

Warkworth Continuation 2014

4

Environmental Impact Statement

Prepared for Warkworth Mining Limited | June 2014

VOLUME 4 — Appendices I to L















COAL & ALLIED

Managed by Rio Tinto Coal Australia

EMM

EMGA Mitchell McLennan

VOLUME 1 — MAIN REPORT

Executive Summary

Chapter 1 Context
Chapter 2 The proposal
Chapter 3 Proposal need
Chapter 4 Improvements and differences from the Warkworth Extension 2010
Chapter 5 The applicant and assessment requirements
Chapter 6 Existing operations
Chapter 7 Legislative considerations
Chapter 8 Stakeholder engagement
Chapter 9 Economics
Chapter 10 Noise and vibration
Chapter 11 Air quality and greenhouse gas
Chapter 12 Ecology
Chapter 13 Final landform and rehabilitation
Chapter 14 Land and soils capability
Chapter 15 Visual amenity
Chapter 16 Groundwater
Chapter 17 Surface water
Chapter 18 Aboriginal cultural heritage
Chapter 19 Historic heritage
Chapter 20 Traffic and transport
Chapter 21 Social assessment
Chapter 22 Environmental management and commitments
Chapter 23 Design considerations and alternatives
Chapter 24 Justification and conclusion

Abbreviations

References

VOLUME 2 — Appendices A to G

Appendix A Schedule of land
Appendix B Study team
Appendix C Surrounding residences and assessment locations
Appendix D Secretary's requirements
Appendix E Economic study
Appendix F Noise and vibration study
Appendix G Air quality and greenhouse gas study

VOLUME 3 — Appendix H

Appendix H Ecology study

VOLUME 4 — Appendices I to L

Appendix I Soil study
Appendix J Visual amenity study
Appendix K Groundwater study
Appendix L Surface water study

VOLUME 5 — Appendices M to N

Appendix M Aboriginal cultural heritage study
Appendix N Historic heritage study

VOLUME 6 — Appendices O to R

Appendix O Traffic and transport study
Appendix P Social impact assessment
Appendix Q Rehabilitation performance/completion criteria
Appendix R Waste management strategy information

Appendix I

Soil study



Appendix I — Soil study



Warkworth Mining Limited

FINAL

WARKWORTH MINE EXTENSION

Soil Survey and Land Resource Assessment Report

February 2010

MML00-002

GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

TABLE OF CONTENTS

1.0 INTRODUCTION 1
1.1 OBJECTIVES 1
1.2 LOCATION 2
1.3 GEOLOGY 2
1.4 TOPOGRAPHY 2
1.5 VEGETATION 2
2.0 SURVEY METHODOLOGY 3
2.1 INTRODUCTION 3
2.2 SOIL MAPPING 3
2.3 SOIL PROFILING 4
2.4 FIELD ASSESSMENT 4
2.5 SOIL LABORATORY TESTING 4
2.6 LAND CAPABILITY ASSESSMENT 5
2.7 AGRICULTURAL SUITABILITY ASSESSMENT 6
3.0 RESULTS 7
3.1 DESKTOP REVIEW 7
3.1.1 Soil Landscape units 7
3.1.2 Soil Units 7
3.2 TOPDRESSING SUITABILITY 15
3.3 EROSION POTENTIAL 16
3.4 POTENTIAL ACID GENERATING MATERIAL 16
3.5 LAND CAPABILITY 16
3.5.1 Pre-mining 17
3.5.2 Post-mining 17
3.6 AGRICULTURAL SUITABILITY 17
3.6.1 Pre-mining 18
3.6.2 Post-mining 18
4.0 DISTURBANCE MANAGEMENT 19
4.1 TOPSOIL STRIPPING AND HANDLING 19
4.2 TOPSOIL RE-SPREADING AND SEEDING 20
4.2.1 Re-spreading 20
4.2.2 Seedbed Preparation 20
4.3 LANDFORM DESIGN, EROSION CONTROL 20
4.3.1 Post Disturbance Regrading 20
4.3.2 Erosion and Sediment Control 20
5.0 REFERENCES 22

TABLES

TABLE 1 – RURAL LAND CAPABILITY CLASSES 5
TABLE 2 – AGRICULTURAL SUITABILITY CLASSIFICATION SYSTEM 6
TABLE 3 – LANDSCAPE UNITS 7
TABLE 4 – SOIL UNIT CLASSIFICATION COMPARISON 8
TABLE 5 – BROWN DUPLEX LOAM PROFILE 9
TABLE 6 – RED DUPLEX LOAM PROFILE 10
TABLE 7 – DUPLEX SAND PROFILE 11
TABLE 8 – GREY-PINK DUPLEX LOAM PROFILE 12
TABLE 9 – UNIFORM SAND PROFILE 13
TABLE 10 – GREY-BROWN GRADATIONAL LOAM PROFILE 14
TABLE 11 – RECOMMENDED STRIPPING DEPTHS FOR REHABILITATED LANDFORMS 15
TABLE 12 – COMPARISON OF PRE AND POST MINING RURAL LAND CAPABILITY CLASSES 16
TABLE 13 – COMPARISON OF PRE AND POST-MINING AGRICULTURAL LAND SUITABILITY CLASSES 17

FIGURES

FIGURE 1 - LOCALITY PLAN 1
FIGURE 2 - SOIL LANDSCAPE UNITS & TEST PIT LOCATIONS 1
FIGURE 3 - SOIL UNITS 7
FIGURE 4 - LAND CAPABILITY 15
FIGURE 5 - POST MINING LAND CAPABILITY 15
FIGURE 6 - AGRICULTURAL SUITABILITY 15

APPENDICES

APPENDIX 1 – FIELD ASSESSMENT PROCEDURE
APPENDIX 2 – SOIL INFORMATION
APPENDIX 3 – GLOSSARY
APPENDIX 4 - SOIL PROFILES FROM SITE INSPECTION

1.0 INTRODUCTION

GSS Environmental (GSSE) was commissioned by Mitchell McLennan on behalf of Warkworth Mining Limited (WML) to undertake a soil and land assessment for the proposed Warkworth Mine Extension (Warkworth Extension).

The proponent for the proposed Warkworth Extension is WML. A general plan showing Warkworth Mine's location within the region is shown in **Figure 1.** Warkworth Mine began operations in 1981 with integration of the Warkworth and Mount Thorley Mines occurring in February 2004 to form an operation known as Mount Thorley Warkworth (MTW). Warkworth and Mount Thorley Mines currently operate under two separate Development Consents held under Part four of the EP&A Act (1979).

The proposed Warkworth Extension includes a westerly extension of the North Pit and West Pit. These extensions cross Wallaby Scrub Road and enter parts of Warkworth Mine's Green Offset zones. The West Pit extension also involves mining within the northern part of the Mount Thorley lease area. Other smaller pits (CD South and Woodlands pit) will be completed in accordance with current approvals. The Warkworth Extension area covers 1,271 hectares (ha) and is here-in-after referred to as the 'study area'. **Figure 2** shows the study area.

A summary of the proposed Warkworth Extension is as follows:

1. maintain maximum approved production rates of 18Mtpa of ROM coal;
2. maintain approximately 13Mtpa of ROM coal capacity at the Warkworth CPP;
3. extend the mine life from the current consent life of 2021 to 2031, which is an extension of current approved mining activities of some 11 years while including the existing area approved for mining;
4. transfer and disposal of overburden at Mount Thorley Mine;
5. replace aging equipment fleet to allow for improved mining efficiencies; and
6. upgrade some support infrastructure.

1.1 Objectives

The major objectives of the assessment undertaken by GSSE include:

- assess areas to be disturbed by the Warkworth Extension at a sufficient level of detail to satisfy the requirements of the Department of Industry and Investment (DII);
- assess pre and post mining rural land capability and class assessment in accordance with Department of Environment, Climate Change and Water (DECCW) guidelines including figures of each;
- assess pre and post mining agricultural suitability assessment in accordance with DII guidelines;
- assess topsoil resources for mining and infrastructure area rehabilitation, management and mitigation measures;
- assess suitable post-mining land uses for the open cut operations; and
- assess potential impacts of the expansion project on alluvial soils of the Wollombi Brook and associated tributaries.



0 10 20 30 40 50km

Scale: 1 : 1 000 000 (A4)

FIGURE 1

Regional Locality Plan

Version	Date:	Author:	Checked:	Approved:
1	6/10/09	LF	AC	RM
2	30/10/09	LF	AC	RM

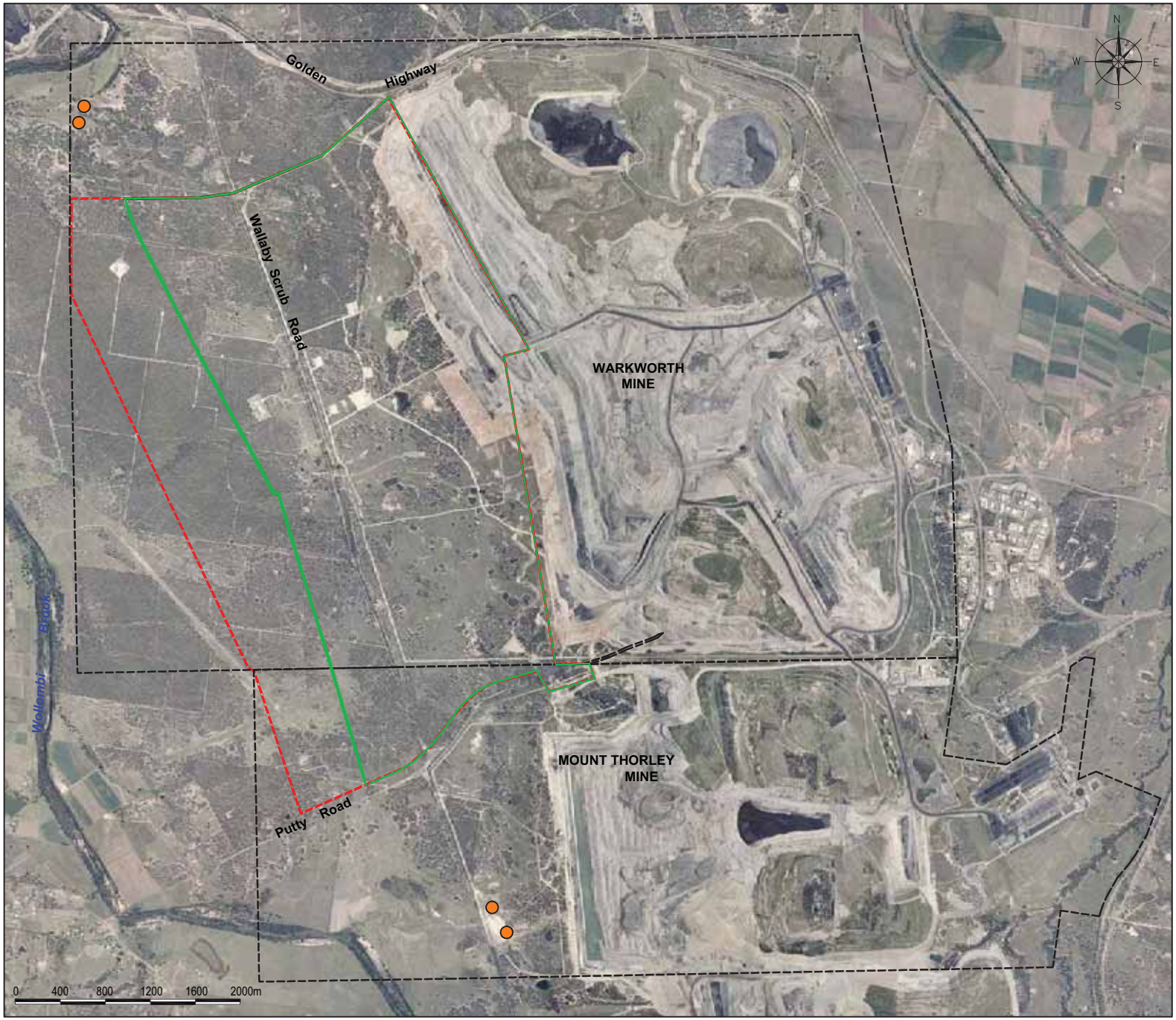
GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg1_MML00-002_Loc Plan_091030

Projection: N/A



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Destruction)
- Alluvial soil profile pits (GSSE 2009)

FIGURE 2

Soil and Land Resources Study Area

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg2_MML00-002_Soilpit_091208

Projection: MGA94 Zone 56

Version:	Date:	Author:	Checked:	Approved:
1	30/10/09	LF	AC	RM
2	12/11/09	LF	AC	RM
3	08/12/09	CC	AC	RM

GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

1.2 Location

Warkworth Mine is situated in the Hunter Valley coalfields of New South Wales (NSW) approximately 15 kilometres (km) south-west from the township of Singleton (refer **Figure 1**). The site is generally bounded by the Golden Highway to the north and east and by Putty Road to the south. Positioned to the east and north of Warkworth Mine is the Hunter River and to the west the Wollombi Brook. The Hunter Valley Coalfields is an active coal extraction area and nearby mines to Warkworth Mine include Hunter Valley Operations (HVO) to the north, Wambo Mine to the northwest, Mount Thorley to the south and Bulga Mine further south.

1.3 Geology

The study area is located in the Central Lowlands topographic zone within the Sydney Basin geological province. The rocks underlying the study area belong to the *Jerrys Plains subgroup of the Wittingham Coal Measures* and to the *Farley Formation, Rutherford Formation, Mulbring Siltstone, Muree Sandstone, Branxton Formation* and *Singleton Coal Measures*. These measures are of Late Permian age and the underlying rocks include coal seams, claystone, tuff, siltstone, sandstone and conglomerate which are overlain in patches by Quaternary Aeolian Sand (Glen and Beckett, 1993). The rocks have been folded resulting in westerly dips of up to 35 degrees on the southern side of the study area.

Two landscape units underpin the study area. These are the Jerrys Plains and Branxton units as delineated by the Soil Landscapes of the Singleton 1:250,000 Sheet (Kovac & Lawrie, 1991). The Jerrys Plains unit underpins most of the study area east of Wallaby Scrub Road and south of Putty Road. The Branxton unit underpins most of the study area west of Wallaby Scrub Road. An additional small landscape unit of Warkworth also occurs in the study area. **Table 3** describes these landscape units.

1.4 Topography

The terrain within the survey area is comprised mostly of low undulating hills and rises with slopes of less than five per cent and broad shallow valleys. The area also contains some closely spaced valleys and steeper slopes of 10-20 per cent. Saddleback Ridge forms the main north-trending ridge through the middle of the lease and separates the Wollombi Brook and Hunter River catchments. A lower ridge runs parallel to Wallaby Scrub Road extending in a north-westerly direction. Overall elevations range from 50-165 metres (m) with the highest point occurring in the southern part of Saddleback Ridge. Slopes have an overall east aspect with drainage trending north towards the Hunter River. There are also some drainage lines sloping west to Wollombi Brook.

1.5 Vegetation

The two main soil landscape units in the study area are associated with particular vegetation types. The Jerrys Plains landscape unit occurs east of Wallaby Scrub Road and typically supports Eucalypt woodland species. These species include the Grey Boxes, Forest Red Gums, Spotted Gums, Narrow-leaved Ironbarks and Bulloaks. Vegetation has been mostly cleared for pastoral activities, however, in the northwestern part of the study area the Jerrys Plains unit is still heavily wooded and supports the endangered Warkworth Sands Woodland vegetation community. The Branxton soil landscape occurs west of Wallaby Scrub Road and typically supports a dry sclerophyll forest. The dominant canopy species are similar to aforementioned with the additions of Rough-barked Apple and Paperbark *Melaleuca decora* combined with a decrease in Spotted Gum density. Extensive clearing has also occurred throughout the Branxton soil landscape unit for pastoral grazing activities.

2.0 SURVEY METHODOLOGY

2.1 Introduction

A site inspection was undertaken by GSSE in August 2009 to classify the soil profile types, particularly those associated with the Wollombi Brook (**Figure 2**). These were located outside the study area however information obtained from the profiles was used to confirm and extrapolate results from previous studies within the study area. Previous studies, as outlined below in **Section 2.2**, have comprehensive surveys of the study area in recent times for both soil attributes and land capability. Accordingly, the soil and land resource assessment for the study area has been developed through desktop studies of previous soil and landscape assessments.

This assessment has been undertaken to determine the following:

1. to classify and determine the soil types in the study area;
2. to assess the suitability of existing soils for future rehabilitation;
3. to identify pre and post mining rural land capability and agricultural suitability; and
4. to identify potential impacts of the extension project on the alluvial soils of the Wollombi Brook and associated tributaries.

The desktop review and survey have been conducted in accordance with the methodology outlined below. The soils and land resource assessment results are presented in **Section 3** of this report.

2.2 Soil Mapping

An initial soil map was developed using the following resources and techniques:

1) Aerial photographs and topographic maps

Aerial photo and topographic map interpretation was used as a remote sensing technique allowing detailed analysis of the landscape, and mapping of features expected to be related to the distribution of soils within the study area.

2) Previous soil survey results

A number of previous studies have been undertaken in the area. Information sourced for this report was compiled from the following studies:

- Kovac & Lawrie (1991) Singleton 1:250,000 Soil Landscapes Sheet

  Describes soil landscapes within the study area at a scale of 1:250,000;

- Global Soil Systems (2002) Warkworth Coal Mine Extension Soil and Land Capability Assessment (includes information provided by HLA Envirosciences (1994) Soil and Land Capability Assessment)

  Describes 17 soil profile sites to assist with the 2002 Warkworth Mine extension soil and land resource assessment. This assessment is bounded by the Golden Highway to the north, Wallaby Scrub Road to the east and Putty Road to the south and covers approximately 50 per cent of the study area;

- Lockwood PV (2009) Mount Thorley-Warkworth extension area soil survey

  Describes 74 soil profile sites and produced a detailed 1:25,000 soils map. This map assessed a similar area as covered by Global Soil Systems in 2002, and covers approximately 30 per cent of the study area;

- Lockwood PV (2007) Warkworth Sands soil survey: Soil sampling and analysis within the Green Offsets and at Archerfield

  Describes 200 soil profile sites and provided a detailed 1:25,000 soils map. This soil survey is west of Wallaby Scrub Road and north of the Golden Highway and covers approximately 50 per cent of the study area. Archerfield is a Green Offset area located north of Warkworth Mine; and

- ERM Mitchell McCotter (1995) Extension of Mount Thorley Operations: Environmental Impact Statement

  Describes five profile soils and provides a detailed soils map located predominately south of Putty Road and east of Charlton Road, and covers approximately 10 per cent of the study area.

These previous studies were assessed and soil units were matched according to descriptive soil profile descriptions. The naming convention of the soil units was developed using a GSSE developed system based on the Northcote Key (1979).

3) Stratified observations

Following the production of a broad soil map, surface soil exposures, topography and vegetation throughout the area was visually assessed to verify potential soil units.

2.3 Soil Profiling

Four additional soil profiles were assessed at selected sites by GSSE in August 2009 to assist in determining the characteristics of soils associated with the Wollombi Brook alluvium. Subsurface exposures were undertaken by backhoe excavation. The test pit locations were selected to assess the potential impact of the extension project on alluvial soils of the Wollombi Brook and associated tributaries. The soil layers were generally distinguished on the basis of changes in texture, structure and colour. Soil colours were assessed according to the Munsell Soil Colour Charts (Macbeth, 1994). Photographs of soil profile exposures were also taken.

Soil profiles were also observed throughout the study area by assessing surface exposures located in existing erosion gullies, access tracks and creek banks. Soil profile site locations are shown in **Figure 2.**

2.4 Field Assessment

Soil profiles within the study area were assessed generally in accordance with the Australian Soil and Land Survey Field Handbook soil classification procedures (McDonald *et al*, 1998). Soil layers at each profile site were also assessed according to a procedure devised by Elliot and Veness (1981) for the recognition of suitable topdressing material. This procedure assesses soils based on grading, texture, structure, consistence, mottling and root presence. The system remains the benchmark for land resource assessment in the Australian coal mining industry. A more detailed explanation of the Elliot and Veness procedure is presented in **Appendix 1** to this report.

2.5 Soil Laboratory Testing

Soil samples from the study area have been rigorously tested for physical and chemical attributes during past surveys. Laboratory analysis of soil samples compliments field assessment and enables soil stripping depth and topdressing recommendations to be determined. Soils are analysed to establish the suitability of surface and near-surface soil horizons as growth media for use in post disturbance rehabilitation operations. Soils are routinely analysed for colour, particle size, Emerson aggregate test, pH and electrical conductivity. A description of the significance of each test and typical values for each soil characteristic is included in **Appendix 2**. **Appendix 3** contains a glossary of commonly used soil terms.

2.6 Land Capability Assessment

The land capability assessment of the study area was conducted in accordance with DECCW's rural land capability classification system. The system consists of eight classes, which classify land on the basis of an increasing soil erosion hazard and decreasing versatility of use. It recognises the following three types of land uses:

- land suitable for cultivation;
- land suitable for grazing; and
- land not suitable for rural production.

These capability classifications identify limitations on the use of the land as a result of the interaction between the physical resources and a specific land use. The principal limitation recognised by these capability classifications is the stability of the soil mantle (Emery KA, 1986).

The method of land capability assessment takes into account a range of factors including climate, soils, geology, geomorphology, soil erosion, topography, and the effects of past land uses. The classification does not necessarily reflect the existing land use, rather it indicates the potential of the land for uses such as crop production, pasture improvement and grazing. Existing remote sensing data was also utilised where available (Department of Natural Resources, 2005).

The system allows for land to be allocated into eight possible classes (with land capability decreasing progressively from Class I to Class VIII). The classes are described in **Table 1** below.

A description of land capability classification for all land within the study area is discussed further in **Section 3.5**.

Table 1 – Rural Land Capability Classes

Land Class	Land Suitability	Land Definition
I	Regular Cultivation	No erosion control requirements
II	Regular Cultivation	Simple requirements such as crop rotation and minor strategic works
III	Regular Cultivation	Intensive soil conservation measures required such contour banks and waterways
IV	Grazing, occasional cultivation	Simple practices such as stock control and fertiliser application
V	Grazing, occasional cultivation	Intensive soil conservation measures required such contour ripping and banks
VI	Grazing only	Managed to ensure ground cover is maintained
VII	Unsuitable for rural production	Green timber maintained to control erosion
VIII	Unsuitable for rural production	Should not be cleared, logged or grazed
U	Urban areas	Unsuitable for rural production
M	Mining and quarrying areas	Unsuitable for rural production

Source: Emery KA (1986) Soil Conservation Service of NSW (now known as DECCW)

2.7 Agricultural Suitability Assessment

The agricultural suitability assessment of the study area was conducted in accordance with the DII's agricultural suitability classification system. The system consists of five classes, providing a ranking of lands according to their productivity for a wide range of agricultural activities with the objective of determining the potential for vegetative growth within certain limits.

The classification is based upon the effects of climate, topography and soil characteristics, the cultural and physical requirements for various crops and pastures, and existing socio-economic factors including local infrastructure and geographic location. These factors combine to determine the productive potential of the land and its capacity to produce crops, pastures and livestock. The classes are described in **Table 2** below.

Table 2 – Agricultural Suitability Classification System

Class	Agricultural Suitability	Land Definition
1	Highly productive land suited to both row and field crops	Arable land suitable for intensive cultivation where constraints to sustained high levels of agricultural production are minor or absent.
2	Highly productive land suited to both row and field crops	Arable land suitable for regular cultivation for crops but not suited to continuous cultivation. It has a moderate to high suitability for agriculture but edaphic (soil factors) or environmental constraints reduce the overall level of production and may limit the cropping phase to a rotation with sown pastures.
3	Moderately productive lands suited to improved pasture and to cropping within a pasture rotation	Grazing land or land well suited to pasture improvement. It may be cultivated or cropped in rotation with pasture. The overall level of production is moderate as a result of edaphic or environmental constraints. Erosion hazard or soil structural breakdown limit the frequency of ground disturbance, and conservation or drainage works may be required.
4	Marginal lands not suitable for cultivation and with a low to very low productivity for grazing	Land suitable for grazing but not for cultivation. Agriculture is based on native or improved pastures established using minimum tillage. Production may be high seasonally but the overall level of production is low as a result of a number of major constraints, both environmental and edaphic.
5	Marginal lands not suitable for cultivation and with a low to very low productivity for grazing	Land unsuitable for agriculture or at best suited only to light grazing. Agricultural production is very low or zero as a result of severe constraints, including economic factors, which preclude improvement.

Source: NSW Agriculture & Fisheries (1990) (now known as DII).

3.0 RESULTS

3.1 Desktop Review

3.1.1 Soil Landscape units

Two soil landscape units underpin the study area. These are the Jerrys Plains and Branxton units as delineated by the Soil Landscapes of the Singleton 1:250,000 Sheet (Kovac & Lawrie, 1991). The Jerrys Plains unit covers most of the study area east of Wallaby Scrub Road and south of Putty Road. The Branxton unit covers most of the study area west of Wallaby Scrub Road. An additional small landscape unit of Warkworth also occurs in the study area. **Table 3** describes these landscape units.

Table 3 – Landscape Units

Landscape Unit	Geology	Typical Landform	Typical Soils*
Jerrys Plains (jp)	*Jerrys Plains Subgroup of the Wittingham Coal Measures* *Parent rock:* Lithic sandstone, mudstone, some siltstone lenses and polymictic conglomerates.	Undulating low hills to the south and west of Jerrys Plains. Hills range in elevation from 80-180m; slopes 2-10% with local relief around 60m.	The main soil type for this landscape unit is Soloths. Soloths occur on hillcrests and midslopes; Solodic soil occur on the lower slopes and in the drainage depressions, with Solodised Solonetz soils found on hill slopes where drainage is impeded by bedrock.
Branxton (bx)	*Farley Formation, Rutherford Formation, Mulbring Siltstone, Muree Sandstone, Branxton Formation and Singelton Coal Measures* *Parent rock:* Sandstone, mudstone, siltstone, shale, tuff, coal, conglomerate and limestone.	Undulating rises to low hills and creek flats. Hulls range in elevation from 50-80m; sloped 3-5% with local relief of 10-40m.	Typically Red Podzolics occur on the hill crests, Yellow Pozolics on the midslopes, and Yellow Soloths on the lower slopes and in the drainage lines.
Warkworth (ww)	*Tertiary gravel and sand and Quaternary alluvium* (aeolian sand)	This unit covers the linear sand dunes found on old river terraces of the Hunter River downstream from Warkworth.	Siliceous Sands
* Soils defined using the Great Soil Groups (Stace et al., 1968)			

Source: Kovac & Lawrie (1991)

3.1.2 Soil Units

3.1.2.1 Wollombi Brook Soil Units

A site inspection was undertaken in August 2009 to classify the soil profile types associated with the Wollombi Brook. The objective of the field assessment was to observe soil profiles (to a maximum depth of 1.5m) that may be of alluvial nature due to their proximity to the Wollombi Brook.

No shallow aquifers (i.e. < 1.5m depth) were identified. The identified soil units were Brown Duplex Loam, Grey-Pink Duplex Loam and Uniform Sand. These profiles were used to confirm and extrapolate results from previous studies within the study area. Descriptions of these soil profiles are included in **Appendix 4**.

3.1.2.2 Study Area

The desktop study of previous soil surveys, as listed in **Section 2.2**, provided high quality data at a scale one order of magnitude greater resolution than the landscape mapping units. These surveys covered 92 per cent of the study area with less than 8 per cent of the area was not comprehensively mapped (4.3 per cent to the southwest and 3.5 per cent to the northwest). These small units of land were located within larger well defined landscape units.

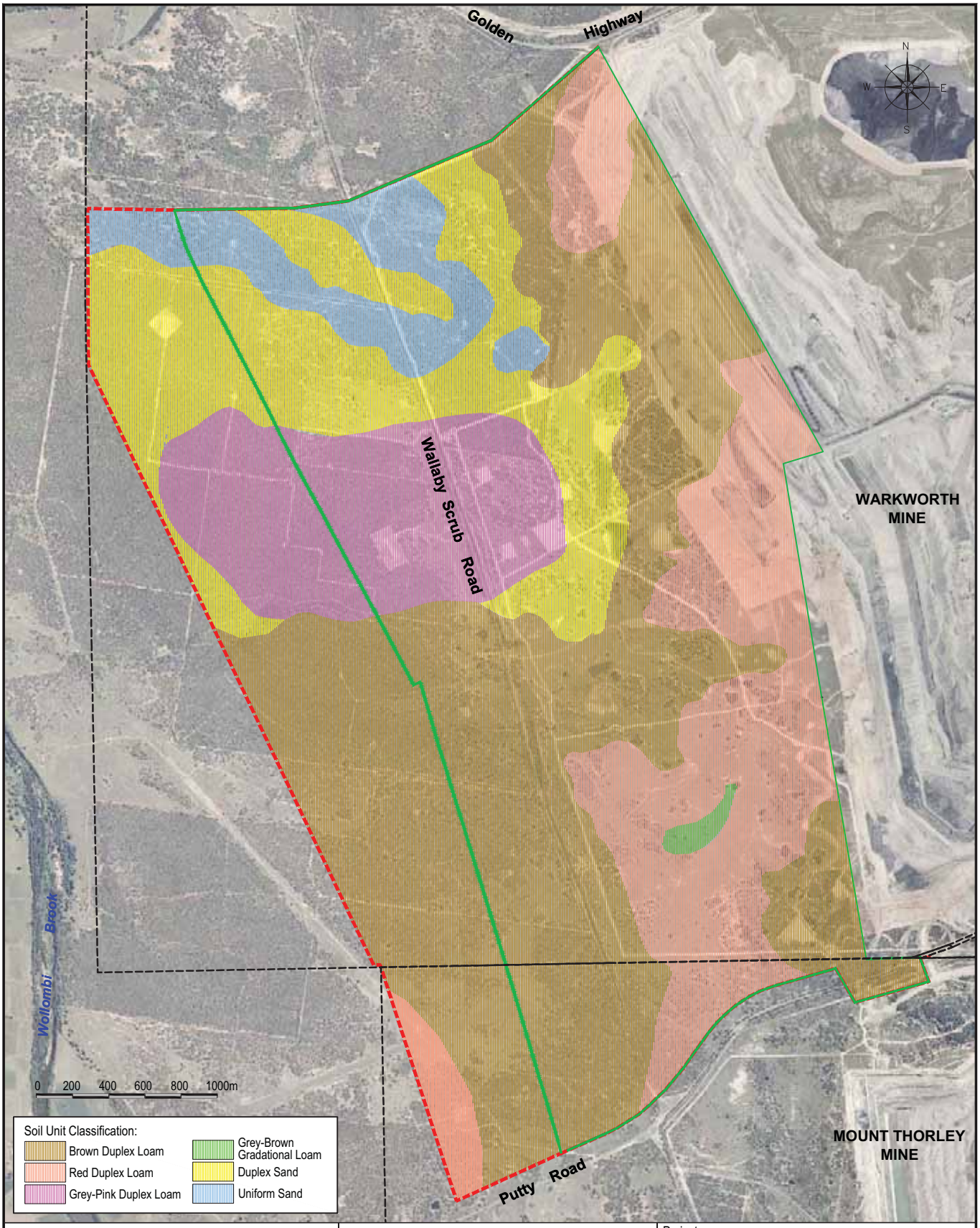
Six soil units were identified within the study area. These units coverage within the study area (expressed as per cent) are provided below:

1. Brown Duplex Loam (40.8%)
2. Red Duplex Loam (25.1)
3. Duplex Sand (16.5%)
4. Grey-Pink Duplex Loam (10.2%)
5. Uniform Sand (6.9%)
6. Grey-Brown Gradation Loam (0.5%)

A soil unit classification comparison shows the correlation between the soil naming conventions used in the assessed reports (refer **Table 4). Tables 5 to 10** describe each of the six soil units. **Figure 3** illustrates the spatial distribution of the soil units.

Table 4 – Soil Unit Classification Comparison

GSSE 2009	Global Soil Systems 2002	Lockwood 2007, 2009	ERM Mitchell McCotter 1995	Kovac & Lawrie 1991
(Soil classification system)	(Adapted Northcote Key)	(Australian Soil Classification)	(Adapted Northcote Key)	(Great Soil Groups)
Brown Duplex Loam	Brown Duplex Loam Yellow Duplex Sandy Loam	Sodosols (Brown and yellow)	Grey-yellow and brown mottled duplex soils	Yellow Soloths (jp unit)
Red Duplex Loam	Red Duplex Loam	Sodosols (red)	Hard pedal red-yellow and yellow-brown duplex Loam	Red Soloths (jp unit)
Duplex Sand	n/a*	Shallow Warkworth sands (Sodosols)	n/a*	Yellow Soloth (bx unit)
Grey-Pink Duplex Loam	n/a*	Sodosols (grey)	n/a*	Yellow Podzolic (bx unit)
Uniform Sand	Uniform Sand	Deep Warkworth sands (Tenosols)	Apedal Massive Sands	Siliceous sands (ww unit)
Grey-Brown Gradational Loam	Grey-Brown Gradational Loam	n/a	Gravelly Sands/Grey-yellow apedal duplex soils	Red earths (jp unit)
*Soil unit outside of area covered by relevant organization				



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Disturbance)

FIGURE 3

Soil Units

Version	Date:	Author:	Checked:	Approved:
1	8/10/09	LF	AC	RM
2	30/10/09	LF	AC	RM
3	12/11/09	LF	AC	RM
4	08/12/09	CC	AC	RM

GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg3_MML00-002_Soil Units_091208

Projection: MGA94 Zone 56

Brown Duplex Loam

Description: This soil unit is characterised by an abrupt texture change between the dark brown silty/ loam surface soil and the clayey brown sandy clay loam and yellowish brown medium heavy clay subsurface layers (duplex soil) (**Table 5**). This soil unit is identified in the Australian Soil Classification as a Sodosol and has also in the past been referred to in Great Soil Group terminology as Solonetz, Solodised-Solonetz and Solodic soils.

Location: This soil unit is the dominant soil in the Warkworth Mine study area (40.8 per cent cover) and is associated with undulating hillslopes, particularly mid-low sloping land and creek flats. This common soil unit was profiled during the Wollombi Brook investigation, refer **Appendix 4, Plate 1** and **Plate 2**.

Management: The surface 0.10m of topsoil is suitable for stripping and reuse as a topdressing material in rehabilitation works. Some topsoil profiles exhibited high sodicity values, however, soil aggregate stability was reasonable due to significant soil organic carbon content. In addition this topsoil's loamy soil texture is desirable for rehabilitation works.

The subsoil is unsuitable for rehabilitation works as it is highly sodic and dispersive.

The topsoil requires standard erosion and sediment control measures if disturbed. Given the soil's sodicity range, additional measures for stockpiling the soil and its reuse during rehabilitation works is recommended. These measures include stockpiling the soil where it is not exposed to wet conditions after stripping as this will limit dispersion and erosion, and the use of soil ameliorants such as gypsum and biosolids to improve aggregate cohesion (refer **Section 4)**.

Table 5 – Brown Duplex Loam Profile

Layer #	Depth (m)	Description	
		Field	**Laboratory**
1	0.00 - 0.02	Dark (yellowish) brown (10 YR 4/4) silty loam to loam exhibiting weak peds of 10 millimetres (mm) or massive pedality. Boundary abrupt.	Moderately acidic with an average pH of 6.0 (range 5.4 - 6.3, n = 5) and non-saline with low Electrical Conductivity (ECe) of less than 1dS/m 9 (range 0.46 – 1.19dS/m, n = 5). Moderately sodic with an average Exchangeable Sodium Percentage (ESP) of 12%, (range 5 - 18.9, n = 5) with generally stable soil aggregates as indicated by Emerson Aggregate Test (EAT) classifications of 3-5.
2	0.02 - 0.12	Dark yellowish brown (10 YR 5/4) silty loam with massive pedality. Boundary sharp.	
3	0.12 - 0.45	Brown (7.5 YR 5/8 - 7.5 YR 4/6) heavy clay with a strong structure (polyhedral to prismatic). Boundary gradual.	Moderately acidic with an average pH of 6.0 (range 5.8 - 6.7, n = 12) and non-saline with average low ECe of less than 2dS/m (range 0.34 - 4.24, n = 12; note >4dS/m was an exception). Highly sodic with an average ESP of 27% (range 14.3 - 37.1; n = 5) and low aggregate stability with EAT classes of 1 and 2 (n = 10).
4	0.45 - 0.70	Yellowish brown (10 YR 5/6) heavy clay with strong structure (polyhedral to angular blocky peds). Boundary gradual.	
5	0.70 - 2.00	Yellowish (10 YR 6/6) medium clay to silty clay with moderate structure (polyhedral to angular blocky peds).	

n = number of replicate soil profile sites, actual data replicates often larger as vertical sampling per layer varied (e.g. layer 2 may have been sampled at 0.05 and 0.10m at some soil profile sites).

Red Duplex Loam

Description: This soil unit is characterised by an abrupt texture change between the dark brown loamy surface soil and the reddish-brown medium clay subsurface soil (duplex soil) (**Table 6**).

Location: This soil unit is the second most dominant soil in the Warkworth Mine's study area (25.1 per cent cover) and is largely associated with the central ridge area in the south-eastern part of the study area.

Management: The surface 0.10m of this soil is marginally suitable for stripping and reuse as topdressing in rehabilitation. The subsoil is not recommended for reuse in rehabilitation due to the limiting factors of apedal texture, high sodicity and possible dispersion problems due to aggregate instability.

The topsoil requires standard erosion and sediment control measures if disturbed. Given the topsoil's weak textural structure and possible sodic issues additional measures for soil stockpiling and soil reuse during rehabilitation works are recommended. Suitable measures include storing the soil where it is not exposed to wet conditions after stripping as this will limit dispersion and erosion, and the use of soil ameliorants (e.g. gypsum) to improve aggregate cohesion. Soil ameliorants that add carbon to the soil (e.g. biosolids) may be an appropriate measure as this will improve soil aggregate stability (refer **Section 4**).

Table 6 – Red Duplex Loam Profile

Layer #	Depth (m)	Description	
		Field	**Laboratory**
1	0.0 006	Brown (10 YR 4/6) loam. A subplastic, slightly sticky, crumbly soil exhibiting weak pedality with 20 - 50mm earthy subangular blocky peds. The soil contains very few 20 – 60mm stones and many roots.	Moderately acidic with an pH of 6.0 - 6.4 (n =2) and non-saline with low ECe of less than 1dS/m (n =2). Aggregate stability is good with an EAT class 3(3) (n = 1). Some possible sodic indications from an associated soil type have been observed.
2	0.06 - 0.20	Dull brown (7.5 YR 5/4) sandy clay loam. A subplastic, weak crumbly apedal soil with no stones. Roots are common.	
3	0.20 - 0.60	Bright reddish brown (5 YR 5/8) light medium clay. A plastic, slightly sticky, moderately strong, apedal clay with less than 2% dispersed 20 - 60mm stones.	Slightly acidic with an pH of 6.3 (range 5.5 - 6.8, n = 4) and non-saline with average low ECe of less than 1dS/m (range 0.43 - 0.90, n = 4). Highly sodic with an ESP of 29% (n = 1) and a variable aggregate stability with EAT classes of 1, 2, 3b and 5 (n = 4).
4	0.60 - >1.40	Weathered fine grained grey sandstone.	n/a

n = number of replicate soil profile sites, actual data replicates often larger as vertical sampling per layer varied (e.g. layer 2 may have been sampled at 0.05 and 0.10m at some soil profile sites).

Duplex Sand

Description: This soil unit is characterised by an abrupt texture change between the sandy surface soil and the medium-heavy clayey subsurface soil (duplex soil). Subsurface soils may be greyish, brownish or yellowish in colour (**Table 7**).

Location: This soil unit is the third most dominant soil in the Warkworth Mine study area (16.5 per cent cover) and is associated with the Uniform Sands in the northern part of the study area.

Management: The top 0.30m of topsoil is suitable to marginally suitable for stripping and reuse as topdressing in rehabilitation works. The top 0.05m of this soil is of suitable nature and the subsequent 0.25m is of marginal nature due to its single grain structure. It is recommended that the full 0.30m of topsoil be utilised, however, additional measures to treat the 0.05-0.30m fraction are recommended. These measures are discussed below.

The subsoil is not recommended for reuse in rehabilitation activities due to the limiting factors of texture, high sodicity and dispersion. Sodicity in the topsoil was observed to increase in a minority of soil profiles which contained clayey sand textures. As sodicity is related to exchangeable cations and soil clay content, these few outliers with small clay contents do not impact overall stripping depth recommendations.

The topsoil requires standard erosion and sediment control measures if disturbed and given its textural structure additional measures are recommended. Suitable measures include storing the soil where it is not exposed to wet conditions after stripping as this will limit dispersion and erosion, and the use of soil ameliorants (e.g. gypsum and biosolids) to improve aggregate cohesion (refer **Section 4**).

This soil unit is closely related to the uniform soil unit (**Table 9**) which supports the endangered Warkworth Sands vegetation community. This soil may contain a viable seed-bank for this community and utilisation of all sandy topsoil to aid restoration efforts in alternative Green Offset zones is feasible. Stripping depth may be in places as deep as 1m for this purpose.

Table 7 – Duplex Sand Profile

Layer	Depth	Description	
#	(m)	Field	Laboratory
1	0.00 - 0.05	Dark yellowish brown (105 YR 4/4) loamy sand with weak subangular structure and very weak consistence. Boundary gradual.	Moderately acidic with an average pH of 6.0 (range 5.8 - 7.5, n = 5) and non-saline with low ECe of less than 1dS/m (range 0.17 - 2.05dS/m, n = 5). Sodicity was low with average ESP of 6.15% (range 2.3 - 12.3, n = 5) and moderate to high aggregate stability with EAT class measurements of 5. The higher ESP was a class 3b.
2	0.05 - 0.30	Pale brown (10 YR 7/3) sand with single grain structure and loose consistence. Boundary abrupt.	
3	0.30 - 0.50+	Light brownish grey to brown (10 YR 6/2 - 10 YR 5/3) medium heavy clay with strong blocky structure and strong consistence.	Slightly acidic with an average pH of 6.3 (range 5.5 - 7.6, n = 13) and non-saline with low ECe of less than 1dS/m (range 0.16 - 1.86dS/m, n = 12). Highly sodic however with an ESP range of 10-50% (n = 3) and low-moderate aggregate stability with EAT classifications of 1 and 2 (n = 12).
n = number of replicate soil profile sites, actual data replicates often larger as vertical sampling per layer varied (e.g. layer 2 may have been sampled at 0.05 and 0.10m at some soil profile sites).			

Grey-Pink Duplex Loam

Description: This soil unit is characterised by an abrupt texture change between the grey-brown sandy-loam surface soil and the underlying grey-pinkish clayey subsurface soil (**Table 8**). This soil unit is also identified in the Australian Soil Classification as a Sodosol. A distinguishing feature of this duplex unit is the grey clayey subsurface horizon. Grey colours occur in the landscape as seasonal saturation of the soil profile mobilises insitu-pigment bearing minerals (iron oxides) which are subsequently lost to free draining waters.

Location: This soil unit occurs mainly in and around Wallaby Scrub Road sloping towards Wollombi Brook. This soil unit generally occurs in the landscape on the lower-slopes and is a minor soil unit covering 10.2 per cent of the study area. Grey layers also occur higher up the hill-slope (termed gley) where impermeable or poorly draining horizons result in a localised saturated environment which favours mobilisation and loss of pigment bearing minerals.

This soil unit was profiled the during the Wollombi Brook investigation, refer **Appendix 4, Plate 3** and **Plate 4**.

Management: The surface 0.30m of this soil is suitable for stripping and reuse as topdressing in rehabilitation. The subsoil is not recommended for reuse in rehabilitation due to the limiting factors of textural structure and likely high sodicity and dispersion issues.

The topsoil soil requires standard erosion and sediment control measures if disturbed. Caution during stripping is advised as mixing of the quality topsoil with the subsoil will negatively impact on rehabilitation works.

Table 8 – Grey-Pink Duplex Loam Profile

Layer	Depth	Description	
#	(m)	Field	Laboratory
1	0.0 - 0.05	Brown (10 YR 4/3) sandy loam with massive structure and weak consistence. Boundary clear.	Moderately acidic with a pH of 6.0 and non-saline with low ECe of less than 0.5dS/m (n = 1). Non sodic with ESP of 5% and high aggregate stability with an EAT classification of 5 (n = 1).
2	0.05 - 0.30	Light grey to pinkish-grey (10 YR 7/2 - 7.5YR 6/2) sandy loam with weak (20 - 30mm block peds) to massive pedality and weak consistence. Boundary abrupt.	
3	0.30 - 0.50+	Light brownish - grey to pinkish-grey (10 YR 6/2 - 7.5YR 6/2) medium clay with moderate structure (blocky, angular peds) and strong consistence.	Slightly acidic with an average pH of 6.3 (range 5.9 - 6.7, n = 2) and non-saline with low ECe of less than 2dS/m (range 1.11 - 2.43dS/m, n = 2). A high sodic value was recorded (ESP of 30%) combined with a low-moderate aggregate stability with EAT classifications of 1 and 2 (n = 2).
n = number of replicate soil profile sites, actual data replicates often larger as vertical sampling per layer varied (e.g. layer 2 may have been sampled at 0.05 and 0.10m at some soil profile sites).			

Uniform Sand

Description: This soil unit is characterised by predominately yellowish-brown sand throughout the soil profile for a minimum of two metres (**Table 9**).

Location: This minor soil unit (6.9 per cent of the study area) occurs in the northern part of the study area, predominately to the north-western boundary. This deep sand is associated with the Warkworth Sands vegetation community. It has developed from aeolian deposition of sand particles and its location reflects recent and past wind direction (McKensie et al., 2008). It is termed a continental dune. This soil unit is identified in the Australian Soil Classification as a Tenosol as it exhibits weak pedological development.

This soil unit was profiled during the Wollombi Brook investigation, refer **Appendix 4, Plate 5** and **Plate 6**.

Management: This soil is not suitable for stripping and reuse as topdressing in mine rehabilitation works due to its single grain sandy structure.

This soil supports the endangered Warkworth Sands vegetation community and as such the stripping and reuse of this soil to support restoration/recreation works in alternative Green Offset zones is feasible. Recommended stripping depth is 1-2m. This soil does not present any sodic, erodibility or acidity issues that would prevent its re-use in this context, either in its removal, transport or storage. Due to its single grain texture, preventing wind erosion during storage is recommended. This soil is strongly acidic which is appropriate for this specific vegetation community. Generally strong soil acidity is not considered optimal for mine rehabilitation works.

Table 9 – Uniform Sand Profile

Layer	Depth	Description	
#	(m)	Field	Laboratory
1	0.00 - 0.05	Grey or Brown sand (7.5 YR 5/1 - 7.5 YR 4/2) sand. Single grained with loose consistence. Boundary diffuse to gradual.	Strongly acidic with a pH of 4.7 - 5.3 throughout the profile (n = 2) and non-saline with low average ECe of less than 1.5dS/m (range 0.13 - 10.23, n = 2).
2	0.05 - 2.00	Pink-greyish or light brown (7.5 YR 6/2 - 7.5 YR 6/4) sand. Single grained with loose consistence.	Non sodic with ESP of <3% (range 1.8 - 6.8, n = 2).
n = number of replicate soil profile sites, actual data replicates often larger as vertical sampling per layer varied (e.g. layer 2 may have been sampled at 0.05 and 0.10m at some soil profile sites).			

Grey-Brown Gradational Loam

Description: This soil unit is characterised by a gradual texture change between the brownish black surface loam and the underlying greyish brown sandy clay loam and sandy clay (**Table 10**).

Location: This soil unit is minor covering 0.5 per cent of the study area, and occurs on top of the central ridge to the south-east of the study area.

Management: The surface 0.08m of this soil is suitable for stripping and reuse as topdressing in rehabilitation. The topsoil requires standard erosion and sediment control measures if disturbed.

The subsoil is not recommended for reuse in rehabilitation due to the limiting factors of high stone content and apedal texture.

Table 10 – Grey-Brown Gradational Loam Profile

Layer #	Depth (m)	Description	
		Field	Laboratory
1	0.00 - 0.08	Brownish-Black (5 YR 2/2) loam with weak structure and 10 - 20mm subangular peds. Contains less than 2% stones and many roots.	*No laboratory results for this minor soil unit.*
2	0.08 - 0.32	Greyish brown (7.5 YR 6/2) sandy clay loam with moderately strong apedal structure. Contains 20 - 50% subrounded unweathered stones up to 60mm across. Boundary is gradational.	
3	0.32 - 0.56	Brownish-grey (7.5 YR 5/1) sandy clay with moderately strong apedal structure. Contains up to 50% of 2-6mm subangular stones and few roots. Boundary is diffuse.	
4	>0.56	Weathered sandstone, orange mottled with grey	

3.2 Topdressing Suitability

Laboratory soil analytical results were used in conjunction with the field assessment (refer **Appendix 1**) to determine the depth of soil material suitable for recovery and re-use as a topdressing material in rehabilitation.

Weak structural soil texture and subsoil sodicity were the two most common and significant limiting factors in determining stripping depth throughout the study area. Some of the soils within the study area are only marginally suitable for use as topdressing materials, however, revegetation of coal fields for pastoral use in the Upper Hunter region generally have a greater degree of success when marginal soils are used relative to alternative use of overburden material (ERM Mitchell McCotter, 1994).

The recommended stripping depth for each soil unit, together with area of land and calculated volumes are provided in **Table 11** below and recommended stripping depths are illustrated in **Figure 4**. The total volume of topsoil available is 1,674,670 cubic metres (m^3), when a handling loss of 10 percent is allowed, (**Table 11**) which approximately equates to an available re-spread topdressing depth of approximately 130mm.

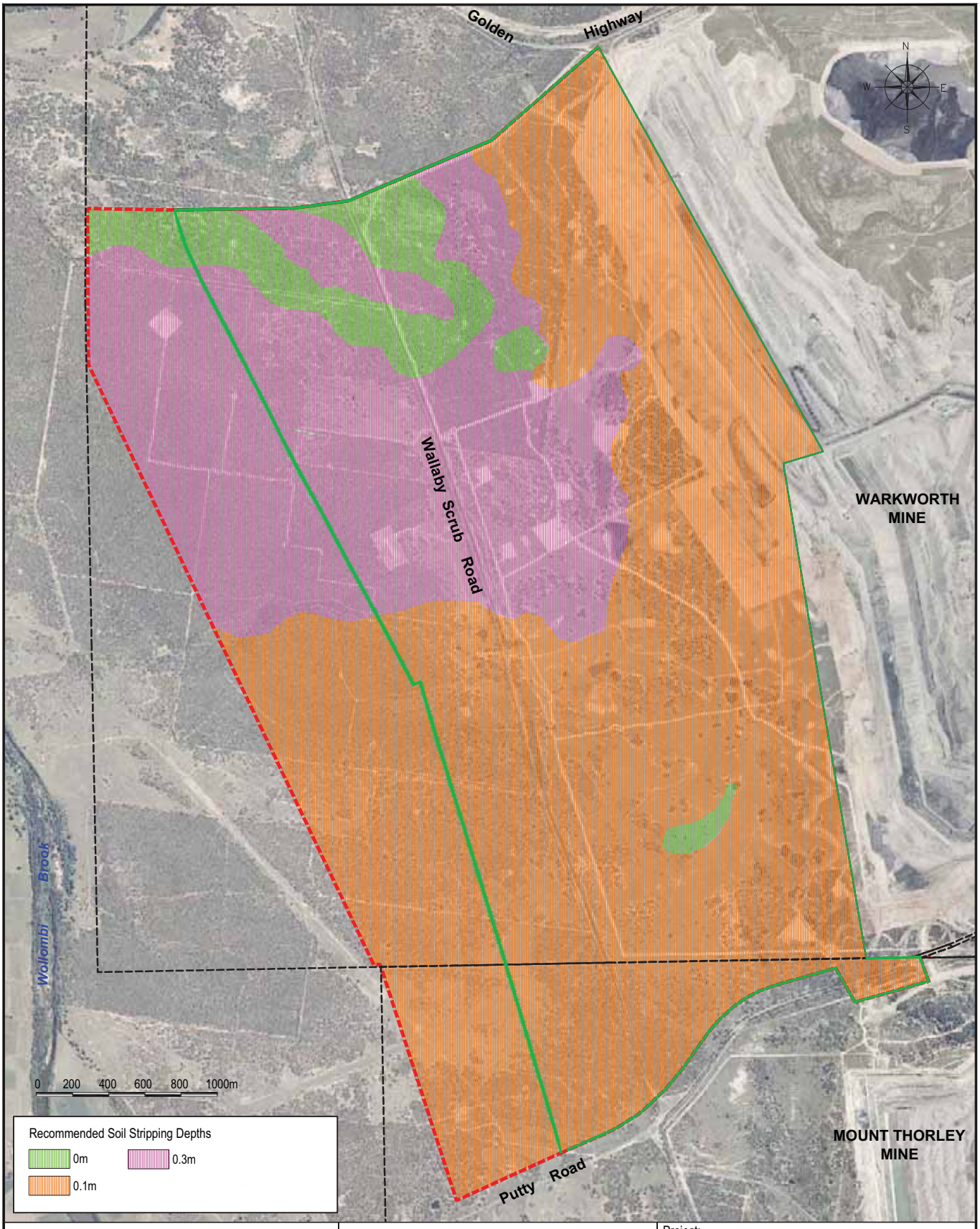
Table 11 – Recommended Stripping Depths for Rehabilitated Landforms

Soil Type	Recommended Stripping Depth (m)	Stripping area (ha)	Volume (m^3)
Brown Duplex Loam	0.1	518.57	518,568
Red Duplex Loam	0.1	319.02	319,021
Duplex Sands	0.3*	209.72	629,145
Grey-Pink Duplex Loam	0.3	129.64	388,926
Uniform Sands	nil**	nil	nil
Grey-Brown Gradational Loam	0.08	6.36	5,084
Total Volume			1,860,744
Total Volume with 10% handling loss allowance			**1,674,670**

* Stripping to 1m for vegetation restoration activities in green offset zones may be viable.

** Stripping recommended up to 2m for vegetation restoration activities in Green Offset zones may be viable.

Allowing for a 10 per cent handling loss, approximately 1,674,670m^3 of suitable topdressing is available within the study area. The majority of topsoil disturbance will result from the excavation of the open cut pit. The Duplex Sands which are located primarily in the northern part of the study area will generate the largest topsoil resource. This is closely followed by the Brown Duplex Loam which is evident throughout the study area, and the Grey-Pink Duplex Loam which is located primarily east of Wallaby Scrub Road.



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Disturbance)

FIGURE 4

Recommended Soil Stripping Depths for Rehabilitated Landforms

Version	Date:	Author:	Checked:	Approved:
1	8/10/09	LF	AC	RM
2	30/10/09	LF	AC	RM
3	12/11/09	LF	AC	RM
4	08/12/09	CC	AC	RM

GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg4_MML00-002_Soil Strip_091208

Projection: MGA94 Zone 56

3.3 Erosion Potential

Soil samples were laboratory tested for dispersion using EAT and ESP tests. These tests indicate the susceptibility of a soil to losing its structure and binding capacity when wet, and therefore the erosion potential of the soil. The results showed a similar pattern with all soil units whereby sodicity increased significantly with depth. The exception was the Uniforms Sands which exhibited limited chemical variability throughout the solum.

The appropriate erosion and sediment control measures should be in place prior to surface disturbance of these soils, as the risk of erosion is high once the subsoil is exposed. Appropriate measures are outlined in **Section 4** of this report. All subsoils are dispersive except the Uniform Sands.

3.4 Potential Acid Generating Material

The potential for acid generation from the topsoil and subsoil (regolith) within the study area is low. This does not include acid potential within the overburden material (consolidated bedrock below two to three metres depth), which was not assessed during this survey.

Acid Sulphate Soils (ASS), which are the main cause of acid generation within the soil mantle, are commonly found less than five metres above sea level, particularly in low-lying coastal areas such as mangroves, salt marshes, floodplains, swamps, wetlands, estuaries, and brackish or tidal lakes. There has been little history of acid generation from regolith material in the Singleton area (which is located approximately 80km from the coast).

3.5 Land Capability

The pre-mining and post-mining rural land capability classification of the study area was carried out in accordance with DECCW. A comparison of the pre and post-mining rural land capability classification is provided in **Table 12**.

Table 12 – Comparison of Pre and Post Mining Rural Land Capability Classes

Land Class	Pre-mining		Post-mining		Change per Class
no.	ha	%	ha	%	%
I	nil	-	nil	-	n/a
II	nil	-	nil	-	n/a
III	nil	-	nil	-	n/a
IV	224.46	17.66%	204.25	16.07%	-1.59%
V	736.54	57.95%	54.53	4.29%	-53.66%
VI	310.00	24.39%	23.89	1.88%	-22.51%
VII	nil	-	609.70	47.97%	+47.97%
VIII	nil	-	378.63	29.79%	+29.79%
Total	**1271**		**1271**		

3.5.1 Pre-mining

Figure 5 illustrates the boundaries for pre-mining land capability by class and **Table 12** provides specifics on the classes by area. The study area encompasses classes IV, V and VI.

The western part of the study area is classified as Class IV land (17.66 per cent). This land comprises the better classes of grazing land and whilst it can sustain cultivation for an occasional crop, it is not suitable for cultivation on a regular basis owing to limitations of slope and erosion potential. Soil conservation practices such as stocking rate control, application of fertiliser and re-establishment of permanent pasture are also recommended.

The eastern part of the study area is classified as Class V land (57.95 per cent). The land is suitable for grazing with occasional cultivation. Structural soil conservation measures are generally required because of slope gradient and soil type / depth and these measures include contour ripping and construction of banks. The south-eastern part of the study area is classified as Class VI land (24.39 per cent). This land is suitable for grazing only and requires soil conservation measures that provide for sufficient ground cover.

3.5.2 Post-mining

Figure 6 illustrates the boundaries for post-mining land capability by class and **Table 12** provides specifics on each class by area. The post-mining study area encompasses land capability class IV and V as well as VI, VII and VIII.

The rehabilitated landforms east of Wallaby Scrub Road are classified Class IV lands (16.07 per cent). The rehabilitated landforms will be suitable for grazing but not be suitable for regular cultivation. Grazing land use is based on native or improved pastures established using minimum tillage amongst stands of native trees and shrubs.

The final void, located primarily east of Wallaby Scrub Road, is classified Class VII and the high wall surrounding the void is Class VIII (47.97 and 29.79 per cent respectively). Class VIII denotes land as unsuitable for rural production. The regraded low wall to the north of the rehabilitated landform and the steeper benches on the landform are Class VI land (1.88 per cent).

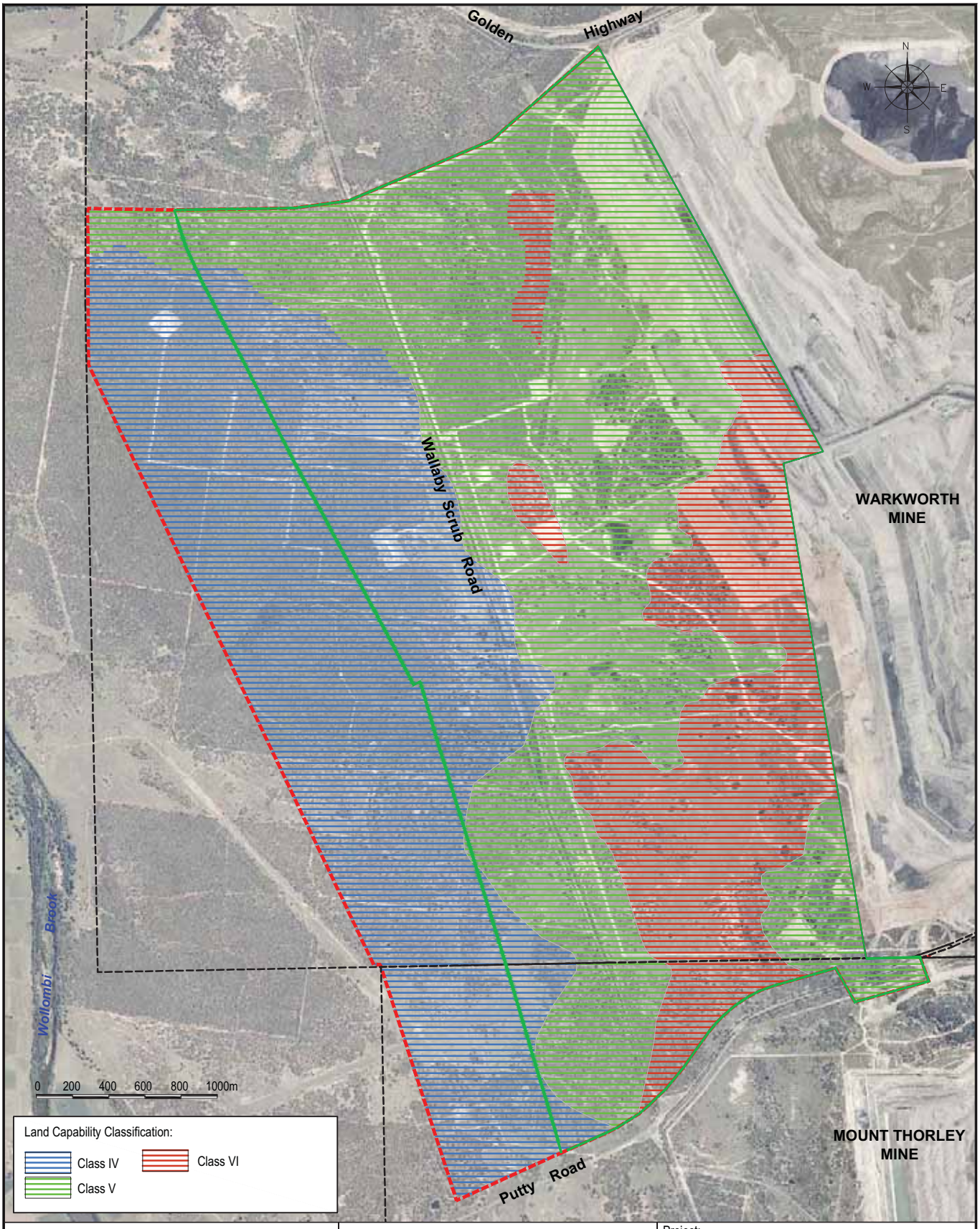
Two small pockets of Class V land (4.29 per cent) occur in the most northern and south-eastern parts of the study area.

3.6 Agricultural Suitability

The pre-mining and post-mining agricultural land suitability classification of the study area was carried out in accordance with DII. A comparison of the pre and post mining agricultural land suitability classification is provided in **Table 13**.

Table 13 – Comparison of Pre and Post-mining Agricultural Land Suitability Classes

Land Class	Pre-mining		Post-mining		Change per Class
no.	ha	%	ha	%	%
1	nil	-	nil	-	n/a
2	nil	-	nil	-	n/a
3	224.46	17.66%	nil	-	-17.66%
4	736.54	57.95%	236.28	18.59%	-39.36%
5	310.00	24.39%	1034.72	81.41%	+57.02%
Total	**1271**		**1271**		



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Disturbance)

FIGURE 5

Pre-Mining Land Capability

Version	Date:	Author:	Checked:	Approved:
1	8/10/09	LF	AC	RM
2	30/10/09	LF	AC	RM
3	12/11/09	LF	AC	RM
4	08/12/09	CC	AC	RM

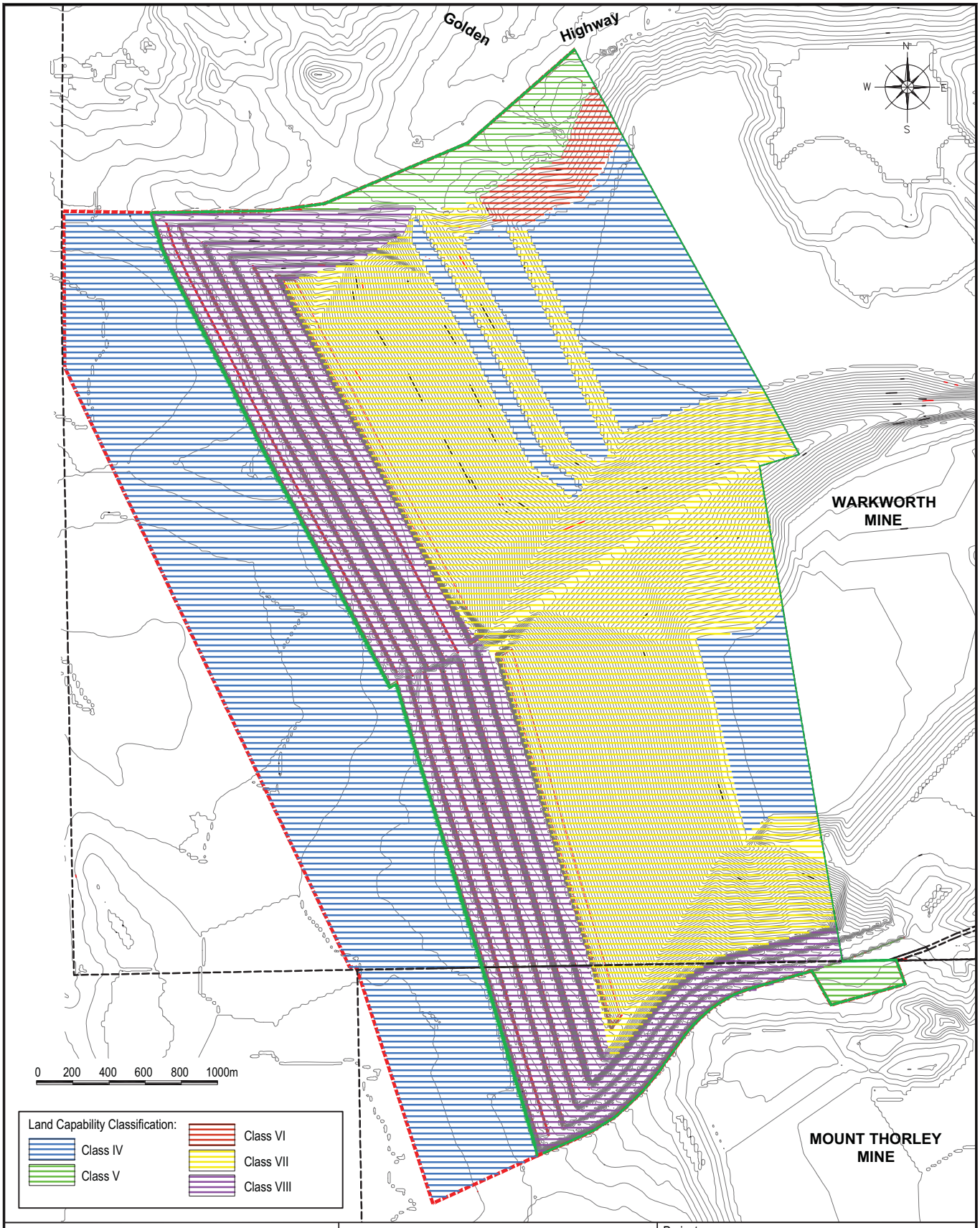
GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg5_MML00-002_Land Cap_091208

Projection: MGA94 Zone 56



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Disturbance)

FIGURE 6

Post Mining Land Capability

Version	Date:	Author:	Checked:	Approved:
1	8/10/09	LF	AC	RM
2	30/10/09	LF	AC	RM
3	12/11/09	LF	AC	RM
4	08/12/09	CC	AC	RM

GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg6_MML00-002_PostLC_091208

Projection: MGA94 Zone 56

3.6.1 Pre-mining

Figure 7 illustrates the boundaries for pre-mining agricultural land suitability by class and **Table 13** provides specifics on the classes by area.

The study area encompasses the agricultural classes 3, 4 and 5. The western part of the study area is classified Class 3 land (17.66 per cent). This is moderately productive land and is suited to grazing, improved pasture use, and some rotation cropping within a pasture regime. The eastern part of the study area is classified Class 4 land (57.95 per cent). Class 4 land is considered to be marginally productive for agricultural purposes and is not suited to cultivation. Grazing is suitable and pasture improvement, with preferably native pasture species, is to be established using minimal tillage.

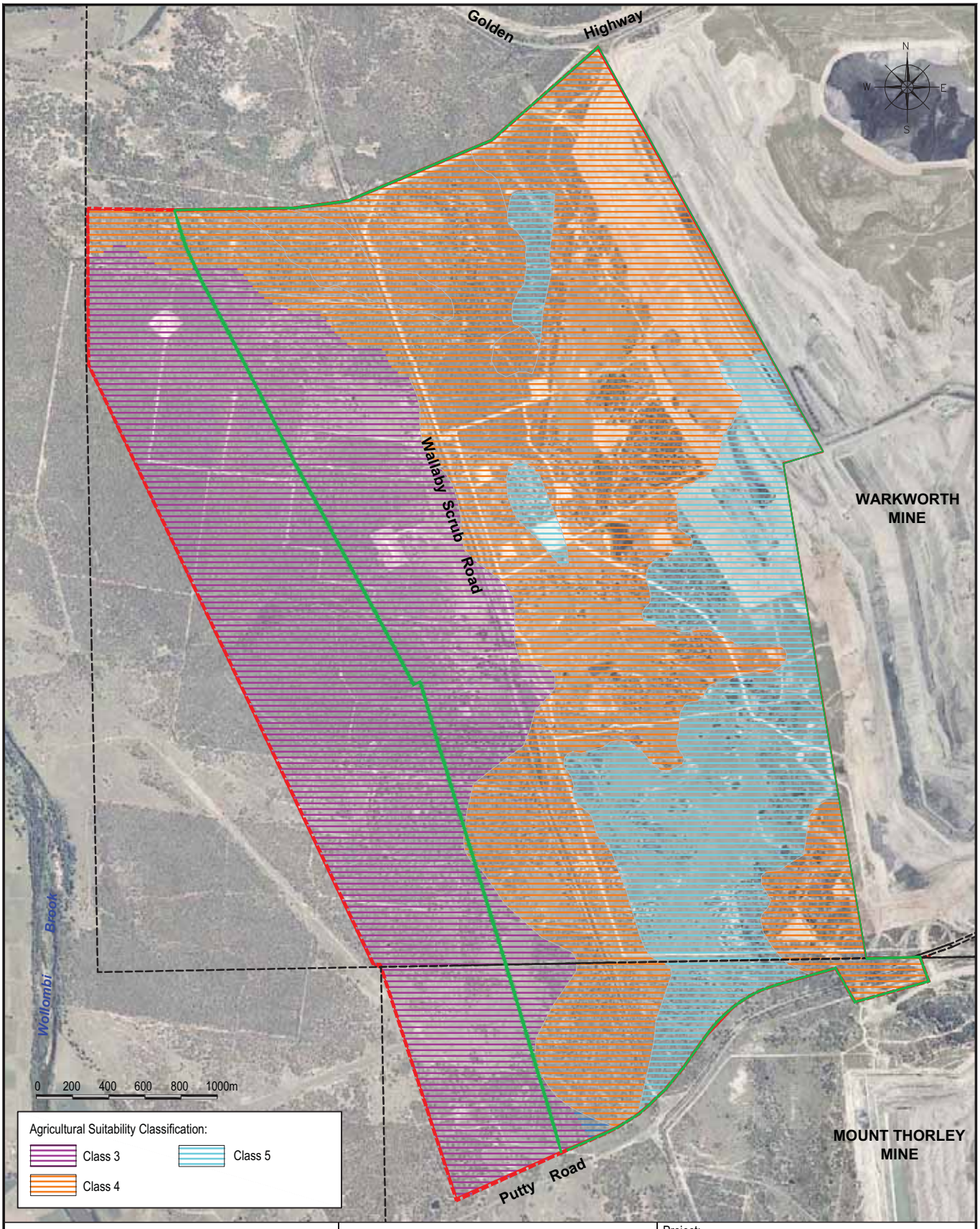
The pockets of Uniform Sand to the north and the Red Duplex Loam to the east of the study area are classified Class 5 (24.39%). Class 5 lands are considered to be marginal with light grazing “at best” being the only suitable agricultural activity. It is not recommended that the Uniform Sands be grazed as they support the endangered Warkworth Sands Vegetation community.

3.6.2 Post-mining

Figure 8 illustrates the boundaries for post mining land suitability by class and **Table 13** provides specifics on the classes by area.

The post mining study area encompasses similar agricultural suitability classes as described in pre-mining, these being classes 4 and 5.

The rehabilitated landforms are classified Class 4 as well as two small land pockets located outside of direct mining activities (total class 4 per cent is 18.59). The final void and its associated high wall at year 2031 are classified Class 5 (81.41 per cent).



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Disturbance)

FIGURE 7

Pre-mining Agricultural Suitability

Version	Date:	Author:	Checked:	Approved:
1	8/10/09	LF	AC	RM
2	30/10/09	LF	AC	RM
3	12/11/09	LF	AC	RM
4	08/12/09	CC	AC	RM

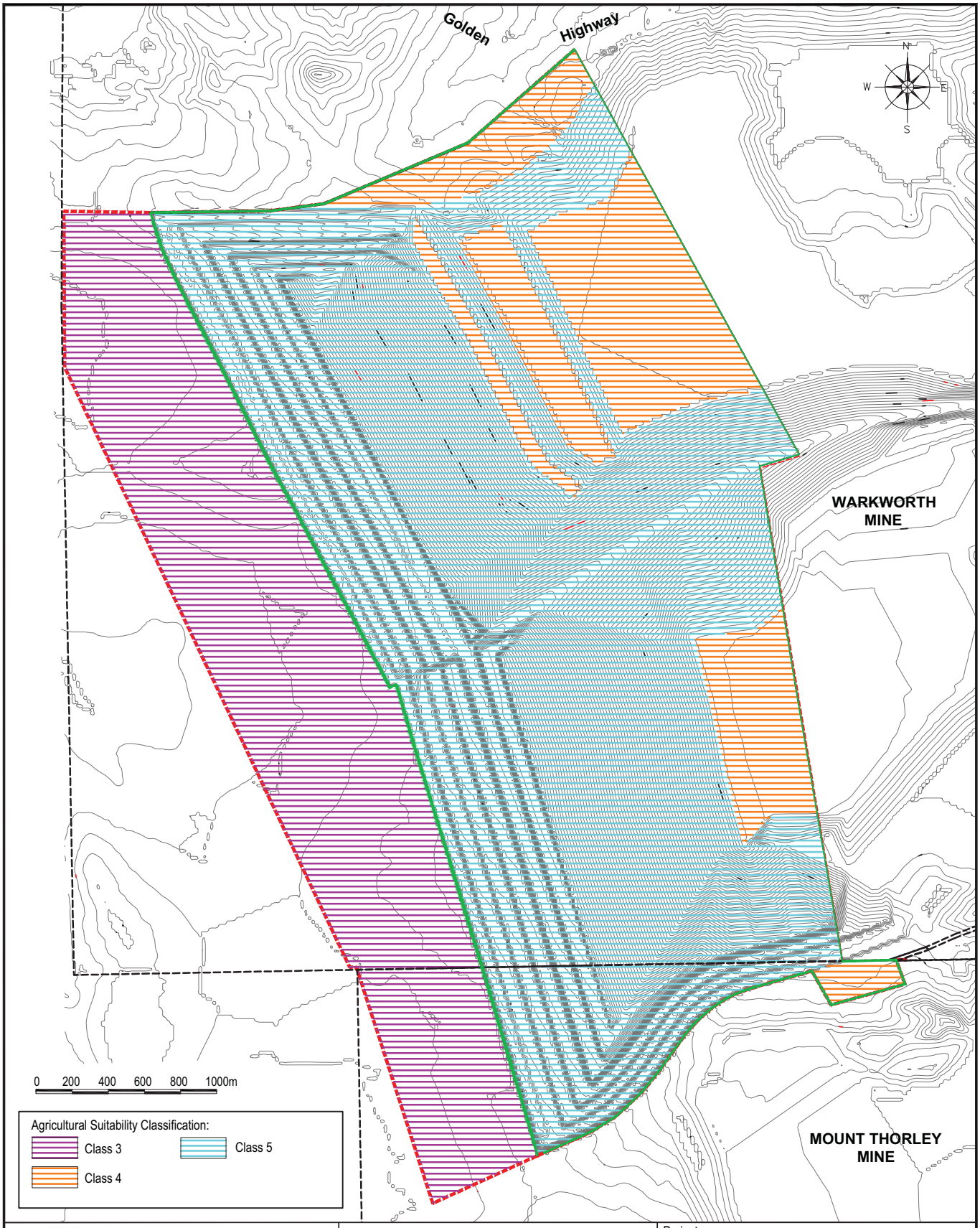
GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg7_MML00-002_Ag Suit_091208

Projection: MGA94 Zone 56



LEGEND

- Constraints boundary
- Tenement boundary
- Study area boundary (Limit of Disturbance)

FIGURE 8

Post Mining Agricultural Suitability

Version	Date:	Author:	Checked:	Approved:
1	**8/10/09**	**LF**	**AC**	**RM**
2	30/10/09	LF	AC	RM
3	12/11/09	LF	AC	RM
4	08/12/09	CC	AC	RM

GSS ENVIRONMENTAL
Environmental, Land and Project Management Consultants

Project: Warkworth Mine Extension Soil Survey (2009)

Client: Warkworth Mining Limited

File: Fg8_MML00-002_PostASuit_091208

Projection: MGA94 Zone 56

4.0 DISTURBANCE MANAGEMENT

In order to reduce the potential for degradation within the study area and adjoining lands, the following management and mitigation strategies are recommended for implementation during mining.

4.1 Topsoil Stripping and Handling

Where topsoil stripping and transportation is required, the following topsoil handling techniques are recommended to prevent excessive soil deterioration:

- strip material to the depths stated in **Table 11**, subject to further investigation as required. Due to the widespread inherent variability in topsoil sodicity it is recommended that rapid field tests using a SASKIT field kit (Rengasamy & Churchman, 2005) be undertaken prior to topsoil stripping. The field kit test results will increase sodic survey intensity and provide detailed variability data that will maximise stripping effectiveness for rehabilitation outcomes. These field results should be used in conjunction with the guidelines provided in **Table 11**.
- topsoil should be maintained in a slightly moist condition during stripping. Material should not be stripped in either an excessively dry or wet condition.
- place stripped material directly onto reshaped overburden and spread immediately (if mining sequences, equipment scheduling and weather conditions permit) to avoid the requirement for stockpiling.
- grading or pushing soil into windrows with graders or dozers for later collection by open bowl scrapers, or for loading into rear dump trucks by front-end loaders, are examples of preferential less aggressive soil handling systems. This minimises compression effects of the heavy equipment that is often necessary for economical transport of soil material.
- soil transported by dump trucks may be placed directly into storage. Soil transported by scrapers is best pushed to form stockpiles by other equipment (e.g. dozer) to avoid tracking over previously laid soil.
- the surface of soil stockpiles should be left in as coarsely textured a condition as possible in order to promote infiltration and minimise erosion until vegetation is established, and to prevent anaerobic zones forming. The addition of gypsum to the surface soil is recommended to promote aggregate stability.
- as a general rule, maintain a maximum stockpile height of three meters. Clayey soils should be stored in lower stockpiles for shorter periods of time compared to sandier soils.
- if long-term stockpiling is planned (i.e. greater than 12 months), seed and fertilise stockpiles as soon as possible. An annual cover crop species that produce sterile florets or seeds should be sown. A rapid growing and healthy annual pasture sward provides sufficient competition to minimise the emergence of undesirable weed species. The annual pasture species will not persist in the rehabilitation areas but will provide sufficient competition for emerging weed species and enhance the desirable micro-organism activity in the soil.
- prior to re-spreading stockpiled topsoil onto reshaped overburden (particularly onto designated tree seeding areas), an assessment of weed infestation on stockpiles should be undertaken to determine if individual stockpiles require herbicide application and / or “scalping” of weed species prior to topsoil spreading.
- an inventory of available soil should be maintained to ensure adequate topsoil materials are available for planned rehabilitation activities.
- topsoil should be spread to a minimum depth of 0.10m.

4.2 Topsoil Re-spreading and Seeding

4.2.1 Re-spreading

Where possible suitable topsoil should be re-spread directly onto reshaped landforms. Where topsoil resources allow, topsoil should be spread to a nominal depth of 100mm on all re-graded spoil.

All soils identified in the study area are of low fertility and accordingly fertiliser additions are recommended. Most soils in the study area also exhibited sodic properties. Sodic soils are not optimal for rehabilitation works as the clay particles tend to disperse and swell producing poor physical soil conditions. These conditions include waterlogging and hard-setting crusts which in turn negatively affect infiltration rates, plant-available water capacity, seedling emergence and root development (Rengasamy & Churchman, 2005).

The application of soil ameliorants that decrease soil dispersibility and increase soil aggregate stability is an important soil rehabilitation management tool. Historically, gypsum has been successfully applied as an ameliorant as it displaces the problematic sodium ion from clay. Accordingly, gypsum application to re-spreaded soils is highly recommended.

Soil carbon also increases soil aggregate stability and adding carbon as a soil ameliorant will improve soil structure (Hammes & Schmidt, 2009). Carbon ameliorants that may be beneficial for this study site's rehabilitated landforms include mulch, biochar and biosolids.

The spreading of topsoil, addition of soil ameliorants and application of seed should be carried out in consecutive operations to reduce the potential for topsoil loss to wind and water erosion.

4.2.2 Seedbed Preparation

Thorough seedbed preparation should be undertaken to ensure optimum establishment and growth of vegetation. All topsoiled areas should be lightly contour ripped (after topsoil spreading) to create a "key" between the soil and the spoil. Ripping should be undertaken on the contour and the tynes lifted for approximately two metres every 200m to reduce the potential for channelised erosion. Best results will be obtained by ripping when soil is moist and when undertaken immediately prior to sowing. The respread topsoil surface should be scarified prior to, or during seeding, to reduce run-off and increase infiltration. This can be undertaken by contour tilling with a fine-tyned plough or disc harrow.

4.3 Landform Design, Erosion Control

Rehabilitation strategies and concepts proposed below have been formulated according to results of industry-wide research and experience.

4.3.1 Post Disturbance Regrading

The main objective of regrading is to produce slope angles, lengths and shapes that are compatible with the proposed land use and not prone to an unacceptable rate of erosion. Integrated with this is a drainage pattern that is capable of conveying runoff from the newly created catchments whilst minimising the risk of erosion and sedimentation.

4.3.2 Erosion and Sediment Control

The most significant means of controlling surface flow on disturbed areas is to construct contour furrows or contour banks at intervals down the slope. The effect of these is to divide a long slope into a series of short slopes with the catchment area commencing at each bank or furrow. This prevents runoff from reaching a depth of flow or velocity that would cause erosion. As the slope angle increases, the banks or furrows must be spaced closer together until a point is reached where they are no longer effective.

Contour ripping across the grade is by far the most common form of structural erosion control on mine sites as it simultaneously provides some measure of erosion protection and cultivates the surface in readiness for sowing.

Graded banks are essentially a much larger version of contour furrows, with a proportionately greater capacity to store runoff and/or drain it to some chosen discharge point. The banks are constructed away from the true contour, at a designed gradient (half a per cent to one per cent) so that they drain water from one part of a slope to another; for example, towards a watercourse or a sediment control dam.

Eventually, runoff that has been intercepted and diverted must be disposed of down slope. The use of engineered waterways using erosion blankets, ground-cover vegetation and/or rip rap is recommended to safely dispose of runoff down slope.

The construction of sediment control dams is recommended for the purpose of capturing sediment laden runoff prior to off-site release. Sediment control dams are responsible for improving water quality throughout the mine site and, through the provision of semi-permanent water storages, enhance the ecological diversity of the area.

The following points should be considered when selecting sites for sediment control dams.

- each dam should be located so that runoff may be easily directed to it, without the need for extensive channel excavation or for excessive channel gradient. Channels must be able to discharge into the dam without risk of erosion. Similarly, spillways must be designed and located so as to safely convey the maximum anticipated discharge.
- the material from which the dam is constructed must be stable. Dispersible clays will require treatment with lime, gypsum and/or bentonite to prevent failure of the wall by tunnel erosion. Failure by tunnelling is most likely in dams which store a considerable depth of water above ground level, or whose water level fluctuates widely. Dams should always be well sealed, as leakage may lead to instability, as well as allowing less control over the storage and release of water.
- the number and capacity of dams should be related to the total area of catchment and the anticipated volume of runoff. The most damaging rains, in terms of erosion and sediment problems are localised, high intensity storms.

5.0 REFERENCES

Department of Natural Resources (2005) *Land Capability Spatial Data*. Resource Information Unit, Hunter Region.

Elliot G.L., Veness, R.A. (1981) *Selection of Topdressing Material for Rehabilitation of Disturbed Areas in the Hunter Valley*, J. Soil Cons. NSW 37 37-40.

Emery K.A. (1986) *Rural Land Capability Mapping*. Soil Conservation Service of NSW. Sydney, NSW.

ERM Mitchell McCotter (1995) Extension of Mount Thorley Operations: Environmental Impact Statement.

Glen R.A., J. Beckett (1993) Hunter Coalfield regional geology, 2nd edition.

Global Soil Systems (2002) Warkworth coal mine extension: soil and land capability survey report. (Project No CNA 2-1, Issue 2)

Hammes K., Schmidt M.W. (2009) Changes of Biochar in soil. In 'Biochar environmental management science and technology'. (Eds J. Lehmann and S. Joseph) (CSIRO, Australia)

Isbell RF (1996) 'The Australian Soil Classification.' (CSIRO Publishing: Melbourne).

Kovac M., Lawrie, J.M. (1991) *Soil Landscapes of the Singleton 1:250 000 Sheet*. Soil Conservation Service of NSW, Sydney.

Lockwood PV (2007) Warkworth Sands soil survey: Soil sampling and analysis within the Green Offsets and at Archerfield. University of England, Armidale.

Lockwood PV (2009) Mount Thorley-Warkworth extension area soil survey. University of England, Armidale.

Macbeth (1994) *Munsell Soil Colour Charts* Revised Edition.

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) 'Australian soil and land survey field handbook.' (Inkata Press: Melbourne).

McKensie I., Jacquier D., Neil J., Brown K. (2004) Australian soils and landscapes: an illustrated compendium. (CSIRO, Australia).

NSW Agriculture & Fisheries (1990) *Agricultural Suitability Maps – Uses and Limitations*. Agfact AC.9 Second Edition.

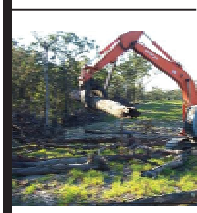
Northcote, K.H. (1979) A Factual Key for the recognition of Australian Soils. (Rellim Technical Publications, South Australia).

Rengasamy P., G.J. Churchman (2005) Cation exchange capacity, exchangeable cations and sodicity. In 'Soil analysis: an interpretation manual'. (Eds K.I. Peverill, L.A. Sparrow and D.J. Reuter) (CSIRO, Australia).

Stace, H. C. T., Hubble, G. D, Brewer, R., Northcote, K. H., Sleeman, J. R., Mulcahy, M. J, Hallsworth, E. G. (1968) 'A Handbook of Australian Soils.' (Rellim Technical Publications, South Australia).

Field Assessment Procedure










APPENDIX 1

FIELD ASSESSMENT PROCEDURE

Elliot and Veness (1981) have described the basic procedure, adopted in this survey, for the recognition of suitable topdressing materials. In this procedure, the following soils factors are analysed. They are listed in decreasing order of importance.

Structure Grade

Good permeability to water and adequate aeration are essential for the germination and establishment of plants. The ability of water to enter soil generally varies with structure grade (Charman, 1978) and depends on the proportion of coarse peds in the soil surface.

Better structured soils have higher infiltration rates and better aeration characteristics. Structureless soils without pores are considered unsuitable as topdressing materials.

Consistence – Shearing Test

The shearing test is used as a measure of the ability of soils to maintain structure grade.

Brittle soils are not considered suitable for revegetation where structure grade is weak or moderate because peds are likely to be destroyed and structure is likely to become massive following mechanical work associated with the extraction, transportation and spreading of topdressing material.

Consequently, surface sealing and reduced infiltration of water may occur which will restrict the establishment of plants.

Consistence – Disruptive Test

The force to disrupt peds, when assessed on soil in a moderately moist state, is an indicator of solidity and the method of ped formation. Deflocculated soils are hard when dry and slake when wet, whereas flocculated soils produce crumbly peds in both the wet and dry state. The deflocculated soils are not suitable for revegetation and may be identified by a strong force required to break aggregates.

Mottling

The presence of mottling within the soil may indicate reducing conditions and poor soil aeration. These factors are common in soil with low permeability's; however, some soils are mottled due to other reasons, including proximity to high water-tables or inheritance of mottles from previous conditions. Reducing soils and poorly aerated soils are unsuitable for revegetation purposes.

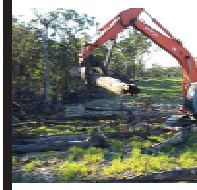
Macrostructure

Refers to the combination or arrangement of the larger aggregates or peds in the soil. Where these peds are larger than 10 cm (smaller dimension) in the subsoil, soils are likely to either slake or be hardsetting and prone to surface sealing. Such soils are undesirable as topdressing materials.

Texture

Sandy soils are poorly suited to plant growth because they are extremely erodible and have low water holding capacities. For these reasons soils with textures equal to or coarser than sandy loams are considered unsuitable as topdressing materials for climates of relatively unreliable rainfall, such as the Hunter Valley.










Soil Information

APPENDIX 2

TEST SIGNIFICANCE AND TYPICAL VALUES

Particle Size Analysis

Particle size analysis measures the size of the soil particles in terms of grainsize fractions, and expresses the proportions of these fractions as a percentage of the sample. The grainsize fractions are:

clay	<0.002mm
silt	0.002 to 0.02mm
fine sand	0.02 to 0.2mm
medium & coarse sand	0.2 to 2mm

Particles greater than 2mm, that is gravel and coarser material, are not included in the analysis.

