfall Measured at Letterbox Tower over Loddon River Gauge Period

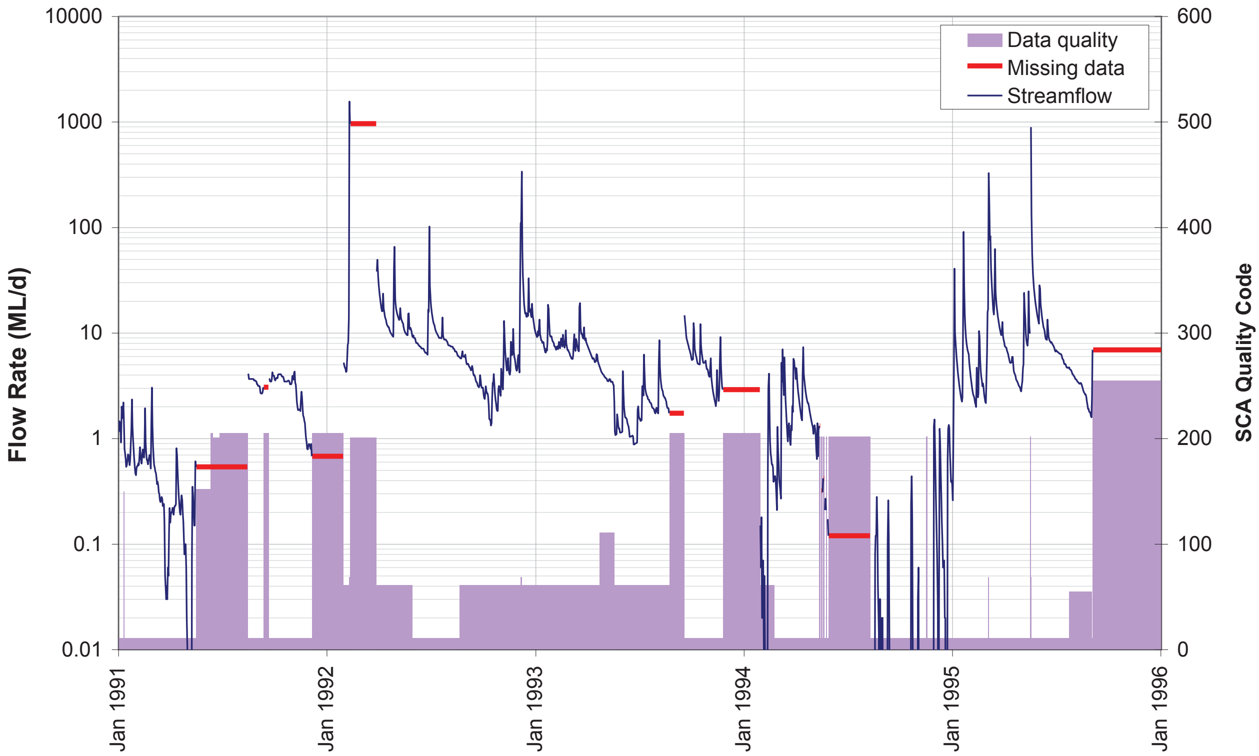


Figure 6.5 Streamflow Measured at Bellambi Creek at South Bulli No. 1

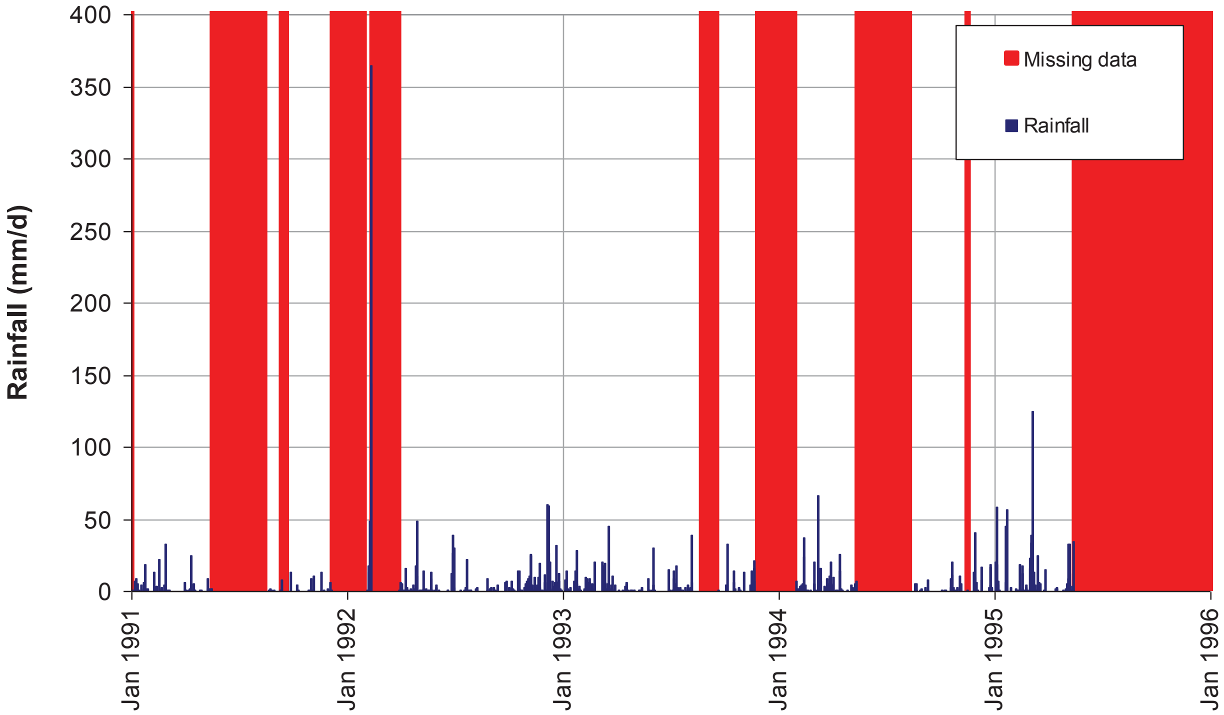


Figure 6.6 Rainfall Measured at Beth Salem Over Bellambi Creek Gauge Period

Table 6.2 SCA Quality Code Descriptions

Quality Code	Description
5	Good quality edited data
6	Reasonably good quality edited data
11	Good quality record processed pre 1995 and coded either 5 or 6
40	Good quality estimate (correlation or other reliable method)
55	Fair quality edited data
57	Fair quality contractor supplied data
61	Fair quality record processed pre 1995 and quality coded 55
69	Fair quality rating extrapolation
90	Fair quality estimation (correlation or other method)
105	Poor quality edited data
111	Poor quality records processed pre 1995 and quality coded 105
119	Poor quality rating extrapolation
140	Estimate that reasonably reflects the actual event with edit comments inserted to explain method of estimation
149	Contractors data supplied without quality codes
150	Data not yet quality coded
151	Backwater affected
152	Data for which quality
162	SENSOR OUT OF WATER WITH NO FLOW
201	Data not recorded - logger/sensor not installed
202	Data not available for release (e.g requires extensive editing)
204	Data lost due to vandalism
205	Data lost
255	Hydsys default - no data

6.3 CALIBRATION OF BELLAMBI CREEK CATCHMENT MODEL

The Bellambi Creek AWBM Model was calibrated over the period between the 1st of January 1991 and the 1st of September 1995.The adopted AWBM parameters are summarised in Table 6.3 below.

Table 6.3 Adopted AWBM Parameters – Bellambi Ck Catchment

Parameter	Value
A1	0.134
A2	0.433
BFI	0.317
C1	6
C2	94
C3	240
K_{base}	0.976
K_{surf}	0.632

It was not possible to perfectly replicate all streamflow features of interest (e.g. annual flow, flow frequency, monthly flow, daily flow, hydrograph shape, and baseflow) at all temporal scales. The calibration parameters were selected to achieve a compromise between matching the above characteristics.

Observed and simulated streamflow time series are compared in Figure 6.7. During the period from mid-1992 to mid-1993 the model underestimates baseflow, and during mid-1995 it overestimates baseflow. This is probably due to rainfall variability, with the earlier discrepancy due to differences between the rainfall recorded at Beth Salem compared to the rest of the catchment, and the latter due to the limitations of using Data Drill rainfall in areas of high rainfall gradient. The presence of Charlesworth Dam in the upper catchment will also tend to reduce flows during dry periods, and possibly slightly delay flow down the catchment.

The streamflow frequency curves in Figure 6.8 show a reasonable match, but flows between 10ML/d and 100ML/d tend to be overestimated by the model, and flows between 1ML/d and 10ML/d are underestimated.

Simulated mean annual runoff is 3,644 ML/a, compared to the observed mean annual runoff 3,279ML/a over the same period.

Objective functions for the calibration reported by the Rainfall Runoff Library Application (Podger, 2004) are:

- Nash Sutcliffe Criterion – Calculated vs Observed (Daily) - 0.81
- Nash Sutcliffe Criterion – Calculated vs Observed (Monthly) - 0.84

The Nash–Sutcliffe model efficiency coefficient E is defined by:

E = 1 – residual variance/data variance

Where:
residual variance is the sum of squares of differences between modelled and observed flow on each day, and data variance is the sum of squares of differences between observed flow on each day and observed mean flow.

A Nash–Sutcliffe model efficiency coefficient of 1 would indicate the model exactly replicated observed flow.

The model fit is reasonable given the limitations of the available data.

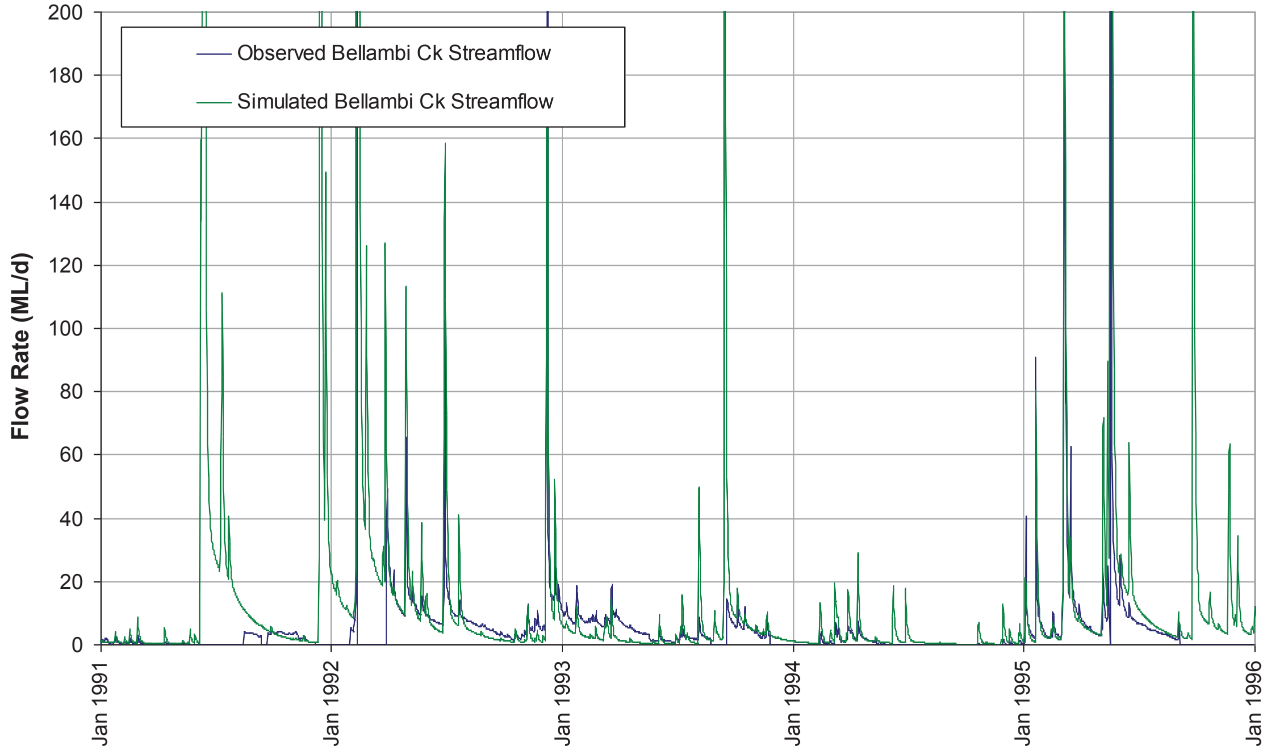


Figure 6.7 Observed and Simulated Streamflow – Bellambi Ck at South Bulli No. 1

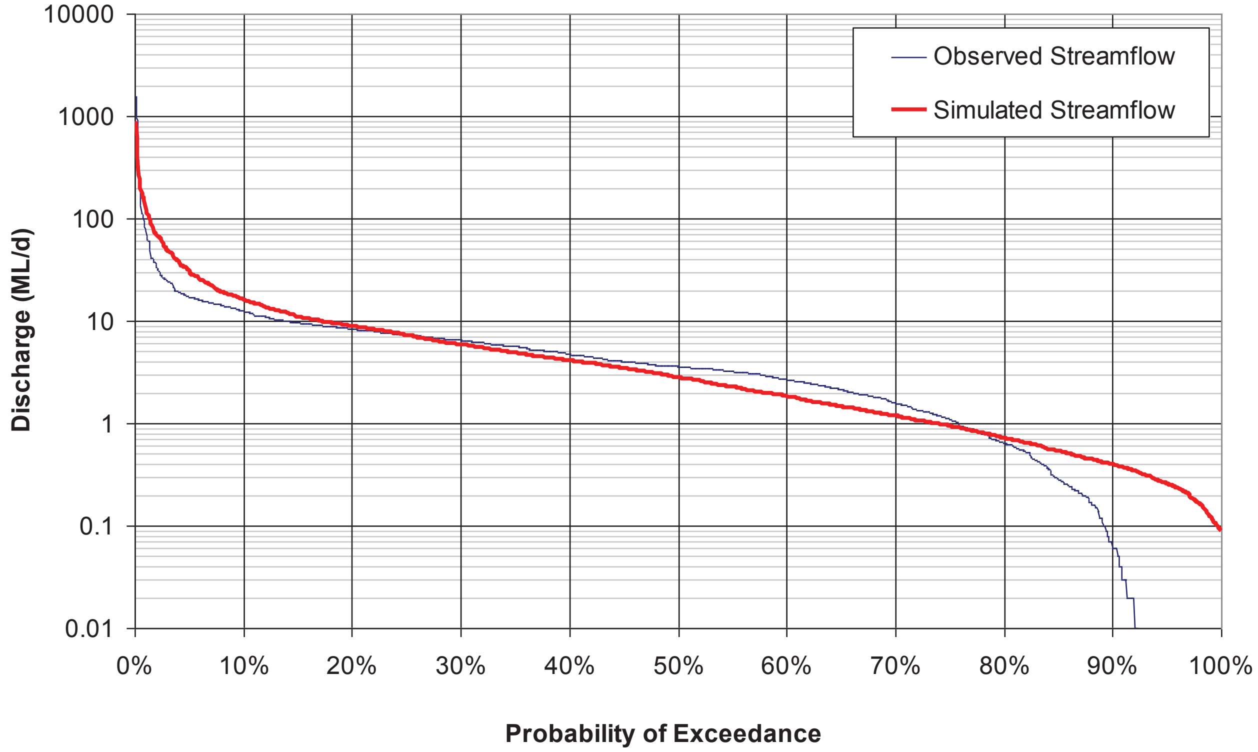


Figure 6.8 Observed and Simulated Streamflow Frequency Curves - Bellambi Ck at South Bulli No.1

6.4 CALIBRATION OF LODDON RIVER CATCHMENT MODEL

The Loddon River AWBM Model was calibrated over the period between the 1st of January 1991 and the 8th of November 2009.The adopted AWBM parameters are summarised in Table 6.4 below.

It was not possible to perfectly replicate all streamflow features of interest (e.g. annual flow, flow frequency, monthly flow, daily flow, hydrograph shape, and baseflow) at all temporal scales. The calibration parameters were selected to achieve a compromise. The calibration parameters were selected to achieve a compromise between matching the above characteristics.

Table 6.4 Adopted AWBM Parameters – Loddon River catchment

Parameter	Value
A1	0.214
A2	0.433
BFI	0.310
C1	3
C2	70
C3	182
K_{base}	0.81
K_{surf}	0

Observed and simulated streamflow time series are compared in Figure 6.9 below.

The model generally underestimates baseflow, which is highlighted in the streamflow frequency curves in Figure 6.10, which show a reasonable match to flows above 10ML/d, but significant discrepancies at lower flows. However, as discussed in section 5.1, flows less than 10ML/d contribute less than 10% of the total runoff volume from the catchment, and flows less than 5 ML/d make up less than 6% of the total Loddon River catchment runoff..

Simulated mean annual runoff is 11,585 ML/a, compared to the observed mean annual runoff of 12,810 ML/a over the same period.

Objective functions for the calibration reported by the Rainfall Runoff Library Application (Podger, 2004) are:

- Nash Sutcliffe Criterion – Calculated vs Observed (Daily) - 0.66
- Nash Sutcliffe Criterion – Calculated vs Observed (Monthly) - 0.79

The model fit is reasonable given the limitations of the available data, however, its applicability is limited when assessing very low flows.

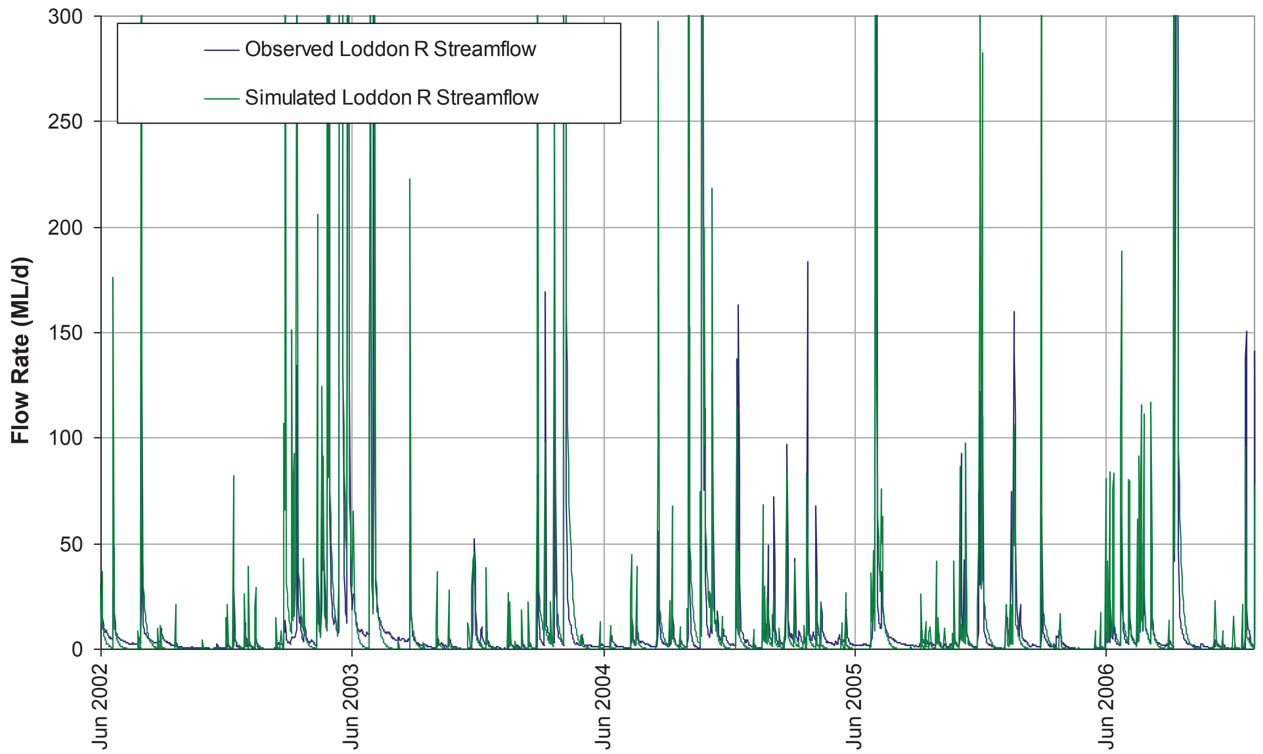


Figure 6.9 Observed and Simulated Streamflow – Loddon River at Bulli Appin Road – Sample of Record from June 2002 to December 2006

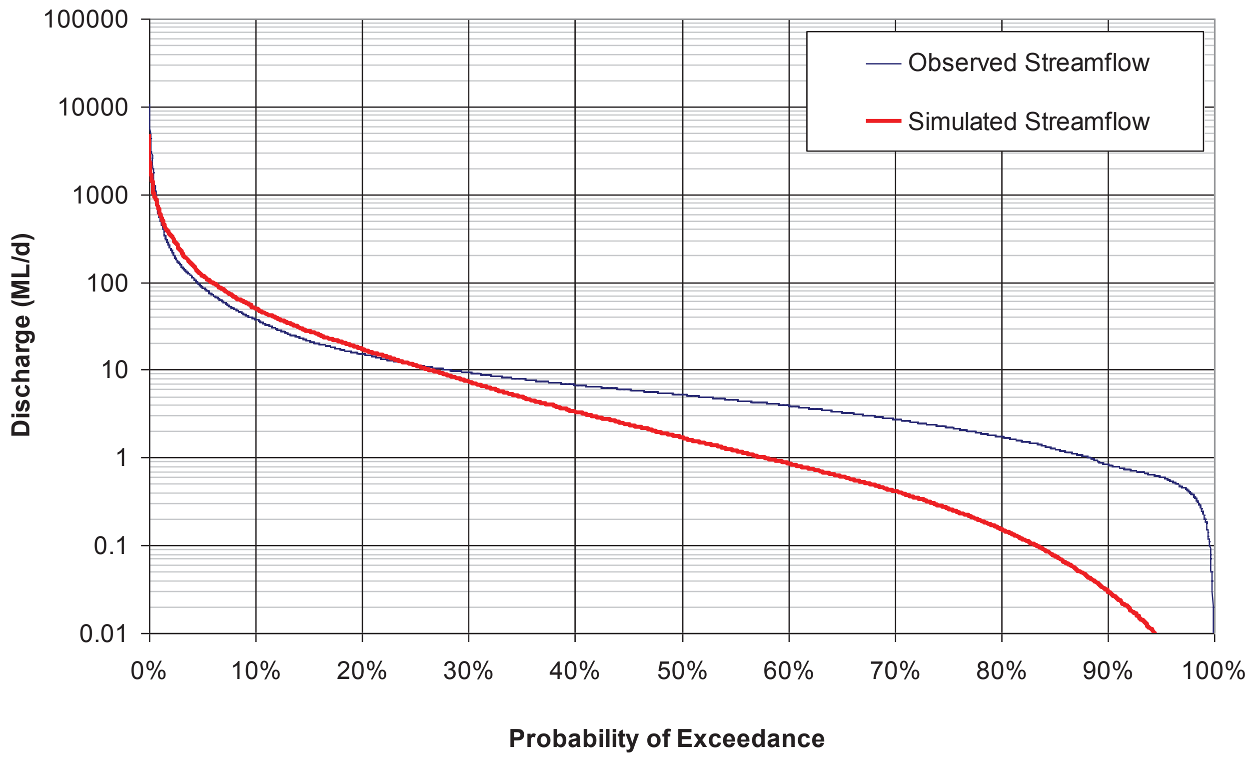


Figure 6.10 Streamflow Frequency Curves for Loddon River at Bulli Appin Road

6.5 VALIDATION OF LAKE CATARACT CATCHMENT MODEL AGAINST LAKE CATARACT BEHAVIOUR

6.5.1 Model Schematisation

The behaviour of Lake Cataract was simulated using a daily time step spreadsheet model comprising the following major components (shown schematically in Figure 6.11):

- Catchment runoff – estimated using recorded streamflow in contributing tributaries where available, and the AWBM rainfall/runoff model where it was not. The highly variable rainfall of the area necessitated subdividing the catchment into four subareas with different combinations of AWBM catchment parameters and input daily climate datasets (as summarised in Figure 6.11).

- Direct rainfall to the lake surface - a daily time series of rainfall depths was obtained from the SILO Patched Point Dataset for Cataract Dam. The rainfall depth was applied to the lake surface area estimated at each time step from the storage curve shown in Section 6.5.2.

- Evaporation from the lake surface – a time series of lake evaporation rates was obtained from the SILO Patched Point Dataset for Cataract Dam (Morton evaporation over shallow lakes). The lake evaporation rate was applied to the lake surface area estimated at each time step from the storage curve shown in section 6.5.2. No further evaporation adjustment factors were applied.

- Releases from the dam – the daily time series of recorded releases provided by SCA were extracted from the storage.