Emerson Aggregate Test

Emerson aggregate test measures the susceptibility to dispersion of the soil in water. Dispersion describes the tendency for the clay fraction of a soil to go into colloidal suspension in water. The test indicates the credibility and structural stability if the soil and its susceptibility to surface sealing under irrigation and rainfall. Soils are divided into eight classes on the basis of the coherence of soil aggregates in water. The eight classes and their properties are:

Class 1:	Very dispersible soils with susceptibility to high tunnel erosion.
Class 2:	Moderately dispersible soils with some susceptibility to tunnel erosion.
Class 3:	Slightly or non-dispersive soils which are generally stable and suitable for soil conservation earthworks.
Class 4-6:	More highly aggregated materials which are less likely to hold water. Special compactive efforts are required in the construction of earthworks.
Class 7-8:	Highly aggregated materials exhibiting low dispersion characteristics.

The following subdivisions within Emerson classes may be applied:

(1) Slight milkiness, immediately adjacent to the aggregate.
(2) Obvious milkiness, less than 50% of the aggregate affected.
(3) Obvious milkiness, more than 50% of the aggregate affected.
(4) Total dispersion, leaving only sand grains.

Salinity

Salinity is measured as electrical conductivity on a 1:5 soil:water suspension to give EC (1:5). The effects of salinity levels expressed as EC at 25^{o} (dS/cm), on plants are:

0 to 1:	Very low salinity, effects on plants mostly negligible.
1 to 2:	Low salinity, only yields of very sensitive crops are restricted.
Greater than 2:	Saline soils, yields of many crops restricted.

pH

The pH is a measure of acidity and alkalinity. For 1:5 soil:water suspensions, soils having pH values less than 4.5 are regarded as strongly acid, 4.5 to 5.0 moderately acidic, and values greater than 7.0 are regarded as alkaline. Most plants grow best in slightly acidic soils.

LABORATORY TEST METHODS

Particle Size Analysis

Determination by sieving and hydrometer of percentage, by weight, of particle size classes: Gravel >2mm, Coarse Sand 0.2-2mm, Fine Sand 0.02-0.2mm, Silt 0.002-0.2mm and Clay <0.002mm; SCS standard method (Bond et al., 1990)

Emerson Aggregate Test

An eight class classification of soil aggregate coherence (slaking and dispersion) in water. SCS standard method closely related to Australian Standard AS1289. The degree of dispersion is included in brackets for class 2 and class 3 aggregates (Bond et al., 1990).

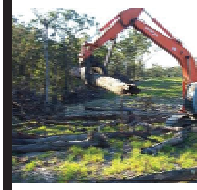
EC

Electrical Conductivity determined on a 1:5 soil:water suspension. Prepared from the sample's fine earth fraction (Bond et al., 1990).

pH

Determined on a 1:5 soil:water suspension, Prepared from the sample's fine earth fraction (Bond et al., 1990).










Glossary

APPENDIX 3

GLOSSARY

A Horizon

The original top layer of mineral soil divided into A1 (typically from 5 to 30 cm thick; generally referred to as topsoil.

Alluvial Soils

Soils developed from recently deposited alluvium, normally characterise little or no modification of the deposited material by soil forming processes, particularly with respect to soil horizon development.

Brown Clays

Soil determined by high clay contents. Typically, moderately deep to very deep soils with uniform colour and texture profiles, weak horizonation mostly related to structure differentiation.

Consistence

Comprises the attributes of the soil material that are expressed by the degree and kind of cohesion and adhesion or by the resistance to deformation or rupture.

Electrical Conductivity

The property of the conduction of electricity through water extract of soil. Used to determine the soluble salts in the extract, and hence soil stability. (Soil Landscapes of Singleton 1991)

Emmerson's Aggregate Test (EAT)

A classification of soil based on soil aggregate coherence when immersed water. Classifies soils into eight classes and assists in identifying whether soils will slake, swell or disperse (Soil Landscapes of Singleton, 1991)

Gravel

The >2 mm materials that occur on the surface and in the A1 horizon and include hard, coarse fragments.

Lithosols

Stony or gravelly soils lacking horizon and structure development. They are usually shallow and contain a large proportion of fragmented rock. Textures usually range from sands to clay loams.

Loam

A medium, textured soil of approximate composition 10 - 25% clay, 25 - 50%, silt and <50% sand.

Mottling

The presence of more than one soil colour in the same soil horizon, not including different nodule or cutan colours.

Particle Size Analysis (PSA)

The determination of the of the amount of the different size fractions in a soil sample such as clay, silt, fine sand, coarse sand and gravel. (Soil Landscapes of Singleton 1991)

Pedality

Refers to the relative proportion of peds in the soil (as strongly pedal, weakly pedal or non-pedal).

pH

A measure of the acidity or alkalinity of a soil.

Solodic Soils

Strong texture differentiation with a very abrupt wavy boundary between A and B horizons, a well-developed bleached A2 horizon and a medium to coarse blocky clay B horizon.

Soloths

Similar to a solodic soil but acidic throughout the profile. Tends to be a more typical soil of the humid regions where the exchangeable cations in the B Horizon of the solodised soils have been leached out.

Podzolics

Podzolic soils are acidic throughout and have a clear boundary between the topsoil and subsoil. The topsoils are loams with a brownish grey colour. The lower part of the topsoil has a pale light colour and may be bleached with a nearly white, light grey colour.

Ped

An individual, natural soil aggregate. (Soil Landscapes of Singleton 1991)

Sodicity

A measure of exchangeable sodium in the soil. High levels adversely affect soil stability, plant growth and/or land use.

Soil mantle

The upper layer of the Earth's mantle, between consolidated bedrock and the surface, that contains the soil. Also known as the regolith.

Soil Profiles from Site Inspection










APPENDIX 4

Brown Duplex Loam

Description: Brown Duplex Loam; description as per **Section 3.1.2.1** in the main report.

Location: This profile was located northwest of the study area. In the landscape it was in a depression and is associated with low slopes and creek flats.

Layer #	Depth (m)	Description
1	0.0- 0.15	Grey-brown silty loam with moderate consistence. Weak pedality (sub-angular 5-10mm); many roots; stones 2-10%; and boundary clear.
1	0.15 - 0.30	Grey clayey loam with moderate consistence. Moderate pedality (sub-angular 10-20mm); few roots; stones 2%; and boundary gradual.
2	0.30 – 1.00	Grey medium clay with 40-50% yellow-brown mottles. Consistence is strong; pedality is massive; no roots or stones.

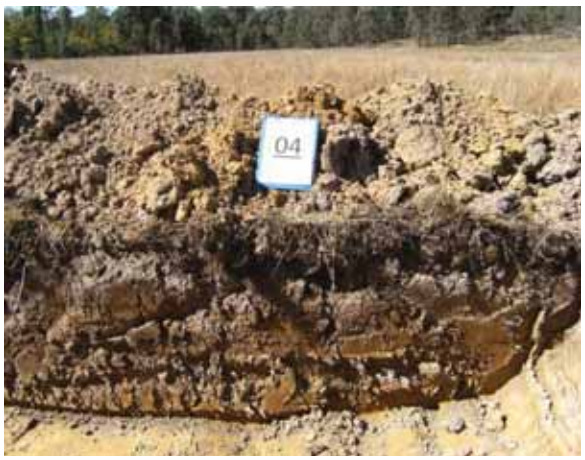


Plate 1: Grey-Brown Duplex Loam - Profile



Plate 2: Grey-Brown Duplex Loam - Landscape

Grey-Pink Duplex Loam

Description: This soil unit is characterised by an abrupt texture change between the grey-brown sandy-loam surface soil and the underlying grey clayey subsurface soil. A distinguishing feature of this duplex unit is the grey clayey subsurface horizon. This horizon is grey in colour as seasonal saturation mobilises insitu pigment bearing minerals (iron oxides) which are subsequently lost to free draining waters.

Location: This profile was located southwest of the study area. In the landscape it was on a lower slope and is associated with undulating hills mid-low slopes.

Layer #	Depth (m)	Description
1	0.0 - 0.30	Grey-brown sandy loam with weak consistence. A weak pedality (sub-angular 2-5mm); roots common to many; stones increasing with depth, 2-10%; and boundary clear and wavy.
2	0.30 – 1.0	Grey sandy clay with 20-50% yellow-brown mottles. Consistence is moderate; pedality is massive; roots few to none; and stones are relatively abundant, 10-20%.



Plate 3: Pink-Grey Duplex Loam - Profile



Plate 4: Pink-Grey Duplex Loam - Landscape

Fine Uniform Sand

Description: This soil unit is characterised by little textural change within the soil profile, and contains limited silt and clay particles.

Location: This profile was located northwest of the study area and is part of the Uniform Sand soil unit which supports the endangered Warkworth Sands vegetation community.

Landuse: The land overlying these soils is currently designated as a restoration area with grazing excluded and rehabilitation of remnant vegetation undertaken by Warkworth Mine. Vegetation is sparse and consists of Old-man Banksia, Flax-leaf Wattle and an understory of Coffee Bush.

Layer #	Depth (m)	Description
1	0.00 - 0.25	Grey-brown loamy with weak consistence. A weak pedality (sub-angular 2mm); roots many; stones 2-10%; and boundary clear and even.
2	0.25 – 1.0	Yellow fine sand with very weak consistence; apedal pedality with no roots or stones.



Plate 5 : Uniform Sand - Profile

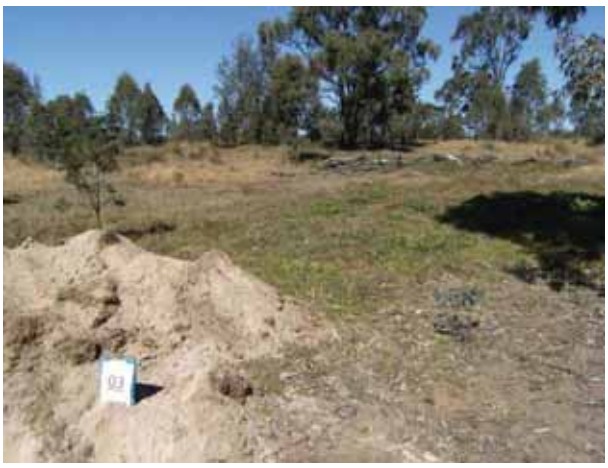


Plate 6: Uniform Sand - Landscape

Appendix J

Visual amenity study



Appendix J — Visual amenity study

J

WARKWORTH CONTINUATION 2014
VISUAL IMPACT ASSESSMENT

PREPARED FOR WARKWORTH MINING LIMITED
JUNE 2014



www.integrateddesignsolutions.com.au

INTEGRATED DESIGN SOLUTIONS

This page has been intentionally left blank

Visual Impact Assessment

Prepared for	**Warkworth Mining Limited**
Prepared by	Esther Dickins
Position	Principal Landscape Architect
Signature	
Date	2 June 2014

This document may only be used for the purpose for which it was commissioned and in accordance with the terms of that commission. Unauthorised use of this document for any other purpose is prohibited and no liability is accepted for such use.

Document control

Version	Date	Prepared by	Reviewed by
A	25 May 2014	Integrated Design Solutions Esther Dickins	DP
B	2 June 2014	Integrated Design Solutions Esther Dickins	DP

INTEGRATED DESIGN SOLUTIONS PTY LTD
T +61 (0) 2 9437 3600
F +61 (0) 2 9437 3666
E studio@integrateddesignsolutions.com.au
Ground floor, Suite 2, 30 Alfred Street
Milsons Point NSW 2061
PO Box 920 Milsons Point NSW 1565
Australia
ABN 92 120 704 116

This page has been intentionally left blank

Contents

Executive Summary 9

1. Introduction 11
1.1 Background 11
1.2 Description of Proposal 11
1.3 Report Findings Summary 13
1.4 Scope of the Visual Impact Assessment 13
1.5 Assessment Requirements 13
1.6 Objectives of the Visual Impact Assessment 14

2. Method 15
2.1 Evaluation of the Visual Environment 15
2.2 Analysis of the Proposal 15
2.3 Analysis of Visual Effects 15
2.4 Visual Sensitivity 15
2.5 Visual Impact 16
2.6 Visual Impact Mitigation 16

3. Analysis of the Existing Visual Environment 17

4. The Proposal 22
4.1 Indicative Mine Plans 22
4.2 Rehabilitation 26
4.3 Final Landform and Land Use 26

5. Visual Impact Assessment 29
5.1 Potential Visual Effects 29
5.2 Potential Visual Sensitivity 29
5.3 Potential Visual Impacts 30
5.3.1 North Sector 30
5.3.2 East Sector 30
5.3.3 South Sector 31
5.3.4 West Sector 31

6.	**Management and Mitigation**	**41**
6.1	Objectives	41
6.2	Proposed Mitigation Measures	41
6.3	On-Site Mitigation Measures	42
6.3.1	Structures	42
6.3.2	Management of Off-Site Lighting Impacts	42
6.3.3	Site and Boundary Areas	43
6.3.4	Putty Road	43
6.3.5	Planting for Vegetation Screening	44
6.3.6	Planting for Bund Screening	44
6.3.7	Landscape Procedures	46
6.4	Off-Site Mitigation Measures	46
6.4.1	Scope	46
6.4.2	Site Specific Visual Assessment	47
6.4.3	Visual Mitigation Treatments	47
7.	**Conclusion**	**53**
References		**55**

Figures

Figure 1.1 The Proposal 12
Figure 2.1 Visual Impact – Effect v Sensitivity (VIAS 2010) 16
Figure 3.1 Hunter River Flood-Plain (VIAS 2010) 17
Figure 3.2 Wollombi Brook Flood-Plain (VIAS 2010) 17
Figure 3.3 Rural Hills (VIAS 2010) 18
Figure 3.4 Rural Footslopes(VIAS 2010) 18
Figure 3.5 Towns (VIAS 2010) 18
Figure 3.6 Surrounding Ranges (VIAS 2010) 19
Figure 3.7 Primary Visual Catchment and Visual Character Units (VIAS 2010) 20
Figure 4.1 Indicative Year 3 Mine Plan 23
Figure 4.2 Indicative Year 9 Mine Plan 24
Figure 4.3 Indicative Year 14 Mine Plan 25
Figure 4.4 Indicative Final Landform 27
Figure 5.1 Visual Sensitivity (VIAS 2010) 29
Figure 5.2 Viewshed Analysis Bulga Village (Indicative Year 3 Mine Plan) 32
Figure 5.3 Viewshed Analysis Bulga Village (Indicative Year 9 Mine Plan) 33
Figure 5.4 Viewshed Analysis Bulga Village (Indicative Year 14 Mine Plan) 34
Figure 5.5 Viewshed Analysis Bulga Village (Indicative Final Landform) 35
Figure 5.6 Putty Road North Photo Montages (VIAS 2010) 36
Figure 5.5 Putty Road South Photo Montages (VIAS 2010) 37
Figure 5.8 Bulga Hotel Photo Montages (VIAS 2010) 38
Figure 5.9 Turnbull Inlet Road Photo Montages (VIAS 2010) 39
Figure 5.10 Wambo Road Photo Montages (VIAS 2010) 40
Figure 6.1 Typical Structures and Equipment 42
Figure 6.2 Typical Vegetation Screen Section 44
Figure 6.3 Typical Planting Matrix – New Screen Planting 45
Figure 6.4 Typical Planting Matrix – Infill Screen Planting 45
Figure 6.5 Typical Bund Screen Section 46
Figure 6.7 Example of Filtered Screen Planting 47
Figure 6.8 Example of Dense Screen Planting 48
Figure 6.9 Site 1: Photograph of Existing View 48
Figure 6.10 Site 1: Photomontage Prior to Mitigation Measures (Indicative Year 9) 49
Figure 6.11 Site 1: Photomontage Post Mitigation Measures 49
Figure 6.12 Site 2: Photograph of Existing View 50
Figure 6.13 Site 2: Photomontage Prior to Mitigation Measures (Indicative Year 9) 51
Figure 6.14 Site 2: Photomontage Post Mitigation Measures 51

This page has been intentionally left blank

Executive Summary

Coal & Allied (Operations) Pty Limited is seeking development consent for the Warkworth Continuation 2014 (the proposal).

Through an analysis of the existing environment surrounding the Warkworth Mine, the proposal's potential visual impacts on the surrounding landscape were assessed. This analysis has determined the proposal would have a range of visual effects and that these are in keeping with those typically resulting from open cut coal mining activities in a similar rural environment. Importantly, it is noted that the environment in which the proposal is to be undertaken contains significant existing mining activity which is now part of the landscape against which it will be viewed. This results in a reduction in the general level of contrast and subsequent visual impacts.

The visual impacts of the proposal have largely been assessed as moderate to low; however some sensitive assessment locations would potentially experience higher impacts. These higher impacts occur mostly from the west where the removal of Saddleback Ridge and emplacement above the level of the existing ridge line in some areas, increase the visibility of the operations compared to the existing approved operations. The majority of the western sector will benefit from existing screening provided by the intervening topography and vegetation. Those residences which may experience high impacts are located in elevated areas around Bulga Village and are likely to require site specific mitigation measures.

The eastern sector may have potentially significant views of the overburden emplacement areas however this would be the case irrespective of the proposal's approval. The progressive rehabilitation of the overburden from the east will result in reduced effects.

Instrumental to the minimisation of the potential visual impacts is the proposed suite of mitigation measures. These measures aim to reduce the impacts of the proposal at all significant viewing points though vegetation planting and bund screening along the boundaries and site specific mitigation to individual residences where a moderate to high impact has been identified.

The progressive establishment of extensive landscape rehabilitation throughout the operations will reduce the level of visual impact over time and will ultimately result in a high level of integration with the surrounding visual environment.

This page has been intentionally left blank

1. Introduction

1.1 BACKGROUND

Warkworth Mine is an open cut coal mine approximately 8 kilometres (km) south-west of Singleton in the Hunter Valley, NSW. The mine is operated by Coal & Allied on behalf of Warkworth Mining Limited (WML). The site currently operates under Development Consent No. DA 300-9-2002-i (the development consent) issued by the then Minister for Planning in May 2003 under Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The site also operates under two separate Commonwealth approvals (*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)): EPBC 2002/629 and EPBC 2009/5081.

Warkworth Mine has been in operation since 1981 and the originally approved operation has been modified several times. Immediately to the south of Warkworth Mine is Mount Thorley Operations. Since 2004, the two mines have integrated at an operational level and are known as Mount Thorley Warkworth (MTW), with a single management team responsible for all the operations. Equipment, personnel, water, rejects and coal preparation are all shared between the mines. The operations involve an existing workforce of approximately 1,300 persons, which includes full-time personnel and a small number of short-term contractors. Ownership of the two mines remains separate.

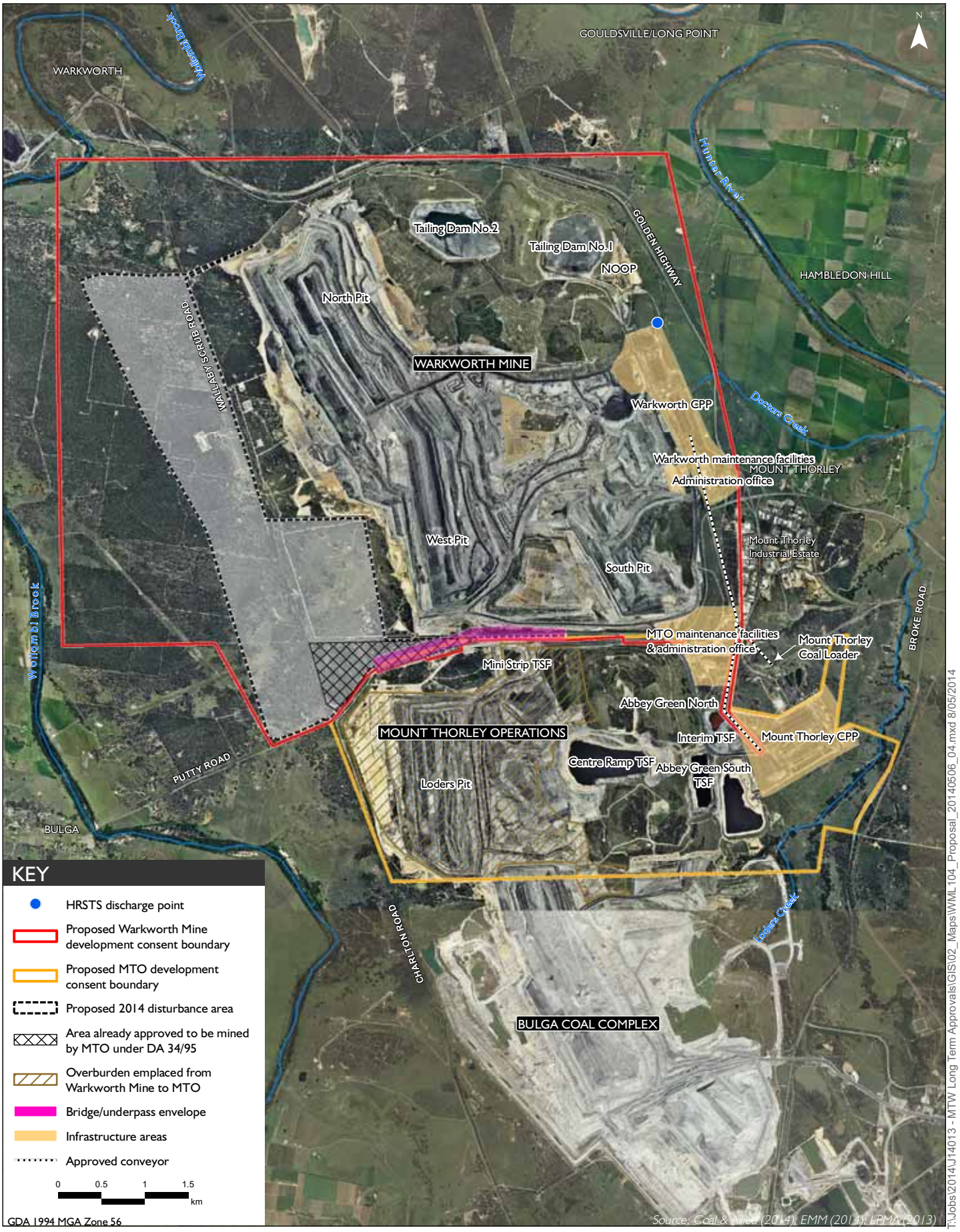
Warkworth Mine currently operates three integrated open cut mining areas, namely North, West and South pits with West and North pits being the focus of production. Run-of-mine (ROM) coal from Warkworth Mine is transported to either the Warkworth or Mount Thorley coal preparation plant (CPP) for processing. Product coal from the CPPs is transported via conveyor to either the Mount Thorley Coal Loader (MTCL) or to the Redbank Power Station. Coal loaded onto trains at the MTCL is transported to the Port of Newcastle for export. The Warkworth Continuation 2014 (the proposal) seeks an approval under Part 4, Division 4.1 of the EP&A Act to extend mining beyond the current limits.

1.2 DESCRIPTION OF PROPOSAL

Warkworth Mine has approval to operate until 19 May 2021 under its development consent. The proposal seeks a 21 year development consent period from the date of approval. If approval is granted in late 2014, operations at Warkworth Mine are forecast to continue to 2035, a 14 year extension over the current approval. The proposal seeks a continuation of all aspects of Warkworth Mine as it presently operates together with:

> an extension of the approved mining footprint by approximately 698ha to the west of current operations (referred to herein as the proposed 2014 extension area);
> the ability to transfer overburden to MTO to complete MTO's final landform;
> the closure of Wallaby Scrub Road;
> an option to develop an underpass beneath Putty Road for the third bridge crossing yet to be constructed (while retaining the current approval for an overpass);
> minor changes to the design of the Northern out-of-pit (NOOP) dam; and
> the continued use of secondary access gates to the mine site and offsets for activities such as drilling, offset management, equipment shutdown pad access amongst other things.

The proposal is shown in Figure 1.1.



COAL & ALLIED

Figure 1.1 The Proposal

1.3 REPORT FINDINGS SUMMARY

This Visual Impact Assessment (VIA) has determined that the overall visual impact of the proposal is likely to be moderate to low however, limited areas such as elevated residences around Bulga Village, at around 2.5 – 5km from the proposal's western most extent, may experience higher impacts.

Visual impact mitigation measures are proposed to be put in place to mitigate the potential impacts on the overall surrounding landscape including vegetation and bund screening to the site's boundary areas. In addition, specific mitigation measures are proposed for individual properties, determined to have high visual impacts. The progressive rehabilitation of Warkworth Mine will reduce the level of contrast of the operations in the viewing landscape and ultimately result in a higher level of visual integration.

1.4 SCOPE OF THE VISUAL IMPACT ASSESSMENT

Integrated Design Solutions (IDS) was commissioned by EMGA Mitchell McLennan (EMM) on behalf of Coal & Allied to prepare this VIA, as required by the Secretary's requirements, to be submitted as part of the Warkworth Continuation 2014 Environmental Impact Statement.

The scope of the VIA is to determine the visual impacts of the proposal and to recommend mitigation measures which may be suitable. The VIA utilises information from the Warkworth Extension Project Visual Impact Assessment Study (VIAS) (Integral Landscape Architecture and Visual Planning, 2010) and the Draft Warkworth Extension Visual Impact Management Plan (VIMP) (Integrated Design Solutions (IDS), 2012) relevant to the proposal.

1.5 ASSESSMENT REQUIREMENTS

This VIA has been prepared in accordance with the Secretary's requirements.

1.6 OBJECTIVES OF THE VISUAL IMPACT ASSESSMENT

The overall intent of this VIA is to provide an assessment of the potential impacts of the proposal on the existing landscape and visual character of the surrounding area. It provides a description of the potential visual changes that could occur, assesses the associated impacts in terms of their significance and proposes mitigation measures to reduce the level of impact where possible.

The objectives of the VIA are as follows:

- Identify areas of the public domain and individual residences within the primary visual catchment which are likely to have significant direct views, in comparison to the current approved operations;
- Develop management and mitigation strategies to ameliorate adverse visual impacts and appearance of structures;
- Detail the process for implementing the mitigation strategies;
- Provide details on the establishment and maintenance of vegetation, construction of structures and bunding for the purposes of maintaining satisfactory visual amenity; and
- Identify potential site specific measures to be undertaken for individual residences to mitigate visual impacts.

This page has been intentionally left blank

2. Method

Visual impact is determined by firstly analysing the existing visual environment and how it is seen from various key viewing locations. Through this analysis the visual character and its visual sensitivity can be determined. The visual effects are then determined by considering a development in this context. The combination of the visual sensitivity and the effect determines the level of impact for which an appropriate level of mitigation can be considered.

This VIA utilises a methodology consistent with that used for the VIAS (2010) as follows.

2.1 EVALUATION OF THE VISUAL ENVIRONMENT

The evaluation of the existing visual environment was undertaken in the VIAS by examining the existing landscape and determining key viewing locations within it based on the existing land uses. This analysis remains relevant to the proposal.

The existing landscape setting is defined through the areas topography, vegetation, waterways and developed features. Visual Character Units (VCUs) were defined to group areas with similar features within the landscape. This allows an understanding of the setting in which the proposal will be viewed.

2.2 ANALYSIS OF THE PROPOSAL

This analysis considers the proposal within the landscape setting defined by the VCUs and provides the basis for determining the visual effect and the sensitivity of the key viewing locations. It is based on the specific characteristics of both the landscape setting and the proposal including form, shape, colour and texture and the level of differences between them.

2.3 ANALYSIS OF VISUAL EFFECTS

The visual effect is a measure of the level of either contrast or integration, between a development and its setting. Mining activities tend to have a varied level of visual effect at various project stages. During extraction operations the pits and overburden emplacement can have a high level of contrast however as vegetation is re-established and final landforms are softened the level of integration can be higher.

In the case of the Warkworth Mine the existing visual environment contains extensive elements of mining operations and therefore, the proposal extends these elements which means the visual effect is reduced as the contrast to the existing landscape setting is less pronounced.

The magnitude of a development's visual effect is determined by considering the level of contrast or integration with its surroundings and the proportion of the view that includes the proposed development for the given level of contrast or integration. The proportion of the view is determined by measuring the occupied percentage of the Primary View Zone (PVZ), the area occupied by an arc created by sight lines radiating vertically and horizontally at angles of 30 degrees around the centre view line from the eye.

The visual effect on the various viewing locations and in particular individual residences may range from high to low depending on screening provided by topography, buildings or vegetation, the viewing distance and orientation towards the development (directly or indirectly).

2.4 VISUAL SENSITIVITY

The visual sensitivity is a measure of how critically the change to the visual environment will be perceived by those viewing it from different land use areas in the vicinity. For the purpose of this VIA consideration is given to both the existing environment and the currently approved operations for Warkworth Mine.

The level of sensitivity varies for different land uses. Residential, tourism and recreation areas tend to have higher visual sensitivity than other land uses such as industrial, agricultural or road / transport corridors. This is because the perceived quality of these sensitive land uses is in part, dependent on the visual amenity of their surroundings. This sensitivity is also dependant on the distance of the nearest visible elements.

2.5 VISUAL IMPACT

The significance of the visual impact is dependent on the interaction between the visual effect and the visual sensitivity as defined in the VIAS (see Figure 2.1). When considering the visual impact of the proposal a significant impact is consider to be high.

The visual effect of assessment locations for the proposal was determined by review of the VIAS field assessment and examination of a GIS model and computer generated three-dimensional model. Allowance was made for the intervening vegetation, included at a height to 12m, however, detailed determination of the precise levels of vegetation screening and orientation towards views is not possible through this process. The assessment undertaken is considered conservative in this context. The levels of impact may be less should orientation be indirect or vegetation screening exist.

Figure 2.1
Visual Impact – Effect v Sensitivity (VIAS 2010)

Visual Effect	Visual Sensitivity		
	High	Moderate	Low
High	High Visual Impact	High / Moderate Visual Impact	Moderate / Low Visual Impact
Moderate	High / Moderate Visual Impact	Moderate Visual Impact	Moderate / Low Visual Impact
Low	Moderate / Low Visual Impact	Moderate / Low Visual Impact	Low Visual Impact

2.6 VISUAL IMPACT MITIGATION

Visual mitigation measures can be implemented on-site, off-site or in combination to reduce the visual impact on an assessment location. This is typically done by reducing either the level of contrast of the development (e.g. through revegetation) or the proportion of the view in which it can be seen from the assessment location.

3. Analysis of the Existing Visual Environment

The proposal will occur in an area where mining is an established feature of the landscape. The proposal site is located in the Hunter Valley coalfields with surrounding land uses predominantly mines and supporting infrastructure including the Hunter Valley Operations, Wambo Mine and Redbank Power Station to the north, MTCL and Mount Thorley Industrial Estate to the east, Mount Thorley Operations and Bulga Coal Complex to the south. A number of rural residential properties are located to the north and east of the Site. To the west of the Site are a number of rural and rural residential properties and Bulga village. The existing visual character of the proposal site includes views of mining operations grazing and cropping.

The landscape character of the local area is dominated by moderate to gently sloping hills with several locally dominant ridges. The highest natural points are Saddleback Ridge within Warkworth Mine and Charlton Ridge within Mount Thorley Operations. From these ridges the land slopes down to the undulating land along the Hunter River and Wollombi Brook. Within this context there are open views along and across the flood-plains and cleared rural lands. Rehabilitated overburden emplacement areas are a significant feature of the existing landscape including areas within Warkworth Mine, Mount Thorley Operations, Bulga Open Cut Spoils and the Wambo Mine.

The Primary Visual Catchment (PVC) is the area containing the majority of views of the proposal and is defined primarily by the surrounding topography. The PVC and VCUs of the proposal site were identified in the VIAS and remain relevant to the proposal (see Figure 3.7). The VCUs are areas of visual uniformity which make up the overall landscape setting. The VCUs are rarely seen in isolation, rather in combination and the mining development will combine with these to create the new view as seen from a particular location.

The VCUs within the PVC are as follows:

> Hunter River and Wollombi Brook flood-plains;
> Rural hills;
> Rural footslopes;
> Town and village areas;
> Surrounding ranges; and
> Mine and Industrial areas.

Hunter River and Wollombi Brook flood-plains

The Hunter River floodplain is characterised by expansive river flats with green grass and croplands in contrast to the dryland grasses and scattered woodlands of the rural lands and foothills. The Wollombi Brook floodplain is less expansive than the Hunter River floodplain and is visually less dominant however it does create a contrast to the surrounding landscape. The flatness of these areas and grass crop cover allow for distant views towards the proposal.



Figure 3.1 Hunter River Flood-Plain (VIAS 2010)



Figure 3.2 Wollombi Brook Flood-Plain (VIAS 2010)

Rural Hills

This VCU includes the foothills to the north, east, south and west surrounding the proposal site. It is largely located adjacent to the flood-plains and consists of gently undulating hills. Vegetation includes open forest woodlands and scattered trees in grasslands.

The elevation rises to approximately 100m in the vicinity of the Golden Highway and Putty Road limiting visibility of the proposal from the north and east including the Singleton urban area. The southern hills have elevations in the order of 150 – 170m and includes the Singleton Military Area which retains the rural character apart from the base which is visually similar to a village. To the west, Saddleback and Charlton ridges rising to 165m and 155m respectively form part of this VCU.



Figure 3.3 Rural Hills (VIAS 2010)

Rural Footslopes

The rural footslopes are located between Wollombi Brook to the east and the steep forested ranges to the west. The area generally has gentle topography but becomes steeper closer to the ranges in the west. It is dominated by grassland with scattered trees and woodland.



Figure 3.4 Rural Footslopes (VIAS 2010)

Town and Village areas

Singleton, around 10km to the north-east, and the smaller villages of Warkworth, Broke and Bulga are included in this VCU. These villages vary greatly in size and have a varying mix of residential, institutional, commercial and industrial land uses. This land use mix along with the open space creates their visual character. These towns contain the majority of residents in the area and this VCU has high sensitivity where it is exposed to the proposal.

Due to intervening topography the proposal is screened from much of Singleton however distant views are possible in some areas. Bulga is a widely scattered rural village approximately 2.5km from Warkworth Mine. Putty Road Bulga has a combination of spread out buildings, varied landscape treatments and surrounding rural areas. Wollemi Peak Road, Inlet Road and Wambo Road each lead from the village to the respective southern, western and northern rural residences within the rural footslopes. Areas of Bulga do experience views of Warkworth Mine.

Broke is located approximately 12km to the south and is shielded from the mine by the hills immediately to the north and local street features. Similarly, Warkworth is shielded by vegetation and topography including Watts Peak.





Figure 3.5 Towns (VIAS 2010)

Surrounding ranges

The surrounding mountain ranges define the edges of the PVC and are located on the western and southern sides of the Hunter Valley. These ranges are steep and have closed forest cover with elevations of 240 – 400m above the valley and foothills below.

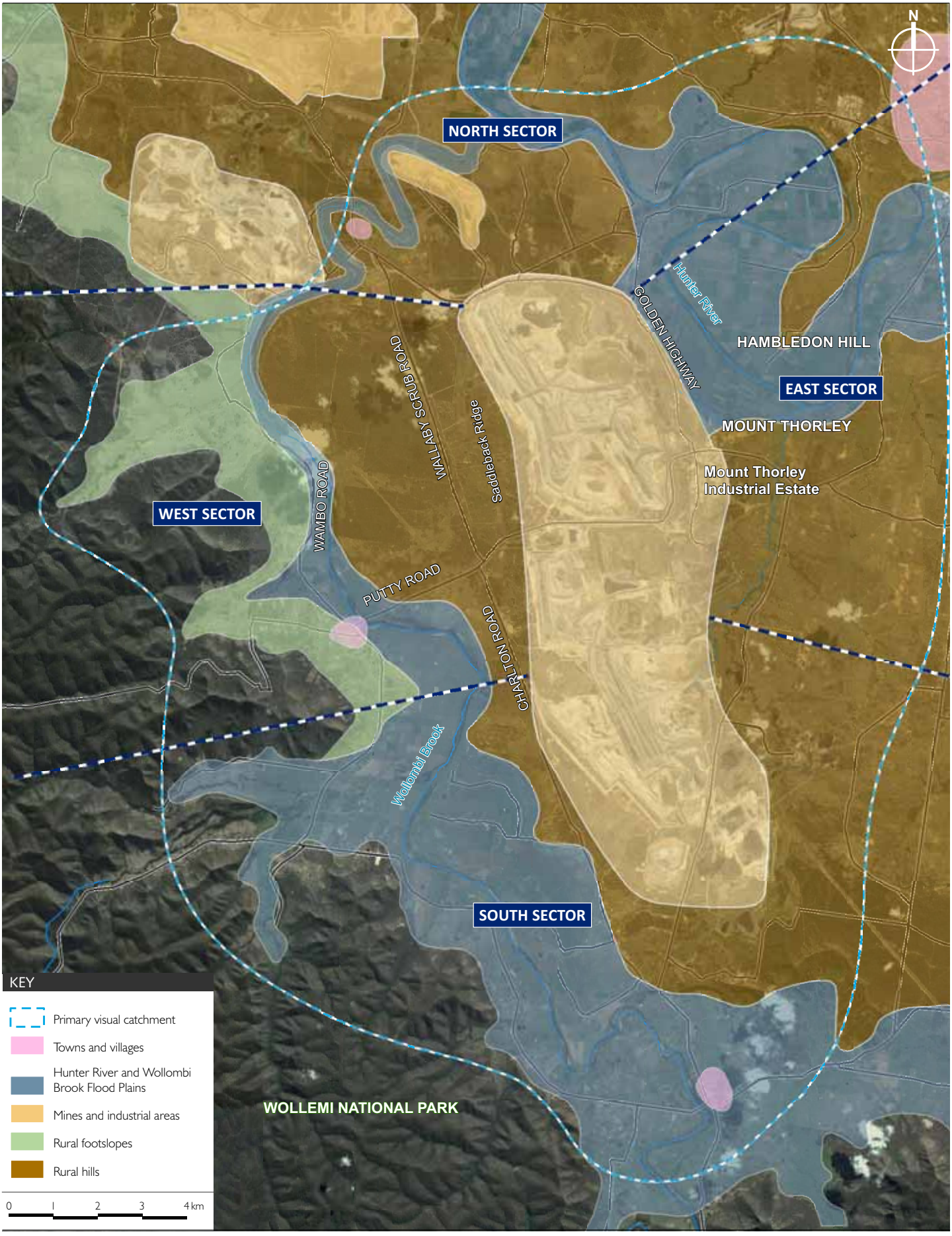
The ranges are generally located a significant distance from Mount Thorley Operations but often create the backdrop to the views. Ridges in the Wollemi National Park rise to over 500m and overlook Mount Thorley Operations and although the proposal would be visible from some locations, the bush would restrict most views. Typically these points are only accessible to bushwalkers or horse riders.



Figure 3.6 Surrounding Ranges (VIAS 2010)

Mine and Industrial areas

Warkworth, Mount Thorley and the Bulga Coal Complex are visually dominated by the overburden emplacements which are visible from various parts of the surrounding areas. The Warkworth CPP is also visible from locations to the north and east, particularly along the Golden Highway. The mines and the Mount Thorley Industrial Estate have a strong industrial character.



030995 VIA F3.1 Rev A 5 May 2014

COAL & ALLIED
Managed by Rio Tinto Coal Australia

Figure 3.7 Primary Visual Catchment and Visual Character Units (VIAS 2010)

This page has been intentionally left blank

4. The Proposal

4.1 INDICATIVE MINE PLANS

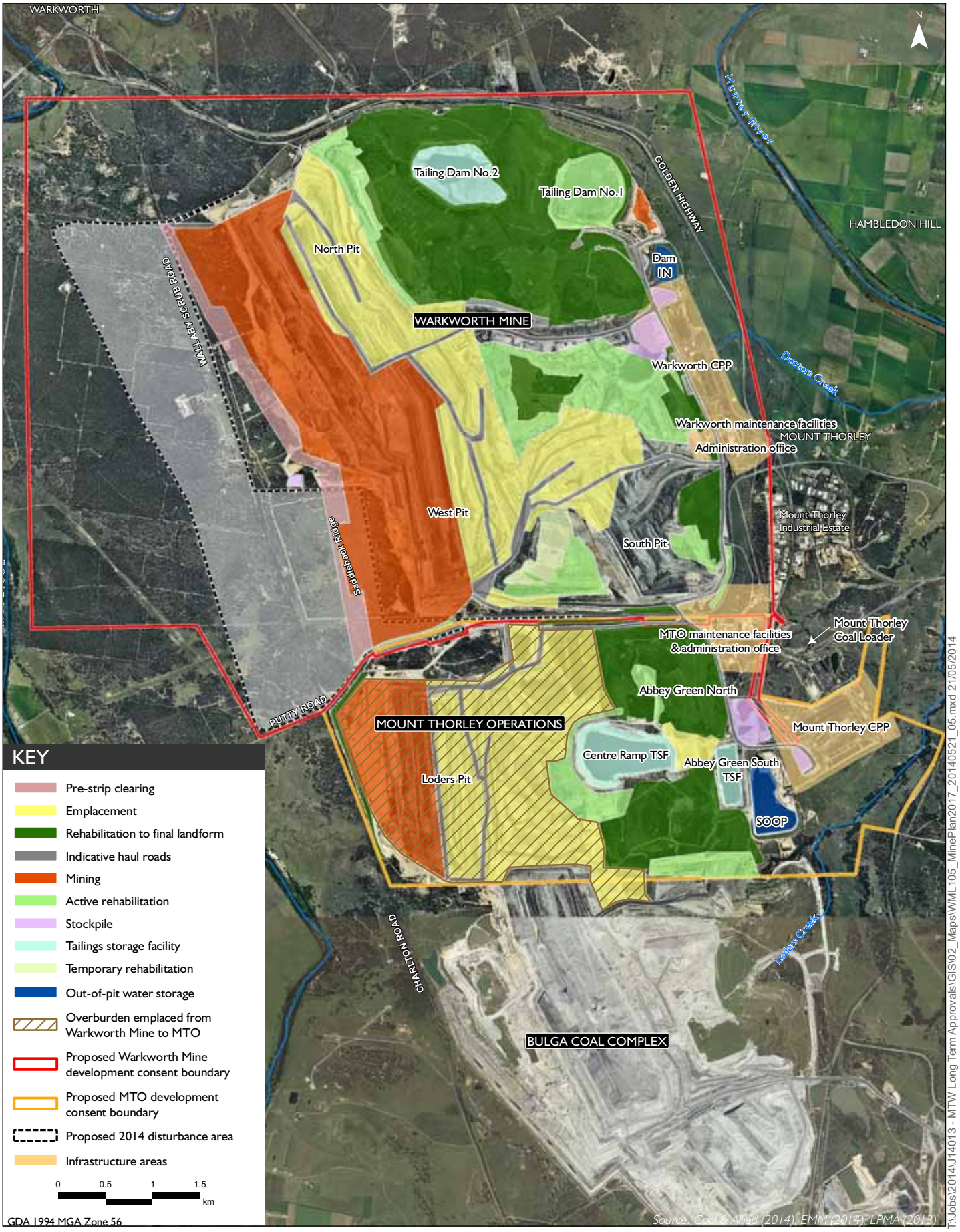
The proposed mining operations over the life of the proposal are indicatively shown for years three, nine and fourteen in Figures 4.1, 4.2 and 4.3, respectively. The year three, nine and fourteen mine plans were chosen as representative snapshots for the development consent.

The key visual features of the indicative year three plan are North pit progressing west, West pit reaching the top of Saddleback Ridge and the completion of South pit. The North pit overburden emplacement moves westward, emplacement at South pit north has begun, with some Warkworth Mine overburden being hauled to Mount Thorley Operations. Rehabilitation works continue at this stage including the completion of the CD emplacements eastern face and reshaping of the South pit dragline spoils. Construction of a visual bund is commenced along Putty Road to screen West pit as it progresses towards the west.

The indicative plan at year nine represents the point at which mining is predicted to have progressed through Saddleback Ridge. At this stage the mine's production will have peaked and be supported by an upgraded equipment fleet to remove the greater volumes of overburden. Mining in West pit will have crossed the location of the former Wallaby Scrub Road which is planned for closure in 2017. The North, West and South pit north overburden emplacement areas progress further west, with South pit north complete. Warkworth overburden continues haulage to Mount Thorley Operations. The visual bunding is continued along Putty Road to screen West pit as it progresses and the north and west pit emplacement areas are progressively rehabilitated with the advancement of completed landform from east to west.

This period represents the time of greatest change in visual impact for views from the west, due to the expanded views of the mine following the removal of Saddleback Ridge and the continuing advancement of the overburden emplacement towards the west. By year nine approximately 40% of rehabilitation at Warkworth Mine is planned to be complete. Following this time frame progressively larger areas of rehabilitation will incrementally reduce the overall level of contrast of the ongoing operations.

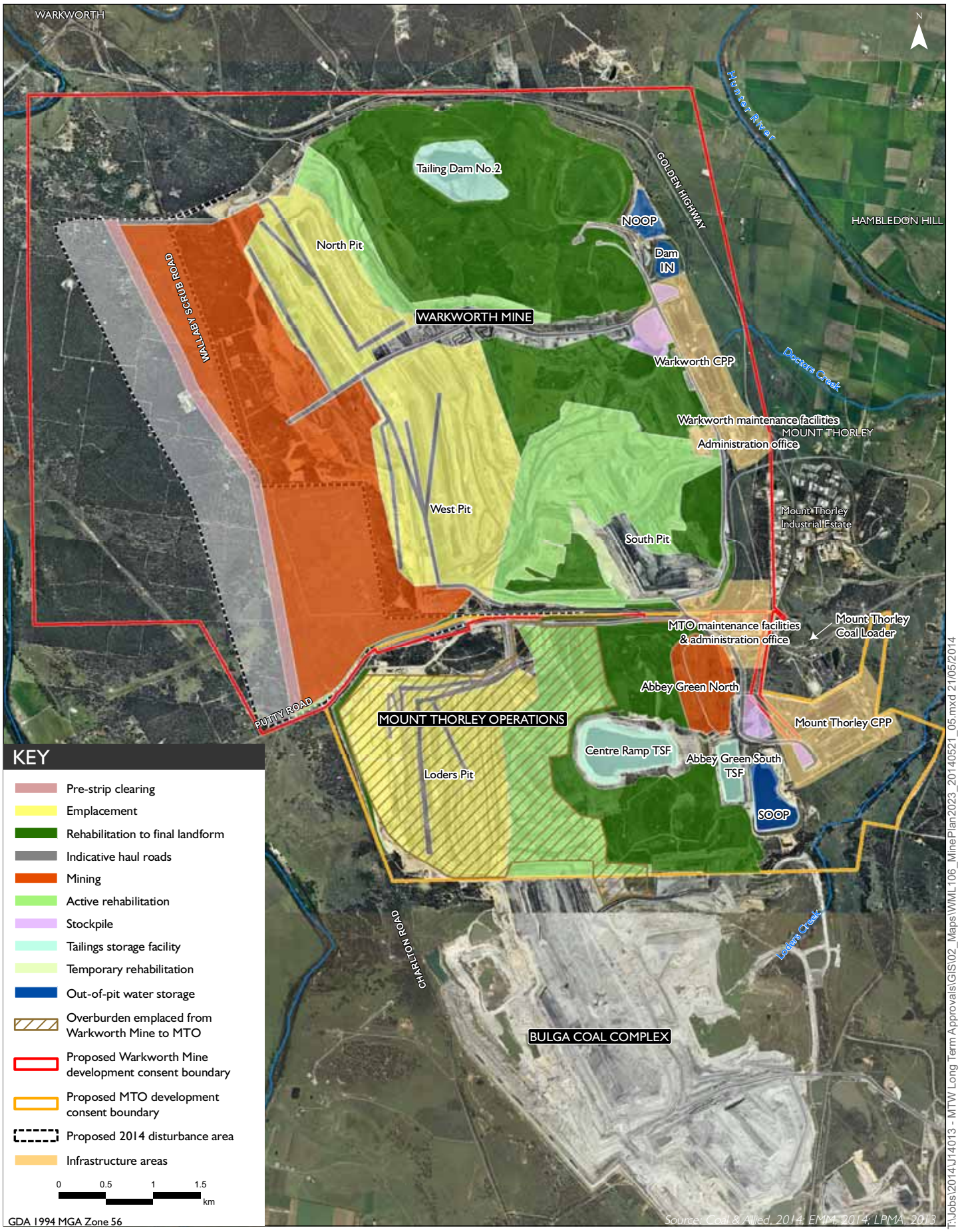
The indicative plan at year fourteen represents when mining reaches its western most extent. The North and West pit overburden emplacement areas will be approaching their western limit with emplacement to South Pit concluded. The visual bund along Putty Road reaches its final extent bending around the final highwall crest of West pit for 250 metres. North and West pit rehabilitation continues to advance towards the west.



COAL & ALLIED

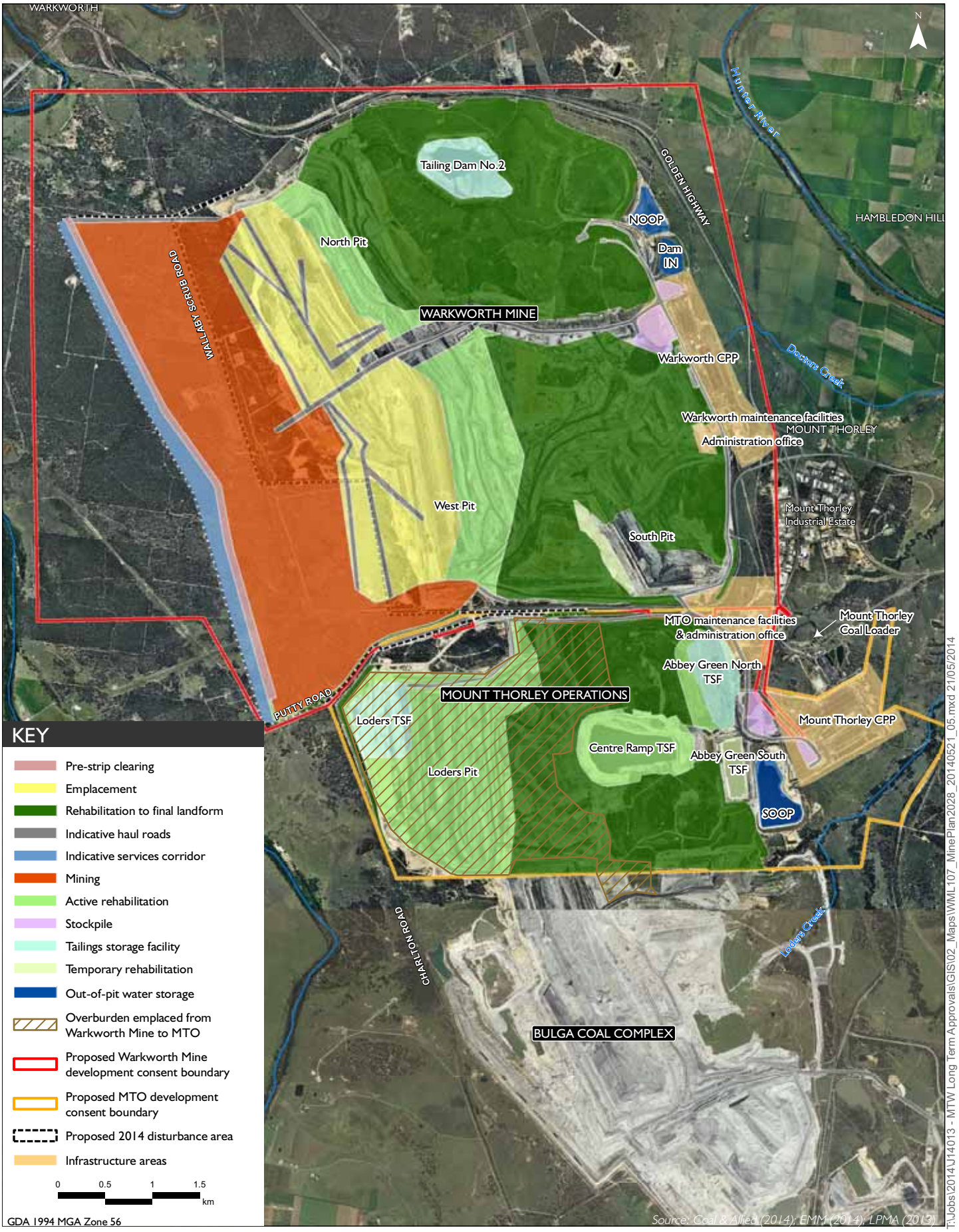
Managed by Rio Tinto Coal Australia

Figure 4.1 Indicative Year 3 Mine Plan



COAL & ALLIED

Figure 4.2 Indicative Year 9 Mine Plan



COAL & ALLIED

Figure 4.3 Indicative Year 14 Mine Plan

4.2 REHABILITATION

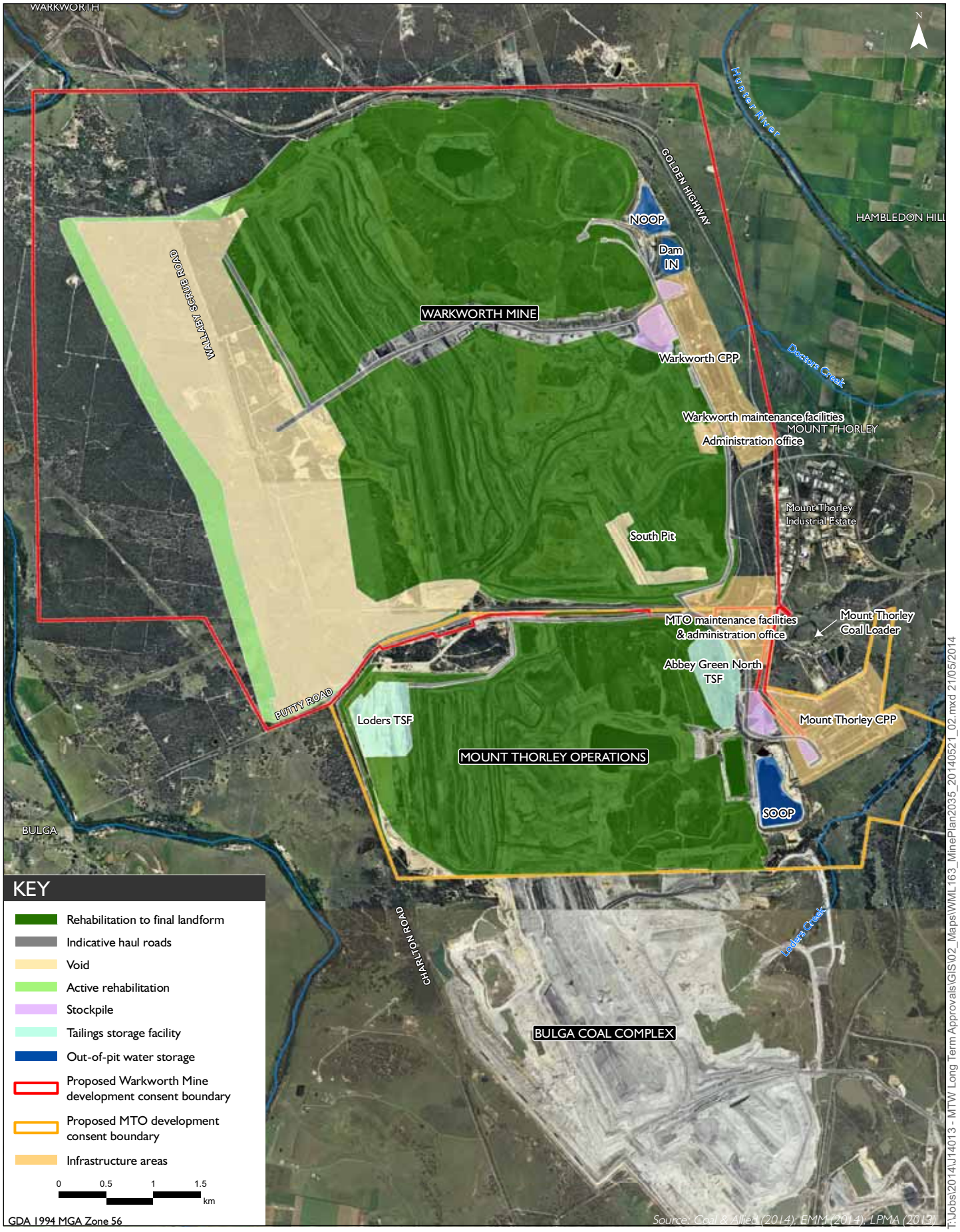
Rehabilitation will be undertaken progressively across the mined area in accordance with rehabilitation strategy presented in the MTW Mining Operations Plan (MOP). In general, the site will be rehabilitated with a mix of grassland and woodland.

4.3 FINAL LANDFORM AND LAND USE

Existing mining operations including overburden emplacement, final voids, tailings storage facilities, roads and infrastructure, have resulted in alterations to the local landform. The MOP outlines the proposed operational and environmental management of MTW, including the final landform and post mining land use vision. As described in the MOP the conceptual final landscape across Warkworth Mine is designed to provide native woodland, grassland, and agricultural land predominantly for cattle grazing consistent with the pre mining land uses.

The final landform will be designed to blend in with the surrounding topography, subject to operational constraints (see Figure 4.4). Slopes will be generally 10 degrees for overburden emplacement and up to 18 degrees for internally draining areas such as low walls and ramps.

A single final void in North and West Pits is planned to remain at the completion of mining with a predicted water level estimated at 8m AHD.



COAL & ALLIED

Figure 4.4 Indicative Final Landform

This page has been intentionally left blank

5. Visual Impact Assessment

5.1 POTENTIAL VISUAL EFFECTS

Visual effect is a measure of the level of contrast a development will have within its landscape setting. The visual effect of a mine changes through time with open pits and active overburden emplacements having high contrast and low visual integration, and creating high impacts at low levels of exposure. Later stage rehabilitated mined land however, represents low contrast and higher integration levels.

Mining operations typically have visual characteristics with a high contrast with the existing landscape in association with neighbouring mining operations. In this case the proposal will extend elements which are already present in the landscape. As a result the proposal will borrow visual character from the existing elements and will not contrast significantly.

The visual effects associated with the proposal considered below are all activities identified as having the potential to effect a change on visual amenity of the environment when compared to the current approved operations at Warkworth Mine. The main variations compared to the existing Warkworth Mine approvals will be the extension of the mining footprint by approximately 698 ha to the west of current operations and extension of the life of North and West pits by 14 years. The proposed extension of time will subsequently extend the period over which the visual effects of Warkworth Mine may be experienced by surrounding areas. The activities within the proposal which have potential visual effects are as follows:

- The progressive advancement of the open cut mining in North and West pits westwards to within approximately 2.6km from Wambo Road at Bulga Village;
- Mining advancing through the existing Saddleback Ridge, an elevated area which currently provides an element of visual screening of the Warkworth Mine operations from some western vantages;
- Continuation westward of the existing overburden emplacements area;
- Construction of new haul roads;
- Establishment of a third crossing of Putty Road between Warkworth Mine and Mount Thorley Operations including consideration of a underpass as proposed in this development as an alternative to the currently approved bridge; and
- Continued night lighting on overburden emplacement areas and on large mining equipment.

5.2 POTENTIAL VISUAL SENSITIVITY

Visual sensitivity is the measure of how critically a change to the existing landscape will be viewed by any particular land use within the PVC. The land uses and their sensitivity levels were defined in the VIAS and remain relevant to the proposal as illustrated in Figure 5.1.

The urban or rural residences within the PVC of the proposal are located within a range of up to 7.5km and, as such, the sensitivity of these residences where the mine is viewed will be high or high / moderate.

Figure 5.1
Visual Sensitivity (VIAS 2010)

Land Use	Visual Sensitivity Levels			
	Nearest visible mine elements less than 2.5km away	Nearest visible mine elements between 2.5km – 7.5km away	Nearest visible mine elements between 7.5km – 12.5km away	Nearest visible mine elements more than 12.5km away
Urban & Rural Dwellings	High Sensitivity	High / Moderate Sensitivity	Moderate Sensitivity	Low Sensitivity
Tourist destination of visually sensitive land uses e.g. horse studs, vineyards etc	High Sensitivity	High / Moderate Sensitivity	Moderate / Low Sensitivity	Low Sensitivity
Designated tourist roads & main roads (Golden Hwy and Putty Road)	High Sensitivity	Moderate Sensitivity	Low Sensitivity	Low Sensitivity
Other roads (Hambledon Hill, Charlton, Wallaby Scrub and Wambo Roads	Moderate Sensitivity	Low Sensitivity	Low Sensitivity	Low Sensitivity
Minor local roads in rural zone	Moderate / Low Sensitivity	Low Sensitivity	Low Sensitivity	Low Sensitivity
Broad acre rural lands	Low Sensitivity	Low Sensitivity	Very Low Sensitivity	Very Low Sensitivity

5.3 POTENTIAL VISUAL IMPACTS

The significance of the visual impact will be low / moderate for the majority of the PVC of the proposal site. The most significant impacts will be to residences in elevated locations in and around Bulga village.

The visual impact on individual residences may range from high to low, depending on the following additional factors:

> Screening effects of any intervening topography, building or vegetation – residences with well screened views will experience lower visual impacts than those with open views;
> The viewing distance from the residence to visible areas of the proposal – the further the distance the lower the visual impact experienced; and
> The general orientation of the residence to the proposal – residences with direct orientation will experience higher visual impacts than those with an oblique orientation.

The potential impacts identified in the North, East, South and West sectors, as shown in Figure 3.7, are described below.

5.3.1 NORTH SECTOR

From the north intervening topography and vegetation means there are no views from Warkworth village, the Golden Highway, or near or medium field locations in the rural foothills to the north of the Warkworth Mine. To the north east there would be views from some sections of the Hunter River flood plain and rural foothills which will be exposed to the overburden emplacement areas on the east of the mine during the initial period of the development. These views are a long distance away from places such as Long Point and Maison Dieu and have low visual effect and moderate to low sensitivity so would experience low additional visual impacts compared to the existing visual impacts experienced from the current mining operations.

The north eastern area includes residences along various rural roads and the Apex Lookout at Gowrie. In these areas even a moderate visual effect will result in a high to moderate impact until such effects are reduced by revegetation. Generally, however, the change in visual effect would be low given the exposure to the existing overburden emplacement areas. The visual sensitivity of these locations is potentially high, so if high to moderate effects are experienced, a temporary high impact would result until rehabilitation is completed. To ameliorate this Warkworth Mine will progressively rehabilitate the outer eastern slopes, in accordance with the MTW MOP.

5.3.2 EAST SECTOR

Views from the east are more direct, particularly towards the southern overburden emplacement area and currently include the expanding areas of revegetated final landform. The existing visual effects vary from high at closer assessment locations such as the Golden Highway and Putty Road which have open and immediate views of the overburden emplacement areas and the Warkworth CPP, to low for more distant locations. Given the moderate sensitivity and low level of change in the visual effects from the existing approved conditions the visual impacts of most of these roads will be low.

Similarly from the Golden Highway adjacent to the mine boundary the impact is determined as moderate to low due to the existing infrastructure and partly rehabilitated overburden emplacement areas. The expansion of revegetation as the final landfom is completed, will continue to decrease the impacts on views from the east. Localised mitigation could be considered to reduce the impact of newly disturbed areas although the elevated roadway and existing low topography are a significant constraint in this regard.

Residences to the east, in proximity to Warkworth Mine along Putty Road and the Golden Highway and on rural roads such as Hambledon Hill Road and Idano Road, have views to the eastern face of the active Warkworth Mine overburden emplacement areas. Whilst the sensitivity of these residences is potentially moderate to high, and the visual effect would vary depending on any changes to the extent of exposed overburden at any given time, it should be noted the final landform and rehabilitation of this overburden emplacement area is currently being established. Localised mitigation could reduce these impacts.

5.3.3 SOUTH SECTOR

From the south the mine is mainly concealed by elevated land, trees, Mount Thorley Operations and the Bulga Coal Complex. A small extent of exposed viewpoints exists in the south western sector, the elevated land of Mount Leonard screening Warkworth Mine from much of the area. Views from this area would mostly see the western face of Mount Thorley Operations and Bulga Coal Complex rather than Warkworth Mine. Some parts of the overburden emplacement areas could be seen where they become raised above the existing approved levels and would have moderate visual effects despite the distance at which they are seen (3 – 5km). The visual sensitivity is high and views in this area could experience high to moderate visual impacts. The overburden emplacement areas will be progressively rehabilitated and the impacts of the proposal will reduce to moderate and low as this takes place.

Putty Road forms the southern boundary to the operations and the visual effects would be moderate to high. Due to its proximity, it has a high sensitivity and high to moderate visual impact as mining extends west beyond the existing approved limits. The exposed areas during the construction of a proposed bund along the northern boundary to Putty Road would itself have a moderate impact prior to its revegetation; however, the impacts would significantly reduce once vegetation cover is established. The proposed underpass beneath Putty Road would have a low visual impact in comparison to the currently approved bridge.

5.3.4 WEST SECTOR

The proposal involves progressing mining further westwards and for viewing locations in this direction exposed to the active areas of the mine the visual effects have the potential to be high. The existing screening provided by Saddleback Ridge will be removed as this is mined through near the middle of the project life.

The removal of Saddleback Ridge and extended mine will remain concealed to a varying extent by the intervening vegetation and topography, particularly in lower lying areas where the view is mostly of trees along Wollombi Brook. The extent of mine views will be dependent on the position of the viewing location. Views from some south westerly view points along Putty Road as well as from some parts of Bulga village will exist above and through the existing foreground trees however the visual effects would be low and as such even where the sensitivity is high the visual impacts would be low / moderate.

The overburden emplacement of the proposal is largely screened from Wambo Road as it is at a lower elevation and benefits from screening by trees along Wollombi Brook. This area is not considered likely to experience any significant change in visual impact.

Changes to the view for road users from Putty Road to the south of Bulga village and along Inlet Road where overburden emplacements of the proposal would be exposed once Saddleback Ridge is removed would be more significant. Initially the colour and form contrasts would cause moderate visual effects, which would reduce to low, as rehabilitation is progressed. These roads would have moderate to low sensitivity at this distance and moderate to low visual impacts.

All residential properties in this area will have a high level of sensitivity and properties in elevated locations throughout Bulga may experience high visual impacts depending on the orientation of the property and intervening screening provided by vegetation. Site Specific Visual Assessments (SSVA) would be undertaken where requested by the landowner and potential site specific mitigation measures determined through this process. See Section 6 for further discussion of proposed mitigation measures.

Viewshed analysis from Bulga Village for the indicative year years three, nine and fourteen mine plans and final landform are shown in Figures 5.2 to 5.5. Following these the photomontages presented in the 2010 VIAS are presented depicting the visual effects from viewpoints in and around Bulga (Figures 5.6 - 5.10). These montages remain representative of the effects of the proposal.

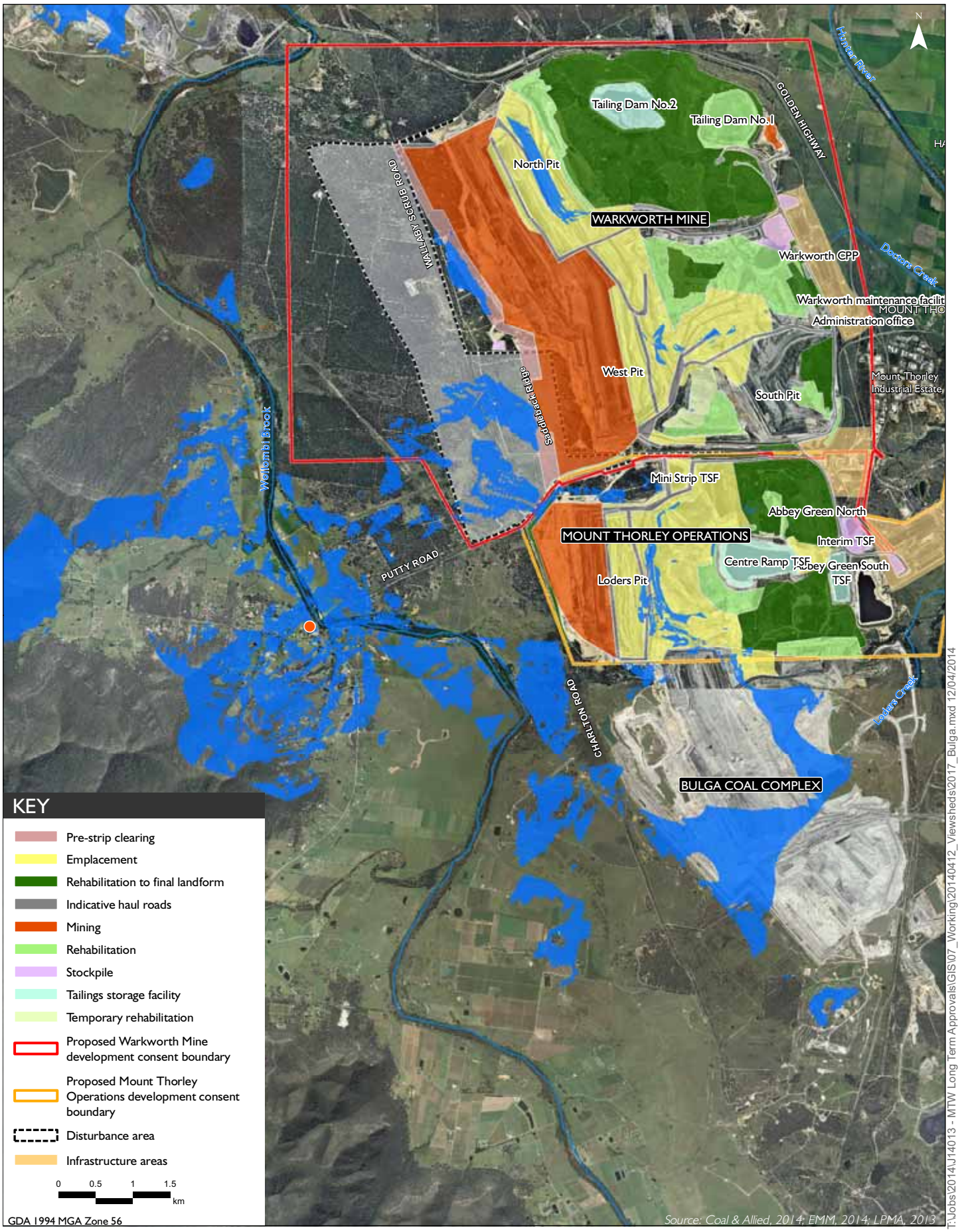


Figure 5.2 Viewshed Analysis Bulga Village (Indicative Year 3 Mine Plan)

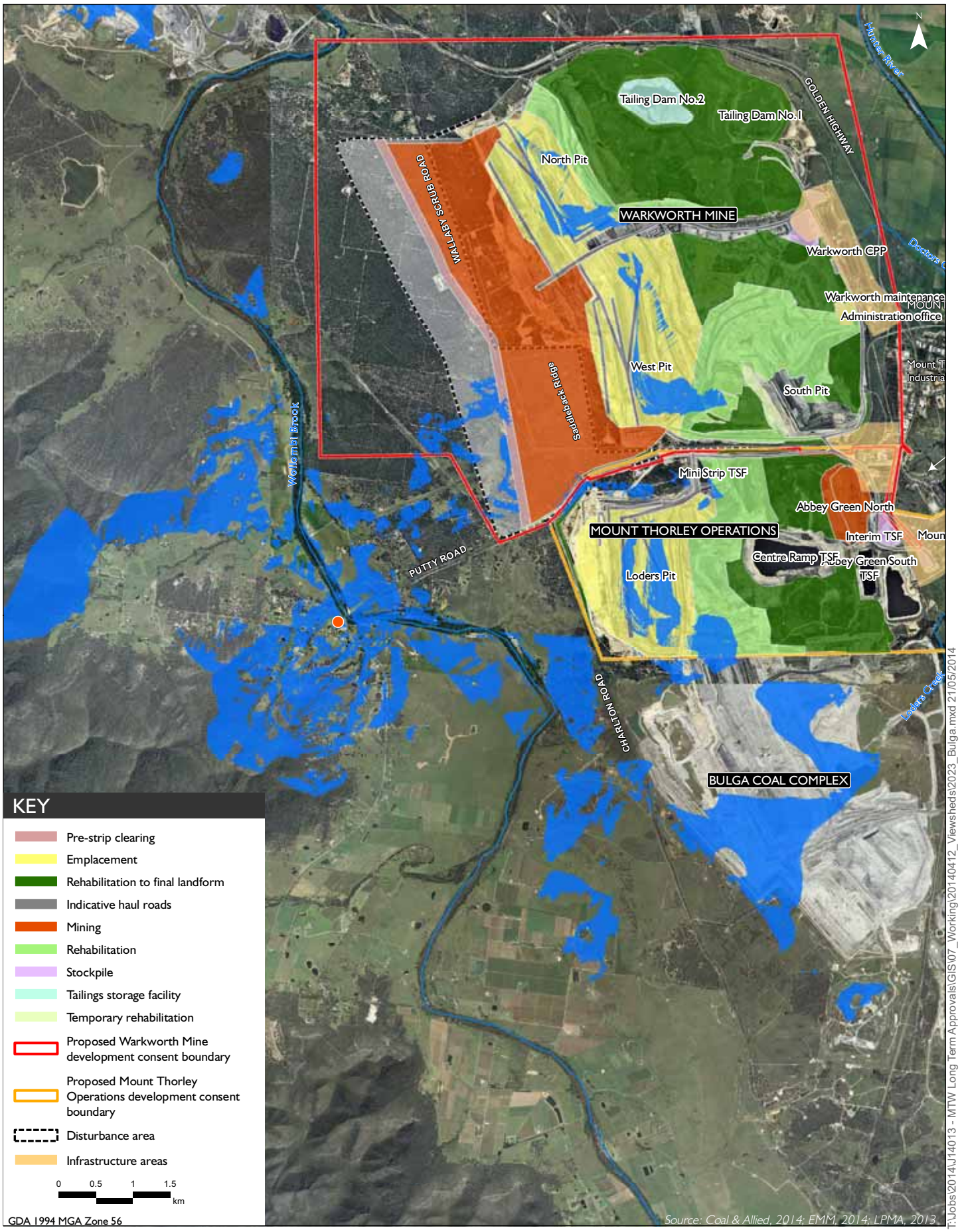


Figure 5.3 Viewshed Analysis Bulga Village (Indicative Year 9 Mine Plan)

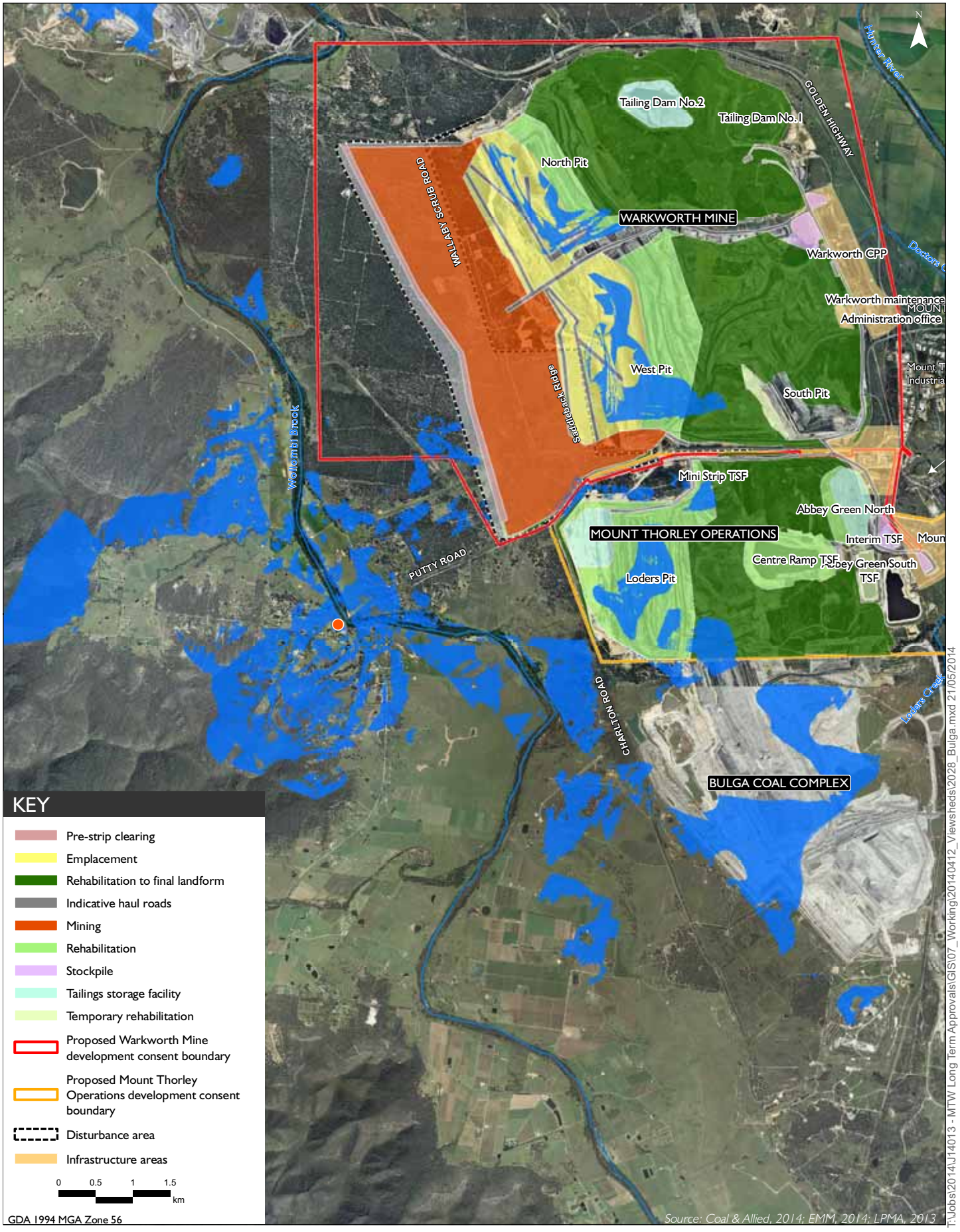


Figure 5.4 Viewshed Analysis Bulga Village (Indicative Year 14 Mine Plan)

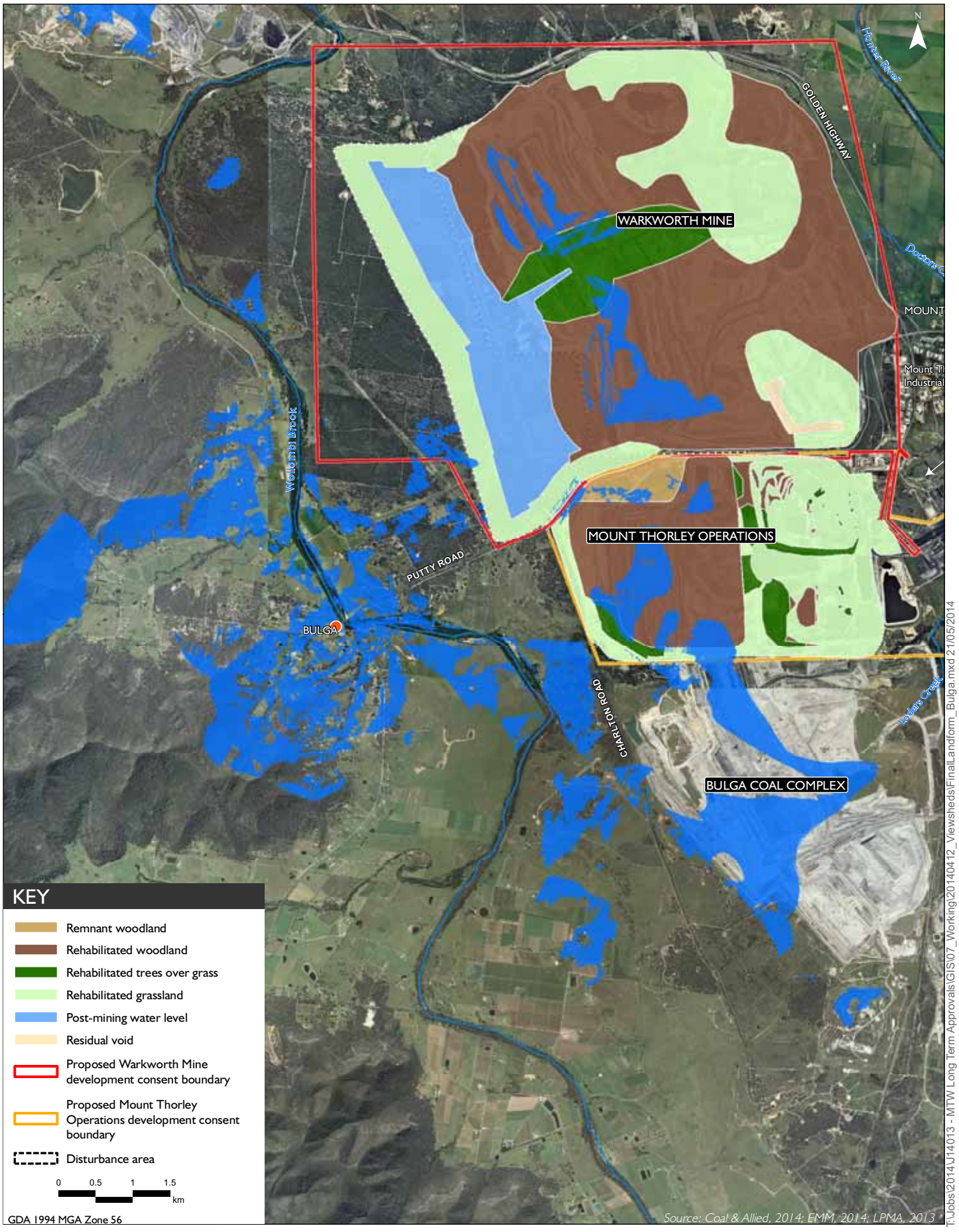


Figure 5.5 Viewshed Analysis Bulga Village (Indicative Final Landform)



Figure 5.6 Putty Road North Photo Montages (VIAS 2010)



Figure 5.7 Putty Road South Photo Montages (VIAS 2010)



Figure 5.8 Bulga Hotel Photo Montages (VIAS 2010)



Figure 5.9 Turnbull Inlet Road Photo Montages (VIAS 2010)



Figure 5.10 Wambo Road Photo Montages (VIAS 2010)

6. Management and Mitigation

6.1 OBJECTIVES

The key elements of mitigation employed will be the utilisation and management of existing native vegetation together with additional plantings and earthworks to achieve suitable visual screening.

The mitigation objectives include:

> Develop mitigation strategies to ameliorate adverse visual impacts;
> Provide details on the establishment of vegetation and bund screening for the purpose of maintaining satisfactory visual amenity; and
> Develop site specific mitigation strategies to ameliorate significant direct views from individual residences.

6.2 PROPOSED MITIGATION MEASURES

Potential visual impacts of the proposal will generally be moderate to low, as the impact on visual amenity will be limited and localised. The existing topography and vegetation will continue to provide screening to the mine to varying extents depending on view location and elevation. Some residences west of the proposal site may have potential to experience high impacts during the proposal's operation prior to the completion of rehabilitation i.e. during active mining.

A number of mitigation measures are currently in place for the approved operations at Warkworth Mine, these include:

> structure design to minimise visual impacts, consistent with engineering principles and practice, and any site constraints;
> direction of lighting away from offsite areas to the greatest degree possible, and the use of sensor lighting where permanent lighting unnecessary; and
> construction of small bunds, vegetated and built screens at appropriate locations along the Site boundary.

The additional strategies proposed to mitigate off-site visual impacts are detailed below.

> Examine in detail any high sensitivity viewing points and determine the opportunity for relevant screening treatments including site boundary treatments or mitigation measures to individual residences.
> Minimise the amount of pre-rehabilitation areas that are exposed to view by establishing grass cover to remove colour contrast; and
> Establish planting patterns of trees and grasses in rehabilitation areas to create a high level of visual integration with the surrounding landscape.

In order to determine the appropriate screening treatments for any high sensitivity viewing point a SSVA will be undertaken. In the case of individual residences, the landowner of an effected property may request a SSVA, which may result in mitigation measures at the affected property or between the property and the source. A conceptual process for implementing SSVAs is documented in the Draft VIMP.

Constraints currently exist to the implementation of any mitigation measures on public land and, therefore, such measures have not been proposed. In addition mitigation on private land is expected to be more effective for the visual impacts identified. Should the existing constraints be overcome and specific works be identified to mitigate high impacts measures on public land may be considered in the future.

The Draft VIMP will be developed and will detail the management of the visual mitigation measures for Warkworth Mine. The following represents the elements of the VIMP as they will apply to the proposal.

6.3 ON-SITE MITIGATION MEASURES

Specific controls that will be adopted on-site to manage the visual impacts of the existing operations, as well as the proposal, are detailed below.

6.3.1 STRUCTURES

Whilst no new buildings are proposed, if any are required, they will be designed to minimise the visual impacts on the surrounding environment, consistent with engineering principles and practice and any site constraints. Any design of buildings and infrastructure will include consideration of:

- The location, form and height of buildings and structures;
- The use of nonreflective and textured building materials to avoid glare;
- The use of colours that will complement the surrounding environment. Muted greens or beige will be favoured, except where bright colours are necessary for safety purposes;
- Where practical, the design and construction of trafficable haul roads shall be such that they occur below or above the natural surface level; and
- Infrastructure will be maintained in good order.

In general buildings will be constructed of a steel frame with metal roofs and wall cladding which would typically be Colorbond or a similar approved equivalent. As illustrated in Figure 6.1



Figure 6.1
Typical Structures and Equipment

6.3.2 MANAGEMENT OF OFF-SITE LIGHTING IMPACTS

Under the proposal, Warkworth Mine will continue to operate 24 hours a day. Lighting can impact properties either directly or through reflection off a low cloud base. The potential light sources include lighting plants, lights on mine infrastructure and the use of lights on vehicles. The Warkworth Mine aims to provide enough light to safely undertake its operations whilst minimising visual disturbance to residences and public roads.

The impact of off-site lighting is minimised by directing lights away from off-site areas to the greatest degree possible, directing lights down onto work areas, using sensor lights where permanent lighting is unnecessary. Regular checks will be undertaken to observe the effects of lighting on public roads and neighbouring properties. Equipment lighting is fitted with shields where practical and is checked and adjusted to minimise the effects on adjacent areas.

Significant portions of Warkworth Mine are concealed by existing vegetation and bunds that provide screening from lighting effects at night and provide visual screening during the day. The areas where this screening is less effective include those areas where vegetation screening filters views alone and when activities are being undertaken on areas which are higher than the surroundings, such as on elevated overburden emplacement areas.

6.3.3 SITE AND BOUNDARY AREAS

Site boundary mitigation measures provide reasonable and feasible measures to minimise potential visual impacts of the Warkworth Mine from the public domain and roads around the site.

The visual impacts of Warkworth Mine will be controlled in most cases through landscape designed to integrate with the rehabilitation strategy outlined in the MTW MOP. Typically this will involve constructed bunds, vegetation screens, or built screens as appropriate to the location. In some cases effective screening may not be reasonable or feasible.

In most areas around the Warkworth Mine boundary there is some level of existing bunding or vegetation and as such additional screening will be achieved through infill planting in areas where gaps allow views of Warkworth Mine rather than new broad scale vegetation screens. The first preference for visual mitigation will be to retain existing vegetation where possible. Where necessary the existing vegetation will be augmented with additional planting to enhance the screening effects.

Bunding at the view source has many positive visual effects including its immediate screening effect, complete screening in narrow depth areas where vegetation would be inadequate to filter views and screening of vehicles and access roads. Bunding is typically utilised in areas where views require a more prompt mitigation or where a combination of bunding and vegetation is determined to provide more appropriate visual mitigation.

Where physical or operational constraints preclude the use of vegetation or bunding on-site, structures will be considered as an alternate means to screen views from sensitive assessment locations. A number of constraints exist within the areas directly adjacent to Warkworth Mine's boundaries including power line easements and Roads and Maritime Services (RMS) owned road reserves in which the opportunities for mitigation measures are limited. Movable built screens may offer a practical mitigation in these areas.

Bunding may be removed when visual impacts associated with the location have lessened following rehabilitation or other removal of the impact source. This allows progressive landscape normalisation ahead of closure rather than having a period of significant activity in the period prior to and across closure.

Areas likely to require mitigation measures to be implemented include, but are not limited to, Putty Road, which is specifically addressed below.

6.3.4 PUTTY ROAD

Impacts will occur to the views along Putty Road as a result of the existing approvals and the proposal, in particular where it passes between Warkworth Mine and Mount Thorley Operations. These views currently vary from direct to filtered and fully screened. The extension of North Pit towards the west will result in increased visual impacts in this area. In general the area available for additional screening is limited. As such, the form of any screening will be determined as part of the detailed mine planning process. A vegetated visual bund is, however, proposed to stretch the length of the pit and return by 250m along the western boundary to provide extensive screening in this area.

Plantings will be undertaken to enhance the existing established vegetation which will be retained where possible. In particular, understory shrub plantings will be introduced to provide low level screening for passing motorists. Fast growing screen species will be selected, using endemic species in line with the principles of MTW's MOP.

A drag line crossing and associated loop road allows public access along Putty Road when the dragline is moved. This access presents direct views into the Warkworth Mine. At this crossing a variety of measures will be considered to mitigate views when the loop road is not in use.

An option for a second bridge crossing between Warkworth Mine and Mount Thorley Operations exists under current approvals. An alternative to provide a tunnel under Putty Road is a component of this application. The bridge itself, however, will have an obvious visual impact, whereas the alternative tunnel would avoid the need for ramp embankments and would have minimal or no visibility from Putty Road.

Views exist into South Pit from Putty Road and as further works are to be undertaken in this area additional screening will be provided if necessary. An existing area of screen planting exists along the boundary with Putty Road which will be augmented with understory shrub species as views through the trunks of the maturing trees are now opening up. A vegetated bund is also proposed to screen views into South Pit between the haul road and the public road at the intersection of Putty Road and the Golden Highway. Generally the area available for screening is limited and as such the form of additional screening required will be determined as part of the detailed mine planning process.