- Spills from the dam – inflows exceeding the remaining water storage were treated as spills.

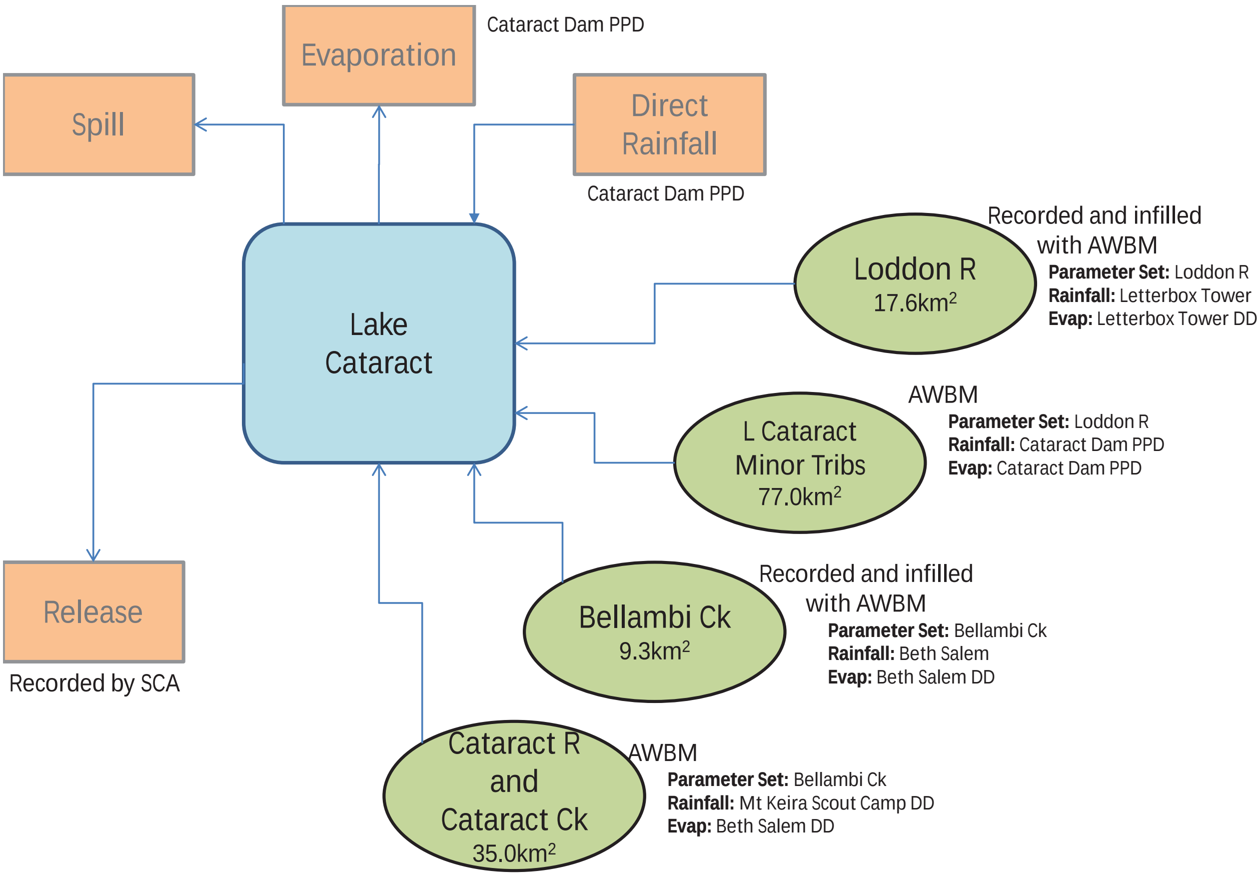


Figure 6.11 Lake Cataract Hydrological Model

6.5.2 Operational Data Supplied by SCA

The SCA provided data pertaining to the operation of Lake Cataract. The daily stored volume, controlled release and spillway discharge information shown in Figure 6.12 was used in the model.

Releases are made from Cataract Dam for the purposes of meeting water supply requirements and providing environmental flows.

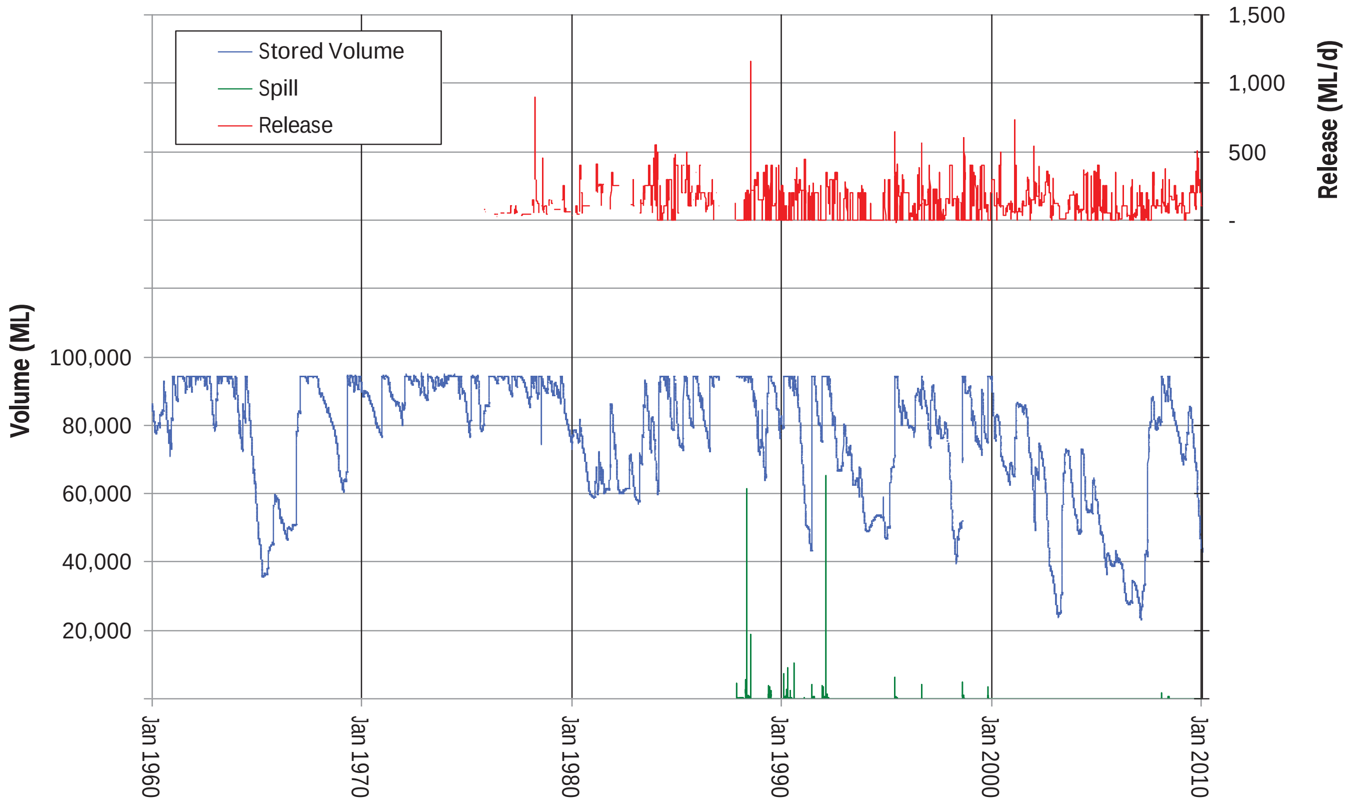


Figure 6.12 Lake Cataract Operational Data

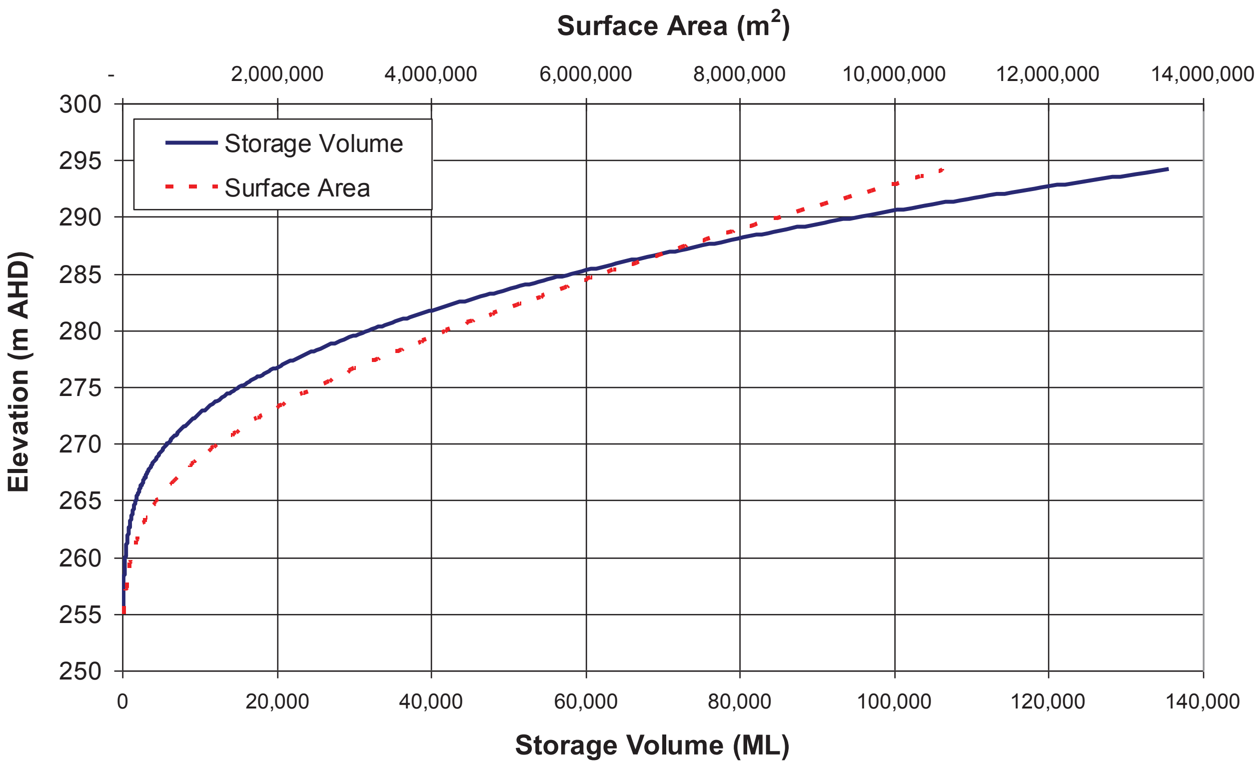


Figure 6.13 Lake Cataract Storage Curves

6.5.3 Model Validation

The results were validated against the recorded stored volume of Lake Cataract between 1976 and 2010, as shown in the following four figures. The modelled stored volume is a good representation of the observed behaviour. However, differences between modelled and observed inflows cause some discrepancies. These differences occur mostly during the larger inflow events, and are probably due to non-uniform rainfall over the catchment.

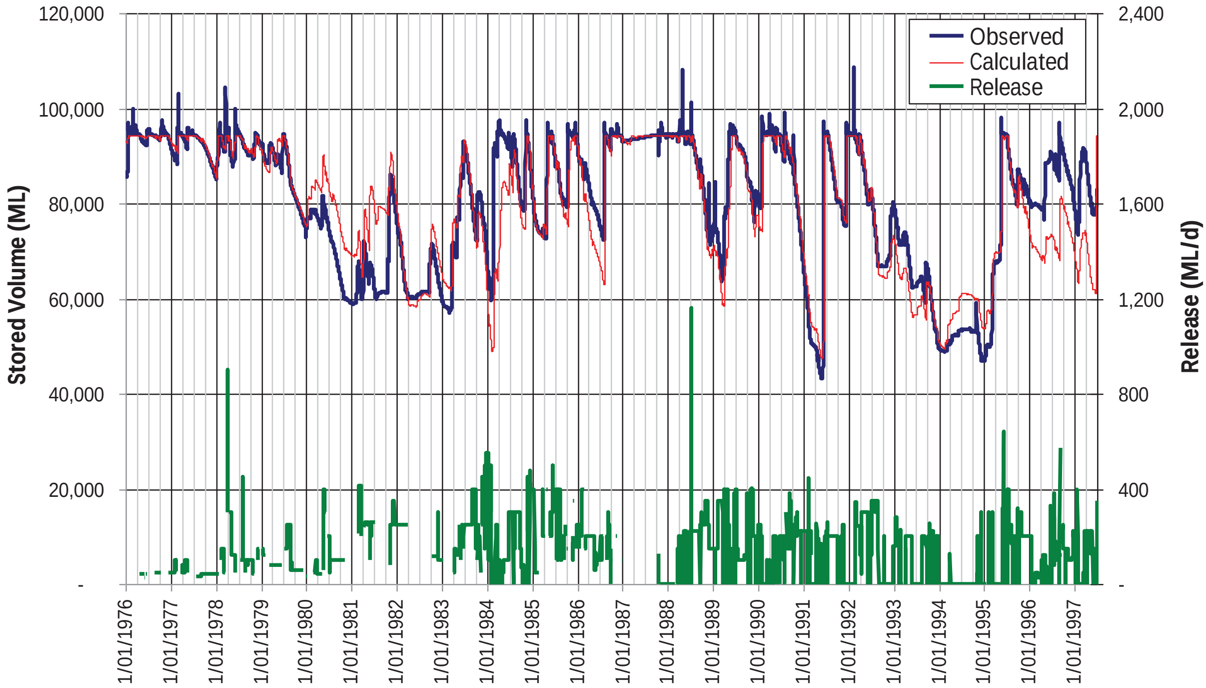


Figure 6.14 Observed and Modelled Storage Behaviour at Lake Cataract 1976 to 1997

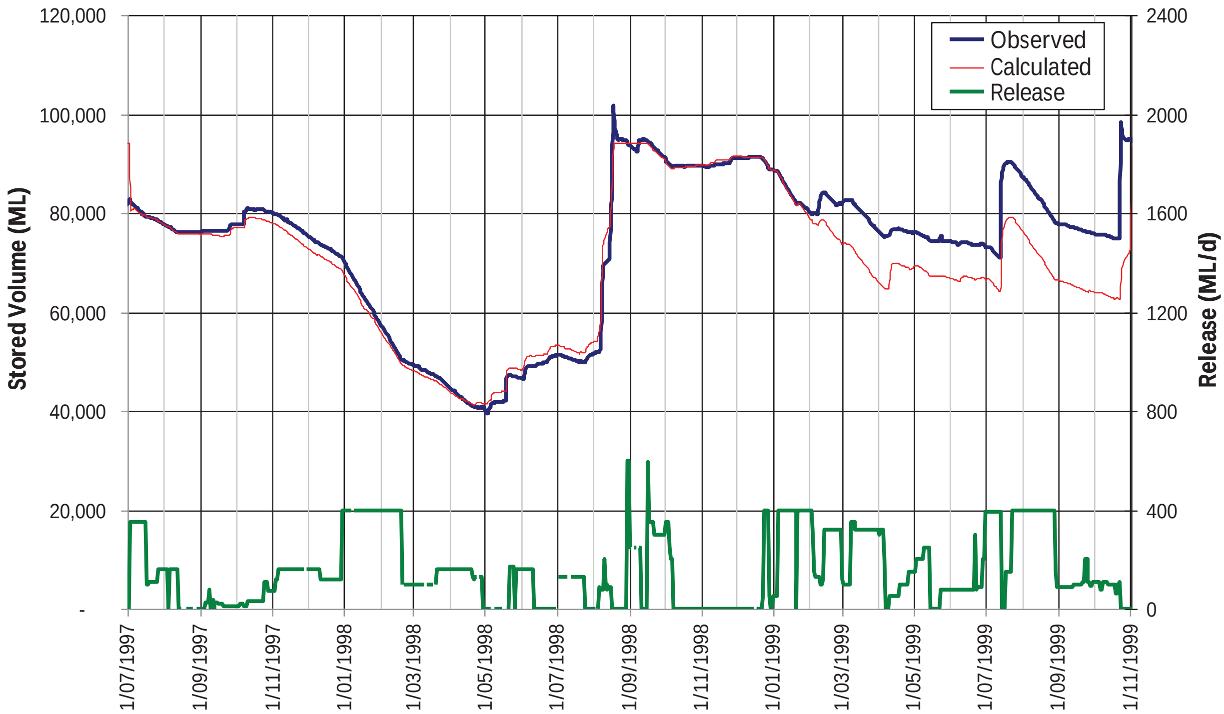


Figure 6.15 Observed and Modelled Storage Behaviour at Lake Cataract 1997 to 1999

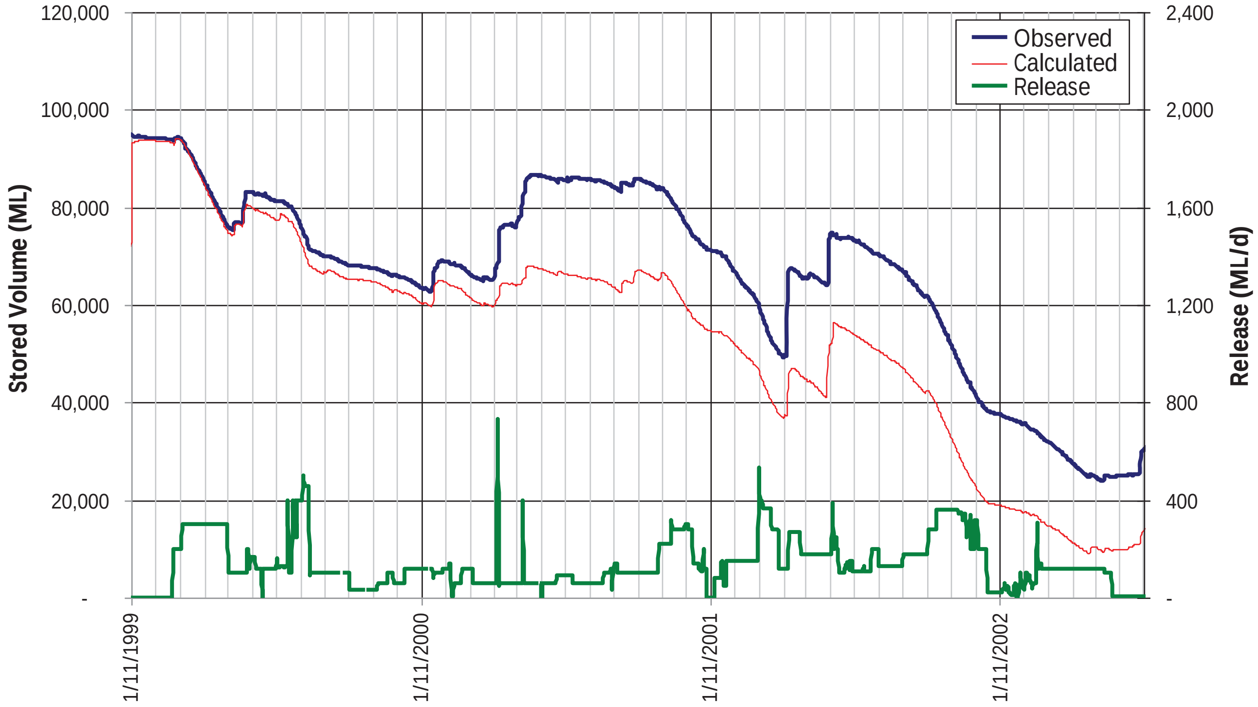


Figure 6.16 Observed and Modelled Storage Behaviour at Lake Cataract 1999 to 2003

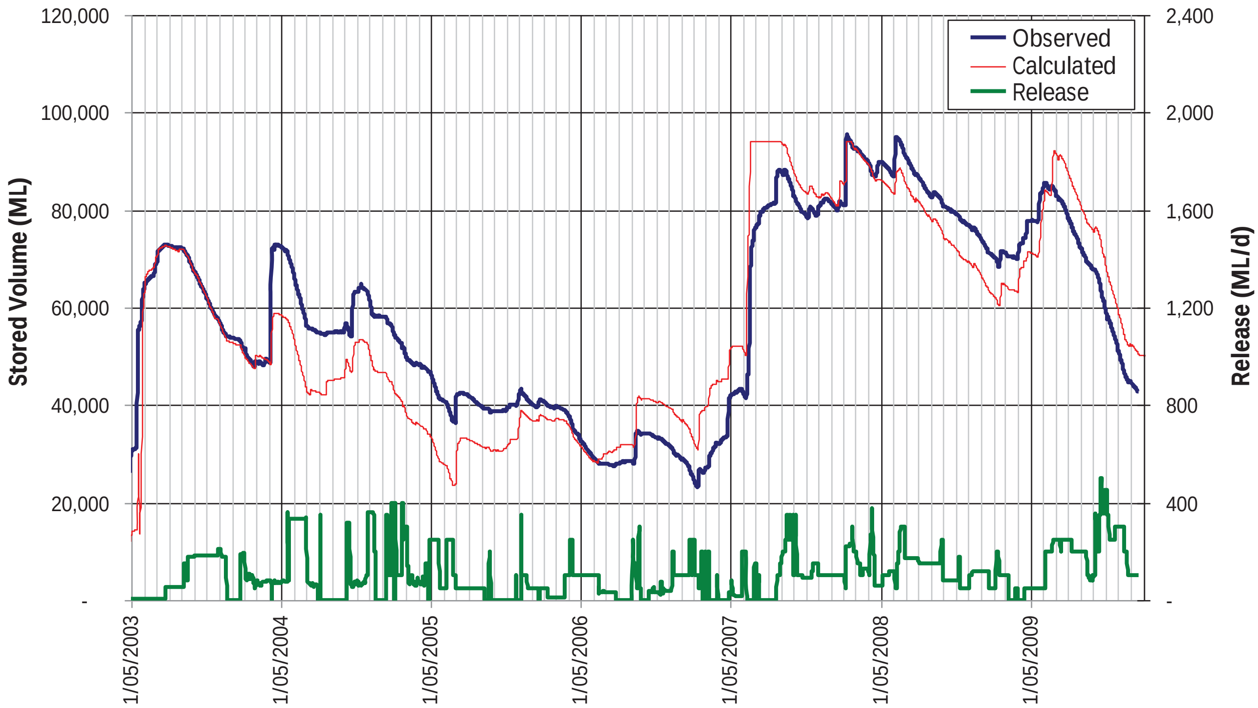


Figure 6.17 Observed and Modelled Storage Behaviour at Lake Cataract 2003 to 2010

6.6 VALIDATION OF WALLANDOOLA AND LIZARD CREEK RUNOFF MODEL AGAINST BROUGHTON'S PASS STREAMFLOW

The behaviour of the Cataract River catchment to Broughton's Pass Weir was simulated using a daily time step spreadsheet model comprising the following major components (shown schematically in Figure 6.18):

- Catchment runoff – estimated using the AWBM rainfall/runoff model. The catchment to Broughton's Pass Weir was subdivided as shown in Figure 6.18. The daily unit runoff time series derived for the Lake Cataract minor tributaries subcatchment was adopted (derived using daily rainfall and evapotranspiration data recorded at Cataract Dam and AWBM parameters transposed from the calibrated Loddon River model).

- Releases from the dam and weir – the daily time series of recorded releases provided by SCA were input to the top of the modelled reach. Diversions to Macarthur Water Treatment Plant (WTP), Upper Canal and environmental releases were also extracted upstream of Broughton's Pass Weir.

- Spills from the dam – the daily time series of recorded spillway discharges provided by SCA were input to the top of the modelled reach.

Releases are frequently made from Cataract Dam, and the effects of instream losses, and gauge errors make it difficult to assess the contribution of catchment runoff to flows at Broughton's Pass Weir.

For the purpose of validating the simulated runoff, the focus was periods of no release from Cataract Dam. Under these conditions, streamflow at Broughton's Pass Weir is largely due to flow from Wallandoola and Lizard Creeks. However, there will also be contributions from Cascade Creek and the residual catchment between Cataract Dam and the Wallandoola Creek confluence. As shown in Figure 6.19 (and the charts in Appendix B), despite these simplifications, the model appears to be reasonably representative of catchment runoff during these times.