6.3.5 PLANTING FOR VEGETATION SCREENING

Visual screen plantings will include trees and shrubs of varying heights and be of sufficient width to provide sustainable and good visual screening. It is proposed that, in new screen planting areas with sufficient width, trees be planted a minimum of four rows deep (where practical), with approximately five metres between the rows with rows offset to provide improved screening from all view angles. Trees and understory planting will be tubestock with shrubs infilling between trees every metre with an additional row of shrubs between each row of trees as shown in Figures 6.2 and 6.3. A mix of shrubs will alternate with taller trees to ensure that the screening is achieved rapidly. The arrangement of native plants will be random, and unevenly distributed to create a natural character.

Where screen planting is augmenting existing vegetation to infill open areas, the same principle will be followed. However, planting will be added to create this matrix in areas where the existing vegetation is sparse. The number of rows of trees will be suitable for the area to be in filled. A typical example of this matrix is illustrated in Figure 6.4.

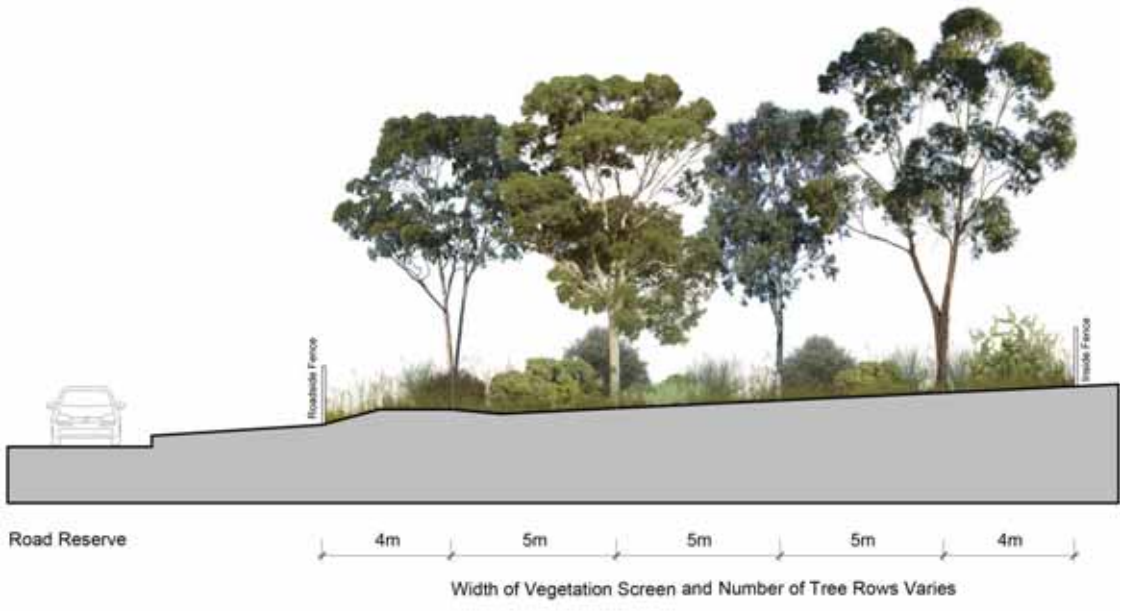
An indicative species list of locally endemic species is provided in the Draft VIMP. Whilst preference will be given to species which are locally endemic, it is recognised that endemic species may not be commercially available in the numbers required to undertake the visual landscape screening. In this case, other appropriate native species which have performed well in the local area will be used.

6.3.6 PLANTING FOR BUND SCREENING

Visual bunds will require a program of planting to achieve a good level of vegetation cover. This program will aim for an initial cover crop followed by seeding of native grass / shrub and tree species. If the base soil conditions are suitable these phases may be undertaken as a single process.

For areas of high sensitivity augmentation plantings with advanced stock may also be undertaken. Large shrubs and small trees will be planted on the lower areas of the bund to screen at low levels with tall trees planted to the top of the bund to maximise its screening height. A typical screening bund is illustrated in Figure 6.5.

Figure 6.2
Typical Vegetation Screen Section



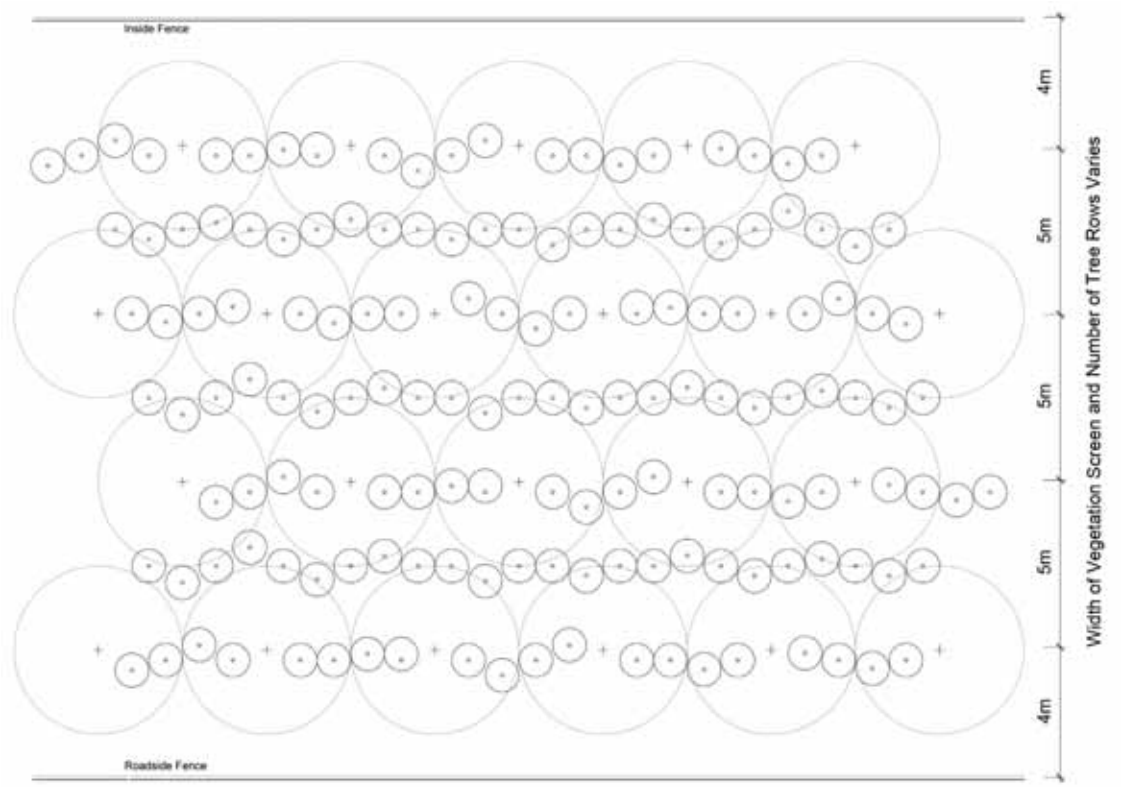


Figure 6.3
Typical Planting Matrix – New Screen Planting

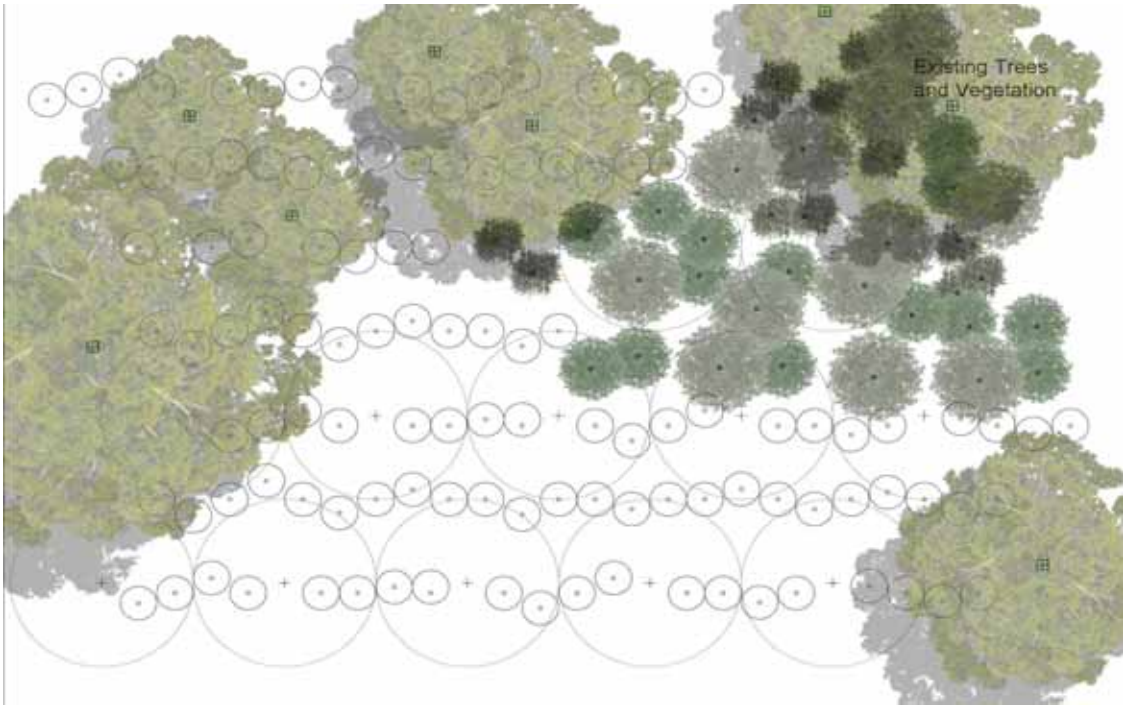
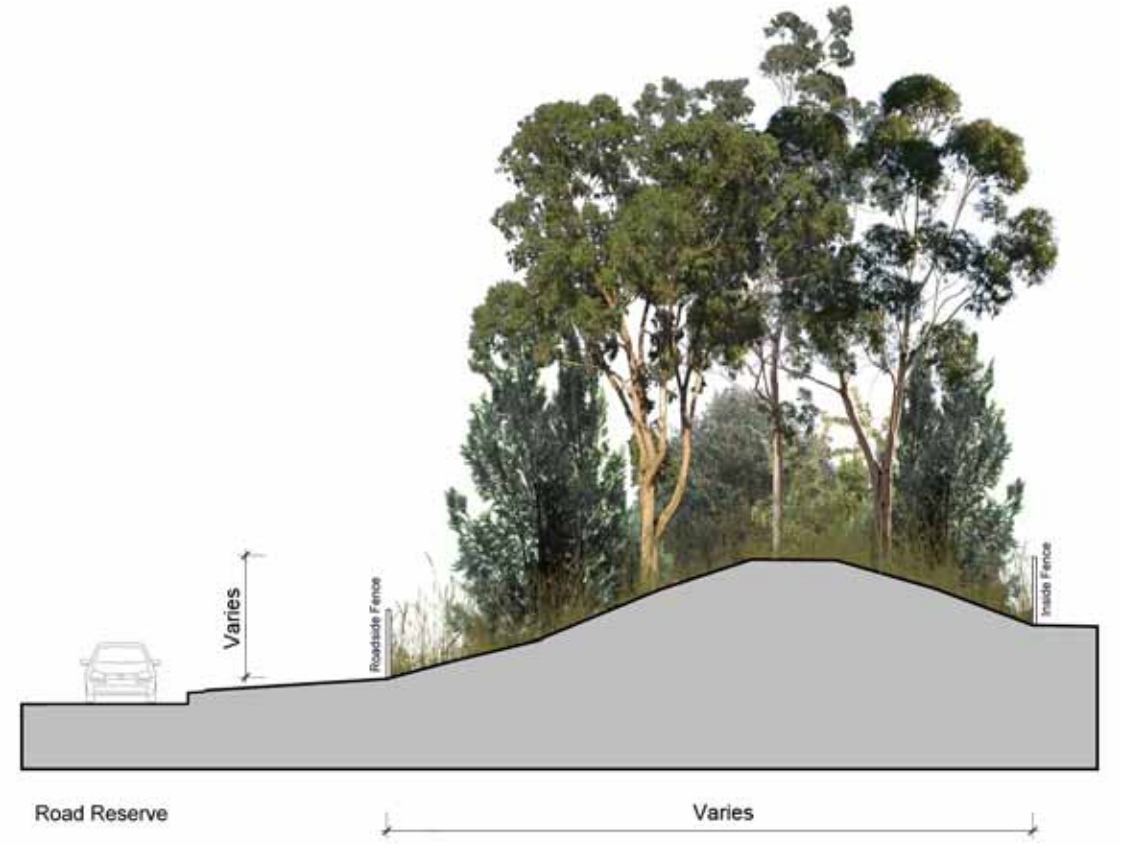


Figure 6.4
Typical Planting Matrix – Infill Screen Planting

Figure 6.5
Typical Bund Screen Section



6.3.7 LANDSCAPE PROCEDURES

The general planting procedures will be as described below, though these may change based on experience and site suitability.

- Where practical and available, topsoil will be translocated from mine advance areas with minimal stockpiling to utilise the native seed bank;
- The method of seeding will be in accordance with site practice and may include aerial seeding, direct seeding, hand broadcasting, brush-matting or hydromulching; and
- Best practice establishment procedures will be used as appropriate to planting sites including but not limited to consideration of: provenance and quality of seed and/or tubestock; ground preparation, planting practices, protection of plantings, and initial and ongoing maintenance.

6.4 OFF-SITE MITIGATION MEASURES

6.4.1 SCOPE

The mitigation measures described in this section apply to existing residences on existing residential allotments.

Visual mitigation of future subdivisions for the purpose of residential allotments are expected to be the responsibility of the developer or thereafter the resident.

6.4.2 SITE SPECIFIC VISUAL ASSESSMENT

Some individual residences within the PVC are likely to have significant direct views of Warkworth Mine with a high visual impact at some stage during the operations.

Due to existing vegetation within the properties and the surrounding areas many of the residences within areas with potentially high visual impacts may not experience this level of impact. As the extent of existing screening is specific to each residence due to its elevation, orientation and layout, it is not possible to determine with any certainty the extent of impact on any individual residence without undertaking a SSVA. Where requested for properties in Bulga village, Coal & Allied will undertake a SSVA to determine the level of significance of the visual impact and the potential suitable mitigation measures to reduce the impact on the view. A conceptual methodology for this assessment and the process through which mitigation measures will be agreed with the land owner is outlined in the Draft VIMP.

Where possible within the permissions of effected landholders vegetation screening will be implemented as early as practicable during the development so as to allow a period for establishment of an effective screen prior to impact occurrence.

6.4.3 VISUAL MITIGATION TREATMENTS

Vegetation screening may be implemented to screen views related to the proposal from significantly impacted residences. Vegetation screening has various screening capacity depending on the significance of the impact. Coal & Allied will be guided by the recommended extent of mitigation based on the SSVA and any associated discussions and agreement with property owners. No work will occur without the owner's consent.

The design including species selection will be undertaken in consultation with the property owner. Designs will be in keeping with the character and design of the residence. All designs will be agreed and signed-off by the landowner prior to implementation.

Plant species will be selected for their suitability for the local area as well as their aesthetic properties. An indicative species list is provided in the Draft VIMP.

Landscape maintenance of planting undertaken on private land will be the responsibility of the landowner from the time of installation, although Coal & Allied will undertake fair and reasonable maintenance replanting of failed stock during the initial screen establishment period of approximately 12 months.



Figure 6.7
Example of Filtered Screen Planting



Figure 6.8
Example of Dense Screen Planting

The photomontages presented in Figures 6.9 through 6.14 illustrate the typical outcomes which can be expected from the proposed mitigation.

Figures 6.9 and 6.12 are photographs of the existing views taken from residences on Inlet Road in the Bulga area. Figures 6.10 and 6.13 illustrate the impacts without mitigation measures based on the indicative year nine view and 6.11 and 6.14 illustrate the views with mitigation measures in place.

Example Site 1 is located at 95 Inlet Road and Figure 6.11 illustrates filtered screen planting using tree and shrub species in keeping with the properties garden planting.



Figure 6.9
Site 1: Photograph of Existing View



Figure 6.10
Site 1: Photomontage Prior to Mitigation Measures (Indicative Year 9)



Figure 6.11
Site 1: Photomontage Post Mitigation Measures

Example Site 2 is located at 29 Inlet Road and Figure 6.14 illustrates dense screen planting. Given the current boundary planting on the property the mitigation planting would include augmenting the existing shrub beds with tree and shrub species in keeping with those already used.

Figure 6.12
Site 2: Photograph of Existing View





Figure 6.13
Site 2: Photomontage Prior to Mitigation Measures (Indicative Year 9)



Figure 6.14
Site 2: Photomontage Post Mitigation Measures

This page has been intentionally left blank

7. Conclusion

The proposal would generate a range of visual effects that are in keeping with those that would typically be expected from the development of an open cut coal mine. The other existing mining activities in the area including Warkworth Mine, Hunter Valley Operations and Bulga Coal Complex have already created a change in the pre mining visual landscape. The proposal will generate an incremental change to this existing condition and a moderate to low level of change in comparison to the current approved operations, reducing the level of visual impact it generates.

The visual impacts under the proposal would for the most part be moderate to low; however, some sensitive assessment locations may experience higher impacts. The eastern viewing areas would be exposed to the overburden emplacement areas however this would have been the case regardless of the proposal. The rehabilitation of this aspect of the development will progress extensively in the early years of the operations and the period over which the impacts could be experienced will be minimised.

The highest impacts occur from the west, in particular, from residential properties in the area around Bulga Village. These impacts are due largely to the removal of Saddleback Ridge and the increased height of the emplacement areas at Warkworth Mine. Impacts are partially limited by the intervening vegetation and topography; however, properties on elevated slopes are likely to require site specific mitigation measures.

The proposed mitigation measures aim to reduce potential visual impacts on the public domain through vegetation and bund screening along the site boundaries. In addition to these, specific foreground treatment measures at individual assessment locations determined to have significant impacts will also be implemented.

The progressive rehabilitation of Warkworth Mine will reduce visual impacts over time with the revegetated final landform having a high level of integration into the natural rural landscape of the surrounding area.

This page has been intentionally left blank

REFERENCES

1. Integral Landscape Architecture and Visual, 2010, Proposed Warkworth Extension Visual Impact Assessment Study. Report prepared for Coal & Allied.

2. Draft Integrated Design Solutions, Warkworth Extension Visual Impact Management Plan, Version 2, 26 September 2012.

3. NSW Land & Environment Court judgement, Bulga Milbrodale Progress Association Inc v Minister for Planning and Infrastructure and Warkworth Mining Limited [2013] NSWLEC 48, 15/04/2013.

4. Coal & Allied Operations Pty Ltd, Mount Thorley Warkworth Mining Operations Plan, Amendment A (Warkworth Modification 6 to DA 300-09-2002), 30 January 2014.

INTEGRATED
DESIGN SOLUTIONS

INTEGRATED DESIGN SOLUTIONS PTY LTD
T +61 (0)2 9437 3600
Ground floor, Suite 2, 30 Alfred Street, Milsons Point
New South Wales, 2061

Copyright © 2014 Integrated Design Solutions Pty Ltd,
all rights reserved. The text, images, graphics and their
arrangement shown in this publication are subject to copyright
and other intellectual property protection. These objects may
not be copied for commercial use, transmitted or distributed
and may not be modified in any form.

www.integrateddesignsolutions.com.au

Appendix K

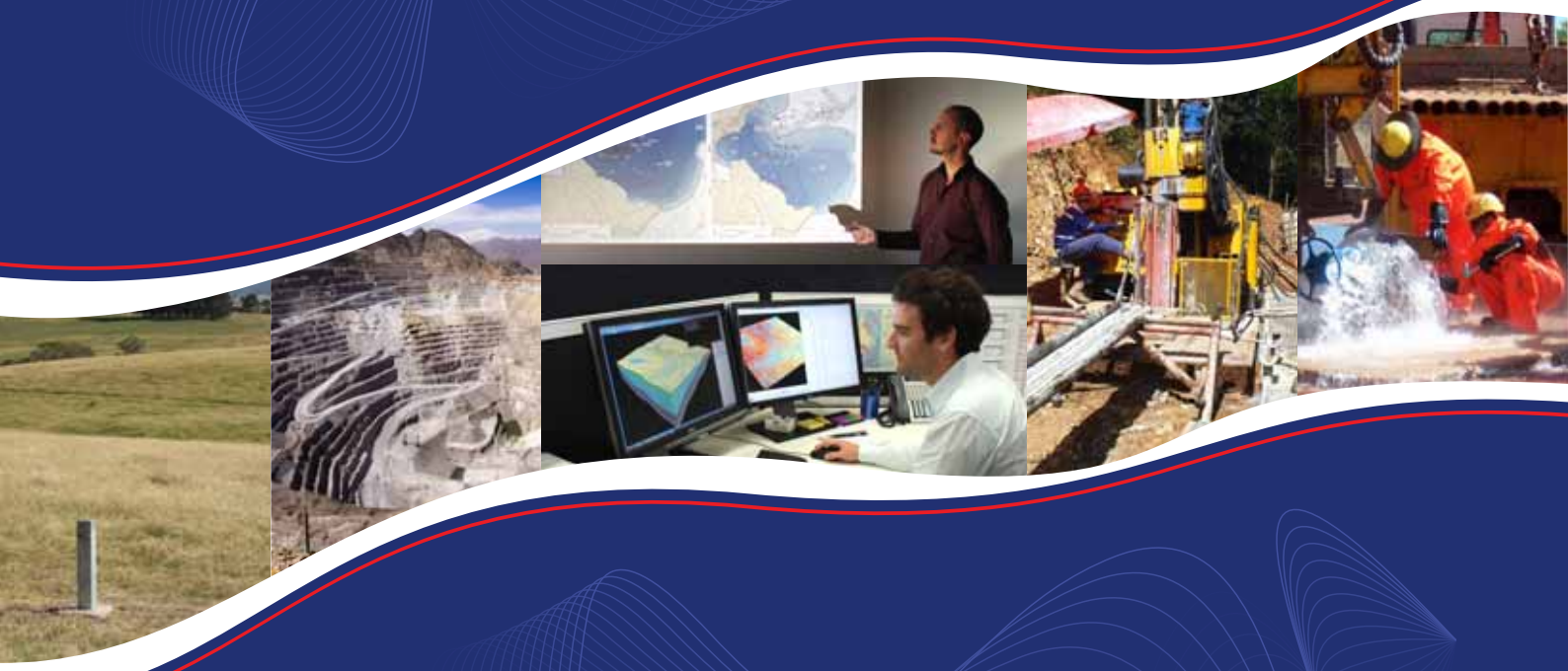
Groundwater study



Appendix K — Groundwater study

K

Australasian
Groundwater
and Environmental
Consultants Pty Ltd
(AGE)



Report on

WARKWORTH CONTINUATION 2014 GROUNDWATER ASSESSMENT

Prepared for

EMGA Mitchell McLennan

Project No. G1468F May 2014

www.ageconsultants.com.au ABN 64 080 238 642

Document History

Document Details:

Project number:	G1468/F
Document title:	Warkworth Continuation 2014 – Groundwater Assessment
Site address:	Putty Road, Mount Thorley, NSW, 2330
File name:	G1468F MTW Long Term Approvals

Document Status and Review:

Edition	Author	Authorised by	Date
1 - Draft	D. McAlister & P. Dvoracek	J. Tomlin	14 March 2014
2 - Draft	D. McAlister & P. Dvoracek	J. Tomlin	24 March 2014
3 - Draft	D. McAlister & P. Dvoracek	J. Tomlin	4 April 2014
4 - Draft	D. McAlister & P. Dvoracek	J. Tomlin	21 May 2014
5 - Final	D. McAlister & P. Dvoracek	J. Tomlin	30 May 2014

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE)

This document is and remains the property of AGE, and may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

Head Office
Level 2 / 15 Mallon Street,
Bowen Hills, QLD 4006, Australia
T. +61 7 3257 2055
F. +61 7 3257 2088
brisbane@ageconsultants.com.au

Newcastle Office
Harbour Pier, Shop 8, 21 Merewether Street,
Newcastle, NSW 2300, Australia
T. +61 2 4926 2811
F. +61 2 4926 2611
newcastle@ageconsultants.com.au

TABLE OF CONTENTS

Page No.

1 INTRODUCTION 1
1.1 Project Description 1
2 OBJECTIVES AND SCOPE OF WORK 6
3 SURROUNDING MINES AND CURRENTLY APPROVED MTW OPERATIONS 7
4 CLIMATE AND SURFACE WATER 10
4.1 Climate 10
4.2 Surface Water 11
5 HYDROGEOLOGICAL REGIME 13
5.1 Groundwater Occurrence 13
5.2 Groundwater Monitoring 17
5.3 Groundwater Levels 17
5.4 Groundwater Gradients 22
5.5 Strata Permeability and Storage 22
5.6 Recharge 24
5.7 Discharge 24
5.7.1 Discharge Processes 24
5.7.2 Baseflow 24
5.8 Water Quality 25
5.9 Groundwater Users 26
5.10 Groundwater Dependent Ecosystems 27
6 POLICY AND LICENSING REQUIREMENTS 30
6.1 Water Act 1912 30
6.2 Water Management Act 2000 30
6.2.1 Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 30
6.3 Aquifer Interference Policy 31
7 MODELLING APPROACH 32
7.1 Numerical Model Development 33
7.2 Numerical Model Calibration 33
7.2.1 Steady State Starting Heads 34
7.2.2 Transient Calibration 36
8 IMPACT ASSESSMENT 42
8.1 Results of the Predictive Model Run 42
8.1.1 Groundwater Levels and Drawdown 42
8.1.2 Impacts on Groundwater Users 48
8.1.3 Impact on Alluvium 49
8.1.4 Impact on Stream Baseflow 50
8.1.5 Impact on Groundwater Dependent Ecosystems 51

8.1.6 Pit inflows *54*
8.1.7 Water Quality and Leachate Migration *55*
8.1.8 Water Licensing *55*
8.1.9 Post Mining Recovery *56*
8.2 Uncertainty Analysis **60**
8.2.1 Background *60*
8.2.2 Results *61*
9 COMPLIANCE **64**
9.1 Accounting for, or Preventing the Take of Water **64**
9.2 Determining Water Predictions in Accordance with AIP (Section 3.2.3) **66**
9.3 Other Requirements to be Reported in Accordance with AIP (Section 3.2.3) **66**
10 MITIGATION AND MONITORING **67**
10.1 Review of Current Monitoring Programme **67**
10.2 Proposed Amendments to Monitoring Programme **67**
10.3 Mine Water Seepage Monitoring **68**
10.4 Trigger Values **68**
10.5 Data Management and Reporting **68**
10.6 Future Model Iterations **68**
10.7 Make Good Agreements **68**
11 CONCLUSION **69**
12 REFERENCES **71**

List of Tables

Table 3.1:SUMMARY OF MINING OPERATIONS 8
Table 4.1: CLIMATE AVERAGES JERRYS PLAINS (STATION 061086) and MTW 10
Table 5.1: FALLING HEAD TEST RESULTS 23
Table 5.2: AGE (2010) LANDHOLDER SURVEY FINDINGS 27
Table 8.1: IMPACTS OF THE MINING ACTIVITIES ON GROUNDWATER USERS 48
Table 9.1: ACCOUNTING FOR OR PREVENTING THE TAKE OF WATER 64
Table 9.2: DETERMINING WATER PREDICTIONS 66
Table 9.3: OTHER REQUIREMENTS 66

List of Figures

Figure 1.1: Indicative Year 3 mine plan....3
Figure 1.2: Indicative Year 9 mine plan....4
Figure 1.3: Indicative Year 14 mine plan....5
Figure 3.1: Local Context....9
Figure 4.1: Cumulative Rainfall Departure – Jerrys Plains....10
Figure 4.2: Wollombi Brook stream levels and climatic conditions....11
Figure 5.1: Geology and monitoring bores....14
Figure 5.2: Stratigraphic column....15
Figure 5.3: West to East Geological Section – Warkworth mine area....16
Figure 5.4: Air photograph and monitoring bores....18
Figure 5.5: Groundwater contours and levels....19
Figure 5.6: Groundwater Levels within the Permian directly north of Warkworth Spoil and TSFs..20
Figure 5.7: Groundwater level within the Permian strata west of Warkworth high-wall....21
Figure 5.8: Change of hydraulic conductivity with depth in coal seams....23
Figure 5.9: Baseflow Assessment for Wollombi Brook....25
Figure 5.10: Schoeller plot of typical alluvium or seam chemistry....26
Figure 5.11: Groundwater Users and GDEs....29
Figure 7.1: Steady state scatter diagram....34
Figure 7.2: Steady state heads start of transient calibration – Layer 1 and Layer 13....35
Figure 7.3: Transient scatter plot of modeller versus observed heads....37
Figure 7.4: Representative transient modelled versus observed hydrographs....39
Figure 7.5: 2013 Heads in Layer 1 and Layer 13 at the end of the calibration run....40
Figure 7.6: Transient model calibration – distribution of residuals....41
Figure 8.1: Modelled heads and drawdowns at the end of model run (2035) – alluvium/regolith (L01)....44
Figure 8.2: Modelled heads and drawdowns at the end of model run (2035) – Woodlands Hill seam (L09)....45
Figure 8.3: Modelled heads and drawdowns at the end of model run (2035) – Mt. Arthur seam (L13)....46
Figure 8.4: Cross-section through the proposal area – geology and groundwater table.....47
Figure 8.5: Additional take from Wollombi Brook and Hunter River alluvium due to the proposal..50
Figure 8.6: Net Change in baseflow....51
Figure 8.7: GDEs and predicted drawdown in the water table (Layer 1)....53
Figure 8.8: Pit inflows to Warkworth Mine....54
Figure 8.9: Spoil recharge rates from TSF versus rainfall infiltration....55
Figure 8.10: Predicted inflows to Warkworth final void (m^3/day)....57
Figure 8.11: Groundwater levels surrounding the post mining void....58
Figure 8.12: Cross-section through proposal area showing long term post closure....59
Figure 8.13: Recovery in net flows to Wollombi Alluvium....60
Figure 8.14: 95th percentile 2m drawdown extent – Layer 1 and Layer 9....62

Appendices

Appendix A: Monitoring Bore Summary Table
Appendix B: Historic Water Quality Data (1993 – 2013)
Appendix C: Numerical Model – Development & Calibration
Appendix D: Numerical Model – Uncertainty Analysis
Appendix E: External Review Report

REPORT ON

WARKWORTH CONTINUATION 2014 GROUNDWATER ASSESSMENT

1 INTRODUCTION

Warkworth Mine is an open cut coal mine approximately 8 kilometres (km) south-west of Singleton in the Hunter Valley, NSW. The mine is operated by Coal & Allied on behalf of Warkworth Mining Limited (WML). The site currently operates under Development Consent No. DA 300-9-2002-i (the development consent) issued by the then Minister for Planning in May 2003 under Part 4 of the NSW *Environmental Planning and Assessment Act* 1979 (EP&A Act). The site also operates under two separate Commonwealth approvals (*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)): EPBC 2002/629 and EPBC 2009/5081.

Warkworth Mine has been in operation since 1981 and the originally approved operation has been modified several times. Immediately to the south of Warkworth Mine is Mount Thorley Operations (MTO). Since 2004, the two mines have integrated at an operational level and are known as Mount Thorley Warkworth (MTW), with a single management team responsible for all the operations. Equipment, personnel, water, rejects and coal preparation are all shared between the mines. The operations involve an existing workforce of approximately 1,300 persons, which includes full-time personnel and a small number of short-term contractors. Ownership of the two mines remains separate.

Warkworth Mine currently operates three integrated open cut mining areas, namely North, West and South pits with West and North pits being the focus of production. Run-of-mine (ROM) coal from Warkworth Mine is transported to either the Warkworth or Mount Thorley coal preparation plant (CPP) for processing. Product coal from the CPPs is transported via conveyor to either the Mount Thorley Coal Loader (MTCL) or to the Redbank Power Station. Coal loaded onto trains at the MTCL is transported to the Port of Newcastle for export.

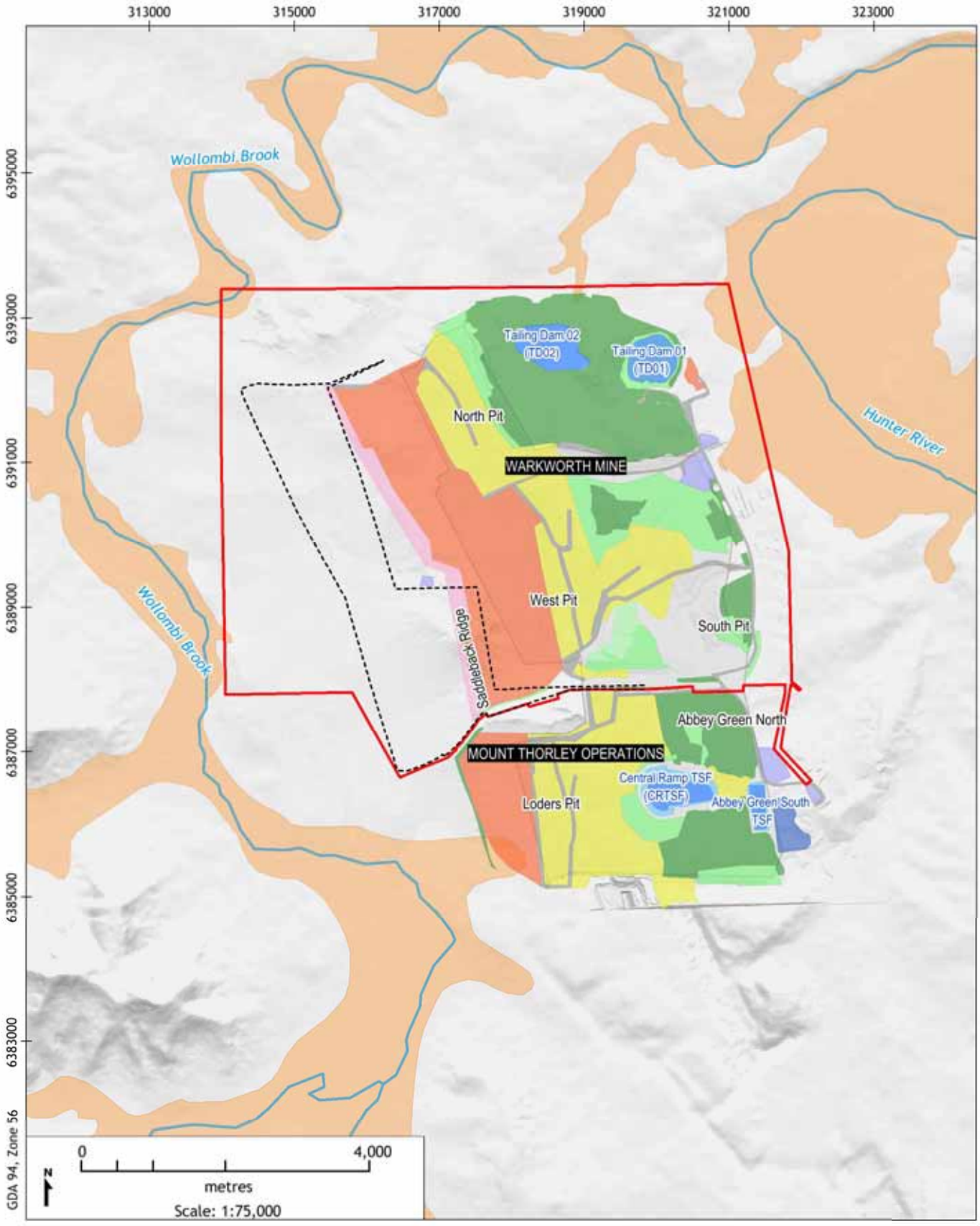
The Warkworth Continuation 2014 (the proposal) seeks an approval under Part 4, Division 4.1 of the EP&A Act to extend mining beyond the current limits.

1.1 Project Description

Warkworth Mine has approval to operate until 19 May 2021 under its development consent. The proposal seeks a 21 year development consent period from the date of any approval. If approval is granted in late 2014, operations at Warkworth Mine are forecast to continue to 2035, a 14 year extension over the current approval. The proposal seeks a continuation of all aspects of Warkworth Mine as it presently operates together with:

- an extension of the approved mining footprint by approximately 698ha to the west of current operations (referred to herein as the proposed 2014 extension area);
- the ability to transfer overburden to MTO to complete MTO's final landform;
- the closure of Wallaby Scrub Road;
- an option to develop an underpass beneath Putty Road for the third bridge crossing yet to be constructed (while retaining the current approval for an overpass);
- minor changes to the design of the Northern out-of-pit (NOOP) dam; and
- the continued use of secondary access gates to the mine site and offsets for activities such as drilling, offset management, equipment shutdown pad access amongst other things.

The proposal is shown in Figure 1.1 to Figure 1.3.



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Watercourse
- Quaternary alluvium (100k)
- Disturbance area

Indicative 2017 mine plan

- Pre-strip clearing
- Mining
- Emplacement
- Stockpile
- Indicative haul roads
- Rehabilitation to final landform
- Rehabilitation
- Temporary rehabilitation
- Out-of-pit water storage
- Tailings storage facility

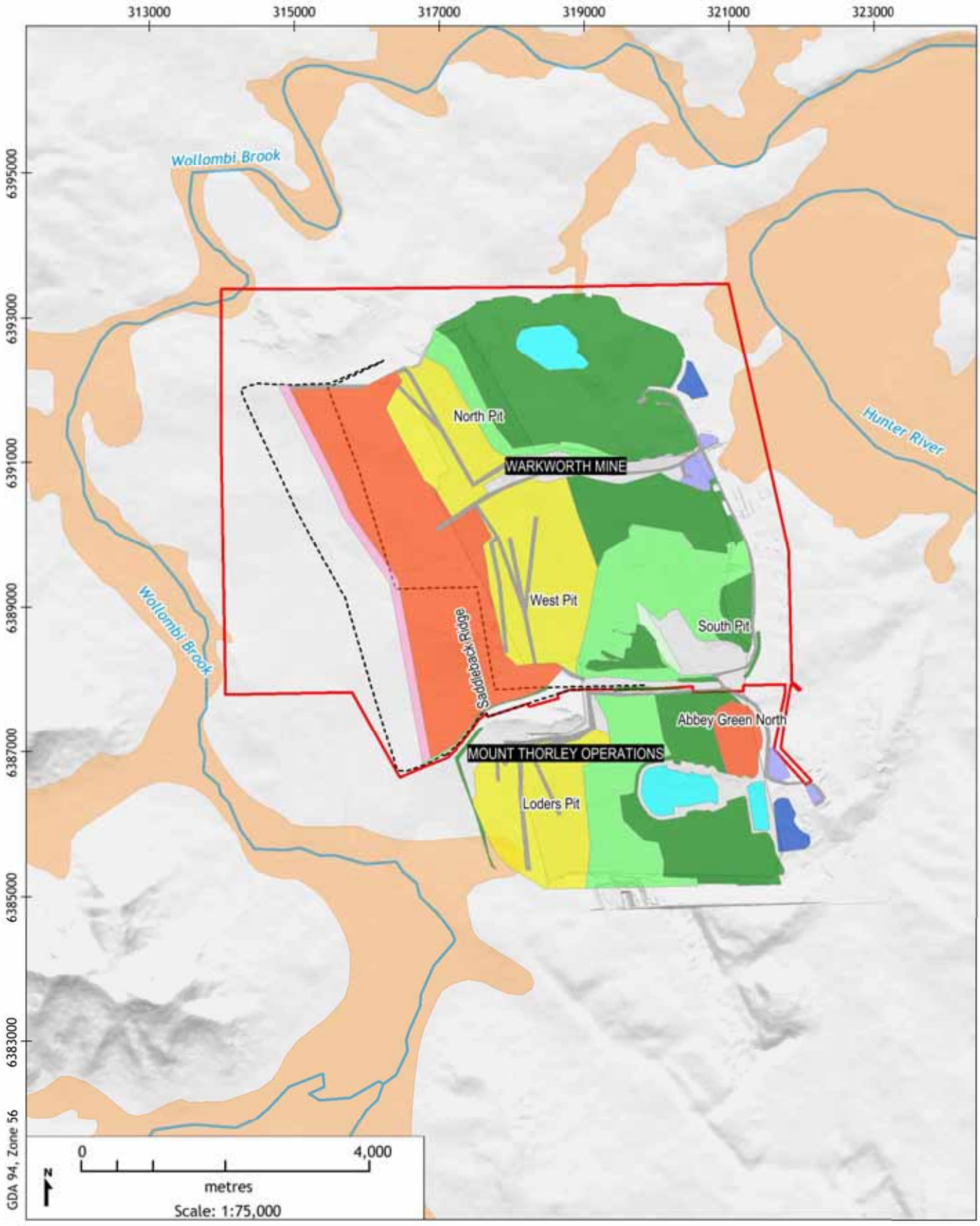
Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Indicative Year 3 Mine Plan

DATE: 14/5/2014

FIGURE No: 1.1

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Watercourse
- Quaternary alluvium (100k)
- Disturbance area

Indicative 2023 mine plan

- Pre-strip clearing
- Mining
- Emplacement
- Stockpile
- Indicative haul roads
- Rehabilitation to final landform
- Rehabilitation
- Temporary rehabilitation
- Out-of-pit water storage
- Tailings storage facility

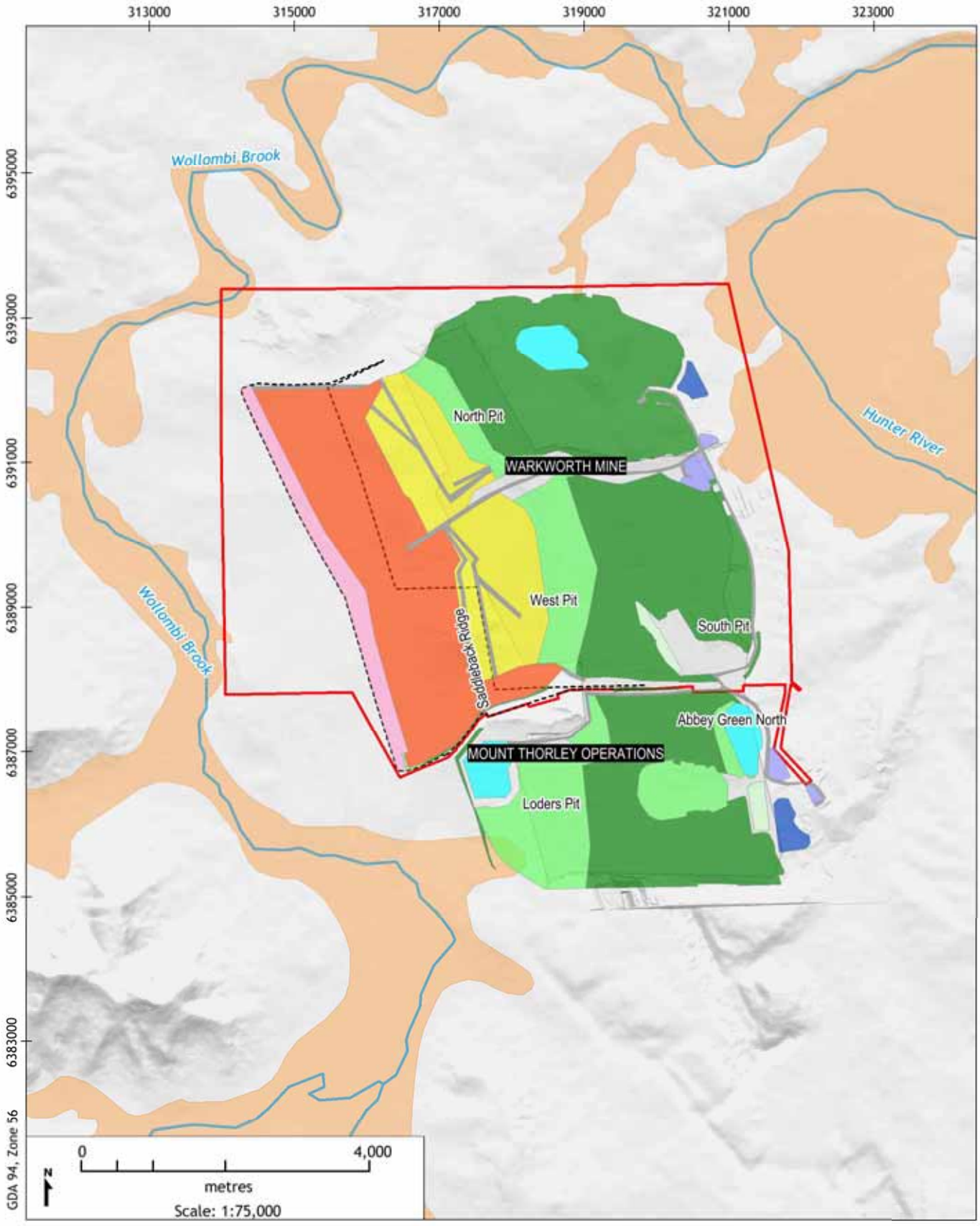
Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Indicative Year 9 Mine Plan

DATE: 14/5/2014

FIGURE No: 1.2

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Watercourse
- Quaternary alluvium (100k)
- Disturbance area

Indicative 2028 mine plan

- Pre-strip clearing
- Mining
- Emplacement
- Stockpile
- Indicative haul roads
- Rehabilitation to final landform
- Rehabilitation
- Temporary rehabilitation
- Out-of-pit water storage
- Tailings storage facility

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Indicative Year 14 Mine Plan

DATE: 14/5/2014

FIGURE No: 1.3

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

2 OBJECTIVES AND SCOPE OF WORK

The objective of the groundwater study was to assess the impact of the proposal on the groundwater regime and also to comply with the requirements of the NSW and Federal governments that include:

- the NSW aquifer interference policy (AIP);
- Water licensing requirements under the *Water Act 1912; and*
- *Water Management Act 2000 including the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources.*

The legislative requirements are discussed further in Section 6. Requirements under the EPBC Act are not necessary for this proposal, as they have already been met for the existing MTW mine plan.

The scope of work to address requirements included:

- describing the existing environment;
- simulating the existing hydrogeological regime with a numerical groundwater model; and
- assessing the impact of the proposal on the groundwater environment, using the model including:
    - Groundwater take due to mine inflow from the Permian Coal Measures (*Water Act 1912);*
    - Groundwater take from the Wollombi Brook and Hunter River alluvial aquifers (*Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources);*
    - Changes to groundwater levels and salinity in private landholder bores (AIP); and
    - Changes of more than 1% increase in groundwater salinity (AIP); and
- develop measures to mitigate and monitor potential impacts.

3 SURROUNDING MINES AND CURRENTLY APPROVED MTW OPERATIONS

The groundwater regime in the study area is influenced by historical and current mining operations at Warkworth Mine and other surrounding mines. The latter comprise MTO adjoining to the south, Wambo to the west, South Lemington in the north (and north-west) and Bulga in the south. Figure 3.1 shows the locality of the mining operations in the vicinity of Warkworth Mine.

Because the groundwater regime has already been disturbed this report assesses the existing cumulative impacts from the historical and approved mining activities and the net impact of the proposal.

Mining at MTW commenced in the early 1980s with mining progressing west (down-dip) from sub-cropping coal seams of the Jerrys Plains Sub-Group. Most Warkworth sub-pits have been mined down to the Mt Arthur Seam with the exception of the North Pit that has been mined down to the shallower Warkworth Seam. The MTO sub-pits are mined to the shallower Woodlands Hill Seam. Mining at Warkworth is approved to continue until 2021, and at MTO until 2017.

Directly south of MTO is the Bulga Coal Complex, which comprises open cut and underground mines. Open cut mining commenced west of Broke Road in the early 1990s extending to the Whybrow Seam, and to the deeper Woodlands Hill Seam since 1999. The Saxonvale Colliery was developed south of Broke Road in the early 1980s with mining targeting the Vaux Seam in the 1990s. Long-wall mining of the Whybrow and Blakefield Seams under the open cut pits was approved to commence from 2010.

The former South Lemington Mine, which is part of Hunter Valley Operations (HVO) South, is located to the north of Warkworth Mine. South Lemington Underground was a bord-and-pillar operation that mined the Bowfield Seam and ceased operating in the early 1990s. The underground footprint underlies Wollombi Brook. The South Lemington Open Pit is currently used as a dam to hold and transfer water between Coal & Allied's Warkworth mine and HVO.

The Wambo Mine is located to the north-west of MTW. It includes both open cut and underground long-wall operations. Mining commenced at Wambo in the late 1960s to early 1970s. Open cut operations have extended down to the Whynot Seam. Currently approved underground mining at Wambo includes long-wall panels in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

Table 3.1 summarises the coal seams mined at MTW, Bulga Coal Complex and Wambo.

Table 3.1:SUMMARY OF MINING OPERATIONS

Stratigraphic Column			Coal Seam	Bulga Coal Complex						Wambo Mine						MTW						Lemington Underground
				Bulga Pit OC	Whybrow Pit OC	Saxonvale/ Vaux Pit OC	Beltana No1 Mine UG	Blakefield North UG	Blakefield South UG	Wambo OC	Arrowfield UG	Bowfield UG	North Wambo UG	Whybrow UG	United Collieries UG	Homestead/Wollemi UG	North Pit	South Pit	West Pit	Loders /Mount Thorley Pit	Abbey Green North	
Regolith/ alluvium																						
Wittingham Coal Measures	Jerrys Plains Subgroup	*Mt Leonard*	Whybrow	x	x	x	x		x	x				x		x	x		x	x		
		Althorpe Fm		(tuff)																		
		Malabar Fm.	Redbank Creek							x							x		x	x		
			Wambo	x						x			x				x		x	x		
			Whynot							x							x		x	x		
			Blakefield	x				x	x								x		x	x		
		Mt. Ogilvie Fm.	Glen Munro	x													x		x	x		
			Woodlands Hill	x											x		x		x	x		
		Milbrodale Fm.		(tuff)																		
		Mt. Thorley Fm.	Arrowfield								x				x		x		x			
			Bowfield									x					x	x	x		x	
			Warkworth														x	x	x		x	
		Fairford Fm.		(tuff)																		
		Burnamwood Fm.	Mt. Arthur															x	x		x	x
			Piercefield																			
			Vaux																			
			Broonie																			
			Bayswater																			

Note:

x Currently approved or historically mined



LEGEND:

- Proposed Warkworth Mine development consent boundary
- NOW stream gauge station
- Watercourse

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Local Context

DATE: 14/5/2014

FIGURE No: **3.1**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

4 CLIMATE AND SURFACE WATER

4.1 Climate

The climate in the vicinity of Warkworth Mine is mostly temperate and is characterised by hot summers with regular thunderstorms and mild dry winters. Table 4.1 summarises the average monthly temperature, rainfall and evaporation rates for the area. This table shows that rainfall recorded at Warkworth Mine (since 2012) has generally been below the long-term average (1889-2013) for Jerrys Plains, and that evaporation exceeds rainfall on a monthly basis. The average annual rainfall at Warkworth Mine is 591 mm, with February being the wettest month.

Table 4.1: CLIMATE AVERAGES JERRYS PLAINS (STATION 061086) and MTW

Statistic	Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Mean max temp (ºC)	SILO[1]	31	30	28	25	21	18	17	19	23	26	29	31	25
Mean evaporation (mm)	SILO	211	166	148	108	75	55	64	87	117	156	181	213	1579
Mean rainfall (mm)	SILO	77	73	61	44	41	49	42	36	42	53	63	67	648
Warkworth Mine mean rainfall	MTW[2]	78	151	87	25	13	48	21	10	26	9	79	26	591
Evaporation minus MTW rainfall	**-**	**133**	**16**	**61**	**83**	**62**	**7**	**43**	**77**	**90**	**147**	**102**	**187**	**989**

1. SILO Patched Point Data (PPD) from Department of Science, Information Technology, Innovation and the Arts (DSITIA) for Jerrys Plains Station. The PPD includes daily climate readings from the Bureau of Meteorology (BoM) as well as interpolated data where readings are not available. The SILO dataset includes long-term daily rainfall, temperature and evaporation readings from 1889 to present.
2. Rainfall recorded by Warkworth Mine from 2012.

Monthly rainfall records were used to calculate the Cumulative Rainfall Departure (CRD – also known as rainfall residual mass) for the Jerrys Plains Station. Figure 4.1 shows the calculated CRD.

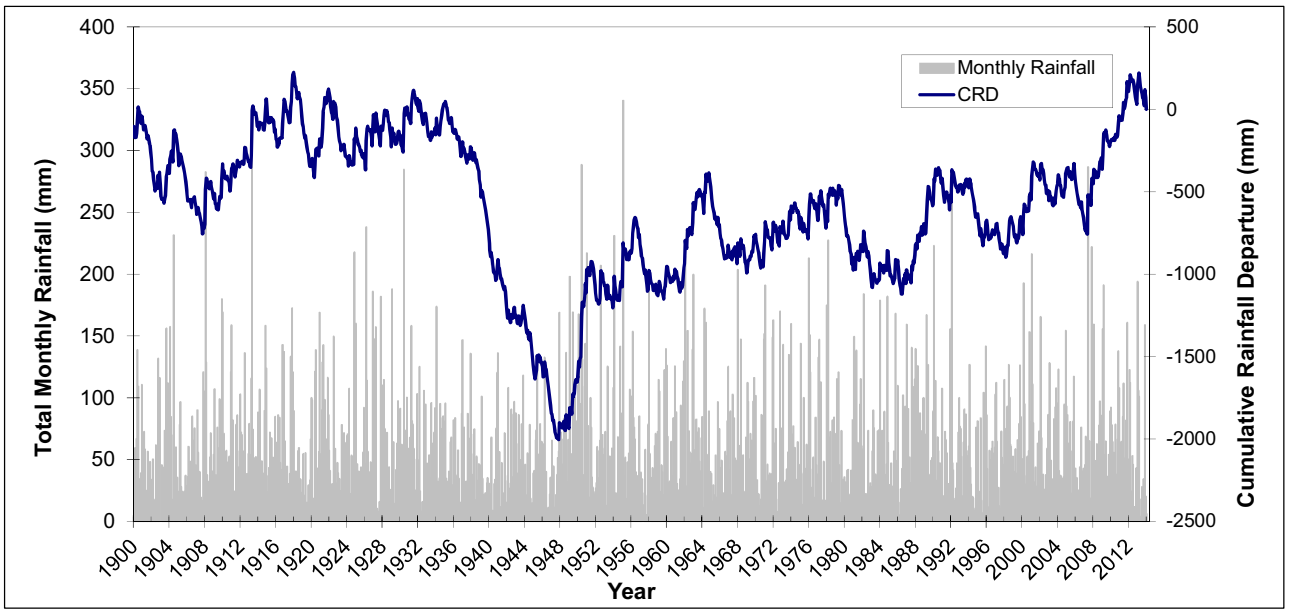


Figure 4.1: Cumulative Rainfall Departure – Jerrys Plains

The CRD shows trends in rainfall relative to the long term average and provides a historical record of relatively wet periods and droughts. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. The CRD in Figure 4.1 indicates that the district experienced above average rainfall between 2007 and 2012, followed by a general decline in rainfall to the present day.

4.2 Surface Water

The main watercourse in the study area is Wollombi Brook, which is located to the west of the proposal. The ephemeral Wollombi Brook is a tributary of the Hunter River and flows in a north to north-easterly direction past Warkworth Mine. The NSW Office of Water (NOW) collects real time stream flow data via the Hunter Integrated Telemetry System (HITS). Figure 3.1 shows the two NOW gauging stations on Wollombi Brook in close proximity to MTW, which are:

- Station 210004 (Wollombi Brook at Warkworth) north of Warkworth Mine (47.8 mRL at zero gauge and 48.4 mRL cease to flow); and
- Station 210028 (Wollombi Brook at Bulga) west of MTO (56.50 mRL at zero gauge and 57.4 mRL cease to flow).

Data on the HITS database indicates Wollombi Brook at Bulga (Station 210028), the closest gauging station west of Warkworth Mine, flows at a median rate of around 41 ML/day. The median flow rate between April and December 2013 is approximately 8.4 ML/day due to below average rainfall.

Figure 4.2 shows stream flow levels recorded at the two stations, compared against daily rainfall and evaporation from 2010 to present.

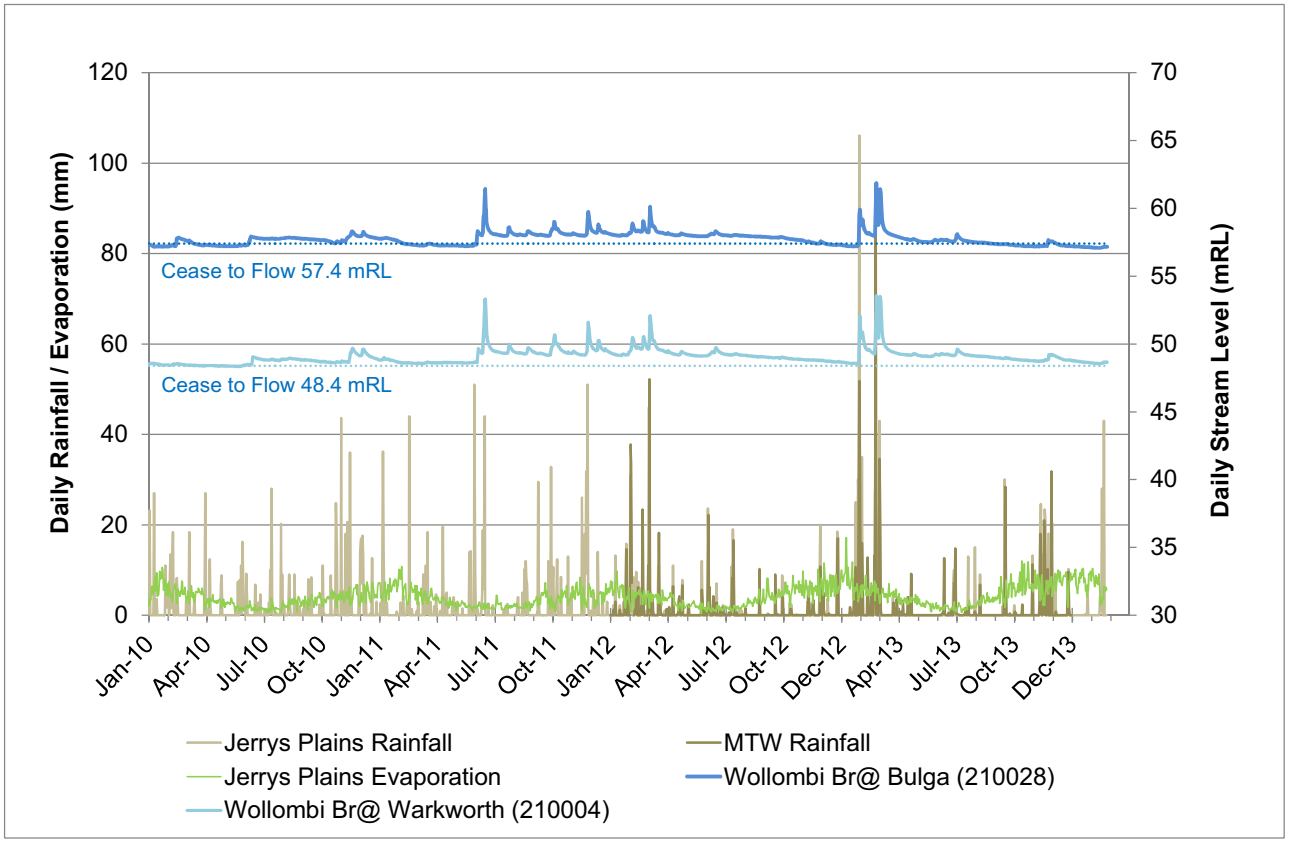


Figure 4.2: Wollombi Brook stream levels and climatic conditions

The graph shows that daily evaporation generally exceeds daily rainfall, and that peaks in stream flow in Wollombi Brook are in response to peak rainfall events. Between peak rainfall events the stream flow shows a steady recession. The graph also shows that stream flow has been maintained in the Wollombi Brook (at Warkworth Station) since 2010. In early 2010 and prior to that date the full record shows that the Wollombi Brook at both Bulga and Warkworth have had extended periods of no flow. In addition, flow volumes were higher downstream of the mine site (Warkworth) than upstream (Bulga). This indicates that there is surface and/or groundwater input to Wollombi Brook between these stations.

5 HYDROGEOLOGICAL REGIME

5.1 Groundwater Occurrence

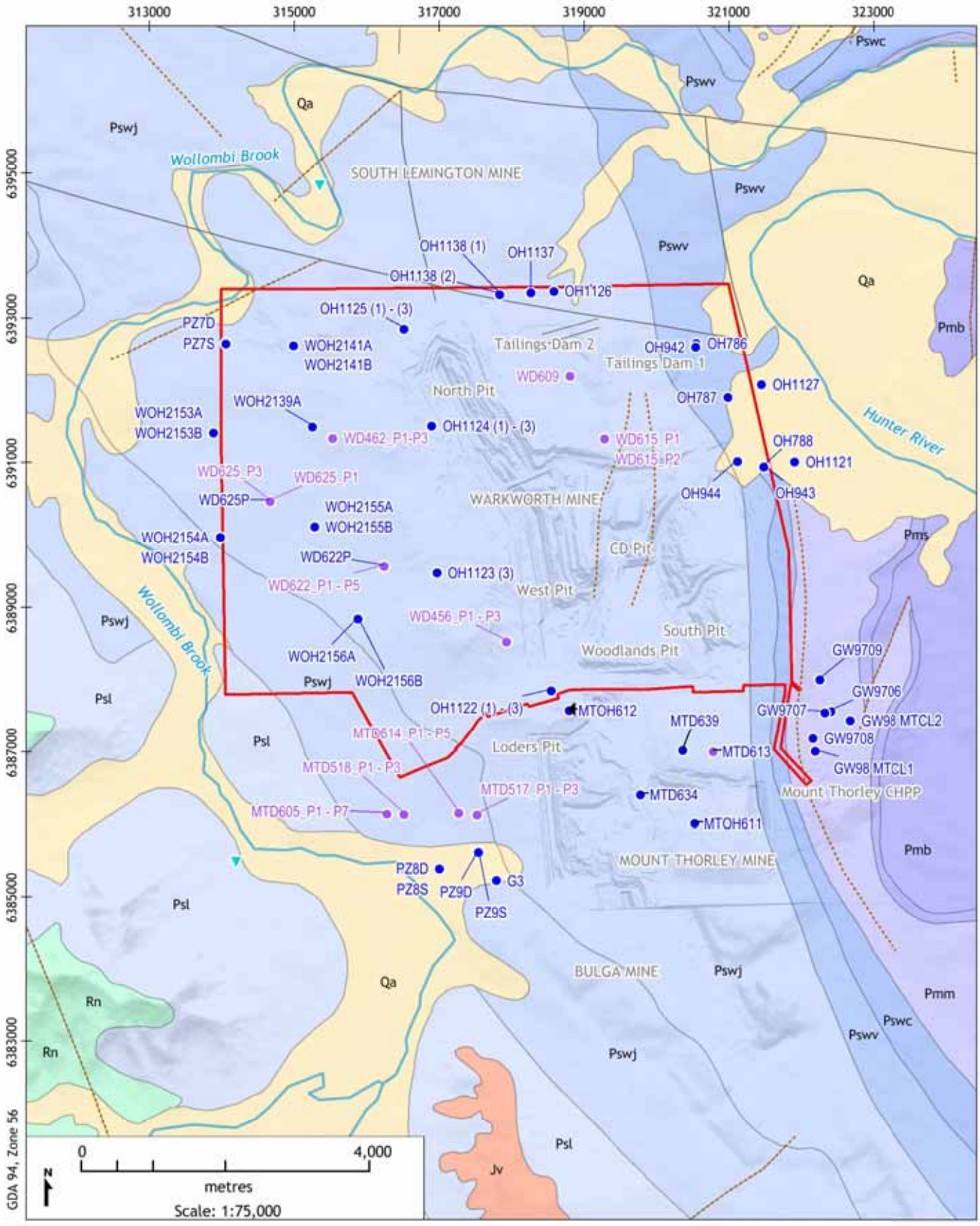
Figure 5.1 shows the outcropping geology units and groundwater systems in the region. The geologic strata at MTW can be categorised into the following hydrogeological units:

- alluvium along Wollombi Brook and the Hunter River that can form a productive aquifer system, although salinity can limit use of the water;
- aeolian sands associated with the Warkworth Sands Woodland to the north-west of Warkworth Pit that forms a thin perched groundwater system of limited extent;
- shallow weathered bedrock (regolith) near ground surface that is mainly present in the more elevated mining areas and is largely dry;
- hydrogeologically “tight” and very low yielding sandstone, siltstone and conglomerate that comprise the majority of the Permian interburden/overburden and is considered an aquitard; and
- low to moderately permeable coal seams that range in thickness from 1 m to 6 m and are the prime water bearing strata within the Permian sequence.

Figure 5.2 shows a stratigraphic column for the Permian sequence.

The Wollombi Brook alluvial aquifer and associated flood plain is largely restricted to the main channel of Wollombi Brook and only extends a short distance up the associated tributaries. The alluvium is typically less than 20 m thick, with many of the private bores intersecting between 10 m and 15 m of sediment. Groundwater entitlements for the Lower Wollombi Brook Water Source total 5,071 ML/year with approximately 55% used for irrigation and approximately 44% used for industrial purposes. This entitlement is distributed across 38 groundwater licences (DWE, 2009). This distribution is considered current, with an updated search of the NSW Government 2013 version of PINEENA groundwater database showing no new bores within the study area since 2010.

Aeolian sands overlie the Permian coal measures to the north-west of the Warkworth Mine (extent shown in Figure 5.1. The sands ability to store and slowly release water supports unique woodland known as the Warkworth Sands Woodland. The fine grained sands are approximately 3 m thick and overlie a low permeability base of residual clay associated with the underlying strata. The low permeability clays reduce vertical flow of groundwater and result in the formation of a thin perched water table at the base of the sand mass. Cumberland Ecology (2014) noted species indicative of a persistent water table can be found in dune swales suggesting some groundwater permanence. The Warkworth Sands aquifer is considered to be perched above, and not directly connect to the regional water table.



LEGEND:

- Proposed Warkworth Mine development consent boundary

Monitoring bore
- Standpipe
- VWP
- NOW stream gauge station
- Fault
- Fold
- Watercourse

Hunter Coalfields 100k Geology
- Qa - Quaternary alluvium
- Jv - Jurassic Volcanics
- Rn - Hawkesbury Sandstone, Narrabeen G.
- Psl - Wollombi Coal Measures
- Pswj - Denman Fmt, Jerrys Plains Subgroup
- Pswv - Archerfield Ss., Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmm - Mulbring Siltstone
- Pms - Muree Sandstone
- Pmb - Braxton Formation

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Geology and Monitoring Bores

DATE: 14/5/2014

FIGURE No: 5.1

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

The Permian deposits occur as a regular layered westerly dipping sedimentary sequence. Coal seams currently mined at Warkworth Mine include the Redbank Creek, Wambo, Whynot, Blakefield, Glen Munro, Woodlands Hill, Arrowfield, Bowfield, Warkworth and Mt Arthur Seams (Figure 5.2). Currently approved mining at MTO targets seams down to the Woodlands Hill. These seams vary in thickness from 0.3 m to more than 6 m. Groundwater usage from the Permian strata is limited by the generally brackish to saline nature of the groundwater and the low and variable yields.

Figure 5.3 shows an east to west schematic cross-section from the Hunter River through the Warkworth Mine area and west to Wollombi Brook. The coal seams outcrop west of the Hunter River, with a slight dip along the Mt Thorley Monocline that is located close to the outcrop area. The dip of the seams becomes more gentle within the mining area. The section shows the coal seams are more than 200 metres below the ground surface to the west where the alluvial sediments associated with Wollombi Brook occur.

The prime users of groundwater from the Permian strata are the underground mines in the area. Warkworth Mine does not report any significant seepage into the pits due to a combination of low permeability formations, and because the evaporation rate generally exceeds the rate of seepage from the mine face. The hydrostratigraphic units of the Permian coal measures typically yield less than 5 L/s, and are therefore classified as 'less productive aquifers' according to the criteria set out in the AIP.

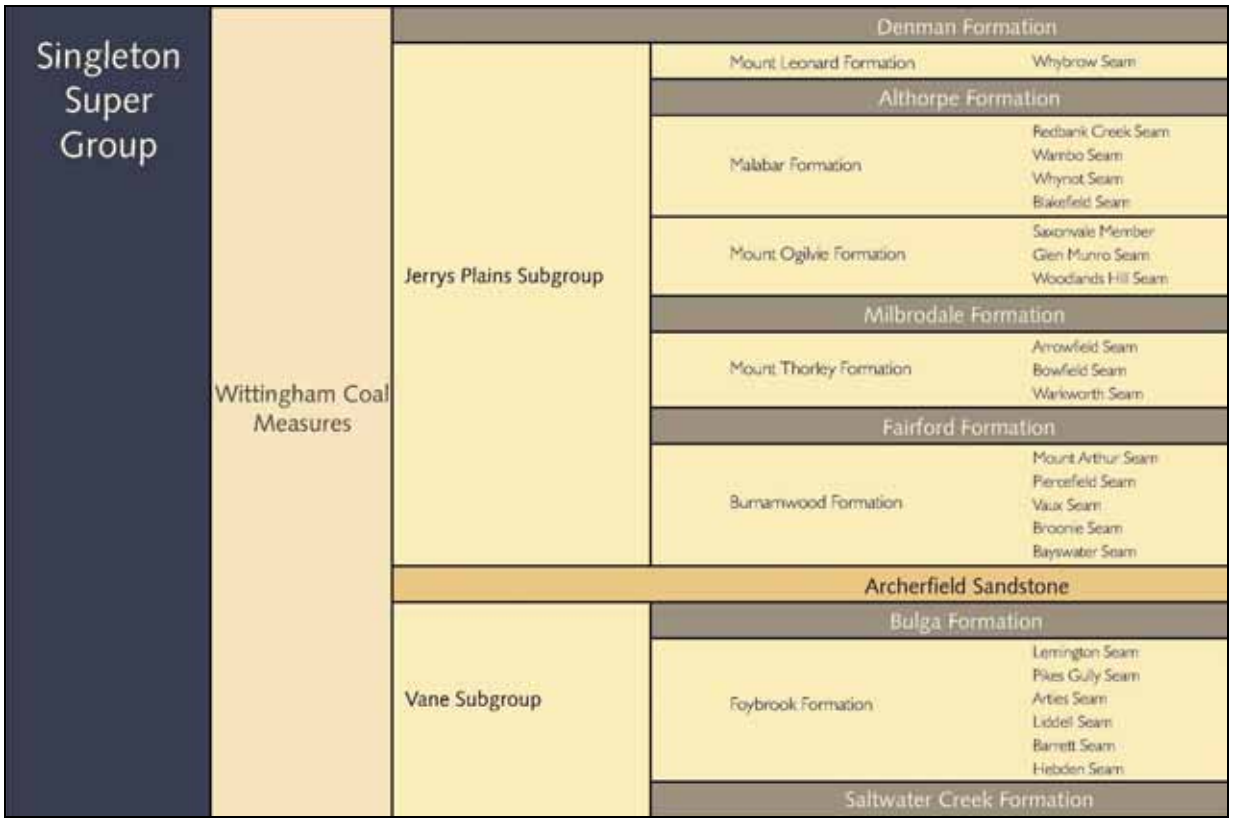
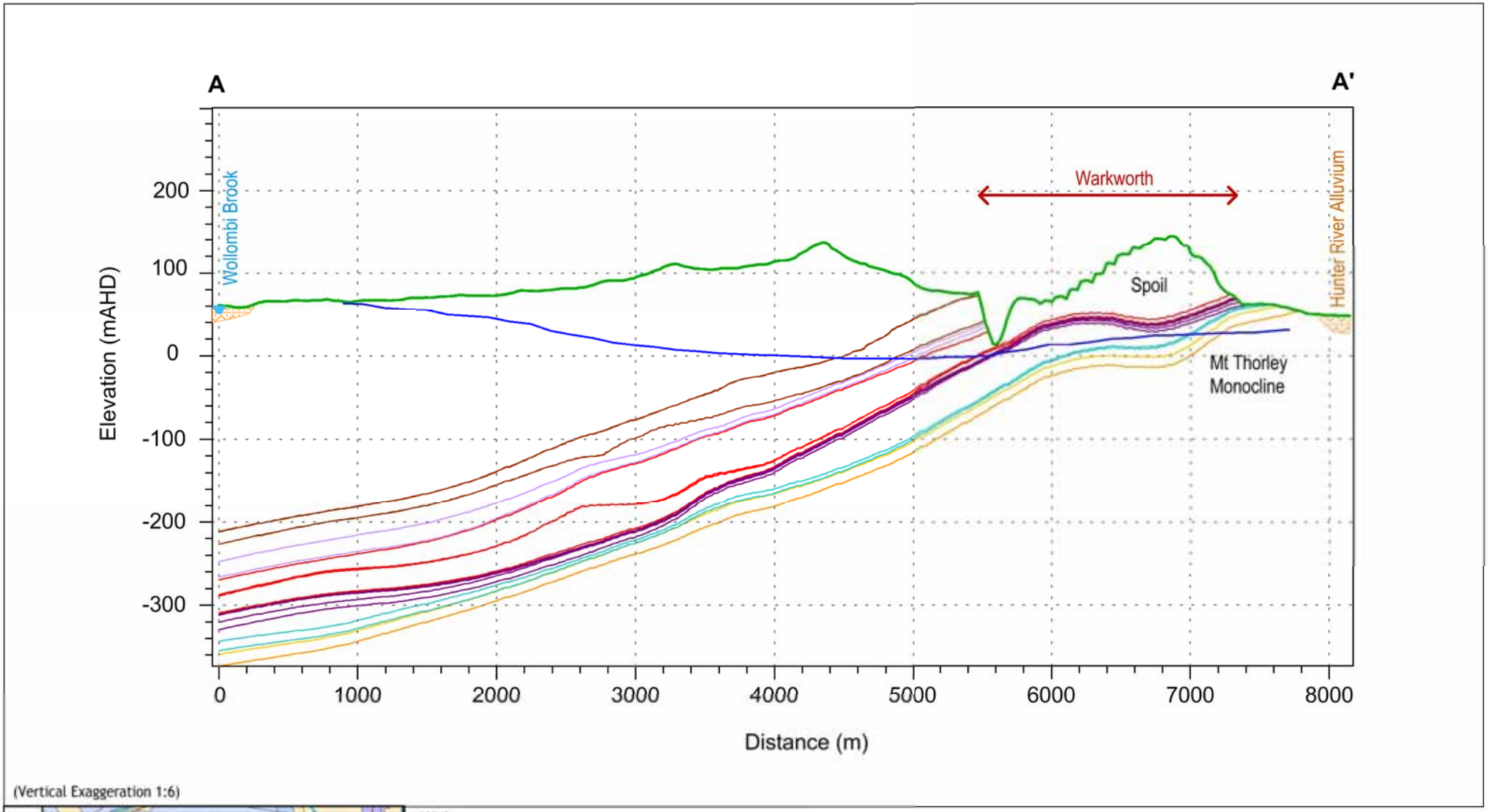


Figure 5.2: Stratigraphic column



Locality Map



LEGEND:

- Inferred Permian Potentiometric Surface
- Alluvium
- Surface Topography
- Arrowfield Seams
- Bowfield Seams
- Warkworth Seams
- Mt Arthur Seams
- Piercefield Seams
- Vaux Seams

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Hydrogeological Cross-Section
Warkworth (A-A')

DATE:
14/5/2014

FIGURE No:
5.3

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

5.2 Groundwater Monitoring

Water levels are routinely measured in a network of monitoring bores at MTW. Figure 5.4 shows the location of monitoring bores relative to an aerial photograph. The monitoring network comprises standpipe style PVC cased monitoring bores, and vibrating wire piezometers (VWPs). Temporal groundwater level data has been gathered via manual dipping of bores and via data loggers since 2003. Some sites have both monitoring bores and VWPs, which allows the study of hydraulic gradients between the alluvium and the Permian sequence, and also within the layered Permian strata and spoil.

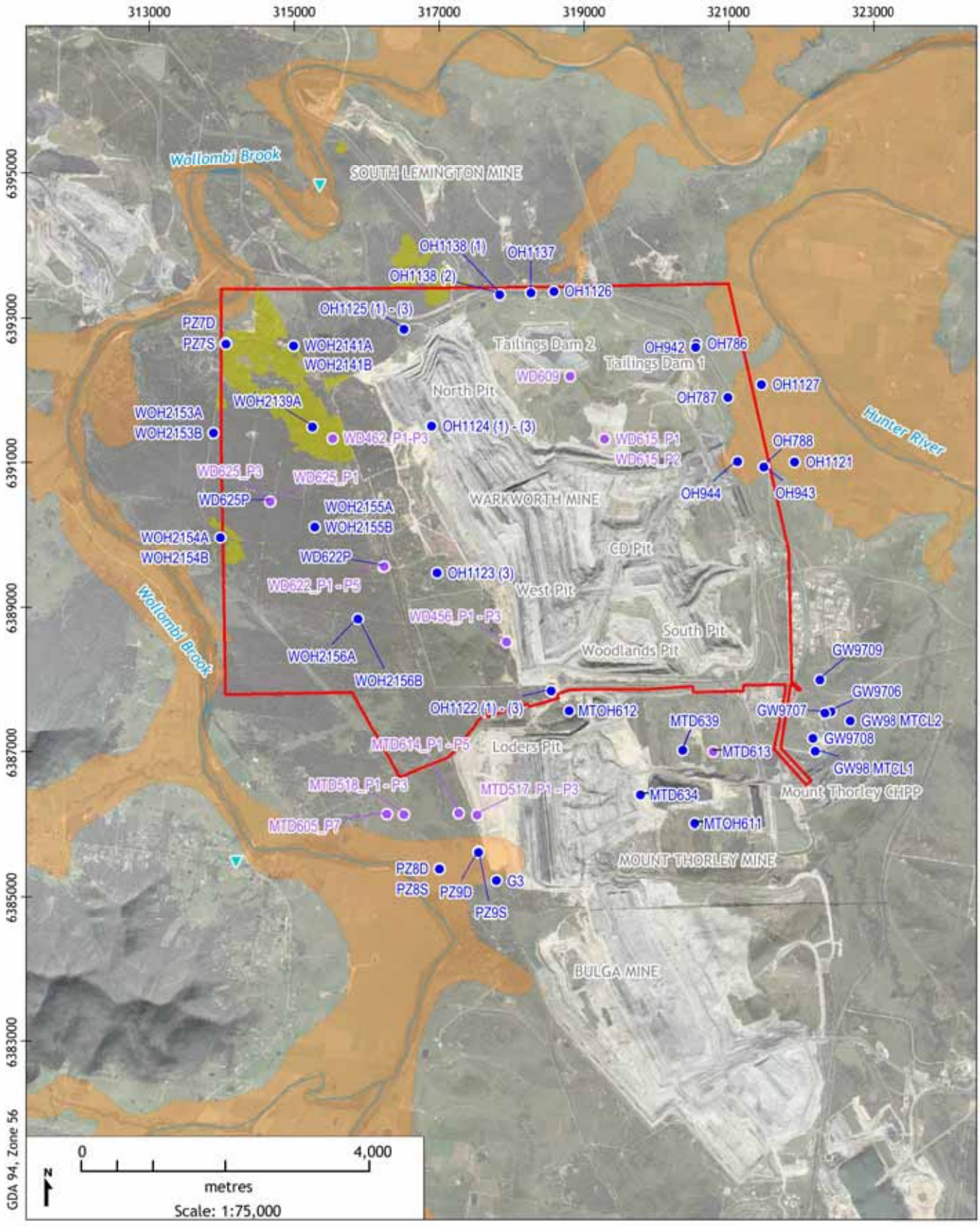
Monitoring bore construction details and recent groundwater levels are detailed in Appendix A.

5.3 Groundwater Levels

Monitoring from the network of bores surrounding the MTW open cut pits shows mining is depressurising the coal seams to the west of the active face, resulting in declining water levels. Monitoring shows the water levels within the alluvium to date are unaffected by mining. Figure 5.5 shows the drawdown of the potentiometric surface within the Permian sequence in late 2013. The cumulative impact of mining is made evident by the flow of groundwater towards the active mine area. This outlines the importance of simulating the existing effects of mining at MTW and regionally appropriately in this study, to identify the impacts from the proposed modification.

Figure 5.5 includes an inset with estimated groundwater levels within the Loders Pit mine spoil. There is limited water level data for the spoils, and therefore data from geophysical logging (Neutron Log) of exploration holes were used to estimate the zone of saturation. The interpreted water levels indicate the spoils are saturated at the base and drain across the historical pit floor towards the open void in the west.

Figure 5.5 highlights the changes to the groundwater regime induced by mining. Prior to mining groundwater levels would have been expected to have been a subtle reflection of the topography, with gradients towards the west and Wollombi Brook. To the west of the Warkworth Mine high-wall a series of multi-level monitoring bores and VWPs are present which monitor both the multi-layered Permian strata and the Wollombi Brook alluvium. The monitoring network shows depressurisation is most significant in the Permian strata in close proximity to the active high-wall and decreases with distance to the west. The cumulative impacts of historical mining are addressed further throughout this report during modelling.



LEGEND:

- Proposed Warkworth Mine development consent boundary

Monitoring bore

- Standpipe
- VWP
- NOW stream gauge station
- Alluvium (100k)
- Warkworth Sands Woodland
- Watercourse

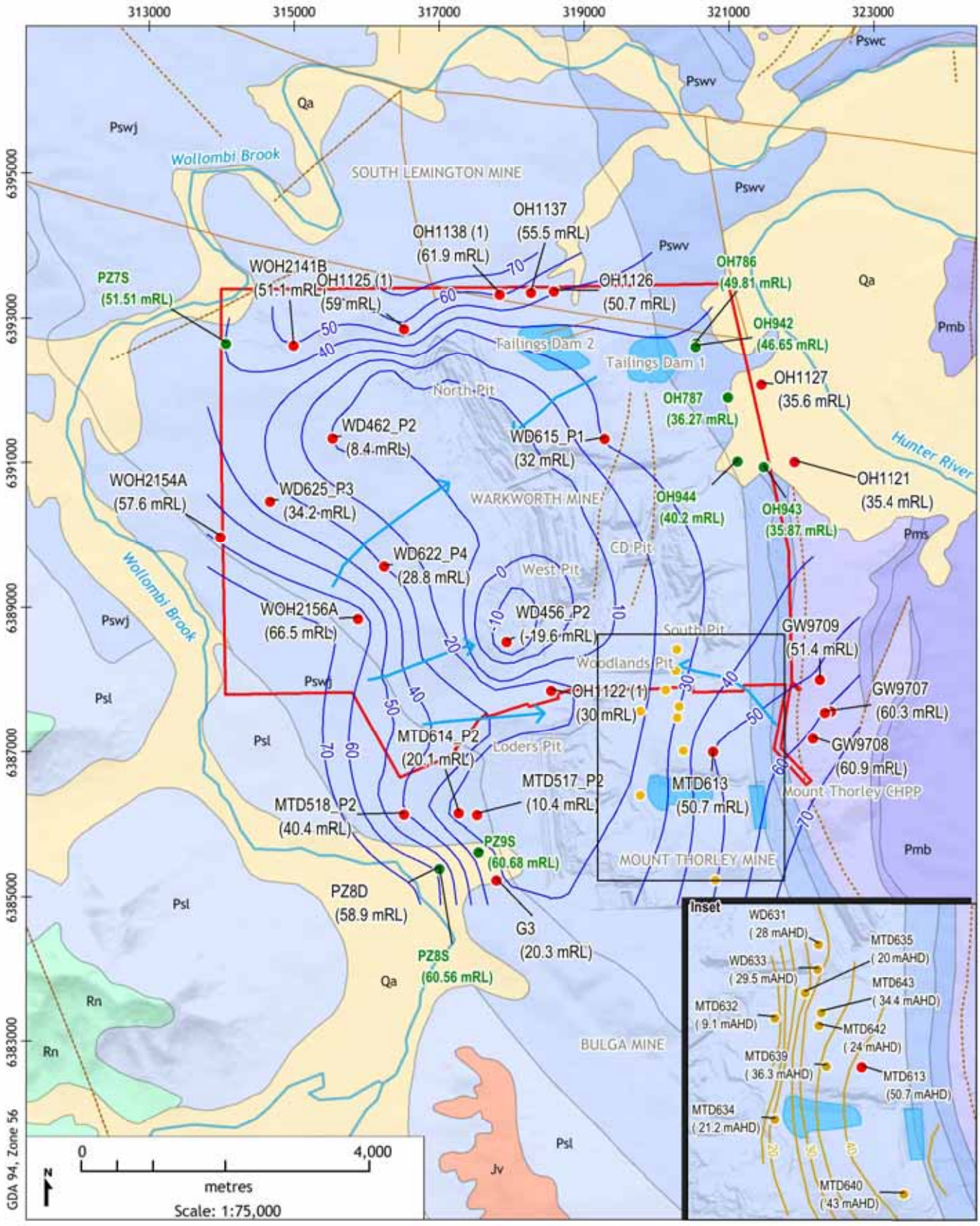
Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Air Photograph and Monitoring Bores

DATE: 14/5/2014

FIGURE No: 5.4

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Monitoring bore (alluvium - SWL mRL)
- Monitoring bore (Permian - SWL mRL)
- Monitoring/Exploration hole (spoil - SWL mRL)
- 10m Inferred Permian Groundwater Contour (RL - Sep/Oct 2013)
- Inferred groundwater flow direction
- 5m inferred spoil groundwater contours (mRL)
- Tailings storage facility
- Fault ---- Fold

Hunter Coalfields 100k Geology

- Qa - Quaternary alluvium
- Jv - Jurassic Volcanics
- Rn - Hawkesbury Sandstone, Narrabeen G.
- Psl - Wollombi Coal Measures
- Pswj - Denman Fmt, Jerrys Plains Subgroup
- Pswv - Archerfield Ss., Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmm - Mulbring Siltstone
- Pms - Muree Sandstone
- Pmb - Braxton Formation

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Groundwater Contours and Groundwater Flow Directions

DATE: 14/5/2014

FIGURE No: 5.5

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

To the north and north-east of the active Warkworth Mine extraction area, where mining and spoil emplacement has been completed, groundwater levels are generally in the range 50 mRL to 65 mRL. These levels are expected to be close to pre-mining levels. Figure 5.6 shows water levels in monitoring bore OH1138 in the Warkworth Seam.

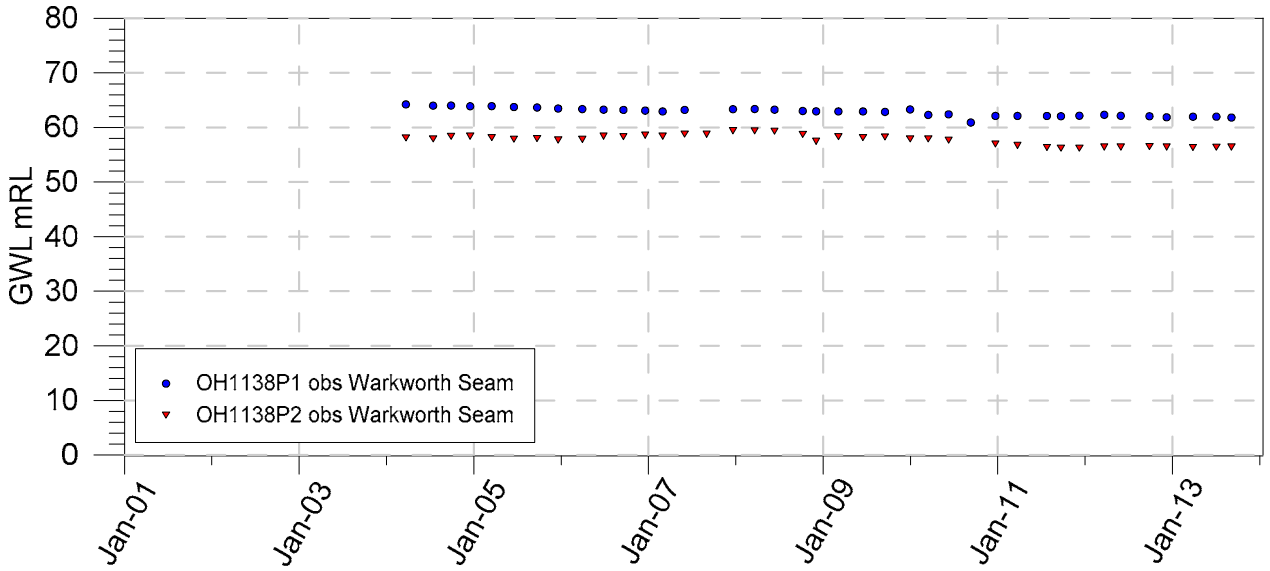


Figure 5.6: Groundwater Levels within the Permian directly north of Warkworth Spoil and TSFs

Groundwater levels at this site have been in the order of 55 mRL to 65 mRL since 2004. It is presumed that when open cut mining passed this area (prior to data collection) levels were lower and have subsequently recovered to the current elevation.

Groundwater levels have been monitored at monitoring bore (WD609 - Figure 5.1) in the Warkworth spoil pile south of Tailings Dam 2; during 2013 the groundwater level was around 45 mRL. This shows that a significant groundwater mound has developed in spoil near the tailings dam, which is thought to be at least in part due to leakage from Tailings Dam 1 and 2. Groundwater levels to the north of the mined areas (Figure 5.6) and within the spoil indicate the presence of a water table in the eastern spoil, which may have assisted the recovery in the groundwater level in unmined Permian strata to the north.

The drawdown is most significant at monitoring sites within the Permian strata in close proximity to and west of the Warkworth active high-walls (i.e. WD456, WD462 and WD622 – Figure 5.1), with less drawdown in monitoring bores that are more distant from the high-walls. Figure 5.7 shows declining groundwater levels measured at monitoring bores west of the Warkworth Mine extraction area.