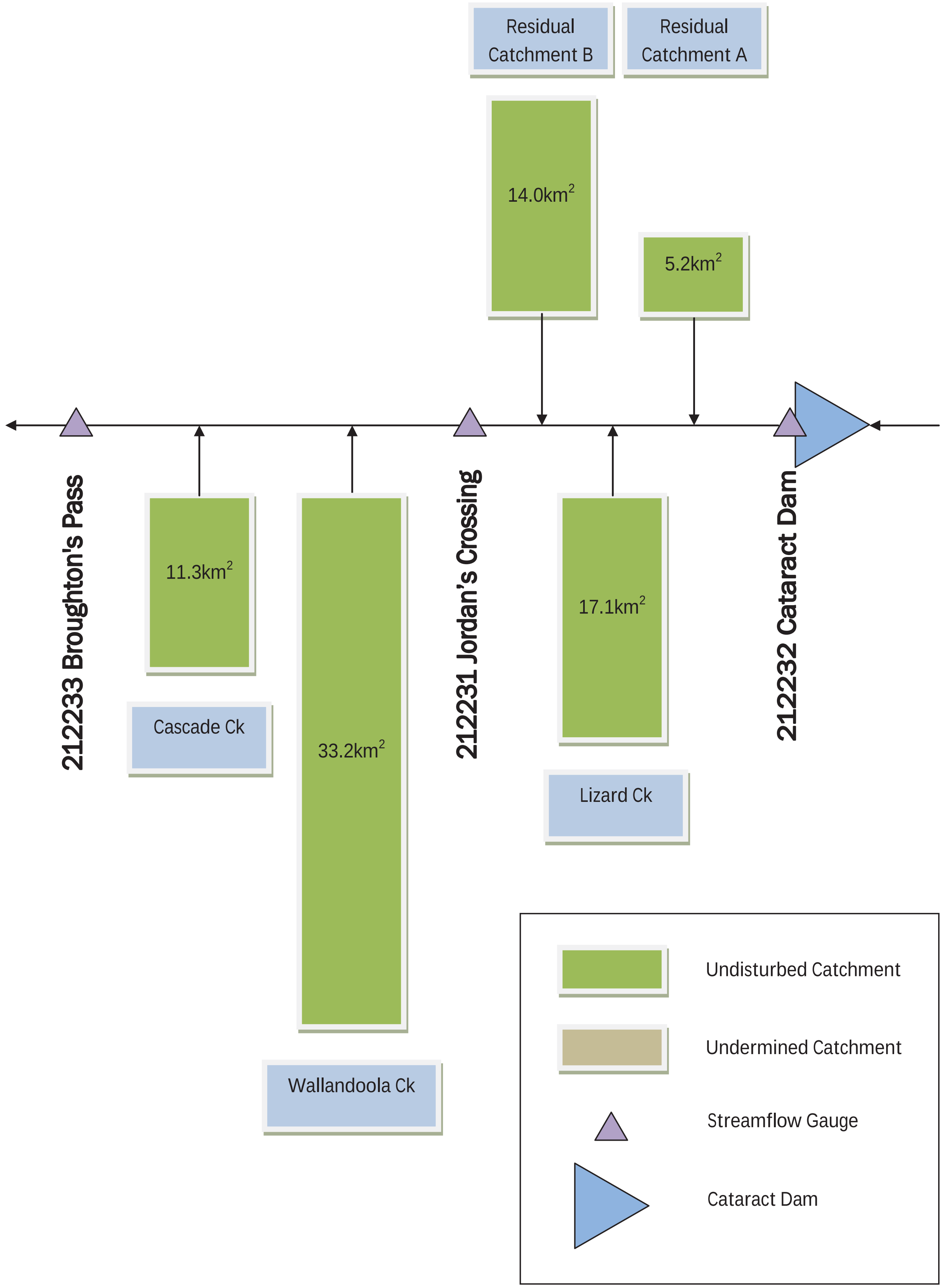


Figure 6.18 Model for validation of adopted Wallandoola and Lizard Ck rainfall-runoff relationships

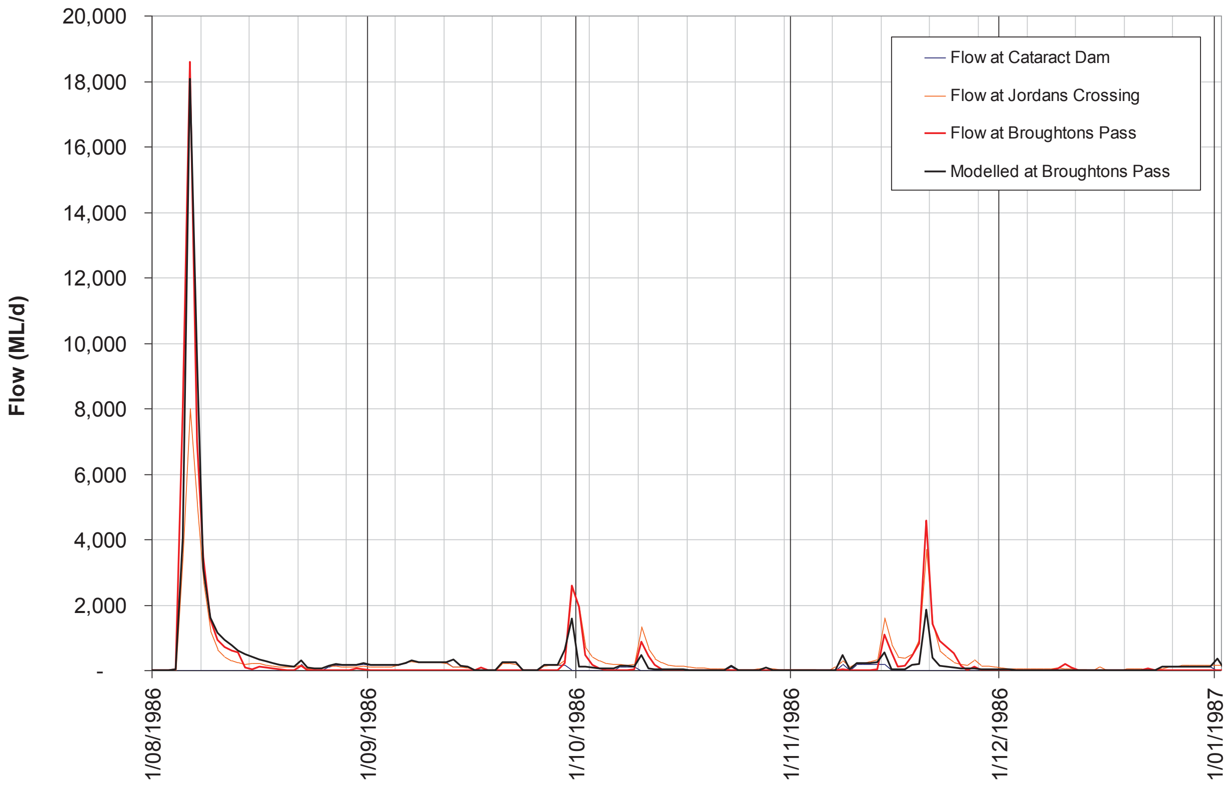


Figure 6.19 Observed and Modelled flow at Broughton's Pass Weir

7 CONTRIBUTION OF CATCHMENTS POTENTIALLY AFFECTED BY SUBSIDENCE

7.1 POTENTIAL MECHANISMS FOR HYDROLOGICAL IMPACTS

The following potential hydrological risks have been raised as stakeholder concerns:

- **Reservoir yield** - the possibility that quantity of water reaching Lake Cataract and Broughtons Pass Weir could be reduced,

- **Stream health** – the possibility that cracking of the stream beds draining into Cataract Dam and Broughtons Pass Weir may induce loss of overland stream flow and adversely affect stream water quality or stream health.

In its review of the Metropolitan Coal Project Environmental Assessment, the Planning Assessment Commission (PAC) Panel cited the following potential mechanisms whereby this may occur (NSW PAC, 2009):

1. Rainfall on the broader catchment, which previously found its way to watercourses by surface or subsurface flow infiltrates through fractures and is permanently lost to the surface water system.
2. Water in streams that are subject to fracturing is lost from the surface water system to the groundwater system and does not reappear.

The above potential risks are addressed in the following sections.

In its submission on the DGR's the Department of Water and Energy required this EA report *demonstrate the project is consistent with the spirit and principle of the NSW State Rivers and Estuaries Policy, Wetland Management Policy, including :*

1. *General description of channel form, river style or other descriptive category of any affected channel, including identification of key geomorphological indicators and conditions within the zone of influence for the proposal.*

2. *Hydrologic and geomorphic character of the riverine system, stream energy and stream power relationships, energy relationships at bankfull stage and at peak flow, and assessment of stream power and critical tractive stress for existing and any modified conditions for any rivers affected by the proposal, which provides details of:*
   - *long profile and cross sectional survey along the channel, and identification of at least the closest upstream and downstream controls on the channel*
   - *assessment of bed and bank material, identification of critical entrainment and destabilisation thresholds*
   - *assessment of the constriction and resultant change in afflux through, past or over the structure, and resultant changes in energy profiles involving the structure*

- *nature of bedload transport, and mechanism(s) to permit bedload transport through the structure*

3. *Procedures to develop stream relocation and reconstruction criteria which utilise best practice management, which must include the principles which underpin any embargoes currently in force under the Water Act, 1912, or operational rules of any Water Sharing Plan in force under the Water Management Act 2000 over the site*

4. *Methodologies by which proposed relocation or reinstatement of watercourses will be undertaken, and whether any proposed ecological offset provisions will provide adequate protection to any instream or groundwater dependent ecosystems which exist on the site*

5. *Mechanism to maintain long profile grade through the structure, or to provide energy dissipation through the structure at the re-entry point design volumes/velocity downstream*

6. *Nature of existing controls along all watercourses on the site, and proposed use of engineered and vegetation to provide long term control to the channel*

7. *Final configuration of any relocation, modification or other impact upon rivers and watercourses on or surrounding the site, including geomorphic character mimicking conditions of undisturbed rivers or watercourses adjacent to the proposal area*

The streams overlying the project area are not being relocated or reinstated, and no instream structures are proposed. The predicted subsidence impacts are expected to result in only small changes to the stream bed profile. As a result, localised reductions in bed gradients are not likely to cause significant additional ponding. Any localised increase in bed gradient is likely to be within the range of those occurring naturally, and as the stream bed material comprises competent rock, the resultant localised increases in stream power and tractive force are unlikely to cause bed scour. As a result, we have not undertaken a detailed assessment of bedload transport mechanisms or afflux.

The proposed workings will potentially disturb the following portions of the catchments in the Study Area (Seedsman, 2010).

Table 7.1 Potential Subsidence Areas Compared to Total Catchment Area

Stream	Catchment Area (km^2)						
	Total Catchment to D/S Confluence	Subsided by More Than 20mm	Percentage Subsided	U/S of Disturbance Envelope	% U/S	D/S of Disturbance Envelope	% D/S
Lizard Creek	17.1	6.3	36.8%	7.5	44.0%	3.3	19.2%
Wallandoola Creek	33.2	2.0	6.0%	8.7	26.2%	22.5	67.7%
Lake Cataract*	127.8	2.3	1.8%	4.0	3.1%	121.5	95.1%
Cataract Creek	5.2	1.4	27.5%	3.7	71.5%	0.05	1.0%
Cataract River	11.6	0.4	3.4%	0.0	0.0%	11.2	96.6%
Belambi Creek	9.3	0.2	1.9%	0.0	0.0%	9.1	98.1%

*Lake Cataract disturbance includes disturbance area in Cataract Creek, Cataract River and Bellambi Creek.

7.2 ASSESSMENT METHODOLOGY

The PAC has previously noted that without special techniques and extensive quality control and checking, the normal accuracy of stream gauging measurements combined with staged measurements and the derivation of rating curves, precludes reliable detection of small absolute changes in stream flows from one location to the next (NSW PAC, 2009). This is further affected by the likelihood that in Hawkesbury Sandstone based waterways such as those within the study area with natural (and potentially induced) bedding plane as well as jointing washouts and fractures, subsurface flow is present that can not be accurately measured, especially during low flow regimes.

In its review of the Metropolitan Coal Project Environmental Assessment, the PAC was of the view that because fracturing is likely to only occur in the surficial groundwater system, and that any increase in initial rainfall runoff losses would be temporary, any surface water losses would therefore be undetectable unless the surficial groundwater system intercepted a permeable subsurface stratum that bypassed the reservoir (NSW PAC, 2009).

Due to the low total predicted subsidence in Wonga East (<200mm), as well as the mine plan that avoids undermining the main channel of Lizard Creek and Wallandoola Creek at Wonga West, the potential for additional fracturing of the creek beds has been minimised.

The Southern Coalfield Inquiry was also of the view that there was no evidence that "*subsidence impacts have resulted in any measurable reduction in runoff to the water supply system operated by the Sydney Catchment Authority or to otherwise represent a threat to the water supply of Sydney or the Illawarra Region." (DECC, 2007)*

However, the PAC did make the case that the issue was not beyond doubt and recommended further investigation of catchment yield impacts.

The rate of water loss from pools affected by subsidence induced cracking has been measured in waterways overlying other projects in the Southern Coalfield (Gilbert, 2008). However, due to the lack and distribution of suitable overland stream flow monitoring sites within the Study Area, it is not possible to accurately determine the loss, if any of stream flow reporting into Cataract Dam or Broughtons Pass Weir.

In addition, mining subsidence effects, if any, in the Cataract River downstream of the Gujarat lease area may, or may not, also be causing stream flow losses in the streams system that reports to Broughtons Pass Weir

Given these limitations, it is not currently feasible to definitively quantify any overland stream flow losses that may, or may not, result from the potential loss mechanisms.

However, the catchment models developed for the study area have been used to describe how a range of modelled loss rates could impact on streamflow downstream of potentially affected subsidence areas.

7.2.1 Potential Impact on Reservoir Yield

The Lake Cataract model presented in Section 6.5 was used to investigate the impact that various loss rates from the upstream catchment would have on reservoir yield.

The modelling focussed on the dry periods from 1996 to 1998 and 2001 to 2007 when stored water volumes dropped below 40,000 ML. During higher flow events, where there was a large discrepancy between the modelled and observed inflow, the modelled inflow was modified to achieve an improved fit to observed volumes.

The results of this adjustment are shown in Figure 7.1 which shows a very close correlation between observed and modelled behaviour.

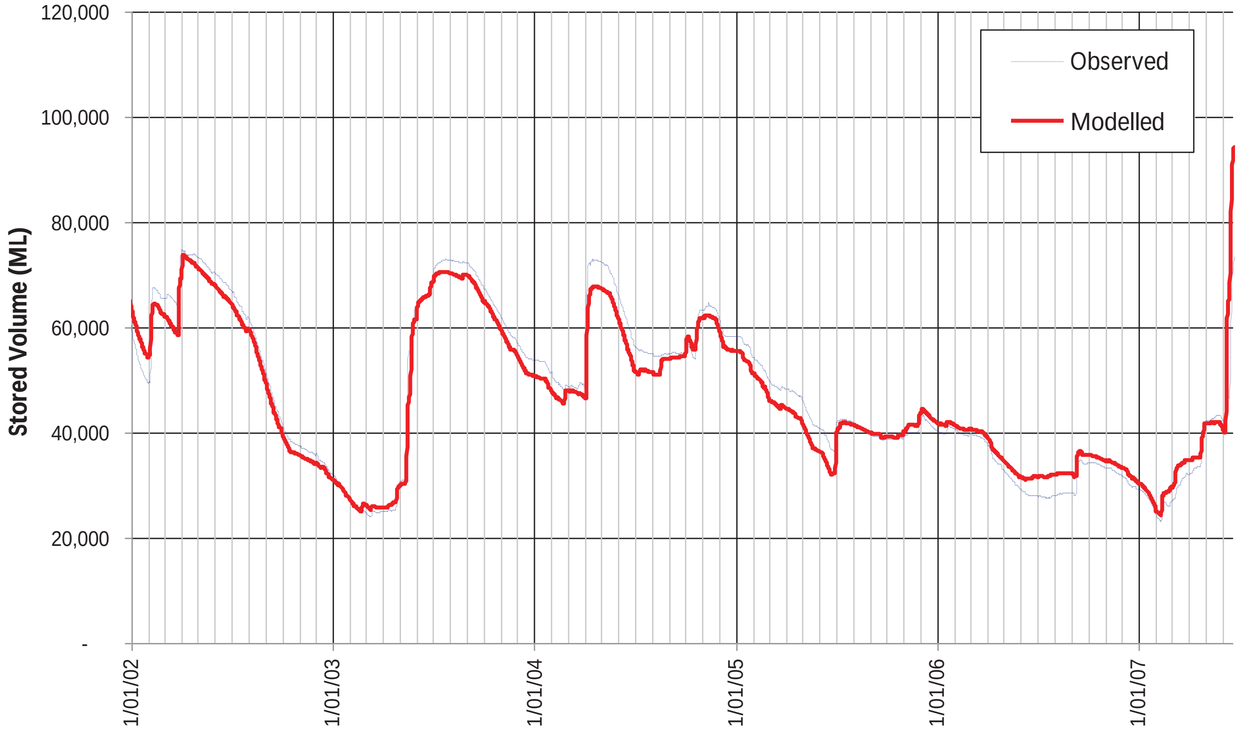


Figure 7.1 Observed and Modelled Dry Period Volume at Cataract Dam after Inflow Adjustment

Catchment and in-stream losses were applied by reducing the Cataract Creek/Cataract River inflow rate by a daily loss rate in ML/d (up to the daily flow rate).

7.2.2 Potential Impact on Streamflow

The Wallandoola and Lizard Creek catchment models described in Section 6 were used to investigate how a range of modelled loss rates would impact key features of streamflow downstream of the affected areas.

Daily flow rates at the reporting locations shown in Figure 7.2 were reduced by 1ML/d, 5 ML/d and 10ML/d to indicate the effect on the hydrograph shape and the flow frequency curves.

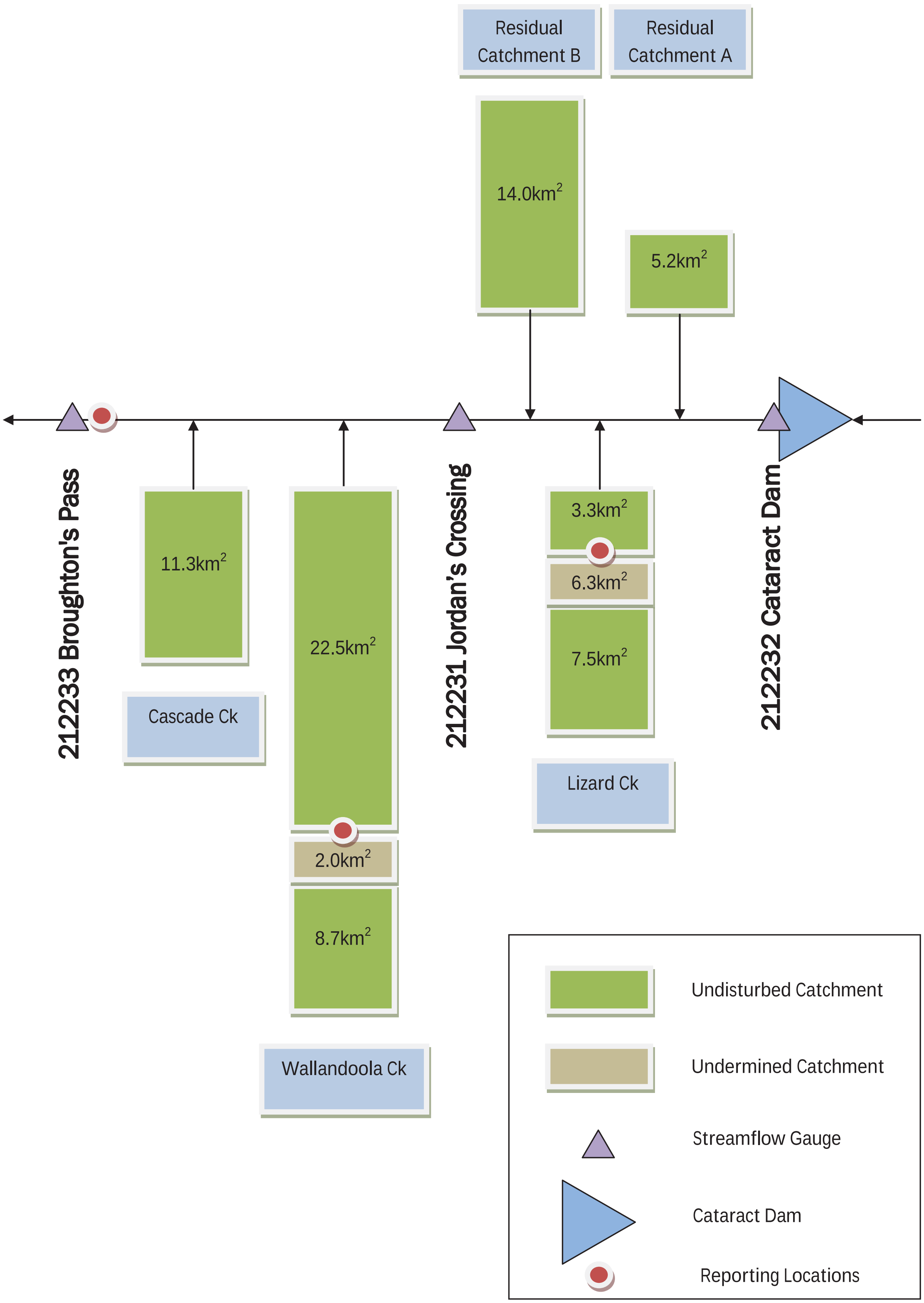


Figure 7.2 Model for illustrating potential impacts of subsidence induced losses on downstream flow

7.3 MODEL RESULTS

7.3.1 Potential Impact on Reservoir Yield

Figure 7.3 below compares the simulated stored water volume with no subsidence losses to those simulated with catchment losses of increasing magnitude.

Based on pool water level reduction rates, overland stream flow loss in the order of 0.5 ML/d have been estimated at other similar projects in the Southern Coalfields (Gilbert, 2008)

The overland stream flow loss rates were applied to the total Cataract River (including Cataract Creek) inflow. The results show that under historical water use and climate conditions recorded since 1976, losses of 1ML/d would have had very little impact on Lake Cataract water levels.

The maximum reduction in stored volume occurs in mid-2007 and ranges from 940ML for a loss of 0.5ML/d to 1,385ML for a loss of 10ML/d. Losses of 10ML/d would not have caused the Lake Cataract Reservoir water volume to fall below 10% of capacity. Such loss rates are very large, and based on previous experience and observations at similar coal mines in the Southern Coalfields (Gilbert, 2008) they are unlikely to eventuate given the anticipated and observed response of the Hawkesbury Sandstone based stream bed to the predicted subsidence along with the proposed panel layout.

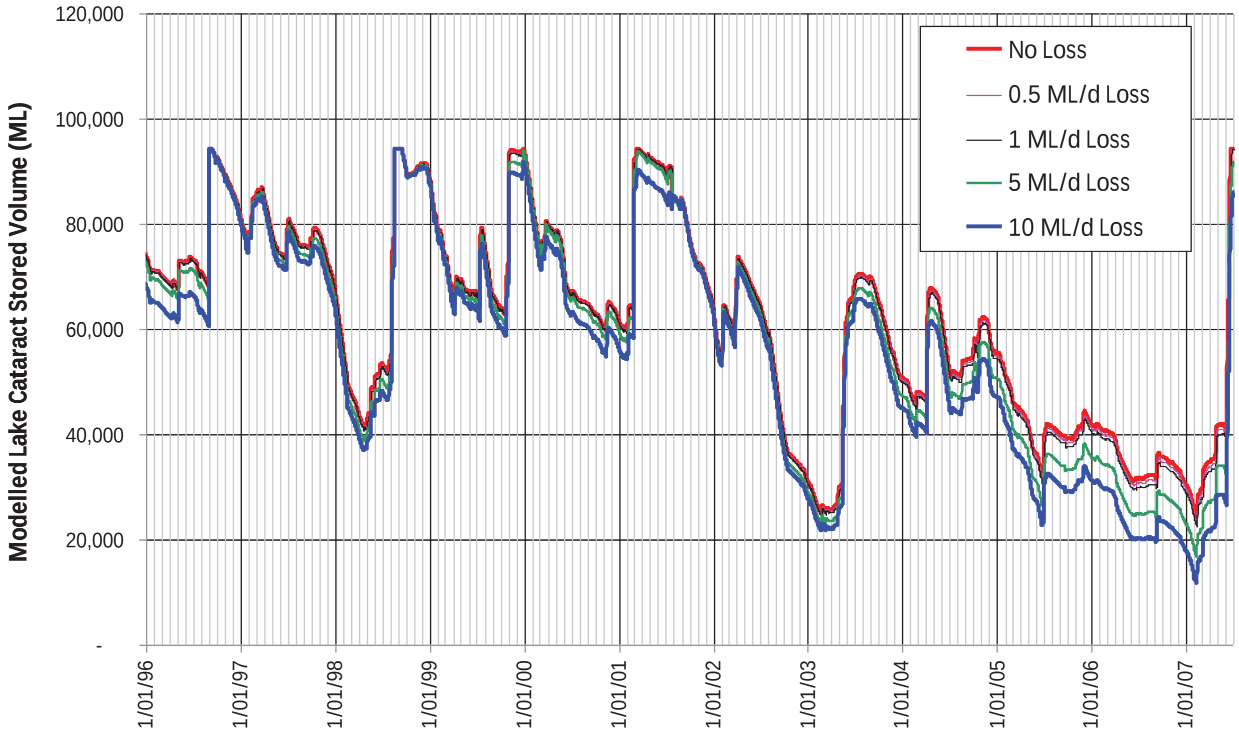


Figure 7.3 Impact of catchment loss on Lake Cataract dry period stored water volume

7.3.2 Potential Impact on Streamflow

The results of the analysis are illustrated in Figure 7.4 and Figure 7.5, which show modelled flow rates at the Reporting locations in Figure 7.2. It should be emphasised that the modelled low flows have not been fully validated against measured low flows due to the physical limitation and difficulty in obtaining sufficient overland stream flow monitoring sites to enable "total" measurement of stream flow as described in Section 5.2

The effect of losses of the magnitude considered would have a proportionally smaller impact on large flows. However, they could constitute a higher portion of baseflow under low flow conditions at the localised affected areas.