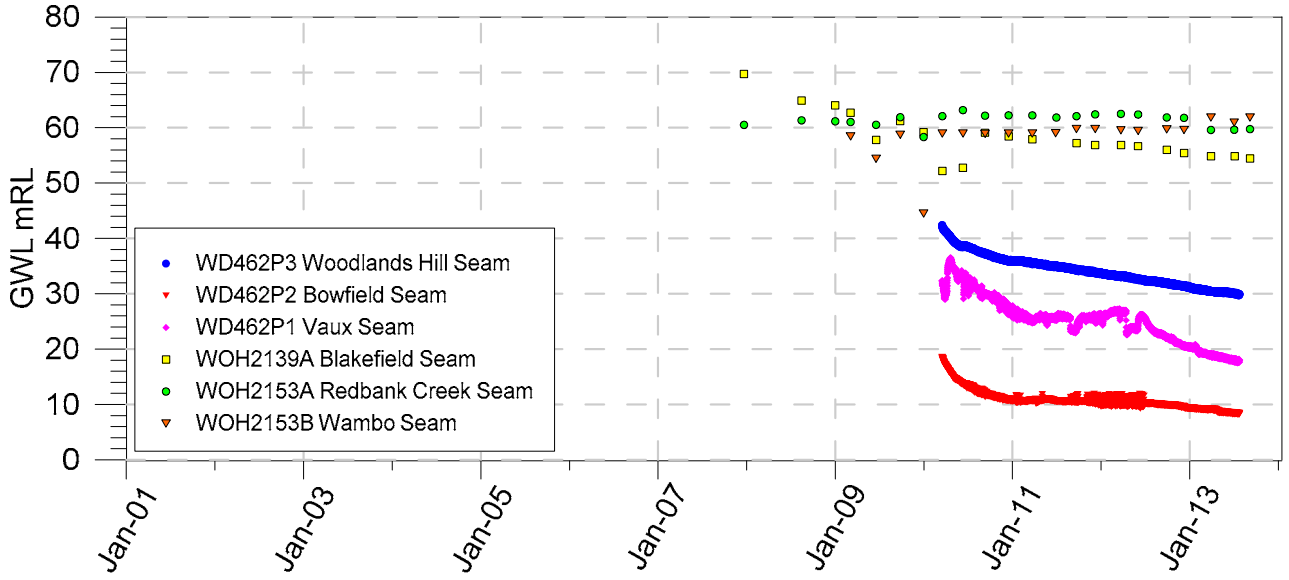


Figure 5.7: Groundwater level within the Permian strata west of Warkworth high-wall

The VWP site WD462, about 700 m from, and the closest site to the current pit crest, has the greatest recorded drawdown observed in P1, which is located in the Vaux Seam below the base of the current pit floor (Mt Arthur Seam). The continued decline in WD462P1 shows that current mining is depressurising seams below the base of current operations within the Warkworth Pit. The majority of the drawdown in WD462P2 is presumed to have occurred prior to the site being installed.

The monitoring bore WOH2139A is located approximately 1 km from the current pit crest and shows some drawdown but not to the extent of the closer VWP site WD462. No drawdown is obvious in the nested monitoring bore site WOH2153 located 2.4 km from the current pit crest.

To the west–north-west of Warkworth Mine the nested monitoring site PZ7 monitors groundwater levels within the Wollombi alluvium and the underlying Permian overburden. Groundwater levels in both locations show no impact from mining, and have remained stable at 52 mRL since being installed in 2010. Section 5.7.2 further discusses alluvial groundwater levels and connectivity with surface water in Wollombi Brook.

Monitoring shows groundwater levels in bores to the east of Warkworth Mine, in the Hunter River alluvium, are unaffected by depressurisation of the coal measures (i.e. OH943). The sub-crop of coal seams and exposure of underlying low permeability sediments at surface between WML and the Hunter River alluvium prevents drawdown within the coal measures reaching the Hunter River alluvium. Water levels in all the alluvial monitoring locations east of Warkworth Mine recorded relatively stable water levels at around 36 mRL (OH943), fluctuating only in response to climatic conditions. Some of the groundwater levels appear to be lower than the Hunter River level, it is not clear in the data available that this is due to the river being a losing system in this area, or due to historic mining.

Monitoring bore OH942 to the east of tailings dam 1 (TD1) is possibly installed in weathered regolith and shows some evidence of leakage from the tailings storage facility (TSF) with levels higher than surrounding alluvial monitoring bores (47 mRL).

In summary, a long history of mining has depressurised the Permian coal measures strata down-dip (west) of the mine site. Drawdown to the north appears to be relatively limited with some recovery of water levels within the spoil piles. No measureable drawdown to date has been

recorded in the Wollombi alluvium monitoring bores. Drawdown to the east in the Hunter River alluvium is constrained by sub-crop of geological formations impeding depressurisation in an easterly direction.

5.4 Groundwater Gradients

Figure 5.5 shows the groundwater contours and generalised[1] flow directions of the Permian groundwater, which generally flows towards the active mine area.

Alluvial groundwater contours could not be interpolated due to the limited number of bores within these sediments. The alluvial groundwater levels however indicate a relatively flat groundwater gradient from the edge of the alluvium towards the main watercourses (i.e. Wollombi Brook and Hunter River). In addition, groundwater levels between the alluvium and Permian units appear to be similar beyond a certain distance away from mining activity. Also, alluvial groundwater levels are notably higher in elevation compared to Permian levels closer to the mine (e.g.PZ9S and G3). As discussed in Section 5.3, these results indicate that the current influence of mining on the potentiometric surface is localised in the Permian strata, with no detectable drawdown in the alluvium.

A number of nested monitoring bores and VWPs surrounding Warkworth Mine enables the analysis of vertical hydraulic gradients between coal seams being mined and in some cases the underlying unmined coal seams.

West of the Warkworth Mine most of these sites show a downward gradient to the Mt Arthur seam which is the base of current open cut operations. Downward gradients comprised of up to 60 m in head difference between coal seams are noted with the vertical gradient appearing to increase closer to the Warkworth Mine. Heads from coal seams below the Mt Arthur tend to show upward gradients, inferring that unmined lower coal seams have not been depressurised extensively from current mining. Some depressurisation is starting to occur in deeper seams however, presumably through leakage to the active pit floors. The majority of the measured vertical hydraulic gradients are presumed to be caused from mining activities, although with no pre-mining data this cannot be confirmed.

5.5 Strata Permeability and Storage

Permeability has been investigated in several site specific studies at MTW and the neighbouring Bulga mine. AGC (1984) and Amoco Australia (1995a and 1995b) are two studies with permeability measurements for coal seams at the site. These studies and one by Mackie (2009) refer to a reduction of coal seam permeability with depth.

In addition, as documented by AGE (2010), a monitoring bore drill program was undertaken to construct monitoring bores at three sites in the Wollombi Brook alluvial plain. At each site separate monitoring bores were constructed in the alluvial sediments (PZ7S, PZ8S and PZ9S) and underlying coal measures and overburden (PZ7D, PZ8D and PZ9D). As a part of the investigation permeability tests were conducted, with the results summarised in Table 5.1. Figure 5.1 shows the locations of these monitoring bores.

[1] The groundwater levels presented in this image are combined for the Permian sequence, where there was more than one coal seam monitored at a given location the lowest value was used to generate the potentiometric surface. Hence, this surface presents the 2013 generalised groundwater flow directions in the Permian.

Table 5.1: FALLING HEAD TEST RESULTS			
Bore ID	**Strata**	**Hydraulic Conductivity**	
		m/sec	**m/day**
PZ7S	Alluvium	3.4×10^{-6}	0.3
P8S		1.9×10^{-5}	1.6
PZ9S		2.8×10^{-6}	0.2
PZ7D	Bedrock	1.2×10^{-6}	0.1
PZ8D		-	-
PZ9D		1.1×10^{-6}	0.1

The results show that the hydraulic conductivity within the alluvium is highly heterogeneous, due to the depositional environment. The hydraulic conductivity measured in the Permian stratigraphy was anomalously high, and may have been due to the shallow nature of these boreholes and weathering in the Permian strata.

In addition to the AGE (2010) field investigation, a recent field investigation by Golder (2013) within the study area has provided a number of results from borehole hydraulic (packer) testing.

Figure 5.8 presents the available data for Permian coal seam hydraulic conductivity versus depth from previous groundwater assessments mentioned in this section.

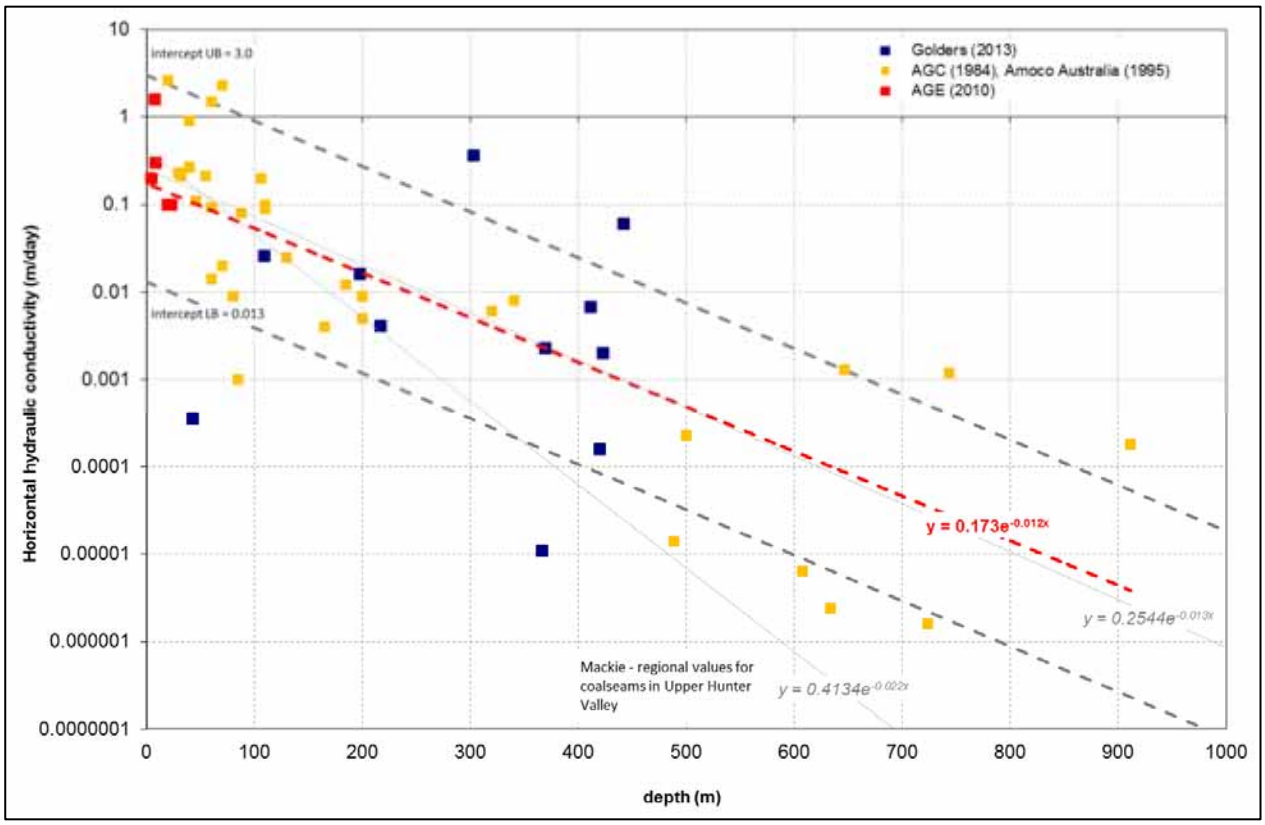


Figure 5.8: Change of hydraulic conductivity with depth in coal seams

Figure 5.8 shows a correlation between depth and declining hydraulic conductivity. The red dotted line shows the best fit through this data, and is similar to that presented by AGE (2010).

Data for hydraulic conductivity of the interburden and overburden is limited. The horizontal hydraulic conductivity of interburden is generally considered at least one, and sometimes several orders of magnitude less permeable than the coal seams.

No site specific data is available for storage properties of local stratigraphy. Mackie (2009) estimated specific storage for the Hunter Region using Young's modulus, and results ranged between 1×10^{-4} and 3×10^{-6} (1/m). These results are based on similar stratigraphy to the proposal area, and are therefore considered applicable to this study.

5.6 Recharge

Recharge to the Permian coal measures can occur where coal seams outcrop or sub-crop close to the surface. Recharge to the alluvium occurs via rainfall infiltration through the unsaturated zone, hill slope runoff and leakage from rivers and streams when and where the surface water levels are above the water table in the alluvium.

Experience in similar studies at MTW (AGE 2010) and within the Hunter Valley suggest recharge to the Permian coal measures is low, typically below 1% of annual rainfall. Recharge to alluvium is between 5% to 10% of rainfall, however, this varies based on alluvial composition.

5.7 Discharge

5.7.1 Discharge Processes

Natural discharge processes in the system are via groundwater flow into water courses as baseflow when the water table in the adjacent groundwater system is higher than either the stream bed or the water levels in the stream channel. It also includes groundwater inflow into mining zones, disposal and/or evaporation, groundwater use by private landholders and evapotranspiration where the water table is within the root zone of plants and trees.

5.7.2 Baseflow

As detailed in Section 4.2, a review of surface water flows and climatic conditions indicates groundwater may contribute to baseflow in Wollombi Brook. The proportion of groundwater in steam flow would tend to increase during times of low flow. Figure 5.9 below compares Wollombi Brook levels to rainfall and groundwater levels within the associated alluvium (PZ7S, PZ8S and PZ9S) and the underlying Permian stratigraphy (PZ8D and PZ9D).

It can be seen in Figure 5.9 that groundwater trends within the alluvium do not respond to rapid changes in stream levels. This is understandable given that the monitoring sites are relatively remote from the stream channel. As bores PZ8 and PZ9 (S and D) are located approximately 2.5 km upstream of Station 210028 (Bulga), and bore PZ7S is located over 3 km upstream of Station 210004 (Warkworth), the river bed elevations next to the bore sites were estimated using LIDAR data. Within the PZ8/PZ9 area the river bed level is approximately 60.5 mRL, and within the PZ7 area the river bed level is approximately 52 mRL. Based on these river bed elevations, the Wollombi Brook within the PZ8/9 area appears to be a gaining system. However, at the downstream PZ7 site the groundwater levels are close to or slightly below river levels, indicating a slightly losing stream system where the alluvium is potentially recharged by Wollombi Brook. This is supported by water quality results, with brackish water quality within the alluvium at PZ7S, compared to the naturally saline water quality at PZ8S and PZ9S (see Section 5.8). Whilst PZ7S is not located in an area where alluvium was mapped on 1:100,000 geological maps in does appear to be at the interface between the Quaternary alluvium and the Warkworth sands.

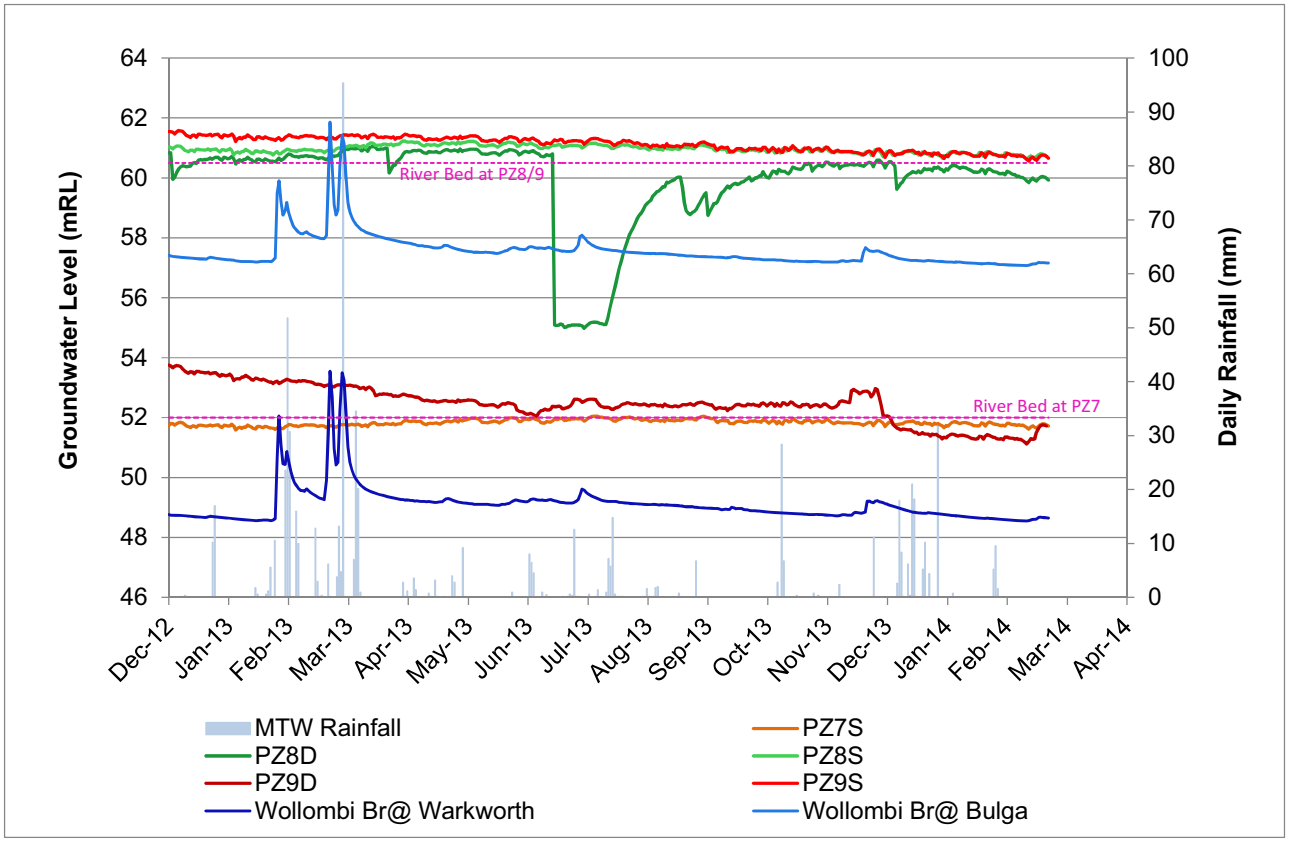


Figure 5.9: Baseflow Assessment for Wollombi Brook

A rapid decline in groundwater levels in June 2013 is visible for PZ8D, which is believed to relate to groundwater sampling. The bore was likely purged during the round of sampling, and the low hydraulic conductivity resulted in a slow rate of groundwater level recovery.

5.8 Water Quality

Groundwater quality has been measured at MTW since 1993. Appendix B summaries the water quality data and includes the median, 5th percentile and 95th percentile for each bore for the following parameters:

- pH - laboratory data from 1993 to 2002 and field data from 2002 to 2013;
- electrical conductivity (EC) - laboratory data from 1993 to 2002 and field data from 2002 to 2013; and
- major ions (calcium, magnesium, potassium, sulphate, phosphate and sodium).

The results show a degree of variability within and between each stratigraphic unit. The alluvium records from both the Hunter River and Wollombi Brook alluvium show relatively saline water quality, while the underlying Redbank Creek Seam generally records moderately saline groundwater. The deeper coal seams (i.e. Blakefield, Woodlands Hill, Bowfield, Warkworth, Vaux and Bayswater seams) also record saline groundwater. Results for the Wollombi Brook, presented by WRM (2014a), show slightly brackish water quality.

Figure 5.10 shows a Schoeller plot for the alluvium and Permian stratigraphy, based on historic (1993 – 2013) water quality data collected at MTW. Figure 5.10 also shows Wollombi Brook

median water quality data (collected by WRM, 2014a) and recent (20/2/2014) spoil water quality data collected by AGE from bore MTO634[2].

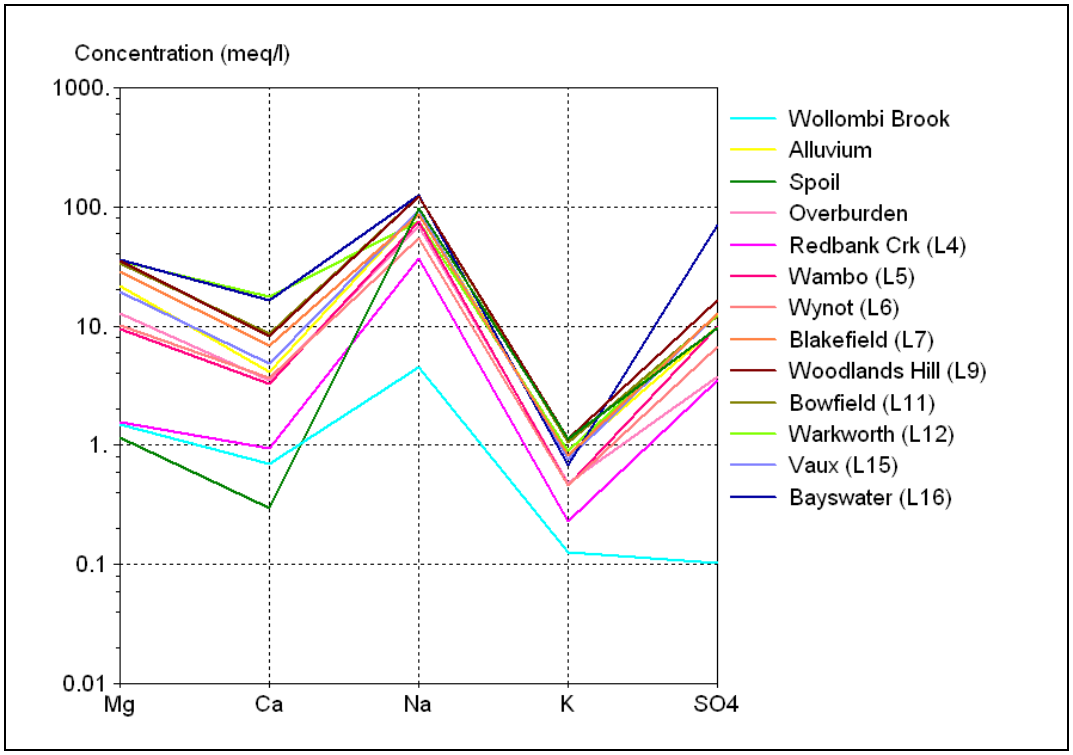


Figure 5.10: Schoeller plot of typical alluvium or seam chemistry

The Schoeller diagram compares chemistry from different samples; similar shaped lines from multiple samples indicate a similarity in origin and vertical displacement of similar lines indicates dilution with fresh water (resulting in downward shift in the line) or concentration/evaporation (resulting in an upward shift).

Figure 5.10 shows that, as expected, the Wollombi Brook has the lowest ion concentrations whilst the deeper Permian coal seams have the highest. The Permian samples have a similar signature indicating similar groundwater provenance. The samples from the spoil show lower concentrations of Mg and Ca compared to the Permian units, indicating potential dilution from rainfall recharge through the more porous spoil material.

5.9 Groundwater Users

AGE (2010) assessed groundwater usage from the groundwater systems by reviewing data held on the NSW Government groundwater database, and by conducting a bore census on private landholdings to the west of the mine. It was also identified during the bore census that bore GW44529 (shown in Figure 5.11) is abandoned, bores GW017462 and GW066590 are located on land owned by MTW, and bore GW080964 is a NOW groundwater monitoring bore.

During the bore census ten bores were visited to the north of the village of Bulga, locations of the bores are shown in Figure 5.11 and findings are detailed in Table 5.2. The census found that nine of the 10 sites were relatively shallow, at about 14 m or less in depth, indicating that these bores are likely to be constructed in the alluvial sediments. Three bores with a depth greater than 60 m are probably constructed in the underlying bedrock. Comparison of the registered bore details and

[2] MTO634 was completed in late 2013 directly down gradient of the CRTSF in MTO, the bore was sampled in early 2014.

the bore census findings indicates that two of the registered bores were not identified in the field and may be abandoned or destroyed. Four additional bores were also identified, which are likely not registered.

An updated search of the NSW Government 2013 version of PINEENA groundwater database outlined no new bores within the study area since 2010.

Table 5.2: AGE (2010) LANDHOLDER SURVEY FINDINGS

Registered Number	AGE (2010) census ID	Depth (mbgl)	Easting	Northing	Owner
GW047667	112-W	9.25	313729	6386469	Laurie & Rhonda Caban
GW078782	128-B	12.15	313408	6386512	Laurie & Rhonda Caban
GW078806	140-W	2.84	313439	6386593	Greg Caban
GW065097	177-W	11.85	313073	6386604	Greg Banks
GW078031	248-B	11.65	313298	6387553	Paul Dunn & Susan Irwin
GW078029	89-B	23.62	313446	6386014	Ian & Annette Bartholomew
Not identified in the field survey					
GW066607	-	6.7†	313269‡	6386399‡	-
GW071569	-	14.6†	313169‡	6387568‡	-
No identifiable registration number					
	138-W	11.82	312996	6386427	Greg Banks
-	217-B	100	313234	6387612	George & Honor Lianos
-	217-W	60	313228	6387595	George & Honor Lianos
-	129-W	100	313233	6386442	Damien & Danielle Hanson

Note: *Coordinates in MGA 94 Zone 56 (field data collected from handheld GPS)*
† *Depth from groundwater database (PINEENA)*
‡ *Coordinates from groundwater database (PINEENA)*

5.10 Groundwater Dependent Ecosystems

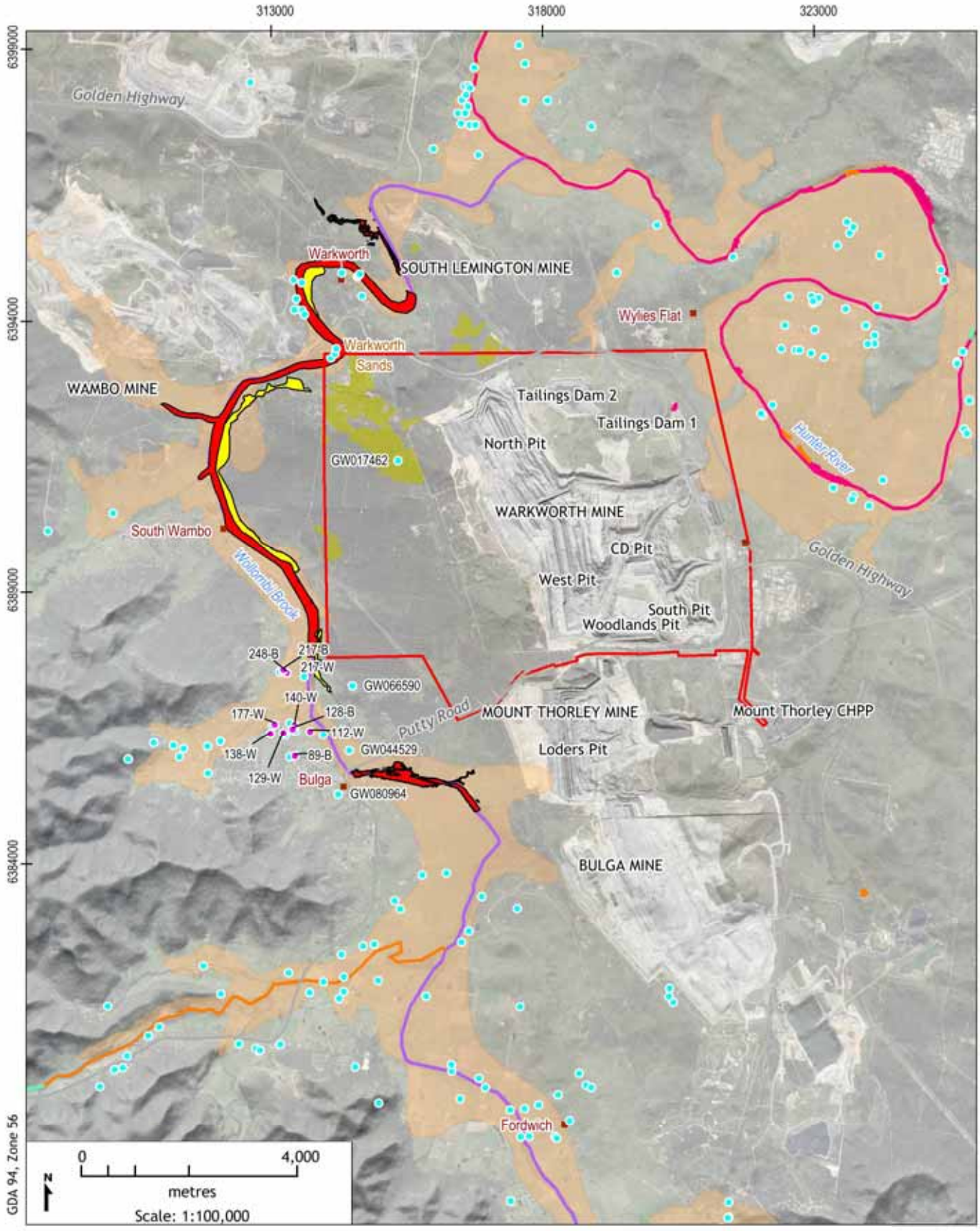
Aquatic or specifically Groundwater Dependent Ecosystems (GDEs) are defined as *"communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater"*. The Project area has historically been partially cleared of vegetation and used for grazing; however, the southern portion of the Project area remains largely vegetated.

The Federal Government has established the National Atlas of GDEs (GDE Atlas), based on the current knowledge of GDEs across Australia. The atlas shows known GDEs and ecosystems that potentially use groundwater, and is considered the most comprehensive inventory of the location and characteristics of GDEs in Australia. The GDE Atlas (Figure 5.11) shows that are known GDEs identified by previous fieldwork along Wollombi Brook. There are also areas identified as having a moderate to high potential for groundwater interaction.

Cumberland Ecology (2010) identified two potentially groundwater dependent vegetation communities along Wollombi Brook. These were the Hunter Valley River Oak Forest and the River Red Gum Floodplain Woodland. The vegetation communities occur in a thin riparian zone along Wollombi Brook, about 4 km from the mining areas (Figure 5.11).

Vegetation associated with the Warkworth sands also has the potential to be a GDE, particularly in swales between dunes. The Warkworth sands are recharged from rainfall derived recharge through the sandy soils. Permian sediments that weather to low permeability clays at the base of the sands are thought to impede downward percolation of recharge forming a locally perched

groundwater system. The permanence of groundwater with the formation is unknown but the water table would be expected to fluctuate with climatic patterns or rainfall and also from evapotranspiration. The thick relatively low permeability Permian overburden is thought to impede leakage of groundwater from the Warkworth sands towards MTW.



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Private Bore (Pineena 2013)
- Bore Census (AGE 2010)
- Road
- Alluvium
- Warkworth Sands Woodland
- Place name

GDE Atlas - Surface Expression

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction
- Identified in previous study: fieldwork

Potential Groundwater Dependent Ecosystems

- Hunter Valley River Oak Forest
- River Red Gum Floodplain Woodland

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Groundwater Users and GDEs

DATE: 14/5/2014

FIGURE No: 5.11

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

6 POLICY AND LICENSING REQUIREMENTS

Groundwater associated with coal measures is governed under the NSW *Water Act 1912* (Water Act), while the NSW *Water Management Act 2000* (WM Act) regulates the use and interference with surface water and alluvial groundwater in the region.

6.1 Water Act 1912

The Water Act governs water licences from water sources including rivers, lakes and groundwater aquifers in NSW. It also manages the trade of water licences and allocations. The Water Act is progressively being replaced by the WM Act, with water sharing plans in place, except for Permian groundwater sources.

6.2 Water Management Act 2000

The objectives of the WM Act include the sustainable and integrated management of the State's water for the benefit of both present and future generations. The WM Act provides clear arrangements for controlling land based activities that affect the quality and quantity of the State's water resources. It provides for three types of approvals:

- *Management works approvals;*
    - water supply work approval;
    - drainable work approval; and
    - flood work approval (Section 90 WM Act);
- *Water use approval – which authorises the use of water at a specified location for a particular purpose, for up to 10 years (Section 89 WM Act);*
- *Activity approvals comprising:*
    - controlled activity approval; and
    - aquifer interference activity approval – which authorises the holder to conduct activities that affect an aquifer such as approval for activities that intersect groundwater, other than water supply bores and may be issued for up to 10 years (Section 91 WM Act).

The proposal to extend the existing mine footprint requires an 'aquifer interference activity approval'. This report addresses the groundwater assessment component required for approval.

6.2.1 Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources

The main tool in the WM Act for managing the State's water resources are water sharing plans. These are used to set out the rules for the sharing of water in a particular water source between water users and the environment and rules for the trading of water in a particular water source. The Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources (henceforth referred to as the Water Sharing Plan) commenced on 1 August 2009. The Water Sharing Plan includes the Hunter unregulated rivers and creeks, the highly connected alluvial groundwater above the tidal limit, and tidal pool areas. A licence holder's access to water is managed in the water sharing plan through the long-term average annual extraction limit which sets the total annual extraction rate through daily access rules.

The long term limit is a management tool against which total extraction will be monitored and managed over the 10-year life of the plan. The rules in the plan that determine when licence holders can and cannot pump on a daily basis are more specific. Basic landholder rights do not require a water access licence. However, water access licences are required for mining activities where these activities intercept an unregulated river or connected aquifer water.

6.3 Aquifer Interference Policy

In September 2012 NOW released the AIP, which covers water licensing and assessment processes for aquifer interference activities within NSW. The AIP was brought out after the AGE (2010) MTW groundwater assessment, which addressed the legislation of the time, the *Water Act* and *WM Act*. The AIP was designed to address the 'incidental' take of groundwater from significant developments (i.e. mines), which was not accounted for in the *Water Act* or *WM Act*. The AIP ensures that all groundwaters are accounted for, in order for a Water Sharing Plan to be implemented and function effectively.

The AIP forms the basis for assessment of aquifer interference activities under the EP&A Act. It clarifies the need to hold water licences under the WM Act and Water Act and establishes whether 'minimal impact' occurs. The policy addresses any activity which involves any of the following:

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

The AIP outlines highly productive and less productive groundwater sources, as well as high and minimal impact interference activities. The alluvial aquifers associated with Wollombi Brook and the Hunter River are both potentially highly productive aquifers, while low permeability units and saline groundwater within the Permian coal measures are classed as a less productive groundwater source. Section 0 addresses the key groundwater related requirements of the AIP processes.

7 MODELLING APPROACH

A numerical groundwater flow model was used to assess the potential influences of the proposal on the groundwater regime. The results of this assessment are described in this section, with the technical details of the modelling included in Appendix C.

In summary, the potential influences were assessed by:

- developing a numerical model using the available hydrogeological data and information (refer Section 5);
- calibrating the model using available historical mine stresses at MTW, Bulga and Wambo (1981 to 2013), groundwater levels and stream flows recorded in the area (refer Appendix C);
- assessing the uncertainty and variability in the calibration by running multiple models with randomly generated parameters held within measured and realistic bounds (refer Appendix D);
- simulating the drawdown and water take of the proposed mining from 2015 to 2035;
- assessing the uncertainty and variance in the predictions (refer Appendix D); and
- simulating recovery of the groundwater system after mine decommissioning for an additional 1000 years.

The impacts of the proposal were simulated by running the following two modelling scenarios:

1. The first model included all the mining associated with the proposal, and all other mining activities within the model domain; and

2. The second model included all surrounding mining (MTO, Wambo and Bulga mines), but excluded the mining operations associated with the proposal.

The model addresses the requirements of the NSW AIP by estimating the:

- volume of water inflow from the Permian strata and coal seams;
- drawdown induced in the Permian strata and coal seams;
- potential for drawdown and groundwater extracted from alluvial aquifers;
- potential for changes in baseflow to Wollombi Brook and the Hunter River;
- potential drawdown of groundwater levels in surrounding private landholder bores; and
- changes in groundwater salinity.

Recent water level data has been collected from the MTW groundwater monitoring network, as well as from new bores installed since the original model by AGE (2010). This data was utilised to gain a good understanding of the groundwater regime within the proposal area, which is detailed under Section 5 . The numerical model has been refined based on this newly collected data, and from peer and independent reviews, creating a robust representation of the local groundwater regime.

As the groundwater regime has been highly modified by mining activities, the model was first used to simulate the approved and historical mining. This then provided the appropriate antecedent conditions prior to the assessment of the current proposal.

Dr Frans Kalf reviewed the modelling work a key stages during the project, and reported on the applicability of the modelling.

7.1 Numerical Model Development

A numerical model, using MODFLOW SURFACT software, was developed to assess the impact of the proposal on the groundwater regime. The model developed by AGE (2010) formed the basis of the numerical model, but a number of changes were implemented to improve the predictive capability of the model including:

- representing the gradual development and recharge process through the spoil piles;
- adding the existing and proposed tailings storage facilities;
- increasing the number of layers to better represent the coal seams and interburden units; and
- conducting a transient calibration using water level data from the monitoring bore / VWP network.

The 16-layer model simulates the key features in the local groundwater regime including the alluvium associated with Wollombi Brook and the Hunter River, the layered interburden and coal seams of the Permian coal measures, as well as the underlying and unmined Permian coal seams. The active model domain, shown in Appendix C Figure C-5 covers an area of approximately 344 km^2 and extends approximately 19 km from west to east and 24 km from north to south. The model domain encompasses MTW, as well as the Bulga and Wambo mines. Further details regarding the model construction and design are included in Appendix C.

7.2 Numerical Model Calibration

Appendix C describes the calibration of the model in detail. The appendix provides sufficient information to assess the model performance against the Australian Modelling Guidelines (Barnett *et al* 2012).

The model was first calibrated manually by adjusting model parameters and then using specialised software (PEST) to optimise the calibration. Parameters adjusted during the calibration were intentionally constrained within logical bounds, which in some cases came at the expense of a better statistical fit between model and observed groundwater level data.

The calibrated steady-state model simulated as close as possible pre-mining water levels. The groundwater levels generated by this model were then used as the initial conditions for a transient calibration. The transient model simulated the currently approved mining at MTW, Bulga and Wambo for the period 1981 to 2013. The model divided this baseline period into annual stress periods with mines advancing in annual blocks. Recharge to the model was applied as a percentage of annual measured rainfall distributed over zones representing the outcropping alluvium, Permian regolith and emplaced spoil areas. The model represented perennial rivers/streams with a constant head set in rivers (using the SURFACT 'River' package) and ephemeral streams as drains (also using the SURFACT 'River' package).

Appendix C describes in more detail the model set-up, parameters, calibration process and uncertainty analysis. Figure C-11 to Figure C-20 within Appendix C present modelled-versus-observed water levels for all monitoring bore/VWP sites. Several of the data points presented in these figures were excluded from the calibration process as they appeared in error compared to surrounding data and the conceptualisation. However, for completeness all data supplied by Coal

& Allied for the study area has been included in these graphs. Appendix C further discusses the excluded datasets.

7.2.1 Steady State Starting Heads

The objective of the steady state model was to simulate pre-mining groundwater levels, and to capture natural background conditions for the alluvial aquifer. The primary requirement of the steady state model was to supply stable starting heads to the transient calibration. Figure 7.1 shows the modelled-versus-observed scatter plot for the steady-state run.

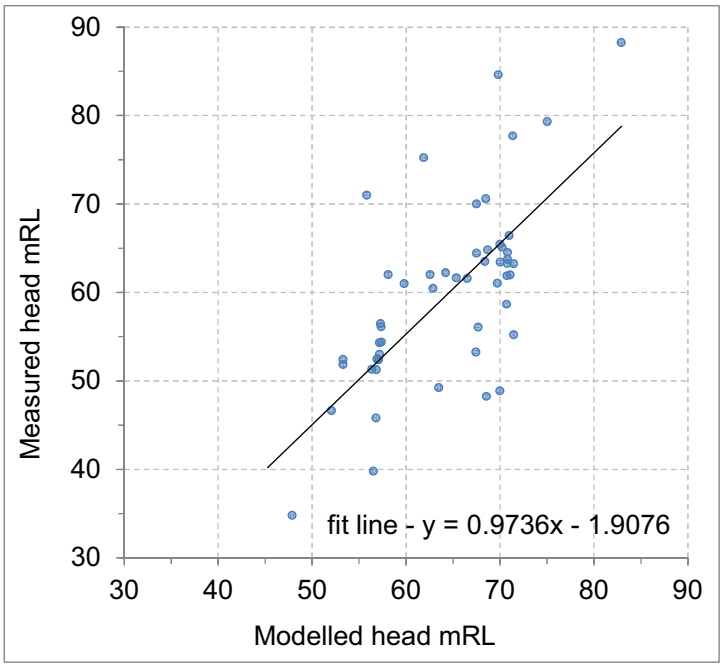


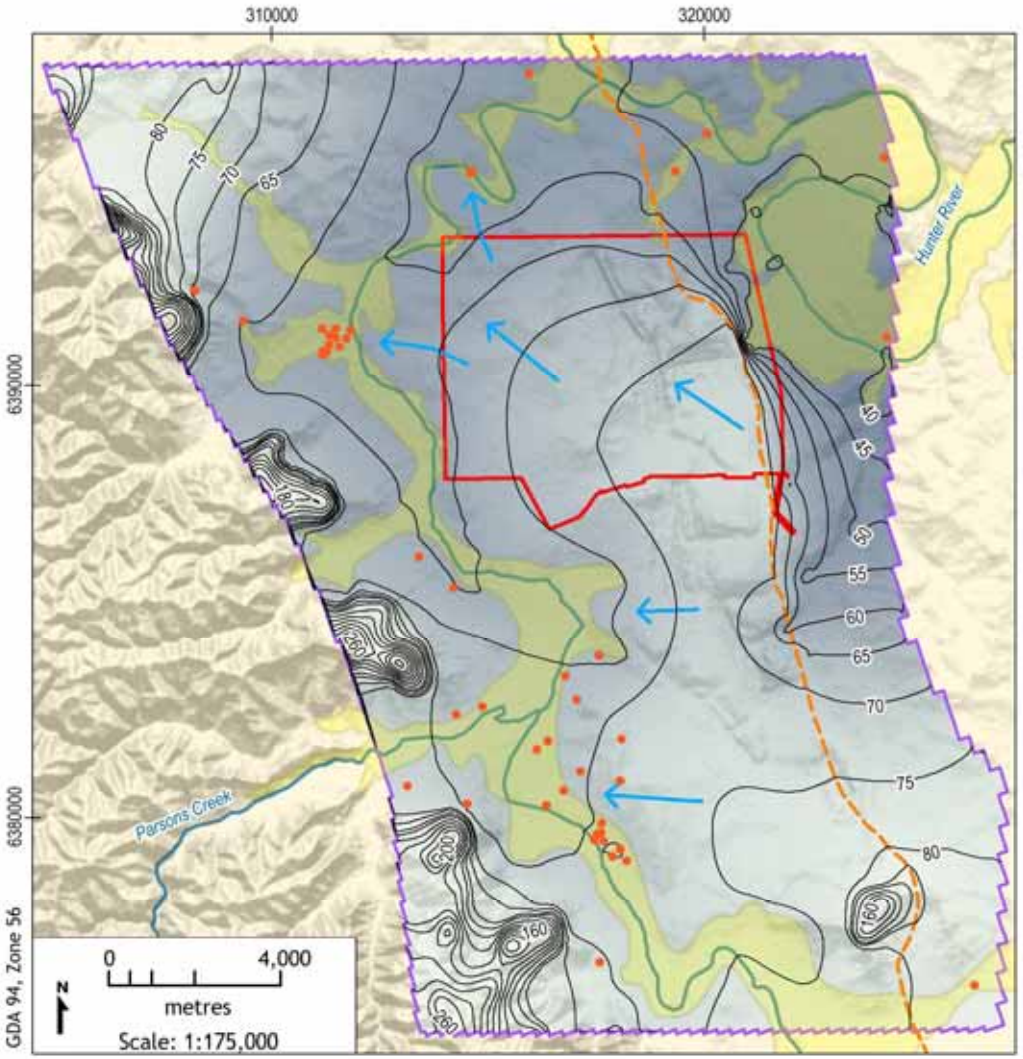
Figure 7.1: Steady state scatter diagram

Whilst the measured and simulated water levels do not correlate perfectly, it is important to note the steady state model was only used to set up a stable starting groundwater level for the pre-mining period. The suitability of much of the data to adequately represent pre-mining conditions is not known. The calibration process therefore put limited weighting on fitting these points.

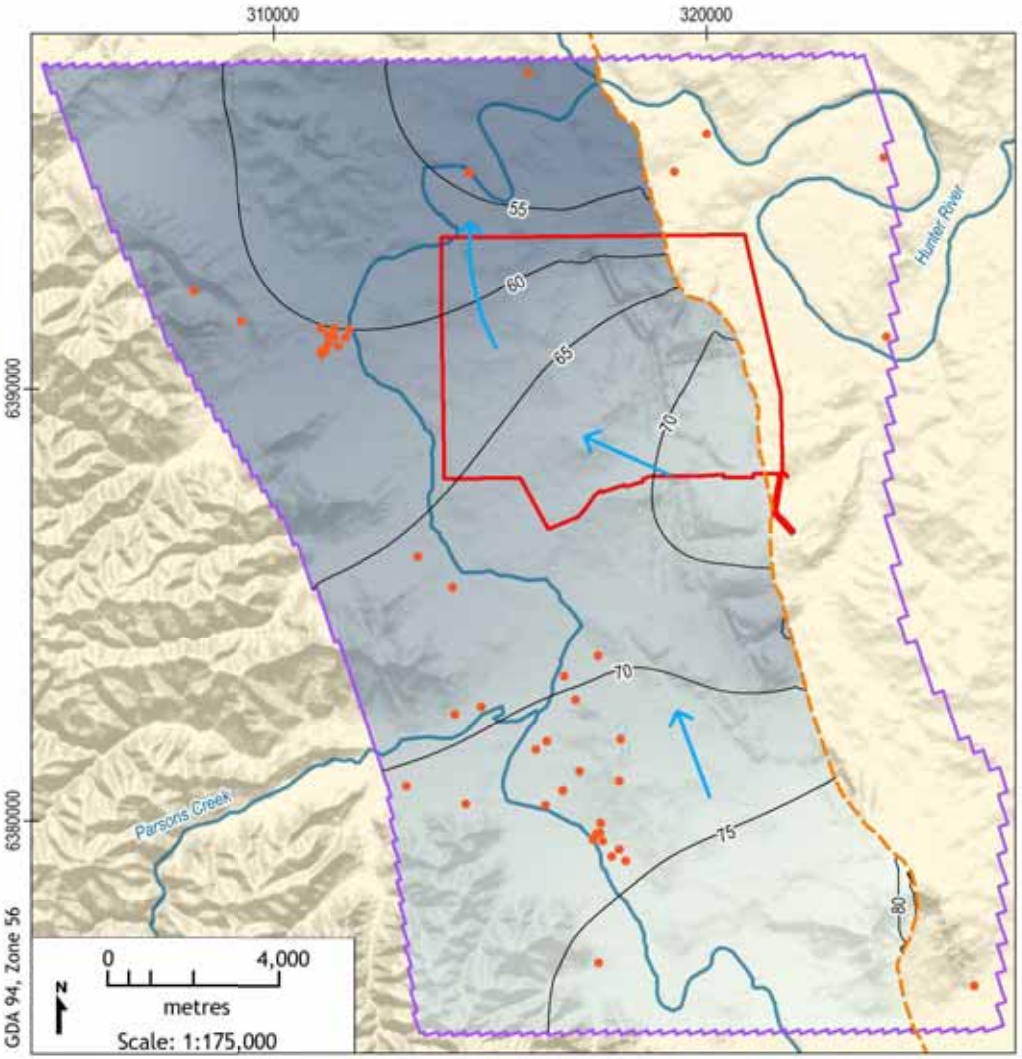
Figure 7.2 shows the simulated steady-state pre-mining groundwater levels in model Layer 1 and Layer 13. The Layer 1 groundwater levels are a smoothed reflection of topography in the region. A topographic high between the MTW and Wollombi Brook is present with groundwater levels reaching 65 mRL. The potentiometric surface within the confined coal sequence shows that groundwater flow is in a generally northerly direction.

The root mean square (RMS) of the steady state model is 9.2 m while the scaled root mean square (SRMS) is 15.7%. This exceeds the 10% suggested by the Australian Groundwater Modelling Guidelines (Barnett *et al* 2012). However, this steady state calibration is considered adequate given the lack of pre-mining groundwater level data, which is due to the extensive history of mining within the region. The suitability of the model predictions is also further assessed through transient calibration, which provides a further measure of the model predictions versus measured groundwater levels.

Steady State Heads - Layer 1 - Alluvium and Regolith



Steady State Heads - Layer 13 - Mount Arthur Seam



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation
- Steady state observation bore
- Groundwater level contour
- Inferred groundwater flow direction
- Major watercourse

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Steady State Heads
Start of Transient Calibration
Layer 1 and Layer 13

DATE:
14/5/2014

FIGURE No:
7.2

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

7.2.2 Transient Calibration

The hydraulic heads and strata hydraulic properties from the steady state model provided the starting values for the transient calibration of the model. The steady state calibration was used to establish pre-mining groundwater conditions (prior to 1980), while the transient calibration was used to establish current groundwater conditions since mining commenced in 1981 until 2014.

Figure 7.3 shows a modelled versus observed transient scatter plot for the transient calibration. Figure 7.4 shows selected representative modelled versus observed hydrographs. Figure 7.5 shows the simulated groundwater levels in Layer 1 and Layer 13 for 2013 at the end of the transient calibrated model run.

The calibrated transient heads output of the model run provided the antecedent conditions prior to simulating the proposed future mining. The zone of depressurisation generated by mining is evident in both groundwater level surfaces (Figure 7.5). The modelled-versus-observed transient hydrographs for all monitoring locations show variable fit, from good matches in key monitoring locations near to and beneath Wollombi Brook alluvium, to some significant over- and under-prediction in some nested VWP data locations (see Appendix C).

Statistically the overall SRMS of the calibration of 15.1% is greater than the upper limit of 10% in the Australian Groundwater Modelling Guidelines (Barnett et al 2012). During initial calibration the SRMS was skewed by the density of data from bores with automatic level recorders. Some bores for example have recorded levels every 15 minutes and this led to over representation of these bores within the statistical analysis. In contrast many other bores have only monthly or greater periods of manual dip data available. Bores with high resolution data were resampled to a weekly average prior to final calibration and reporting of statistics.

The SRMS shows statistically what is evident graphically in the hydrographs in Appendix C, that there are some predictions, particularly those from VWPs in the Permian strata that are significantly different than observed. In general, however, transient modelled head data reflects the zone of depressurisation that is being generated by the active mining. It should also be noted that roughly as many monitoring data points over-predict as under-predict, indicating the calibration is in middle ground between under- and over-prediction. Figure 7.6 shows the average residual for each monitoring location with red dots showing where the model is over predicting heads and the blue dots are where the model is under predicting. Generally the model over predicts drawdown close to the current mine areas and under predicts effects further to the west. Critically, predictions are good in Layers 1 to 9 around the key assessment location of Wollombi Brook alluvium. Predictions near these key sensitive receptors were considered to be more important than predictions near the active pit. Even though the calibration statistics are above the criteria recommended in the Australian model guidelines, the model is still considered to represent well the major processes occurring in the groundwater regime and the impact of mining.

Appendix C discusses in more detail the simulated and observed groundwater levels. A key limiting factor in the calibration is the lack of information on the historical sequence of mining. This, in effect, inputs another variable into the model that may further prevent significant improvement in the current calibration.

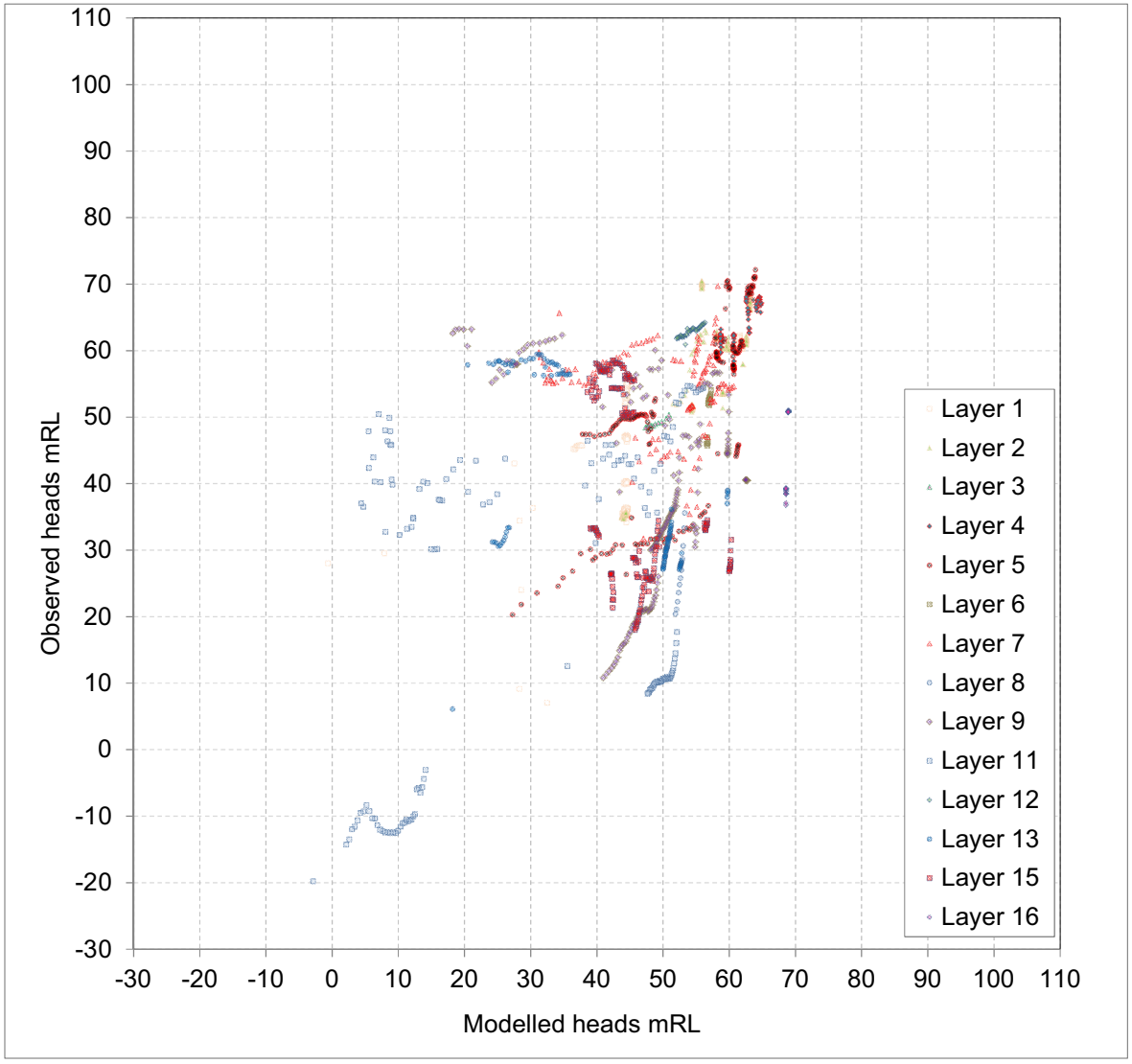


Figure 7.3: Transient scatter plot of modeller versus observed heads

Figure 7.4-A shows example modelled versus observed groundwater heads to the north east of the Warkworth spoil. The observed data shows that there has been a recovery of any significant mine induced drawdown in this area from mining in the Warkworth pit in the 1980s and 1990s. The simulated mine effects can be seen in modelled data with a maximum drawdown around 2000 and subsequent recovery. Other bores in this area to the north east of the Warkworth spoil show similar groundwater heads that appear to have recovered since prior mining (see Appendix C, Figure C-12).

Figure 7.4-B shows example modelled versus observed groundwater heads directly to the north (350 m) of the Warkworth pit. The model data shows an over prediction in drawdown at this site. The use of MODFLOW Drain cells to simulated mine pit dewatering is thought to overestimated impacts close to the pit high and low-walls. The exact prediction of pore pressures in the pit high-wall and low-walls was not a priority for this study, with distal effects at bore users and alluvium deemed more important for the EIS. This over prediction of drawdown at this site is thought conservative, resulting in over prediction of inflows from the Permian coal measures. Appendix C, Figure C-11 shows results from other nested bores in the area north and north east of Warkworth pit.

Figure 7.4-C shows example modelled versus observed groundwater heads to the west of the Warkworth high-wall. The observed data from this site is from a multi-level VWP and shows a significant vertical hydraulic gradient between seams. The modelled data shows good agreement at the sensor in Layer 13 which monitors the Mt Arthur seam, the base of mining in the Warkworth pit. Other sensors at this site show both over and under predictions. The level of fit at this site demonstrates that the model is predicting hydraulic gradient between seams. Appendix C, Figures C-13 to C-15 shows results from other nested monitoring sites west of the Warkworth Pit high-wall.

Figure 7.4-D shows example modelled versus observed groundwater heads to the east of the current active Warkworth pit within the pit spoil south of TD2 (WD609) and within unmined ground below the spoil (WD615P1). WD609 data demonstrates that a significant mounded water table is present in the spoil next to TD2. The modelled data for WD609 shows the effects of mining at this location with maximum drawdown in 2001 and a subsequent recovery in spoil from enhanced rainfall recharge leakage from TD2. ATC (2014b) discusses the potential for tailings dams to leak significant quantities of water during early tailings emplacement with a reduction in leakage as the sediment thickness increases and compacts within the TSF. The model has been built and calibrated to simulate this TSF leakage and calibrated to WD609 water levels.

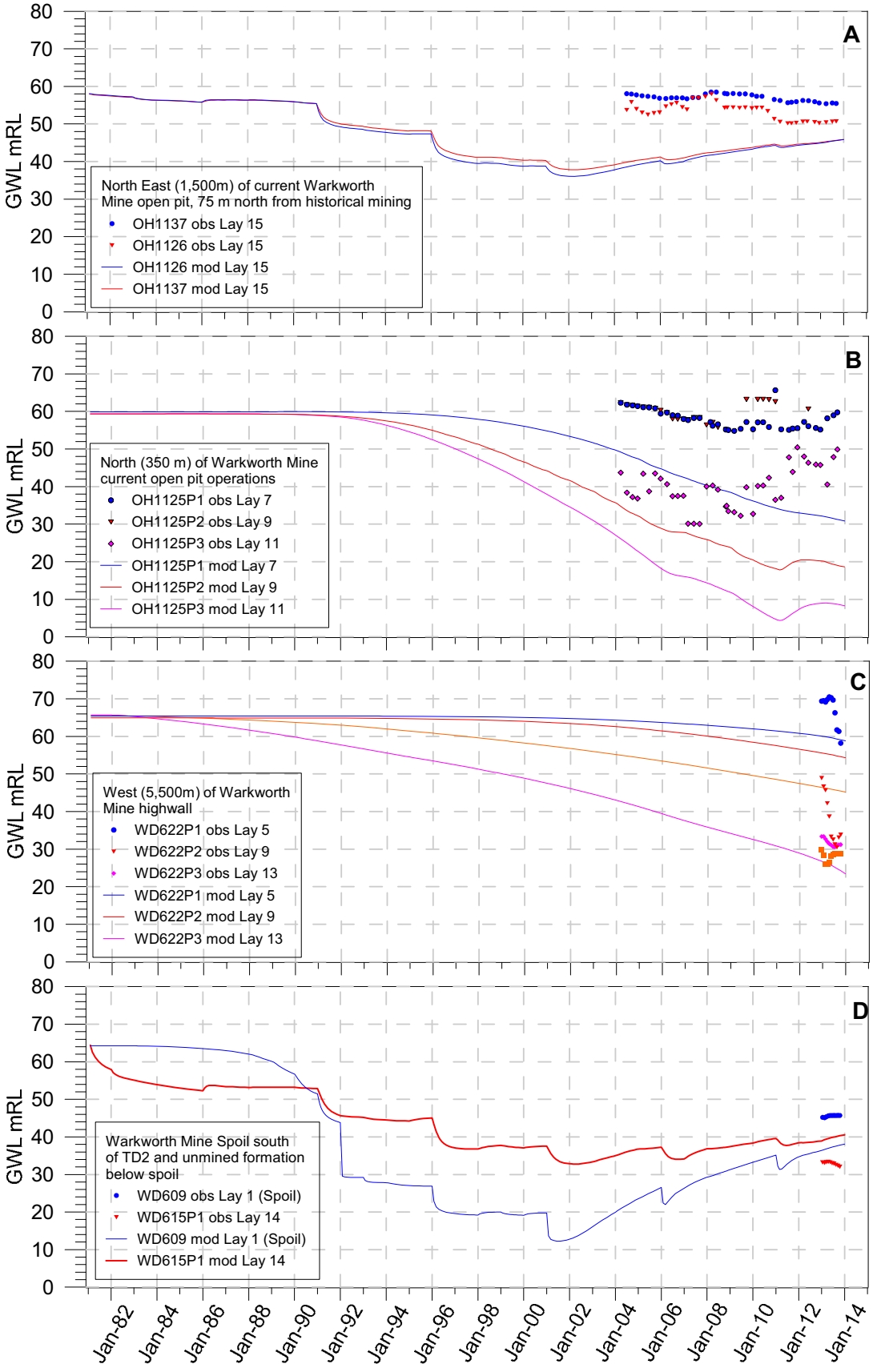
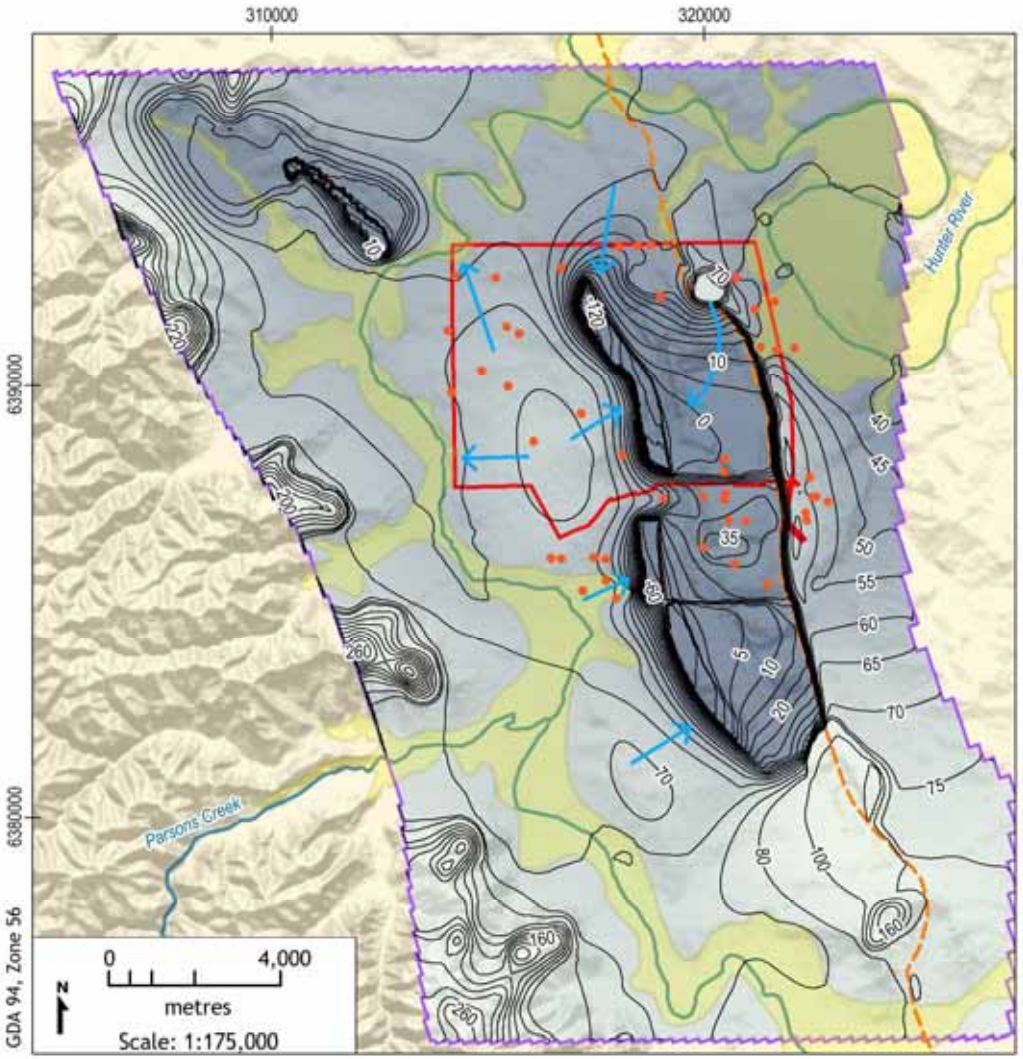
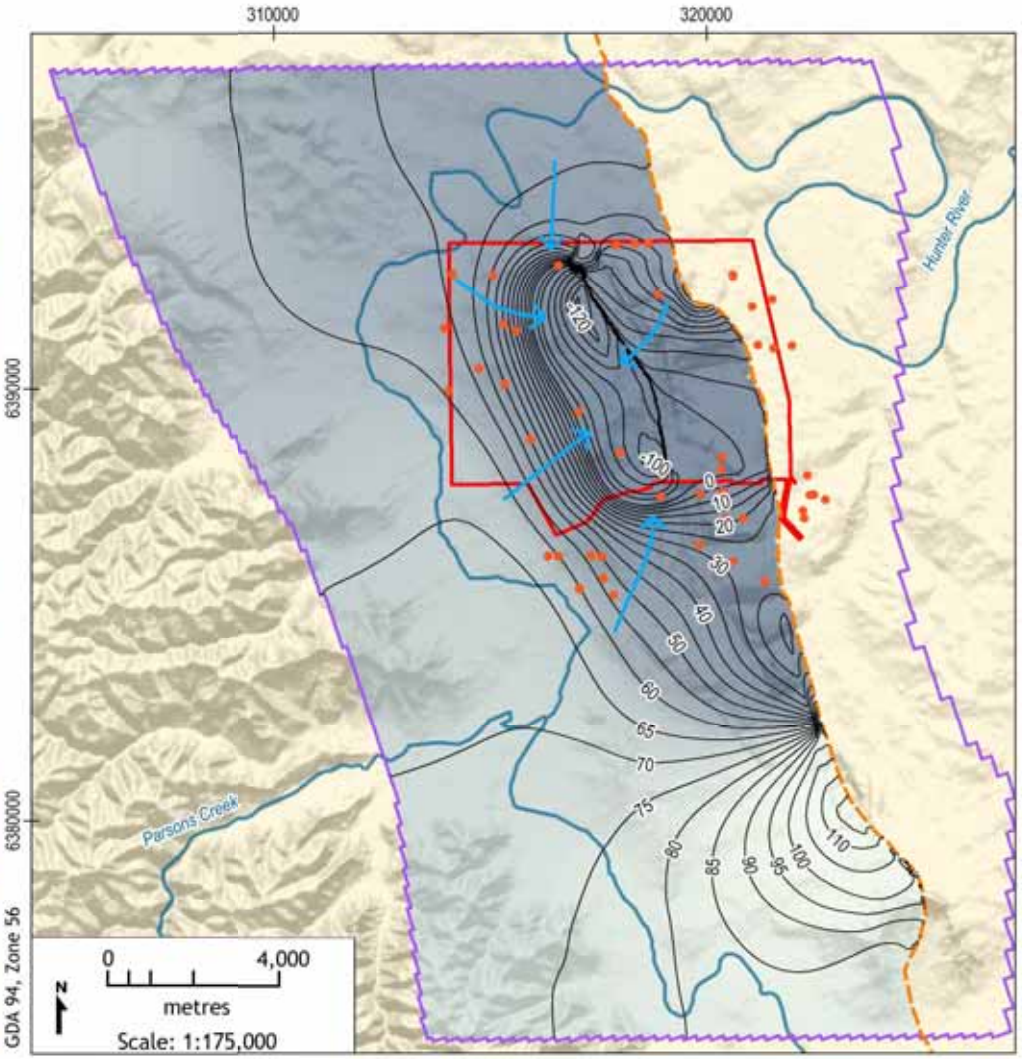


Figure 7.4: Representative transient modelled versus observed hydrographs

Heads - Layer 1 - Alluvium and Regolith



Heads - Layer 13 - Mount Arthur Seam



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation
- Transient observation bore
- Groundwater level contour
- Inferred groundwater flow direction
- Major watercourse

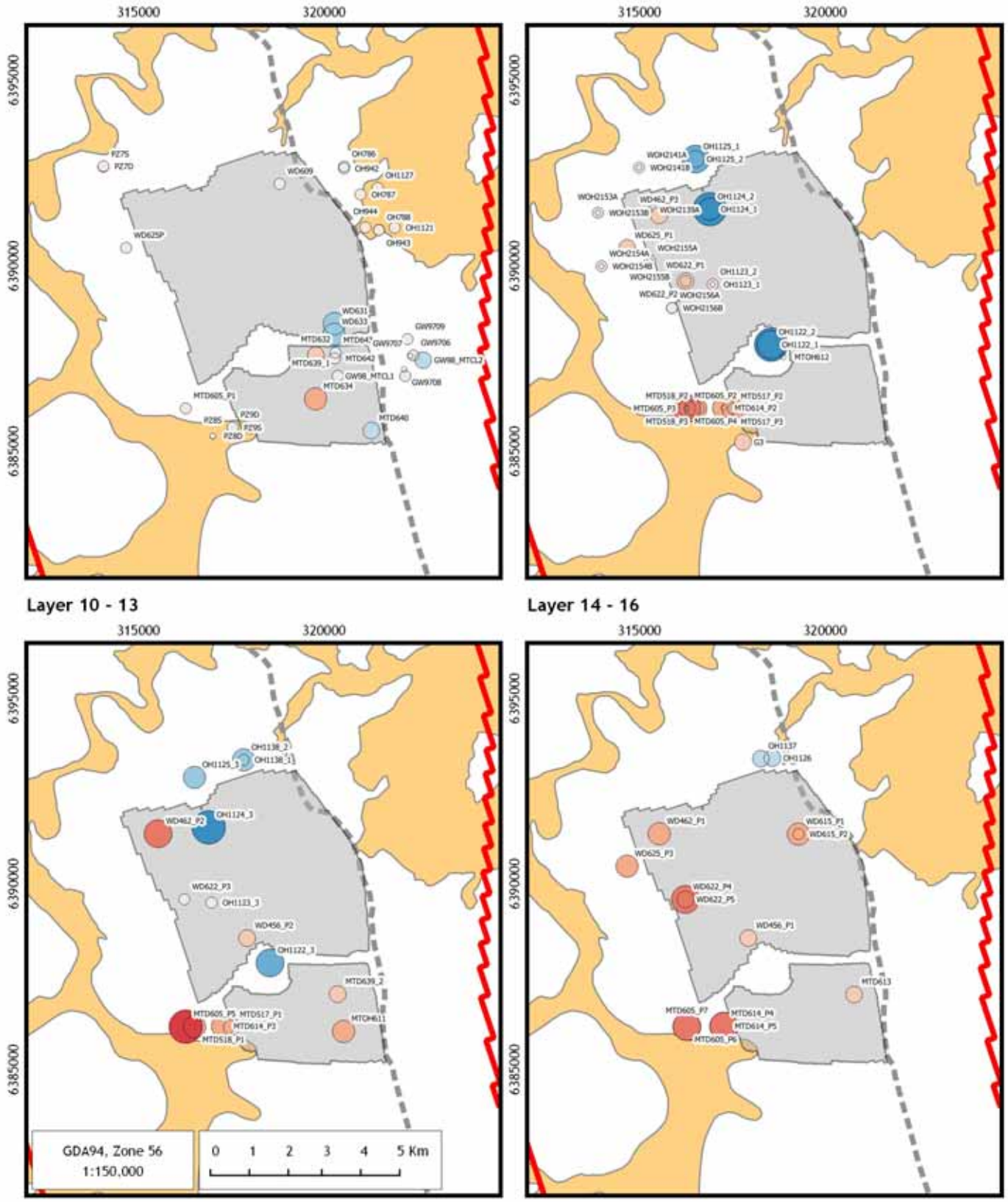
Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Heads at the End of Calibration Run (Year 2013)

DATE: 14/5/2014

FIGURE No: **7.5**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



LEGEND

- Active grid boundary
- Mt Thorley mine
- Warkworth mine
- Subcrop line Jerrys Plains
- Alluvium

Residuals

Overpredicting

- -50 to -40
- -40 to -30
- -30 to -20
- -20 to -10
- -10 to -2
- -2 to +2
- +2 to +10
- +10 to +20
- +20 to +30
- +30 to +40
- +40 to +50

Underpredicting

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Model Calibration - Distribution of Residuals

DATE 14/5/2014

FIGURE No: **7.6**

© 2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

8 IMPACT ASSESSMENT

As discussed previously the proposal is located in an area already disturbed by mining activities. The contribution of the proposal to the cumulative impacts on the groundwater regime was assessed. The impacts assessed from the model results included:

- drawdowns associated with the Proposal;
- magnitude of drawdowns on the private landholder bores;
- magnitude of drawdown and water take from the alluvium of Wollombi Brook and Hunter River;
- changes to stream baseflow and salinity;
- negative influence on GDEs;
- seepage rates into the Warkworth Mine;
- implications for groundwater licensing;
- post mining recovery, including final void water levels; and
- water quality and leachate migration from mine spoil and TSFs.

8.1 Results of the Predictive Model Run

8.1.1 Groundwater Levels and Drawdown

Two model runs were used to predict the change in groundwater levels due to mining. The first run was a simulation without the proposal, and therefore only included the surrounding mining and historical mining at Warkworth. The second run included the proposal as well as the surrounding mining. The drawdown due to the proposal only, was determined by subtracting the drawdown simulated by each model run. It is important to note the first scenario assumed all mining ends at 2015, and there are no final voids remaining. This was a conservative assumption that allowed groundwater levels to recovery relatively rapidly from 2015 in the first scenario, and magnified the difference with the second scenario that had mining continuing until 2035.

Figure 8.1, Figure 8.2, Figure 8.3 show simulated groundwater levels and drawdown at the end of the proposed mining for:

- Layer 1 - alluvium and shallow regolith;
- Layer 9 - Woodlands Hill coal seam - base of MTO; and
- Layer 13 - Mt. Arthur coal seam - base of Warkworth Mine.

Figure 8.1 shows the extent of the drawdown in the water table at the end of mining within the alluvium and regolith outside the floodplain. As shown in Figure 8.1, drawdown within the Wollombi Brook alluvium is predicted to be less than 1 m at the end of mining. A thin tongue of the Hunter River alluvium that encroaches close to Warkworth Mine is predicted to record about 5 m drawdown due to the low transmissivity of this zone. As the Hunter River alluvium thickens to the east, the drawdown decreases to less than 1 m.

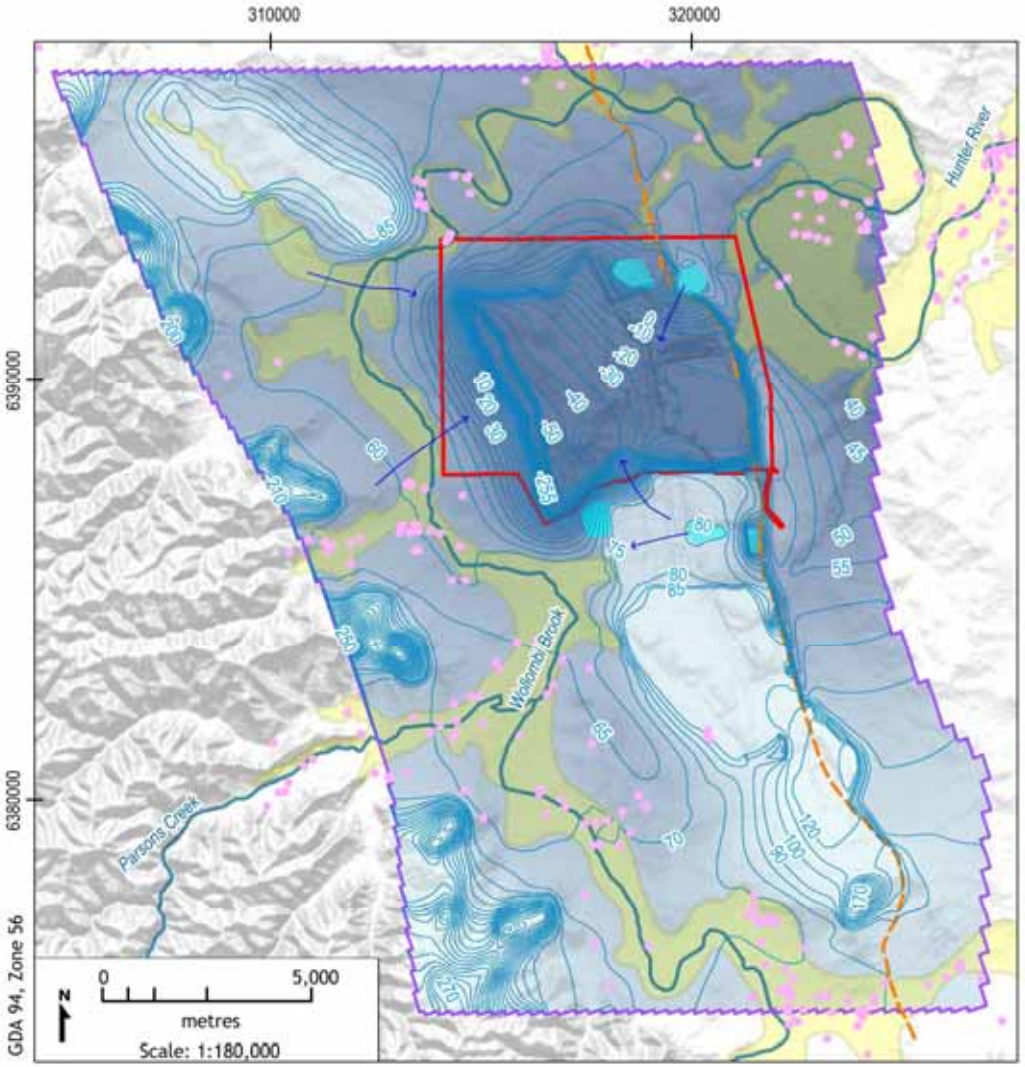
Figure 8.2 shows groundwater levels in Layer 9, which represents the Woodlands Hill seam. The contours clearly show the cumulative impacts of surrounding mining that are depressurising this coal seam. As shown in Figure 8.2, drawdown is predicted to extend westwards beneath portions of Wollombi Brook.

Figure 8.3 shows the predicted drawdown in Layer 13, which represents the Mt Arthur Seam and indicates a slightly larger zone of depressurisation in the deeper coal seam. Figure 8.3 shows drawdown extending to the northern boundary of the model, a “no flow” at the Hunter River Cross Fault. This fault offsets the coal seams and therefore acts as a barrier to movement of groundwater. The groundwater level contours show the cumulative impacts in the Mt Arthur Seam are limited as the Warkworth Mine is the primary mine targeting this seam in the region.

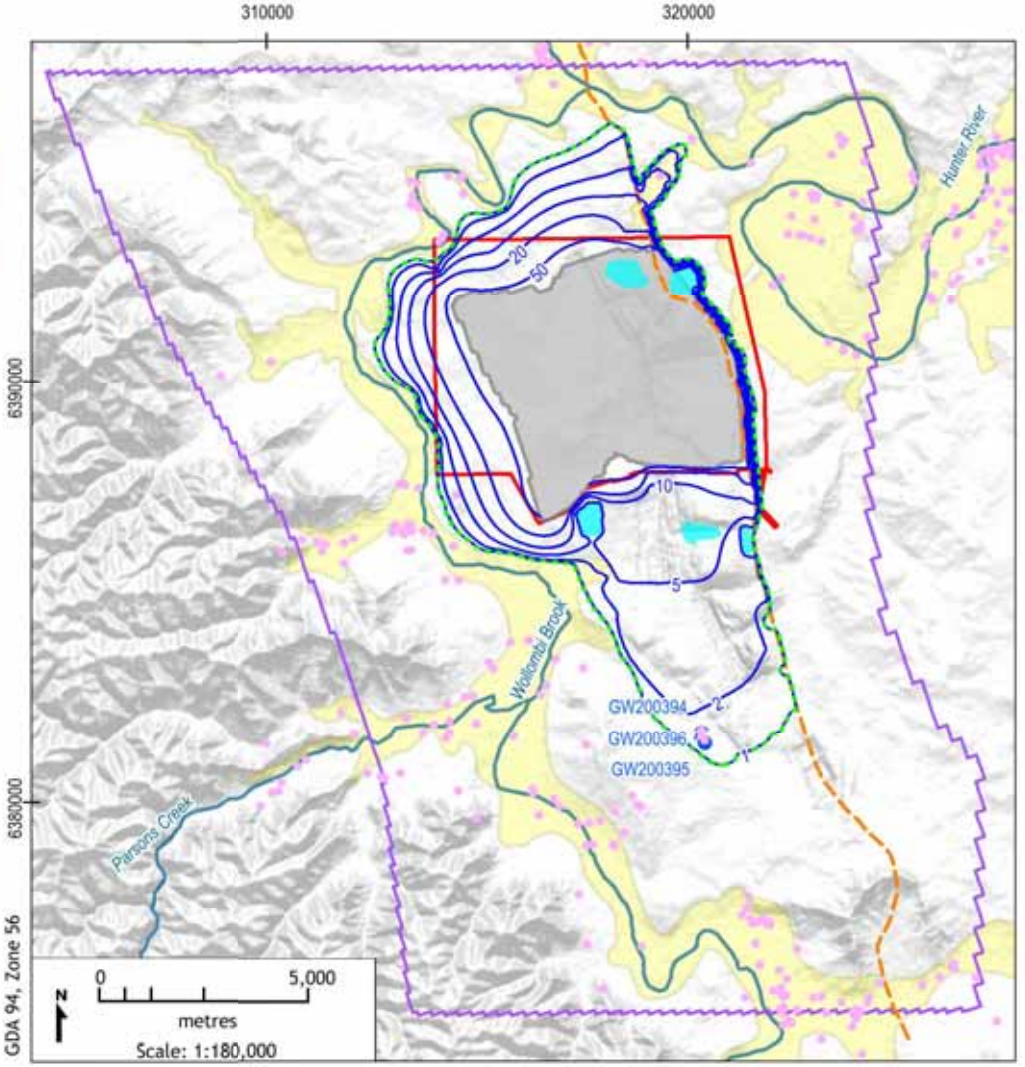
Figure 8.4 shows a schematic west-to-east cross section at the end of mining in 2035. Layer 1 heads show a steep hydraulic gradient next to the high-wall and a shallow hydraulic gradient in the Wollombi Brook alluvium away from the river. The latter is indicative of river leakage from the Wollombi Brook and groundwater flow towards the pit.

A sensitivity analysis was conducted to determine if leakage from the Wollombi Brook was buffering drawdown with the alluvium, by leaking water through the river bed into the aquifer. For this scenario there was no flow in Wollombi Brook for the proposed 21 years of mining. Figure 8.1 shows the 1 m drawdown contours are very close to those of the calibrated model, indicating leakage from the brook does not buffer drawdowns during prediction.