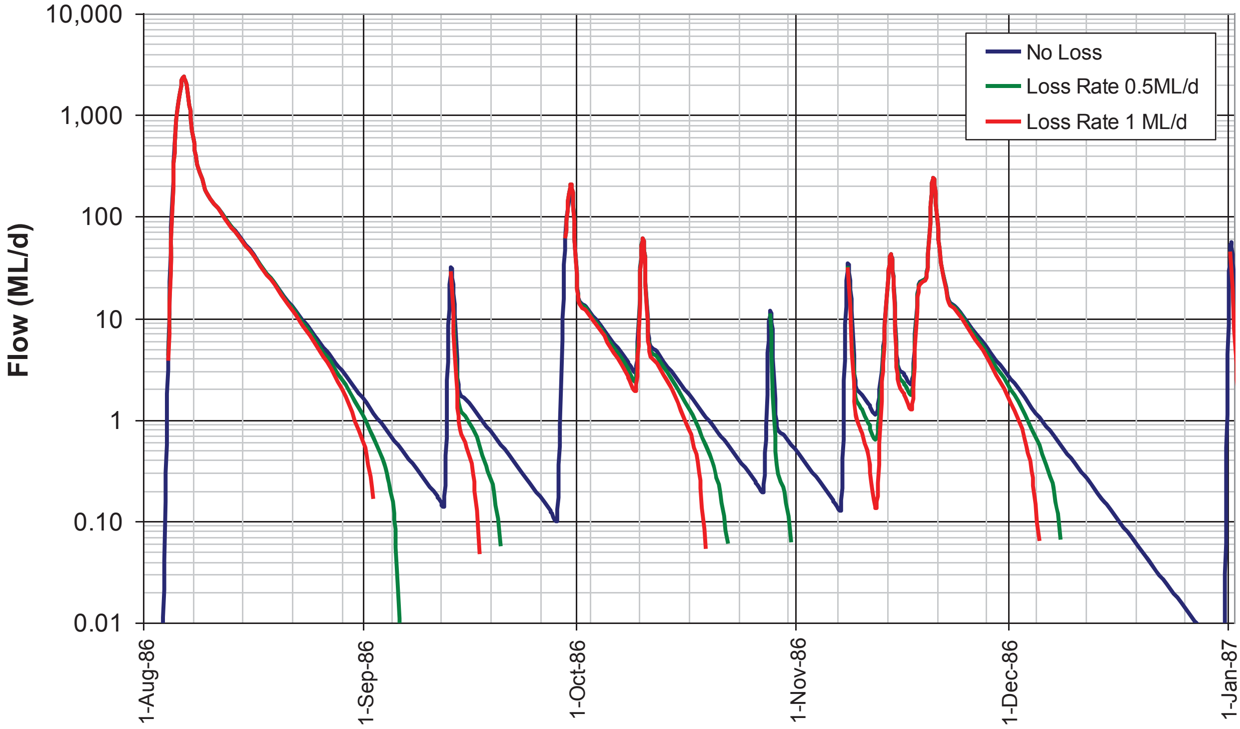


Figure 7.4 Example impact of flow loss on hydrograph shape Lizard Creek – Late 1986

The impact of the losses over the modelled period between 1983 and 2009 is illustrated more completely in Figure 7.5. The following observations can be drawn from these results:

- A loss of 0.5ML/d would reduce the frequency of flows greater than 1.0ML/d from around 38% to 32%. A loss of 1.0 ML/d would reduce the frequency of 1.0ML/d flows to 28%.
- A loss of 0.5ML/d would reduce the frequency of flows greater than 0.1ML/d from around 70% to 46%. A loss of 1.0 ML/d would reduce the frequency of 0.1ML/d flows to 37%.

Flows in Lizard Creek and Wallandoola Creek at the reporting locations just downstream of the proposed impact zone, are similar.

It should be noted that if flow losses occurred from a reach of the affected streams, it is thought that the flow would return to the channel further downstream. The impacts described above are therefore likely to affect only limited portions of the affected streams.

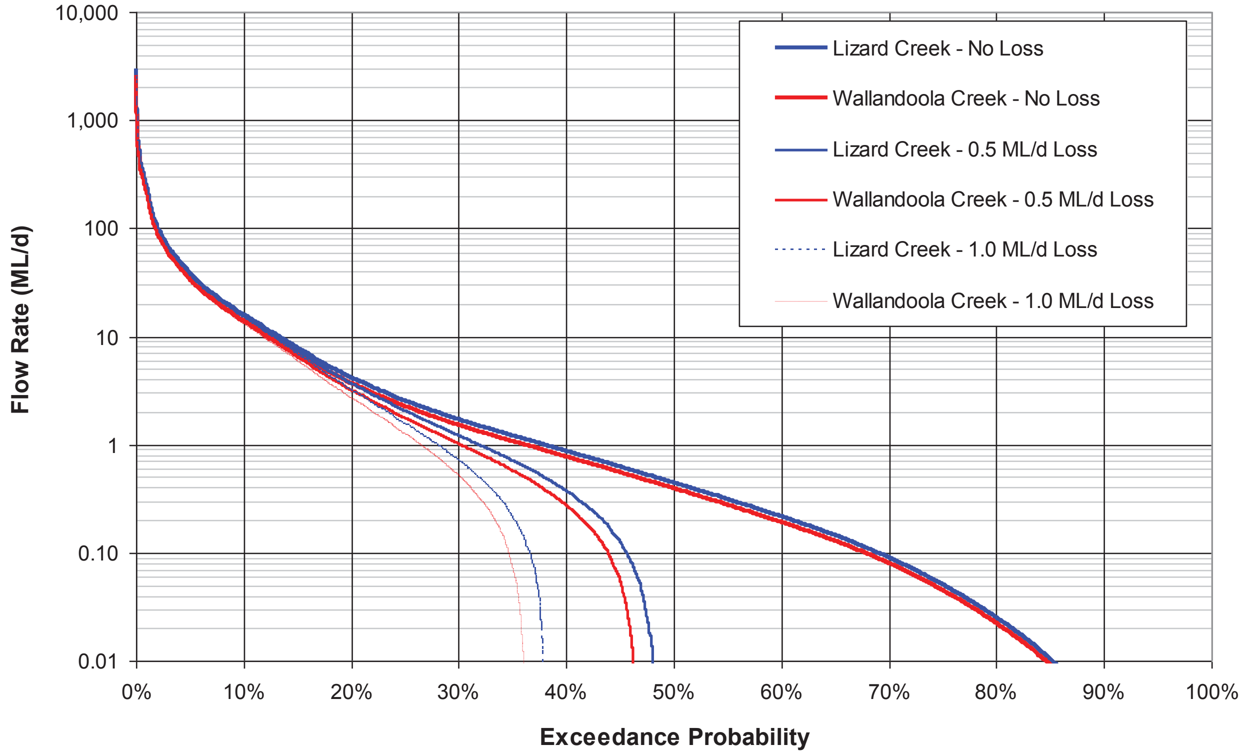


Figure 7.5 Impact of losses on flow frequency curve – Lizard Creek and Wallandoola Creek

8 CONCLUSIONS

The proposed mine panel layout has been designed to minimise adverse effects on the catchment and channels of Lizard and Wallandoola Creeks that could be affected by subsidence associated with the proposed Wonga West workings.

The catchment of Cataract Creek, Bellambi Creek and Cataract River are not anticipated to be adversely affected by the less than 200mm of predicted subsidence over the Wonga East workings.

Details are summarised below, for subsidence exceeding 20mm:

1. Lizard Creek. The predicted Wonga West 20mm subsidence zone underlies a 4.5km stretch of the creek. Of the total Lizard Creek catchment area of 17.1km^2, 7.4km^2 has been identified as potentially subsided by the proposed workings.

2. Wallandoola Creek. The predicted Wonga West 20mm subsidence zone underlies a 1.5km length of the upper reaches of the stream. Of the total Wallandoola Creek catchment area of 33.2km^2, 3.2km^2 has been identified as potentially subsided by the proposed workings.

3. Cataract Creek. The proposed Wonga East workings are located between Chainage 3,100m and Chainage 4,200m. Of the total Cataract Creek catchment area of 5.2km^2, 1.4km^2 has been identified as potentially subsided by the proposed workings.

4. Cataract River. The proposed Wonga East workings do not underlie the Cataract River. The predicted 20mm subsidence zone runs adjacent to the Lake Cataract backwater for a distance of about 600m. Of the total Cataract River catchment area of 11.6km^2, 0.1km^2 has been identified as potentially subsided by the proposed workings. The western end of Panel 10 in the Wonga East workings extends under the high water extent of the northern bank of the Lake Cataract backwater in the Cataract River.

Subsidence induced cracking could potentially reduce overland streamflow in isolated reaches overlying the proposed workings. However, monitoring in similar mining areas within the Southern Coalfield concluded these impacts are restricted to short reaches where flow infiltrates into cracks in the bed then remerges further downstream with no measureable loss of total catchment flow into the creek reaches downstream of the affected area.

Based on a catchment yield model calibrated to historical records since 1976, overland flow losses of 1ML/d would have very little impact on Lake Cataract water levels. The maximum reduction in stored volume occurs in mid-2007 and ranges from 940ML for a loss of 0.5ML/d to 1,385ML for a loss of 10ML/d. Losses of 10ML/d would not have caused the Lake Cataract Reservoir water volume to fall below 10% of capacity. Such a loss rate is very large, and unlikely to eventuate given the underlying geology and proposed mining method.

In the absence of long-term streamflow records on Lizard and Wallandoola Creek, the impact of losses from the affected reaches on the persistence of baseflow has been estimated by extracting a constant daily loss rate from a simulated streamflow record. The model parameters were transposed from AWBM models calibrated to adjacent catchment runoff records and validated against portions of the streamflow record at Broughton's Pass Weir. Flows in Lizard Creek and Wallandoola Creek at the reporting locations just downstream of the proposed 20mm subsidence zone, are similar.

A loss of 0.5ML/d would reduce the frequency of flows greater than 1.0ML/d from around 38% to 32% of the time. The frequency of flows greater than 0.1ML/d would be reduced from around 70% of the time to 46% of the time. A greater loss of 1.0 ML/d would further reduce the frequency of 1.0ML/d flows to 28% of the time. The frequency of flows greater than 0.1ML/d would be reduced further to 37%.

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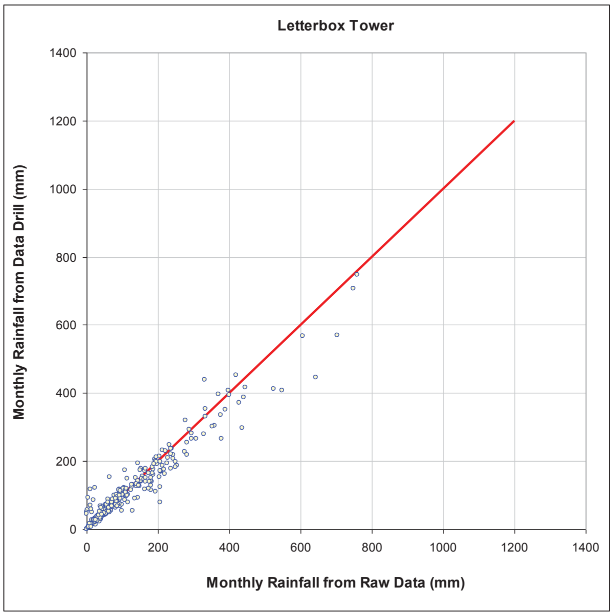
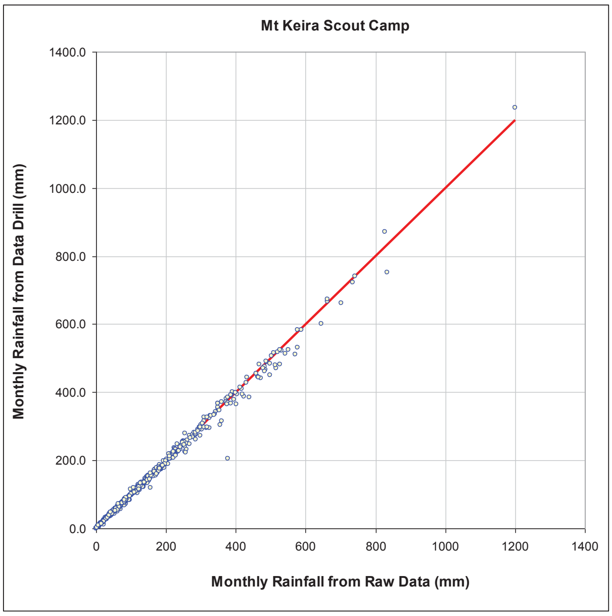
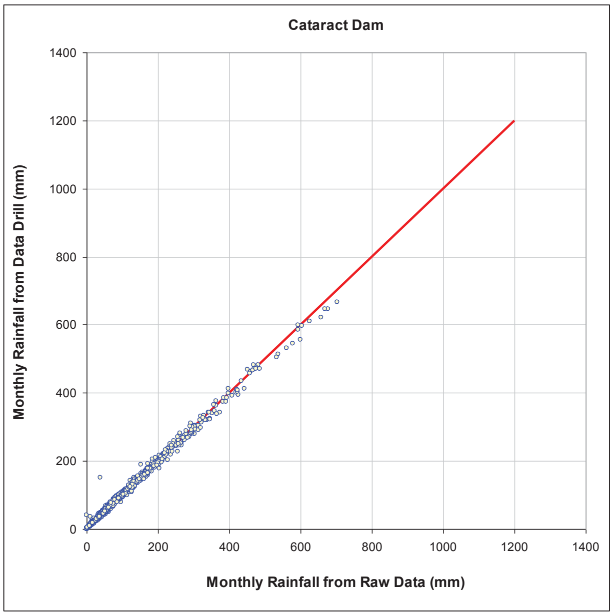
APPENDIX A

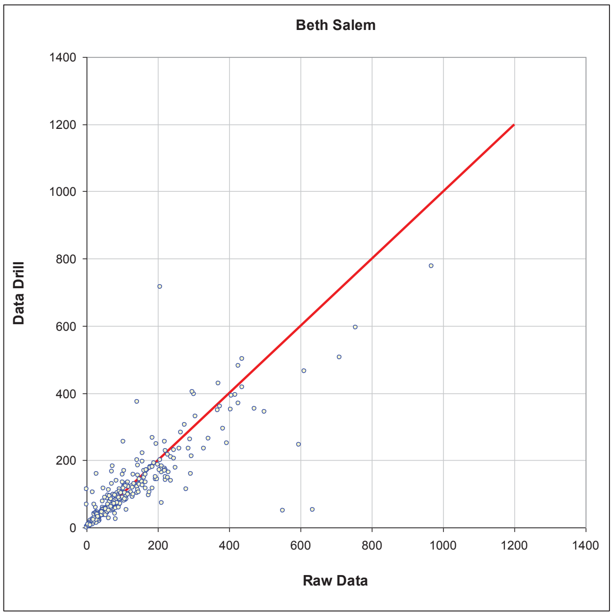
COMPARISON OF RAW RAINFALL DATA AND

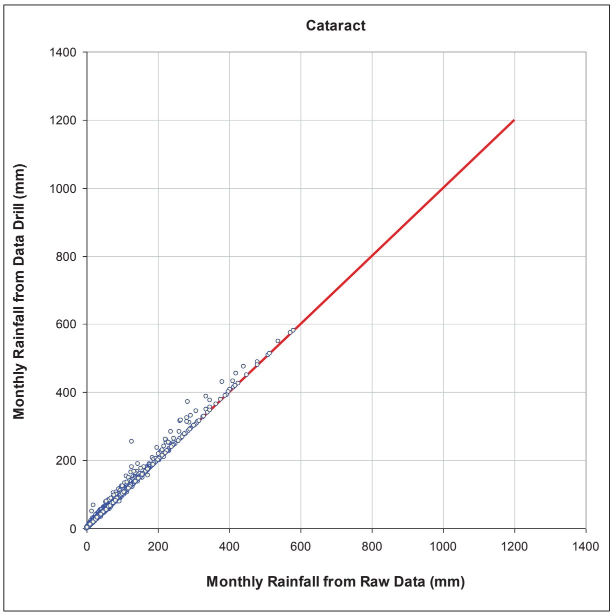
SILO DATA DRILL RAINFALL DATA

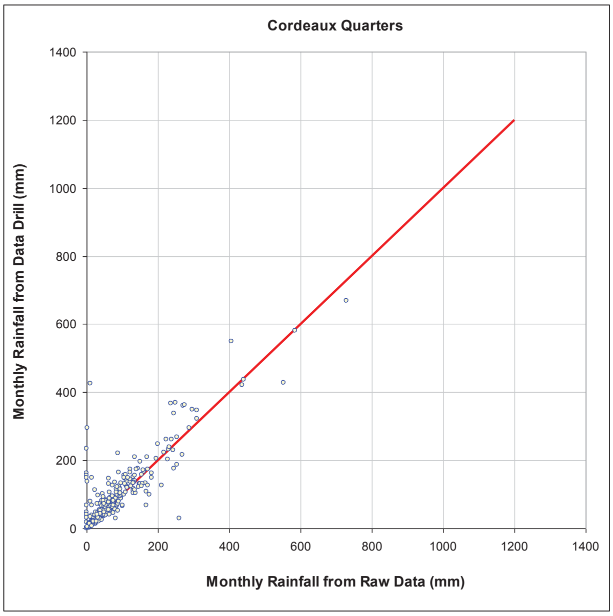

Letterbox Tower
Monthly Rainfall from Data Drill (mm)
Monthly Rainfall from Raw Data (mm)


Mt Keira Scout Camp
Monthly Rainfall from Data Drill (mm)
Monthly Rainfall from Raw Data (mm)


Cataract Dam
Monthly Rainfall from Data Drill (mm)
Monthly Rainfall from Raw Data (mm)

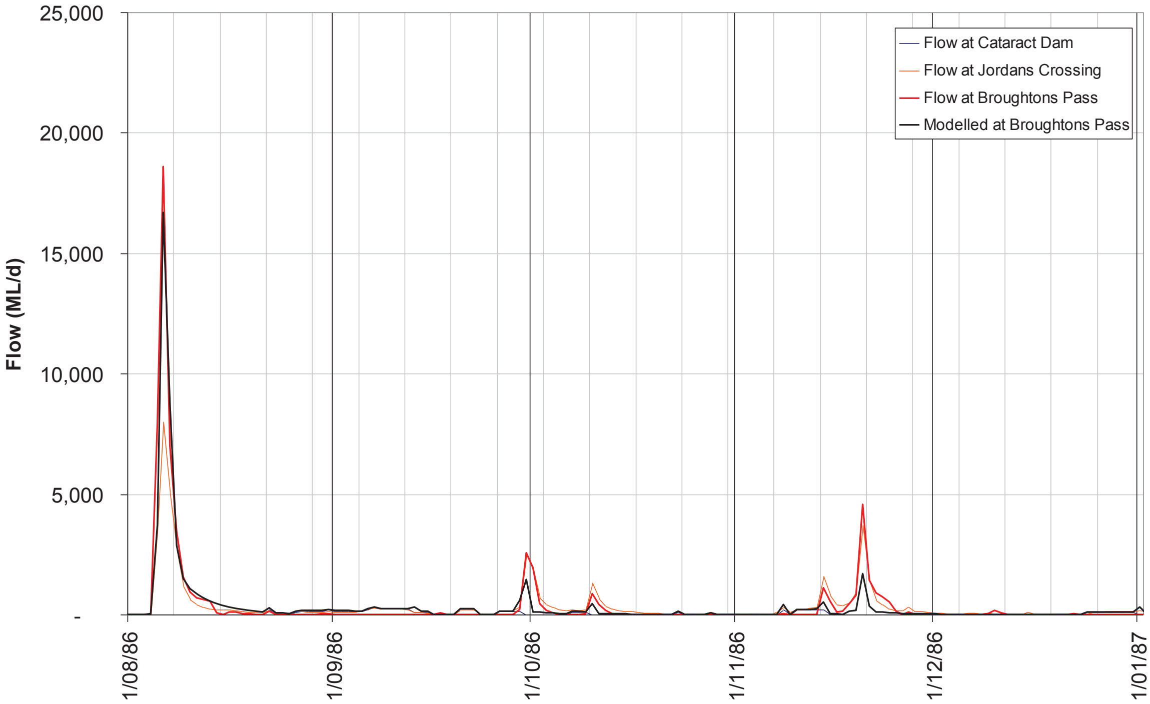

Beth Salem
Data Drill
Raw Data

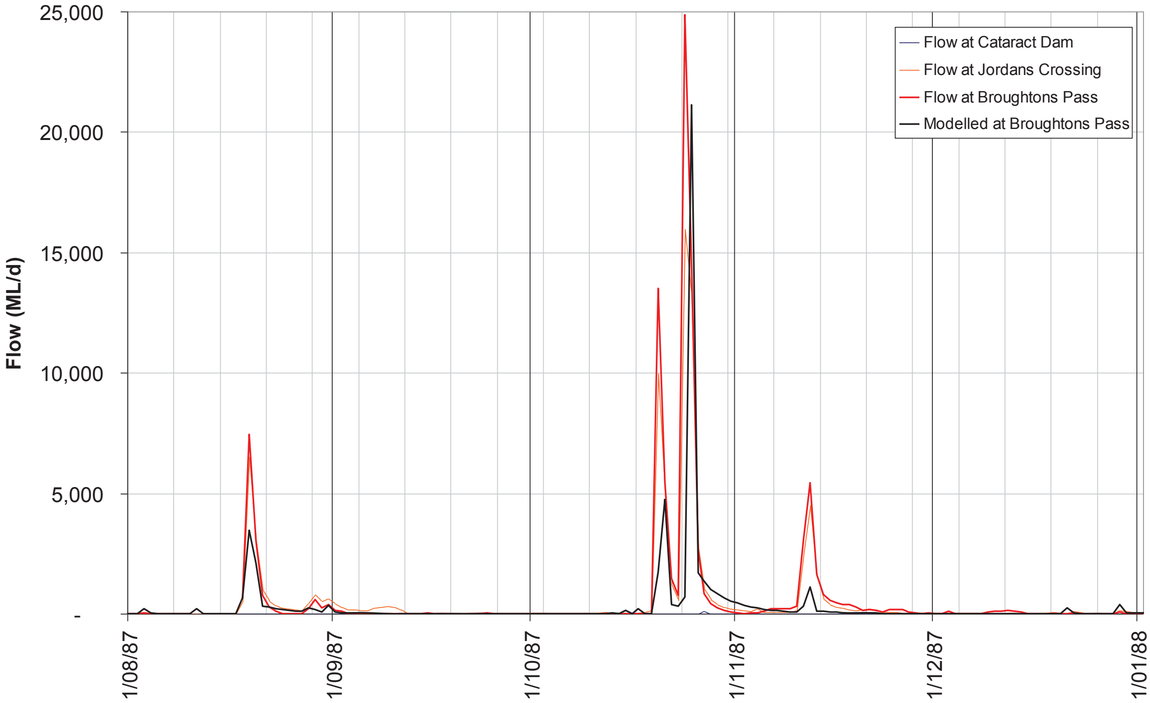

Cataract
Monthly Rainfall from Data Drill (mm)
Monthly Rainfall from Raw Data (mm)