Groundwater Levels - Alluvium/ Regolith (Layer 1) Year 21 (2035)



Change in Groundwater Levels - Alluvium/ Regolith (Layer 1) Year 21 (2035)



LEGEND:

- 5m EOM Groundwater Contours (mAHD)
- Groundwater drawdown contours (m)
- Inferred groundwater flow direction
- 1m drawdown - sensitivity run
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Active model boundary
- Quaternary alluvium (100k)
- Tailings storage facility
- Excavated mine area
- Proposed Warkworth Mine development consent boundary
- Major watercourse
- Subcrop of Jerrys Plains Formati

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

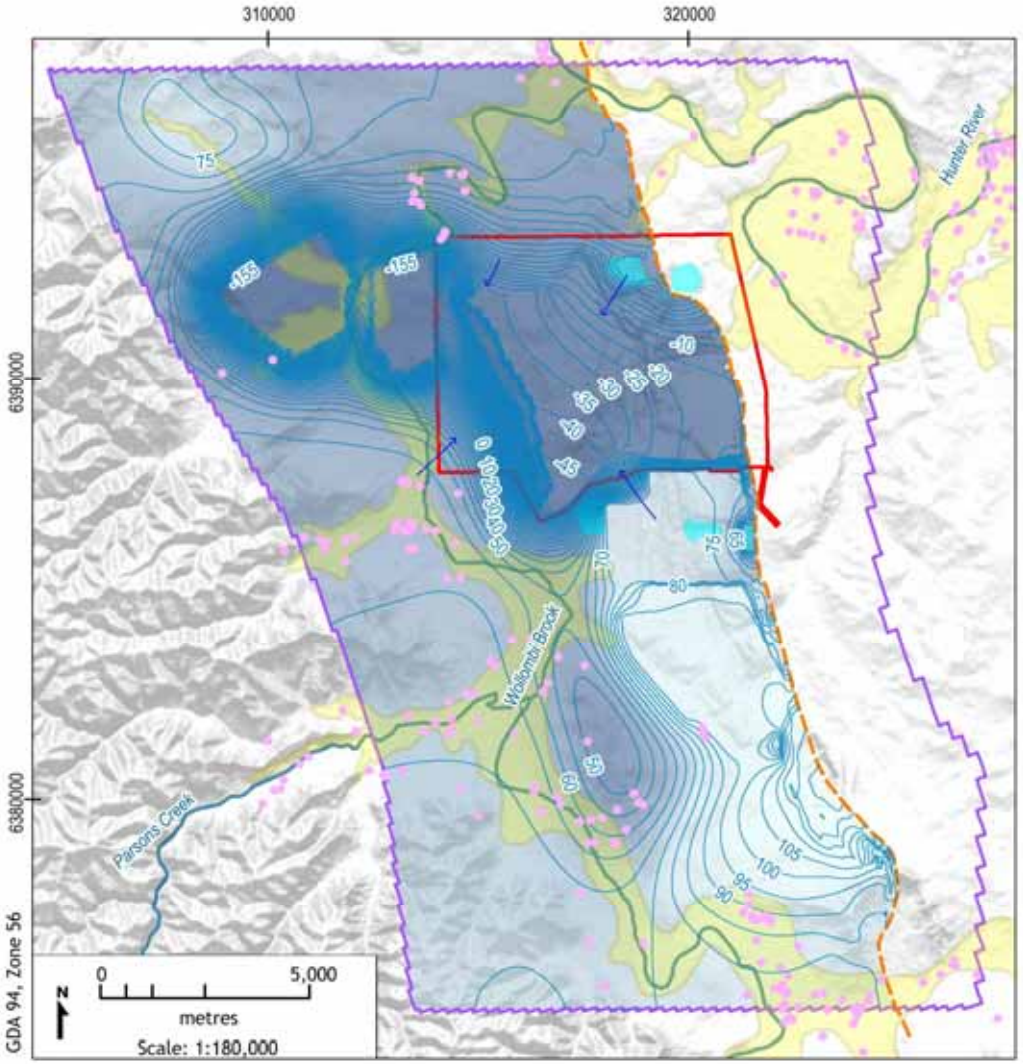
End of Mining Groundwater Levels & Change in Groundwater Levels Layer 1

DATE: 14/5/2014

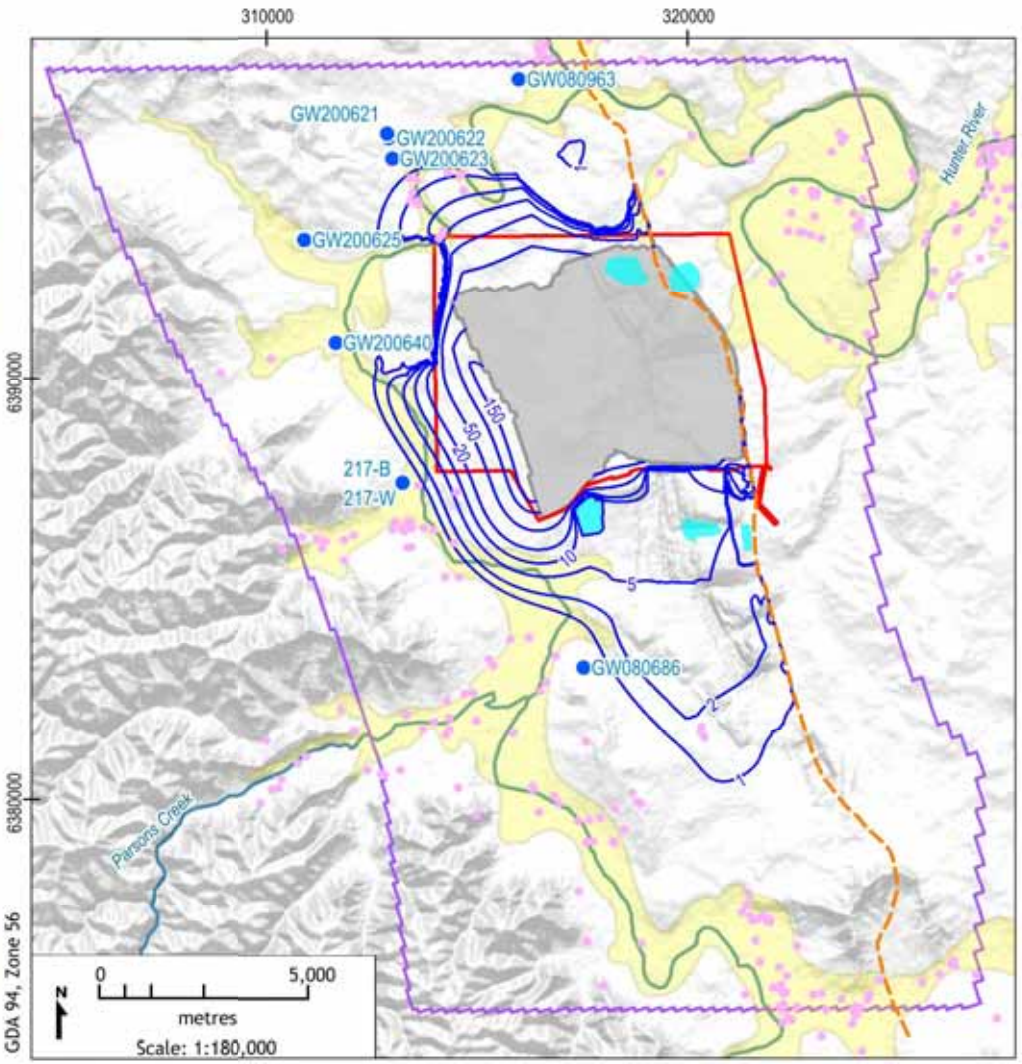
FIGURE No: **8.1**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Groundwater Heads - (Layer 9) Year 21 (2035)



Change in Groundwater Levels - (Layer 9) Year 21 (2035)



LEGEND:

- 5m EOM Groundwater Contours (mAHD)
- Groundwater drawdown contours (m)
- Inferred groundwater flow direction
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Quaternary alluvium (100k, Layer 1)
- Excavated mine area
- Tailings storage facility
- Major watercourse
- Subcrop of Jerrys Plains Formation

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

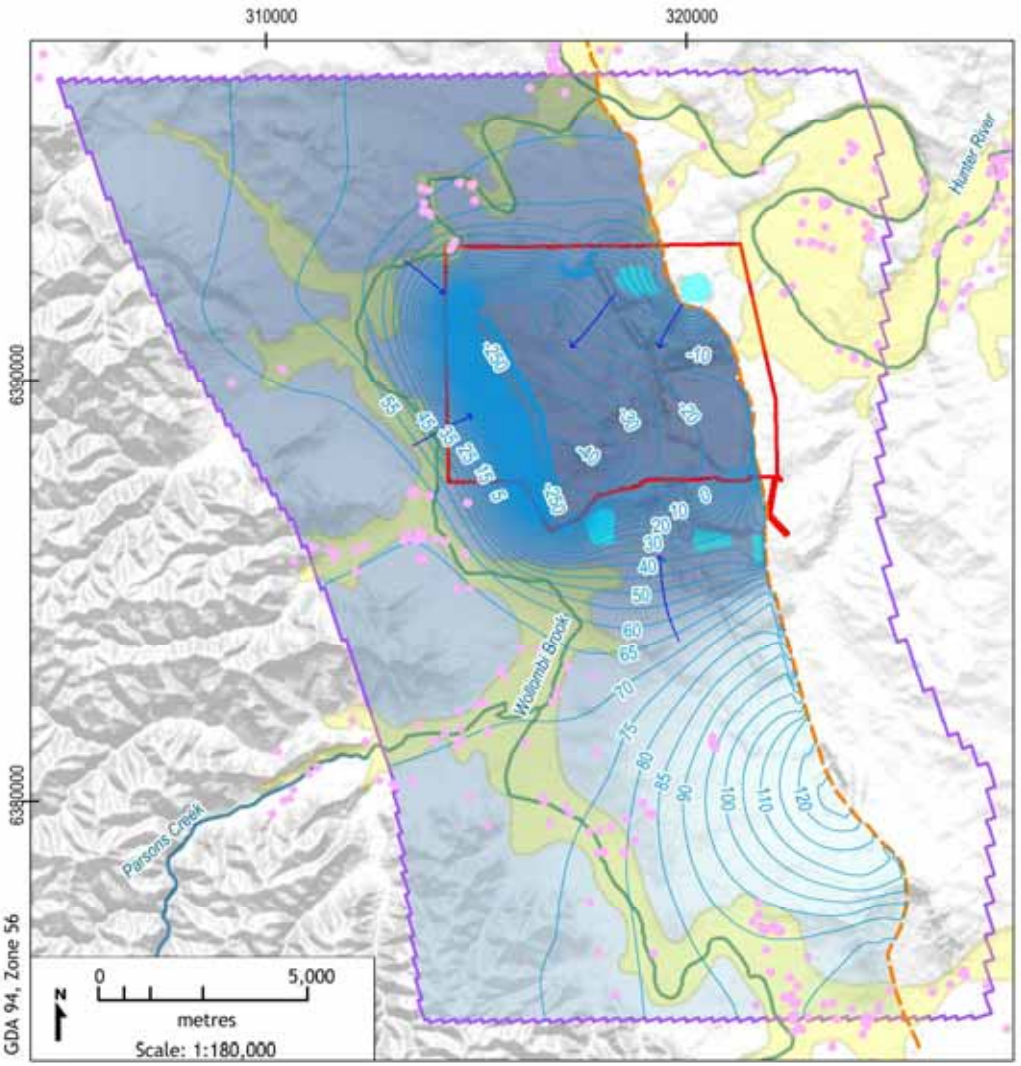
End of Mining Groundwater Levels & Change in Groundwater Levels Layer 9

DATE: 14/5/2014

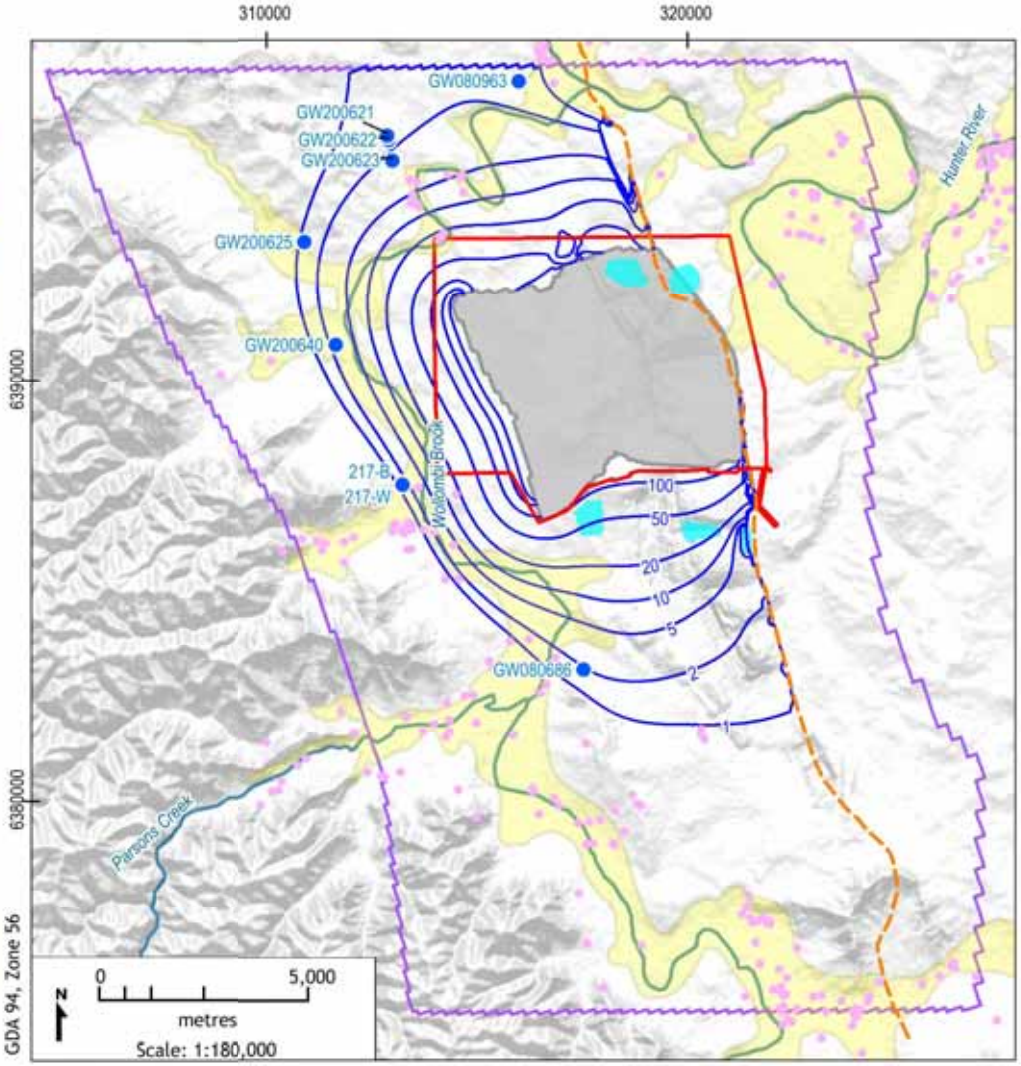
FIGURE No: **8.2**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Groundwater Levels - Mt Arthur Seam (Layer 13) Year 21 (2035)



Change in Groundwater Levels - Mt Arthur Seam (Layer 13) Year 21 (2035)



LEGEND:

- 5m EOM Groundwater Contours (mAHD)
- Groundwater drawdown contours (m)
- Inferred groundwater flow direction
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Quaternary alluvium (100k, Layer 1)
- Excavated mine area
- Tailings storage facility
- Major watercourse
- Subcrop of Jerrys Plains Formation

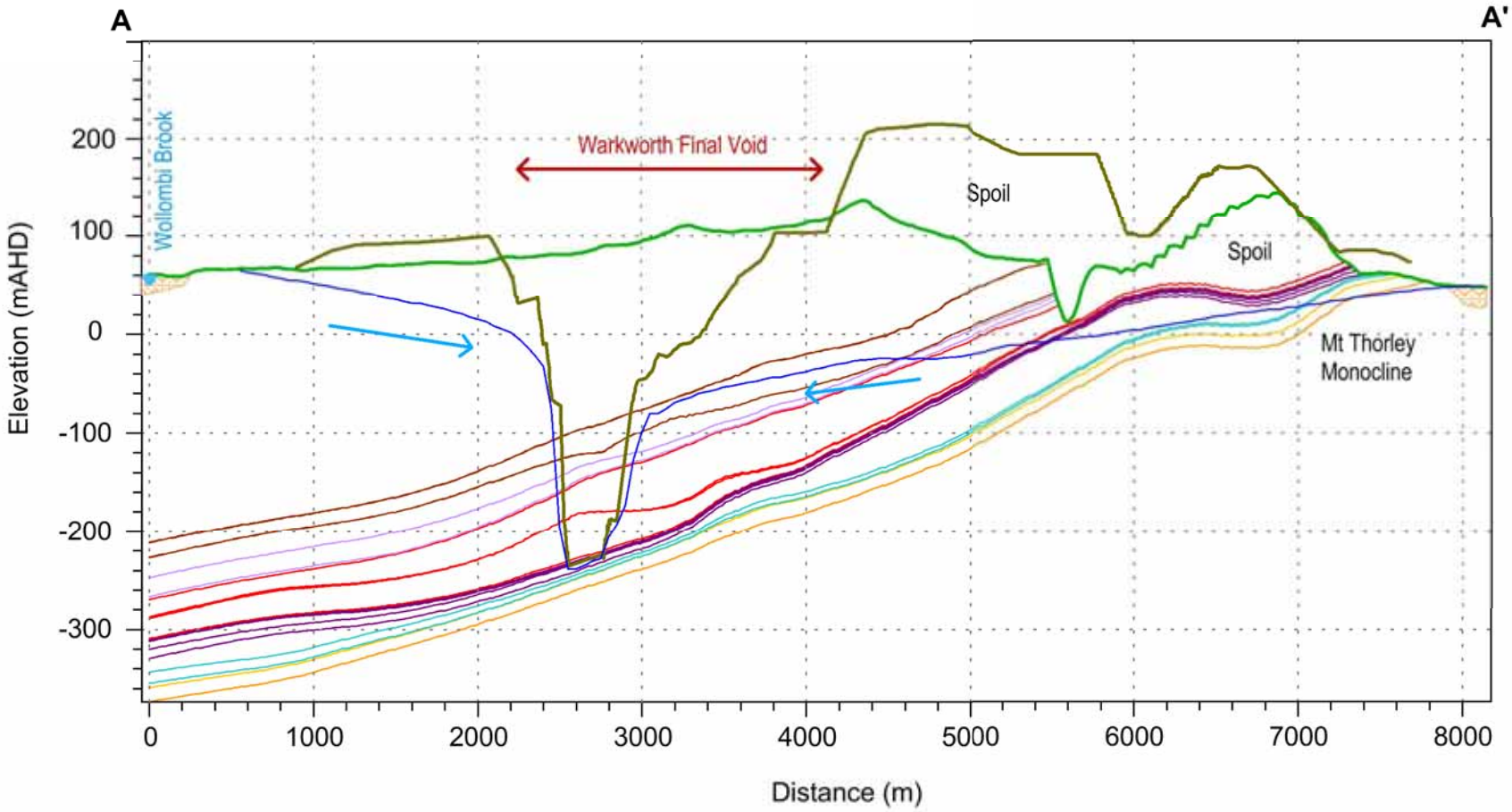
Warkworth Continuation 2014
Groundwater Assessment (G1468F)

End of Mining Groundwater Heads & Change in Groundwater Levels Layer 13

DATE: 14/5/2014

FIGURE No: **8.3**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



(Vertical Exaggeration 1:6)

Locality Map



LEGEND:

- Modelled groundwater level - Layer 1 EOM
- Alluvium
- Current surface topography
- Modelled final landform
- Arrowfield Seams
- Bowfield Seams
- Inferred groundwater flow direction
- Warkworth Seams
- Mt Arthur Seams
- Piercefield Seams
- Vaux Seams

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Model End of Mining
Groundwater Levels (Layer 1
Warkworth Cross-Section (A-A')

DATE:
14/5/2014

FIGURE No:
8.4

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

8.1.2 Impacts on Groundwater Users

The AIP stipulates that within highly productive groundwater sources (i.e. alluvial water sources) and less productive sources (i.e. porous and fractured rock) the maximum cumulative drawdown at any water supply bore should not be more than 2 m. The modelling predicts drawdowns in most private bores of less than one metre due to the Proposal. The majority of the private bores are screened in the Wollombi Brook alluvium, which experiences less drawdown than the Permian sequence due to a number of factors. These include buffering effect of upstream flow through the alluvium, higher rate of diffuse rainfall recharge, stream bed leakage and impeded hydraulic connection with the underlying coal seams due to the very low vertical permeability of the interburden strata.

The NOW groundwater database shows a total of 12 water bores as being present within the predicted zone of depressurisation where drawdown exceeds one metre in the Permian strata. Table 8.1 shows the predicted drawdown within the Permian sequence at the bores, five of which are owned by private landholders and seven that are owned by mines. Table 8.1 also shows the cumulative drawdown for all 12 bores.

Table 8.1: IMPACTS OF THE MINING ACTIVITIES ON GROUNDWATER USERS

Bore ID	Easting	Northing	Depth	Formation	Owner	Drawdown	
						Proposal Component	Total Cumulative
GW200394	320338	6381740	20	Permian regolith	Bulga Coal	1.7	13.2
GW200396	320329	6381589	5	Permian regolith	Bulga Coal	1.5	9.8
GW200395	320406	6381484	20	Permian regolith	Bulga Coal	1.5	9.3
GW200640	311638	6390920	50	Permian	Wambo Mining	2.5	195*
GW200623	312982	6395319	31	Permian	Mining related - United Colliery	2.2	7.1
GW080686	317535	6383211	n/a	Permian	Bulga Coal	2.0	19
GW200622	312901	6395806	30	Permian	Mining related - United Colliery	1.7	4.5
GW200621	312857	6395909	37	Permian	Mining related - United Colliery	1.7	4.2
217-B[1]	313234	6387612	100	Permian	George & Honor Lianos	1.6	0.5
GW080963	315994	6397209	84	Permian	Mining related, NOW - Coal & Allied	1.5	0.1
217-W[1]	313228	6387595	60	Permian	George & Honor Lianos	1.5	0.5
GW200625	310901	6393375	270	Permian	Mining related - Wambo Mining	1.1	232[2]

1 – no registered number available

2 - results influenced by simplistic representation of Wambo Mine underground due to limited information in public domain

The predicted reduction in groundwater levels is relatively small compared with the available drawdown in each bore, and is considered unlikely to noticeably reduce the pumping yield from any bore.

As detailed above, the AIP requires that aquifer interference activities do not induce a decline of more than 2 m in the water table or water pressure at any water supply work, (i.e. a bore or a well) in both highly and less productive groundwater sources. While the modelling predicted no

drawdown >1 m in any private bores within alluvium, three private bores (GW200640, GW200623 and GW080686 - Figure 8.3) within Permian units are predicted to record drawdowns of over 2 m. Table 8.1 shows that these three bores are all owned by neighbouring mines, not private landowner bores. The drawdowns in these bores are based on available data within the NOW PINNEENA groundwater database.

8.1.3 Impact on Alluvium

In the early years of the calibration, i.e. the 1980s, the model predicts there is a net upward flow entering the alluvium from the Permian formations across the whole model domain. As mining operations in the region expand over time, the Permian strata depressurises within the zone of influence, decreasing upward flow of groundwater from the Permian to the alluvium. As water quality within the Permian stratigraphy is brackish to saline, a reduction in upward flow will consequently reduce the salinity levels within the alluvium.

Similar to drawdown, two model runs were used to estimate the change in groundwater flow from the Permian to the alluvial aquifers. The first run was a simulation without mining under the proposal, and therefore only included the surrounding mining zones, while the second run included mining under the proposal as well as the surrounding mining zones. The change in flow from the Permian to the alluvial aquifer during mining was calculated as the difference in the fluxes to the alluvial zone between the two model runs.

Figure 8.5 shows the predicted additional take from Wollombi Brook and Hunter River alluvium resulting from the proposal. It is important to note the additional ‘take’ represents the difference in net flow across the Wollombi Brook and Hunter River alluvial zones in the model. In some areas of these zones there is upward flow from the Permian to the alluvium, and in others there is downward flow from alluvium to the Permian.

Figure 8.5 shows the net difference for each zone for the two modelled scenarios with, and without the proposal.

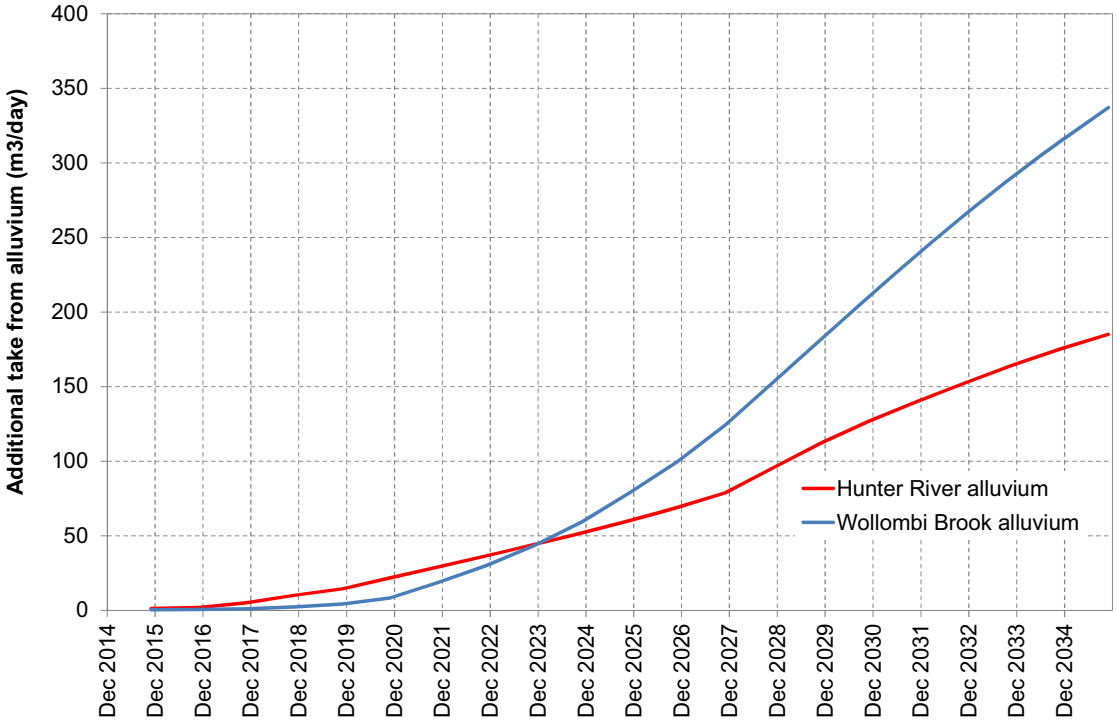


Figure 8.5: Additional take from Wollombi Brook and Hunter River alluvium due to the proposal

A gradual increase in take from the Wollombi Brook alluvium to a peak of 338 m^3/day in 2035 is predicted. As shown in Figure 5.8 a peak additional take of 185 m^3/day from the Hunter River alluvium is predicted at the end of mining. It could be argued this represents a net environmental benefit, as the rate of brackish and saline Permian groundwater reaching the alluvium reduces.

As discussed above, it is important to understand the modelling scenarios used to calculate the results. Similar to the drawdown, the change in fluxes to the alluvium were calculated by comparing fluxes from two scenarios, firstly with mining ceasing in 2015, and secondly continuing to 2035. In the model run where mining ceases in 2015, the water levels within the spoil begin to recover, and because of the highly permeable nature of the spoil fluxes of groundwater towards the Hunter River alluvium exceed pre-mining rates. When this is compared with the fluxes from the second scenario where mining continues to 2035 the net difference between the two scenarios is greater than if compared with pre-mining fluxes, meaning the predictions are conservative.

In summary the maximum additional take associated with the proposal from the Wollombi Brook alluvium (at the end of mining) is estimated at 124 ML/yr (338 m^3/day). Maximum additional take from the Hunter River alluvium is estimated at 68 ML/yr (185 m^3/day).

8.1.4 Impact on Stream Baseflow

In the absence of mining, the river and creek network surrounding Warkworth Mine is largely a gaining stream from groundwater discharge (baseflow). As mining expands in the region, the model predicts drawdown will occur within the alluvium, but it will be less than 1 m. This slight lowering of groundwater levels in the Wollombi Brook alluvium reduces baseflow in the Wollombi Brook.

Figure 8.6 presents the net change in the baseflow in response to mining. This was determined by subtracting the net river/creek flows in the predictive model from the scenario that removed mining due to the proposal.

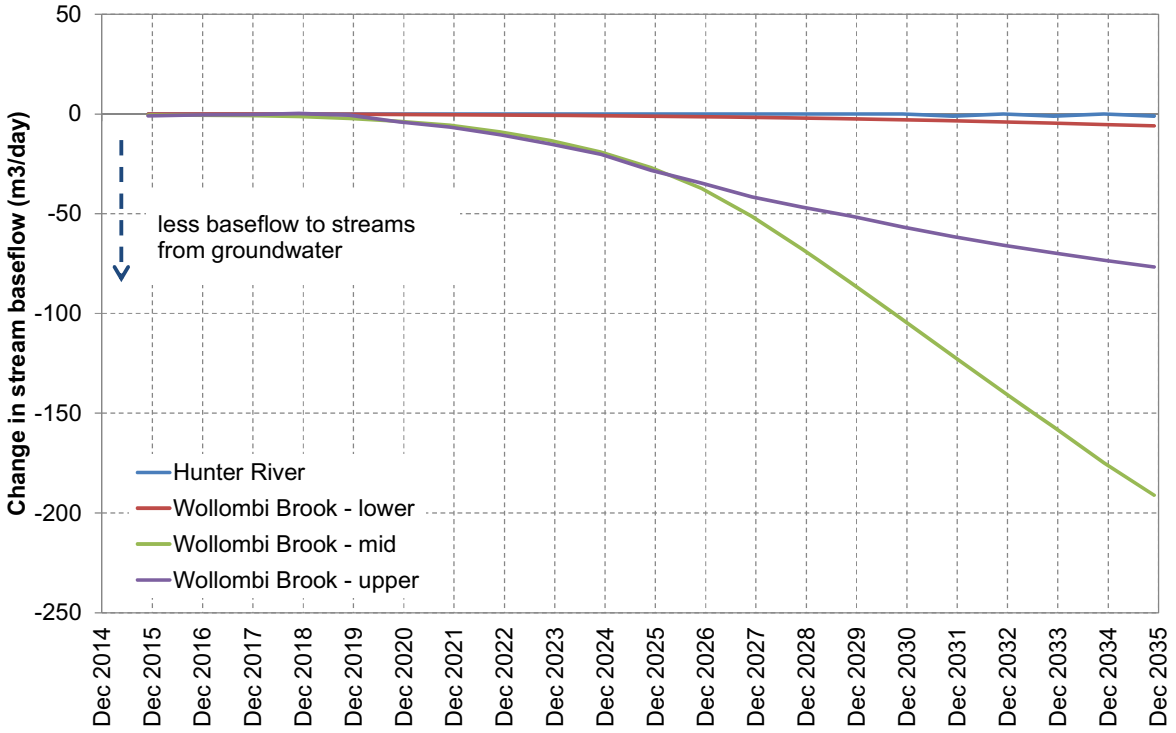


Figure 8.6: Net Change in baseflow

Figure 8.6 shows a reduction in baseflow to the Wollombi Brook under the proposal. The majority of the loss in Wollombi Brook baseflow is in the upper reach above the stream gauge at Bulga (Station 210028) and the mid reach to the stream gauge north of Warkworth Mine (Station 210004), with only negligible loss in the lower reach to the confluence with the Hunter River. Baseflow reduction for Wollombi Brook (all reaches) is at a maximum of 273 m^3/day at the end of mining in 2035. Hunter River baseflow is not impacted.

It is important to note from a water accounting point of view, the reduction in baseflow is accounted for in calculated reduced groundwater flow from the Permian to the alluvium. The groundwater flow from the Permian to the alluvium decreases up to 338 m^3/day, which in turn reduces baseflow up to 273 m^3/day. The applicant currently holds water licences to account for the predicted transfer of water from the Wollombi Brook to the underlying alluvium.

8.1.5 Impact on Groundwater Dependent Ecosystems

Figure 8.7 shows the location of mapped and potential GDEs against predicted drawdown at the end of mining in Layer 1. This is the best representation of drawdown in the water table that can be represented by the model.

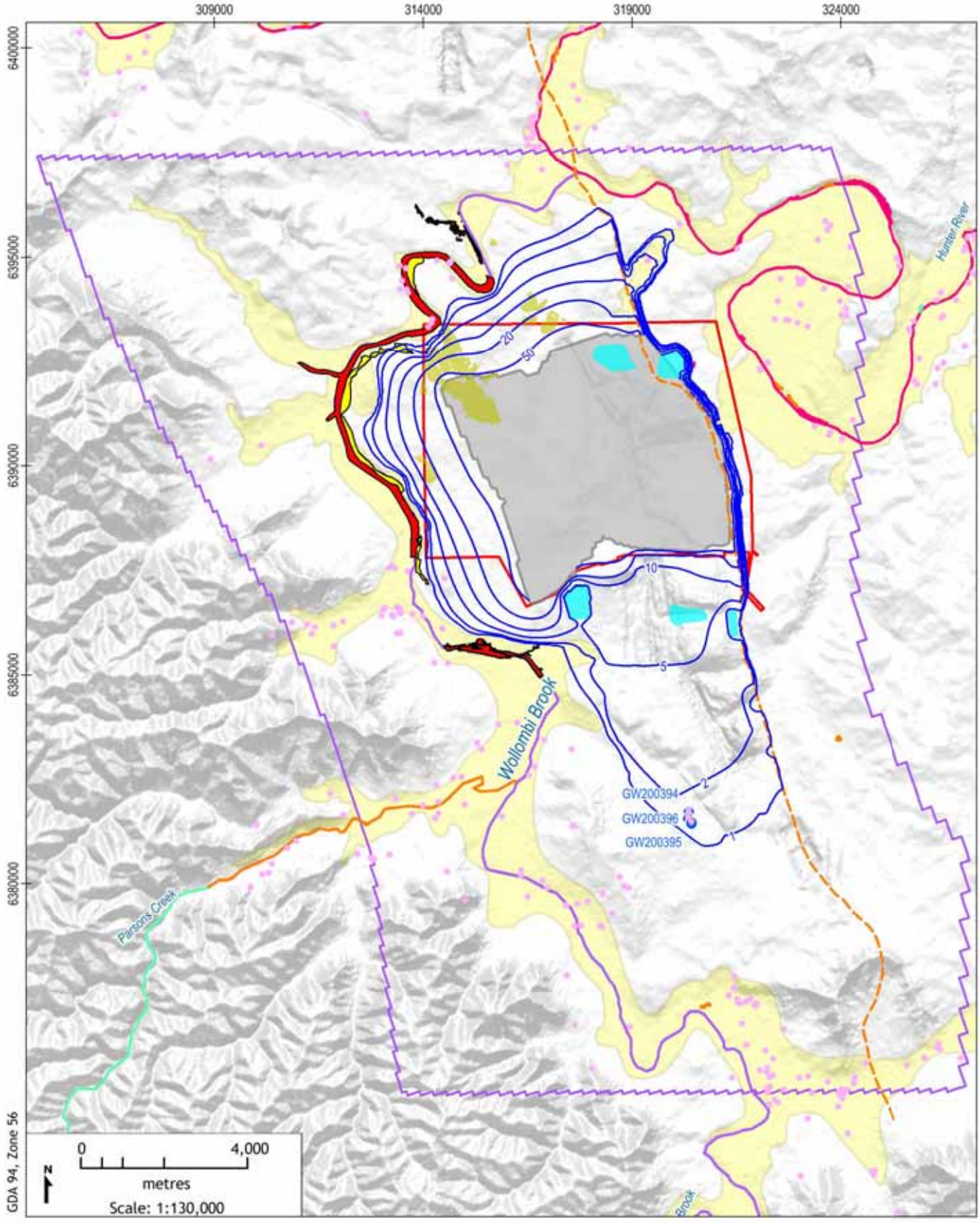
An ephemeral perched groundwater system is present in the aeolian Warkworth Sands that overlies the coal measures to the north-west of Warkworth Mine. Due to their ability to store water, the sands support a unique woodland known as the Warkworth Sands Woodland vegetation community. The fine grained sands are up to approximately 3 m in thickness and overlie a low permeability base of residual clay associated with the underlying strata. The low permeability clays

are thought to reduce vertical flow of groundwater and results in the formation of an ephemeral perched water table at the base of the sand mass.

Figure 8.7 shows a significant drawdown in the Permian regolith below the Warkworth Sands Woodland. The water table formed at the base of the Warkworth Sands is perched and is not in direct hydraulic connection with the underlying Permian fractured rock. Therefore, the proposal is not expected to have any effect on the Warkworth Sands ephemeral aquifer or the associated vegetation community.

The groundwater dependent vegetation communities in the Southern Biodiversity Area (Hunter Valley Oak Forest and River Red Gum Floodplain Woodland) are located on the eastern bank of Wollombi Brook about 2.5 km from the proposed mine extension and within the alluvial aquifer. These vegetation communities are likely to be extracting groundwater from the shallow alluvial aquifer, which will not be impacted by mine dewatering in this location.

Model predictions do not predict a significant change in baseflow to the Wollombi Brook or Hunter River and therefore any associated or aquatic and riparian ecosystems will not be impacted by the proposal.



LEGEND:

- Groundwater drawdown contour (m)
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Proposed Warkworth Mine development consent boundary
- Tailings storage facility
- Active model boundary
- Excavated mine area
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation

GDE Atlas - Surface Expression

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction
- Identified in previous study: fieldwork

Potential Groundwater Dependent Ecosystems

- Hunter Valley River Oak Forest
- River Red Gum Floodplain Woodland
- Warkworth Sands Woodland

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

GDEs and Predicted Drawdown in the Water Table (Layer 1)

DATE: 14/5/2014

FIGURE No: 8.7

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

8.1.6 Pit inflows

Figure 8.8 shows simulated inflows to Warkworth Mine that includes water sourced from leakage through spoil, known as low-wall seepage, combined with seepage through the Permian coal measures, known as high-wall seepage.

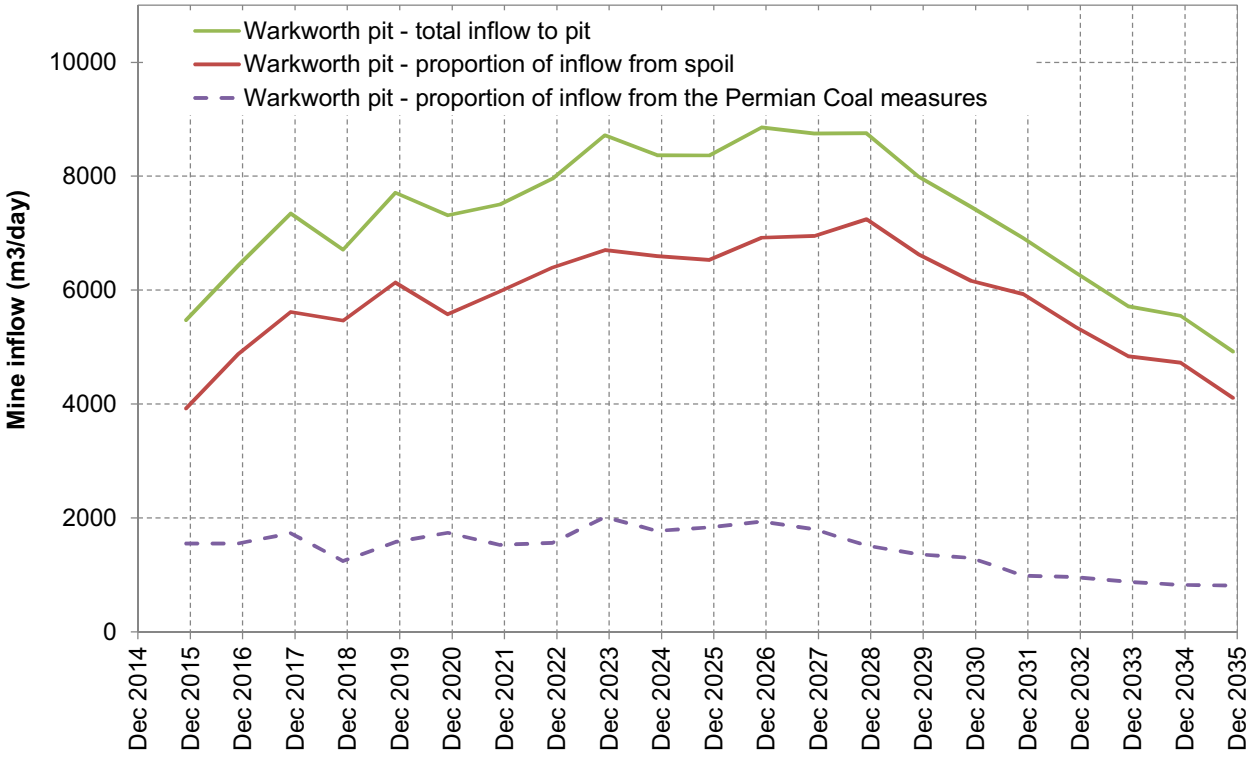


Figure 8.8: Pit inflows to Warkworth Mine

The inflow from the Permian is 1,550 m^3/day in the first year of predicted mining in 2015, peaking at 2,014 m^3/day in 2023. Simulated inflow from the Permian decreases after 2020 to 812 m^3/day at 2035. The simulated inflows shown in Figure 8.8 include water lost through evaporation at the pit face and water that remains bound in coal. The modelled flux of water will not appear at the pit floor during mining for pumping due to these losses.

The majority of the seepage is predicted by the model to be sourced from the low-wall, rainfall seepage through the spoils and leakage through the base of the tailings dams. It is important to understand that this does not represent groundwater that has been removed from the aquifer systems, but infiltrating rainfall through the spoil and recycled water (lost to tails) from the coal handling and preparation plant. The inflow from the spoil is initially 3,920 m^3/day in the first year of mining in 2015, peaking at 7,241 m^3/day in 2028, and reducing to 4108 m^3/day at 2035. The irregularities in the inflow are influenced by the mine progression and changes in the level and thickness of Tailings Dam 2.

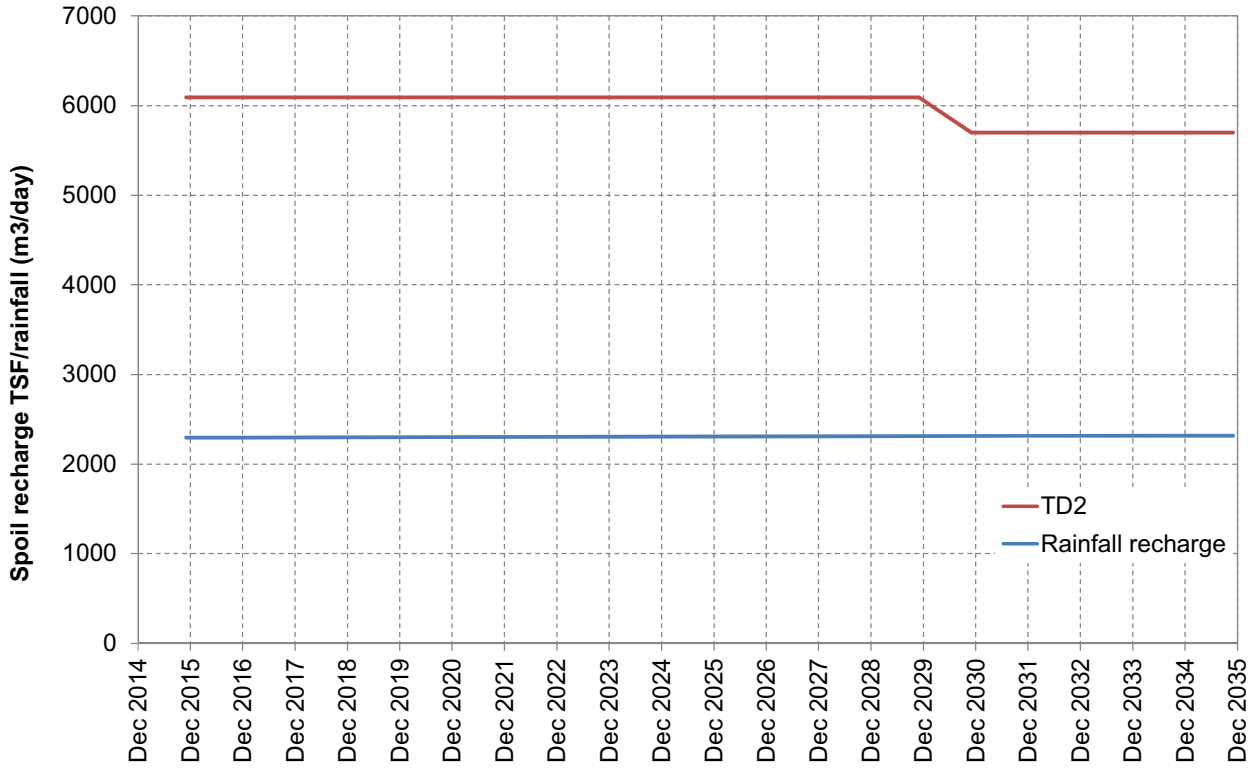


Figure 8.9: Spoil recharge rates from TSF versus rainfall infiltration

Figure 8.9 shows the modelled proportion of low-wall seepage from the tailings dams and rainfall seepage through the spoils; approximately three quarters of the inflow to spoil is derived from TSF leakage.

In summary, a maximum of 736 ML/yr (2,014 m^3/day) will be required to account for groundwater take from the Permian strata as required under the Water Act. The water that accumulates on the pit floor derived from spoil (sourced from TSF leakage and rainfall recharge to spoil) is not required to be licensed.

8.1.7 Water Quality and Leachate Migration

To protect surface water the AIP requires "no increase of more than 1% per activity in the long term average salinity in a highly connected surface water source at the nearest point to the activity". As detailed in Section 8.1.4, groundwater flow from the Permian to the Wollombi Brook alluvium will decrease by up to 338 m^3/day, which in turn will reduce baseflow by up to 273 m^3/day. As a result there will be less baseflow of brackish to saline groundwater entering Wollombi Brook and therefore a corresponding limited potential for an increase in salinity in Wollombi Brook surface water during operations.

8.1.8 Water Licensing

The two key pieces of legislation for the management of water in NSW are the WM Act and the Water Act. Operations at MTW have the potential to interact with water sources that require licensing, namely:

- the Permian groundwater described in Section 5, which is not yet covered by a water sharing plan and is therefore still under the Water Act; and
- the alluvium associated with the Wollombi Brook and Hunter River, which is covered by the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009 (WSPHUAWS).

The Water Sharing Plan for the Hunter Regulated River Water Source 2003 (WSPHRRWS) is not relevant to the proposal as there will be no take from the Hunter River or other Hunter regulated water sources.

Coal & Allied will have sufficient water licenses in place to account for the predicted water takes summarised in Section 9 of this report.

8.1.9 Post Mining Recovery

The recovery model commenced from the end of mining and used the final groundwater levels at the end of mining (2035) as the starting heads. The 'drains' simulating groundwater inflow into the mining pits were removed from the model to enable groundwater levels to recover.

Warkworth Mine comprises two pits, North and West pit. For the purposes of the assessment, the results for the two pit's final voids are presented together. The final voids will cover a combined area of approximately 950 ha, and will be up to approximately 250 m to 300 m deep. Groundwater, surface runoff and rainfall inflows will slowly fill the void forming a lake and eventually reaching an equilibrium water level created by a balance between seepages from groundwater, surface runoff/infiltration from the spoil pile and losses from evaporation.

At the cessation of mining, there will be a relatively high hydraulic gradient between the open void and the surrounding groundwater system, which will result in relatively high seepage rates. As a void lake water level begins to rise, the groundwater inflow rate will decrease until equilibrium conditions are established.

The rate of recovery of groundwater levels in the groundwater system will depend on rainfall, with years of below average rainfall extending the recovery period, and wet years reducing the time for equilibrium conditions to be established. Evaporation of water from the final void water body will incur a groundwater level at equilibrium that will be at a lower elevation than the pre-mining water level.

The topography of the final void was set-up in the model and compared to the existing model layers. The model grid and layer elevations remained identical to the predictive model. Model cell centre elevations that were located above the final void surface and below the original ground surface were assigned a high horizontal and vertical hydraulic conductivity (100 m/day) and storage parameters (specific yield and storage coefficient of 1.0), to simulate free water movement within the void.

The recovery model was run for a period of 1000 years post mining. Rainfall, evaporation and surface run-off to the Warkworth final void were supplied by WRM Consultants as used in their calculations of final void water levels (WRM 2014b). Rainfall was a looped record of available data to simulate variable climatic periods. Surface water inflows to the final void were through the Recharge package in MODFLOW. Evapotranspiration from the final landform and open water evaporation were set using the final landform surface using the EVT package in MODFLOW.

Inflow results to the final void from the simulation were supplied to WRM consultants for calculations of final void water level and salinity. Figure 8.10 shows the groundwater inflows to the Warkworth Mine final void, which are initially dominated by inflows from the spoil area for the first 50 years post mining. The reduction in inflow from spoil over this 50 year period is from dissipated mounded heads around the capped TSF TD2[3] and also as a result of the filling lake in the final void which reduces the hydraulic gradient from the spoil. The long term average inflow from spoil levels out after about 100 years post mining around 2,700 m^3/day.

Long term average inflow from the Permian coal measures to the Warkworth final void is 1365 m^3/day with a maximum of 1507 m^3/day. The maximum inflow is thought the worst case long term inflow from the Permian and equates to 551 ML/yr take from the Permian post closure. This is less than the 736 ML/yr (2,014 m3/day) peak calculated during mining.

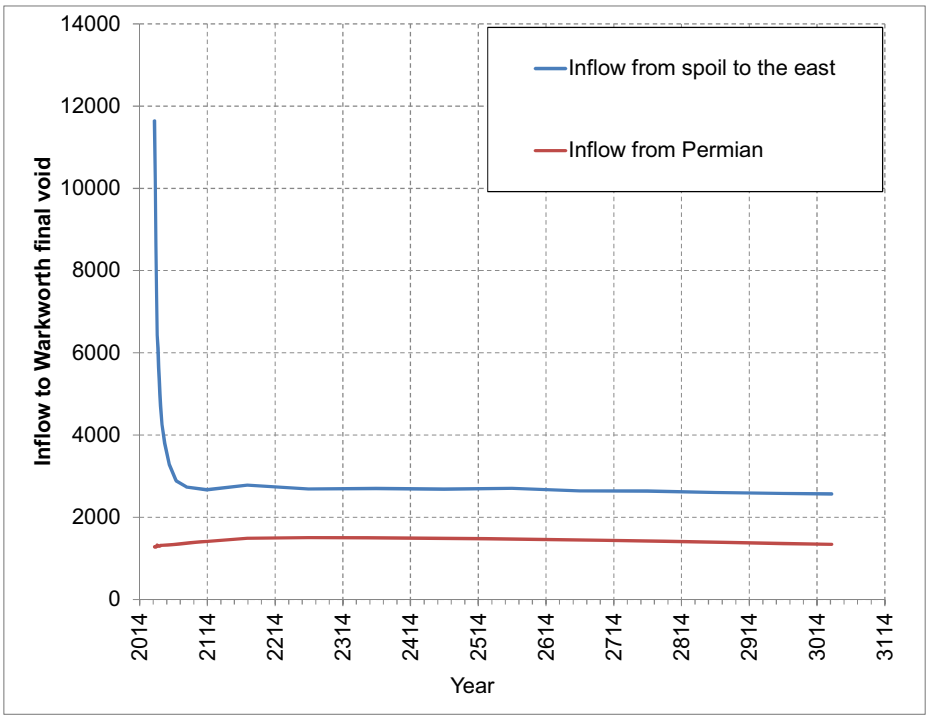
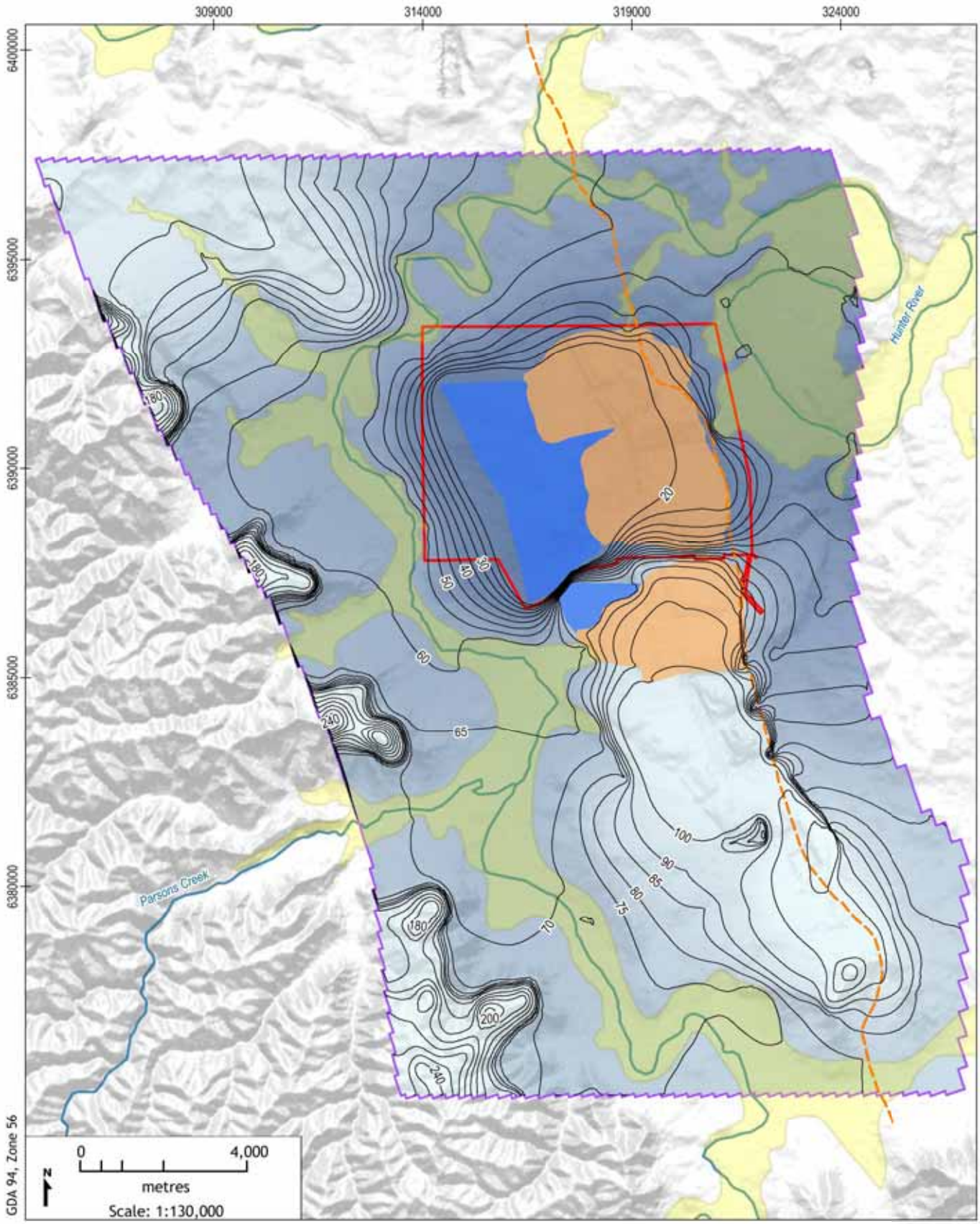


Figure 8.10: Predicted inflows to Warkworth final void (m^3/day)

Figure 8.11 presents the predicted groundwater levels surrounding the final void post mining. Groundwater levels show the Warkworth final void is a 'sink' in the local environment. WRM (2014b) using the OPSIM model calculated that the final void lake water level will reach 20 mRL and the final lake salinity will reach 30,000 µS/cm. This is due to the concentration of salts from evaporation. Due to the final void lake being a 'sink' in the local groundwater environment the pit lake final salinity does not pose a risk to salinity increases in the surrounding aquifer systems.

Figure 8.12 shows a west to east cross-section through the model area at the end of mining and long term post closure Layer 1 model heads superimposed. As can be seen in this section the steep cone of depression nearing the Warkworth Mine high-wall at the end of mining can be seen to flatten for the post closure case.

[3] TD2 was simulated with a surface water head at surface during mining to simulate slurry input and resultant water leakage to spoil, this slurry input was turned off in the post closure model to simulate the capped TSF.



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation
- Groundwater level contour
- Major watercourse
- Modelled pit lake
- Modelled spoil zone

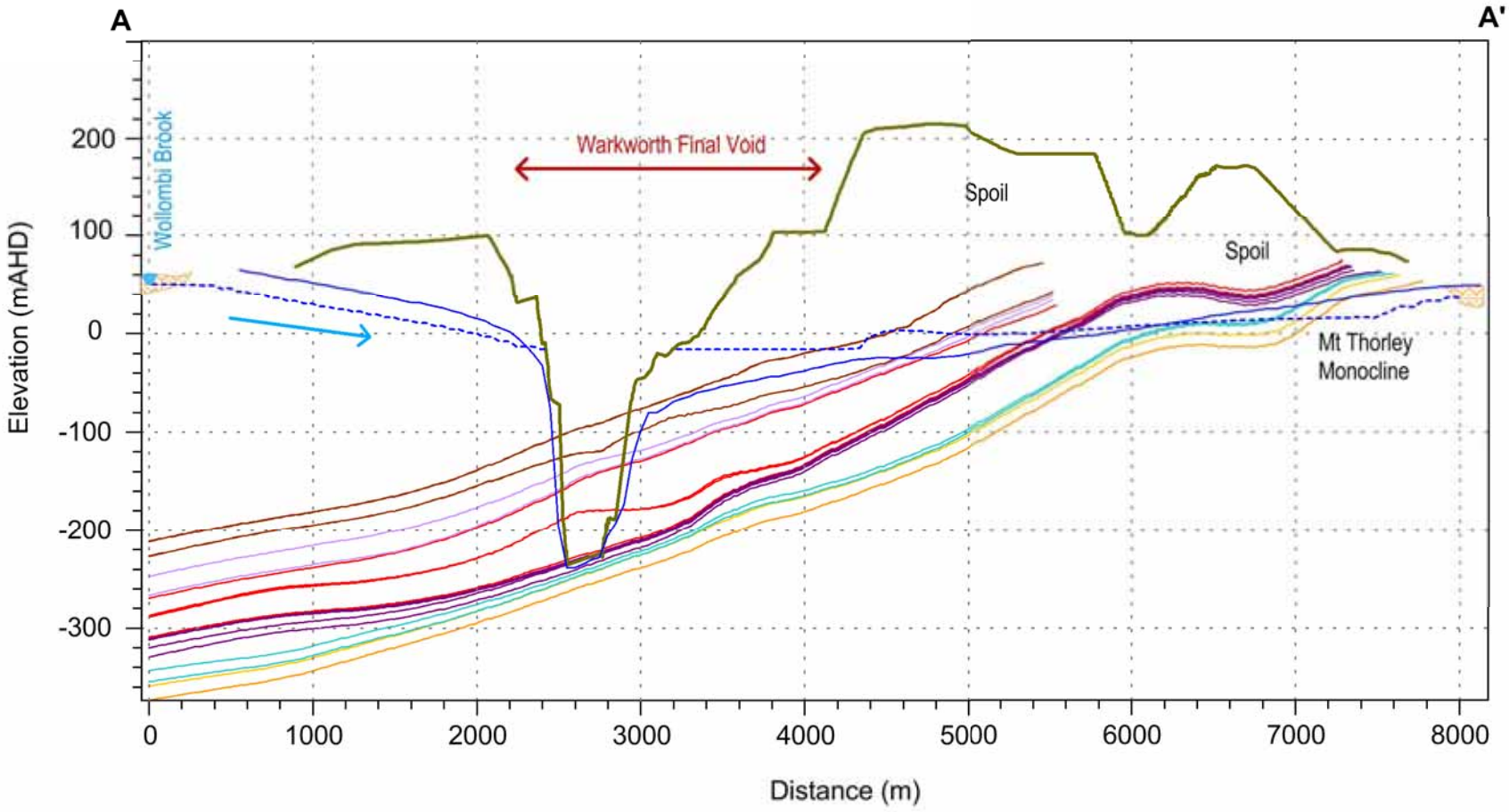
Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Groundwater Levels Surrounding th Post Mining Void

DATE: 14/5/2014

FIGURE No: **8.11**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



(Vertical Exaggeration 1:6)

Locality Map



LEGEND:

- Modelled recovery groundwater levels - Layer 1 (mAHD)
- Modelled groundwater level - Layer 1 EOM
- Alluvium
- Modelled final landform
- Arrowfield Seams
- Bowfield Seams
- Warkworth Seams
- Mt Arthur Seams
- Piercefield Seams
- Vaux Seams

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Model Recovery (1000 Years Post Mining)
Groundwater Levels (Layer 1
Warkworth Cross-Section (A-A')

DATE:
14/5/2014

FIGURE No:
8.12

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Figure 8.13 shows the net flow in (positive) and out (negative) for the Wollombi Alluvium next to MTW for the calibration, proposed mining and post closure periods. The data presented in this figure includes all proposed mining at both Warkworth and Mt. Thorley to demonstrate how long term post closure net flow to and from the alluvium compares to both approved and proposed mining periods. The impact of currently approved mining can be seen in the downward trend in the plotted line up to 2015. During the proposed mining period and into the post closure period a recovery can be seen in flow from the Permian to the Wollombi Brook alluvium. This recovery in net flow can be attributed to cessation of mining in both Mt Thorley and Bulga mines and increase recharge to spoil.

Figure 8.13 shows the long term post closure net flow to alluvium recovers substantially and is less than the peak recorded during mining. The impact of the Warkworth final void can be seen in the fact the net flow to alluvium does not recover to the original flows simulated pre-mining. The peak take from the alluvium simulated during mining is more than enough to account for long term effects post closure.

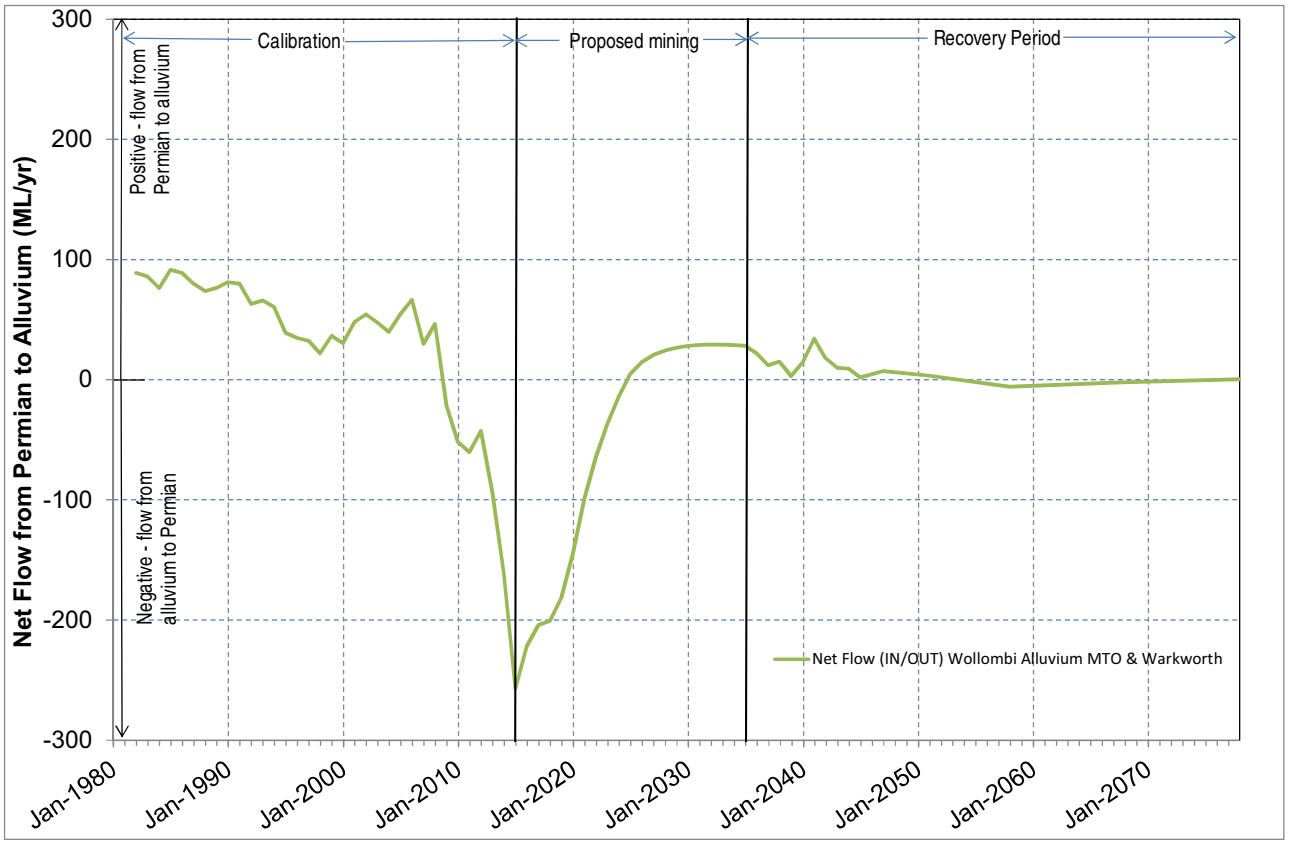


Figure 8.13: Recovery in net flows to Wollombi Alluvium

Due to a recovery in potentiometric levels post mining, no additional private bore users will be affected post closure other than those already documented in this report.

8.2 Uncertainty Analysis

8.2.1 Background

This section assesses the uncertainty of the model predictions to natural variability in the calibrated parameters. Analysis of the uncertainty of model outputs is referred to as “uncertainty analysis”. Model calibration does not necessarily result in a unique set of parameter values, especially if the model employs a number of parameters to simulate system complexity. As the

model was calibrated to known measurements, a calibration-constrained Monte Carlo analysis was carried out, rather than an unconstrained uncertainly analysis.

The objectives of uncertainty analysis were:

- to describe the numerical approach for quantification of uncertainty for this model; and
- to report the results of applying the methodology to estimate the potential uncertainty associated with the 30-year transient calibration model, and the 20-year development of mining areas.

Detailed reporting of the methodology, implementation, results and recommendations is presented as Appendix D.

Calibration-constrained Monte Carlo method for predictive uncertainty analysis uses many different parameter sets that still match (with certain level of misfit) the measured data. The level of misfit between modelled outcomes and measured field data is in proportion to potential measurement errors within observed data. These errors are represented by ranges defined by parameter bounds obtained by statistical analysis of field data. Two hundred such parameter sets, based on the calibrated mean and range of expected values, were generated. 200 models were rerun and checked against the baseline calibration statistics to ensure the model remained calibrated to observed data. 127 realised models were determined suitable and were therefore used in the calibration and predictive analysis.

It should be noted that the calibrated model used to base the uncertainty analysis on was not the final calibration discussed within this document. Time constraints to maintain the project deliverable meant that uncertainty analysis had to be conducted prior to final model completion. Although the uncertainty analysis was not based on the final model calibration the results of this analysis are still thought of worth in the discussion on the measurement error in the calibration.

All hydraulic parameters explored in the automatic calibration were explored in the analysis, including horizontal hydraulic conductivity, vertical hydraulic conductivity multipliers, specific storage, specific yield, groundwater recharge, and riverbed conductance.

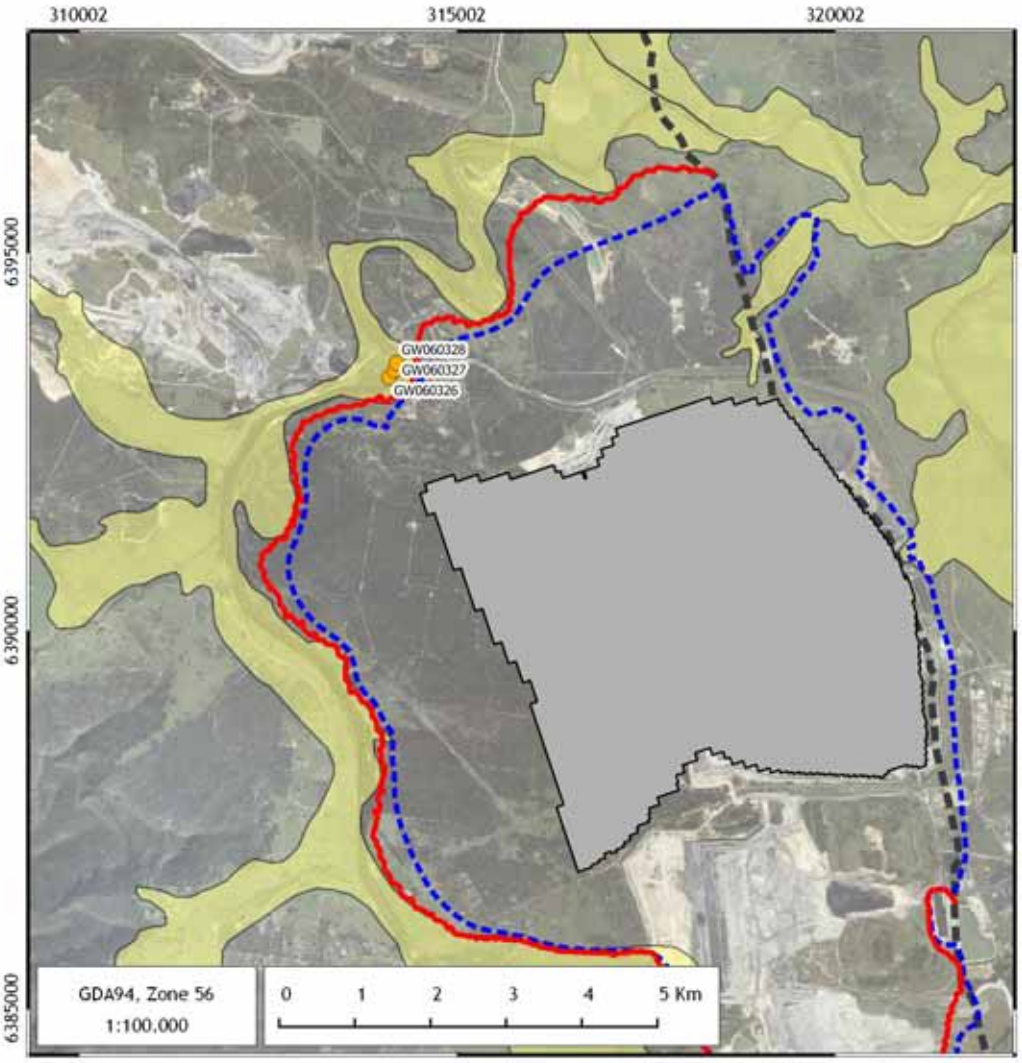
8.2.2 Results

Results from the uncertainty analysis have been discussed in the context of the predicted impacts during mining to put potential errors bars around predictive results. In each case the 95th percentile worst case result from the uncertainty analysis has been discussed.

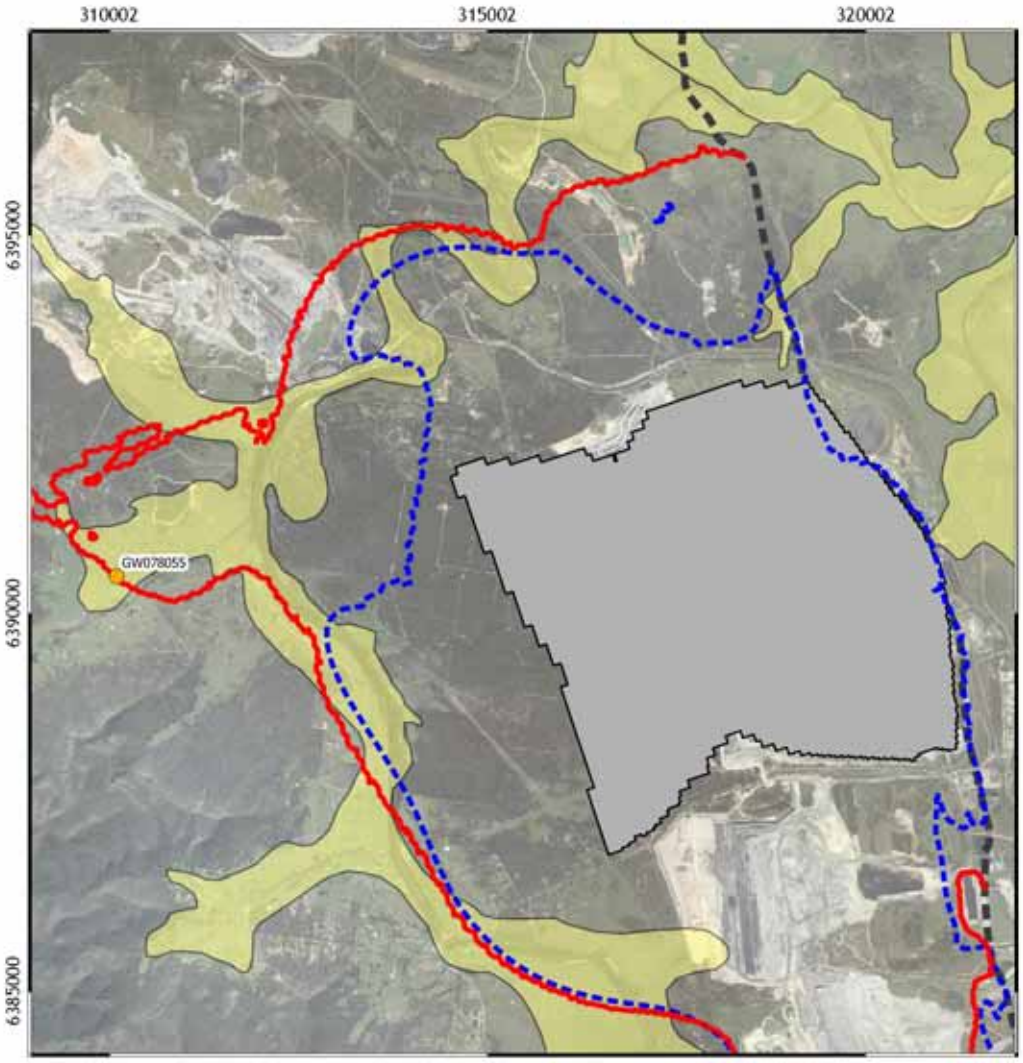
8.2.2.1 Drawdowns

Figure 8.14 shows the 2 m drawdown (Layer 1 and Layer 9) from the calibrated model against the 95th percentile 2 m drawdown from the uncertainty analysis. The 95th percentile drawdown in Layer 1 extends slightly further west than the calibrated model but does seem to be buffered by alluvium boundary. The effects of the river boundary condition were investigated and discussed earlier within Section 8. The 95th percentile drawdown in Layer 9 can be seen to extend further west below Wollombi Brook than the calibrated model.

Layer 1



Layer 9



LEGEND

- Groundwater users - 95th percentile drawdown > 1m
- Calibrated model 2m drawdown
- 95th percentile 2m drawdown
- Warkworth mine
- Alluvium
- Subcrop line Jerrys Plains

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

95th percentile 2m drawdown extent - Layer 1 and Layer 9

DATE
14/5/2014

FIGURE No:
8.14

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

8.2.2.2 Groundwater Users

The uncertainty analysis 95th percentile drawdown identified an additional three private bores within Wollombi Brook alluvium (GW200326, GW200327 and GW200328 [Figure 8.14]) with >1 m drawdown compared to the bores already identified in Section 8. The bores are location to the north of Wollombi Brook on land owned by Wambo Mine. Drawdowns at all three bores are <2 m.

The 95th percentile drawdown in the Permian model Layer 9 identified one additional private bore (GW078055) west of Wollombi Brook alluvium that may have a worst case drawdown of 2 m.

8.2.2.3 Impact on Alluvium

The predictive model simulation showed a gradual increase in groundwater take from the Wollombi Brook alluvium associated with the Proposal to a peak of 338 m^3/day (124 ML/yr) in 2035 (Section 8). The 95th percentile worst case groundwater take from the Wollombi Brook Alluvium is 462 m^3/day (169 ML/yr). This is a 37% increase over the calibrated predicative model and shows relatively tight variance in the uncertainty results.

8.2.2.4 Groundwater Inflow to Mining Areas

The predictive model simulation showed inflow from the Permian to the Warkworth Mine open pit peaks at 2,014 m^3/day (736 ML/yr) in 2023. The 95th percentile worst case inflows peak at 2399 m^3/day (876 ML/yr) also at 2023. This is a 19% increase over the calibrated predicative model and shows relatively tight variance in the uncertainty results.

9 COMPLIANCE

Assessment of the proposed modification against the NSW AIP is detailed under Section 9.1 to Section 9.3, below.

9.1 Accounting for, or Preventing the Take of Water

Table 9.1: ACCOUNTING FOR OR PREVENTING THE TAKE OF WATER		
AIP Requirement		**Proponent response**
1	Described the water source (s) the activity will take water from?	Based on the AIP the groundwater system impacted by the proposed modification can be separated into two systems, as follows: • porous and/or fractured consolidated sedimentary rock of the Permian coal measures; and • groundwater within alluvium associated with the Wollombi Brook and Hunter River alluvium. Water quality and yields for the coal measures and Wollombi Brook is considered a less productive aquifer according to the AIP, while the Hunter River alluvium is considered a highly productive aquifer.
2	Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Predicted peak annual take from: • Permian coal measures: 736ML/yr • Wollombi Brook alluvium: 124ML/yr • Wollombi Brook (surface water): 100ML/yr (account for in alluvial take) • Hunter River alluvium: 68ML/yr • Hunter River (surface water): none See Section 8 for further details.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Predicted take from: • Permian coal measures: 551ML/yr • Wollombi Brook alluvium: <124ML/yr • Wollombi Brook (surface water): <124ML/yr (accounted for in the alluvial take) • Hunter River alluvium: <68ML/yr • Hunter River (surface water): <68ML/yr (accounted for in the alluvial take) See Section 8 for further details.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on three dimensional numerical modelling
5	Described how and in what proportions this take will be	Predicted take from:

Table 9.1: ACCOUNTING FOR OR PREVENTING THE TAKE OF WATER		
AIP Requirement		**Proponent response**
	assigned to the affected aquifers and connected surface water sources?	• Permian coal measures: 736ML/yr • Wollombi Brook alluvium: 124ML/yr • Wollombi Brook (surface water): 100 ML/yr (accounted for in the alluvial take) • Hunter River alluvium: 68 ML/yr • Hunter River (surface water): none See Section 8 for further details.
6	Described how any licence exemptions might apply?	Not necessary.
7	Described the characteristics of the water requirements?	There are no water requirements; however, additional interception of groundwater due to the proposed modification is predicted.
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Coal & Allied will make sure appropriate water license are in place to account for predicted takes See Section 8.1.8 for further details.
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Compliant – see Section 8 of report
10	Determined how it will obtain the required water?	Via seepage to the high-wall face, but most will likely evaporate or be removed as moisture in coal and will not enter the site water circuit.
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	
12	Considered actions required both during and post-closure to minimize the risk of inflows to a mine void as a result of flooding?	Flood assessment was undertaken as part of the Warkworth Extension Project. The results indicated that the Project's footprint was above the 1 in 100 year ARI flood event.
13	Developed a strategy to account for any water taken beyond the life of the operation of the project?	Surrender of existing water entitlements that are used to license take of water.
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorized water users? *Items 14-16 must be addressed if so.*	Risks to groundwater systems are low as the proposal does not entail any modification to the disturbance footprint, and involves resurfacing of the final mine void. Uncertainty analysis, presented in Section 8.2, indicates that the predicted impact on alluvium and Permian units has a relatively low degree of uncertainty (±37% and ±19%, respectively).
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	See Section 8 of report
15	Quantified any other uncertainties in the groundwater	Risks to groundwater systems are low as the proposal does not entail any modification to the disturbance footprint, and involves resurfacing of the final

Table 9.1: ACCOUNTING FOR OR PREVENTING THE TAKE OF WATER		
AIP Requirement		**Proponent response**
	or surface water impact modelling conducted for the activity?	mine void. Available monitoring data indicates the two existing groundwater models MER (2002) and AGE (2010), and the current model results presented in this report have been relatively conservative. Despite this conservatism the predicted impacts are still negligible and manageable, so the uncertainty in the predictions is not considered to have the potential to impact on the environment or water users.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the project, and how these requirements will be accounted for?	Yes. See Section 10 of report

9.2 Determining Water Predictions in Accordance with AIP (Section 3.2.3)

Table 9.2: DETERMINING WATER PREDICTIONS		
AIP Requirement		Proponent response
1	Addressed the minimum requirements found on page 27 of the AIP for the estimation of water quantities both during and following cessation of the proposed activity?	Based on conservative numerical modelling, see Section 8 and Appendix C of report.

9.3 Other Requirements to be Reported in Accordance with AIP (Section 3.2.3)

Table 9.3: OTHER REQUIREMENTS		
AIP Requirement		Proponent response
1	Establishment of baseline groundwater conditions?	Compliant – see Section 5 of report.
2	A strategy for complying with any water access rules?	Water licences held by or will be purchased by proponent
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	No predicted impact of over 2m for water supply bores in alluvium or Permian. Predicted impacts over 2m are restricted to bores located on land owned by adjoining mines. See Section 8.1.2
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	No predicted impact of over 2m for water supply bores in alluvium or Permian. Predicted impacts over 2m are restricted to bores located on land owned by adjoining mines. See Section 8.1.2

Table 9.3: OTHER REQUIREMENTS		
AIP Requirement		Proponent response
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	None predicted - see Section 8.1.5 of report
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	None predicted - see Section 8.1.5 of report
7	Potential to cause or enhance hydraulic connection between aquifers?	None predicted - see Section 8 of report
8	Potential for river bank instability, or high-wall instability or failure to occur?	Not assessed, but improbable.
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A

10 MITIGATION AND MONITORING

10.1 Review of Current Monitoring Programme

Groundwater management is currently undertaken based on the existing MTW groundwater monitoring program, which is included in the Water Management Plan (WMP) (Coal & Allied, 2013). The WMP includes scheduled monitoring of 30 groundwater monitoring bores within and around MTW. Review of the MTW groundwater database indicates that groundwater level data is currently collected at 50 monitoring locations (see Appendix A).

The Groundwater Monitoring Programme (Appendix F of WMP) details that the monitoring bores will be monitored for field parameters of pH, EC and water level on a quarterly basis, and a comprehensive water quality analysis conducted annually.

Review of the MTW groundwater database indicates that the groundwater samples are being collected on an annual basis for all bores.

10.2 Proposed Amendments to Monitoring Programme

It is recommended the following to update the existing monitoring programme, to assist ongoing assessment and quantification of any potential surface water and groundwater impacts:

- Installation of nested monitoring bores along the Wollombi Brook (PZ10, PZ11, PZ12); and
- Installation of monitors bores with the Warkworth Sands system.

Yearly audits of the performance of the monitoring network should also be included as part of the annual groundwater review, and optimisation of the monitoring sites and frequency should be undertaken where required.

10.3 Mine Water Seepage Monitoring

It is recommended that monitoring of in pit mine water seepage be undertaken, particularly to identify seepage rates and quality. The seepage monitoring program should include:

- recording of the time, location and estimated volume of any unexpected increased groundwater outflow from the high-wall and end-wall;
- measurement of water pumped from the void, preferably using flow meters or other suitable gauging apparatus;
- correlation of rainfall records with mine seepage records so groundwater and surface water can be separated; and
- monitoring of coal moisture content.

10.4 Trigger Values

Trigger values provide a quantifiable measure for identifying adverse changes in groundwater levels and quality. The existing WMP (Coal & Allied, 2013) details that key water quality triggers include pH, EC and Total Suspended Solids (TSS). In the absence of licence or applicable ANZECC (2000) criteria, the 95th percentile of the available data is adopted and compared to monitoring results on a monthly basis. Water quality trigger levels at the 95th/5th percentile, based on baseline data, is considered adequate to identify mine related impacts, while still accounting for natural and seasonal variations.

As detailed in the WMP A site specific investigation into trigger level exceedance if:

- *"professional judgement determines that the single deviation or a developing trend could result in environmental harm; or*
- *Three consecutive measurements exceed trigger values."*

10.5 Data Management and Reporting

It is recommended that data management and reporting include:

- establishment of trigger levels;
- quarterly review of groundwater levels and field water quality against trigger levels, with site specific investigations initiated, as detailed in Section 10.4;
- annual reporting (including all water level and water quality data); and
- all groundwater data should be stored in a database customised for MTW with suitable QA / QC controls.

10.6 Future Model Iterations

Every three years the validity of the model predictions should be assessed. If these data indicate substantial differences (previously unrecognised information) to those interpreted, these data should be incorporated into the model and revised predictions made and reported.

10.7 Make Good Agreements

According to the AIP, make good agreements are required when a 2 m or greater cumulative decline occurs at any water supply work. As detailed in Section 8.1.2, drawdowns of greater than 2 m are not predicted to occur at any privately owned bores.

11 CONCLUSION

Warkworth Mine is an open cut coal mine approximately 8 kilometres (km) south-west of Singleton in the Hunter Valley, NSW. Warkworth Mine has been in operation since 1981 and the originally approved operation has been modified several times. The Warkworth Continuation 2014 (the proposal) seeks an approval under Part 4, Division 4.1 of the EP&A Act to extend mining beyond the current limits.

All available geological and groundwater data was assessed to develop a conceptual understanding of the hydrogeological regime at Warkworth Mine. As shown in Figure 5.3, the coal measures of the Jerrys Plains Subgroup dip towards the west of Warkworth Mine. The multiple coal seams in the Jerrys Plains Sub-group form low to moderately permeable groundwater system, confined by very low yielding interburden/overburden. The coal measures sub-crop immediately east of the mine area, along the Mt Thorley Monocline, with the basal Archerfield Sandstone and Bulga Formation of the Vane Subgroup underlying the Hunter River.

Groundwater levels within the Permian stratigraphy are highly influenced by existing mining, flowing towards the active open-cut pits at MTW (see Figure 5.5). The Permian stratigraphy is mainly recharged where it occurs at sub-crop, to the east. However, the saline water quality and high ion concentrations indicate that the Permian groundwater has a low rate of recharge and also of long residence time. Groundwater within the Wollombi Brook alluvium appears to be unaffected by current mining, and contains brackish to saline groundwater. Review of stream flow levels and alluvial groundwater levels indicates that the Wollombi Brook west of MTO is a gaining stream (baseflow contributions from Permian), while to the north it is likely a losing stream (downward leakage to Warkworth Sands and Permian stratigraphy).

Review of the NSW groundwater database (PINEENA, 2013) identified that there are numerous private groundwater users along Wollombi Brook, primarily accessing the alluvial groundwater. There are also some private bores intercepting the Permian stratigraphy, however, these are largely located on land owned by mines. There are also GDEs identified from previous studies along the Wollombi Brook (see Figure 5.11).

Results from the numerical groundwater model identified:

- impact on the Wollombi Brook alluvium, with:
    - drawdown levels within the Wollombi Brook alluvium predicted to be less than 1 m at the end of mining;
    - predicted reduction in baseflow to the Wollombi Brook (all reaches) at a maximum rate of 273 m^3/day (100 ML/yr) at the end of mining in 2035; and
    - predicted maximum additional take from the Wollombi Brook alluvium (at the end of mining) is estimated at 338 m^3/day (124 ML/yr);
- minimal impact on the Hunter River and Hunter River alluvium, with:
    - drawdown levels in the Hunter River alluvium is less than 1 m, except in an isolated area that encroaches close to Warkworth Mine, which is predicted to have a 5 m drawdown;
    - no predicted impacts on Hunter River baseflow; and
    - predicted maximum additional take from the Hunter River alluvium is estimated at 68 ML/yr (185 m^3/day);
- minimal impact on groundwater users, with:

  - no predicted drawdown <2m in any private bores within alluvium;
  - drawdowns of over 2 m are predicted for three private bores (GW200640, GW200623 and GW080686) within Permian units;
  - no predicted impacts on GDEs relating to the Warkworth Sands, as it has a perched groundwater system that is not in direct hydraulic connection with the underlying Permian fractured rock; and
  - no predicted impacts on GDEs in the Southern Biodiversity Area as these vegetation communities are likely to be extracting groundwater from the shallow alluvial aquifer, which will not be impacted by mine dewatering in this location;

- mine pit inflow estimates of:
  - predicted inflow to the proposal from the Permian units peaks at 2,014 m^3/day in 2023, and declines to 812 m^3/day at the end of mining (2035); and
  - predicted inflow from the spoil into the proposal peaks at 7,241 m^3/day in 2028, reducing to 4108 m^3/day at the end of mining (2035);
- predicted groundwater levels within the final void will slowly recover and reach equilibrium at about 20 mRL, after approximately 1,000 years post mining. Groundwater levels remain below the regional water table by approximately 40 m to 50 m, indicating the pit lake void will act as a groundwater sink, not a source.

12 REFERENCES

Amoco Australia Petroleum Company (1995a), "Bulga # 1, Final Well Report, PEL 267, Sydney Basin".

Amoco Australia Petroleum Company, (1995b), "Wollombi Brook # 1, Final Well Report, PEL 267, Sydney Basin".

Anderson, M. P. and Woessner, W. W., (1992), *"Applied Groundwater Modelling, Simulation of Flow and Advective Transport"*, Academic Press.

ATC, (2014a), Rio Tinto Coal Australia Ltd, Mount Thorley Warkworth Hunter Valley, NSW – Warkworth No1 Tailings Dam, Operations and Maintenance Manual. January 2014 99029R40 Rev 4.0.

ATC, (2014b), Rio Tinto Coal Australia Ltd, Mount Thorley Warkworth Hunter Valley, NSW – Warkworth No2 Tailings Dam, Operations and Maintenance Manual. January 2014 99029R39 Rev 5.0.

ATC, (2014c), Rio Tinto Coal Australia Ltd, Mount Thorley Warkworth Hunter Valley, NSW – Central Ramp Tailings Storage Facility, Operations and Maintenance Manual. January 2014 99029R09 Rev 4.0.

ATC, (2014d), Rio Tinto Coal Australia Ltd, Mount Thorley Warkworth Hunter Valley, NSW – Abbey Green South Tailings Storage Facility, Operations and Maintenance Manual. January 2014 99029R09 Rev 2.0-R1.

Australian Groundwater Consultants Pty Ltd, (June 1984), "Effects of Coal Mining on Groundwater Resources in the Upper Hunter Valley", Volume 1.

Australasian Groundwater and Environmental Consultants Pty Ltd, (2010), *"Warkworth Mine Extension, Groundwater Impact Assessment"*, G1468, February 2010.

Australasian Groundwater and Environmental Consultants Pty Ltd, (2013), *"Warkworth Mine Modification Groundwater Impact Assessment"*, G1468D, August 2013.

Australasian Groundwater and Environmental Consultants Pty Ltd, (2014), *"2013 HVO South Groundwater Impacts Report"*, G1593F, February 2014.

Australian and New Zealand Environment and Conservation Council, (2000), "*Australian and New Zealand Guidelines for Fresh and Marine Water Quality"*. National Conservation Council and Agriculture and Resources Management Council of Australia and New Zealand, Paper No. 4, October 2000.

Barnett B., Townley L.R., Post V., Evans R.E., Hunt R.J., Peeters L., Richardson S., Werner A.D., Knapton A. and Boronkay A., (2012), *"Australian groundwater modelling guidelines"*, Waterlines report, National Water Commission, Canberra, June 2012.

Chaing W.H. and Kinzelbach W., (1996), "Processing MODFLOW for Windows".

Cumberland Ecology (2010), *"Warkworth Mine Extension: Ecological Assessment for Warkworth Mining Limited"*, Carlingford Court, NSW.

Cumberland Ecology (2014): Warkworth Continuation 2014, Ecological Impact Assessment.

Deutsch, C.V., and Journal, A.G. 1992. GSLIB: Geostatistical Software Library and User's Guide. Oxford University Press, Oxford, New York, 340 pp.

Department of Water and Energy (2009), *"Lower Wollombi Brook Water Source – Report Card".*

Golder (2013). " Factual Report on Hydrogeological Investigations at Mount Thorley/ Warkworth (MTW). Report 117621019-62-R-Rev0 May 2013.

Mackie Environmental Research, (2002), *"Extension of Warkworth Coal Mine Assessment of Environmental Impacts Surface and Groundwater Management Studies"*, August 2002.

Mackie Environmental Research, (2009), Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in The Upper Hunter Valley of NSW.

New South Wales Office of Water, (2012), *"Aquifer Interference Policy".*

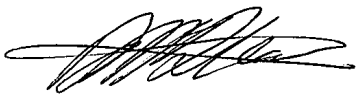
Tonkin, M.J., and Doherty, J. 2009. Calibration-constrained Monte Carlo analysis of highly-parameterized models using subspace techniques. Water Resources Research, 45: W00B10.

WRM, (2014a), Mount Thorley Warkworth Water Balance Model Update 2013. Report No 0969-01-C2 January 2014.

WRM, (2014b), Mount Thorley Operations 2014 and Warkworth Mine 2014 Surface Water Assessment, Coal & Allied Operations Pty Limited, prepared by WRM Water & Environment Pty Ltd, April 2014.

AUSTRALASIAN GROUNDWATER AND ENVIRONMENTAL CONSULTANTS PTY LTD

Reviewed by:





DOUG MCALISTER
Principal Hydrogeologist

JAMES TOMLIN
Principal Hydrogeologist



PAVEL DVORACEK
Senior Modeller

LIMITATIONS OF REPORT

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) has prepared this report for the use of EMGA Mitchell McLennan in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in Proposal dated 11 February 2014, and Change of Scope dated 24 February 2014 and 2 May 2014.

The methodology adopted and sources of information used by AGE are outlined in this report. AGE has made no independent verification of this information beyond the agreed scope of works and AGE assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to AGE was false.