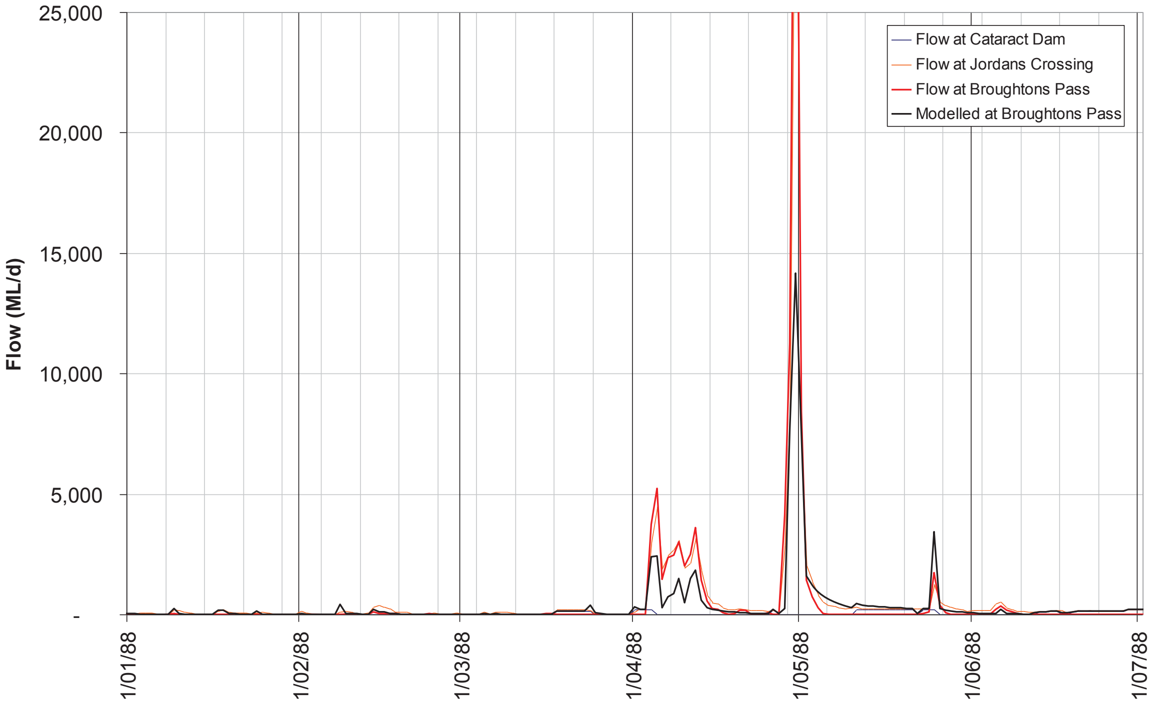

Cordeaux Quarters
Monthly Rainfall from Data Drill (mm)
Monthly Rainfall from Raw Data (mm)

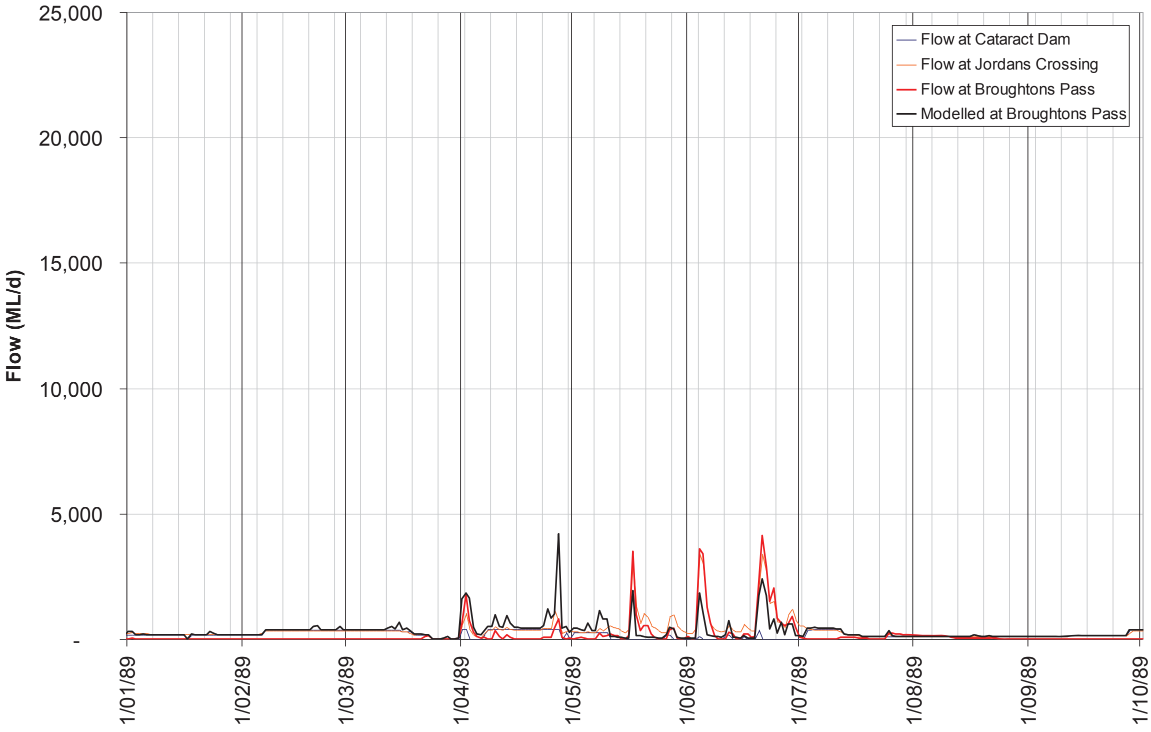
APPENDIX B

MODELLED AND OBSERVED STREAMFLOW DOWNSTREAM OF CATARACT DAM DURING PERIODS OF NO RELEASE


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/08/86
1/09/86
1/10/86
1/11/86
1/12/86
1/01/87
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/08/87
1/09/87
1/10/87
1/11/87
1/12/87
1/01/88
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/01/88
1/02/88
1/03/88
1/04/88
1/05/88
1/06/88
1/07/88
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass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20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/01/89
1/02/89
1/03/89
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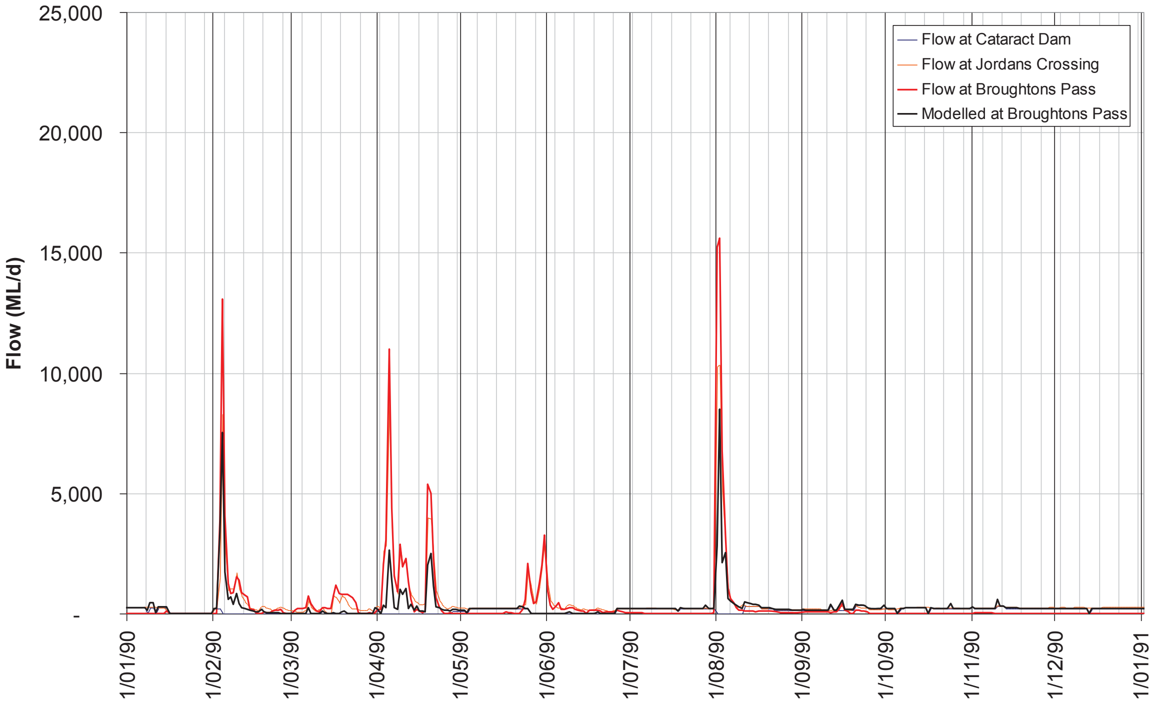
1/05/89
1/06/89
1/07/89
1/08/89
1/09/89
1/10/89
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass
1/01/90
1/02/90
1/03/90
1/04/90
1/05/90
1/06/90
1/07/90
1/08/90
1/09/90
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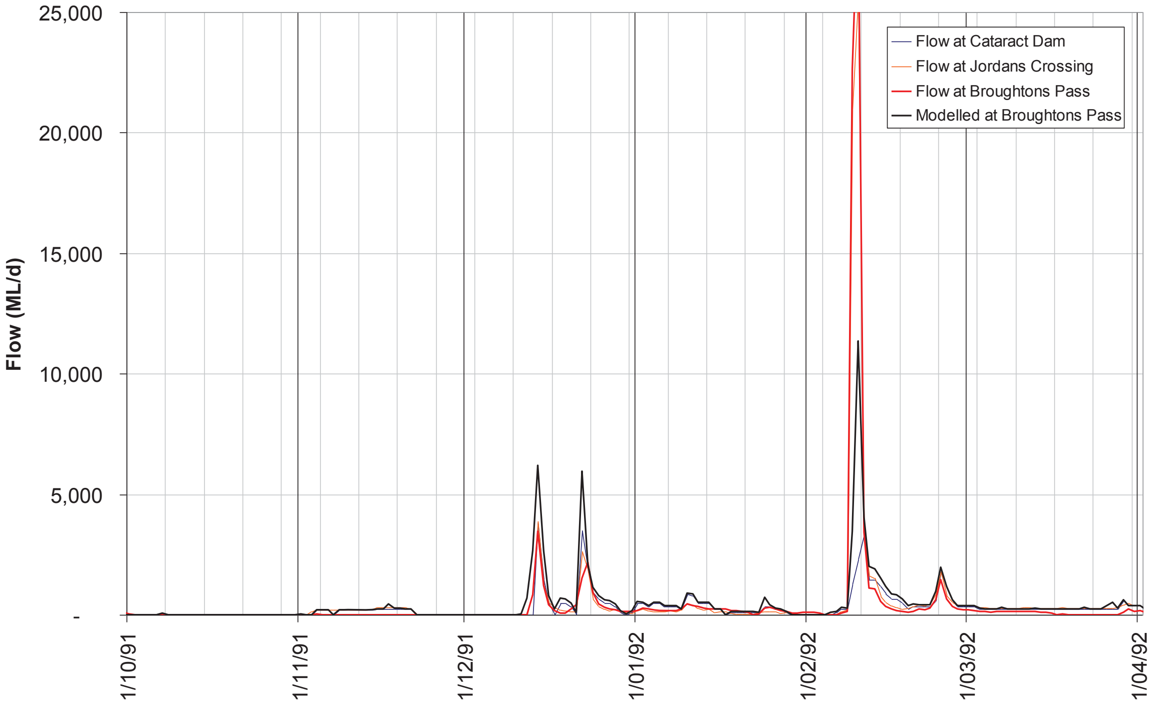
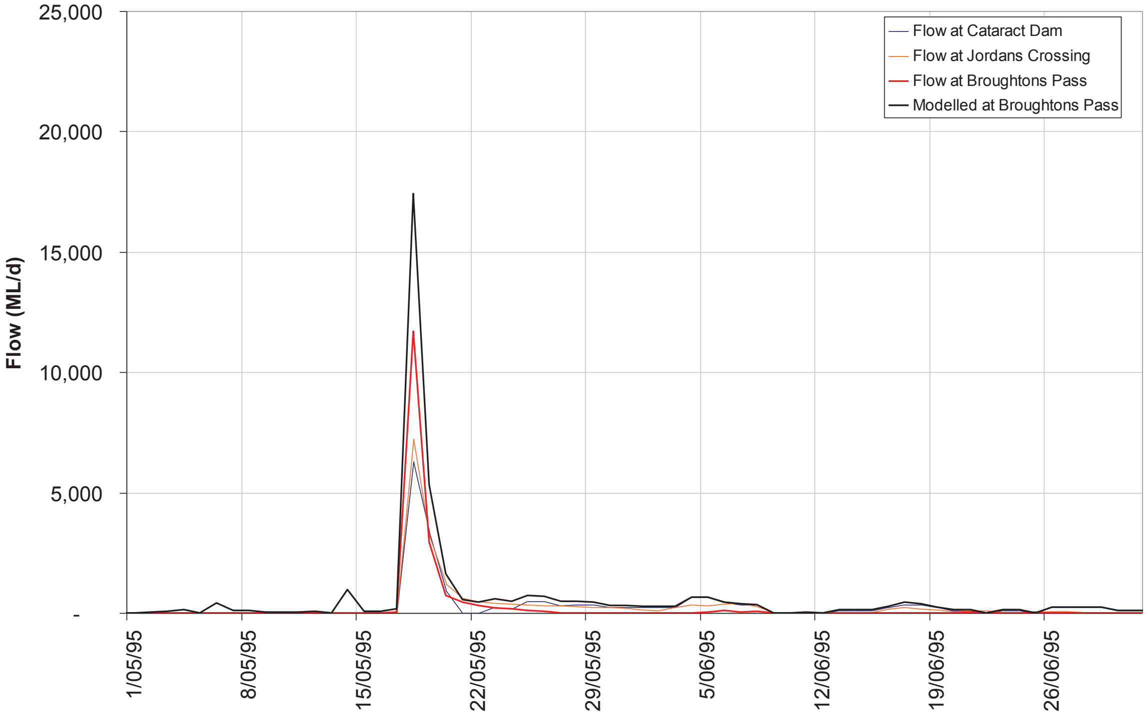
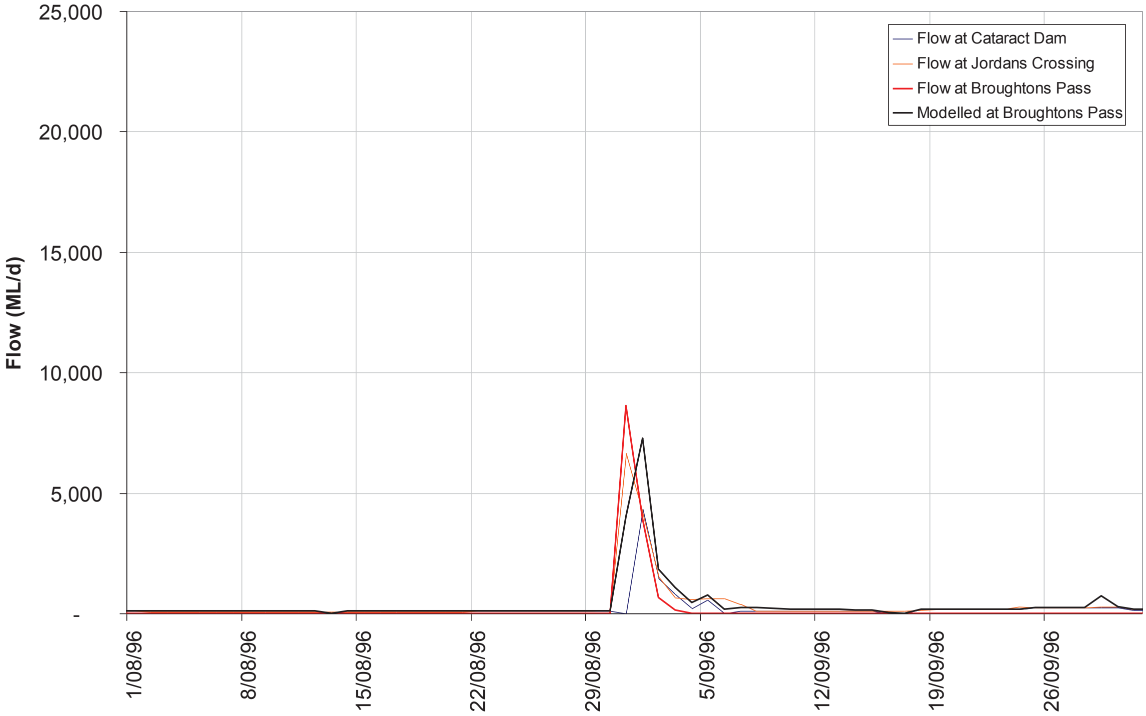
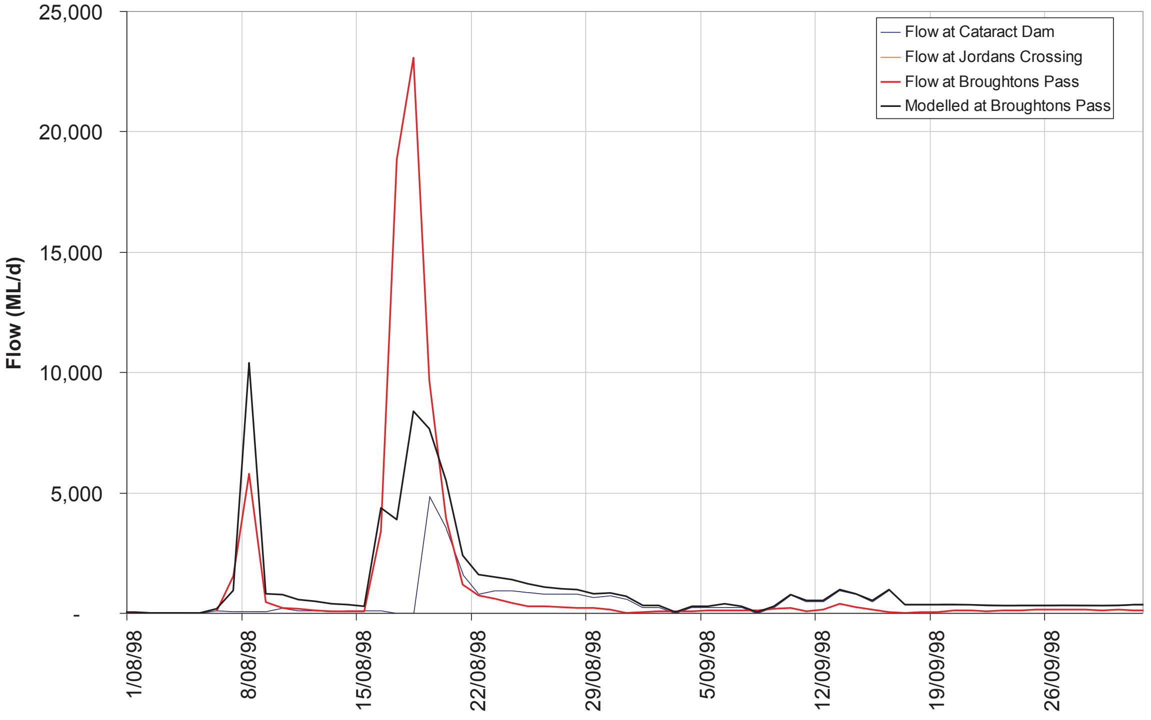
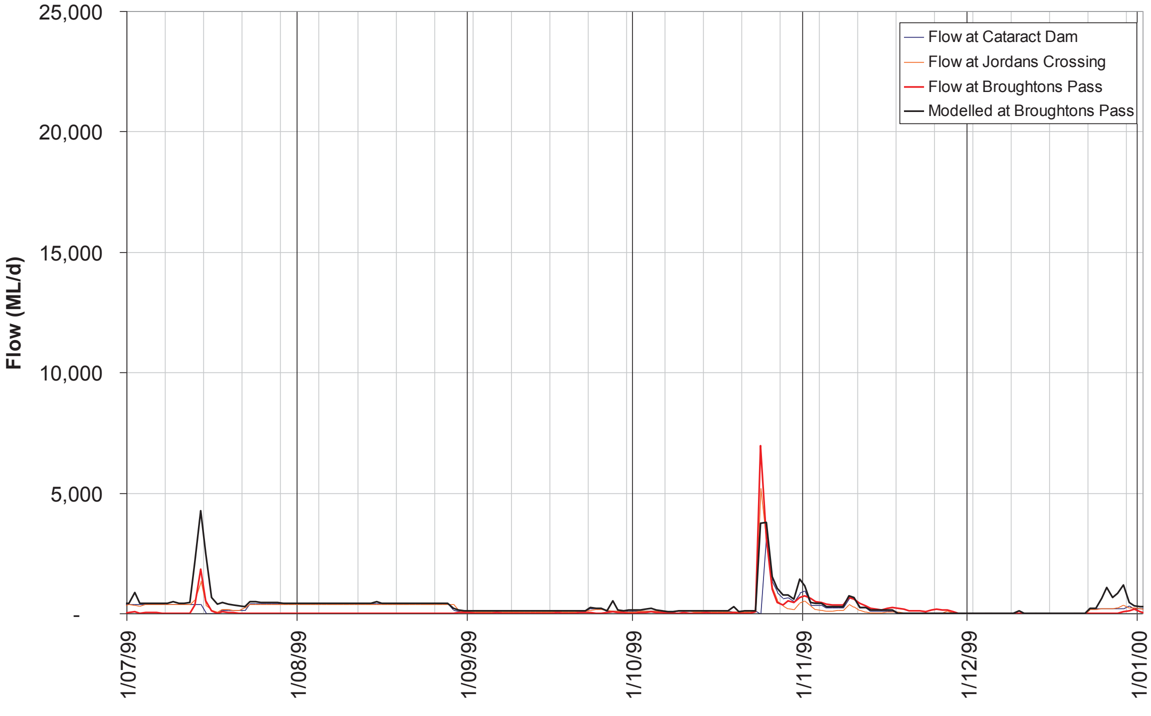
1/11/90
1/12/90
1/01/91

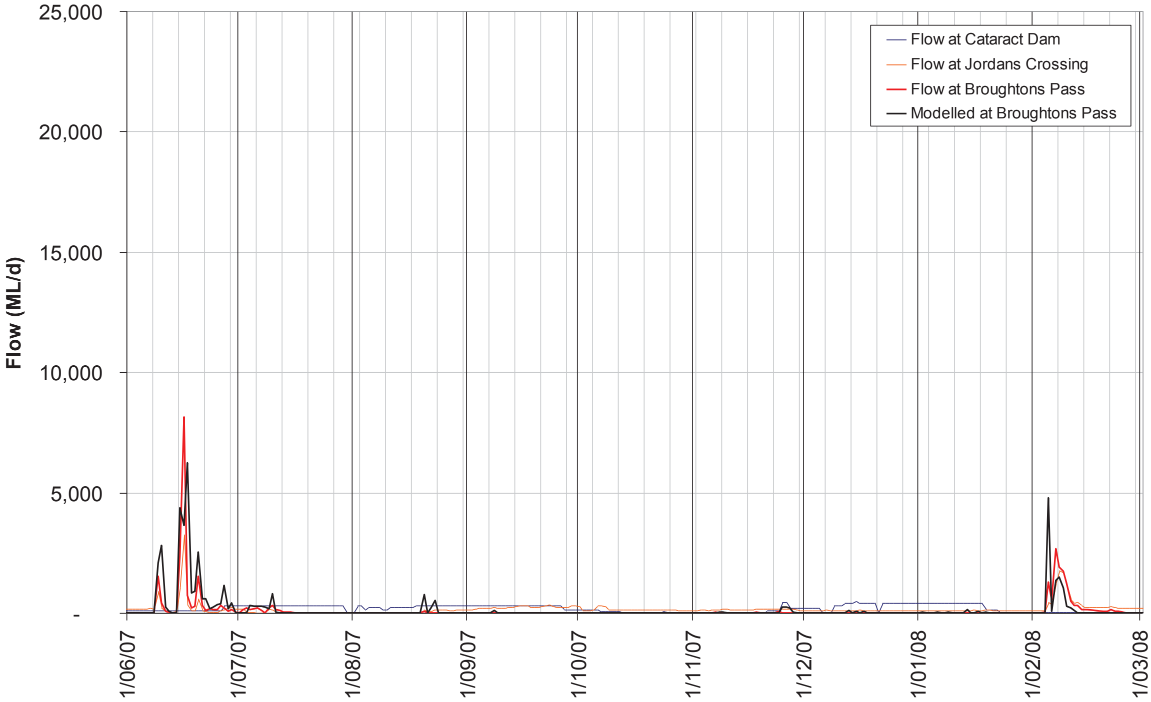

25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass
1/10/91
1/11/91
1/12/91
1/01/92
1/02/92
1/03/92
1/04/92


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/05/95
8/05/95
15/05/95
22/05/95
29/05/95
5/06/95
12/06/95
19/06/95
26/06/95
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/08/96
8/08/96
15/08/96
22/08/96
29/08/96
5/09/96
12/09/96
19/09/96
26/09/96
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/08/98
8/08/98
15/08/98
22/08/98
29/08/98
5/09/98
12/09/98
19/09/98
26/09/98
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


25,000
20,000
15,000
10,000
5,000
-
Flow (ML/d)
1/07/99
1/08/99
1/09/99
1/10/99
1/11/99
1/12/99
1/01/00
Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass


Flow at Cataract Dam
Flow at Jordans Crossing
Flow at Broughtons Pass
Modelled at Broughtons Pass
Flow (ML/d)
25,000
20,000
15,000
10,000
5,000
-
1/06/07
1/07/07
1/08/07
1/09/07
1/10/07
1/11/07
1/12/07
1/01/08
1/02/08
1/03/08

APPENDIX B

STREAM SIGNIFICANCE ASSESSMENT

Stream Values	Stream Name	CC2 - CC3	CC1 - CC4	CC5 - CC6	CC6- CC7	CC7-CC8	CC8-CC9	CC9 - CC10	CT1	Above Cataract Ck
Scale	**Total Catchment (km2)**	6	6	6	6	6	6	6	6	29
	Sub - Catchment (km2)	1.6	1.8	0.5	0.7	0.8	0.5	0.2	0.4	13.1
	Maximum Stream Order	**3rd**	**3rd**	**4th**	**4th**	**4th**	**4th**	**4th**	**2nd**	**4th**
	Reach Rise (m)	10	14	5	7	9	5	3	20	20
	Reach Length (m)	560	1190	245	435	655	460	445	270	2750
	Av. Gradient	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.07	0.01
Hydrologic Value	**Flow Regime**	perm.	perm.	perm.	perm.	perm.	perm.	perm.	ephemeral	perm.
	% of Cataract Ck Catchment	25.8	29.2	9.0	12.3	13.0	8.8	3.5	6.7	45.2
	% of Cataract Dam Catchment	1.12	1.26	0.39	0.53	0.56	0.38	0.15	0.29	9.45
Environmental Quality	**Reach Geomorphology / Geology**	pool / rifle / sand / clay / exposed sandstone / claystone	pool / rifle / sand / clay / exposed sandstone / claystone	pool / rifle / sand / clay / exposed sandstone / claystone	pool / rifle / sand / clay / exposed sandstone / claystone	pool / rifle / sand / clay / exposed sandstone / claystone	pool / rifle / sand / clay / exposed sandstone / claystone	pool / sand	pool / sand / clay / exposed sandstone / claystone	pool / rifle / sand / clay / exposed sandstone and claystone
	Setting	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area
	Public Accessibility	limited	limited	nil	nil	nil	nil	nil	nil	nil
	Median pH	6.18 - 6.09	5.56 - 6.25	6.35 - 6.37	6.35 - 6.37	6.35 - 6.37	6.35 - 6.37	6.35 - 6.37	6.07	n/a
	Median EC (uS/cm)	145 - 130	134 - 132	125 - 135	125 - 135	125 - 135	125 - 135	125 - 135	81	n/a
	Reach previously undermined (km)	560m (Bulli pillar & Balgownie longwalls)	1190m (Bulli bord and pillar)	245m (Bulli bord pillar/ pillar extraction Balgownie LWs)	435m (Bulli bord pillar/ pillar extraction Balgownie LWs)	655m (Bulli bord pillar/ pillar extraction Balgownie LWs)	460m (Bulli bord pillar/ pillar extraction Balgownie LWs)	445m (Bulli bord pillar/ pillar extraction, Balgownie LWs)	270m (Bulli bord pillar/ pillar extraction, Balgownie LWs)	not undermined
	Distance from Closest Centreline to Proposed Nearest Panel (m)	over A1 LW2 and 3	310m to A2 LW2	over gateroad to A2 LW4	abutment pillar A2 LW5, over gateroad to A2 LW5	over gateroad to A2 LW6 and A2 LW7 and over A2 LW8	over A2 LW8 and A2 LW9	over A2 LW9;	over A2 LW5	closest workings are 100m to A2 LW8
Predicted Subsidence	**Predicted Max. Subsidence (m)**	0.16	<0.02	<0.02	<0.02	0.8	0.8	0.26	1.07	<0.02
	Predicted Max. Tensile Strain (mm/m)	<1	<1	<1	<1	5	5	1.3	5.6	<1
	Predicted Max. Compressive Strain (mm/m)	-2	<-1	<-1	<-1	-9.3	-9.3	<-1	-8	<-1
	Predicted Max. Tilt (mm/m)	3	<1	<1	2	6	<1	<1	9	<1
	Max. Equivalent Valley Height (m)	16	will not be undermined	15	20	23	18	19	16	will not be undermined
	Max. Predicted Upsidence (m)	60	will not be undermined	60	60	60	60	60	60	will not be undermined
	Max. Predicted Valley Closure (m)	100	will not be undermined	100	100	100	100	100	100	will not be undermined
Ecological Importance	**Survey Effort**	No direct aquatic or terrestrial fauna sampling.	Frog habitat survey	Aquatic survey (Site 5 and 6) Spring and Autumn 2008 - 2011. Macquarie Perch Survey Summer 2009/2010. Frog habitat survey. Bird point count.	Aquatic survey (Site 5 and 6) Spring and Autumn 2008 - 2011. Macquarie Perch Survey Summer 2009/2010. Frog habitat survey. Bird point count.	Aquatic survey (Site 5 and 6) Spring and Autumn 2008 - 2011. Macquarie Perch Survey Summer 2009/2010. Frog habitat survey. Bird point count.	Aquatic survey (Site 5 and 6) Spring and Autumn 2008 - 2011. Macquarie Perch Survey Summer 2009/2010. Frog habitat survey. Bird point count.	No direct aquatic sampling. Macquarie Perch Survey Summe 2009/2010. Frog habitat survey, bird point count	No direct aquatic sampling.	Aquatic survey (Sites 9 and 10) controls Spring and Autumn 2008 - 2011. No terrestrial fauna sampling
	Threatened Ecological Communities in Riparian Zone	None identified	None identified	None identified	None identified	None identified	None identified	None identified	None identified	None identified
	Threatened Species and Swamps Specialists Recorded	None identified	None identified	**Macquarie Perch** and **Silver Perch** identified CC6. *Maccullochella* sp identified may be Trout Cod or Murray Cod. Both species have been introduced into Cataract Dam	**Macquarie Perch** and **Silver Perch** identified CC6. *Maccullochella* sp identified may be Trout Cod or Murray Cod. Both species have been introduced into Cataract Dam	**Macquarie Perch** and **Silver Perch** identified CC6. *Maccullochella* sp identified may be Trout Cod or Murray Cod. Both species have been introduced into Cataract Dam	**Macquarie Perch** and **Silver Perch** identified CC6. *Maccullochella* sp identified may be Trout Cod or Murray Cod. Both species have been introduced into Cataract Dam	Macquarie Perch and Silver Perch identified. *Maccullochella* sp identified may be **Trout Cod or Murray Cod**. Both species have been introduced into Cataract Dam.	None identified	None identified
	Threatened Species Predicted	Potential habitat for Adams Emerald Dragonfly	Stuttering Barred Frog breeding habitat (good quality) identified.	Potential habitat for Adams Emerald Dragonfly. Stuttering Barred Frog breeding habitat (good quality) identified.	Potential habitat for Adams Emerald Dragonfly. Stuttering Barred Frog breeding habitat (good quality) identified.	Potential habitat for Adams Emerald Dragonfly. Stuttering Barred Frog breeding habitat (marginal quality grading to good) identified.	Potential habitat for Adams Emerald Dragonfly.	Potential habitat for Adams Emerald Dragonfly		Potential habitat for Adams Emerald Dragonfly and Sydney Hawk Dragonfly.
	Associated Upland Swamps	CCUS1, CCUS2, CCUS17, CCUS18, CCUS19, CCUS15 and CCUS14	-	CCUS7	CCUS7 and CCUS8.	CCUS3, CCUS23, CCUS9 and CCUS10	CCUS4, CCUS5, CCUS7, CCUS8, CCUS10 and CCUS11	CCUS12	CCUS6, CCUS20 and CCUS21	CRUS1, CRUS2, CRUS3, CRUS4 and CRUS5

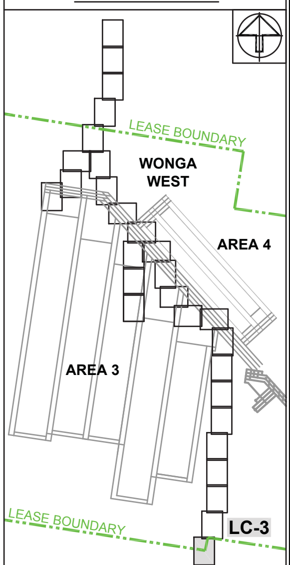
Stream Values	Stream Name	Lizard Creek								
	Stream Attribute	**LC1 - LC2**	**LC2 - LC3**	**LC3 - Waterfall L1**	**Waterfall L1 - LC4**	**LC4 - LC5**	**LC5 - LC6**	**LC6 - LC7**	**LCT1**	**LCT2**
Scale	**Total Catchment (km2)**	17.1	–	–	–	–	–	–	–	–
	Sub - Catchment (km2)	5.7	0.8	1.6	0.3	0.4	1.1	1.4	1.7	3.7
	Maximum Stream Order	**3rd**	**3rd**	**3rd**	**3rd**	**3rd**	**3rd**	**4th**	**3rd**	**3rd**
	Reach Rise (m)	6	5	24	20	3	9	16	21	25
	Reach Length (m)	650	785	1320	315	390	1200	1670	940	820
	Av. Gradient	0.01	0.01	0.02	0.06	0.01	0.01	0.01	0.02	0.03
Hydrologic Value	**Flow Regime**	perm.	perm.	perm.	perm.	perm.	intermittent	perm.	intermittent	intermittent
	% of Catchment	33.3	4.6	9.3	2.1	2.3	6.4	8.1	9.9	21.6
Environmental Quality	**Reach Geomorphology / Geology**	valley fill swamp	valley fill swamp	pool / riffle / exposed sandstone / waterfall L1	pool / riffle / exposed sandstone	pool / riffle / sand / exposed sandstone	exposed sandstone / pool / riffle / sand	pool / riffle / exposed sandstone	exposed sandstone / pool / riffle	exposed sandstone / pool / riffle
	Setting	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area
	Public Accessibility	limited	limited	nil	nil	nil	nil	nil	nil	nil
	Median pH	4.5 - 5.5	5.44 - 5.93	5.93 - 6.44	5.93 - 6.44	6.44 - 6.30	6.30 - 6.11	6.11 - 6.25	4.54	5.4
	Median EC (uS/cm)	66 - 110	110 - 118	118 - 153	118 - 153	152 - 135	135 - 138	138 - 188	175	205
	Reach previously undermined (km)	680m (Cordeaux LW18, 19)	800m (Cordeaux LW20) / N S headings	1330m (N S & EW headings, LW202)	325m (EW headings LW303)	320m (LW303)	1270m (LW303 - 307)	720m (LW307 - 309)	1450m (LW307 - 309)	not undermined
	Distance from Closest Centreline to Proposed Nearest Panel (m)	920m to A2 LW3	390m to A2 LW3	125m to A3 LW1	125m to A3 LW1	170m to A3 LW1	165m to A3 LW3	130m to A4 LW7	over A3 LW3	120m to A3 LW5
Predicted Subsidence	**Predicted Max. Subsidence (m)**	<0.02	<0.02	0.2	0.2	<0.02	0.25	0.25	2.5	<0.02
	Predicted Max. Tensile Strain (mm/m)	<1	<1	2	<1	2	5	3	7	<1
	Predicted Max. Compressive Strain (mm/m)	<-1	<-1	<-1	<-1	<-1	<-1	<-1	-7	<-1
	Predicted Max. Tilt (mm/m)	<1	<1	3	<1	<1	3	<1.0	13	<1
	Max. Equivalent Valley Height (m)	will not be undermined	will not be undermined	8	15	38	46	22	31	36
	Max. Predicted Upsidence (m)	will not be undermined	will not be undermined	120	120	120	120	120	120	120
	Max. Predicted Valley Closure (m)	will not be undermined	will not be undermined	200	200	200	200	200	200	200
Ecological Importance	**Survey Effort**	Bird Area Survey, Floristic Survey	Bird Area Survey, Floristic Survey	Floristic Survey, Bird Area Search, Frog Habitat Survey, Spotlighting, Call Broadcasting, Anabat Survey, Hair Funnels	Bird Area Search	No direct aquatic or terrestrial fauna sampling.	Bird Count Point, Aquatic Survey (Site 3 and 17) Spring and Autumn 2008 - 2011	Bird Count Point, Aquatic Survey (Site 4) Spring and Autumn 2008 - 2011	Frog habitat survey, Spotlighting, Call broadcast, Hair funnels, Florisitic Survey.	Floristic Survey
	Threatened Ecological Communities in Riparian Zone	**Coastal Upland Swamps EEC (State)**	**Coastal Upland Swamps EEC (State)**	**Coastal Upland Swamps EEC (State)**	-	-	-	-	**Coastal Upland Swamp EEC (State)**	**Coastal Upland Swamp EEC (State)**
	Threatened Species and Swamps Specialists Recorded	Southern Emu Wren (regional significance)	*Monotoca ledifolia* (RoTAP). Red-crowned Toadlet (regional significance). Southern Emu Wren (regional significance).	Eastern Bentwing Bat, Eastern Falsistrelle	-	-	**Giant Burrowing Frog (national significance)**. Red-crowned Toadlet (regional significance). Beautiful Firetail (regional significance).	-	Powerful Owl, **Giant Burrowing Frog (national)**	**Giant Burrowing Frog (national)**
	Threatened Species Predicted	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly
	Associated Upland Swamps	LCUS1	LCUS1	LCUS2, LCUS3, LCUS4, LCUS5, LCUS6, LCUS7, LCUS8, LCUS10, LCUS11, LCUS12, LCUS13, LCUS14, LCUS15, LCUS16 and LCUS13	LCUS17, LCUS33, LCUS13, LCUS14, LCUS15 and LCUS16	-	-	LCUS22, LCUS23 and LCUS24	LCUS18, LCUS20, LCUS21 and LCUS19	LCUS25 and LCUS26

Stream Values	Stream Name	Wallandoola Ck				
	Stream Attribute	**WC1 - WC2**	**WC2 - WC3**	**WC3 - WC4**	**WC4 - Waterfall W1**	**Waterfall W1 - WC5**
Scale	**Total Catchment (km2)**	33.2	_	_	_	_
	Sub - Catchment (km2)	6.1	0.9	2.4	0.1	0.6
	Maximum Stream Order	**3rd**	3rd	3rd	3rd	3rd
	Reach Rise (m)	6	5	7	3	32
	Reach Length (m)	1120	580	1310	120	340
	Av. Gradient	0.01	0.01	0.01	0.03	0.09
Hydrologic Value	**Flow Regime**	perm.	perm.	perm.	intermittent	perm.
	% of Catchment	18.5	2.7	7.3	0.3	1.8
Environmental Quality	**Reach Geomorphology / Geology**	valley fill swamp	pool / riffle / exposed sandstone	pool / exposed sandstone	pool / exposed sandstone / Waterfall W1	exposed sandstone / pool
	Setting	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area	SCA Metropolitan Special Area
	Public Accessibility	limited	limited	nil	nil	nil
	Median pH	5.65 - 6.02	6.02 - 5.49	5.49 - 6.19	6.19 - 6.1	6.19 - 6.1
	Median EC (uS/cm)	112 - 124	124 - 114	114 - 142	142 - 138	142 - 138
	Reach previously undermined (km)	285m (Cordeaux LW22)	475m (LW P and LW208)	1310m (LW208 - 11)	on the W 20mm subsidence edge of LW211	on the W 20mm subsidence edge of LW211
	Distance from Closest Centreline to Proposed Nearest Panel (m)	565m to A3 LW2	170m to A3 LW2	65m to A3 LW4	220m to A3 LW5	305m to A3 LW5
Predicted Subsidence	**Predicted Max. Subsidence (m)**	<0.02	0.02	0.5	<0.02	<0.02
	Predicted Max. Tensile Strain (mm/m)	<1	2	6	<1	<1
	Predicted Max. Compressive Strain (mm/m)	<-1	<-1	<-1	<-1	<-1
	Predicted Max. Tilt (mm/m)	<1	<1	3	<1	<1
	Max. Equivalent Valley Height (m)	will not be undermined	will not be undermined	12	21	will not be undermined
	Max. Predicted Upsidence (m)	will not be undermined	will not be undermined	120	120	will not be undermined
	Max. Predicted Valley Closure (m)	will not be undermined	will not be undermined	200	200	will not be undermined
Ecological Importance	**Survey Effort**	Bird Area Search, Anabat Survey, Hair Funnels.	No direct aquatic or terrestrial fauna sampling.	Frog Habitat Survey, Bird Count Point, Floristic Survey.	No direct aquatic or terrestrial fauna sampling.	Bird Count Point.
	Threatened Ecological Communities in Riparian Zone	**Coastal Upland Swamp EEC (State)**	**Coastal Upland Swamp EEC (State)**	**Coastal Upland Swamp EEC (State)**	-	-
	Threatened Species and Swamps Specialists Recorded	Eastern Bentwing-bat, East Coast Freetail Bat	-	-	-	-
	Threatened Species Predicted	Potential habitat for Adam's Emerald Dragonfly	Potential habitat for Adam's Emerald Dragonfly, Heath Frog	Potential habitat for Adam's Emerald Dragonfly, Giant Burrowing Frog and Heath Frog	Potential habitat for Adam's Emerald Dragonfly, Giant Burrowing Frog	Potential habitat for Adam's Emerald Dragonfly, Giant Burrowing Frog
	Associated Upland Swamps	WCUS1 and WCUS2	WCUS1	WCUS3, WCUS4, WCUS5, WCUS6, WCUS7, WCUS8, WCUS9, WCUS11 and WCUS12	WCUS10	-

APPENDIX C

LIZARD CREEK AND WALLANDOOLA CREEK STREAM REACH AERIAL PHOTOGRAPHS (courtesy Photomaps by NearMap)

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

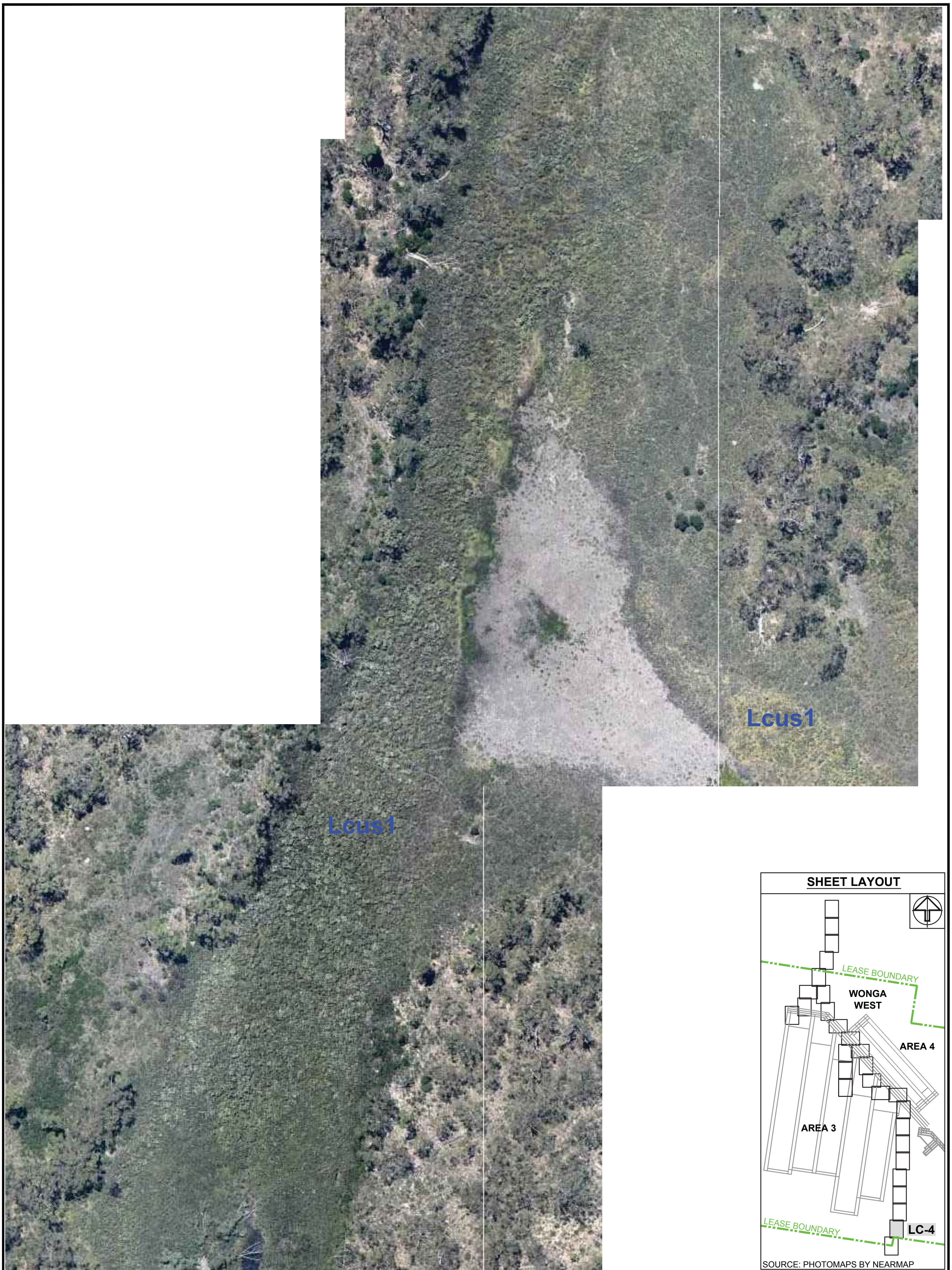
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-3



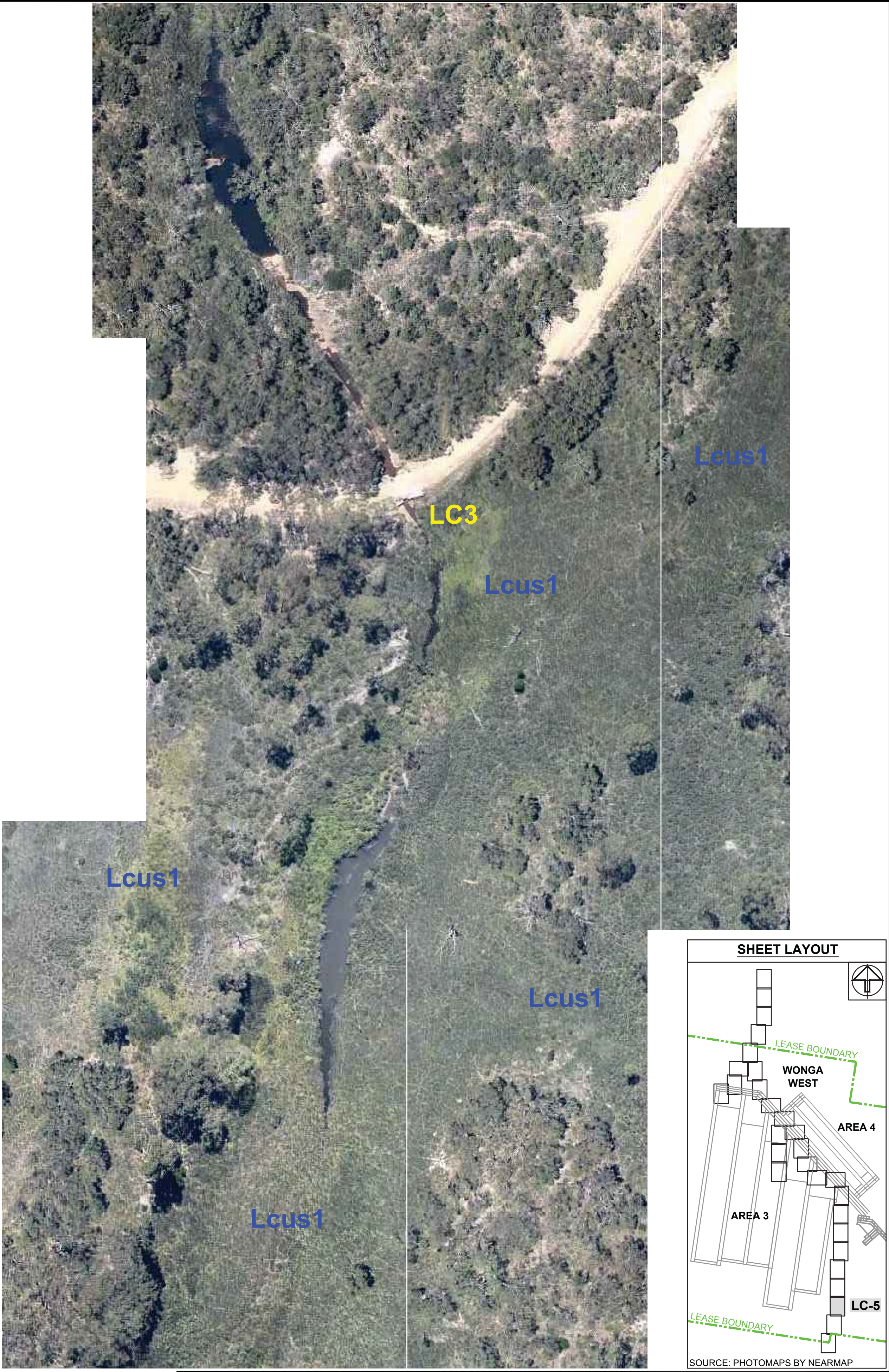
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-4