This study was undertaken between January 2014 and May 2014 and is based on the conditions encountered and the information available at the time of preparation of the report. AGE disclaims responsibility for any changes that may occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. It may not contain sufficient information for the purposes of other parties or other users. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing and other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. Where borehole logs are provided they indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the frequency and method of sampling, and the uniformity of the site, as constrained by the project budget limitations. The behaviour of groundwater is complex. Our conclusions are based upon the analytical data presented in this report and our experience.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, AGE must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge, information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

Appendix A

Monitoring Bore Summary Table

Table A- 1- MONITORING BORE SUMMARY

Bore ID	Alternate ID	Easting	Northing	Type	Collar Elevation mRL	Target Formation Bottom	SWL (mRL)		Model Layer
							Av.	Q4 2013	
OH786	OH786	320542	6392674	Standpipe	55.65	Alluvium	53.9	49.8	1
OH787	OH787	320982	6391921	Standpipe	49.96	Alluvium	36.0	36.3	1
OH788	OH788	321482	6390967	Standpipe	45.38	Alluvium	35.7	35.8	1
OH942	OH942	320536	6392622	Standpipe	55.75	Alluvium	46.9	46.7	1
OH943	OH943	321476	6390963	Standpipe	45.04	Alluvium	35.7	35.9	1
OH944	OH944	321113	6391035	Standpipe	47.88	Alluvium	40.1	40.2	1
OH1121	OH1121 (1?)	321902	6391030	Standpipe	45.64	Vaux Seam	35.1	35.4	15
OH1122 (1)	OH1122 (1)	318545	6387877	Standpipe	101.19	Blakefield Seam	52.7	55.8	7
OH1122 (2)	OH1122 (2)	318545	6387877	Standpipe	101.18	Woodlands Hill Seam*	44.4	-	9
OH1122 (3)	OH1122 (3)	318545	6387877	Standpipe	101.15	Bowfield Seam*	42.4	30.0	11
OH1123 (1)	OH1123 (1)	316967	6389501	Standpipe	99.2	Woodlands Hill Seam	51.8	51.5	9
OH1123 (2)	OH1123 (2)	316967	6389501	Standpipe	99.22	Blakefield Seam	47.6	40.3	7
OH1123 (3)	OH1123 (3)	316967	6389501	Standpipe	99.18	Bowfield Seam	45.4	39.7	11
OH1124 (1)	OH1124 (1)	316893	6391526	Standpipe	88.2	Unknown - no depth info		-	7
OH1124 (2)	OH1124 (2)	316893	6391526	Standpipe	88.2	Unknown - no depth info	41.8	-	9
OH1124 (3)	OH1124 (3)	316893	6391526	Standpipe	88.2	Unknown - no depth info	42.1	-	11
OH1125 (1)	OH1125 (1)	316511	6392875	Standpipe	85.4	Unknown - no depth info	58.0	59.8	7
OH1125 (2)	OH1125 (2)	316511	6392875	Standpipe	85.4	Unknown - no depth info	60.0	-	9
OH1125 (3)	OH1125 (3)	316511	6392875	Standpipe	85.4	Unknown - no depth info	39.8	49.9	11
OH1126	OH1126	318579	6393394	Standpipe	63.7	Vaux Seam*	53.4	50.7	15
OH1127	OH1127(1?)	321444	6392097	Standpipe	51.22	Bayswater Seam*	35.5	35.6	16
OH1137	OH1137	318266	6393377	Standpipe	67.7	Vaux Seam	57.0	55.5	15
OH1138 (1)	OH1138 (1)	317835	6393346	Standpipe	70.72	Warkworth Seam	62.9	61.8	12
OH1138 (2)	OH1138 (2)	317835	6393346	Standpipe	70.72	Warkworth Seam	57.7	56.4	13
GW9706	GW9706	322404	6387589	Standpipe	64.24	Bayswater Seam*	62.1	61.9	16
GW9707	GW9707	322319	6387569	Standpipe	63.93	Bayswater Seam*	60.8	60.3	16
GW9708	GW9708	322158	6387209	Standpipe	73.14	Bayswater Seam*	61.6	60.9	16
GW9709	GW9709	322251	6388026	Standpipe	60.33	Bayswater Seam*	53.6	51.4	16
G3	G3	317786	6385251	Standpipe	73.04	Wambo Seam*	30.5	20.3	5
WOH2141A	PZ6	314989	6392647	Standpipe	91.59	Wynot Seam B-D	0.0	-	6
WOH2141B	PZ6	314989	6392647	Standpipe	91.52	Blakefield Seam - E, F	0.0	51.1	7
WOH2139A	PZ5	315249	6391511	Standpipe	91.71	Blakefield Seam - E, F	0.0	54.5	7
WOH2153A	PZ2	313881	6391429	Standpipe	68.26	Redbank Creek Seam - D, E	0.0	59.8	4
WOH2153B	PZ2	313881	6391429	Standpipe	68.26	Wambo Seam - B, C	0.0	61.9	5
WOH2154A	"PZ1"	313976	6389990	Standpipe	68.89	Redbank Creek Seam - D, E	0.0	57.6	4
WOH2154B	"PZ1"	313976	6389990	Standpipe	68.65	Wambo Seam - B, C	0.0	60.7	5
WOH2155A	PZ4	315278	6390138	Standpipe	74.55	Redbank Creek Seam - D, E	0.0	67.5	4
WOH2155B	PZ4	315278	6390138	Standpipe	74.55	Wambo Seam - B, C	0.0	59.8	5
WOH2156A	PZ3	315874	6388866	Standpipe	80.38	Redbank Ck Seam - D, E	0.0	66.5	4
WOH2156B	PZ3	315874	6388866	Standpipe	80.38	Wambo Seam - B, C	0.0	69.5	5
PZ7D	PZ7D	314057	6392684	Standpipe	58.42	Shallow overburden	51.6	51.8	2

Table A- 1- MONITORING BORE SUMMARY

Bore ID	Alternate ID	Easting	Northing	Type	Collar Elevation mRL	Target Formation Bottom	SWL (mRL)		Model Layer
							Av.	Q4 2013	
PZ7S	PZ7S	314055	6392671	Standpipe	58.44	Alluvium/*Whybrow Seam /OVB	51.3	51.5	1
PZ8D	PZ8D	317001	6385418	Standpipe	65.77	Shallow overburden	60.1	59.0	2
PZ8S	PZ8S	317002	6385411	Standpipe	65.75	Alluvium	60.5	60.6	1
PZ9D	PZ9D	317541	6385652	Standpipe	65.52	Shallow overburden	58.6	52.0	2
PZ9S	PZ9S	317542	6385642	Standpipe	65.43	Alluvium	61.6	60.7	1
GW98 MTCL1	GW98 MTCL1	322188	6387032	Standpipe	77.75	Bayswater Seam*	67.2	66.3	16
GW98 MTCL2	GW98 MTCL2	322669	6387462	Standpipe	79.47	Bayswater Seam*	70.0	69.3	16
WD609	UG_10	318803	6392211	VWP	129.98	Spoil	0.0	45.7	1
WD615_P1	UG_15_VWP1	319281	6391347	VWP	159.96	Piercefeild Seam	0.0	32.0	14
WD615_P2	UG_15_VWP2	319281	6391347	VWP	159.96	Bayswater Seam	0.0	39.2	16
WD625_P1	UG_16_VWP1	314663	6390483	VWP	76.42	Woodlands Hill Seam	0.0	44.3	9
WD625_P3	UG_16_VWP3	314663	6390483	VWP	76.42	Vaux Seam	0.0	34.3	15
WD625P	UG_16	314669	6390487	Standpipe	76.4	Whybrow Seam	0.0	57.9	2
WD622_P1	UG_24_VWP1	316236	6389588	VWP	84.52	Wambo Seam	0.0	58.0	5
WD622_P2	UG_24_VWP2	316236	6389588	VWP	84.52	Woodlands Hill Seam	0.0	33.6	9
WD622_P3	UG_24_VWP3	316236	6389588	VWP	84.52	Mt Arthur Seam	0.0	31.3	13
WD622_P4	UG_24_VWP4	316236	6389588	VWP	84.52	Vaux Seam	0.0	28.8	15
WD622_P5	UG_24_VWP5	316236	6389588	VWP	84.52	Bayswater Seam	0.0	34.6	16
WD622P	UG_24	316229	6389585	Standpipe	84.46	Wambo Seam			5
MTD613	UG_48	320778	6387025	VWP	150.45	Broonie Seam (possible)/Bayswater	50.8	50.7	16
MTD605_P1	UG_49_VWP1	317265	6386174	VWP	77.08	Weathering zone above Whybrow Seam*	54.6	54.0	2
MTD605_P2	UG_49_VWP2	317265	6386174	VWP	77.08	Whybrow Seam*	59.8	56.5	3
MTD605_P3	UG_49_VWP3	317265	6386174	VWP	77.08	Between Wambo and Whynot seams	47.8	47.3	6
MTD605_P4	UG_49_VWP4	317265	6386174	VWP	77.08	Blakefield Seam	30.9	28.2	7
MTD605_P5	UG_49_VWP5	317265	6386174	VWP	77.08	Mt Arthur Seam	13.4	12.1	13
MTD605_P6	UG_49_VWP6	317265	6386174	VWP	77.08	Vaux Seam	33.0	31.0	15
MTD605_P7	UG_49_VWP7	317265	6386174	VWP	77.08	Bayswater Seam	36.4	35.0	16
MTD614_P1	UG_50_VWP1	317265	6386174	VWP	72.43	Whybrow Seam	49.0	48.3	3
MTD614_P2	UG_50_VWP2	317265	6386174	VWP	73.43	Glen Munro Seam	26.5	20.2	8
MTD614_P3	UG_50_VWP3	317265	6386174	VWP	74.43	Mt Arthur Seam	27.9	27.0	13
MTD614_P4	UG_50_VWP4	317265	6386174	VWP	75.43	Vaux Seam	28.0	26.7	15
MTD614_P5	UG_50_VWP5	317265	6386174	VWP	76.43	Bayswater Seam	38.6	39.2	16
WD456_P1	C09_21_P1	317929	6388545	VWP	100.59	Vaux Seam	24.8	-	15
WD456_P2	C09_21_P2	317929	6388545	VWP	100.59	Bowfield Seam	-10.2	52.0	11
WD456_P3	C09_21_P3	317929	6388545	VWP	100.59	Blakefield Seam	82.9	60.7	7
WD462_P1	C09_04_P1	315529	6391358	VWP	101.67	Vaux Seam	25.2	17.8	15
WD462_P2	C09_04_P2	315529	6391358	VWP	101.67	Bowfield Seam	10.7	8.3	11
WD462_P3	C09_04_P3	315529	6391358	VWP	101.67	Woodlands Hill Seam	34.2	29.9	9
MTD517_P1	UG09_21_P1	317521	6386147	VWP	77.27	Mt Arthur Seam	30.6	26.9	13
MTD517_P2	UG09_21_P2	317521	6386147	VWP	77.27	Woodlands Seam	18.7	10.5	9

Table A- 1- MONITORING BORE SUMMARY

Bore ID	Alternate ID	Easting	Northing	Type	Collar Elevation mRL	Target Formation Bottom	SWL (mRL)		Model Layer
							Av.	Q4 2013	
MTD517_P3	UG09_21_P3	317521	6386147	VWP	77.27	Wambo Seam*	49.2	47.4	5
MTD518_P1	UG09_20_P1	316512	6386156	VWP	79.96	Mt Arthur Seam	38.7	37.0	13
MTD518_P2	UG09_20_P2	316512	6386156	VWP	79.96	Blakefield Seam/Woodlands Hill	40.5	40.5	9
MTD518_P3	UG09_20_P3	316512	6386156	VWP	79.96	Wambo Seam	45.1	44.0	5

Notes: Projection MGA94 Zone 56

* in Target Formation infers a best estimate was made based on available data

Appendix B

HISTORIC WATER QUALITY DATA (1993 – 2013)

APPENDIX B: Historic Water Quality Data (1993 - 2013)

(Project: G1468F)

Bore ID	Alternate ID	Target Formation Bottom	Model Layer	EC (Field)			PH (Field)			Ca (mg/L)			Mg (mg/L)			K (mg/L)			SO_4 (mg/L)			P (mg/L)			Na (mg/L)		
				Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%
WRM 2014		Wollombi Brook	1	764	368	1060	7.4	7.0	8.0	14	12	15	18	16	19	5	4	6	5	2	13	0.02	0.02	0.02	104	102	110
OH786	OH786	Alluvium	1	931	931	21270	7.4	7.4	8.0	70	70	130	22	22	38	11	11	15	18	18	90	1.25	1.25	2.82	89	89	191
OH787	OH787	Alluvium	1	17230	17230	26700	7.6	7.6	8.0	95	95	170	323	323	339	40	40	47	244	244	275	1.46	1.46	2.89	3770	3770	4009
OH788	OH788	Alluvium	1	12590	12590	27800	7.4	7.4	8.0	145	145	181	219	219	296	37	37	60	427	427	537	0.34	0.34	1.03	2040	2040	2636
OH942	OH942	Alluvium	1	13505	13505	26365	6.8	6.8	8.3	120	120	191	651	651	896	40	40	64	863	863	929	0.10	0.10	0.33	4140	4140	5432
OH943	OH943	Alluvium	1	8520	8520	9626	7.5	7.5	8.3	36	36	104	186	186	195	33	33	36	153	153	153	10.55	10.55	12.76	1515	1515	1547
OH944	OH944	Alluvium	1	7710	7710	8847	7.8	7.8	8.9	35	35	51	54	54	55	30	30	31	750	750	794	0.55	0.55	6.15	1650	1650	1740
PZ7S	PZ7S	Alluvium?	1	1563	1563	2152	6.9	6.9	7.6	46	46	66	37	37	60	10	10	10	19	19	21	0.57	0.57	1.19	208	208	219
PZ8S	PZ8S	Alluvium	1	14335	14335	15245	6.7	6.7	7.0	109	109	113	337	337	374	17	17	18	493	493	505	0.08	0.08	0.08	2780	2780	2859
PZ9S	PZ9S	Alluvium	1	15130	15130	16620	6.8	6.8	6.9	95	95	99	554	554	755	71	71	79	821	821	859	0.14	0.14	0.20	2775	2775	2900
PZ7D	PZ7D	Shallow overburden	2	1730	1730	2084	8.0	8.0	8.1	14	14	23	15	15	26	6	6	6	31	31	31	0.03	0.03	0.14	376	376	410
PZ8D	PZ8D	Shallow overburden	2	8295	8295	8815	7.7	7.7	8.0	33	33	41	46	46	60	15	15	16	50	50	56	0.34	0.34	0.48	1945	1945	1960
PZ9D	PZ9D	Shallow overburden	2	9925	9925	10625	7.1	7.1	7.3	167	167	177	344	344	428	33	33	36	407	407	481	0.05	0.05	0.11	1690	1690	1774
WD625P	UG_16	Whybrow	2	12000	12000	12099	7.2	7.2	7.2	67	67	67	212	212	212	21	21	21	241	241	241	0.04	0.04	0.04	2270	2270	2270
WOH2153A	PZ2	Redbank Ck - D, E	4	1848	1848	2010	7.8	7.8	8.1	5	5	9	3	3	3	4	4	5	62	62	76	0.15	0.15	13.82	426	426	485
WOH2154A	"PZ1"	Redbank Ck - D, E	4	4690	4690	4830	7.6	7.6	7.8	6	6	15	5	5	18	9	9	10	118	118	141	0.10	0.10	10.13	1080	1080	1174
WOH2155A	PZ4	Redbank Ck - D, E	4	7040	7040	7301	7.6	7.6	7.7	32	32	48	57	57	94	16	16	21	321	321	875	0.09	0.09	3.17	1470	1470	1928
WOH2156A	PZ3	Redbank Ck - D, E	4	2360	2360	11090	7.3	7.3	7.6	21	21	104	12	12	239	9	9	30	238	238	1142	0.34	0.34	3.56	367	367	3734
G3	G3	Wambo?	5	7275	7275	7673	7.3	7.3	7.8	32	32	37	27	27	29	25	25	29	0	0	0	0.32	0.32	0.89	1660	1660	1767
WD622P	UG_24	Wambo	5	14075	14075	17698	7.2	7.2	7.5	167	167	167	533	533	533	42	42	42	1470	1470	1470	0.03	0.03	0.03	3720	3720	3720
WOH2153B	PZ2	Wambo - B, C	5	1840	1840	1947	7.8	7.8	8.1	5	5	8	5	5	8	4	4	6	57	57	70	0.20	0.20	3.64	466	466	478
WOH2154B	"PZ1"	Wambo - B, C	5	4700	4700	4815	7.6	7.6	7.9	5	5	6	6	6	9	8	8	11	112	112	134	0.16	0.16	3.64	1100	1100	1172
WOH2155B	PZ4	Wambo - B, C	5	6180	6180	7424	7.5	7.5	7.6	44	44	44	44	44	75	14	14	17	344	344	583	0.22	0.22	4.13	1385	1385	1660
WOH2156B	PZ3	Wambo - B, C	5	8375	8375	15859	7.4	7.4	7.9	75	75	107	70	70	263	18	18	37	402	402	1253	0.52	0.52	4.26	1960	1960	3848
WOH2141A	PZ6	Wynot B-D	6	6690	6690	6848	7.5	7.5	7.8	74	74	84	123	123	164	18	18	19	320	320	425	0.11	0.11	3.60	1250	1250	1370
OH1122 (1)	OH1122 (1)	Blakefield Seam	7	12880	12880	14164	7.1	7.1	7.5	93	93	175	259	259	370	37	37	48	457	457	755	0.26	0.26	0.35	2490	2490	2616
OH1123 (2)	OH1123 (2)	Blakefield	7	18250	18250	19602	6.8	6.8	7.4	135	135	201	488	488	562	45	45	52	1260	1260	1474	0.23	0.23	0.29	3858	3858	4090
OH1124 (1)	OH1124 (1)	Unknown	7	16675	16675	17863	6.7	6.7	7.1	260	260	302	586	586	668	56	56	58	885	885	885	1.08	1.08	2.00	1314	1314	2476
OH1125 (1)	OH1125 (1)	Unknown	7	16115	16115	18070	6.7	6.7	7.0	274	274	301	683	683	772	35	35	46	860	860	922	0.23	0.23	2.98	2175	2175	2633
WOH2139A	PZ5	Blakefield - E, F	7	2010	2010	2230	7.2	7.2	7.4	18	18	37	15	15	43	7	7	9	15	15	39	0.26	0.26	3.44	426	426	460
WOH2141B	PZ6	Blakefield - E, F	7	5770	5770	8727	8.6	8.6	10.3	41	41	47	67	67	76	15	15	17	228	228	272	1.45	1.45	4.11	1690	1690	1780
OH1122 (2)	OH1122 (2)	Woodlands Hill	9	13230	13230	14428	6.9	6.9	7.7	100	100	143	267	267	293	37	37	39	695	695	721	6.22	6.22	11.42	2825	2825	2857
OH1123 (1)	OH1123 (1)	Woodlands	9	17550	17550	19318	6.9	6.9	7.3	130	130	213	316	316	468	42	42	52	895	895	1220	0.10	0.10	12.04	3925	3925	4158
OH1124 (2)	OH1124 (2)	Unknown	9	13680	13680	14353	6.9	6.9	7.3	160	160	298	360	360	361	35	35	36	692	692	692	6.58	6.58	12.36	2310	2310	2391
OH1125 (2)	OH1125 (2)	Unknown	9	16150	16150	17130	6.7	6.7	7.6	270	270	320	747	747	816	63	63	87	857	857	890	0.41	0.41	0.58	2145	2145	2366
OH1122 (3)	OH1122 (3)	Bowfield Seam?	11	12090	12090	12899	7.3	7.3	7.8	82	82	97	262	262	338	39	39	48	296	296	385	0.39	0.39	1.02	2460	2460	2582
OH1123 (3)	OH1123 (3)	Bowfield	11	17720	17720	19610	6.9	6.9	7.5	130	130	157	188	188	384	37	37	47	400	400	1047	0.22	0.22	1.33	4035	4035	4386
OH1124 (3)	OH1124 (3)	Unknown	11	13915	13915	15863	6.8	6.8	7.1	190	190	275	491	491	580	54	54	74	830	830	830	0.08	0.08	0.09	2460	2460	2586
OH1125 (3)	OH1125 (3)	Unknown	11	15290	15290	16458	6.7	6.7	7.3	289	289	506	673	673	810	35	35	43	833	833	918	0.08	0.08	12.02	2225	2225	2308
OH1138 (1)	OH1138 (1)	Warkworth Seam	12	13000	13000	15820	6.9	6.9	7.3	324	324	474	470	470	711	42	42	77	418	418	572	0.18	0.18	0.44	1920	1920	2848
OH1138 (2)	OH1138 (2)	Warkworth Seam	12	10750	10750	11791	6.9	6.9	7.1	375	375	462	375	375	429	27	27	32	780	780	934	0.16	0.16	0.32	1570	1570	1628
OH1121	OH1121 (1?)	Vaux	15	7730	7730	8658	7.0	7.0	7.2	99	99	182	117	117	222	15	15	24	180	180	821	0.08	0.08	1.72	1490	1490	1765
OH1126	OH1126	Vaux?	15	7960	7960	8468	7.1	7.1	7.3	78	78	86	195	195	200	32	32	34	867	867	1168	0.16	0.16	0.26	1550	1550	1610
OH1137	OH1137	Vaux	15	15290	15290	17554	7.0	7.0	7.4	110	110	150	396	396	532	42	42	54	808	808	886	0.20	0.20	3.03	3310	3310	3970
GW9706	GW9706	Bayswater Seam?	16	3625	3625	5385	7.3	7.3	7.7	144	144	156	110	110	137	16	16	17	1110	1110	1292	0.02	0.02	0.05	828	828	1130
GW9707	GW9707	Bayswater Seam?	16	16760	16760	20900	7.3	7.3	7.8	315	315	370	635	635	729	23	23	34	4160	4160	5060	0.08	0.08	0.14	4690	4690	4823
GW9708	GW9708	Bayswater Seam?	16	14450	14450	16080	6.9	6.9	7.1	460	460	488	457	457	494	27	27	35	4020	4020	5012	0.05	0.05	0.11	2370	2370	3018
GW9709	GW9709	Bayswater Seam?	16	22900	22900	24700	6.9	6.9	7.3	546	546	616	923	923	959	30	30	42	5500	5500	6168	0.03	0.03	0.09	4975	4975	5123
GW98 MTCL1	GW98 MTCL1	Bayswater?	16	9645	9645	10033	7.2	7.2	7.6	90	90	396	182	182	403	24	24	29	870	870	4223	0.10	0.10	0.32	1935	1935	2253
GW98 MTCL2	GW98 MTCL2	Bayswater?	16	15700	15700	16322	6.9	6.9	7.2	603	603	728	599	599	788	48	48	64	4300	4300	4596	0.12	0.12	0.33	2700	2700	2875
OH1127	OH1127(1?)	Bayswater Seam?	16	11610	11610	12895	6.9	6.9	7.2	134	134	145	145	145	150	22	22	26	5	5	8	0.03	0.03	0.55	2450	2450	2577

Appendix C

NUMERICAL MODEL – DEVELOPMENT & CALIBRATION

1. MODEL DEVELOPMENT AND CALIBRATION

1.1 Model Objectives

A numerical model was developed to assess the impacts of the Proposal on the surrounding groundwater regime. Whilst developing the model, the requirements of the NSW AIP were considered to ensure the model would predict the:

- volume of water produced by dewatering Permian strata and coal seams;
- drawdown induced in the Permian strata and coal seams groundwater system;
- drawdown (or water take) from alluvial aquifers;
- potential for changes in baseflow to Wollombi Brook and the Hunter River;
- potential for drawdown in surrounding private landholder bores; and
- potential for changes in groundwater salinity.

1.2 Previous Models

In 2002 Coal & Allied commissioned Mackie Environmental Research (MER, 2002) to assess the impact of a proposed extension to Warkworth Mine on surface- and groundwater as part of the 2002 Environmental Impact Statement (EIS). That study included the development of a numerical groundwater flow model and recommended that additional monitoring bores be installed to monitor depressurisation and water quality in areas to the west of the proposed extension. Coal & Allied subsequently installed monitoring bores WOH2154A to WOH2141A in 2004 after planning approval was granted in 2003. Groundwater level monitoring in these bores has shown that the predictions of MER (2002) were conservative as the magnitude or the extent of depressurisation has not been as extensive as predicted by the model. The inflows to the open cut pit have also not reached the rates predicted by MER (2002).

In 2010, Coal & Allied proposed to further extend Warkworth Mine (the *Warkworth Extension Project*) about 1 km down-dip (to the west) of the area approved in 2003 and commissioned Australasian Groundwater and Environment (AGE) to assess potentially associated groundwater impacts (AGE, 2010). That study included the development of another numerical model that built upon the work of MER (2002). Both the Commonwealth and NSW Governments approved this project, but a subsequent appeal in the NSW Land and Environment Court overturned the approval based on issues unrelated to groundwater.

Since 2010 Coal & Allied have increased the groundwater monitoring network through the installation of several multi-level vibrating wire piezometers (VWPs) west and down-dip of the active MTW mining areas (Golder, 2013). The data obtained from those VWPs have been included in the calibration of the latest (AGE, 2014 – this report) model, discussed below.

Four new monitoring bores within the Permian coal measures around the Project and within the spoil (Loders Pit) were installed in early 2014. Groundwater level and water quality data from these were included in the 2014 model calibration.

1.3 Model Design and Construction

1.3.1 Conceptual Model and Extent

A conceptual understanding of the groundwater regime developed from field measurements, observations and experience is the basis for the development of any numerical groundwater flow model. Section 5 of this report outlines the conceptual groundwater model for Mount Thorley Warkworth (MTW). This conceptual model is a summary of how the groundwater system is believed to operate based upon the available information and represents the natural system in an idealised and simplified way.

The extent of the numerical model boundaries were selected to be suffiently distant from the currently approved and proposed mining so as to not influence the drawdown predictions. These boundaries are as follows:

- The eastern model boundary was defined along the line of sub-crop of the Jerrys Plain Subgroup. The Jerries Pains Subgroup is the target of current and future mining activities and groundwater level monitoring has indicated that there is very limited hydraulic connection between the mine and the area to the east of this line.

- The western model boundary was defined along the base of the outcropping Hawkesbury Sandstone. This sandstone has not been included in the model as previous work has indicated that groundwater drawdown associated with currently approved and proposed mining would not extend far beyond Wollombi Brook.

- The northern and southern boundaries have been set at a distance to capture cumulative impacts from the adjacent active mines of Wambo and Bulga, and lie well beyond the likely influence of the proposed mining activity being assessed at Warkworth.

1.3.2 Software Used

The MODFLOW SURFACT code (referred to as SURFACT for the remainder of the report) was used to simulate of groundwater flow.

SURFACT is a commercial derivative of the standard MODFLOW code and has some distinct advantages over the standard MODFLOW for simulating mining projects. SURFACT simulates variably saturated conditions. This is beneficial for mining where coal seams can become progressively dewatered which avoids the rewetting of cells that can be problemetic with standard MODFLOW. The SURFACT also includes adaptive time-steps, and robust numerical solver that help to converge the numerical solution.

The MODFLOW pre- and post-processor PMWIN (Chaing and Kinzelbach, 1996) was used to generate some of the input files for the SURFACT model. Where files differ to allow for the additional capabilities of SURFACT, these changes were undertaken through manual editing of the model files.

1.3.3 Time

The model used days as the unit of time. The model represented the progress of mining and recharge with annual stress periods. The stress period duration was set as one year (365.25 days).The model simulated mining in stages representing the progression of the pit floor (using drain cells) and creation of spoil piles (by changing hydraulic properties with time). After every modelling stage, the model paused and the hydraulic heads were extracted to use as the

starting conditions for the next stage. The hydraulic properties of the spoils were updated, and the next stage started. The stage duration for the calibrated model was:

- five years for the first six stages from 1981 to 2010;
- four years for stage seven from 2011 to 2014; and
- annual increments of one year length for predictive modelling years 2014 to 2035.

The first seven stages from 1981 to 2013 were used to calibrate the model as groundwater monitoring data was available for this period. Stages eight to 28 from 2014 to 2035 simulated the currently approved and proposed mining to predict future impacts on the groundwater regime.

1.3.4 Model Dimensions, Extent and Layers

The model grid consisted of 98,644 cells per model layer (271 columns, 364 rows, 76,089 active cells per layer, 16 layers). The upper left corner of the grid was set at: x = 304400, y = 6397500 (GDA94, MGA zone 56) and rotated by 18.43°. The cell size varied from a minimum of 30 x 30 m in the mining areas to a maximum of 100 x 225 m outside these zones. Figure C-5 shows the rotated grid and active model domain, as well as the refined grid over MTW.

The main difference between the current and previous models is that the interburden between selected major coal seams was represented with a model layer, whereas in the AGE (2010) model the interburden aquitards were simulated using the vertical conductance term in SURFACT. More coal seams were also added to the updated model to better represent the geology and mining activities in different pits at MTW.

Each of the coal seams within the Jerrys Plains subgroup have numerous plies, typically between 5 and 15, that coalesce and split over the mining area. The complexity of the coal seam structure was simplified for the numerical model by merging several coal seams plys into single model layers. In all instances the total measured thickness of the coal plys was preserved in the model to ensure seam transmissivity remains the same. The model consists of 16 model layers including seven coal seams. Table C- 1 summarises the hydrostratigraphic units represented by each model layer and the seams targeted by each mining operation.

Table C- 1:UPDATED MODEL LAYERING

Unit			Coal Seam	Model Layer
Alluvium/ Regolith				L1
Wittingham Coal Measures	Jerrys Plains Subgrp.	Mt. Leonard	*Overburden*	L2
			Whybrow	L3
			Interburden	L4
		Althorpe Fmtn.		
		Malabar Fmtn.	*Interburden*	
			Redbank Crk	
			Interburden	
			Wambo	L5
			Interburden	L6
			Whynot	
			Interburden	
			Blakefield	L7
		Mt. Ogilvie Fmtn.	*Interburden*	L8
			Glen Munro	
			Interburden	
			Woodlands Hill	L9

Table C- 1:UPDATED MODEL LAYERING

Unit	Coal Seam	Model Layer
	Interburden	L10
Milbrodale Fmtn.		
Mt. Thorley Fmtn	*Interburden*	
	Arrowfield	
	Interburden	
	Bowfield	L11
	Interburden	L12
	Warkworth	
	Interburden	
Fairford Fmtn.		
Burnamwood Fmtn.	*Interburden*	
	Mt. Arthur	L13
	Interburden	L14
	Piercefield	
	Interburden	
	Vaux	L15
	Interburden	L16
	Broonie	
	Interburden	
	Bayswater	

The model layers represent:

- Layer 1:
  - alluvial aquifers associated with Wollombi Brook and the Hunter River - the thickness of the alluvial sediments was based on the available driller's logs;
  - outside the alluvial plain where the Permian strata outcrop, the thickness of Layer 1 was set at 5 m to represent a regolith / soil zone;
- Layer 2 - the overburden above the uppermost coal seams;
- Layer 3 - the Whybrow Seam, with an average thickness of 5.1m;
- Layer 4 - interburden;
- Layer 5 - the Wambo and Redbank Seams, with a combined average thickness of 3.8 m measured from the base of the Wambo Seam;
- Layer 6 - interburden;
- Layer 7 - the Blakefield and Whynot Seams, with a combined average thickness of 5.4 m measured from the base of the Blakefield Seam;
- Layer 8 - interburden;
- Layer 9 - Glen Munro and Woodlands Hill Seams, with a combined average thickness of 6.4 m measured from the base of the Woodlands Hill Seam (base of mining in MTO);
- Layer 10 - interburden including the Milbrodale Formation;
- Layer 11 - the Arrowfield and Bowfield Seams, with a combined average thickness of 5.7 m measured from the base of the Bowfield Seam;
- Layer 12 - interburden including the Fairford Formation;

- Layer 13 - Mt Arthur Seam, with an average thickness of 4.15 m measured from the base of the seam (base of mining in Warkworth Mine);
- Layer 14 - interburden;
- Layer 15 - the Piercefield and Vaux Seams, with a combine average thickness of 4.85 m measured from the base of the Vaux Seam, representing an in coal seam below the Proposal; and
- Layer 16 - interburden and the top of the low permeability Archerfield Sandstone at the base of the Jerrys Plain sub-group.

Figure C- 1 shows a west to east cross section through the model. The thin blue lines show the cells representing the individual coal seams.

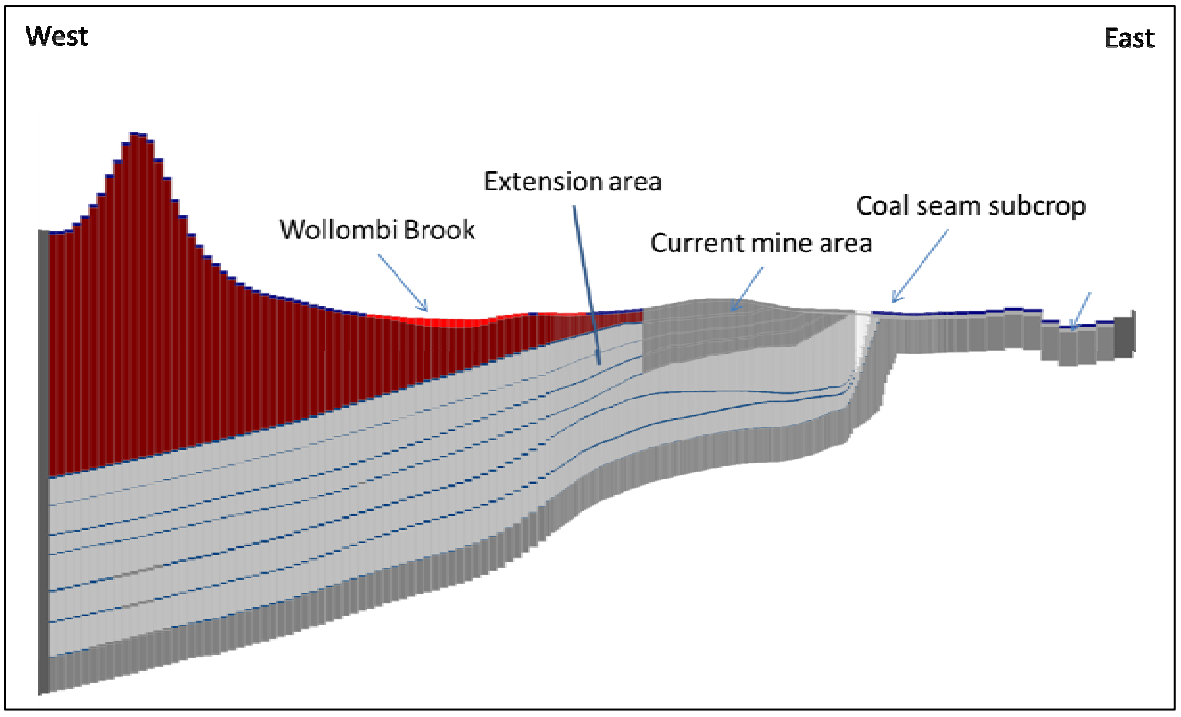
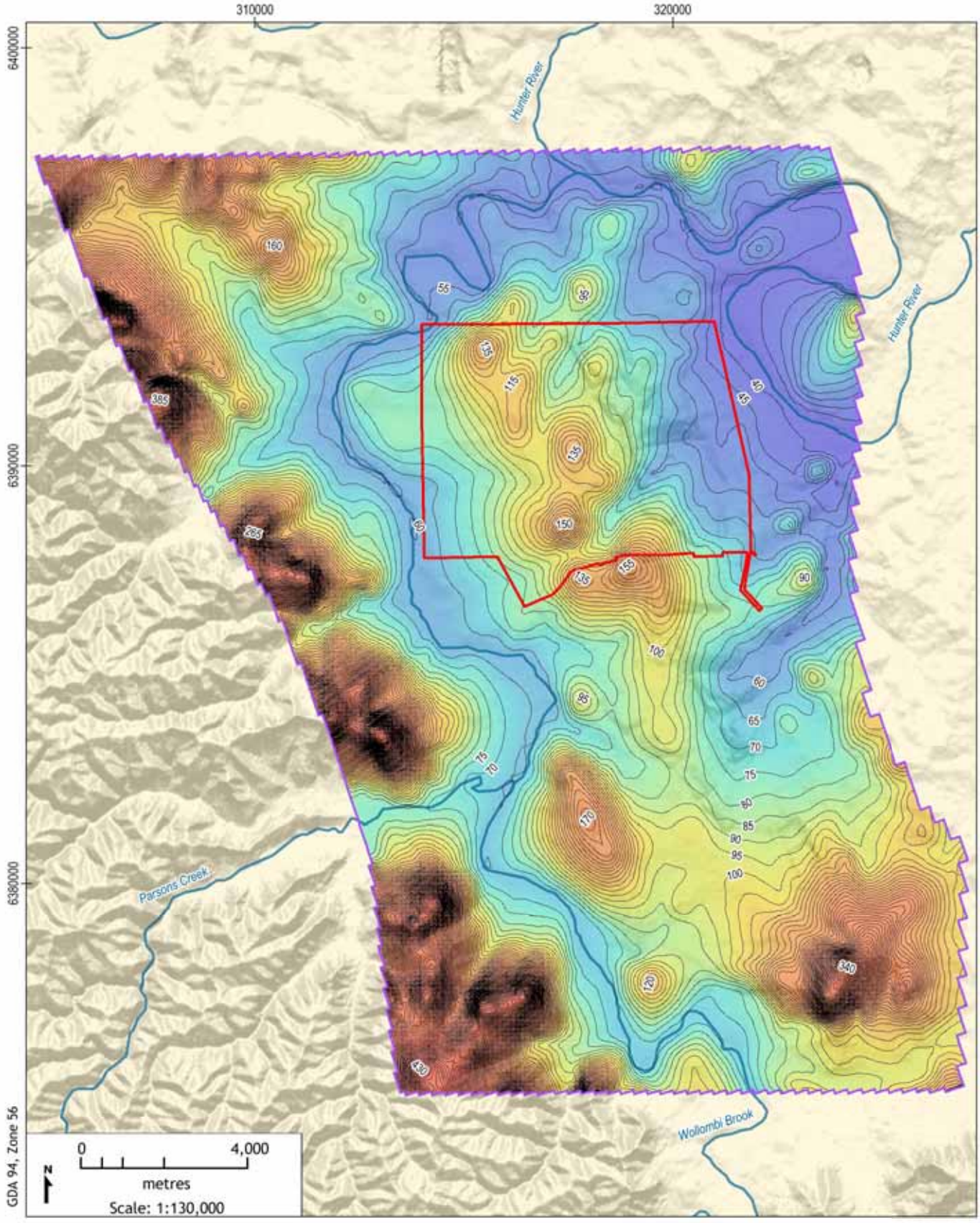


Figure C- 1: West to east cross-section through the model layers

Publicly available nine-second digital elevation data with a 250m x 250m grid spacing were used to represent the ground surface in the model during calibration. These data were chosen as the open cut pits were not evident and therefore the dataset was suitable for the pre-mining calibration. Figure C- 2 shows the top of Layer 1 in the model showing the pre-mining land surface.



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Contour (5m interval)
- Major watercourse

Elevation (mAHD)

- 485
- 300
- 200
- 100
- 90
- 80
- 70
- 60
- 50
- 35

Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Model Topographic Surface

DATE: 3/4/2014

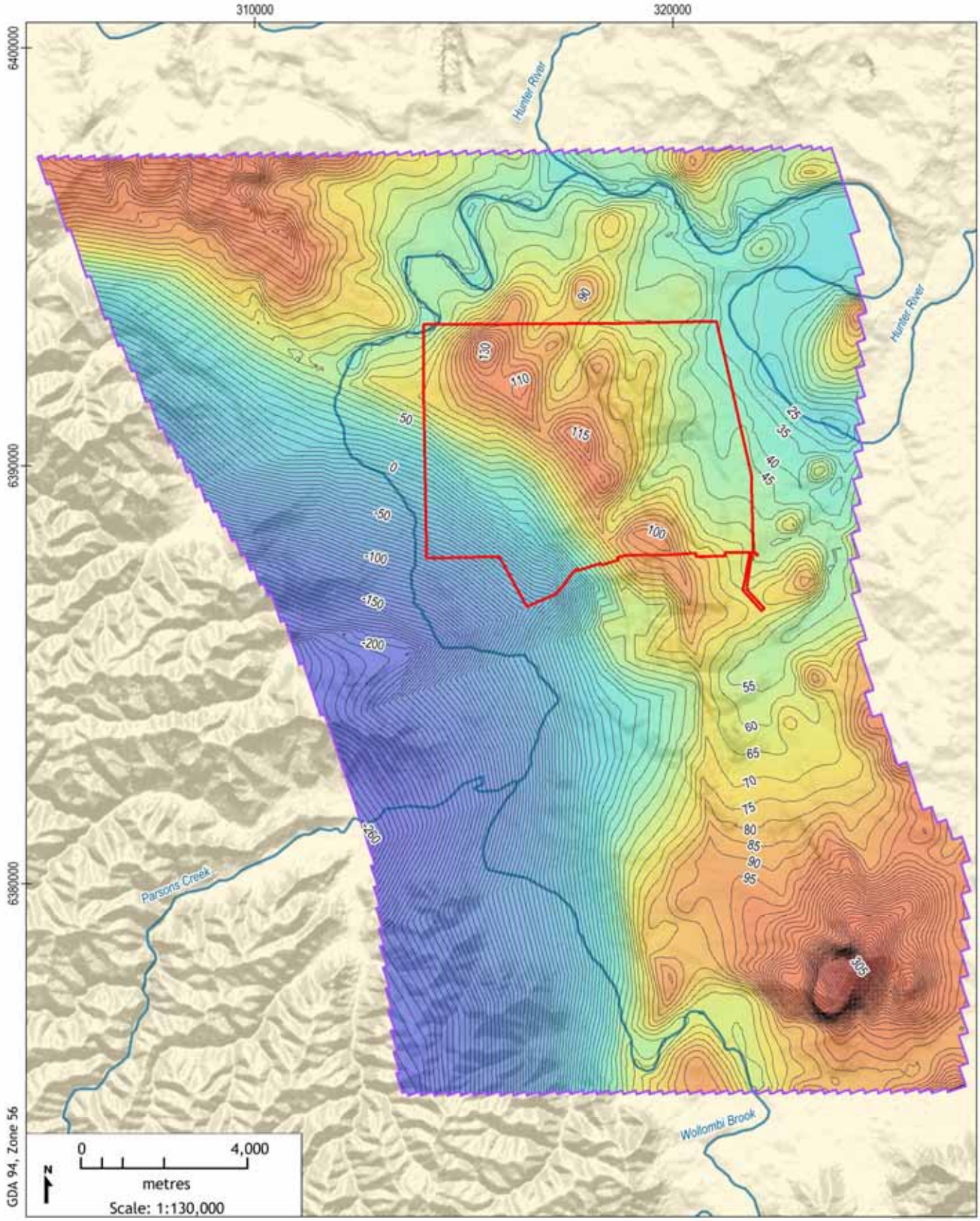
FIGURE No: C-2

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Within MTW, the structure of the coal seams being mined has been mapped on relatively close drill spacing by the exploration program. As the groundwater model extended outside the mining lease, geologists from MTW mapped the structure of the key coal seams using publicly available data from exploration companies, regional exploration data and the NSW Geological Survey.

In the western section of the model, in the Wollemi National Park area, no data on coal seam structure was available due to a lack of exploration. In this area the coal seams were extended to the west with a constant dip and terminated at the Redmanvale Fault zone, which marks the western boundary of the model. The coal seam structure is considered to be accurate within the mining lease but less certain outside this area due to the limited availability of spatial data.

Figure C- 3 and Figure C- 4 show the base of Layer 3 (Whybrow Seam) and base of Layer 13 (Mt Arthur Seam) to show the westerly dipping structure within the model.



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Contour (5m interval)
- Major watercourse

Elevation (mAHD)

- 310
- 200
- 100
- 70
- 60
- 50
- 0
- -50
- -100
- -265

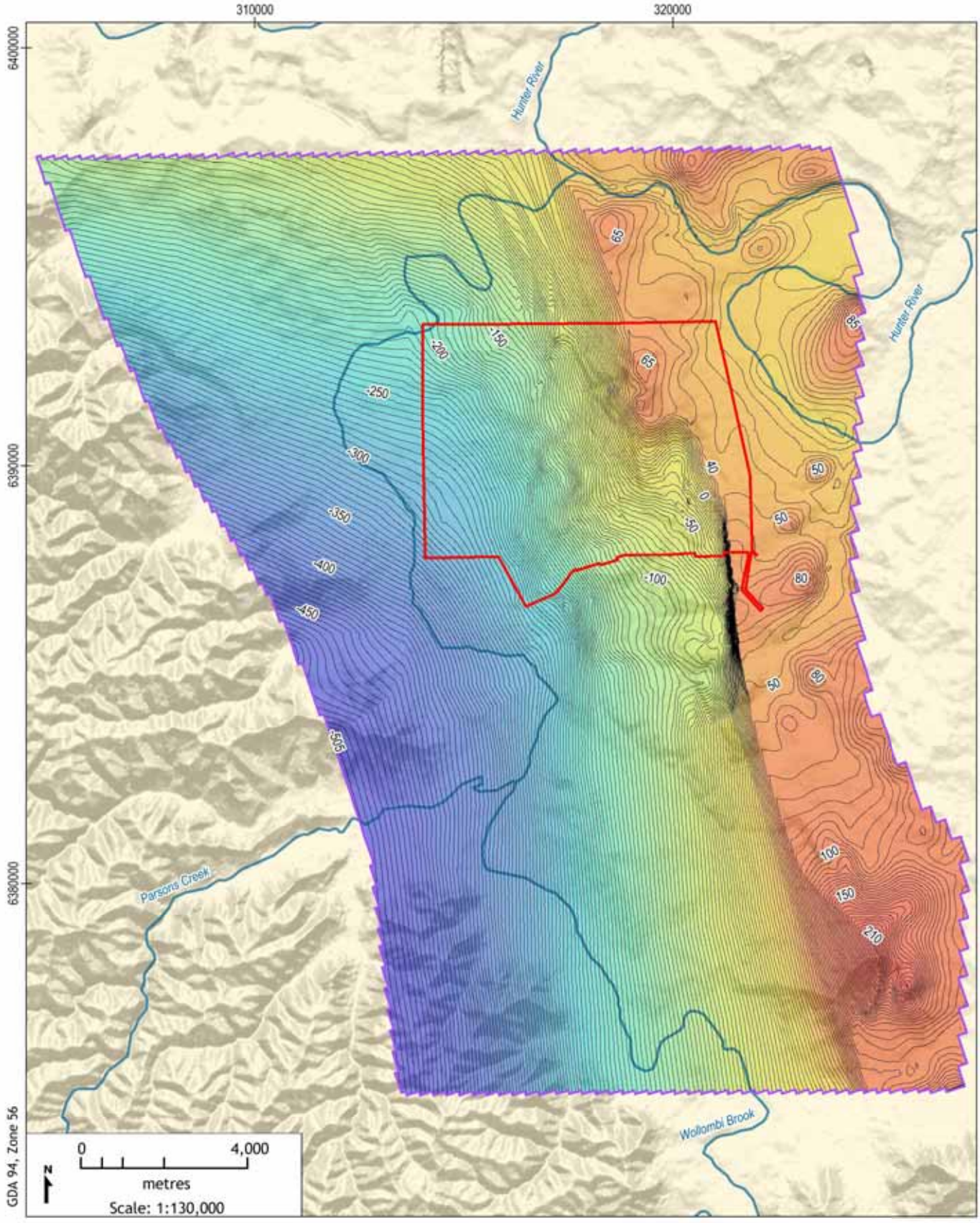
Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Model Layer 3 - Floor Whybrow Seam

DATE: 3/4/2014

FIGURE No: C-3

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Contour (5m interval)
- Major watercourse

Elevation (mAHD)

220
100
50
0
-50
-100
-200
-300
-400
-510

Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Model Layer 13 - Floor Mount Arthur Seam

DATE: 3/4/2014

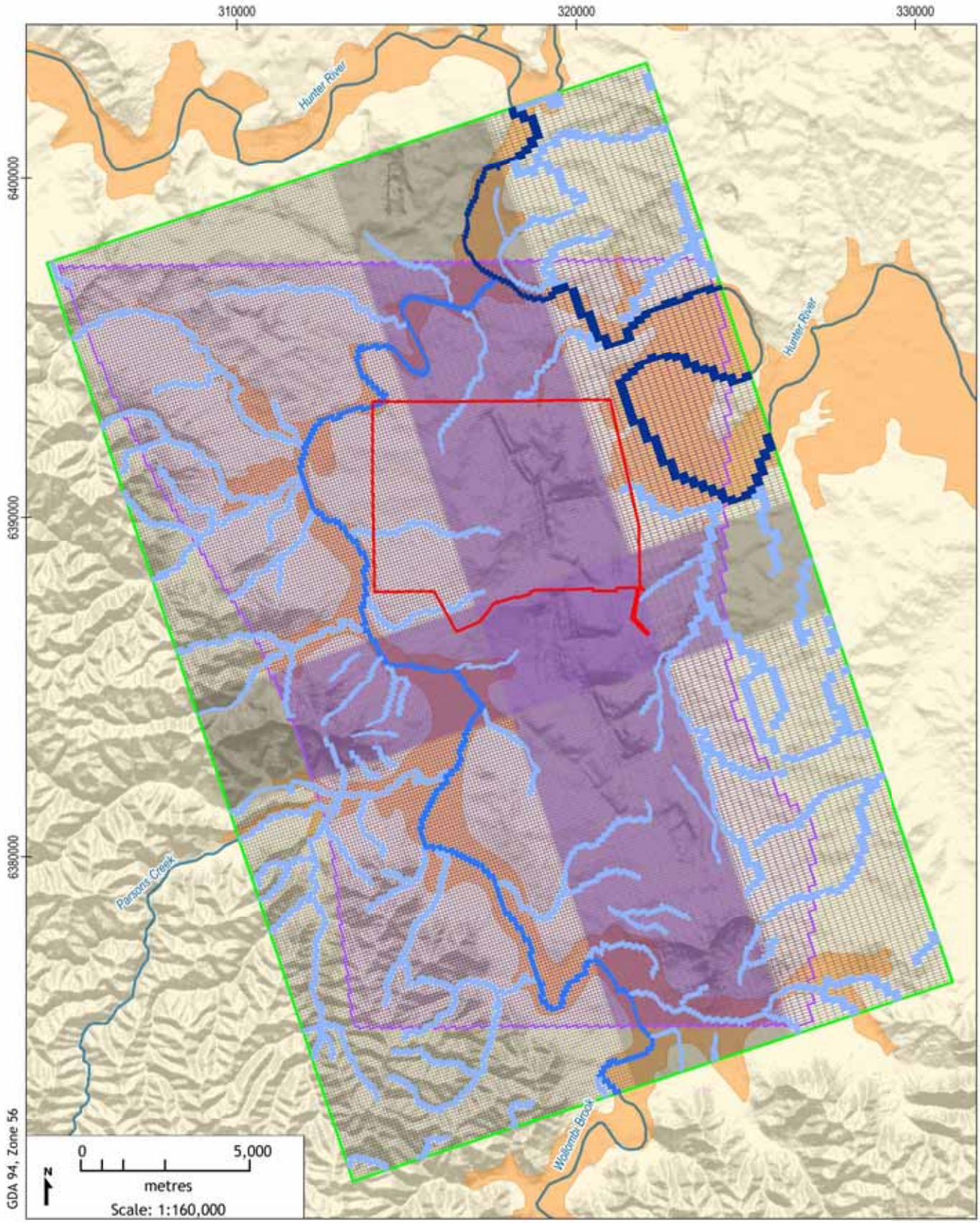
FIGURE No: **C-4**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

The model domain is surrounded by “no flow” boundaries as follows:

- the Redmanvale Fault Zone under the Wollemi National Park marks the western boundary;
- the outcrop of the Jerrys Plains subgroup along the Loder Anticline marks the eastern boundary - note the outcrop zone for each seam varies;
- the Hunter River Cross Fault marks the northern boundary;
- an arbitrary distance to the south judged to be beyond the influence of MTW; and
- the base of Layer 16 in the model, which represents the floor of the Bayswater Seam/ top of Archerfield Sandstone.

Figure C- 5 shows the model domain and boundaries.



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Active model grid
- Model domain
- InActive model grid

Model river cells

- Hunter River
- Wollombi Brook
- Surface drainage

- Quaternary alluvium (100k)
- Major watercourse

Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Model Domain and River Cells

DATE: 3/4/2014

FIGURE No: C-5

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

1.3.5 Data Exclusions

Prior to the transient calibration, datasets representing the vibrating wire piezometers (VWP) were used to help with the conceptualisation of vertical leakage between different hydrostratigraphic units. Given the model stress period length (one year for the predictive part of the model run), the use of the high density (15 minutes intervals) data for the transient calibration was not practical and did not contribute to the quality of the calibration. The dataset was thus resampled from the 15 minutes intervals to monthly intervals in order to speed up the processing of the modelled results.

During the calibration process, several bores with detrimental influence on the calibration process were identified. These observations were either not relevant to the performance of model in the critical areas, identified as faulty (providing data contradicting to the observation in surrounding areas) or identified as influenced by underground works previously unacounted for in the model. Such observations were removed from the calibration by weighting their contribution towards the objective function to zero.

Bores weighted out of the calibration were: OH1122_1, OH1122_2, OH1122_3, OH1124_1, OH1124_2, OH1124_3, wd615_p2, wd622_p5

1.3.6 Boundary Conditions

1.3.6.1 Rivers and Streams

The SURFACT River package can represent the permanent rivers and ephemeral streams within the active model domain. The river boundary condition was set with a permanent 0.5 m of water in the Hunter River, and 0.1 m in Wollombi Brook to allow for surface – groundwater interconnectivity. The minor surface drainage lines were set as drains and only discharged groundwater from the groundwater systems if groundwater level reached the base of the rivers. Figure C- 5 shows the location of the river cells.

LIDAR elevation data was available for the reach of Wollombi Brook adjacent to MTW. The LIDAR data was used to set the level of the river bed, the coarser SRTM data used where LIDAR coverage was not available. The availability of LIDAR means the bed elevation is accurate along a critical reach of Wollombi Brook (adjacent to the proposed mining).

The vertical hydraulic conductivity of the bed of Wollombi Brook and Hunter River river boundary cells were set as 0.01 m/day and 0.1 m/day respectively. The bed thickness was 2 m for the Hunter River and 1.5 m for the Wollombi Brook. The sensitivity analysis also simulated an extended dry period with no flow in the Wollombi Brook by removing the fixed stream water level.

1.3.6.2 Recharge

Table C-2 shows rainfall data used for the model calibration – sourced from Bulga mine.

Table C- 2: ANNUAL RAINFALL FROM BULGA USED IN MODEL CALIBRATION

Year	Rainfall (mm/year)	Year	Rainfall (mm/year)
1981	810.8	1998	797.4
1982	601	1999	641.6
1983	641.9	2000	777.7

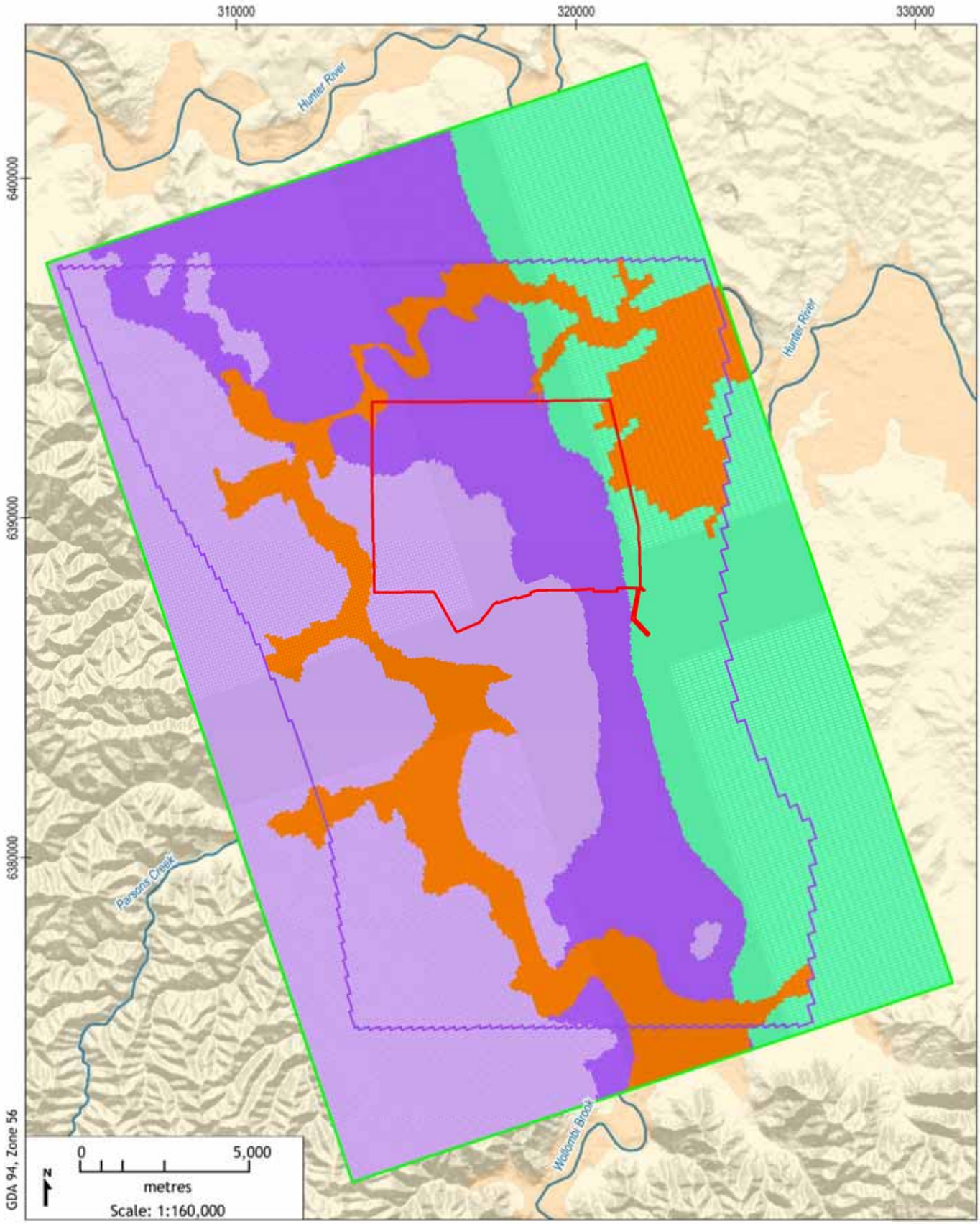
Table C- 2: ANNUAL RAINFALL FROM BULGA USED IN MODEL CALIBRATION			
Year	**Rainfall (mm/year)**	**Year**	**Rainfall (mm/year)**
1984	791	2001	579.98
1985	588	2002	505.7
1986	618.6	2003	615.5
1987	748.8	2004	750.66
1988	867	2005	566.9
1989	860	2006	385.6
1990	742.6	2007	875.3
1991	603.6	2008	659.55
1992	700.6	2009	705.7
1993	540.6	2010	820.3
1994	487.2	2011	871.4
1995	658.6	2012	606.5
1996	619.4	2013	833.9
1997	622.2		

The SURFACT Recharge package applied recharge to the first layer in the model. The rate of recharge to the alluvial aquifer was initially set at 12.5% of rainfall. The recharge rate for the Permian outcrop areas (similar to the rate adopted by MER 2002) was initially set at 0.5 % of rainfall. These values were used as initial starting point to calibrate the model and were the values previously adopted by AGE (2010). The recharge rate (as a proportion of rainfall) was later varied in subsequent transient model calibration runs.

Figure C-6 shows the recharge zones for the alluvium and Permian derived regolith. The model applied recharge over the calibration period as a fixed proportion of annual rainfall recorded at Bulga. Water levels in both the Permian and alluvium recorded with data loggers show a very subdued response to rainfall events. Individual rainfall events therefore did not need to be represented in the model. Table C-3 shows calibrated model recharge values.

As mining progressed, the model increased recharge to the expanding zones of spoil.

Table C-3: CALIBRATED RECHARGE		
Recharge zone		**% of annual rainfall**
Zone 1	alluvium	3.00
Zone 2	regolith	1.50×10^{-1}
Zone 3	Permian outcrops west of Jerrys Plains Subgrp outcrop line	9.27×10^{-2}
Zone 4	Permian outcrops east of Jerrys Plains Subgrp outcrop line	1.00×10^{-7}
Zone 5	spoil	10.32



LEGEND:

Recharge zones:
- Alluvium
- Regolith and Permian overburden
- Permian coalseams outcrop/subcrop
- Archerfield Sandstone (below Bayswater seam)

- Model domain
- Model grid
- Active model boundary
- Proposed Warkworth Mine development consent boundary
- Quaternary alluvium (100k)
- Major watercourse

Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Recharge Zones - Layer 1

DATE: 13/5/2014

FIGURE No: **C-6**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

1.3.6.3 Drain Cells, Mining and Spoil

The SURFACT drain package was used to simulate both open-cut and underground mining. A conductance term of 100m/day was applied to all drain cells.

Available mine plans for MTW and publically available mine plans for Bulga and Wambo open-cut and underground mines were used to define the yearly progress of mining for the calibration period from 1980 to 2013. The main body of the report (Section 3) documents the coal seams targeted by each mining operation.

Figure C- 7 shows the simulated progress for mining in all model layers. In each case drain cells were set at the base of the layer that best represented the basal seam being mined in each open pit or longwall.

Within each stage of mining the model increased the amount of the drain cells to simulate the progress of the mine, and at the end of the stage, the hydraulic properties of the mined area changed to represent spoil in the open-cut or the goaf in underground mines.

The lengthy transient calibration period, and the detailed mine progress was implemented to provide the best antecedent conditions possible prior to the proposed mining.

Due to limited availability of historic mine plans each yearly mine strip was simulated by applying drain cells to the base of the seam being mined in each pit or underground operation. This approach may have overestimated the drawdowns during the simulation, and also affected the ability of the model to match observed water levels in some bores during the calibration process.

1.3.6.4 Tailings Storage Facilities

Tailings at MTW are stored in several cells within the spoil heaps and are represented in the model by river cells. The main report Figure 1.1 shows the locations of the tailings storage facilities (TSF). The base of each TSF river cell was set at TSF floor elevation, with the bed thickness increased with time to simulate filling with tailings.

When the TSF were actively being filled the water level within the cells was set at 1 m above the fill elevation. The hydraulic conductivity (k) of the thickening TSF (b) was held constant, resulting in the conductance term (proportional to k/b) reducing as the TSF filled with sediment. This supports field evidence that the TSF have initially high leakage rates which progressively reduce over time as the tailings consolidate and thicken.

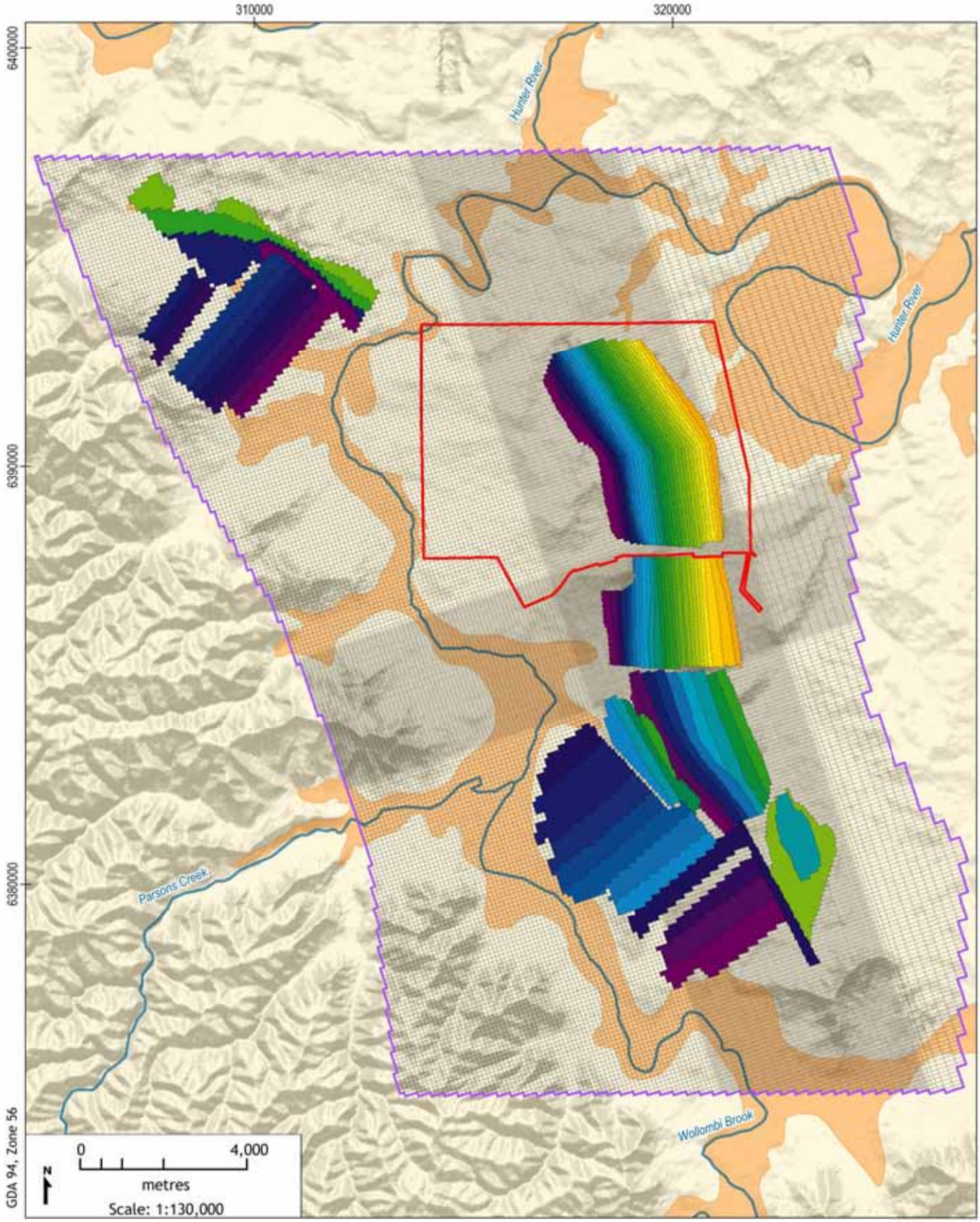
All simulated TSFs are located on or within spoil piles and (based on field evidence) contributed to mounded water tables within spoils. The mounding within spoils appears to have contributed to groundwater level recovery in Permian units north of Warkworth mine spoil following mining.

Historical information of TSF fill rates and timing was sourced from ATC (2014a) for Tailings Dam 1 (TD1), ATC (2014b) for Tailings Dam 2 (TD2), ATC (2014c) for the Centre Ramp Tailing Storage Facility (CRTSF) and ATC (2014d) for Abbey Green South (AGS). The smaller mining strip TSF located between Warkworth Pit and Loders pit was not simulated. Table C-4 summarises input data collated for the simulated TSFs, the area of each TSF has also been used to calculated bed conductance through time for each TSF as they fill.

Table C- 4: TSF BED CONDUCTANCE, FILL RATES AND CAPPING SCHEDULES

	Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)		Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)
	Tailings Dam 1 - TD01					Tailings Dam 2 - TD02			
Tailings Dam 1 - TD01	1984	1	59	37.944	Tailings Dam 2 - TD02	2001	6	121	6.324
	1985	3	61	12.648		2002	7	122	5.421
	1986	5	63	7.589		2003	7	122	5.421
	1987	7	65	5.421		2004	8	123	4.743
	1988	9	67	4.216		2005	8	123	4.743
	1989	11	69	3.449		2006	9	124	4.216
	1990	13	71	2.919		2007	10	125	3.794
	1991	15	73	2.53		2008	12	127	3.162
	1992	17	75	2.232		2009	14	129	2.71
	1993	19	77	1.997		2010	15	130	2.53
	1994	21	79	1.807		2011	15	130	2.53
	1995	23	81	1.65		2012	14.5	129.5	2.617
	1996	23	81	1.65		2013	14.5	129.5	2.617
	1997	23	81	1.65		2014	14.5	129.5	2.617
	1998	23	81	1.65		2015	14.5	129.5	2.617
	1999	23	80.1	1.65		2016	14.5	129.5	2.617
	2000	23	80.1	1.65		2017	14.5	129.5	2.617
	2001	23	80.1	1.65		2018	14.5	129.5	2.617
	2002	23	80.1	1.65		2019	14.5	129.5	2.617
	2003	23	80.1	1.65		2020	14.5	129.5	2.617
	2004	23	80.1	1.65		2021	14.5	129.5	2.617
	2005	23	80.1	1.65		2022	14.5	129.5	2.617
	2006	23	80.1	1.65		2023	14.5	129.5	2.617
	2007	23	80.1	1.65		2024	14.5	129.5	2.617
	2008	23	80.1	1.65		2025	14.5	129.5	2.617
	2009	23	80.1	1.65		2026	14.5	129.5	2.617
	2010	23	80.1	1.65		2027	14.5	129.5	2.617
	2011	23	80.1	1.65		2028	14.5	129.5	2.617
	2012	23	80.1	1.65		2029	14.5	129.5	2.617
	2013	23	80.1	1.65		2030	14.5	128.5	2.617
	2014	23	80.1	1.65		2031	14.5	128.5	2.617
	Abby Green South - AGS					2032	14.5	128.5	2.617
Abby Green South - AGS	2010	20	29	0.045		2033	14.5	128.5	2.617
	2011	20	29	0.045		2034	14.5	128.5	2.617
	2012	24	36	0.038		2035	14.5	128.5	2.617
	2013	50	62	0.018		2036	14.5	128.5	2.617
	2014	50	61	0.018		Central Ramp TSF			
	2015	57	68	0.016	Central Ramp TSF	2001	30	56	0.379
	2016	65	76	0.014		2002	48	74	0.237
	2017	70	81	0.013		2003	64	90	0.178
	2018	70	79	0.013		2004	72	98	0.158
	2019	70	79	0.013		2005	78	104	0.146
	2020	70	79	0.013		2006	78	104	0.146
	2021	70	79	0.013		2007	80	106	0.142

Table C- 4: TSF BED CONDUCTANCE, FILL RATES AND CAPPING SCHEDULES									
	Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)		Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)
	2022	70	79	0.013		2008	84	110	0.136
	2023	70	79	0.013		2009	90	116	0.126
	2024	70	79	0.013		2010	92	118	0.124
	2025	70	79	0.013		2011	98	124	0.116
	2026	70	79	0.013		2012	100	126	0.114
	2027	70	79	0.013		2013	102	128	0.112
	2028	70	79	0.013		2014	106	132	0.107
	2029	70	79	0.013		2015	112	138	0.102
	2030	70	79	0.013		2016	118	144	0.096
	2031	70	79	0.013		2017	122	148	0.093
	2032	70	79	0.013		2018	126	152	0.09
	2033	70	79	0.013		2019	130	156	0.088
	2034	70	79	0.013		2020	135	161	0.084
	2035	70	79	0.013		2021	140	166	0.081
	2036	70	79	0.013		2022	145	171	0.079
	Loders TSF					2023	149	175	0.076
Loders TSF	2020	1	-78	11.383		2024	149	175	0.076
	2021	30	-49	0.379		2025	149	175	0.076
	2022	55	-24	0.207		2026	149	175	0.076
	2023	80	1	0.142		2027	149	175	0.076
	2024	90	11	0.126		2028	149	175	0.076
	2025	100	21	0.114		2029	149	175	0.076
	2026	110	31	0.103		2030	149	175	0.076
	2027	120	41	0.095		2031	149	175	0.076
	2028	130	51	0.088		2032	149	175	0.076
	2029	130	51	0.088		2033	149	175	0.076
	2030	130	51	0.088		2034	149	175	0.076
	2031	130	51	0.088		2035	149	175	0.076
	2032	130	51	0.088		2036	149	175	0.076
	2033	130	51	0.088					
	2034	130	51	0.088					
	2035	130	51	0.088					
	2036	130	51	0.088					



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Active model grid
- Quaternary alluvium
- Major watercourse

Mine progress

1981	1990	1999	2008
1982	1991	2000	2009
1983	1992	2001	2010
1984	1993	2002	2011
1985	1994	2003	2012
1986	1995	2004	2013
1987	1996	2005	
1988	1997	2006	
1989	1998	2007	

Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Mine Progress

DATE: 3/4/2014

FIGURE No: C-7

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

1.4 Model Calibration

Calibration of a groundwater flow model is a process that demonstrates that a model is capable of replicating observed field data. Calibration is accomplished by finding a set of parameters, boundary conditions and stresses that produce simulated heads and fluxes that match field measured values within an acceptable range of error.

1.4.1 Calibration Method

The model calibration method was primarily driven by adjusting selected parameters within realistic ranges to match transient groundwater levels. A secondary calibration target was baseflow in Wollombi Brook.

The calibration strategy initially involved manual testing and adjusting parameters to obtain an initial fit against the observation data. The final calibration was completed using PEST to refine the manual calibration. The PEST control file was later used to guide uncertainty analysis.

Matching declining water level trends where these had been measured at monitoring sites was the primary objective of the manual calibration process; whilst obtaining an absolute match was considered secondary. Less weighting was given to bores close to the mine pit face, with groundwater levels at a distance from the mine (towards third-party groundwater users and alluvial aquifers) deemed more important. Parameters were only adjusted within realistic parameter bounds, and were not allowed to move to extremes just to meet statistical objectives.

The steady state model simulated pre-mining conditions and starting heads for the transient model which commenced in 1981. It should be noted that some surrounding mining did commence prior to 1981, with some unknown dewatering effects prior to mining. This historical mining was not simulated in the steady state model, however its impact on groundwater levels is considered to be relatively minor.

A long transient model run from 1981 to 2000 simulated the cumulative impact of mining and served as a suitably long period to represent antecedent conditions prior to the first groundwater levels measurements at MTW in the early 2000's.

The transient model was calibrated or verified against available transient groundwater level data for the MTW site. A significant data set from multiple locations surrounding the mine was available for this including multi-level monitoring at point locations. Unfortunately no transient groundwater level data was available from the adjoining mines.

1.4.2 Calibration Targets

A selection of groundwater levels measured in monitoring bores and registered water bores were used as the calibration targets for the steady-state model representing approximately pre-mine conditions. Therefore bores which had been potentially affected by mining activities were removed from the calibration process. A total of 60 bores were used to calibrate the steady-state model.

Groundwater levels were collated for monitoring bores at Wambo Mine and Bulga Mine from publicly available AEMR reports. Water levels for registered bores were obtained from NSW Office of Water (NOW), and water levels for the mine monitoring bores were provided by MTW.

All available transient groundwater level data was initially used in the calibration. The main report (Section 5, Figure 5.4) shows the location of bores and VWPs with transient data. Some erroneous outlying data points were given zero weighting during the calibration (see Section 1.3.5). Due to

some boreholes only having manual dip data and some bores sites having finely spaced automatic data equal weighting to the calibration was given to each bore site. Following initial calibration a higher weighting was given the three key nested bores in and below the Wollombi Alluvium (PZ7, PZ8 and PZ9).

1.4.3 Calibrated Parameters

Adjustable parameters for all model layers within the calibration process were:

- horizontal hydraulic conductivity (HC);
- vertical hydraulic conductivity (VHC) converted to VCONT in SURFACT;
- specific yield and specific storage;
- river bed vertical conductivity (rivers/streams and TSFs); and
- recharge.

The first model layer was divided into two zones: alluvium and regolith. All other model layers comprised a single zone. The alluvium, interburden and regolith were assigned uniform hydraulic properties for each layer. The hydraulic conductivity of the coal seam layers decreased with depth according to Equation 1 below.

$$HC = HC_0 \times e^{(-0.012*depth)} \quad \text{(Eq. 1)}$$

Where: *HC* is horizontal hydraulic conductivity at specific depth
HC_0 is horizontal hydraulic conductivity at depth of 0 m (surface)
depth is depth of the floor of the coalseam

The Equation 1 was derived from field data presented in the main report. Figure C- 8 shows how hydraulic conductivity was assumed to decrease with depth.

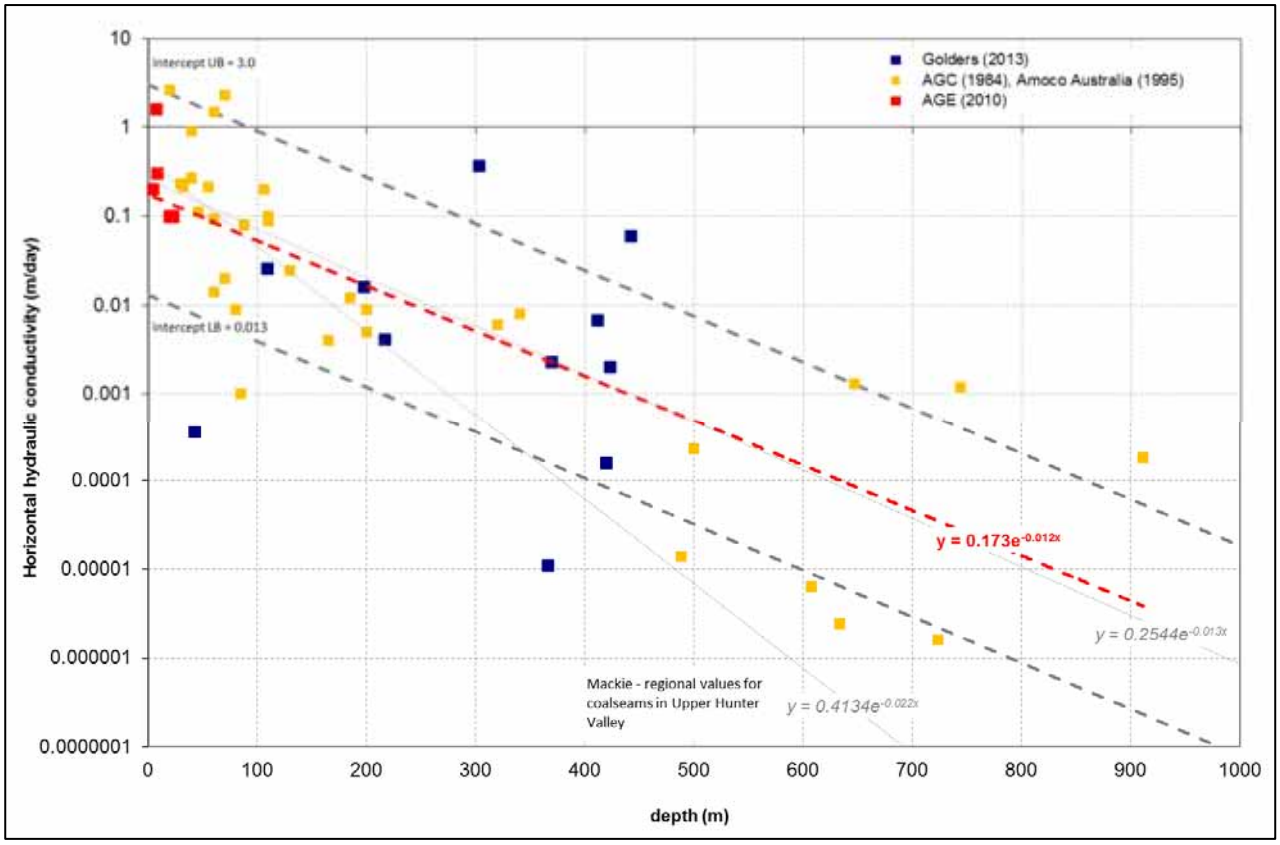


Figure C- 8: Change of hydraulic conductivity with depth – field data

The red fit line shown in this figure was the starting point to the calibration with an upper bound and lower constraints as shown by two grey dotted line in Figure C- 8. The bounds these were set manually within measured data ranges. It is possible setting these tight bounds limited the ability of the model to reproduce some local scale drawdowns processes observed in the monitoring data. However it was considered that keeping parameters within realistic ranges was more important than achieving an absolute fit through measured data points.

Vertical hydraulic conductivity was calculated using the VHC factor (multiplier) using Equation 2. In the case of coal seams VHC (derived from variable HC) is also depth dependant.

$$VHC = HC \times VHC_{factor} \quad \text{(Eq. 2)}$$

Table C-5summarises the calibrated hydraulic properties.

Table C-5: CALIBRATED HYDRAULIC PROPERTIES

Model layer		HC, HC0 (m/day)	VHC factor (-)	SS (-)	SY (-)
L01	Regolith	2.37×10^{-01}	1.04×10^{-03}	2.00×10^{-03}	5.00×10^{-03}
L01	Alluvium	$9.44 \times 10^{+00}$	4.01×10^{-04}	2.00×10^{-03}	8.00×10^{-02}
L01 - L02	Permian outcrop	1.00×10^{-05}	1.00×10^{-02}	1.00×10^{-05}	1.00×10^{-04}
L02	Overburden	3.36×10^{-03}	1.00×10^{-02}	1.97×10^{-05}	2.19×10^{-04}
L03	Whybrow Seam	9.38×10^{-02}	9.39×10^{-03}	6.27×10^{-06}	5.50×10^{-03}
L04	Interburden	3.40×10^{-04}	4.22×10^{-03}	6.28×10^{-06}	1.10×10^{-03}
L05	Wambo Seam	3.36×10^{-02}	1.00×10^{-02}	6.30×10^{-06}	5.50×10^{-03}

Table C-5: CALIBRATED HYDRAULIC PROPERTIES					
Model layer		HC, HC0 (m/day)	VHC factor (-)	SS (-)	SY (-)
L06	Interburden	1.76×10^{-04}	4.66×10^{-03}	6.30×10^{-06}	1.10×10^{-03}
L07	Blakefield Seam	1.30×10^{-02}	1.00×10^{-02}	4.00×10^{-06}	5.50×10^{-03}
L08	Interburden	3.18×10^{-04}	4.66×10^{-03}	4.00×10^{-06}	1.10×10^{-03}
L09	Woodlands Hill Seam	2.69×10^{-02}	6.15×10^{-03}	5.92×10^{-06}	5.50×10^{-03}
L10	Interburden	5.00×10^{-05}	2.87×10^{-03}	5.92×10^{-06}	1.10×10^{-03}
L11	Bowfield Seam	2.12×10^{-02}	6.15×10^{-03}	8.77×10^{-06}	5.50×10^{-03}
L12	Interburden	5.00×10^{-05}	2.87×10^{-03}	8.77×10^{-06}	1.10×10^{-03}
L13	Mt Arthur Seam	1.65×10^{-01}	4.70×10^{-03}	4.32×10^{-06}	5.50×10^{-03}
L14	Interburden	1.08×10^{-04}	2.19×10^{-03}	4.32×10^{-06}	1.10×10^{-03}
L15	Vaux Seam	1.68×10^{-01}	2.35×10^{-03}	4.00×10^{-06}	5.50×10^{-03}
L16	Basement	1.00×10^{-06}	1.00×10^{-02}	1.00×10^{-06}	1.00×10^{-03}
L01 - L13	spoil - open cut	$1.33 \times 10^{+00}$	1.13×10^{-02}	1.00×10^{-04}	1.09×10^{-02}
L03 - L15	spoil - underground	5.00×10^{-01}	1.00×10^{-03}	1.00×10^{-04}	1.00×10^{-01}

Note: *HC – horizontal hydraulic conductivity, HC0 – horizontal hydraulic conductivity at depth of 0m, SS – specific storage, SY – specific yield.*

Table C-5 also presents the calibrated storage parameters. Optimal calibration occurred with a specific yield (sy) in the alluvium of 5% with 2% for the regolith. Specific yield for open cut spoil was estimated to be 2%.

Figure C- 9 shows the calibrated coal seam hydraulic conductivity values for each coal seam. The graph indicates the calibrated values are towards the lower bound, but still well within the measured data limits.

The model calibrated to a low value of vertical hydraulic conductivity for the interburden, which is considered reasonable given that the interburden sediments effectively confine individual coal seams. Vertical hydraulic conductivity for alluvium was set to a low value to represent vertical conductance between the alluvium and underlying Permian overburden.

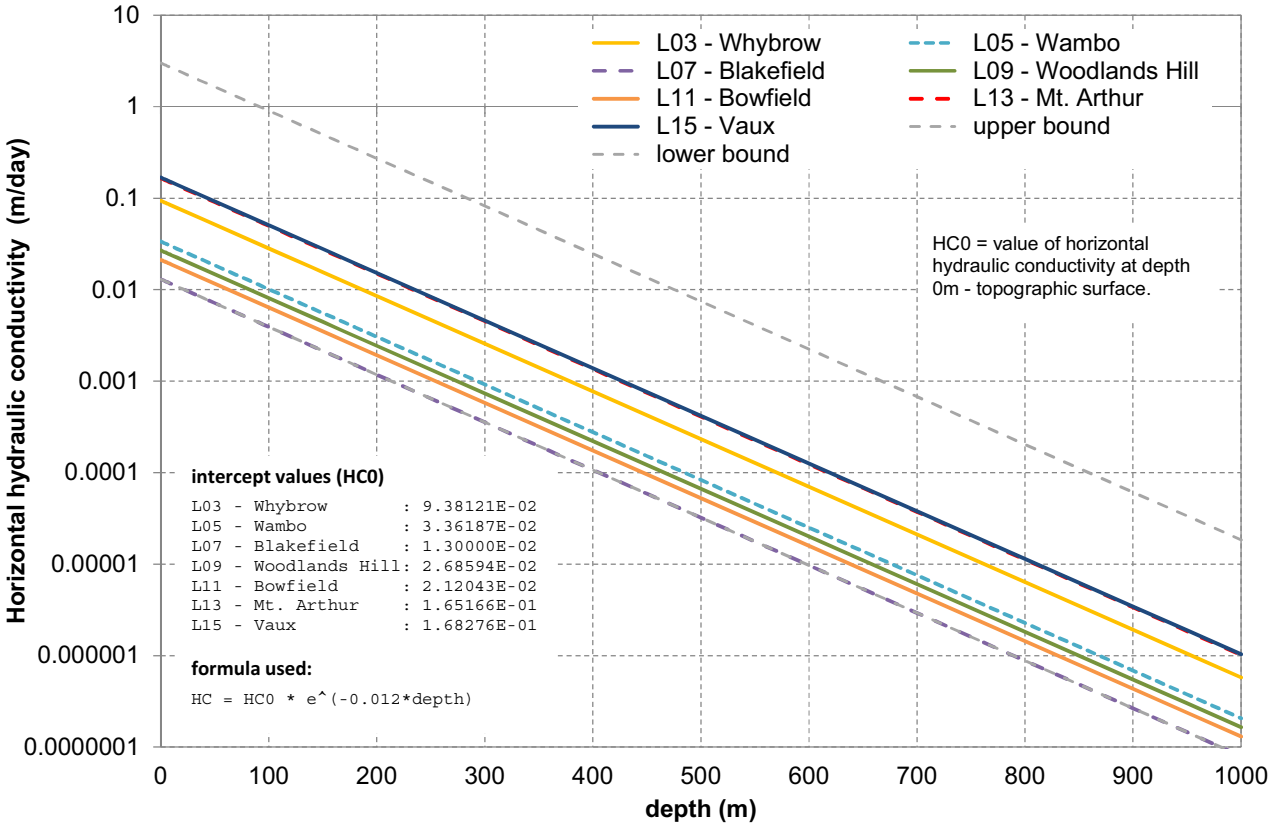


Figure C- 9: Change of hydraulic conductivity with depth – calibrated model data

Optimal calibration was achieved for recharge within expected bounds, with 3% of annual rainfall for the alluvium, 0.15% for the Permian regolith west of the Jerrys Plains subcrop line, 10^{-7}% for the regolith east of Jerrys Plains subcrop line and 10.3% for spoil.

The parameter calibrated for the river boundary condition was the vertical conductivity of the stream bed. As presented in Table C-6 below, the bed vertical conductivity was estimated to be 0.10 m/day for Hunter River, 0.01m/day for Wollombi Brook and 0.10m/day for minor surface drainage.

Table C- 3: CALIBRATED RIVER PARAMETERS

River zone	Bed thickness (m)	Bed vertical conductivity (m/day)	Head (m)
RIV1 - Hunter River	2.00	0.10	1.00
RIV2 - Wollombi Brook	1.50	0.01	1.00
RIV3 - minor surface drainage	1.00	0.10	0.00

1.4.4 Hydraulic Heads

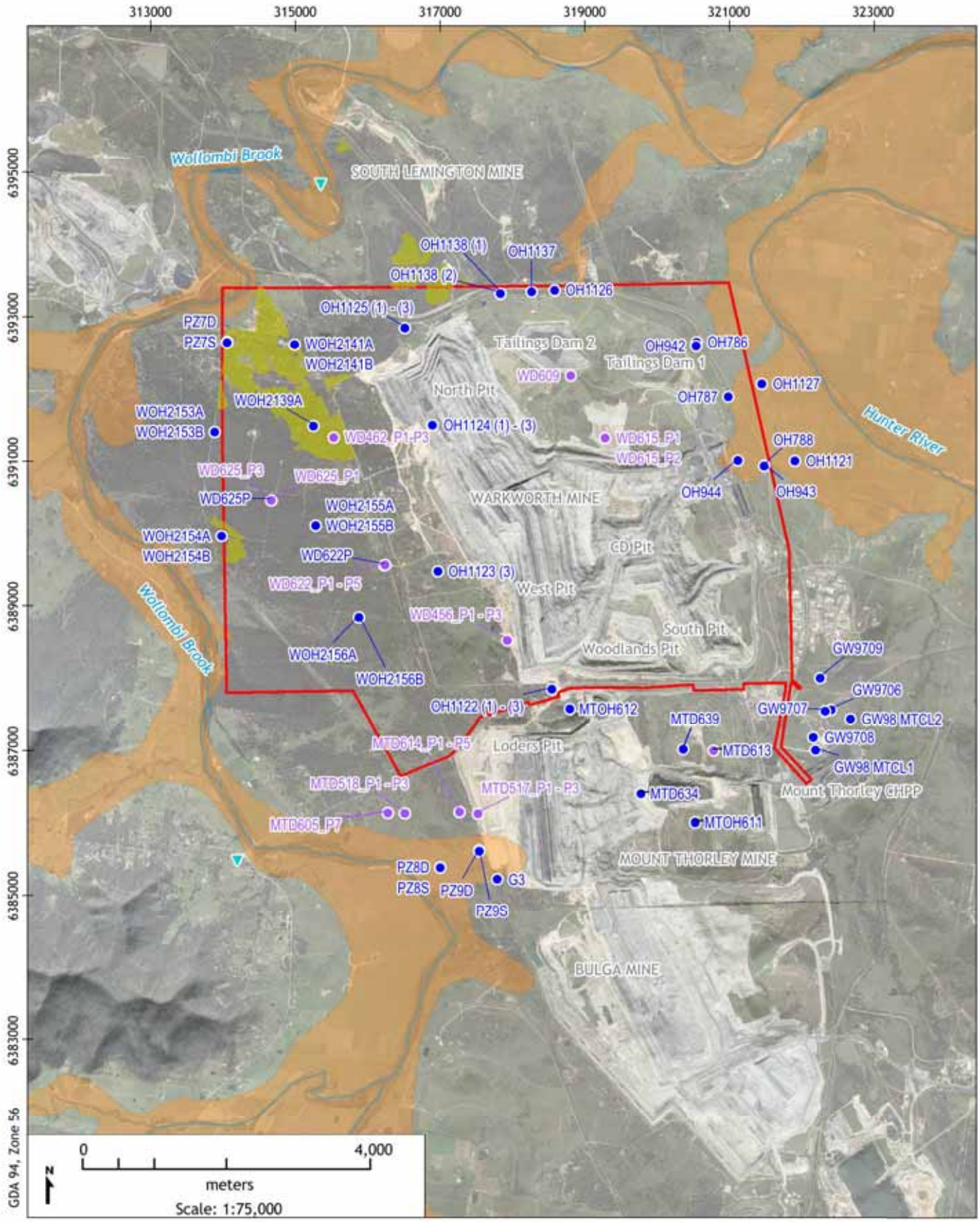
Table C-7 shows the steady state model calibration statistics. As described above this was run to generate the initial heads for the transient model run. Table C-7 shows that the steady state run is above the 10% target (15%) for SRMS lined out in the Australian Groundwater Modelling Guidelines (Barnett *et al* 2012).

Table C- 4: STEADY STATE CALIBRATION STATISTICS		
Parameter	**Value**	**Unit**
sum of residuals (SR):	354.04	[m]
mean sum of residuals (MSR):	7.53	[m]
scaled mean sum of residuals (SMSR):	12.90	[%]
sum of squares (SSQ):	3941.94	[m^2]
mean sum of squares (MSSQ):	83.87	[m^2]
root mean square (RMS):	9.16	[m]
root mean fraction square (RMFS):	18.70	[m]
scaled RMFS (SRMFS):	18.85	[%]
scaled RMS (SRMS):	15.68	[%]

Statistics for the transient run are presented in Table C-8 and these also show SRMS above the target described within the guidelines. Whilst the transient model has statistics above prescribed limits it is still deemed a suitable simulation of the Proposal. This is because the parameters remain within realistic ranges and the model simulates the groundwater depressurisation trends. Further discussion about calibrated model results are present in the main body of the report in Section 7 with contour plots of steady state heads and heads at the end of the calibration for Layer 1 and Layer 13 also presented.

Table C- 5: TRANSIENT CALIBRATION STATISTICS		
Parameter	**Value**	**Unit**
sum of residuals (SR):	21410.65	[m]
mean sum of residuals (MSR):	12.93	[m]
scaled mean sum of residuals (SMSR):	10.91	[%]
sum of squares (SSQ):	530229.79	[m^2]
mean sum of squares (MSSQ):	320.19	[m^2]
root mean square (RMS):	17.89	[m]
root mean fraction square (RMFS):	82.35	[m]
scaled RMFS (SRMFS):	31.86	[%]
scaled RMS (SRMS):	15.10	[%]

The modelled-versus-observed hydrographs for all bores surrounding MTW are included in Figures C-11 to C-20. Figure C- 10 shows the location of the calibration bores.



LEGEND:

- Proposed Warkworth Mine development consent boundary

Monitoring bore

- Standpipe
- VWP
- NOW stream gauge station
- Alluvium (100k)
- Warkworth Sands Woodland
- Watercourse

Warkworth Mine 2014 EIS Project
Groundwater Assessment (G1468F)

Monitoring Bores

DATE: 9/5/2014

FIGURE No: C-10

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

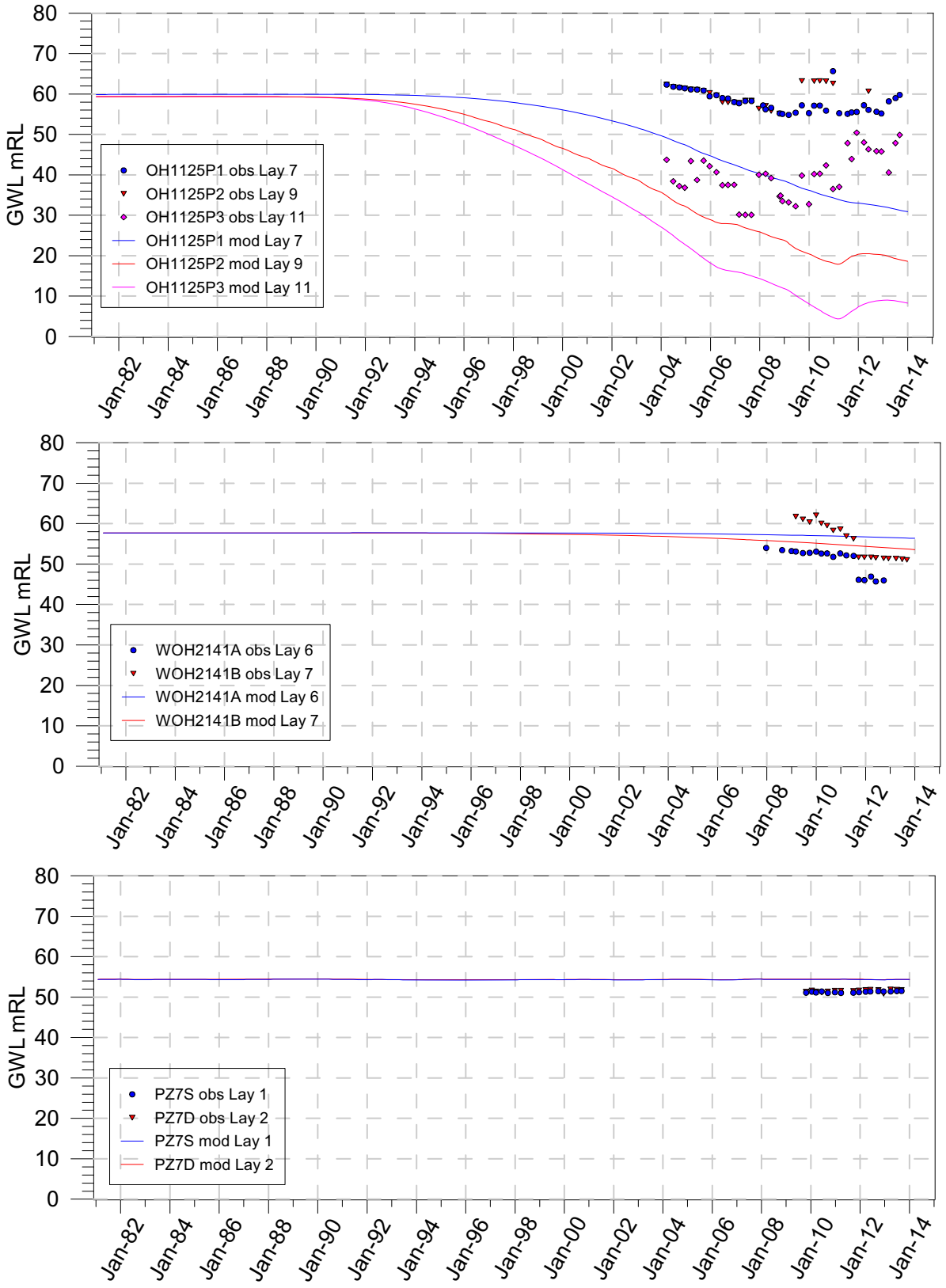


Figure C- 11: Transient modelled versus observed hydrographs

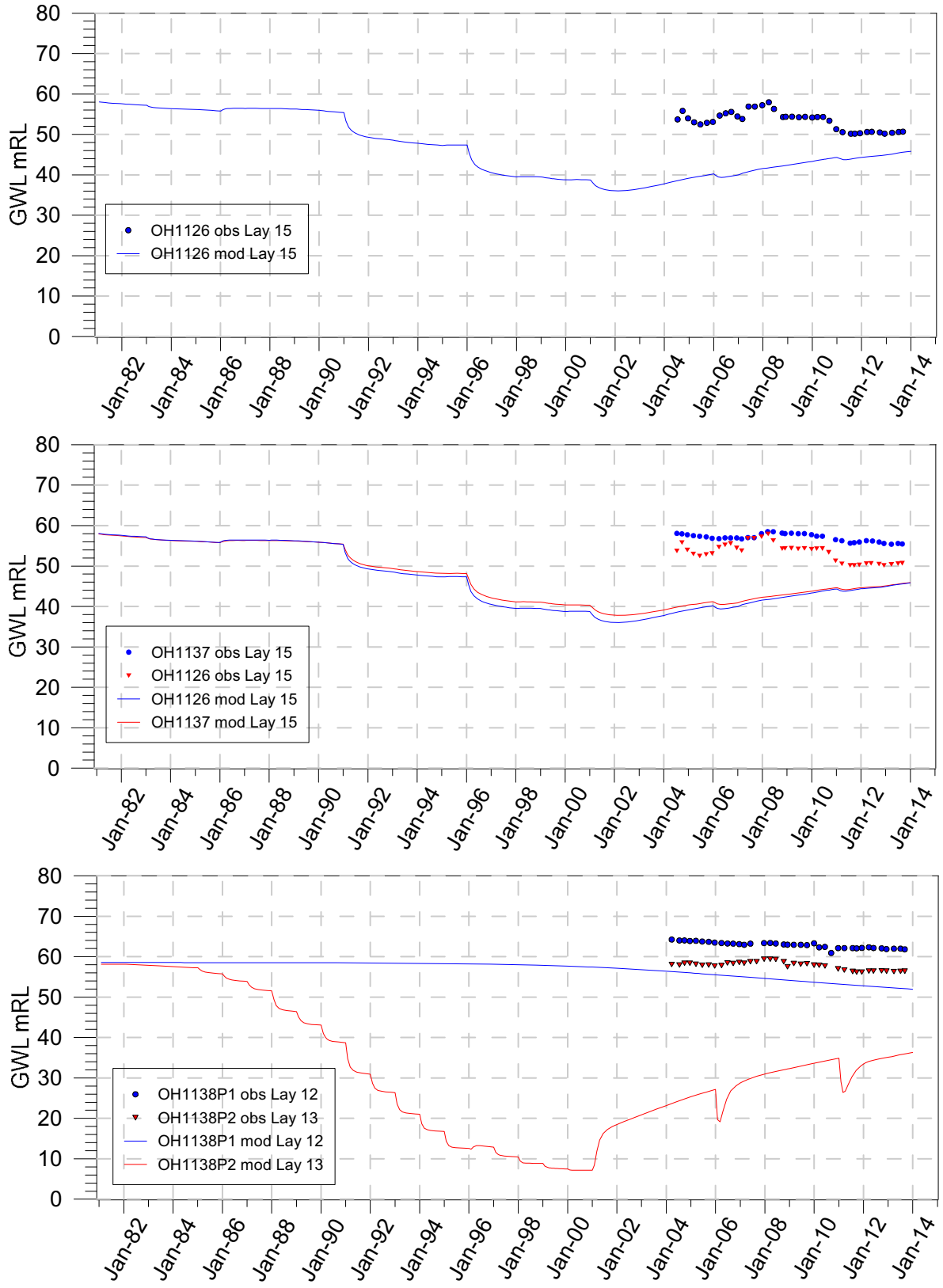


Figure C- 12: Transient modelled versus observed hydrographs

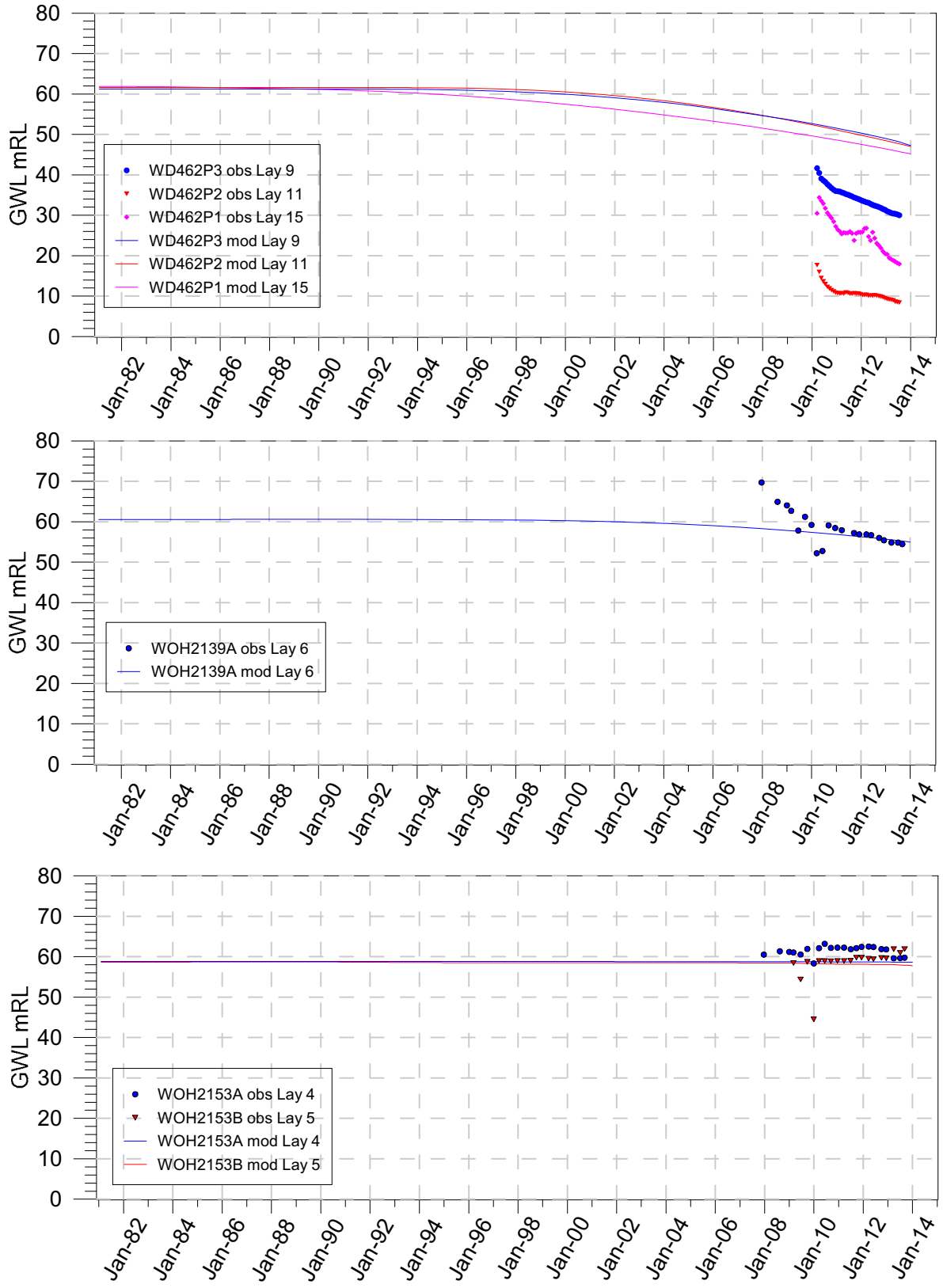


Figure C- 13: Transient modelled versus observed hydrographs

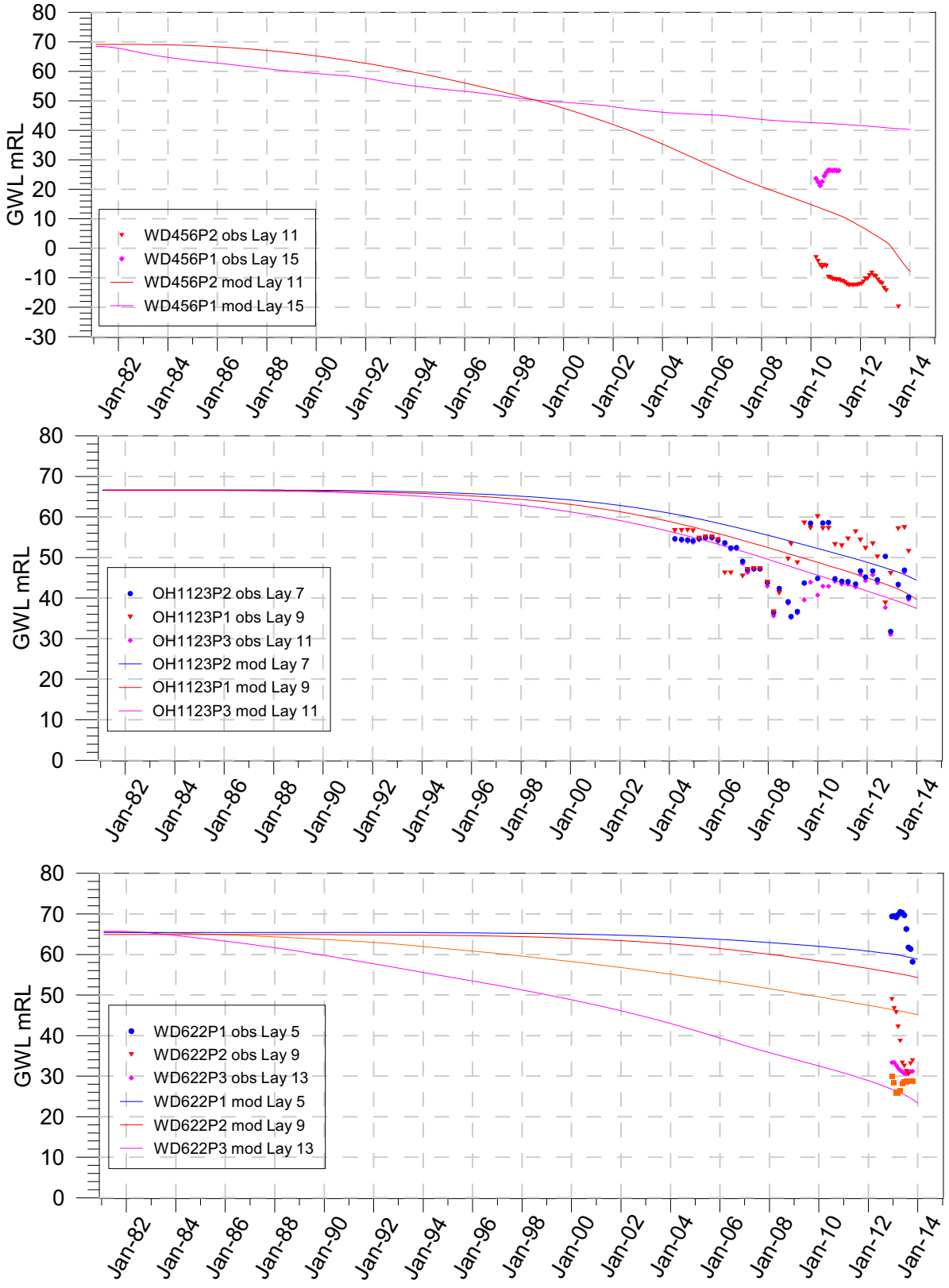


Figure C- 14: Transient modelled versus observed hydrographs

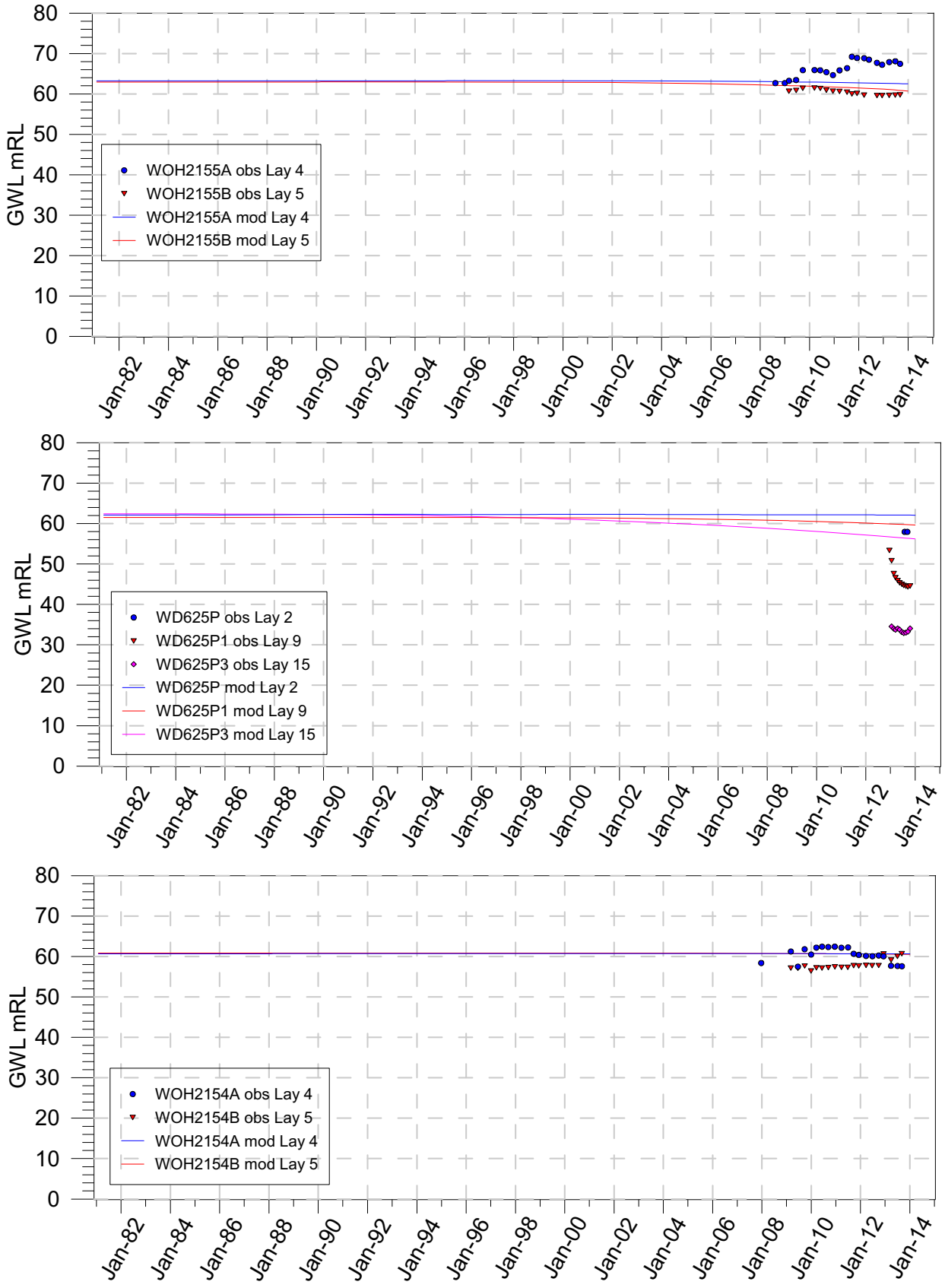


Figure C- 15: Transient modelled versus observed hydrographs

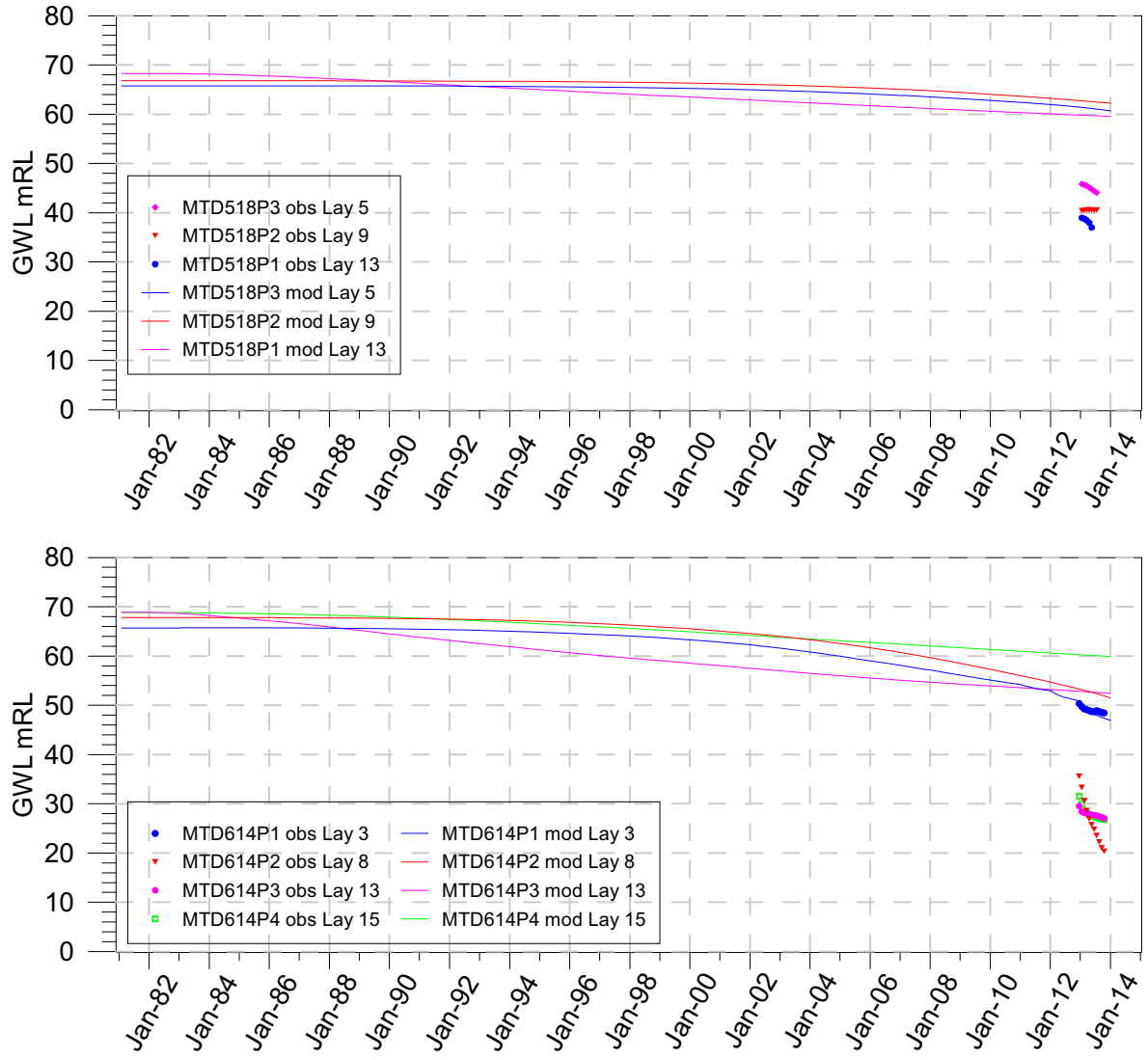


Figure C- 16: Transient modelled versus observed hydrographs

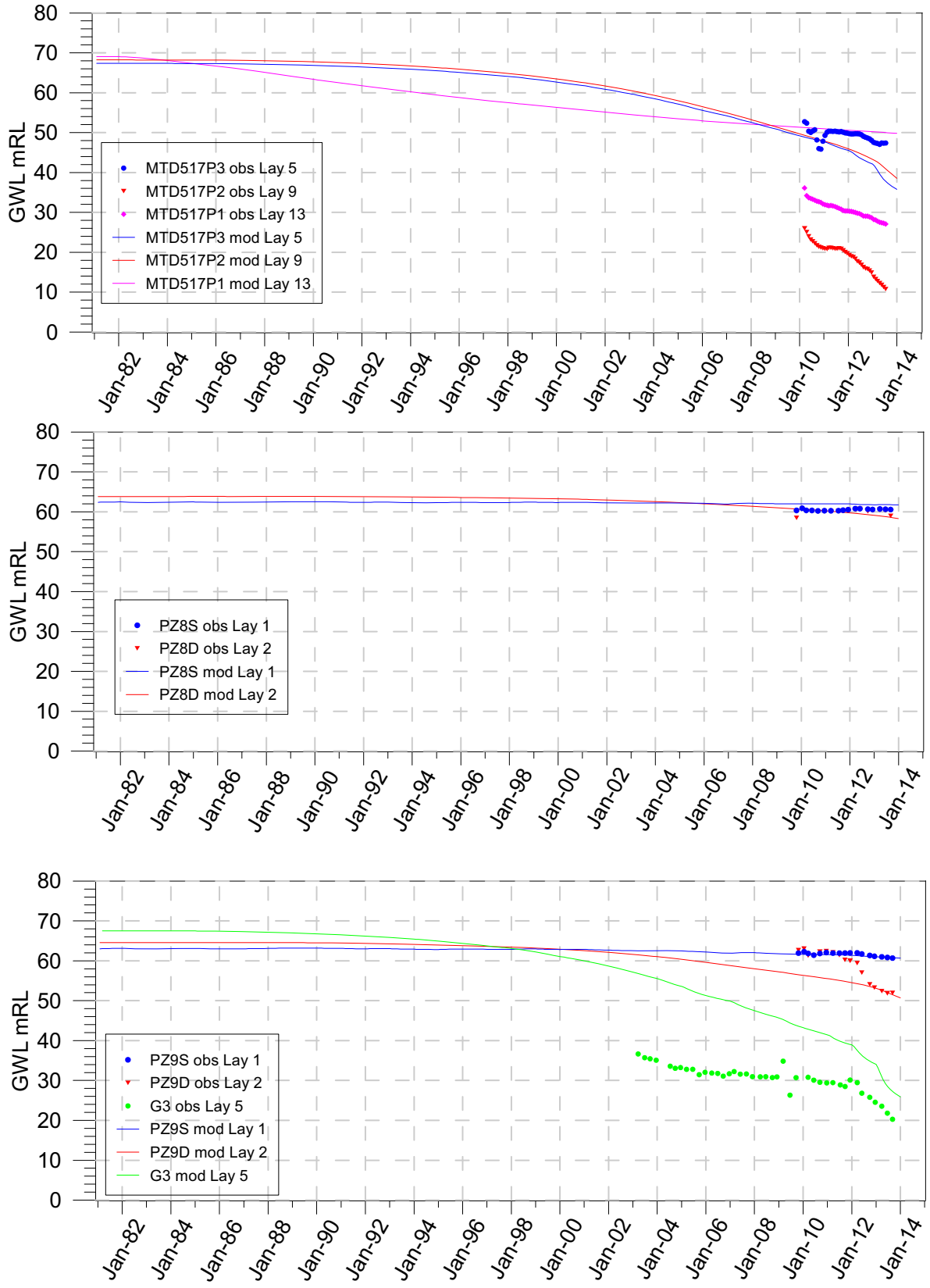


Figure C- 17: Transient modelled versus observed hydrographs

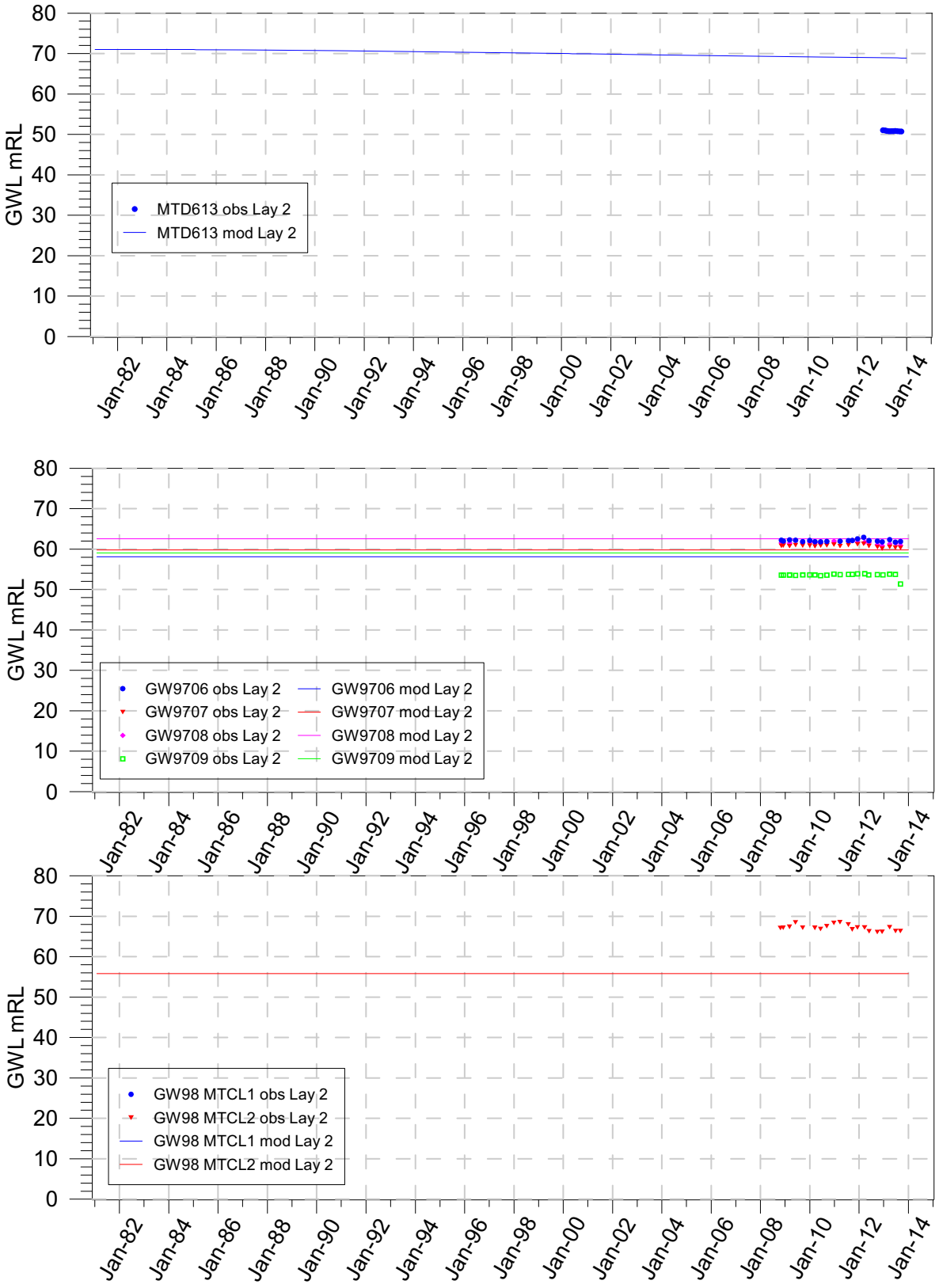


Figure C- 18: Transient modelled versus observed hydrographs

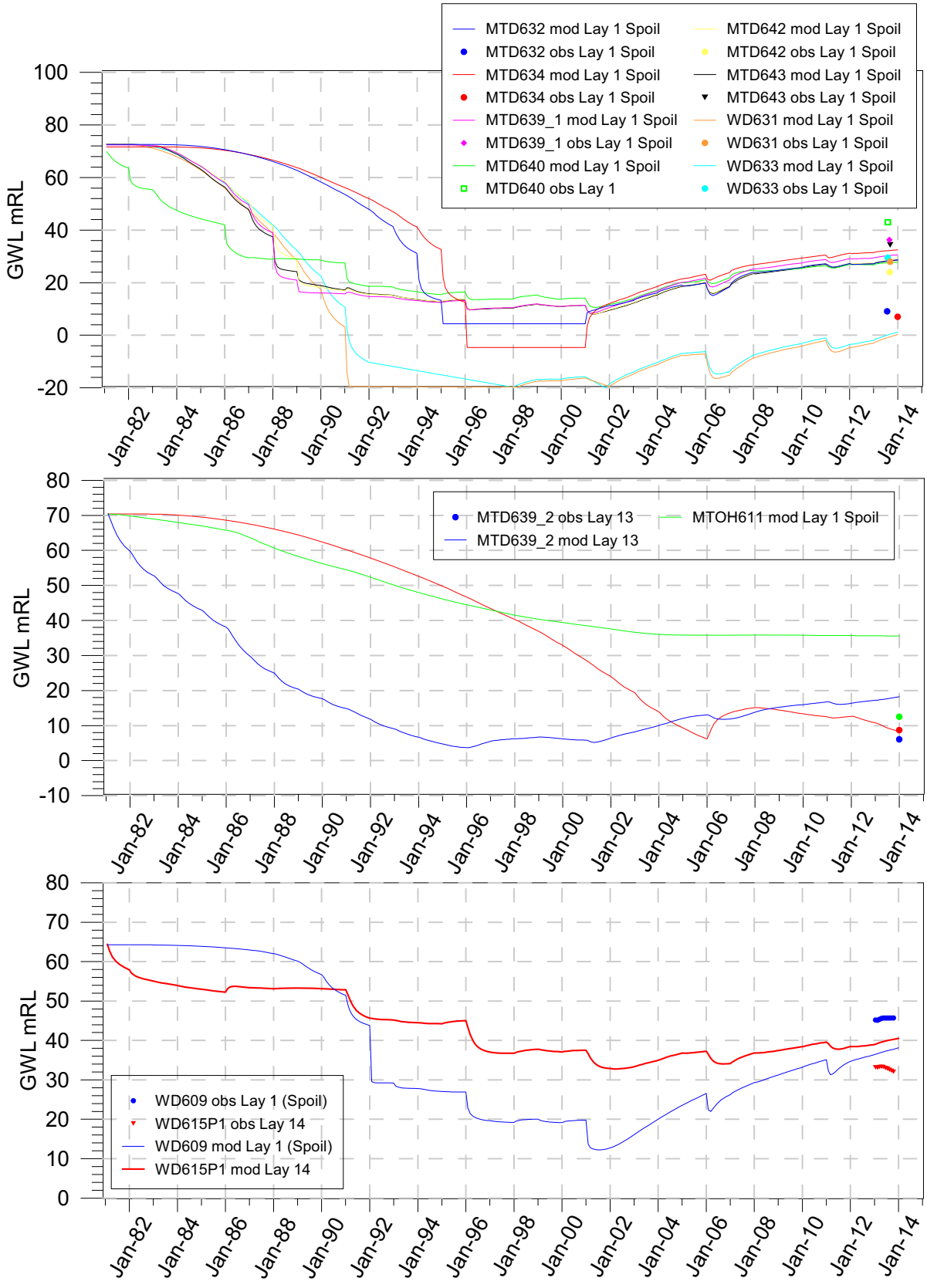


Figure C- 19: Transient modelled versus observed hydrographs

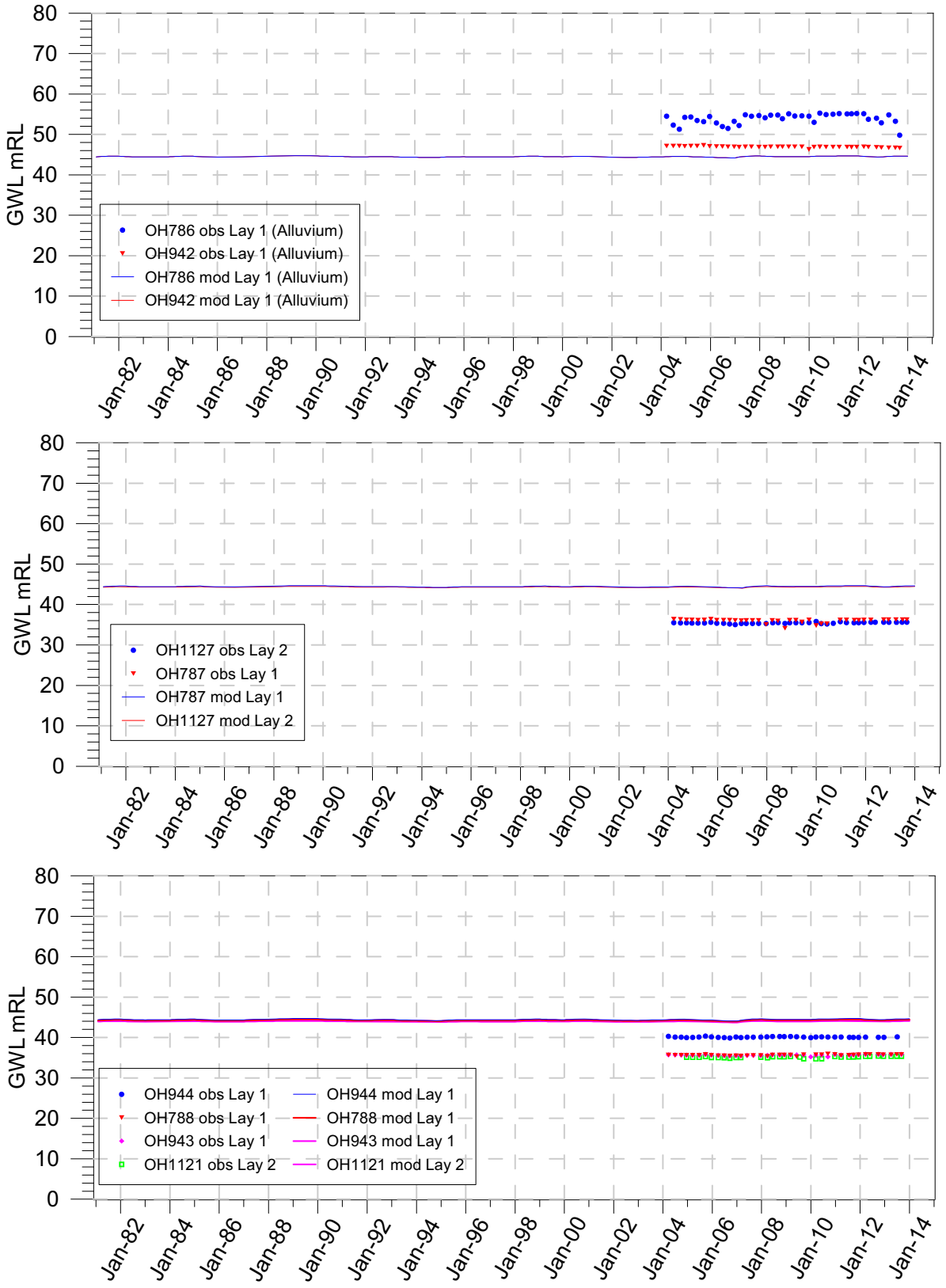


Figure C- 20: Transient modelled versus observed hydrographs

1.5 Calibrated Model Sensitivity Analysis

Following manual calibration, the transient model was calibrated with PEST. Figure C- 21 shows the parameters sensitivities for the first optimisation in the PEST.

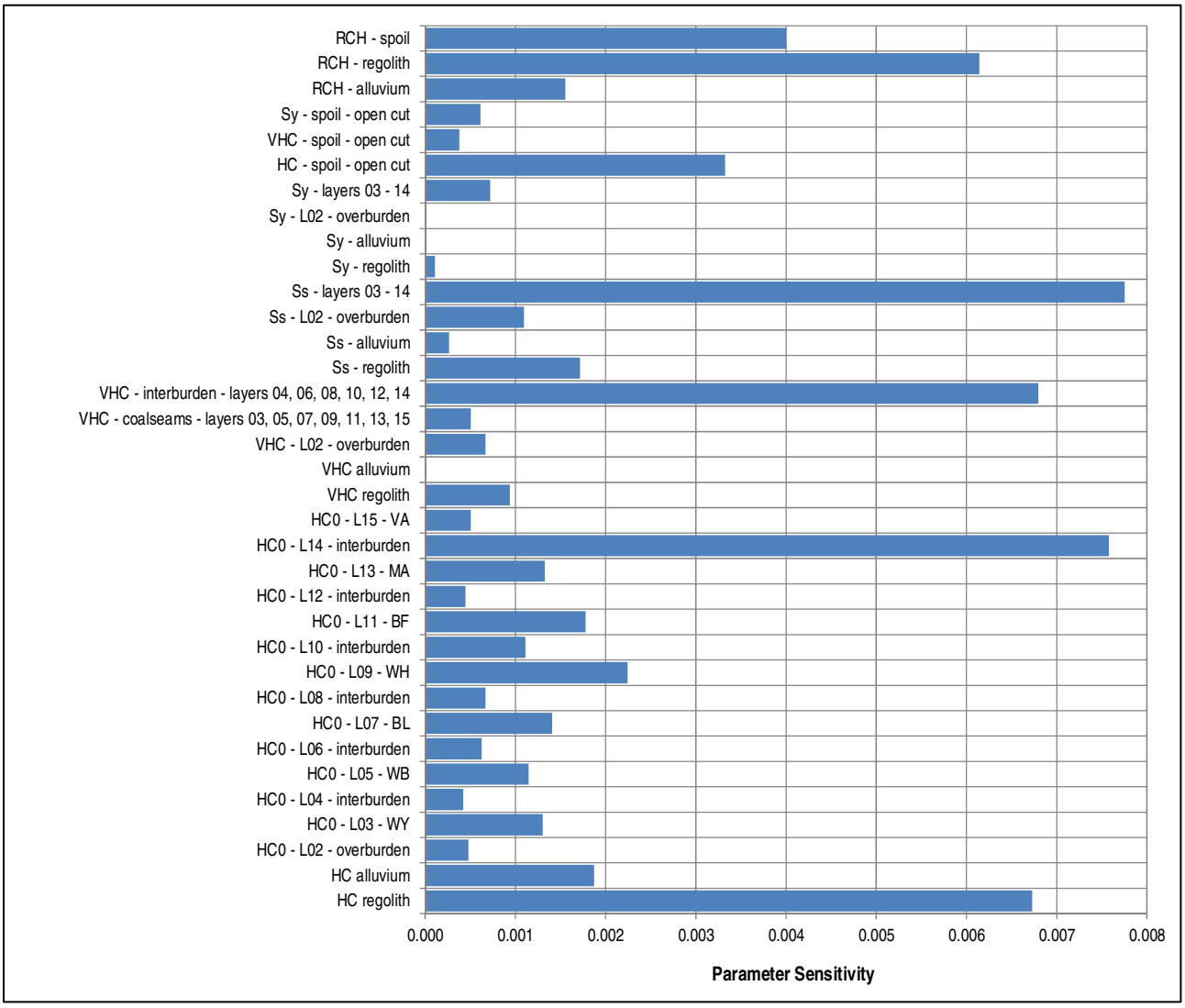


Figure C- 21: Initial automated calibration parameter sensitivities

As some parameters were tied during the initial calibration run they appear with combined sensitivities. Sensitive parameter groups were:

- recharge (RCH) to spoil and regolith (Permian);
- specific storage (ss) in all confined layers;
- horizontal (HCO) and vertical (VHC) hydraulic conductivity in interburden aquitards; and
- horizontal hydraulic conductivity in regolith.

The remaining parameter groups had lower sensitivity. The sensitivity analysis confirms what was evident from manual calibration that the permeability of interburden aquitards plays an important role confining each coal seam, and producing the hydraulic gradient seen on most nested monitoring sites.

Appendix D

NUMERICAL MODEL – UNCERTAINTY ANALYSIS

1. UNCERTAINTY ANALYSIS

1.1 Introduction

This section assesses the uncertainty of the model predictions to natural variability in the calibrated parameters. Analysis of the uncertainty of model outputs is referred to as "uncertainty analysis". Model calibration does not necessarily result in a unique set of parameter values, especially if the model employs a number of parameters to simulate system complexity. As the model was calibrated to known measurements, a calibration-constrained Monte Carlo analysis was carried out, rather than an unconstrained uncertainly analysis.

Typically, groundwater models employ numerous levels of simplification and assumptions, in order to represent reality. Therefore, a number of issues may arise, including:

(i) adequacy in representing naturally complex processes;

(ii) gaps in our understanding of the hydrogeological system process; and,

(iii) measurement 'noise' in observed aquifer measurements.

A calibration-constrained Monte Carlo analysis was carried out with the following objectives:

- to describe a numerically-tractable approach for quantification of uncertainty for this model; and
- report the results of potential uncertainty associated with calibration and predictive model simulations.

The calibration-constrained Monte Carlo method was used for predictive uncertainty analysis to generate variable model parameter sets. To ensure the model remained calibrated, the results from the models were then compared against observed data, accounting for intrinsic errors associated with observed data (i.e. measurement error).

It should be noted that the calibrated model used to base the uncertainty analysis on was not the final calibration discussed within this document. Time constraints to maintain the project deliverable meant that uncertainty analysis had to be conducted prior to final model completion. Although the uncertainty analysis was not based on the final model calibration the results of this analysis are still thought of worth in the discussion on the measurement error in the calibration.

1.2 Methodology

During the pre-calibration stage, appropriate bounds were established for each parameter set, based on observed data, textbook sources and best knowledge. These bounds could represent, for example, the 95th confidence interval of field hydraulic testing data, or one-magnitude variability in specific storage as suggested from similar hydrostratigraphic units in the region. The groundwater model was manually calibrated using these conceptual bounds as parameter limits then set in the automated calibration software, (e.g. PEST).

Model calibration does not necessarily produce a unique set of parameter values, therefore model predictions can vary with a 'calibrated' parameter set. The analysis of the variability in these predictions is known as a calibration-constrained Monte Carlo approach.

Given large variability in the expected range of hydraulic parameters required to create a groundwater model, it is assumed that the predictive results will be subject to a similar level of uncertainty (although the level of uncertaimty depends on type of prediction).In this study,

predictive uncertainty analysis was applied to the MTW Underground groundwater model, which was calibrated to a measurement dataset. This dataset was selected to best represent the groundwater response to seasonal and mining induced stresses on the system from years 1981 to 2014. These parameter sets were 'realized' using a stochastic random number generator, using an adopted set of parameter statistical properties to best represent the observed and/or estimated range.

The randomised realized fields represent the possible variability of the parameter dataset that leads to variability in model predictions. An acceptable level of 'de-calibration' of the calibration model was sought to ensure a calibration constrained and therefore realistic analysis was honoured.

Randomised parameter sets were generated by allowing random heterogeneity on a cell-by-cell basis, to better represent the type of aquifer variability that exists in the real world (Tonkin and Doherty, 2009). Each spatial parameter field was generated using a cell-by-cell stochastic field generator (e.g. the GSLIB geostatistical suite of Deutsch and Journel, 1998). Cell-by-cell variability of parameters also assumed a log-normal prior probability distribution, with means corresponding to optimised parameter values and a variogram sill (upper bound) corresponding to the assumed parameter variance.

200 realised parameter sets were explored for the calibration model, using bounds to correspond with 95% confidence intervals from the expected calibrated parameter bounds used in PEST. The rejection of these parameter sets was determined by ranking the objective function (i.e. Phi) from the transient calibration simulation for each realisation. Realisations that exceeded the calibrated objective function by more than 200% were rejected from the predictive calibration analysis, which was determined from the spread of the Phi results and subsequent levels of de-calibration. Of the 200 realised parameter sets, 127 fell within the acceptable calibrated objective function. The suite of 127 realisations was used to predict the degree of uncertainty within the model outputs, and computing the statistical probabilities of the results (e.g. groundwater drawdown) from all model runs.

1.3 Application of Uncertainty Analysis

1.3.1 Variable Parameters

All hydraulic parameters explored in the automatic calibration were explored in the analysis, including horizontal hydraulic conductivity, vertical hydraulic conductivity multipliers, specific storage, specific yield, groundwater recharge, and riverbed conductance.

The original calibration process employed layer-wide parameters to represent aquifer hydraulic properties for the undisturbed country rock, spoil and underground longwall areas. Thus, these parameters were replaced with spatially varying fields to replicate cell-by-cell variability across the model domain.

The reduction of hydraulic conductivity with depth below surface was represented using an exponential decline function determined from measurement data (refer Section 5.5 of the main report). To introduce a variability of hydraulic parameters, the obsereved decline of horizontal hydraulic conductivity with depth was honored, however a multiplier array changing the calculated hydraulic conductivity value was applied. The multiplier array adjusted the calculated horizontal hydraulic conductivity of the coal seam by a value of 1 standard derivation of the calibrated parameter interval.

Cell-by cell groundwater recharge rates from diffuse rainfall were also included in the uncertainty analyses, using the random-generated multiplication fields. Realised fields representing daily recharge rates were generated for the regolith and alluvial zones, using bounds utilised in the automated calibration process.

Zonal parameter schemes for vertical riverbed permeability were modified for uncertainty analyses, again using random-generated multiplier field (using statistical bounds of expected riverbed conductance rates). The application of vertical riverbed conductivity was split into three separate zones, namely the Hunter River, Wollombi River and 'other' zones.

1.3.2 Statistical Representation

The covariance matrix C(**k**) represents information on hydraulic properties available from outside of the calibration process, and represents "expert knowledge" in the model parameterisation process. The hydraulic parameters within the C(**k**) matrix were set realistic bounds based on the "expert knowledge". The uncertainty of the predictions made by an uncalibrated model is a function of C(**k**).

Information used to assemble the components of the C(**k**) matrix for random parameter generation is presented in Figure D-1 to Figure D- **7**. All parameters and standard deviations were converted to log values given the relationship between parameter and model output is likely to approach linearity. Note, the exponential variogram range in kilometres applied to realised parameter fields was based on expected structural variances in the model (e.g. 2000 m).

Within Table D-1 to Table D- **7**, the calculation of standard deviation of each parameter was based on the assumption that the parameter has a normal distribution and parameter bounds represent the 95% confidence limit. Variance, or the multiplying range applied to the random number generator, is the square of the standard deviation. The mean represents the calibrated value attained from automated PEST calibration, which best replicates the calibrated parameter set. Section 1.4 presents the spatial distribution of the randomised fields, and their native parameter values across the model domain.

Table D-1: HYDRAULIC CONDUCTIVITY CELL-BY-CELL FIELD GENERATION STATISTICS

Parameter Zone	Parameter Name	Mean (m/day)	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	4.19E-01	0.37	0.14	2000
2	Interburden 1	3.95E-03	0.42	0.18	2000
3	Whybrow Seam	7.61E-02	0.50	0.25	2000
4	Interburden 2	2.19E-04	0.25	0.06	2000
5	Wambo Seam	2.79E-02	0.50	0.25	2000
6	Interburden 3	1.48E-04	0.25	0.06	2000
7	Blakefield Seam	2.56E-02	0.50	0.25	2000
8	Interburden 4	7.31E-05	0.25	0.06	2000
9	Woodlands Seam	2.60E-02	0.50	0.25	2000
10	Interburden 5	6.97E-05	0.25	0.06	2000
11	Bowfield Seam	2.17E-02	0.50	0.25	2000
12	Interburden 6	5.00E-05	0.25	0.06	2000

Table D-1: HYDRAULIC CONDUCTIVITY CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m/day)	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
13	Mt Arthur Seam	7.79E-02	0.50	0.25	2000
14	Interburden 7	1.92E-04	0.25	0.06	2000
15	Vaux Seam	5.00E-02	0.50	0.25	2000
16	Interburden 8	1.00E-06	0.42	0.18	2000
17	Alluvium	1.00E+01	0.08	0.01	2000
18	Spoil	3.54E-01	0.45	0.20	2000
19	Underground	5.00E-01	0.50	0.25	2000

Table D- 2: COAL SEAM CONDUCTANCE MULTIPLIER FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Coal Seam	1.00	0.5	0.25	2000

Table D- 3: VERTICAL CONDUCTIVITY MULTIPIER FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	6.89E-04	0.58	0.33	2000
2	Interburden 1	1.00E-02	0.33	0.11	2000
3	Whybrow Seam	1.00E-02	0.33	0.11	2000
4	Interburden 2	4.12E-03	0.33	0.11	2000
5	Wambo Seam	1.00E-02	0.33	0.11	2000
6	Interburden 3	4.12E-03	0.33	0.11	2000
7	Blakefield Seam	1.00E-02	0.33	0.11	2000
8	Interburden 4	4.12E-03	0.33	0.11	2000
9	Woodlands Seam	1.00E-02	0.33	0.11	2000
10	Interburden 5	4.12E-03	0.33	0.11	2000
11	Bowfield Seam	1.00E-02	0.33	0.11	2000
12	Interburden 6	4.12E-03	0.33	0.11	2000
13	Mt Arthur Seam	1.00E-02	0.33	0.11	2000
14	Interburden 7	4.12E-03	0.33	0.11	2000
15	Vaux Seam	5.00E-03	0.25	0.06	2000
16	Interburden 8	1.00E-02	0.33	0.11	2000
17	Alluvium	8.35E-04	0.50	0.25	2000
18	Spoil	2.95E-02	0.25	0.06	2000

Table D- 3: VERTICAL CONDUCTIVITY MULTIPIER FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
19	Underground	1.00E-03	0.25	0.06	2000

Table D- 4: SPECIFIC YIELD FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	2.00E-02	0.15	0.02	2000
2	Interburden 1	1.02E-04	0.50	0.25	2000
3	Whybrow Seam	4.74E-03	0.67	0.46	2000
4	Interburden 2	9.49E-04	0.58	0.33	2000
5	Wambo Seam	4.74E-03	0.67	0.46	2000
6	Interburden 3	9.49E-04	0.58	0.33	2000
7	Blakefield Seam	4.74E-03	0.67	0.46	2000
8	Interburden 4	9.49E-04	0.58	0.33	2000
9	Woodlands Seam	4.74E-03	0.67	0.46	2000
10	Interburden 5	9.49E-04	0.58	0.33	2000
11	Bowfield Seam	4.74E-03	0.67	0.46	2000
12	Interburden 6	9.49E-04	0.58	0.33	2000
13	Mt Arthur Seam	4.74E-03	0.67	0.46	2000
14	Interburden 7	9.49E-04	0.58	0.33	2000
15	Vaux Seam	4.74E-03	0.67	0.46	2000
16	Interburden 8	1.00E-03	0.58	0.33	2000
17	Alluvium	5.00E-02	0.29	0.09	2000
18	Spoil	1.98E-02	0.33	0.11	2000
19	Underground	1.00E-01	1.00	1.00	2000

Table D- 5: SPECIFIC STORAGE FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m^{-1})	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	8.33E-04	0.33	0.11	2000
2	Interburden 1	4.68E-05	0.25	0.06	2000
3	Whybrow Seam	6.28E-06	0.42	0.18	2000
4	Interburden 2	6.28E-06	0.42	0.18	2000
5	Wambo Seam	6.28E-06	0.42	0.18	2000

Table D- 5: SPECIFIC STORAGE FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m^{-1})	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
6	Interburden 3	6.28E-06	0.42	0.18	2000
7	Blakefield Seam	6.28E-06	0.42	0.18	2000
8	Interburden 4	6.28E-06	0.42	0.18	2000
9	Woodlands Seam	6.28E-06	0.42	0.18	2000
10	Interburden 5	6.28E-06	0.42	0.18	2000
11	Bowfield Seam	6.28E-06	0.42	0.18	2000
12	Interburden 6	6.28E-06	0.42	0.18	2000
13	Mt Arthur Seam	6.28E-06	0.42	0.18	2000
14	Interburden 7	6.28E-06	0.42	0.18	2000
15	Vaux Seam	6.28E-06	0.42	0.18	2000
16	Interburden 8	1.00E-06	0.42	0.18	2000
17	Alluvium	6.03E-04	0.33	0.11	2000
18	Spoil	1.00E-04	0.42	0.18	2000
19	Underground	1.00E-04	0.50	0.25	2000

Table D- 6: RECHARGE FACTOR FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	4.23E-03	0.17	0.03	2000
2	Alluvium	3.00E-02	0.13	0.02	2000
3	Spoil	7.45E-02	0.17	0.03	2000

Table D- 7: VERTICAL RIVERBED CONDUCTIVITY FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m/day)	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Hunter	1.00E-01	0.58	0.33	2000
2	Wollombi	1.00E-02	0.58	0.33	2000
3	Minor drains	1.00E-01	0.58	0.33	2000

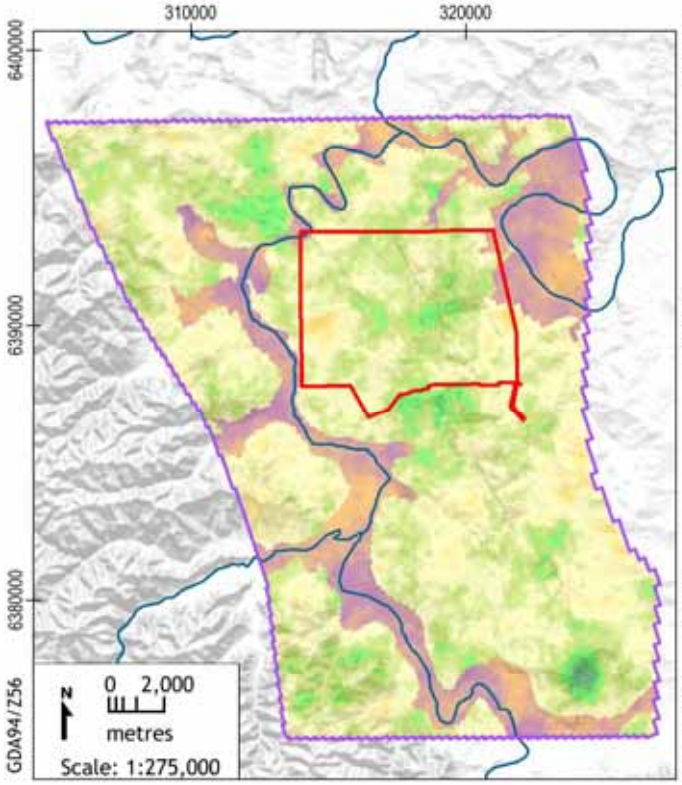
1.4 Application

Two hundred randomised realisations were generated with FIELDGEN using the parameters listed in Section 1.3.2. All 200 realisations were tested using PEST, and the objective function (sum of squared residuals) from each run was examined. The calibrated objective function[1] (Phi) was determined as 399,200 m^2, and a suitable cut off for "de-calibration" was set to be 200% of the calibrated Phi (i.e. 798,400 m^2). 127 realisations meet these criteria, and 73 realisations were rejected from further analysis. Of these 73 realisations, a total of 4 simulations failed to converge, meaning that the combination of varied parameters e.g. high recharge and low hydraulic parameters, caused numerical instability.

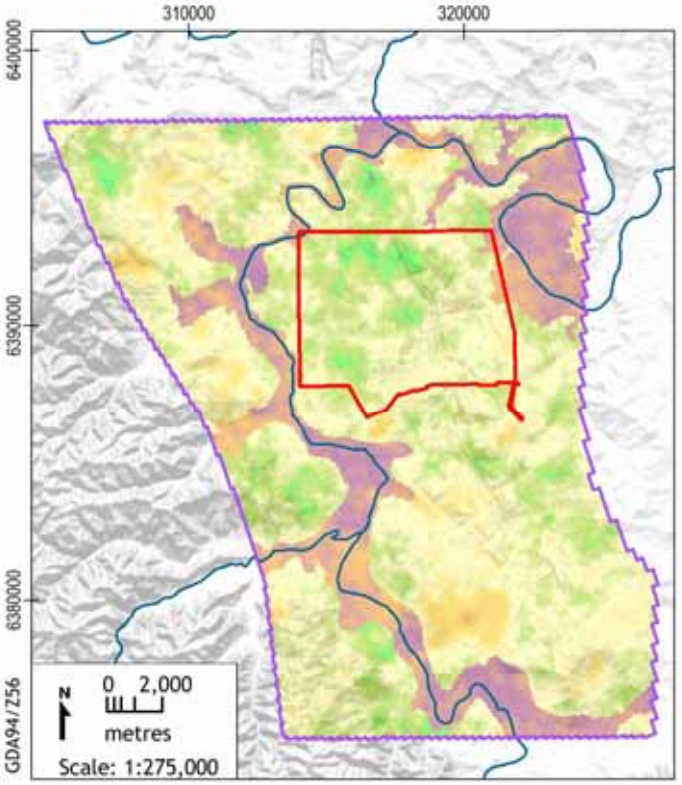
Figure D1 to Figure D-6 show a sample of the 127 realisations for the hydraulic conductivity, vertical conductivity, confined aquifer storage coefficient and specific yield for layers 1, 3, 6 and 13.

[1] The initial model calibration Phi used for uncertainty analysis.

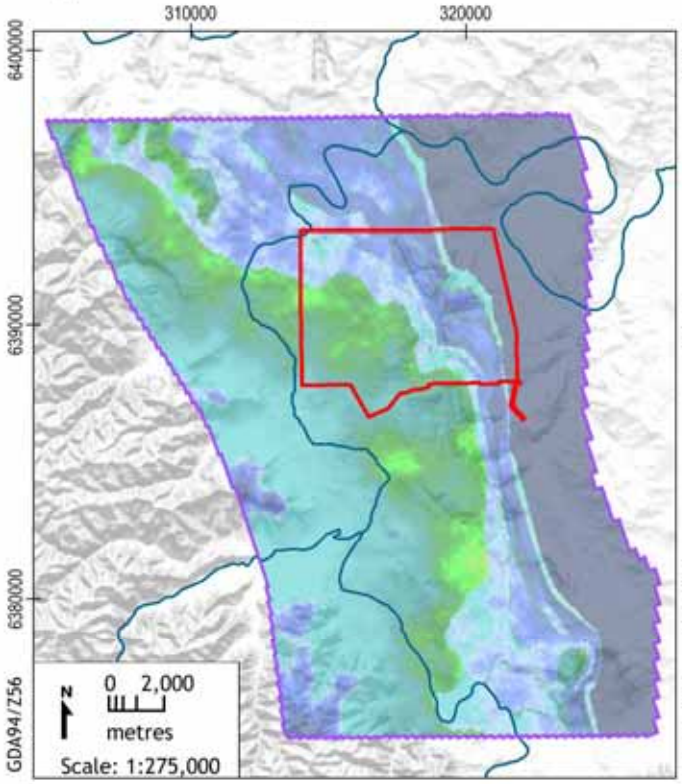
Layer 1 - Realization 10



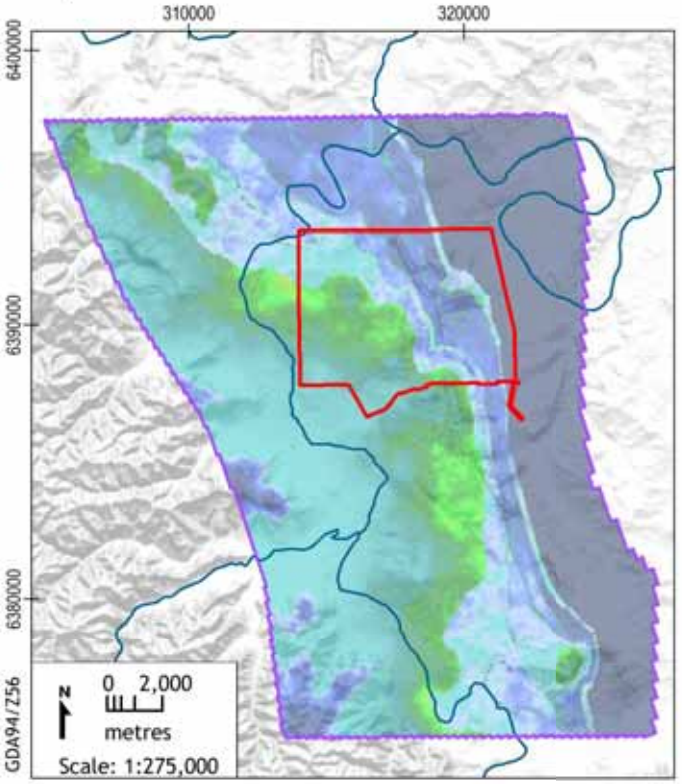
Layer 1 - Realization 100



Layer 3 - Realization 10



Layer 3 - Realization 100



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Major watercourse

Hydraulic Conductivity (m/day)

18	0.05
12	0.02
7	0.0003
2	0.0002
0.5	0.0001
0.2	0
0.1	

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

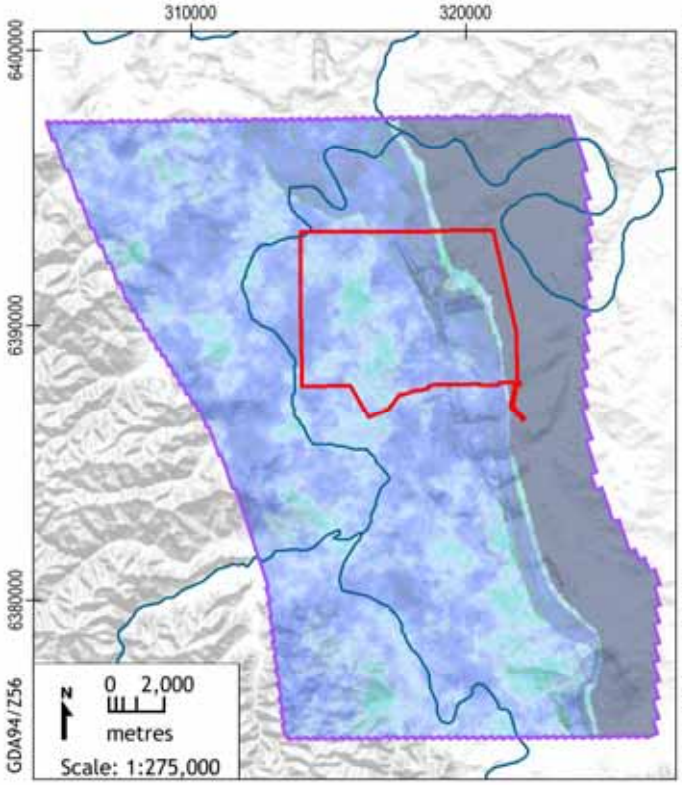
Uncertainty
Hydraulic conductivity (m/day)

DATE: 3/4/2014

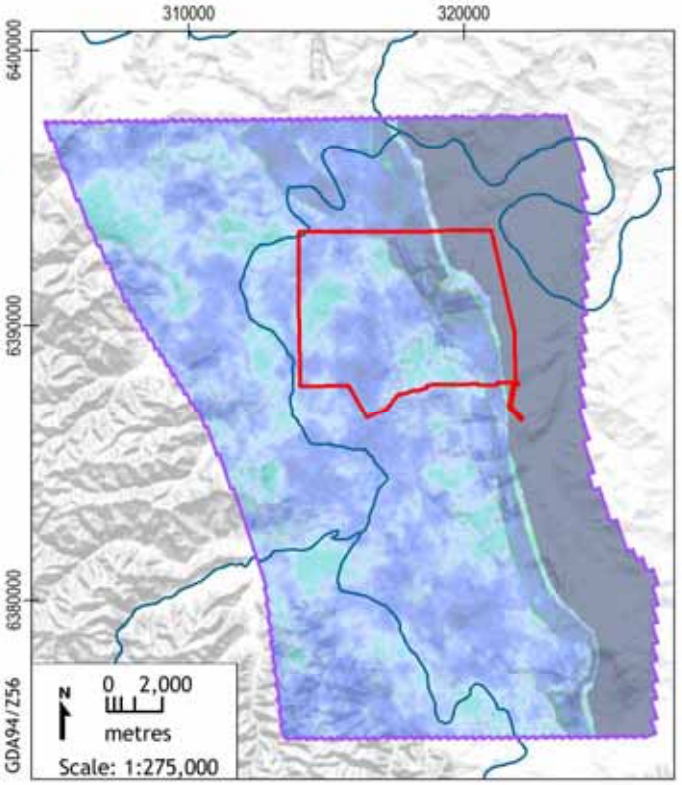
FIGURE No: **D-1**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

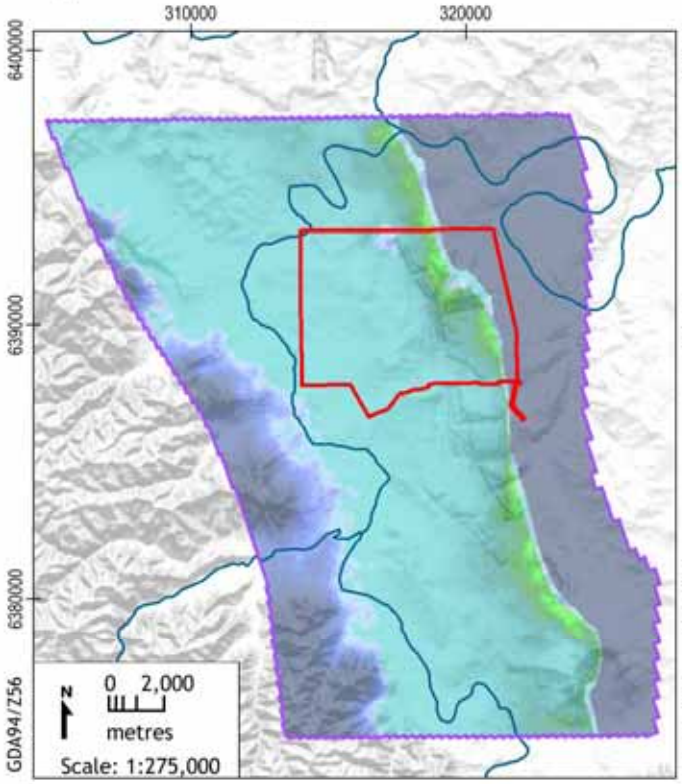
Layer 6 - Realization 10



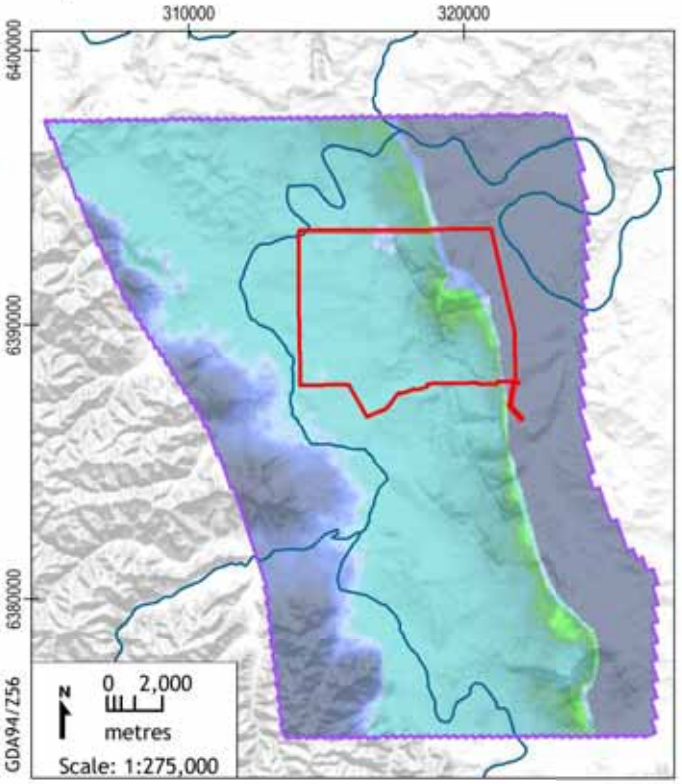
Layer 6 - Realization 100



Layer 13 - Realization 10



Layer 13 - Realization 100



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Major watercourse

Hydraulic Conductivity (m/day)

18	0.05
12	0.02
7	0.0003
2	0.0002
0.5	0.0001
0.2	0
0.1	

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

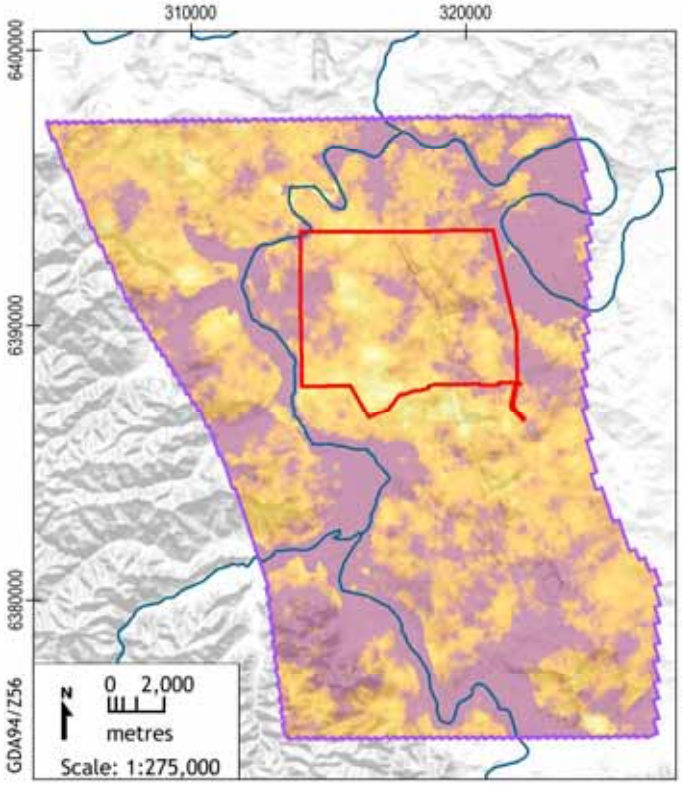
Uncertainty
Hydraulic conductivity (m/day)

DATE: 3/4/2014

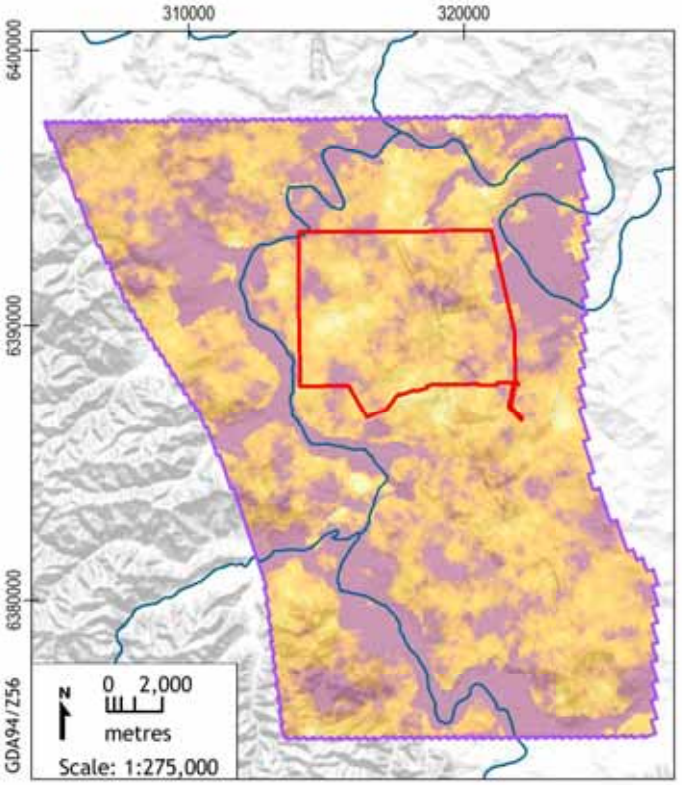
FIGURE No: **D-2**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

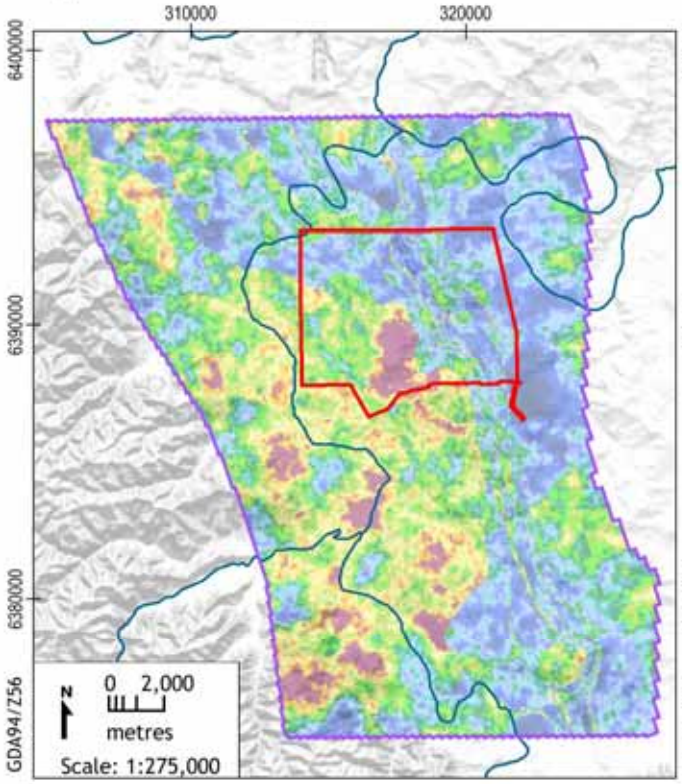
Layer 1 - Realization 110



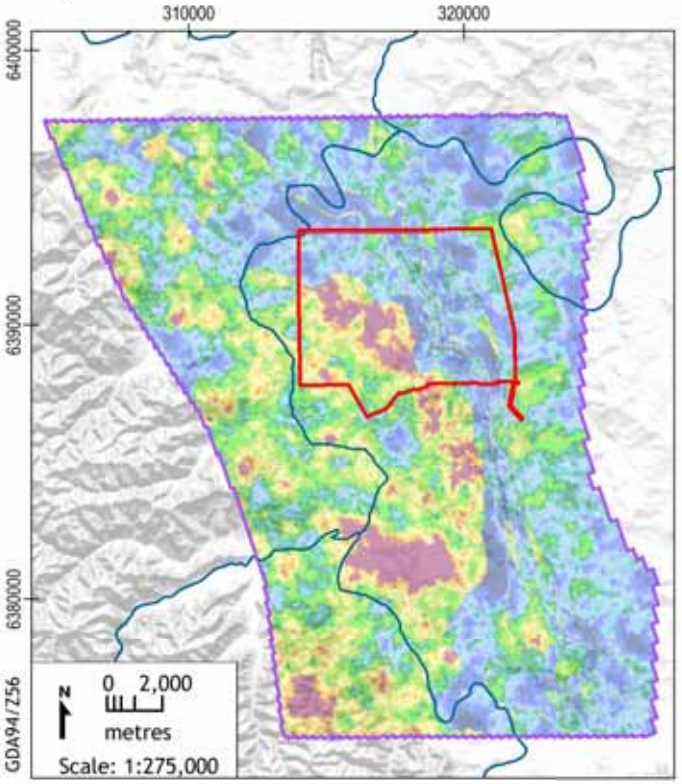
Layer 1 - Realization 168



Layer 3 - Realization 36



Layer 13 - Realization 83



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Major watercourse

Specific Yield

0.7	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

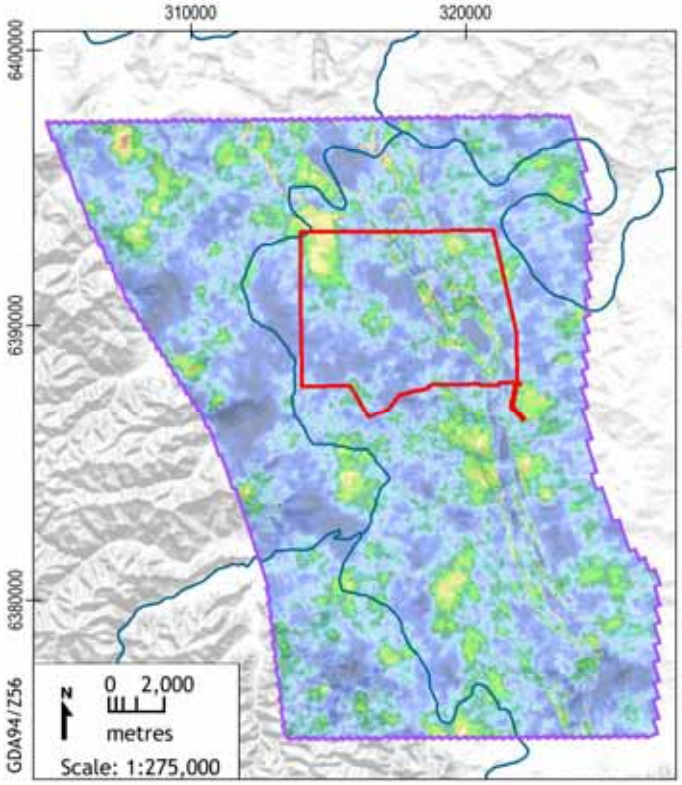
Uncertainty
Specific Yield

DATE: 3/4/2014

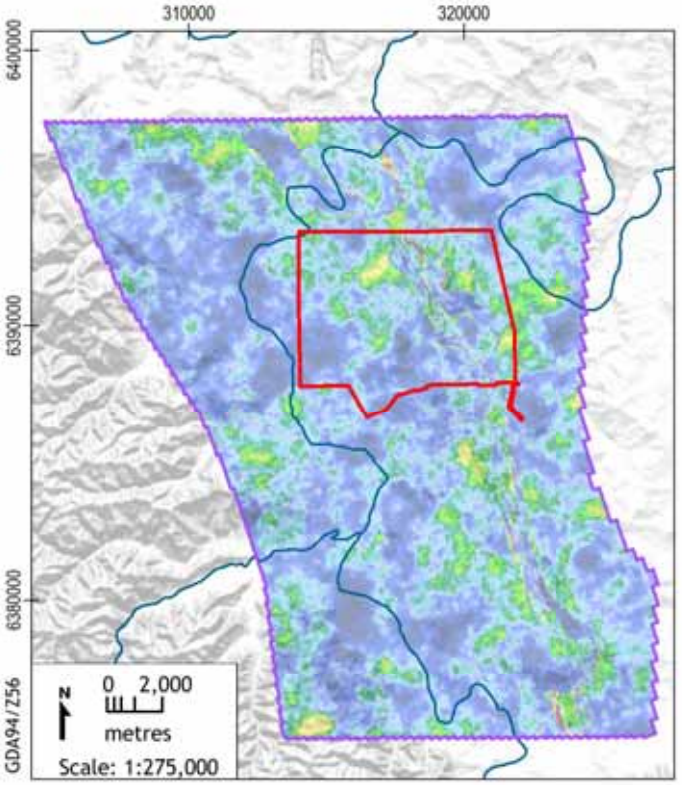
FIGURE No: **D-3**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

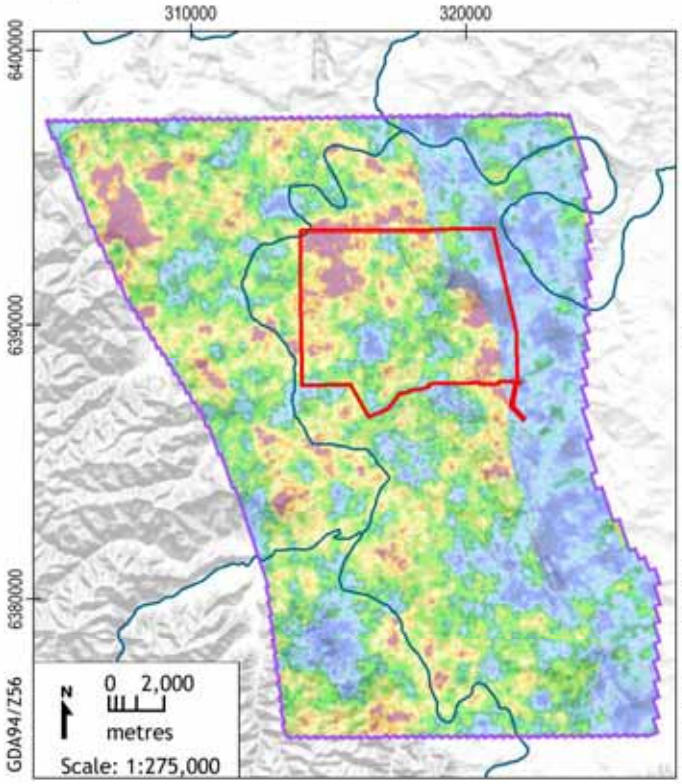
Layer 6 - Realization 9



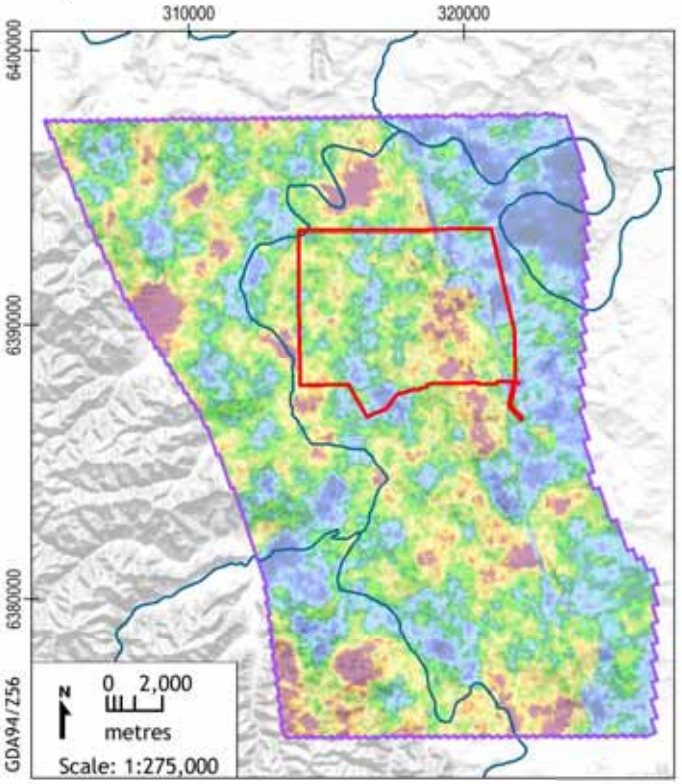
Layer 6 - Realization 58



Layer 13 - Realization 90



Layer 13 - Realization 130



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Major watercourse

Specific Yield

0.7	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

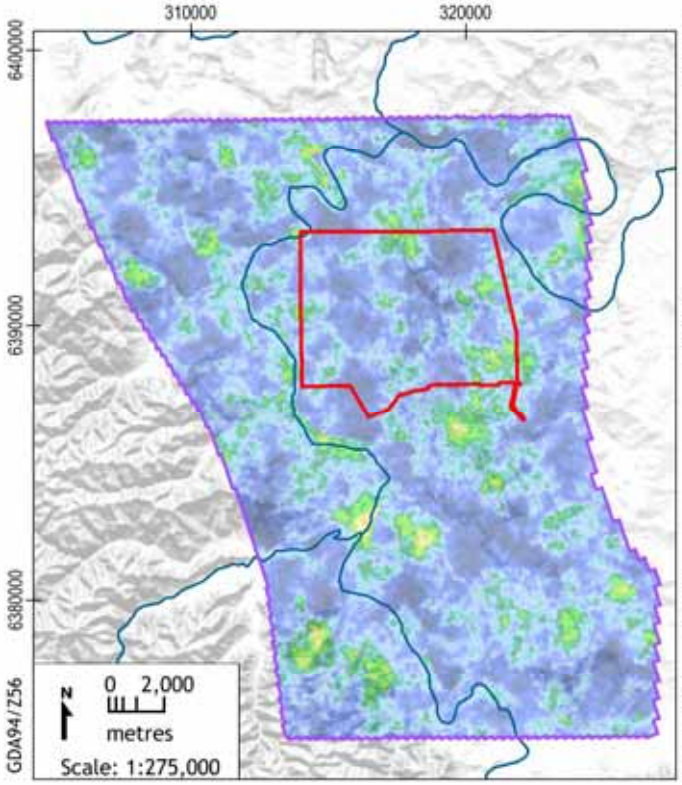
Uncertainty
Specific Yield

DATE: 3/4/2014

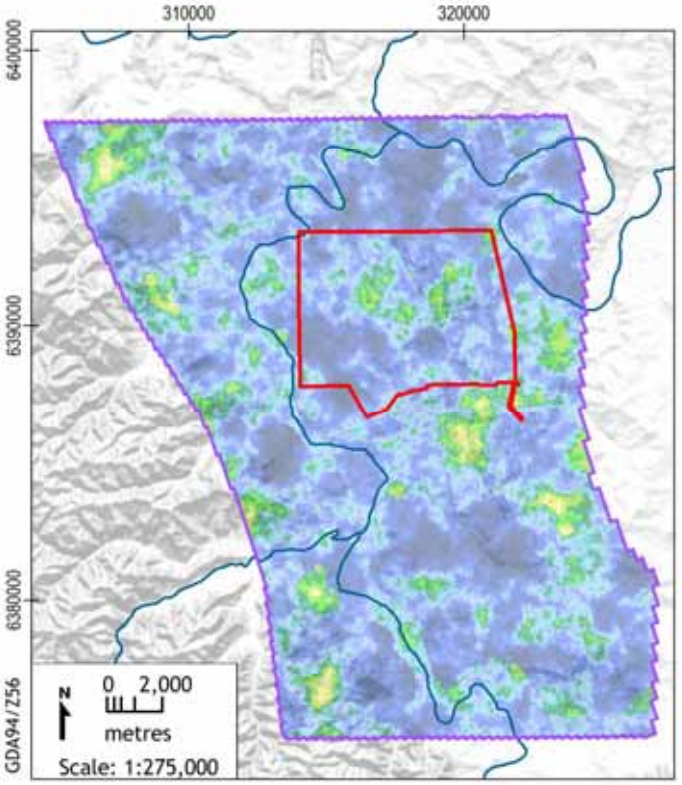
FIGURE No: **D-4**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

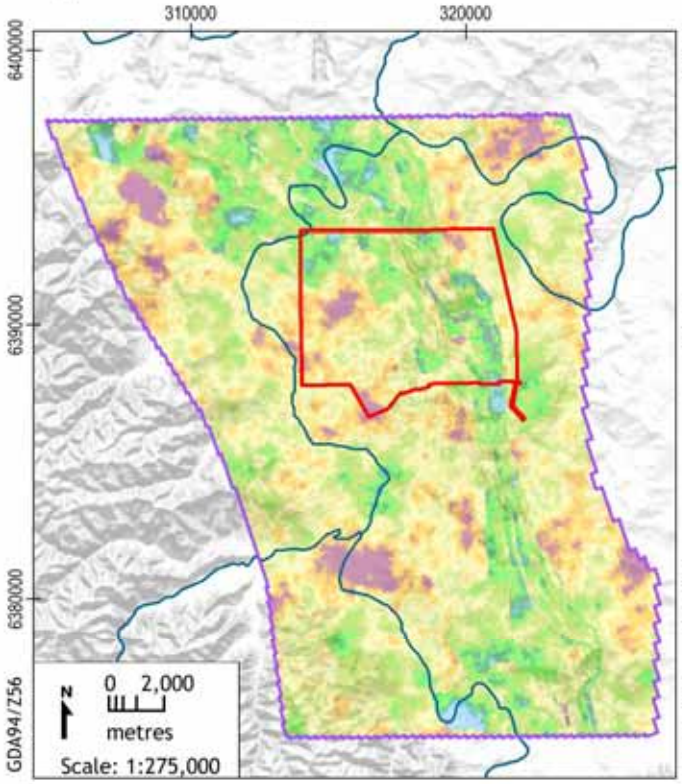
Layer 1 - Realization 58



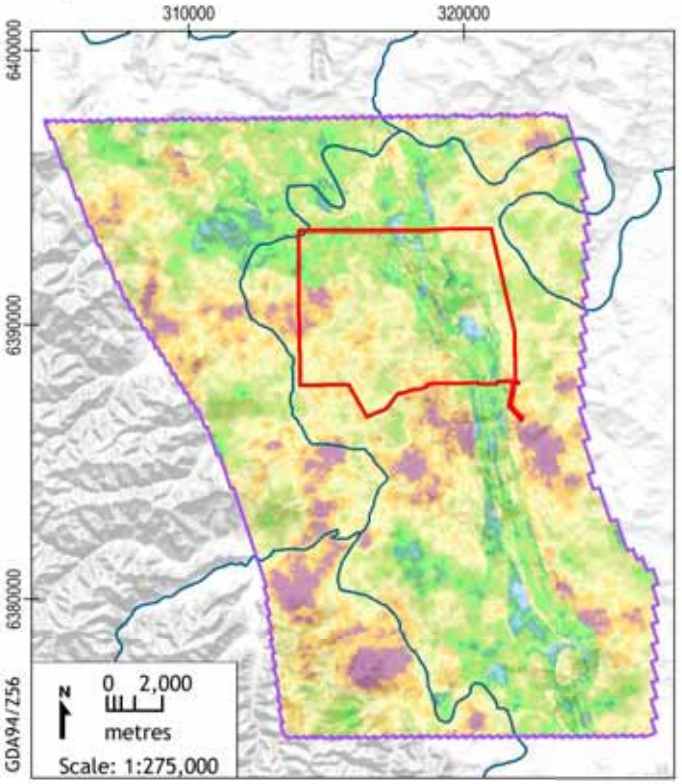
Layer 1 - Realization 111



Layer 3 - Realization 119



Layer 13 - Realization 175



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Major watercourse

Vertical Hydraulic Conductivity Factor

0.1	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

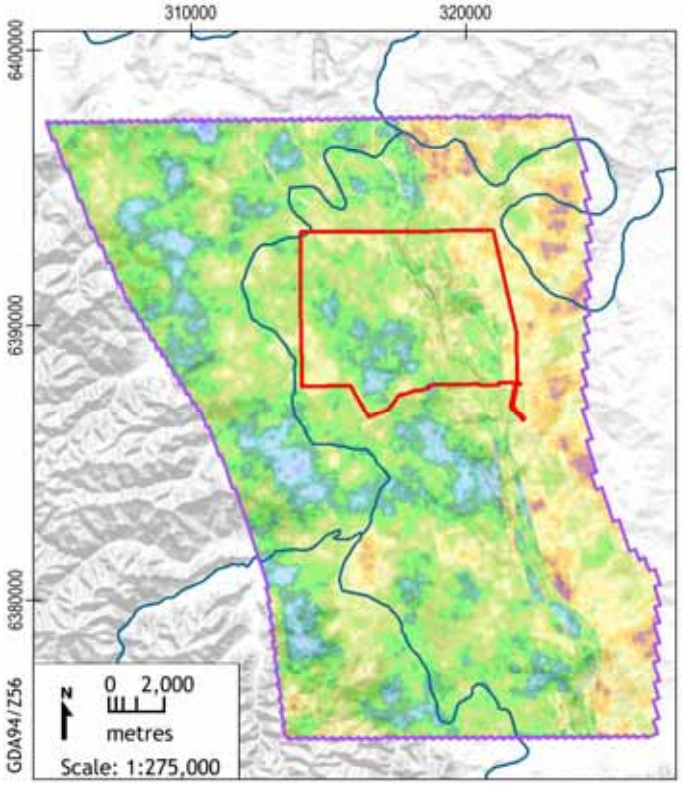
Uncertainty
Vertical Hydraulic Conductivity Factor

DATE: 3/4/2014

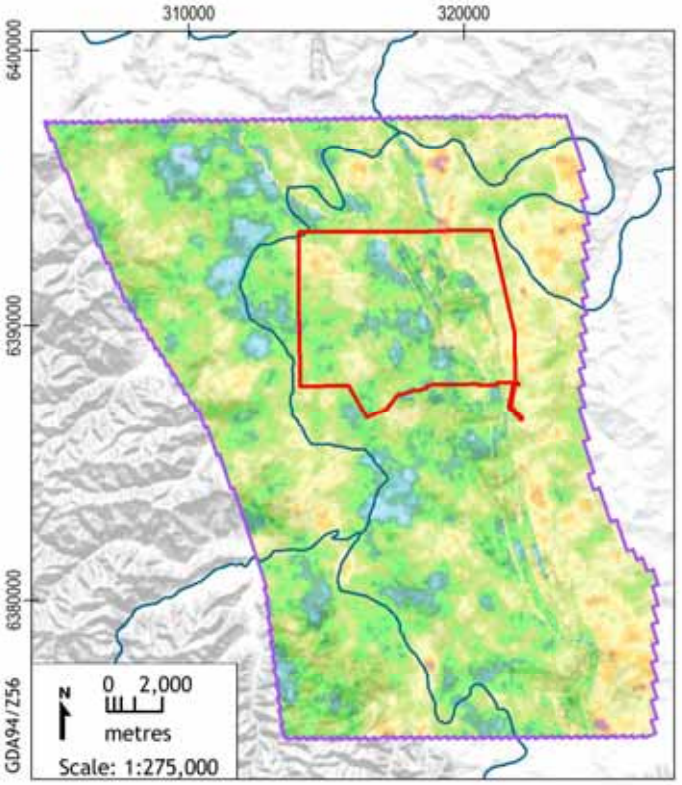
FIGURE No: **D-5**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

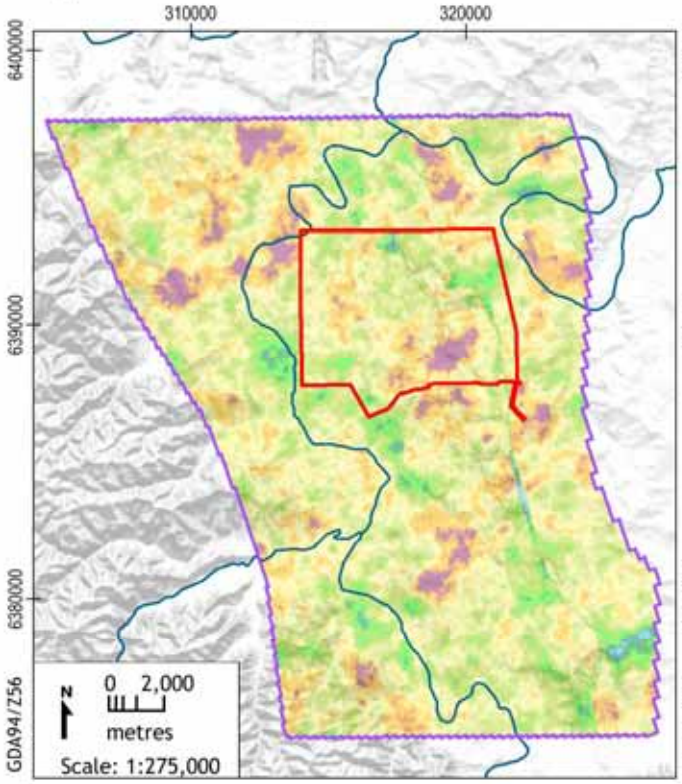
Layer 6 - Realization 43



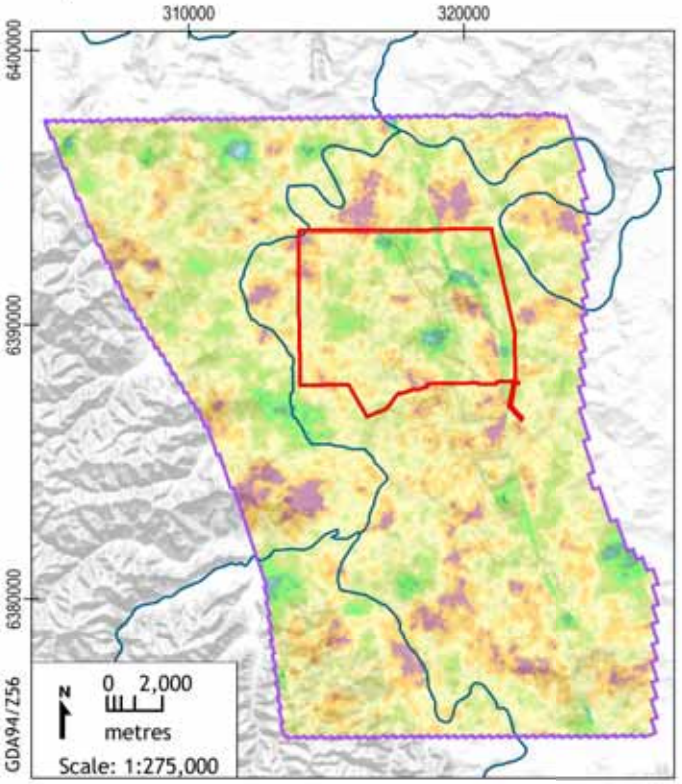
Layer 6 - Realization 124



Layer 13 - Realization 81



Layer 13 - Realization 110



LEGEND:

- Proposed Warkworth Mine development consent boundary
- Active model boundary
- Major watercourse

Vertical Hydraulic Conductivity Factor

0.1	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Warkworth Continuation 2014
Groundwater Assessment (G1468F)

Uncertainty
Vertical Hydraulic Conductivity Factor

DATE: 3/4/2014

FIGURE No: **D-6**

©2014 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Figure D- 7 shows the results from the calibration uncertainty analysis (Realisations), as well as the calibrated and cutoff levels for the objective function (Phi).