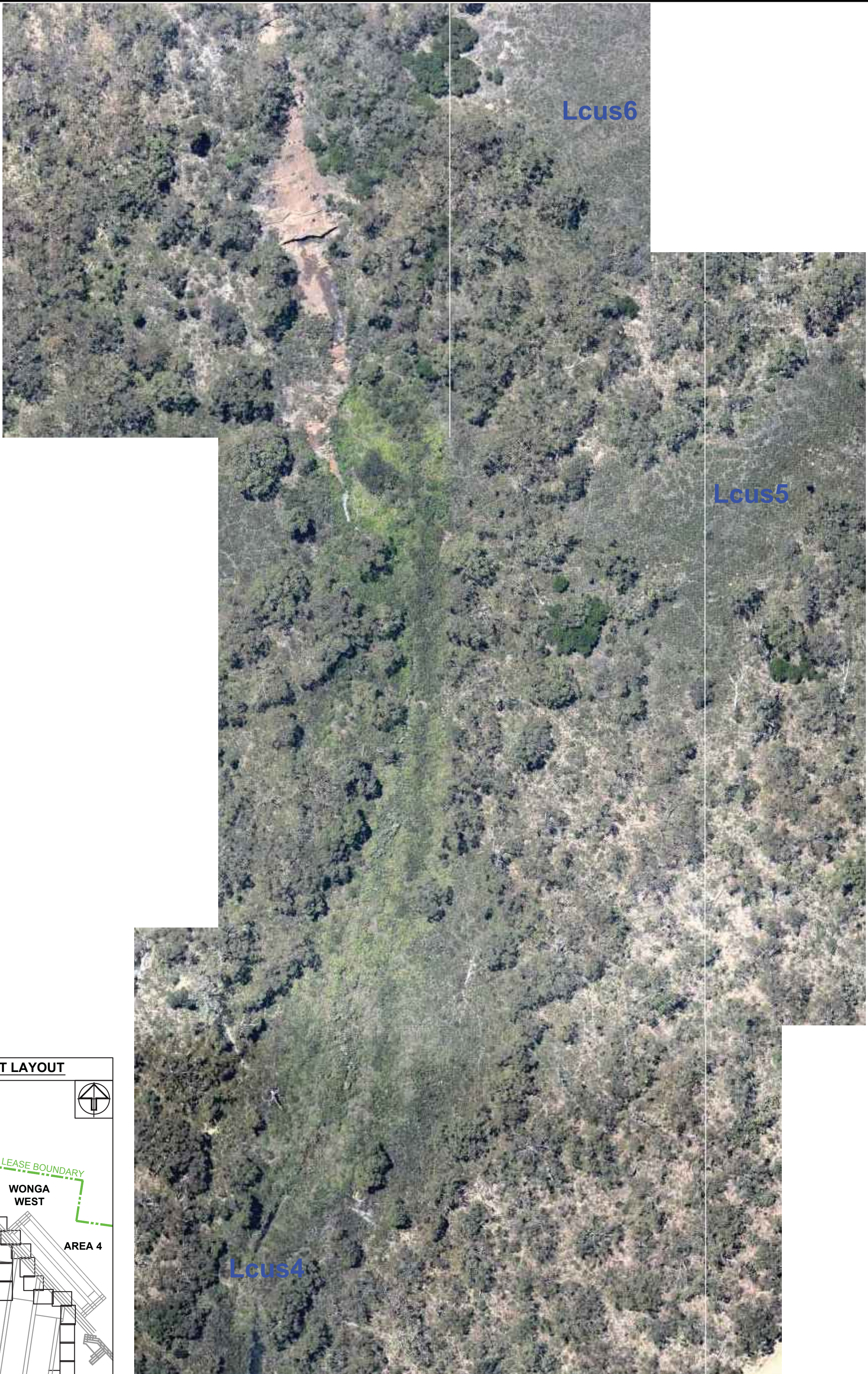
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

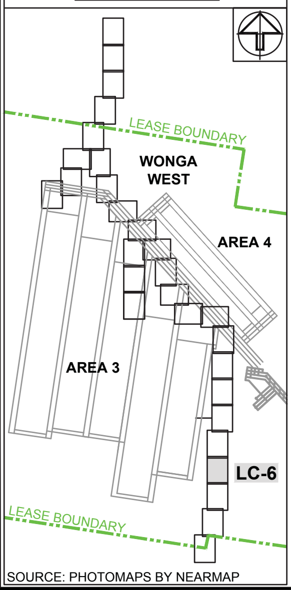
LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-5

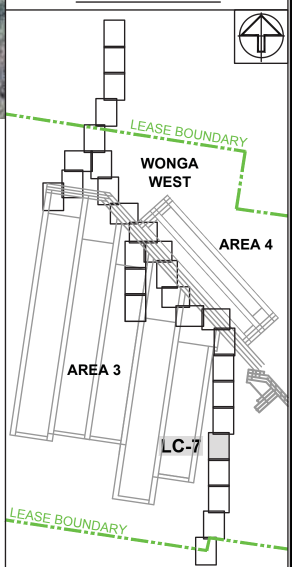


SHEET LAYOUT



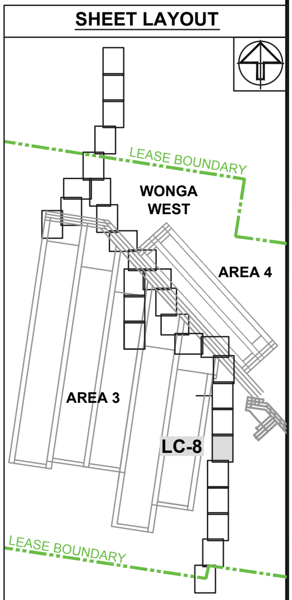
SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1	GUJARAT NRE COKING COAL PTY LTD MAJOR EXPANSION PROJECT BELLAMBI, NSW	GeoTerra
DRAWN:	A. DAWKINS		
DATE:	23 Nov 2012		FIGURE LC-6
SCALE:	1:1000	LIZARD CREEK MAPPING	



SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1	GUJARAT NRE COKING COAL PTY LTD MAJOR EXPANSION PROJECT BELLAMBI, NSW	GeoTerra	
DRAWN:	A. DAWKINS			
DATE:	23 Nov 2012			
SCALE:	1:1000	LIZARD CREEK MAPPING	FIGURE LC-7	



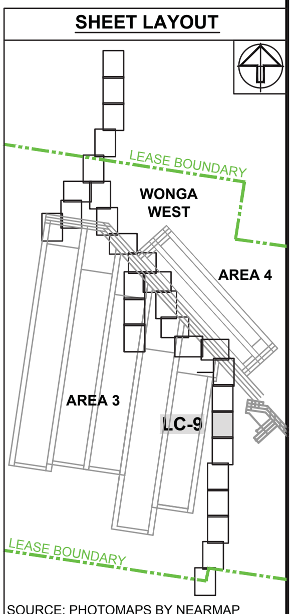
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-8



PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

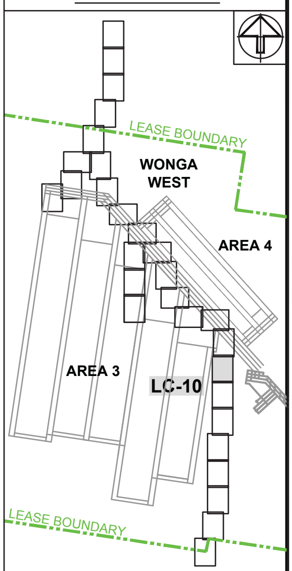
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-9

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

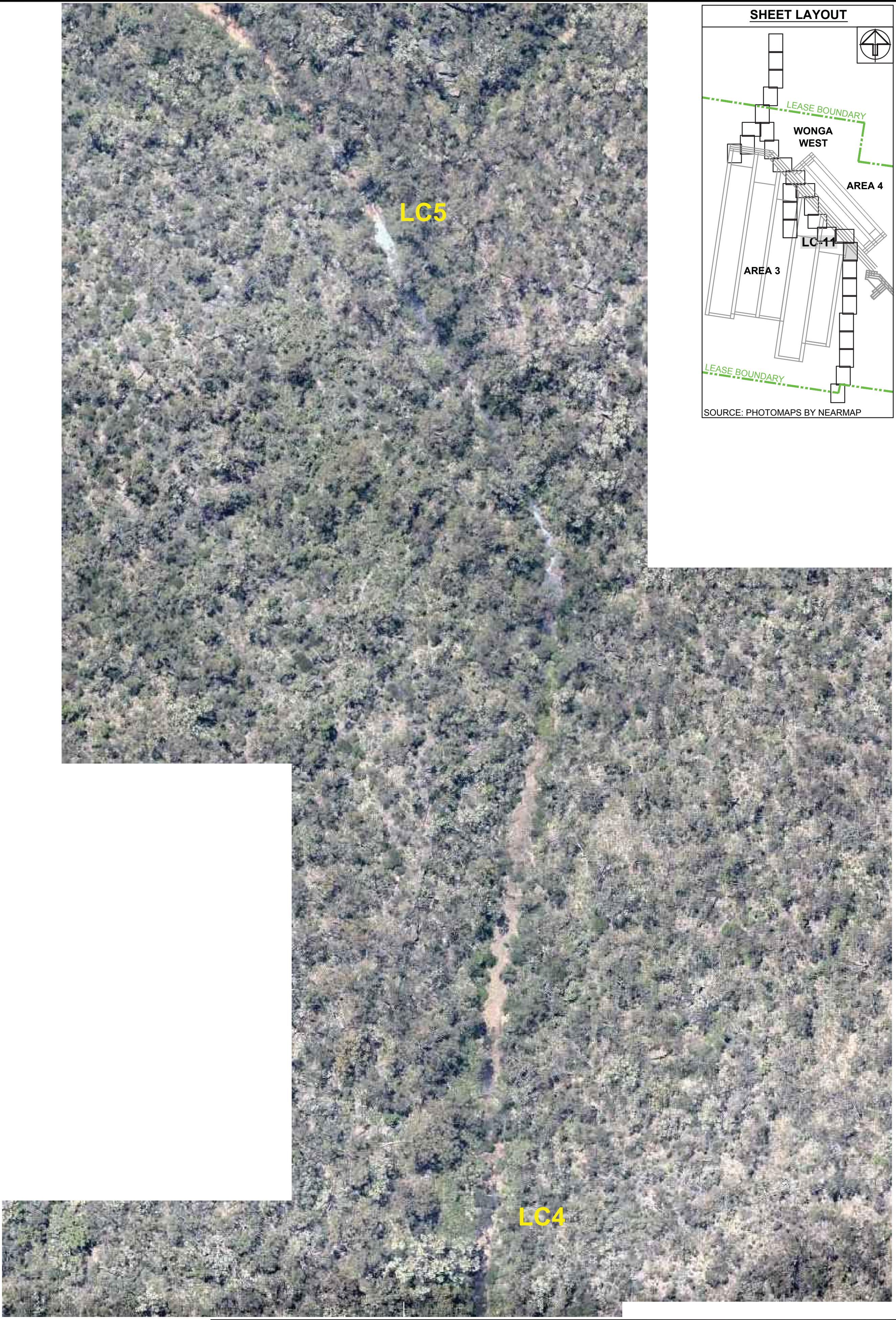
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-10



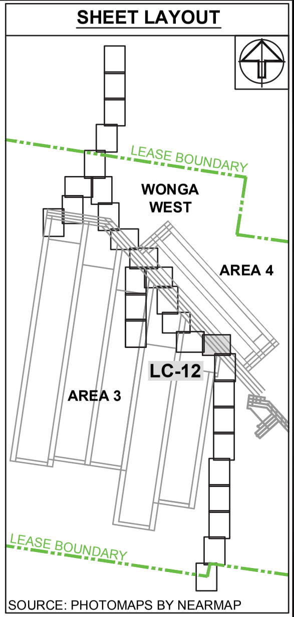
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	13 Sept 2010
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-11



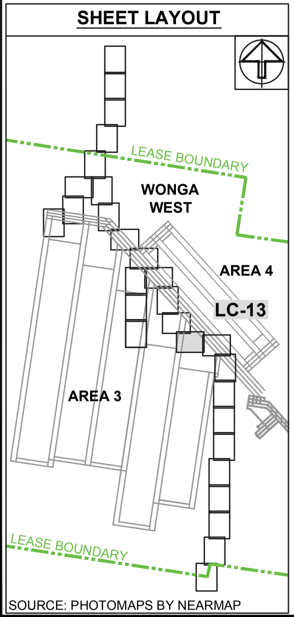
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	13 Sept 2010
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-12



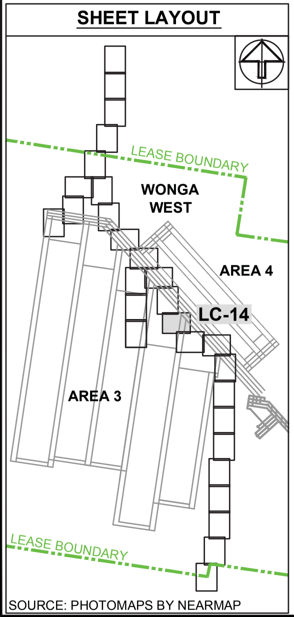
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-13



PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-14

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-15

PROJECT:	GUJ1 R1	
DRAWN:	A. DAWKINS	
DATE:	23 Nov 2012	
SCALE:	1:1000	

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-16

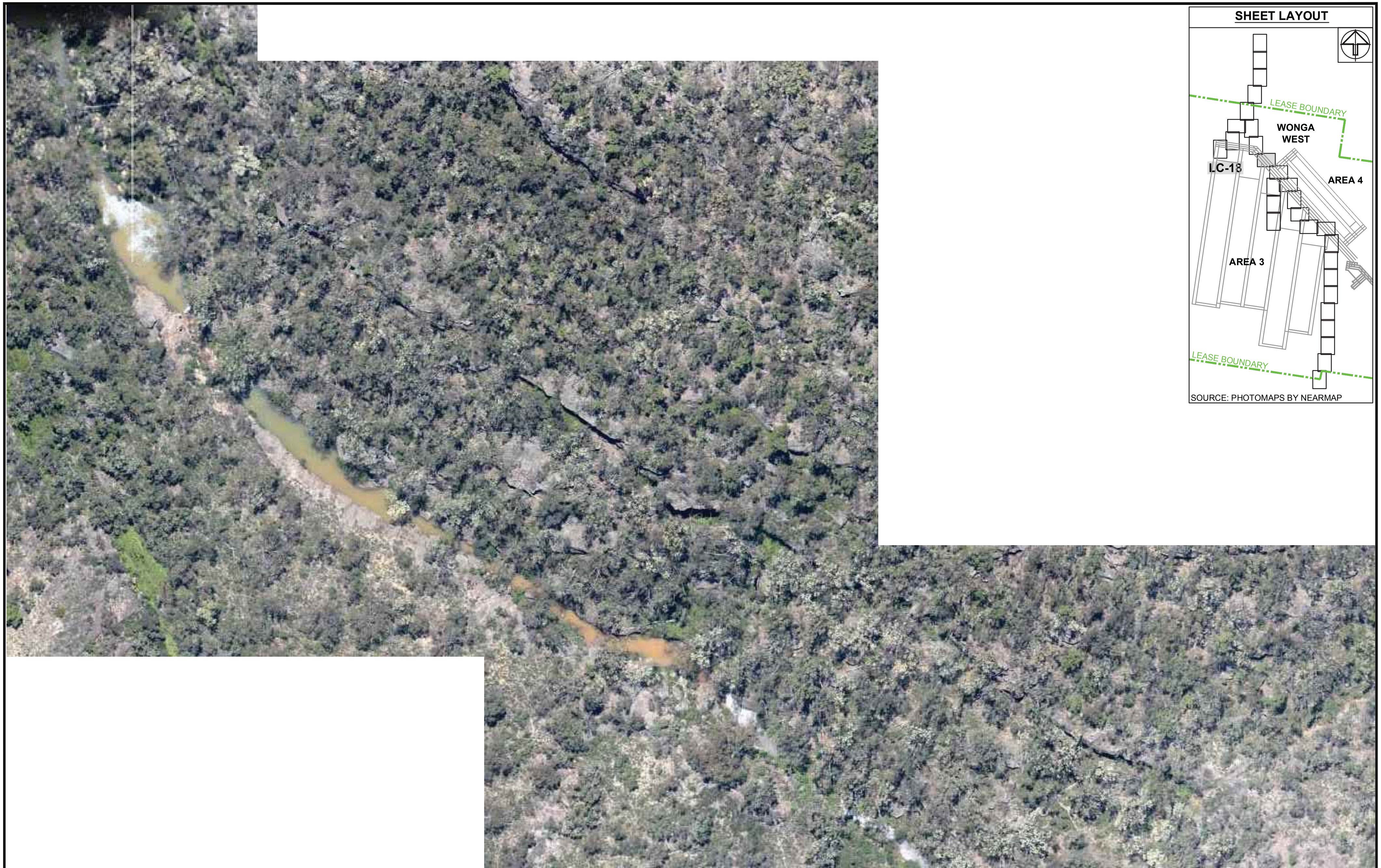
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-17



PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

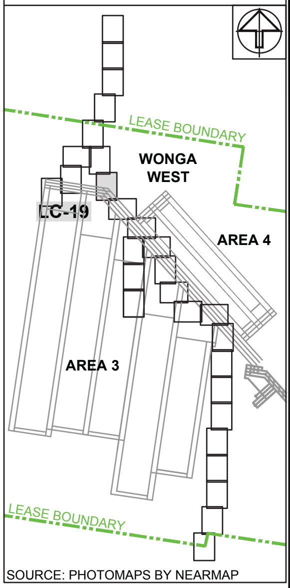
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-18

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

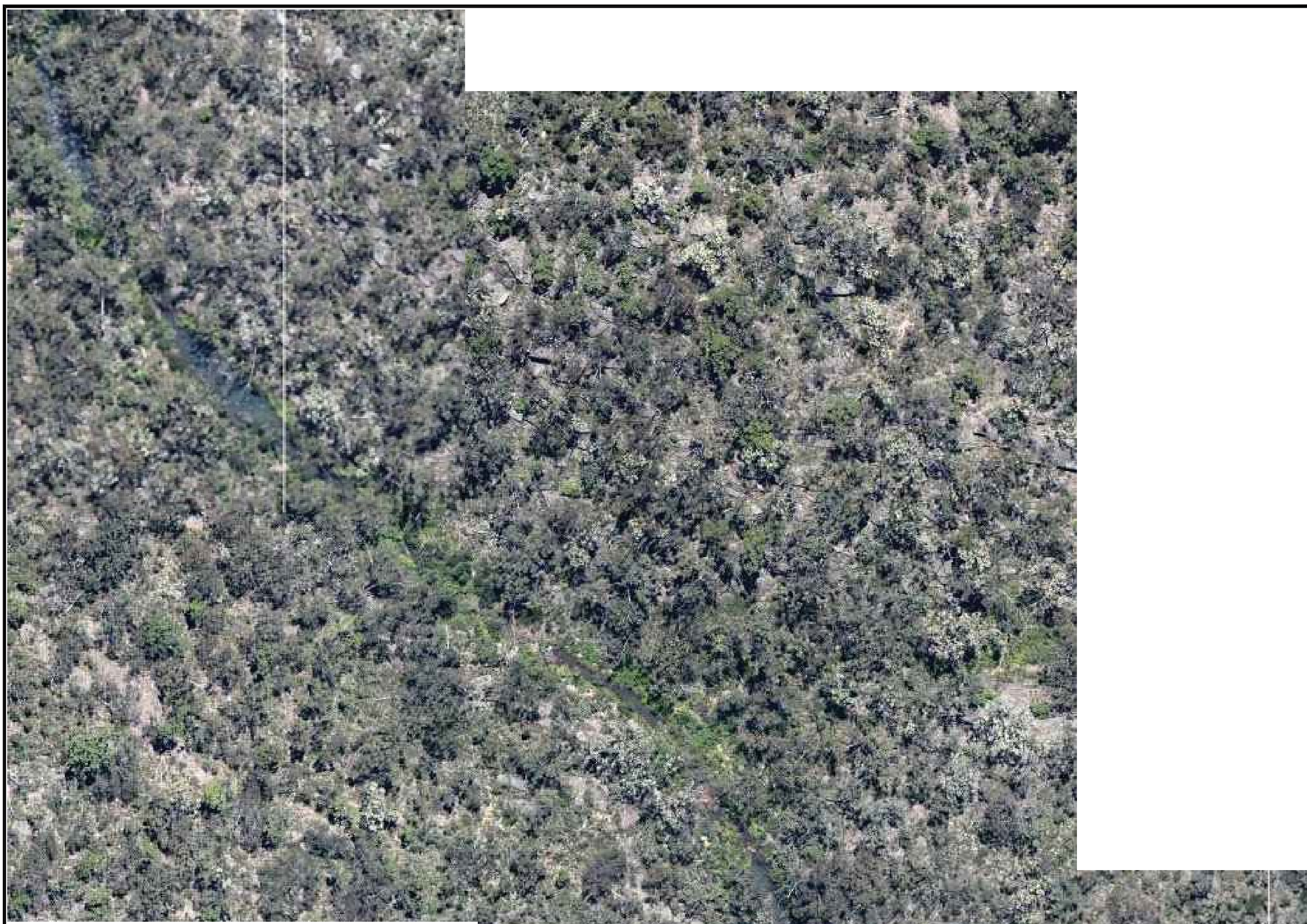
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

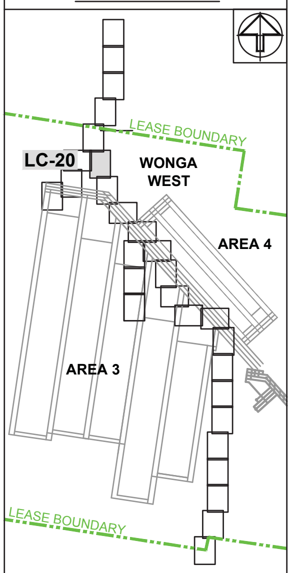
LIZARD CREEK MAPPING

GeoTerra

FIGURE LC-19




SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

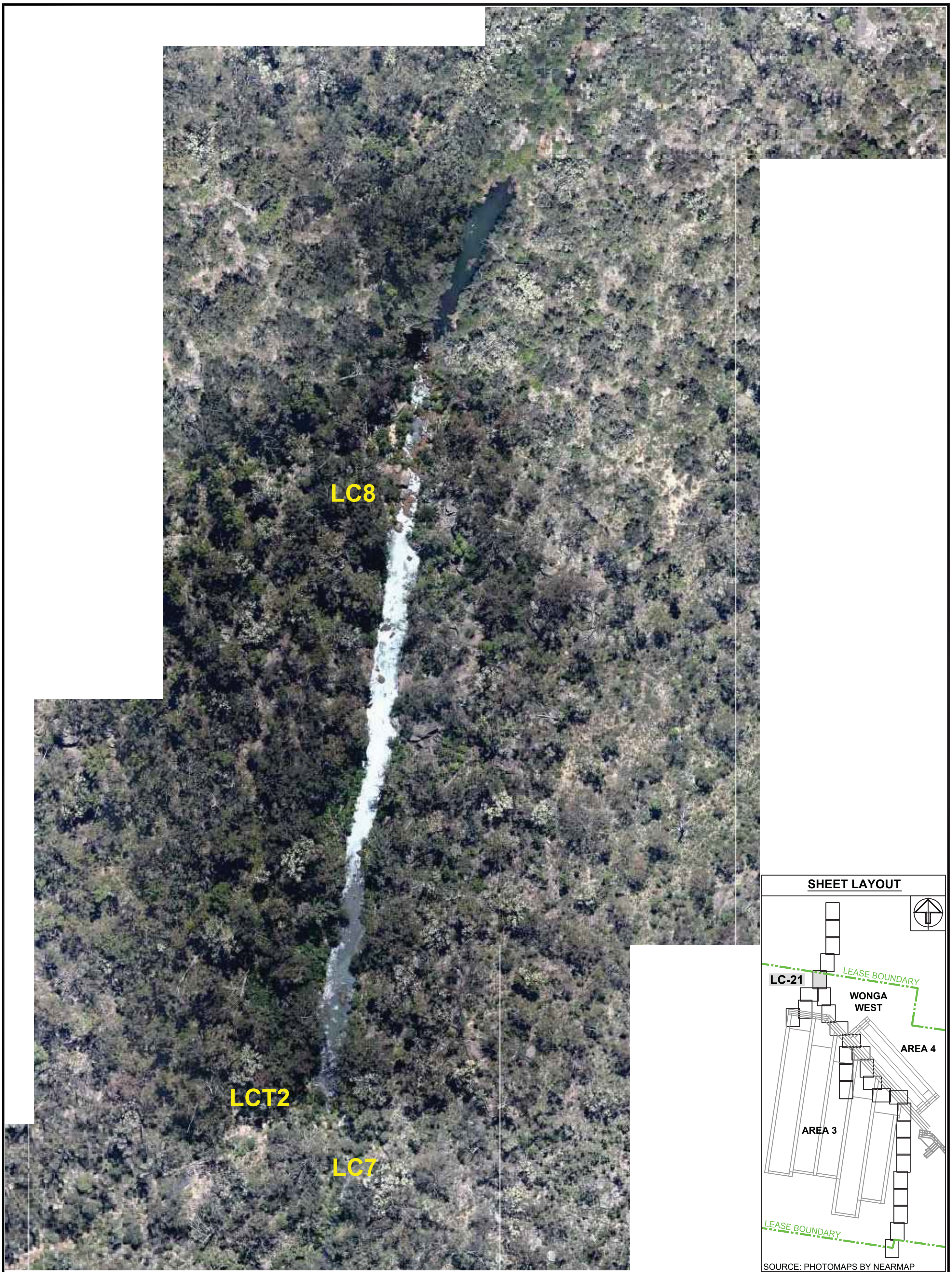
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

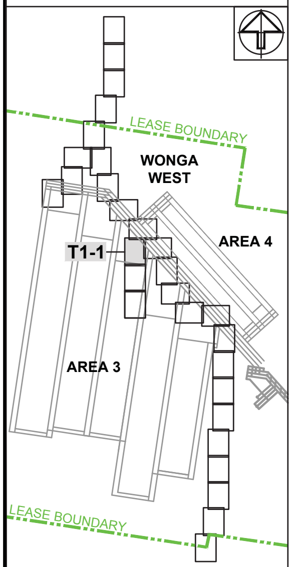
GeoTerra

FIGURE LC-20



PROJECT:	GUJ1 R1	GUJARAT NRE COKING COAL PTY LTD MAJOR EXPANSION PROJECT BELLAMBI, NSW LIZARD CREEK MAPPING	GeoTerra	
DRAWN:	A. DAWKINS			
DATE:	23 Nov 2012		FIGURE LC-21	
SCALE:	1:1000			

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

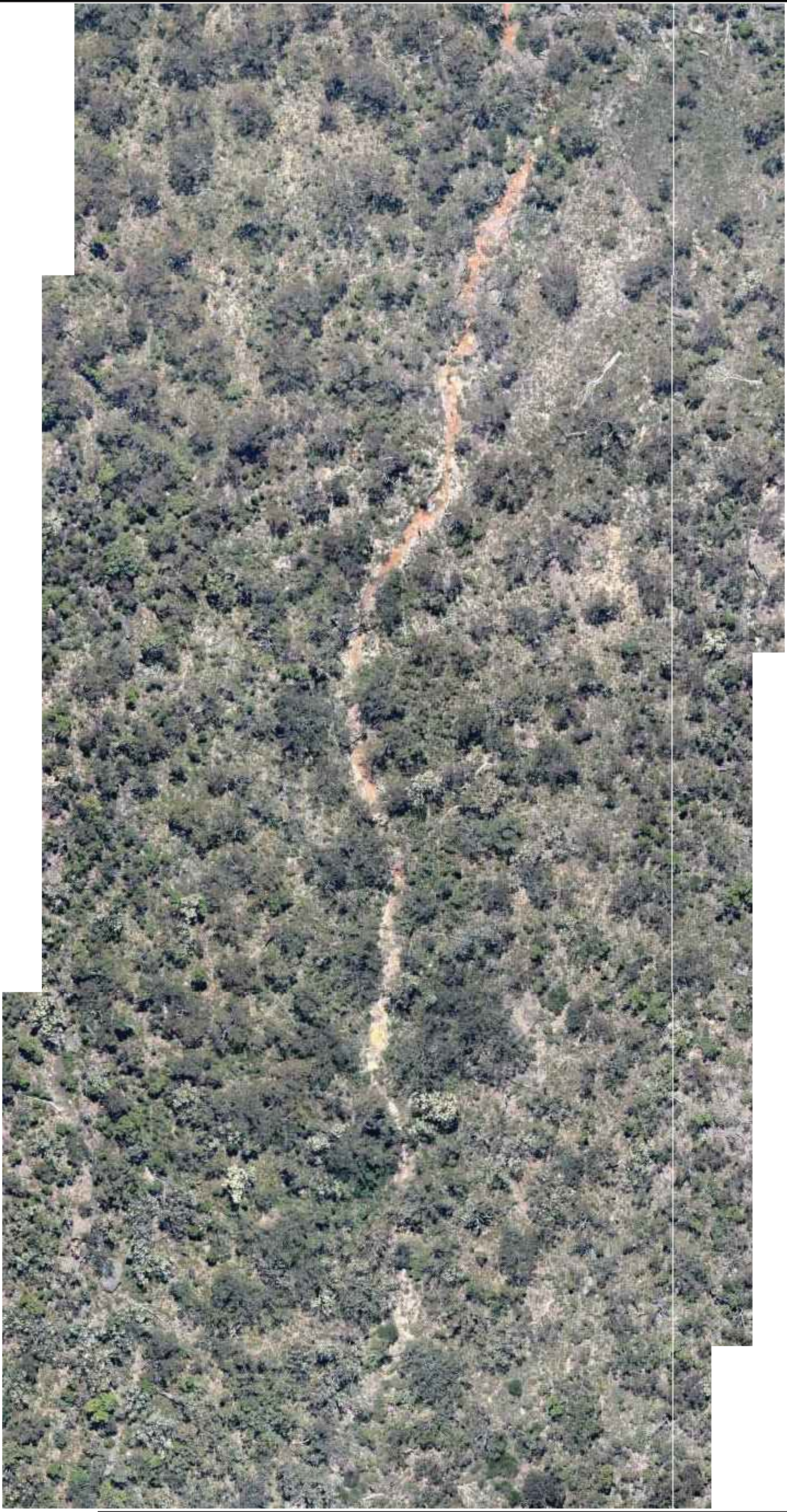
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

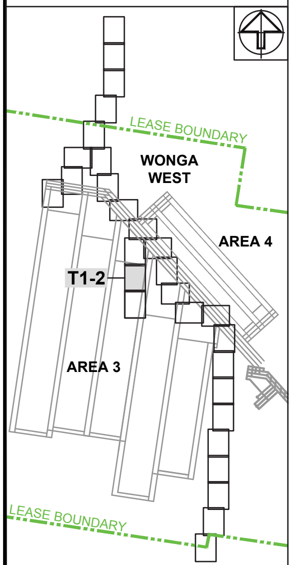
LIZARD CREEK MAPPING

GeoTerra

FIGURE T1-1



SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

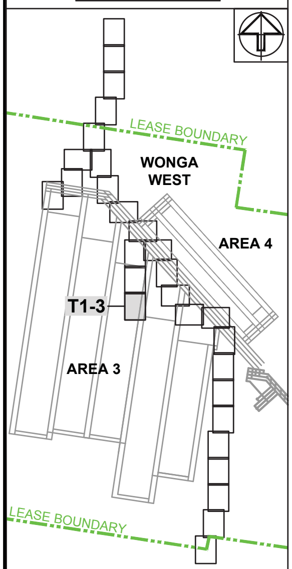
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE T1-2

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

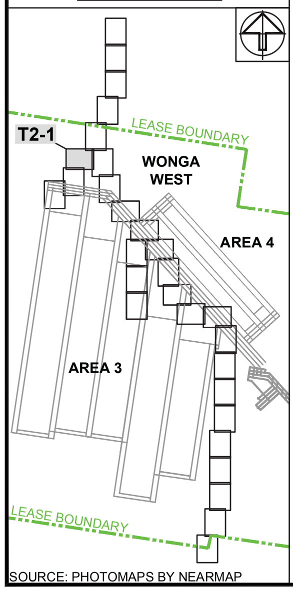
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE T1-3



PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

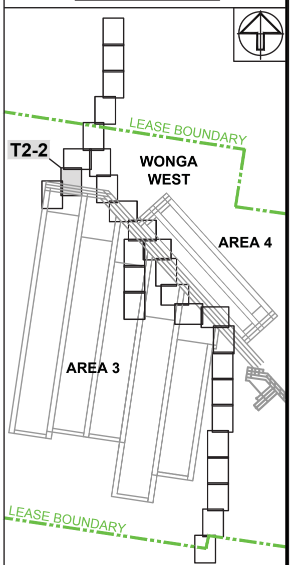
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE T2-1

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

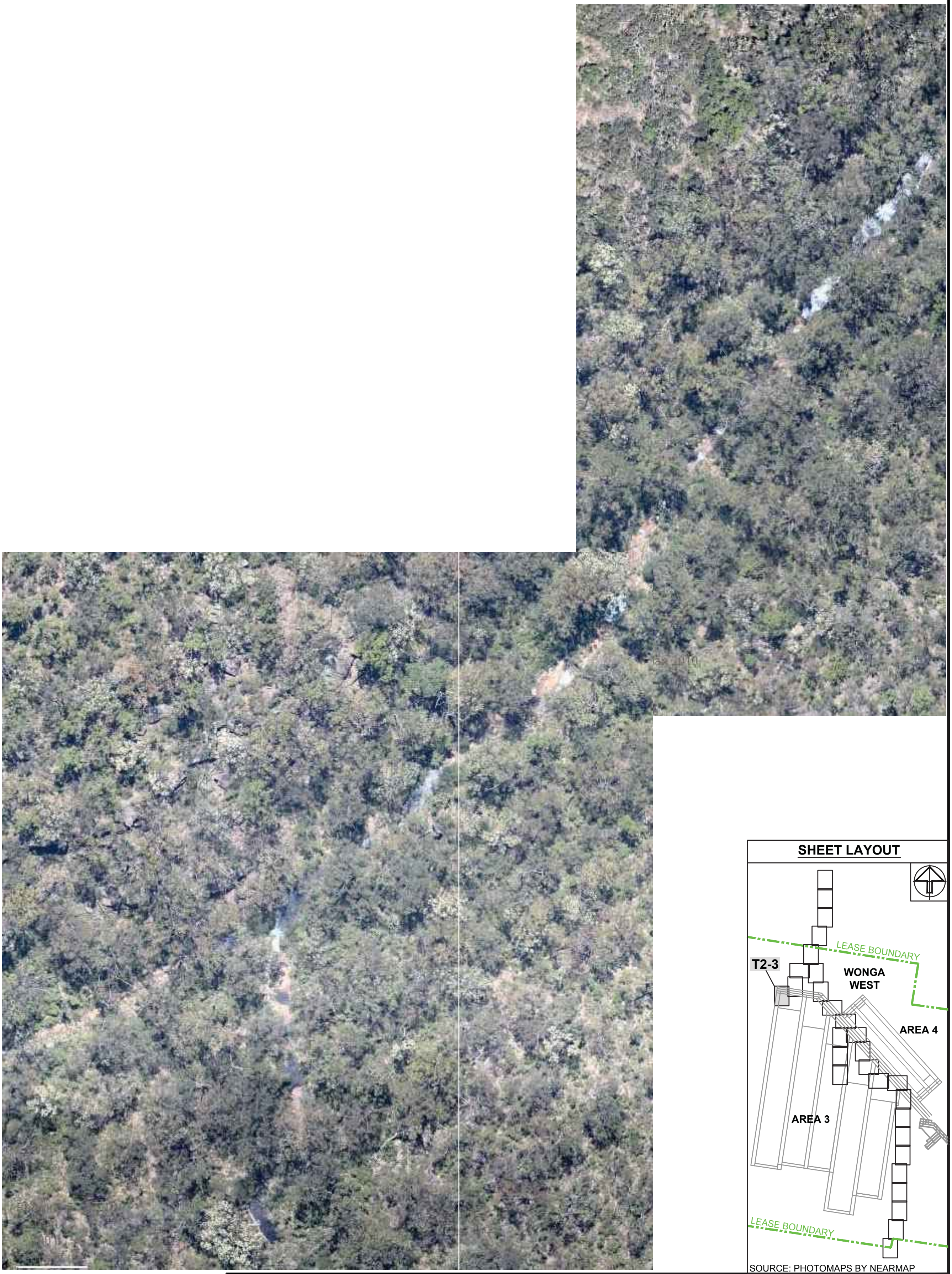
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE T2-2



SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

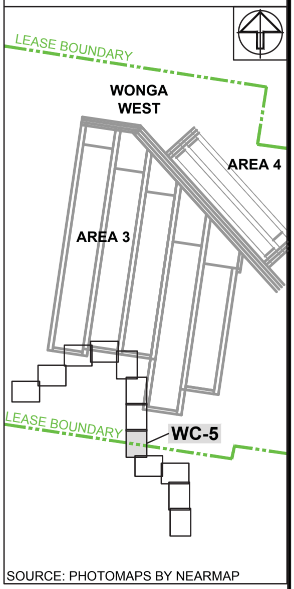
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

LIZARD CREEK MAPPING

GeoTerra

FIGURE T2-2

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

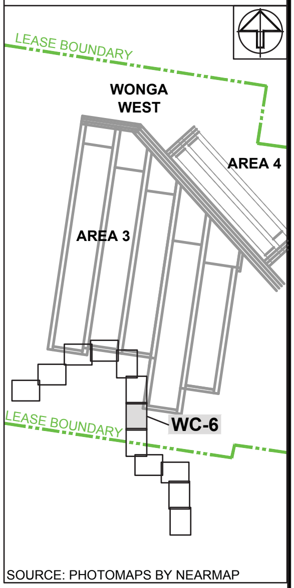
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-5

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

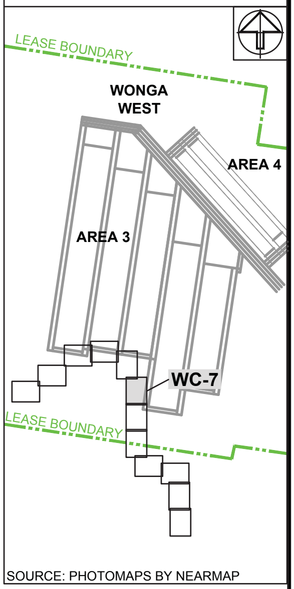
GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-6

SHEET LAYOUT



SOURCE: PHOTOMAPS BY NEARMAP

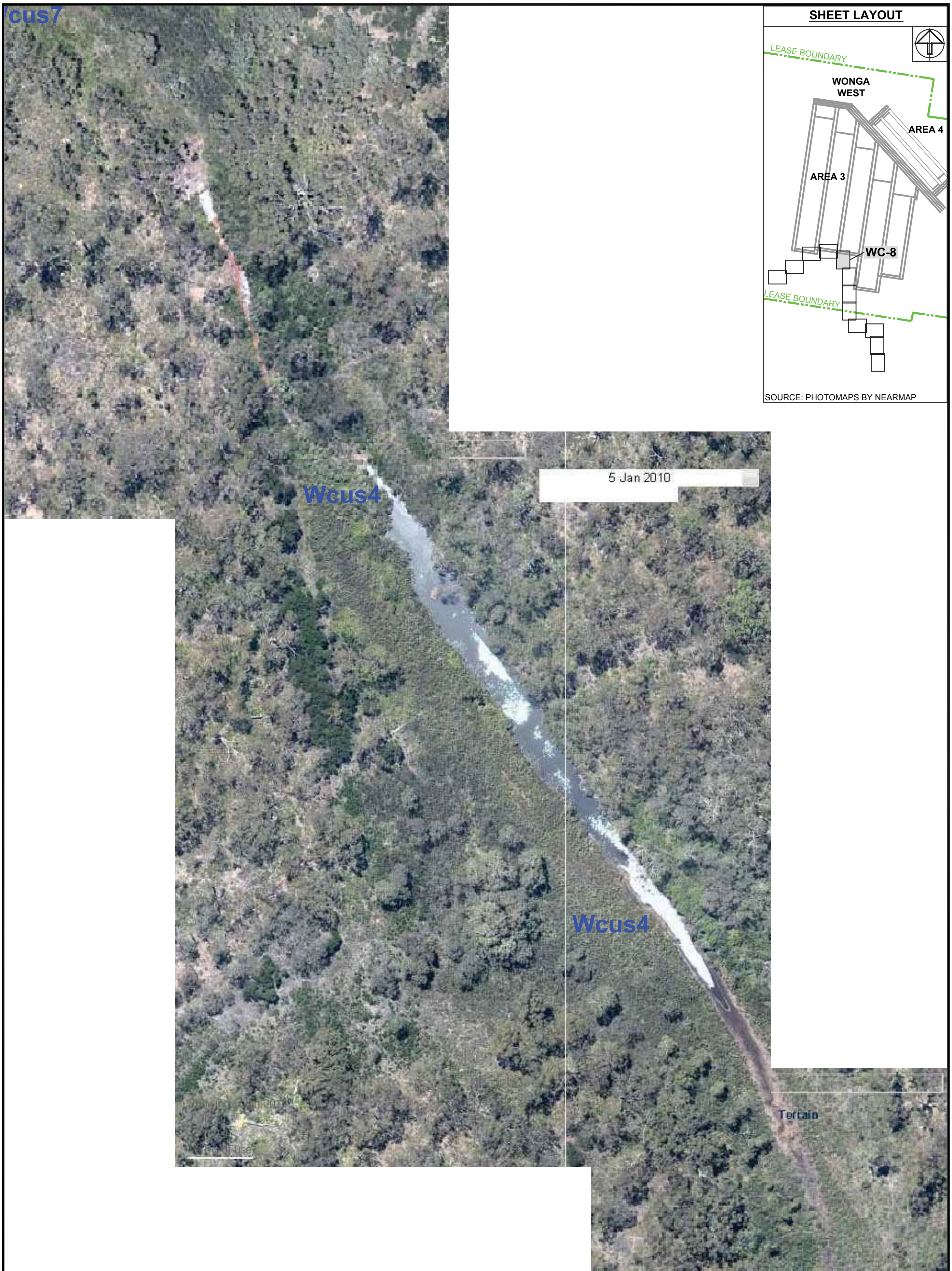
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-7



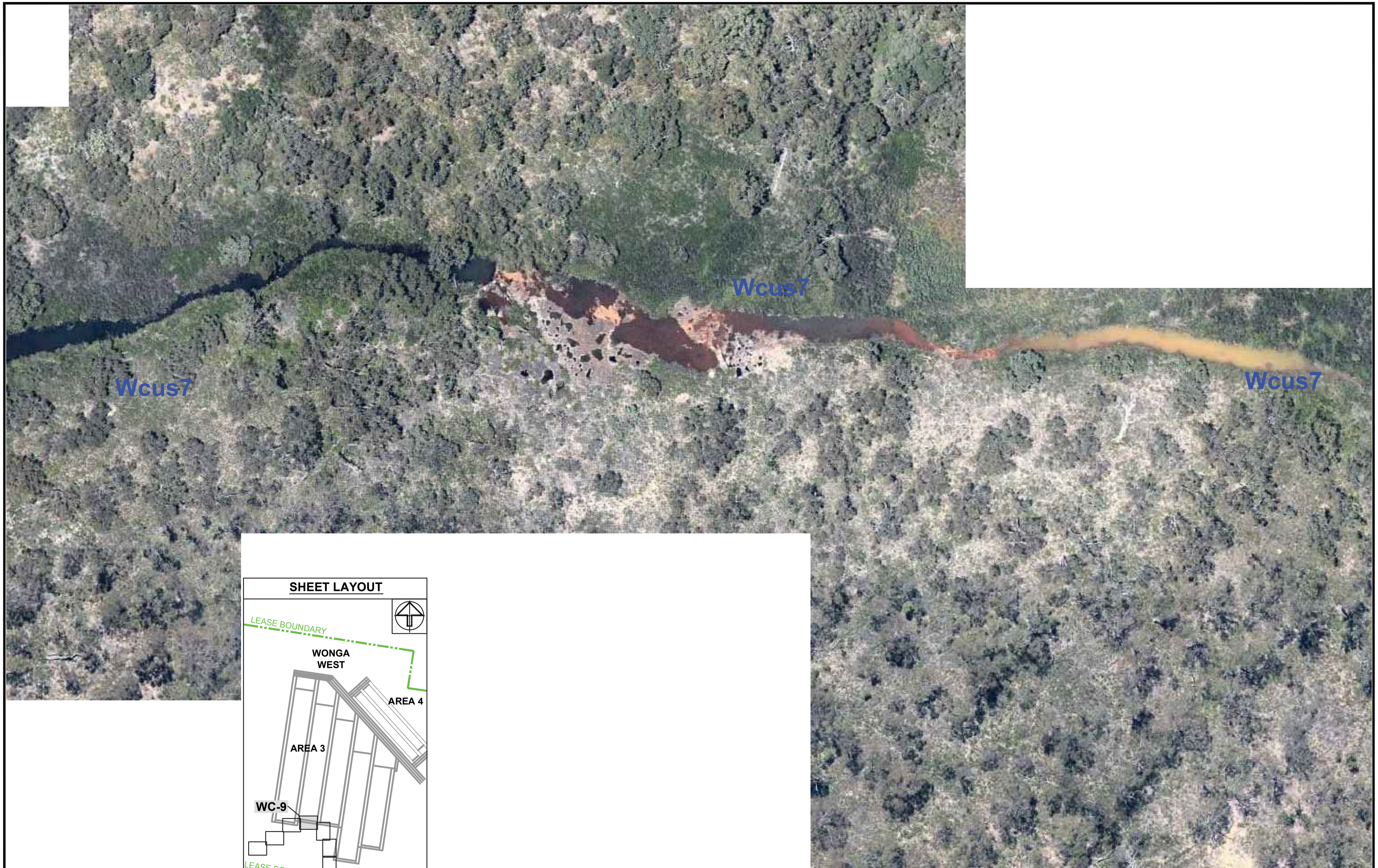
PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

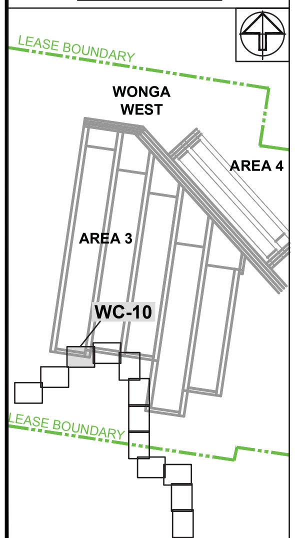
WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-8



PROJECT:	GUJ1 R1	GUJARAT NRE COKING COAL PTY LTD MAJOR EXPANSION PROJECT BELLAMBI, NSW	GeoTerra
DRAWN:	A. DAWKINS		
DATE:	23 Nov 2012		
SCALE:	1:1000	WALLANDOOLA CREEK MAPPING	FIGURE WC-9



PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-10

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-11

SOURCE: PHOTOMAPS BY NEARMAP

PROJECT:	GUJ1 R1
DRAWN:	A. DAWKINS
DATE:	23 Nov 2012
SCALE:	1:1000

GUJARAT NRE COKING COAL PTY LTD
MAJOR EXPANSION PROJECT
BELLAMBI, NSW

WALLANDOOLA CREEK MAPPING

GeoTerra

FIGURE WC-12

Annex P

Groundwater Assessment