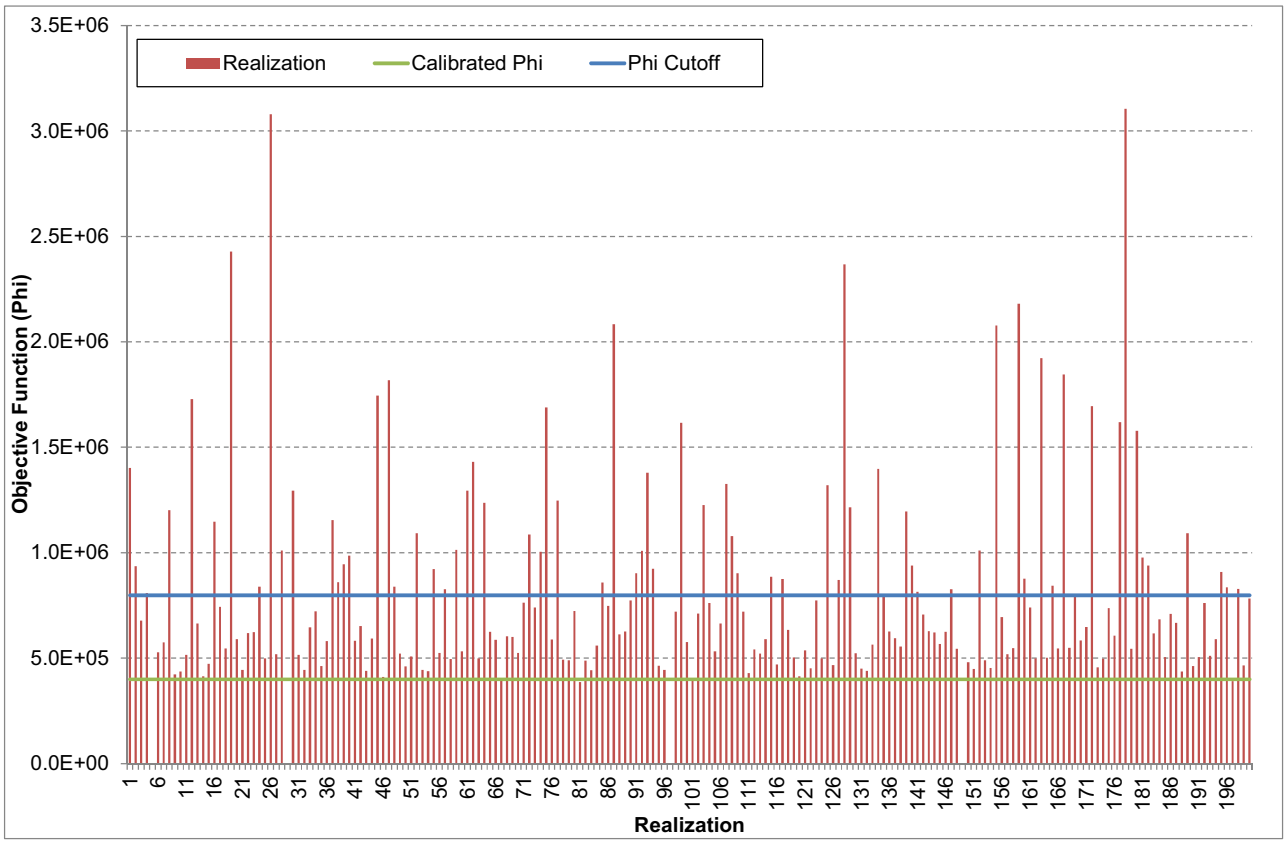


Figure D- 7: Ranking of Objective Function (Phi) from Calibration Runs

Appendix E

EXTERNAL REVIEW REPORT

KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

Phone 61 2 99187478
Fax 61 2 99182667
A.B.N 67 079 152 462

52 York Terrace
BILGOLA NSW 2107
AUSTRALIA

23 May 2014

Warkworth Continuation 2014
KA Final Peer Review of the AGE Groundwater Assessment

Background

The Peer Review presented herein is for the proposed continuation mining at the Warkworth mine site Upper Hunter Valley. The mine is seeking approval under Part 4, Division 4.1 of the EP&A Act to extend mining beyond the current limits.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) have completed a report (AGE 2014) that describes the groundwater conditions at the site and used numerical model analysis to predict the impact of the proposed continued mining extension on the surrounding groundwater system.

The KA peer review was completed in two parts: First a detailed preliminary review report was prepared of requested clarifications and also corrections, and error tabulation. AGE has in turn addressed most of these items in response. This report provides the final peer review documentation of the re-issued updated final report.

In the following review the National Water Commission modelling guidelines have been taken into consideration.

Review

Overall the AGE (2014) report's hydrogeological description and assessment is comprehensive with suitable numerical modelling procedures applied together with uncertainty analysis. The AGE report provides a detailed description of the model development and calibration in an Appendix C.

The AGE 2014 model is based on previous models developed by MER (2002) and subsequently by AGE (2010). The groundwater assessment based on the AGE 2010 work was previously approved by both Commonwealth and NSW governments and subsequently overturned by the NSW Land and Environment Court. Since that time more monitoring bores have been installed that has allowed a much larger data base of groundwater levels since 2010 to be established.

Hydrogeological Description

The hydrogeology of the site and surrounding area is described in detail and covers groundwater occurrence, monitoring, water levels, gradients, strata permeability and

storage, recharge, discharge, water quality, users and groundwater dependent ecosystems, policy and licensing requirements.

Conceptual Model

The area has had a long history of mining both on the Warkworth site and in adjacent mining zones and the geology and hydrogeology are well understood. The conceptual model used as the basis for the numerical model is considered suitable.

Model Software and Extent

The modelling software used for this project by AGE was MODFLOW-SURFACT (MS) which is suitable for this kind of modelling assessment. The model covers an adequate of area of 344 km^2 extending about 19 km from west to east and 24 km from north to south.

Model layers and cells

Model layering adopted is considered suitable with sixteen layers used to represent Permian coal bearing hydrogeological units both within the mining zone and below, as well as the overlying alluvial sediments of the drainage streams in the area, in particular Wollombi Brook and also Hunter River. The layering has provided sufficient vertical resolution in the model and differs from the AGE (2010) model by including interburden as separate layers rather than as vertical conductances. Model cells used were 30m x 30m within the mining zone increasing up to 100m x 225m outside this zone.

Boundary conditions

Boundary conditions set for the model are suitable. Ephemeral streams were set initially using the 'river package' with very low stage but then with zero surface flow over an extended period as part of the uncertainty analysis. Recharge was applied as net recharge but the evapotranspiration function was also used to assist in final void water level determination.

Model parameters

Initial model parameters were applied based on values used in previous modelling work and then subsequently calibrated using the new 2014 AGE model. Calibration was achieved by initial trial and error and then applying the PEST algorithm.

Calibration

Both steady state calibration using interpolated bore water level measurements and transient analysis calibration was conducted. Steady state calibration was problematic because of the considerable activity within the mining area over many years of operation both within the mine itself and in adjacent mines. Therefore the groundwater levels so obtained can only be considered to be a set of starting heads for the transient analysis.

Examination of the transient analysis scatter diagram indicates very good to poor fit. Statistically the results yielded an overall RMS value of 18% (and sRMS = 15%). This lies outside the range of 5% to 10% suggested in the modelling guidelines. There are some mitigation circumstances however. First is that the Warkworth hydrogeological system is highly disturbed and is also confounded by the lack of precise knowledge about the historical mining sequences in the region. The scatter diagram outliers also are over represented by having a longer duration of high frequency measurements.

KA in the preliminary review requested AGE to indicate the location of these outlier water levels. AGE has responded with a Figure 7.6. This puts those measurements in perspective. It shows that they relate to the deeper Permian model strata but not to the upper model layers that are more important in assessing any predicted drawdown influence both on the adjacent Wollombi Brook alluvium and any corresponding domestic bores within those sediments. That is, the drawdown residuals in layer 1 and 2 for example are relatively

smaller and therefore would likely lie within the 5 to 10% suggested limits, but also that they over predict drawdown compared to that measured rather than under-predict.

Overall drawdown distributions depicted in Figure 7.5, that shows the regional extent of potentiometric heads at the end of the calibration period in both the alluvium and regolith and within the Mt Arthur coal seam, are consistent and appear plausible.

Predictions and Potential Impacts

Prediction of potentiometric heads and changes in head in Figures 8.1 to 8.3 also appear consistent and plausible

Predicted inflows to the mining zones and the influence to baseflows presented are considered to be plausible. Inflows from the high salinity Permian groundwater will vary throughout the mining period from initial 1550 m^3/day peaking at 2014 m^3/day in 2023 decreasing to 812 m^3/day in 2035. These inflows include losses due to direct evaporation from the pit.

Baseflow reduction from Wollombi Brook would peak at 273 m^3/day in 2035 with negligible loss to the Hunter River surface water flow. It should be noted that the baseflow reduction is due in part to the capture of brackish to saline groundwater from the Permian strata that would have otherwise entered Wollombi Brook alluvium and its stream channel.

Modelling indicates drawdown in most private bores penetrating alluvium to be less than 1m due to the proposal. Of the twelve NOW registered bores that penetrate Permian strata only two are predicted to have drawdowns greater than 2m (i.e. 2.5m and 2.2m respectively) with drawdown in the others in the range 1.1m to 1.7m due to the proposal. AGE has indicated the cumulative influence in their report.

The main GDE in the area is the Warkworth Sands Woodland situated north-west of the Warkworth mine. However groundwater in these Sands comprise a perched system with limited hydraulic connection to the main regional watertable and therefore would not be significantly affected by mine drawdown.

The Southern Biodiversity Area (Valley Oak Forest and River Red Gum Woodland) are situated 2.5km from the proposed mine extension in alluvium along the Wollombi eastern bank. These zones will not be influenced by mine drawdown.

There would be no increase in salinity created in the alluvium and Wollombi Brook stream flow by the proposal. On the contrary the reduction in groundwater flow from the Permian strata to the Wollombi alluvium will be up to 338 m^3/day[1] (and 185 m^3/day reduction to Hunter River alluvium) therefore correspondingly less brackish to saline groundwater would enter the alluvium and as Wollombi stream baseflow.

Post Mining

Determination of post mining final void level was conducted by AGE in association with the surface water consultants (WRM). The final voids will form a lake with long term average groundwater inflow from the Permian strata of 1365 m^3/day and maximum of 1507 m^3/day. Void water salinity is likely to rise to 30,000 microSeimens/cm but the void will remain a sink in perpetuity without any egress of stored water.

Conclusion

[1] Of the 338 m^3/day groundwater reduction from the Permian to the alluvium, 273 m^3/day is the baseflow component.

The AGE groundwater assessment report is comprehensive and has satisfactorily provided descriptions of the hydrogeological system of the Warkworth site. The model setup, calibration and predications are also considered to be suitable. Model analyses of the proposed continuation of mining indicate that the impacts will be minimal with respect to drawdown influence and beneficial to surface and groundwater quality. Simulations results are considered reasonable and plausible. Ongoing monitoring of water levels and a model update every 5 years during operations is recommended to compare model predicted drawdowns with measured drawdown influence.



F. R. Kalf B.Sc, M.App.Sc., PhD

References

Australasian Groundwater and Environmental (AGE) 2010 *Warkworth Mine Extension, Groundwater Impact Assessment. Project No G1468. Feb.*

Australasian Groundwater and Environmental (AGE) 2014 *Warkworth Continualtion 2014 Groundwater Assessment. Prepared for EMGA Mitchell McLennan. Project No G1468/F. May*

Mackie Environmental Research (2002) *Extension of Warkworth Coal Mine Assessment of Environmental Impacts Surface and Groundwater Systems in the Upper Hunter Valley of NSW. August .*

Appendix L

Surface water study



Appendix L — Surface water study

L

MOUNT THORLEY OPERATIONS 2014 AND WARKWORTH CONTINUATION 2014 SURFACE WATER ASSESSMENT

Prepared for Coal & Allied Operations Pty Limited
June 2014

www.wrmwater.com.au

WRM Water & Environment Pty Ltd
ABN: 96 107 404 544 ACN: 107 404 544
Level 9, 135 Wickham Tce, Spring Hill
PO Box 10703
Brisbane Adelaide St QLD 4000
tel +61 7 3225 0200 fax +61 7 3225 0299
www.wrmwater.com.au

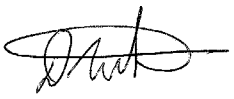
REPORT TITLE: Mount Thorley Operations 2014 and Warkworth Continuation 2014 – Surface Water Assessment

CLIENT: Coal & Allied Operations Pty Limited

REPORT NUMBER: 0605-09-D7

Revision Number	Report Date	Description	Report Author	Reviewer
D7	2 June 2014	Final Report	TK	DN

For and on behalf of
WRM Water & Environment Pty Ltd



David Newton
Director

NOTE: This report has been prepared on the assumption that all information, data and reports provided to us by our client, on behalf of our client, or by third parties (e.g. government agencies) is complete and accurate and on the basis that such other assumptions we have identified (whether or not those assumptions have been identified in this advice) are correct. You must inform us if any of the assumptions are not complete or accurate. We retain ownership of all copyright in this report. Except where you obtain our prior written consent, this report may only be used by our client for the purpose for which it has been provided by us.

EXECUTIVE SUMMARY

WRM Water & Environment Pty Ltd was commissioned by EMGA Mitchell McLennan (EMGA), on behalf of Coal & Allied Operations Pty Limited (Coal & Allied), to undertake a surface water impact assessment to determine potential impacts on surface water resources due to the Mount Thorley Operations (MTO) and Warkworth Continuation 2014 Projects (the proposal).

The proposal involves an extension to the approved mining footprint at Warkworth Mine and completion of mining at MTO (among other things), for a period of 21 years.

MTO is an open cut coal mine approximately 15 kilometres (km) south-west of Singleton in the Hunter Valley, NSW. The mine is operated by Coal & Allied on behalf of Mount Thorley Joint Venture (MTJV). Immediately to the north is Warkworth Mine, operated by Warkworth Mining Limited on behalf of MTJV. Since 2004, the two mines have integrated at an operational level and are known as Mount Thorley Warkworth (MTW), with a single management team responsible for the operations.

MTW currently holds a high security Water Access Licence with an allocation of up to 1,012 mega Litres (ML) enabling extraction from the Hunter River, as well as two licenced discharge locations, operated in accordance with the Hunter River Salinity Trading Scheme (HRSTS) and existing Environmental Protection Licences (EPL) 1376 and 1976.

Under current catchment conditions (since the upgrade to the Glenbawn Dam in 1988), the Hunter River is perennial. The Hunter River water quality is characterised by low salinity and moderate alkalinity. However, numerous water quality parameters exceed water quality guidelines, particularly for nutrients and pH. Wollombi Brook is ephemeral, and has a high level of connectivity between surface water and the groundwater aquifer. Water quality in Wollombi Brook is characterised by low salinity and slight alkalinity. Parameters which exceed water quality guidelines include chloride and sodium.

The potential changes to surface water and water management during the life of the proposal that have been investigated include:

- Additional water demand from external third party sources (ie neighbouring mines or the Hunter River) to meet increased operational water requirements for the proposal;
- Loss of catchment area draining to Wollombi Brook and the Hunter River due to capture of runoff within onsite storages during mining. This could potentially reduce runoff volumes to Wollombi Brook and the Hunter River;
- Adverse impacts on the quality of surface runoff draining from the local site catchment to Wollombi Brook and the Hunter River;
- Change in downstream water quality associated with possible overflows from the mine water management system;
- Increase in saline water controlled discharges (HRSTS); and
- Interference with flood flows along Wollombi Brook and the Hunter River associated with changes in the respective flood plains.

A key component of the methodology for the surface water impact assessment has been the development of a detailed computer model of the mine water balance. The model was configured to represent the inflows to and outflows from the mine water management system as well as transfers of water between mine site storages. The mine water balance model was

calibrated against observed system performance during 2012 to 2013. The mine water system model was simulated on a daily basis over the 21 year life of the proposal using 93 difference rainfall sequences based on recorded historical data.

The results of the water balance model indicate that there is a step change in external water requirements which occurs in around Year 2, consistent with the increase in production at Warkworth Mine and the decrease in groundwater inflows to at MTO. External water requirement from Year 3 to year 21 are generally consistent with:

- A 50 per cent chance that between 1,500ML/a to 2,000ML/a of external water will be required; and
- A 10 per cent chance that between 3,000ML/a to 3,700ML/a of external water will be required.

Note that the current MTJV allocation is 1,012ML/a (at 100% Available Water Determination (AWD)).

The results of the water balance modelling indicate a low probability of pit inundation, and no offsite uncontrolled release (overflows) from saline storages.

HRSTS discharges will be required for site water management, with the following discharge characteristics:

- Overall, much greater volumes are discharged from MTO than Warkworth Mine, which is consistent with the capacity of the discharges structures (300ML/d at MTO and 100ML/d at Warkworth Mine) and dam volumes;
- There is a 50 per cent chance of controlled releases from MTO will not be required in any year of project life, and small volumes of controlled discharges (100ML) will be required from Warkworth Mine in any year of project life; and
- There is a 10 per cent chance of controlled releases from MTO of between 1,000ML to 2,000ML will be required in any year of project life, and around 400ML from Warkworth Mine in any year of project life.

There is a maximum reduction of 0.56 per cent of the Wollombi Brook catchment to the Hunter River, and a maximum reduction of 0.19 per cent of the Hunter River (not including Wollombi Brook) during mining. Post-mining, the reduction in catchment area is 0.44 per cent and 0.04 per cent for Wollombi Brook and the Hunter River respectively. There is a median net runoff reduction to the Hunter River of up to 75ML/a during mining, and up to 104ML/a post-mining.

MTW currently undertakes an extensive surface water monitoring program, which will continue to be implemented for the proposal. Monitoring includes on site dams (both saline and sediment), receiving waters (upstream and downstream Hunter River, Wollombi Brook and their tributaries), and additional monitoring which is undertaken during periods of controlled release under the HRSTS. Additional saline storages and sediment dams constructed as part of the proposal will be monitored in accordance with the current monitoring program.

Overall, the impacts of the Project on surface water resources are unlikely to be significantly greater than those of the existing mining operation.

TABLE OF CONTENTS

Page

1 INTRODUCTION 9

1.1 OVERVIEW 9
1.2 MOUNT THORLEY OPERATIONS EIS 9
1.2.1 Background 9
1.2.2 Proposal Description 10
1.3 WARKWORTH MINE EIS 12
1.3.1 Background 12
1.3.2 Proposal Description 12
1.4 DIRECTOR-GENERAL'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS 13
1.5 REPORT STRUCTURE 13

2 EXISTING SURFACE WATER ENVIRONMENT 14

2.1 RAINFALL AND EVAPORATION 14
2.2 REGIONAL DRAINAGE NETWORK 16
2.3 LOCAL DRAINAGE NETWORK 16
2.4 STREAMFLOW 19
2.4.1 Hunter River 19
2.4.2 Wollombi Brook 19
2.5 EXISTING MINE WATER MANAGEMENT SYSTEM 24
2.6 SURFACE WATER QUALITY 27
2.6.1 New South Wales Office of Water (NOW) Monitoring 27
2.6.2 Coal & Allied Monitoring 27
2.6.3 Water Quality Monitoring Results Analysis 28

3 RELEVANT LEGISLATION AND GUIDELINES 33

3.1 OVERVIEW 33
3.2 PROTECTION OF THE ENVIRONMENT OPERATIONS ACT 1997 33
3.3 WATER MANAGEMENT ACT 2000 34
3.3.1 Water Sharing Plans 34
3.4 STATE WATER MANAGEMENT OUTCOMES PLAN (SWMOP) AND HUNTER AND CENTRAL RIVERS CATCHMENT ACTION PLAN (CAP) 34
3.5 PROTECTION OF THE ENVIRONMENT OPERATIONS (HUNTER RIVER SALINITY TRADING SCHEME) REGULATION 2002 34

4 IMPACT ASSESSMENT 36

4.1 OVERVIEW 36
4.2 MINE SITE WATER REQUIREMENTS 36
4.3 LOSS OF CATCHMENT AREA 37
4.4 SURFACE WATER QUALITY 38
4.5 UNCONTROLLED OFFSITE RELEASES 38
4.6 IMPACTS OF CONTROLLED RELEASES UNDER HRSTS 39
4.6.1 Overview 39
4.6.2 Hunter River Flow Volume 41
4.6.3 Stream Condition 42

4.6.4 Water Quality Impacts 43
4.7 FLOODING AND STREAM GEOMORPHOLOGY 46
4.8 WATER ALLOCATIONS 46

5 FLOODING 49

5.1 OVERVIEW 49
5.2 HUNTER RIVER FLOODING 49
5.3 WOLLOMBI BROOK FLOODING 50
5.3.1 Previous Flood Investigations 50
5.3.2 Design Flood Discharges 50
5.3.3 Design Flood Levels 51
5.3.4 Flood Impacts 52

6 MINE WATER BALANCE 55

6.1 OVERVIEW 55
6.2 SIMULATION METHODOLOGY 55
6.3 SIMULATION OF RAINFALL RUNOFF 56
6.4 WATER BALANCE MODEL CALIBRATION 58
6.5 PROPOSED WATER MANAGEMENT SYSTEM 58
6.5.1 Proposed Mine Water Storages 58
6.5.2 Water Management System Layout and Operating Rules 59
6.5.3 Groundwater Inflows 67
6.5.4 Catchments and Land Use Classifications 68
6.5.5 Water Quality 77
6.5.6 Water Demands 77
6.5.7 Proposed Sediment Dams 80
6.5.8 Hunter River Salinity Trading Scheme 81
6.6 WATER MANAGEMENT SYSTEM PERFORMANCE ASSESSMENT 81
6.6.1 Overview 81
6.6.2 Interpretation of Results 82
6.6.3 Overall Site Water Balance 82
6.6.4 Pit Storage Characteristics 83
6.6.5 Out-of-Pit Storage Characteristics 86
6.6.6 Controlled HRSTS Discharges to Hunter River 87
6.6.7 External Water Requirements 89
6.6.8 Uncontrolled Offsite Discharges 90
6.7 FINAL LANDFORM STORAGE AND WATER QUALITY BEHAVIOUR 91
6.7.1 Overview 91
6.7.2 Groundwater Behaviour 91
6.7.3 OPSIM Model Configuration 92
6.7.4 OPSIM Model Results 94
6.8 MINE WATER BALANCE SUMMARY 96
6.9 ADAPTIVE MANAGEMENT OF MINE WATER BALANCE 97

7 MITIGATION MEASURES 98

7.1 OVERVIEW 98
7.2 MINE WATER MANAGEMENT SYSTEM 98
7.3 EROSION AND SEDIMENT CONTROL PLAN 99
7.4 DRAINAGE OF FINAL LANDFORM 99
7.5 SURFACE WATER MONITORING PROGRAM 99

8 CONCLUSION 100

9 REFERENCES 102

APPENDIX A 104

SUMMARY OF MTW WATER QUALITY MONITORING PROGRAM RESULTS

APPENDIX B 105

MTW CATCHMENT AND LAND USE CLASSIFICATION TABLES

APPENDIX C 116

MODELLING OF RELEASES UNDER THE HRSTS

LIST OF TABLES

		Page
Table 2.1	BOM Rainfall Stations – Open (Australian Government Bureau of Meteorology, 2014)	14
Table 2.2	Mean Monthly Rainfall and Evaporation (mm/month)	15
Table 2.3	Annual Rainfall and Runoff Volumes for Wollombi Brook to Bulga Gauging Station	23
Table 2.4	Assessment of Low Flow Losses, Wollombi Brook	24
Table 2.5	Summary of Discrete NOW Water Quality Data - Hunter River at Singleton and Wollombi Brook at Warkworth (New South Wales Office of Water, 2011) and ANZECC Trigger Values	30
Table 3.1	MTO & Warkworth Mine Discharge Conditions (EPL 1376 & 1976)	33
Table 3.2	HRSTS Flow & River Salinity Thresholds, Lower Sector	35
Table 4.1	Receiving Waters Catchment Area during and after MTW Mining Operations	38
Table 4.2	Net Impact of Mine Water Management System on Hunter River Flow Volumes over Project Life	41
Table 4.3	Water Quality - Hunter River and MTW Discharge Dams	44
Table 4.4	Surface Water Allocations	47
Table 5.1	Peak Recorded Levels for June 2007 Event	49
Table 5.2	Design Discharges for Wollombi Brook	51
Table 5.3	Recorded and Estimated Flood Levels for June 2007 Event	52
Table 6.1	Application of Representative Mine Stage to Full Mine Life	56
Table 6.2	MTW Catchment Yield (AWBM) Parameters	57
Table 6.3	Proposal OPSIM Model Operating Rules	61
Table 6.4	Adopted Groundwater Inflows (ML/a)	68
Table 6.5	MTW Salinity Generation Rates	77
Table 6.6	Warkworth Mine CPP (North Plant) – Year 0	78
Table 6.7	Warkworth Mine CPP (North Plant) – Year 3 to Year 21	78
Table 6.8	MTO CPP (South Plant) – Year 0	78
Table 6.9	MTO CPP (South Plant) – Year 3 to Year 21	79
Table 6.10	Estimated Haul Road Dust Suppression Requirements	79
Table 6.11	Summary of Demands (ML/a)	80
Table 6.12	Proposed Sediment Dam Sizing	81
Table 6.13	MTW Average Water Balance for Each Mine Stage over all Climatic Realisations	83

LIST OF FIGURES

		Page
Figure 1.1	Proposal Site Layout	11
Figure 2.1	Distribution of Monthly Rainfall and Pan Evaporation at Jerrys Plains Post Office (Australian Government Bureau of Meteorology, 2014)	15
Figure 2.2	MTW Regional Drainage	16
Figure 2.3	MTW Local Drainage (Background Aerial Photography: Coal & Allied, Google Earth)	18
Figure 2.4	NOW Stream Gauging Locations	20
Figure 2.5	Stream Discharge Duration Curve #210001 Hunter River at Singleton	21
Figure 2.6	Stream Discharge Duration Curve #210004 Wollombi Brook at Warkworth, #210028 Wollombi Brook at Bulga	21
Figure 2.7	Annual Runoff versus Rainfall for Wollombi Brook at Bulga Gauging Station	22
Figure 2.8	MTW Water Management System Infrastructure - Existing	25
Figure 2.9	MTW Water Management System Schematic - Existing	26
Figure 2.10	MTW Receiving Water Monitoring Locations	29
Figure 2.11	Hunter River EC Monitoring Data – Box and Whisker Plot	32
Figure 2.12	Hunter River TSS Monitoring Data – Box and Whisker Plot	32
Figure 4.1	MTO Discharges to Hunter River	40
Figure 4.2	Warkworth Mine Discharges to Hunter River	40
Figure 4.3	Hunter River Discharges (IQQM Simulated) Flow Characteristics – Impact of MTW HRSTS Discharges	42
Figure 4.4	Undisturbed Catchment Areas Requiring Water Allocation Licence for Runoff Capture	48
Figure 5.1	Flood Frequency Analysis Plot, Wollombi Brook at Bulga	51
Figure 5.2	HEC-RAS Model Configuration and 100 Year ARI Design Flood Extent	53
Figure 5.3	Flood Level at Cross-Section A, Adjacent to Extended Pit Highwall	54
Figure 6.1	AWBM Model Configuration	57
Figure 6.2	Combined Site Inventory, Recorded vs. Simulated	58
Figure 6.3	Proposed Water Management System Schematic	60
Figure 6.4	MTW Surface Catchments & Land Use Classifications – Year 3	69
Figure 6.5	MTW Baseflow Catchments & Land Use Classifications – Year 3	70
Figure 6.6	MTW Surface Catchments & Land Use Classifications – Year 9	71
Figure 6.7	MTW Baseflow Catchments & Land Use Classifications – Year 9	72
Figure 6.8	MTW Surface Catchments & Land Use Classifications – Year 14	73
Figure 6.9	MTW Baseflow Catchments & Land Use Classifications – Year 14	74
Figure 6.10	MTW Surface Catchments & Land Use Classifications – Year 21	75
Figure 6.11	MTW Baseflow Catchments & Land Use Classifications – Year 21	76
Figure 6.12	Total In-Pit Storage Inventory (ML)	84

Figure 6.13 North Pit Inundation Characteristics 84
Figure 6.14 West Pit Inundation Characteristics 85
Figure 6.15 South Pit Inundation Characteristics 85
Figure 6.16 Loders Pit Inundation Characteristics 86
Figure 6.17 Out-of-Pit Water Inventory 87
Figure 6.18 MTO Discharges to Hunter River 88
Figure 6.19 Warkworth Mine Discharges to Hunter River 88
Figure 6.20 MTW External Water Requirements 90
Figure 6.21 Sediment Dam Offsite Overflows (ML/a) 91
Figure 6.22 Final Void Groundwater Inflow/Outflow (AGE, 2014) 92
Figure 6.23 MTW Final Landform Catchment Plan 93
Figure 6.24 Warkworth Final Void Water Level and Salinity 94
Figure 6.25 Loders Depression Water Level 95
Figure 6.26 Loders Depression Stored Volume 95
Figure 6.27 Loders Depression Salinity (Monthly Average) 96

1 INTRODUCTION

1.1 OVERVIEW

WRM Water & Environment Pty Ltd (WRM) was commissioned by EMGA Mitchell McLennan Pty Limited (EMM), on behalf of Coal & Allied Operations Pty Limited (Coal & Allied), to undertake an assessment of surface water impacts due to the Mount Thorley Operations (MTO) 2014; as well as the Warkworth Continuation 2014.

As the water management systems at MTO and Warkworth Mine are significantly integrated, the surface water impact assessment has been based on the combined projects (the proposal). This assessment forms part of the environmental impact statement (EIS) for each project. Details of the proposal and the methodology and results of the surface water impact assessment are provided in this report.

1.2 MOUNT THORLEY OPERATIONS EIS

1.2.1 Background

Mount Thorley Operations (MTO) is an open cut coal mine approximately 15 kilometres (km) south-west of Singleton in the Hunter Valley, NSW. The mine is operated by Coal & Allied on behalf of Mount Thorley Joint Venture (MTJV). The site currently operates under Development Consent No. DA 34/95 (the MTO development consent) issued by the then Minister for Planning on 22 June 1996 under Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

Immediately to the north is Warkworth Mine. Since 2004, the two mines have integrated at an operational level and are known as Mount Thorley Warkworth (MTW), with a single management team responsible for all the operations. Equipment, personnel, water, rejects and coal preparation are all shared between the mines. The MTW operations involve employ approximately 1,300 persons, which includes full-time personnel and a small number of short-term contractors. Ownership of the two mines remains separate.

Mining activities approved under DA 34/95 have mostly been completed with the exception of Loders Pit and Abbey Green North Pit (AGN); rehabilitation is well-progressed on the east of the site. Run-of-mine (ROM) coal from MTO is transported to either the MTO or Warkworth Mine coal preparation plant (CPP) for processing. Extraction of coal from other pits has been completed; overburden emplacement is ongoing. Product coal from the CPPs is transported via conveyor to the Mount Thorley Coal Loader (MTCL). Coal loaded onto trains at the MTCL is transported to the Port of Newcastle for export.

The proposal at MTO seeks an approval under Part 4, Division 4.1 of the EP&A Act to complete mining and rehabilitation activities within the current limits of approval.

1.2.2 Proposal Description

MTO has approval to mine until 22 June 2017 under its development consent. The proposal seeks a 21 year development consent period from the date of any approval. If approval is granted in 2015, operations at MTO are forecast to continue to the end of 2035, an 18 year extension over the current approval. The proposal seeks a continuation of all aspects of MTO as it presently operates and extends or alters them, including:

- Mining in Loders Pit and AGN Pit. Mining in Loders Pit is expected to be completed in approximately 2020. Mining in AGN Pit is yet to commence; however, it is anticipated to take approximately two years and be completed before 2022;
- Transfer of overburden between MTO and Warkworth Mine to assist in rehabilitation and development of the final landform;
- Maintain existing extraction rate of 10 million tonnes per year (Mtpa) of ROM coal;
- Maintain and upgrade to the integrated MTW water management system (WMS), including:
  - upgrade to the approved discharge point and rate of discharge into Loders Creek from 100ML/d to 300ML/d via the Hunter River Salinity Trading Scheme (HRSTS);
  - ability to transfer and accept mine water from neighbouring operations (ie Bulga Coal Complex, Wambo Mine, Warkworth Mine and Hunter Valley Operations);
  - increase in the storage capacity of the southern out-of-pit (SOOP) dam from 1.6 giga litres (GL) to 2.2GL
- Maintain and upgrade the integrated MTW tailings management:
  - including use of the northern part of Loders Pit as a TSF after completion of mining; and
  - wall lift to Centre Ramp Tailings Facility to approximately RL150
- Upgrade to the MTO CPP to facilitate an increase in maximum throughput to 18Mtpa with the ability to receive this coal from Warkworth Mine;
- Acknowledge all approved interactions with Bulga Coal Complex; and
- Continuation of coal transfer between Warkworth Mine and MTO and transportation of coal via the MTCL to Port of Newcastle.

All activities, including coal extraction will be within disturbance areas approved under the existing development consent.

The proposal is shown in Figure 1.1.

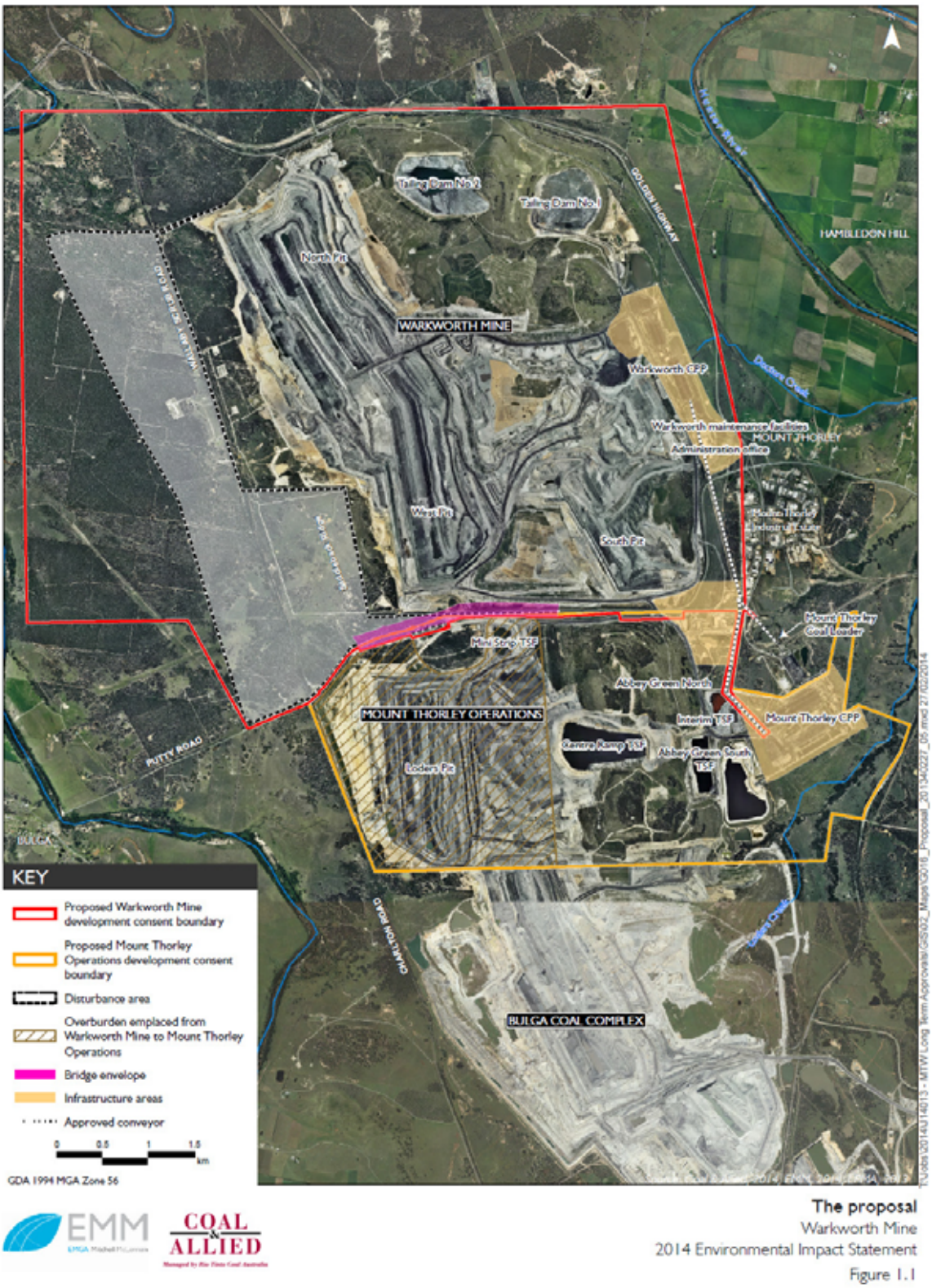


Figure 1.1 Proposal Site Layout

1.3 WARKWORTH MINE EIS

1.3.1 Background

Warkworth Mine is an open cut coal mine approximately eight kilometres (km) south-west of Singleton in the Hunter Valley, NSW. The mine is operated by Coal & Allied on behalf of Warkworth Mining Limited. The site currently operates under Development Consent No. DA 300-9-2002-i (the Warkworth Mine development consent) issued by the then Minister for Planning in May 2003 under Part 4 of the EP&A Act. The site also operates under two separate Commonwealth approvals (*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)); EPBC 2002/629 and EPBC 2009/5081.

Warkworth Mine has been in operation since 1981 and the originally approved operation has been modified several times. Immediately to the south of Warkworth Mine is MTO. As noted in Section 1.2.1, the two mines have integrated at an operational level, however, ownership remains separate.

Warkworth Mine currently operates three integrated open cut mining areas, namely North, West and South pits with West and North pits being the focus of production. ROM coal from Warkworth Mine is transported to either the Warkworth or Mount Thorley CPP for processing. Product coal from the CPPs is transported via conveyor to either the MTCL or to the Redbank Power Station. Coal loaded onto trains at the MTCL is transported to the Port of Newcastle for export.

The proposal at Warkworth Mine seeks an approval under Part 4, Division 4.1 of the EP&A Act to extend mining beyond the current limits.

1.3.2 Proposal Description

Warkworth Mine has approval to operate until 19 May 2021 under its development consent. The proposal seeks a 21 year development consent period from the date of any approval. If approval is granted in late 2014, operations at Warkworth Mine are forecast to continue to 2035, a 14 year extension over the current approval. The proposal seeks a continuation of all aspects of Warkworth Mine as it presently operates together with:

- An extension of the approved mining footprint by approximately 698ha to the west of current operations (referred to herein as the proposed 2014 extension area);
- The ability to transfer overburden to MTO to complete MTO's final landform;
- The closure of Wallaby Scrub Road;
- An option to develop an underpass beneath Putty Road for the third bridge crossing yet to be constructed (while retaining the current approval for an overpass);
- Minor changes to the design of the Northern out-of-pit (NOOP) dam; and
- The continued use of secondary access gates to the mine site and offsets for activities such as drilling, offset management, equipment shutdown pad access amongst other things.

The proposal is shown in Figure 1.1.

1.4 DIRECTOR-GENERAL'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS

Section 78A(8A) of the EP&A Act states that a development application for a State Significant Development must be accompanied by an EIS prepared in accordance with the Environmental Planning & Assessment Regulation 2000 (EP&A Regulation). Clause 3 of Schedule 2 of the EP&A Regulation states that prior to the preparation of an EIA, the applicant must make a written application to the Director-General for Environmental Assessment Requirements (DGRs). A request for DGRs was made by Coal & Allied on 1 April 2014. This assessment, which forms part of the EIS, addresses the DGRs concerning surface water.

1.5 REPORT STRUCTURE

This report is structured as follows:

- Section 2 describes the existing surface water environment in the vicinity of the proposal;
- Section 3 provides an overview of the relevant legislation and guidelines relating to surface water resources;
- Section 4 details the assessment of the potential surface water impacts from the proposal;
- Section 5 details the flooding impacts from the proposal;
- Section 6 provides more detail on the site water balance used for the assessment of impacts;
- Section 7 describes the management and monitoring which will be undertaken as part of the proposal; and
- Section 8 summarises the outcomes of the study.

2 EXISTING SURFACE WATER ENVIRONMENT

2.1 RAINFALL AND EVAPORATION

Summary details of existing Bureau of Meteorology (BOM) rainfall stations in the vicinity of MTW are shown in Table 2.1. Bulga (Down Town) is the closest open BOM rainfall station to MTW, whereas Jerrys Plains has the longest period of record (130 years). Table 2.2 shows mean monthly rainfalls for the Jerrys Plains and Bulga (Down Town) rainfall stations, over the entire period of record as well as coincident periods of record (1960 to 2013). The mean annual rainfall over the long term (1884 to 2013) at Jerrys Plains station is 645mm. The mean annual rainfall over the coincident period is 668mm and 695mm at Jerrys Plains and Bulga Down Town, respectively. This indicates that rainfalls are around four per cent higher at Bulga than Jerrys Plains.

Table 2.1 BOM Rainfall Stations – Open (Australian Government Bureau of Meteorology, 2014)

Station Name	Station No.	Lat.	Long.	Opened	Elevation	Distance from MTW
Jerrys Plains Post Office	061086	32.50°	150.91°	1884	87 m	17 km NW
Bulga (South Wambo)	061191	32.61°	150.98°	1959	80 m	7.2 km W
Bulga (Down Town)	061143	32.65°	151.02°	1960	69 m	4 km W
Singleton STP	061397	32.59°	151.17°	2002	45 m	8.5 km E
Mibrodale (Hillsdale)	061309	32.69°	150.97°	1963	120 m	9.7 km SW
Mibrodale School	061422	32.70°	151.00°	2010	88 m	7.4 km SW

Long term daily rainfall for the MTW site from January 1889 to December 2012 (124 years) has been obtained from the DSITIA Data Drill service. Table 2.2 shows the Data Drill rainfall long term (124 years) monthly averages. The Data Drill rainfall is filtered to reduce anomalies such as missing data or accumulated rainfall totals and has been adopted for the water balance modelled for this study.

Table 2.2 also shows mean monthly pan evaporation (based on Class A evaporation pan) recorded by the BOM at Jerrys Plains over the period 1957 to 1972. Mean annual evaporation is 1,641mm, with significant seasonal variation, as shown in Figure 2.1. Table 2.2 shows a comparison of the long term monthly averages of Morton's lake evaporation. Average annual lake evaporation is more than double the average annual rainfall.

Table 2.2 Mean Monthly Rainfall and Evaporation (mm/month)

Month	Rainfall					Pan Evaporation	Lake Evaporation
	Jerrys Plains		Bulga Down Town	Data Drill Rainfall		Jerrys Plains	Data Drill
	1884-2013	1960-2013	1960-2013	1960-2012	1889-2012	1957-1972	1889-2012
Jan	77.7	84.5	85.2	76.2	73.0	220.1	186.1
Feb	73.1	82.8	91.3	83.6	77.8	169.5	150.9
Mar	59.1	60.1	73.3	62.5	66.8	155.0	135.2
Apr	44.0	40.6	45.6	46.7	49.1	120.0	92.0
May	40.7	46.1	49.4	44.9	43.9	89.9	59.3
Jun	48.3	44.9	46.3	45.2	50.0	60.0	40.8
Jul	42.7	35.8	27.2	29.6	38.8	71.3	48.3
Aug	36.1	36.7	34.9	34.1	35.1	80.6	74.3
Sep	41.7	43.1	39.0	38.8	40.1	111.0	105.1
Oct	52.1	57.6	56.9	53.4	52.4	164.3	143.4
Nov	62.3	68.4	69.7	62.8	59.7	195.0	165.5
Dec	68.1	70.3	75.1	72.3	70.9	204.6	89.2
Total	**645**	**668**	**695**	**650**	**658**	**1,641**	**1,390**

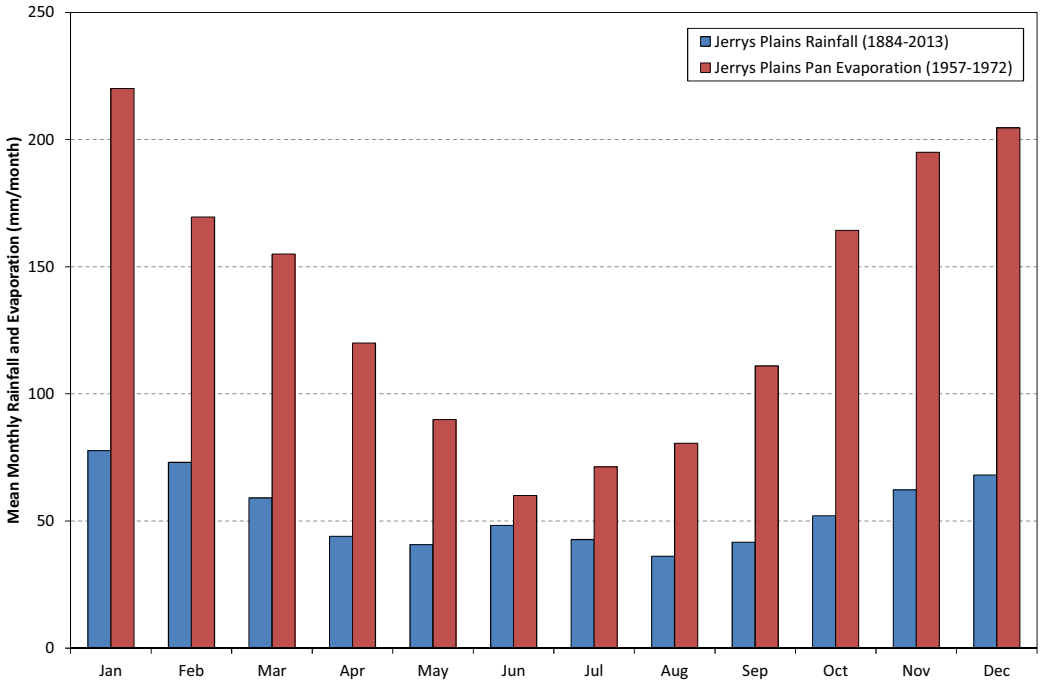


Figure 2.1 Distribution of Monthly Rainfall and Pan Evaporation at Jerrys Plains Post Office (Australian Government Bureau of Meteorology, 2014)

2.2 REGIONAL DRAINAGE NETWORK

The regional drainage network in the area of interest is shown in Figure 2.2. MTW is located on the southern side of the Hunter River, and the eastern side of Wollombi Brook. The Hunter River has a catchment area of approximately 16,400km^2 to Singleton.

The Hunter River catchment upstream of MTW includes Glennies Creek Dam (located 25km north of Singleton) and Glenbawn Dam (located 22km north of Muswellbrook), which command catchment areas of approximately 233km^2 and 1,300km^2 respectively, or a combined nine per cent of the total river catchment to Singleton. Glennies Creek Dam was completed in 1983 with a total storage capacity of 283,000ML. Glenbawn Dam was commissioned in 1957 with a storage capacity of 300,000ML. The Glenbawn Dam was raised in 1988 to a total storage capacity of about 750,000ML.

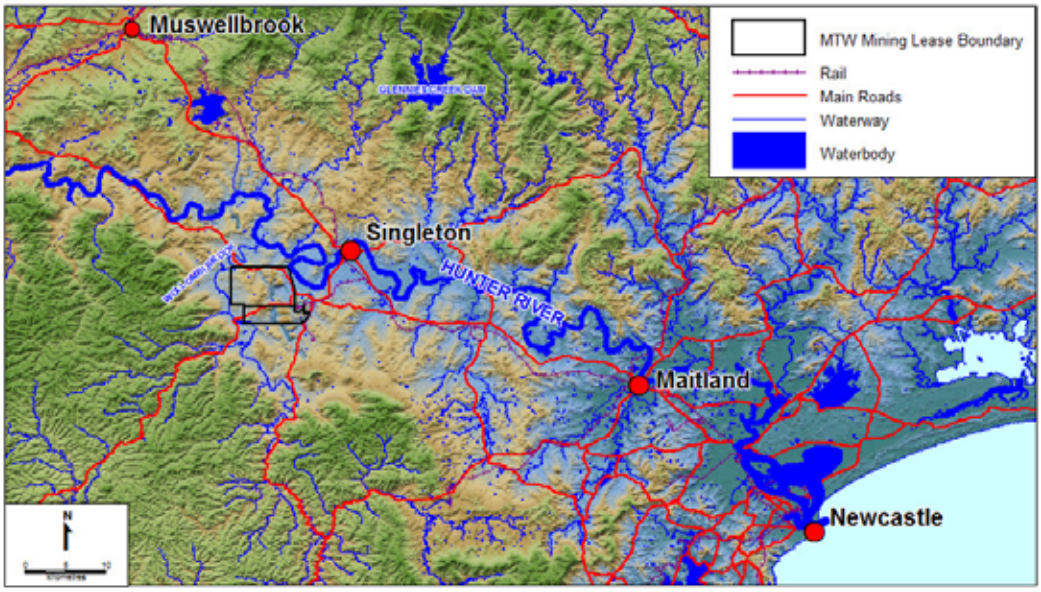


Figure 2.2 MTW Regional Drainage

2.3 LOCAL DRAINAGE NETWORK

Figure 2.3 shows the local drainage network in the vicinity of MTW. Wollombi Brook drains in a north-easterly direction around the site and joins the Hunter River approximately 3.5km north of MTW.

North and West Pit at Warkworth Mine are surrounded by natural landforms that slope inwards towards the active mining areas, however in the proposed extension area of Warkworth mine the natural landform generally slopes westwards towards Wollombi Brook. Clean water diversions (Dam 6N) have been constructed to divert clean water away from the active pits. Doctors Creek diversion protects West Pit, and Sandy Hollow Creek diversion protects North Pit. The catchment areas and the diversion structures are progressively changing with the westward advancing highwall.

At MTO, the clean catchment west of Loders Pit (Salt Pan Creek) drains westward towards Wollombi Brook. Doctors Creek and Loders Creek capture runoff from undisturbed areas east of

the mining operations, and are the receiving waterways for controlled site discharges under the HRSTS (refer Section 3.5).

Other drainage lines within the mining lease mostly drain westward or north-westward to Wollombi Brook. All are ephemeral and first or second order watercourses as identified from 1:25,000 topographic maps.

There are no surface water bodies in the disturbance area of the proposal.

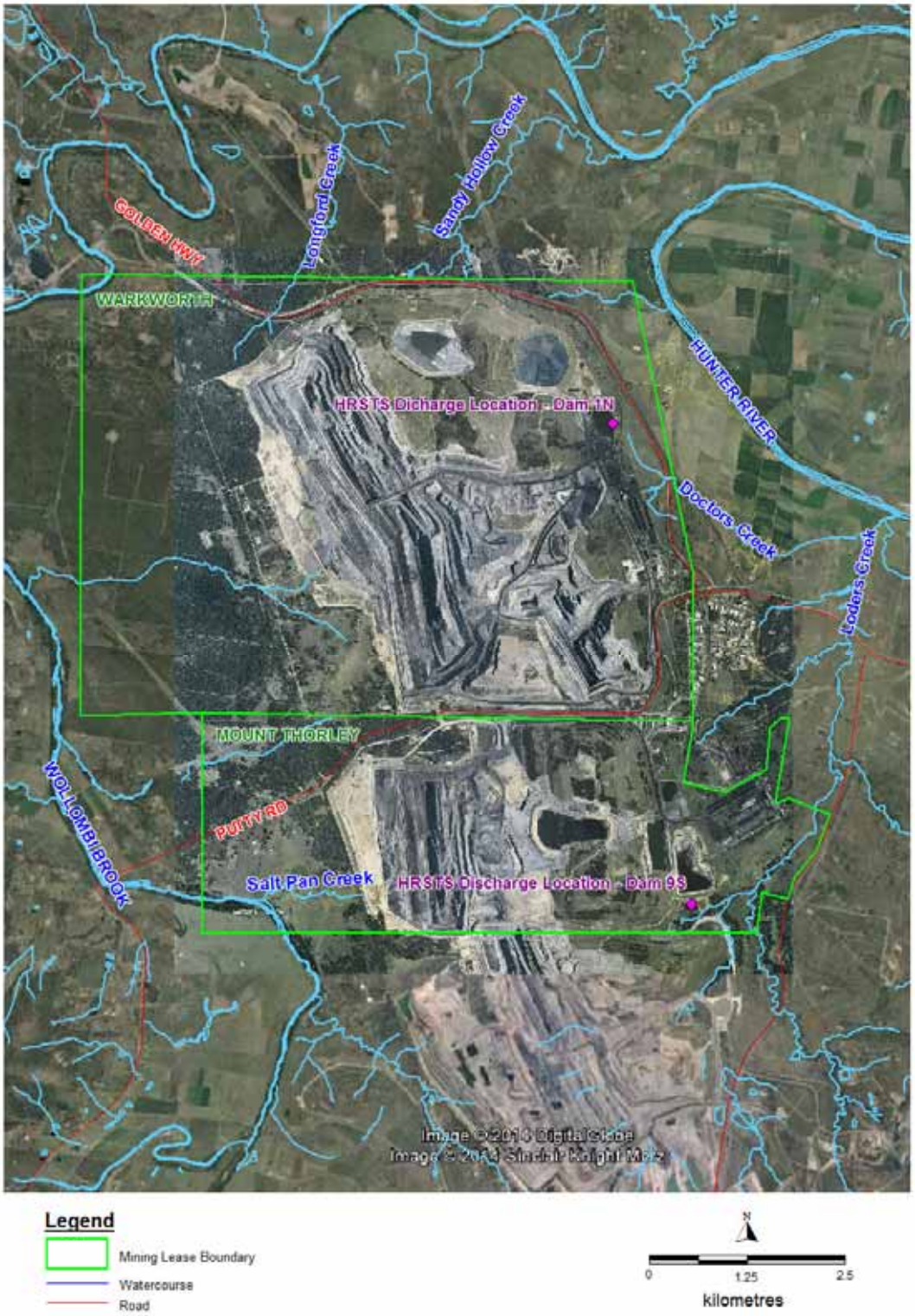


Figure 2.3 MTW Local Drainage (Background Aerial Photography: Coal & Allied, Google Earth)

2.4 STREAMFLOW

Figure 2.4 shows the New South Wales Office of Water (NOW) stream gauging locations in the vicinity of MTW. Flow data is presented for the following three locations:

- Station No. 210001 - Hunter River at Singleton 210001 (approximately 28km downstream of Wollombi Brook confluence). The catchment area of the river to the gauge is approximately 16,400km^2.
- Station No. 210004 - Wollombi Brook at Warkworth (approximately 7km upstream of the Hunter River confluence). The catchment area of the brook to the gauge is approximately 1,848km^2.
- Station No. 210028 – Wollombi Brook at Bulga (20km upstream of the Hunter River confluence). The catchment area of the brook to the gauge is approximately 1,672km^2.

The following sections present the recorded flow information for Wollombi Brook and the Hunter River.

2.4.1 Hunter River

The recorded flow-duration relationship for the Hunter River at Singleton (Station No. 210001) is shown in Figure 2.5 for the periods 1913 to 1957, 1958 to 1987, and 1988 to 2013. Glenbawn Dam was completed in 1958 and upgraded in 1987. Under current catchment conditions (since the upgrade to Glenbawn Dam in 1987), the river is perennial, with a minimum flow rate of about 10 Megalitres / day (ML/d). The median (50th percentile) flow rate is about 300 ML/d and the 95th percentile flow rate is greater than 100ML/d. Comparison of the three flow-duration curves indicates that the upgraded Glenbawn Dam has increased the frequency of low flows (due to regulation) and moderately reduced the frequency of high flows.

2.4.2 Wollombi Brook

Figure 2.6 shows the recorded flow-duration relationship for Wollombi Brook at Warkworth (Station No. 210004), for the periods 1908 to 2013 and 1949 to 2013. Figure 2.6 also shows the recorded flow-duration relationship for Wollombi Brook at Bulga (Station No. #210028) for the period 1949 to 2013. The flow-duration relationship indicates the brook is ephemeral, with an 80th percentile flow rate of about 2ML/d at Warkworth, and about 0.2ML/d at Bulga. The median (50th percentile) flow rate is about 40ML/d at Warkworth, and about 30ML/d at Bulga. During significant flood events, water levels at the Warkworth stream gauge may be affected by backwater from the Hunter River.



Figure 2.4 NOW Stream Gauging Locations

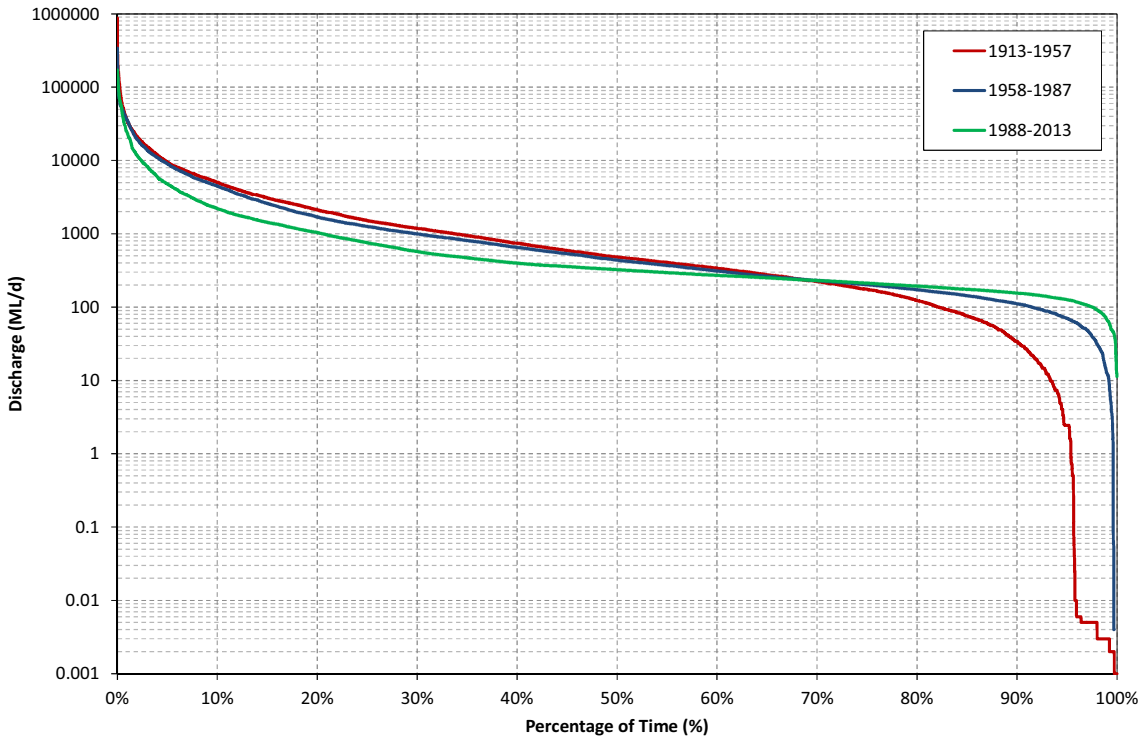


Figure 2.5 Stream Discharge Duration Curve #210001 Hunter River at Singleton

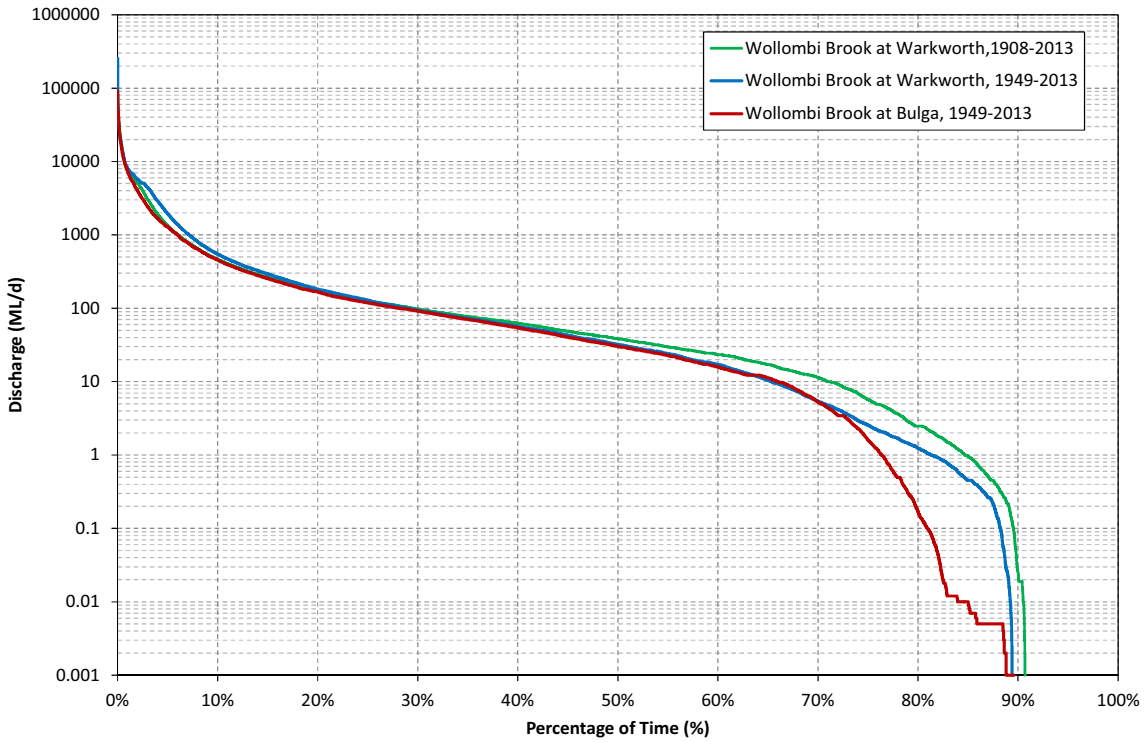


Figure 2.6 Stream Discharge Duration Curve #210004 Wollombi Brook at Warkworth, #210028 Wollombi Brook at Bulga

Table 2.3 shows the estimated annual runoff volume for the Wollombi Brook catchment to the Bulga gauge. The volumetric runoff coefficient is relatively high, with a mean value of about 11 per cent. There are no significant water storages on Wollombi Brook, however there is a high level of connectivity between surface water and the groundwater aquifer (ref. *Water sharing in the Lower Wollombi Brook water source*, http://www.hcr.cma.nsw.gov.au/water_sharing/macro_hunter_lowerwollombibrook.pdf).

Figure 2.7 shows a plot of annual runoff versus rainfall for the Wollombi Brook catchment at Bulga. Very little runoff is generated by the catchment when annual rainfall is less than about 400mm. Once annual rainfall exceeds this value, the volume of surface runoff increases substantially.

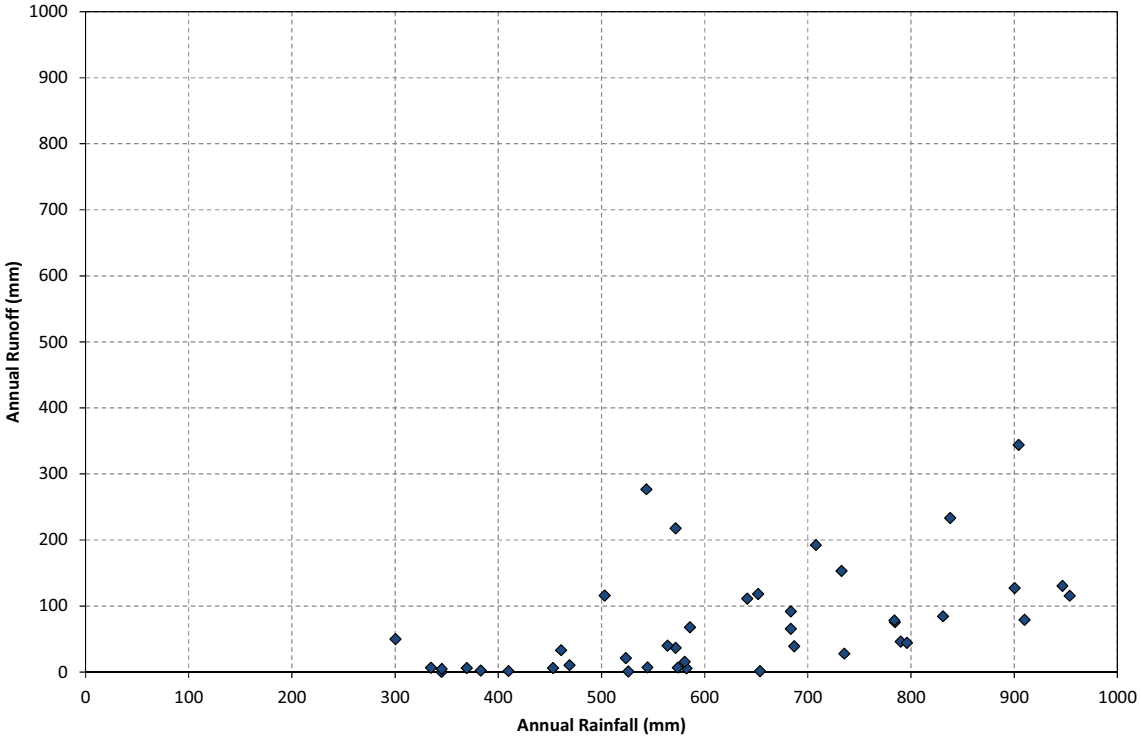


Figure 2.7 Annual Runoff versus Rainfall for Wollombi Brook at Bulga Gauging Station

Table 2.3 Annual Rainfall and Runoff Volumes for Wollombi Brook to Bulga Gauging Station

Year	Annual Rainfall [a] (mm)	Annual Runoff Volume		Volumetric Runoff Coefficient
		(GL)	(mm)	
1953	544	463	277	0.509
1954	831	141	84	0.101
1955	572	364	217	0.380
1956	708	322	192	0.272
1957	335	11	6	0.019
1958	582	9	6	0.010
1963	904	575	344	0.380
1964	503	194	116	0.230
1965	383	4	2	0.006
1966	410	3	1	0.004
1967	586	113	68	0.116
1968	735	47	28	0.038
1969	790	77	46	0.058
1970	574	11	7	0.012
1971	641	186	111	0.173
1972	785	126	75	0.096
1973	796	74	44	0.055
1974	733	256	153	0.209
1975	572	61	37	0.064
1976	838	390	233	0.278
1977	652	197	118	0.181
1978	947	218	130	0.138
1979	581	26	15	0.026
1980	345	0	0	0.000
1981	784	131	78	0.100
1982	564	66	40	0.070
1983	545	12	7	0.013
1984	900	212	127	0.141
1985	687	65	39	0.057
1986	524	35	21	0.040
2001	684	153	92	0.134
2002	461	55	33	0.072
2003	526	2	1	0.002
2004	654	2	1	0.002
2005	369	10	6	0.016
2006	345	7	4	0.012
2007	954	193	116	0.121
2008	684	109	65	0.096
2009	469	17	10	0.022
2010	453	10	6	0.014
2011	910	132	79	0.087
2012	300	84	50	0.167
Mean	**623**	**123**	**73**	**0.108**

[a] Based on rainfall for the Broke (Harrowby) Station which has been adopted as representative of rainfall over the Wollombi Brook catchment.

An analysis of flow data for Wollombi Brook at the Bulga and Warkworth stream gauges indicates that a loss of flow is sometimes observed along the reach of Wollombi Brook adjacent to MTW, despite an additional catchment area of 176km^2 between the two stations. The magnitude of flow losses is difficult to quantify due to the potentially large impact of inaccuracies in the rating curves at both stream gauges. Since the accuracy of flow rating curves typically decreases as flow rate increases, periods that include moderate to high flows can sometimes indicate a large loss of flow which may be an artefact of the site rating curves rather than an actual loss of flow. For this reason, estimates of flow losses were made for periods that excluded high flows.

Table 2.4 shows the minimum, mean and maximum loss of monthly flow between the two stations. Results are shown for three cases, which each exclude flows above a threshold mean monthly flow. Note that months that showed an increase in flow were assigned a flow loss of zero. The analysis is based on 489 months from 1954 to 2013 over which corresponding flow data was available for both the Bulga and Warkworth stations.

The results of the low flow analysis, summarised in Table 2.4, show that the estimated loss of flow is sensitive to the adopted threshold of high flows that are excluded from the analysis. However, it is apparent that a measureable loss of flow from Wollombi Brook, perhaps of the order of 10 to 50ML per month, occurs adjacent to MTW under existing conditions.

Given the significant surface and groundwater entitlements in the area, some loss of flow along this reach is not unexpected. However, due to the large number of potential locations for extraction of flow, it is not possible to accurately determine where the flow loss is occurring.

Table 2.4 Assessment of Low Flow Losses, Wollombi Brook

	Flow Loss, Bulga to Warkworth (ML/month)		
Adopted Threshold Mean Monthly Flow [a]	**Minimum**	**Mean**	**Maximum**
30th percentile = 90 ML/d (2,740 ML/m)	0	70	1725
50th percentile = 29 ML/d (882 ML/m)	0	16	733
70th percentile = 6 ML/d (183 ML/m) b	0	3	156

[a] Months with mean monthly flow above the threshold value were not included in the analysis

2.5 EXISTING MINE WATER MANAGEMENT SYSTEM

The MTW water management system is a network of infrastructure (ie dams, pipelines, contour drains) to control the movement of water around the site and prevent unscheduled release of water off site. Water is managed according to its type. Water type is determined by catchment area, quality and use. The main types of water managed at MTW include mine water , sediment water and clean water.

Figure 2.8 shows the main elements of the water management system. Figure 2.9 shows a schematic diagram of the conceptual configuration of the existing mine water management system. The existing MTW mine water management system is described in detail in MTW's Water Management Plan (Coal & Allied, 2012).

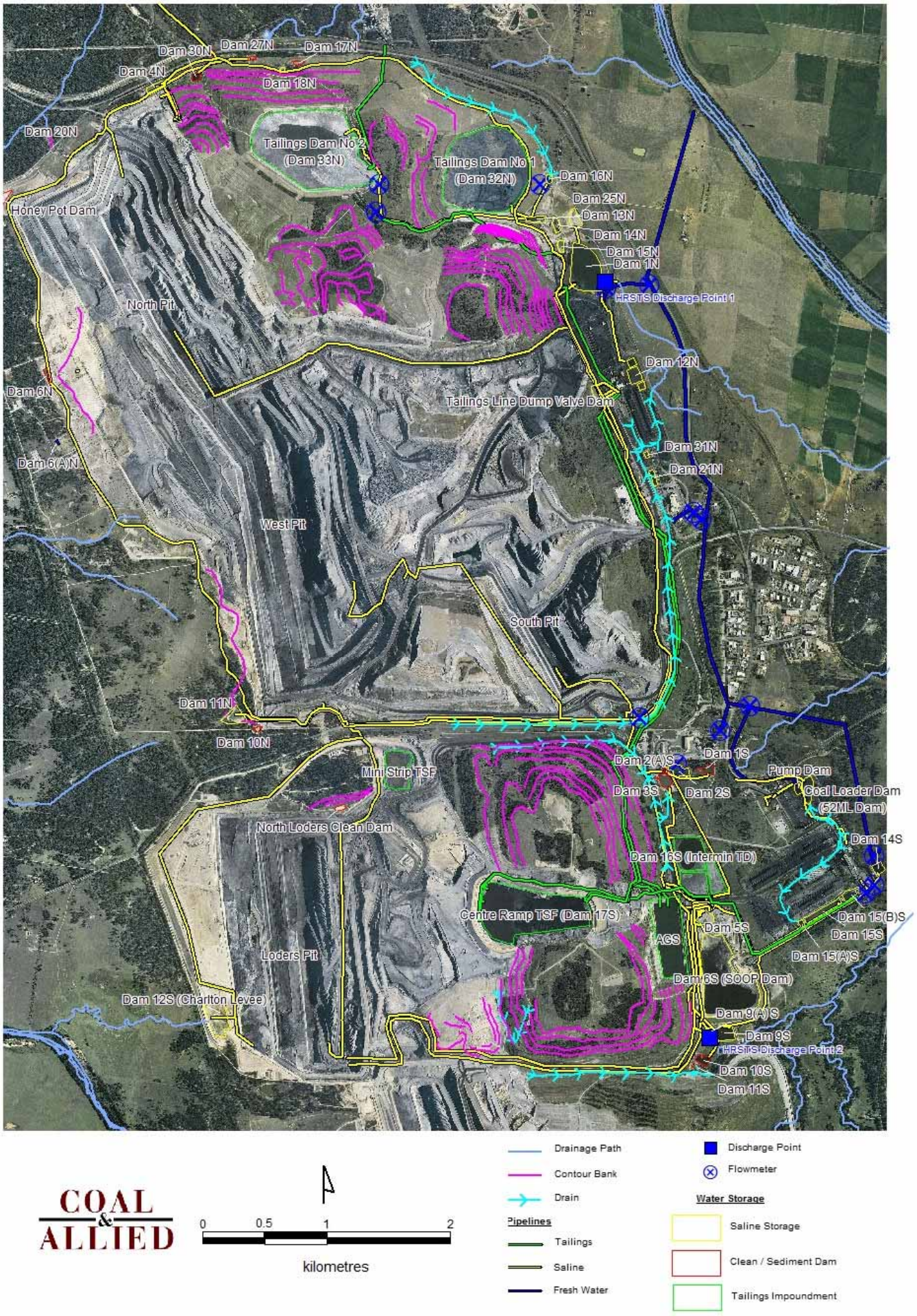


Figure 2.8 MTW Water Management System Infrastructure - Existing

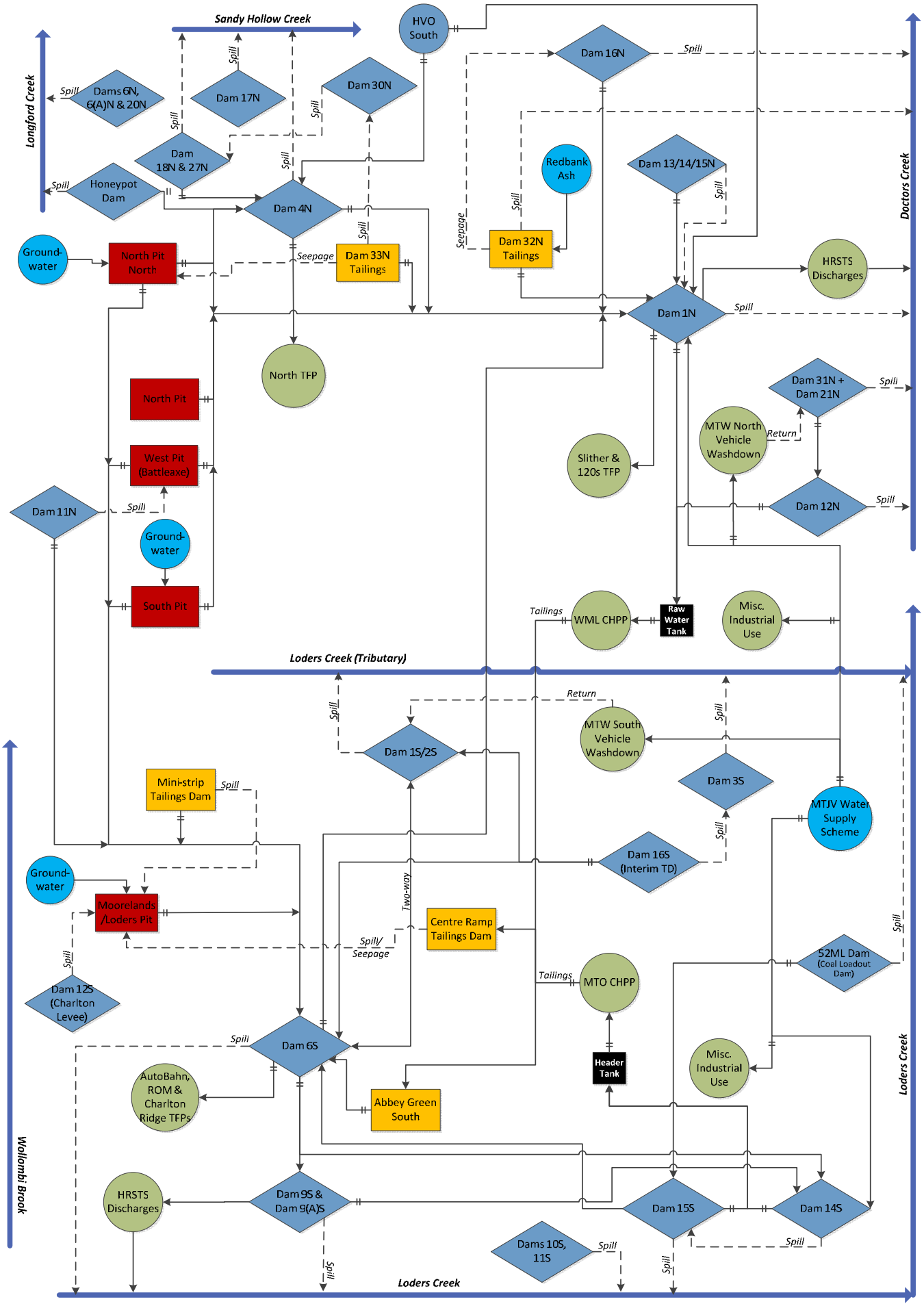


Figure 2.9 MTW Water Management System Schematic - Existing

2.6 SURFACE WATER QUALITY

2.6.1 New South Wales Office of Water (NOW) Monitoring

Hunter River water quality data has been collected by NOW since the 1970s. Discrete data collected in the Hunter River at Singleton (#210001) and Wollombi Brook at Warkworth (#210004) is summarised in Table 2.5 and compared to the trigger values in the Australia and New Zealand Environment Conservation Council (ANZECC) water quality guidelines (2000). Additionally, electrical conductivity (EC) has been monitored continuously at Wollombi Brook at Warkworth (#210004) since 1992, and Hunter River Upstream of Singleton (#210129) since 1993. Locations of the water quality gauging stations are shown in Figure 2.4. Note that the trigger value for mercury (ecosystem protection) is less than the Limit of Reporting; therefore it cannot be determined if the mercury values measured are higher or lower than the ANZECC trigger value for ecosystem protection.

Review of the NOW water quality data indicates the Hunter River:

- Is moderately alkaline, with a median pH of 8.24;
- Is fresh, with a median EC of 621µS/cm;
- Has a median value greater than the ANZECC guideline trigger value for pH (ecosystem protection), total nitrogen (ecosystem protection) and total phosphorus (ecosystem protection); and
- Has a median value lower than the ANZECC guideline trigger value for all other monitored parameters.

Review of the NOW water quality data indicates Wollombi Brook:

- Is slightly alkaline, with a median pH of 7.56;
- Is fresh, with a median EC of 595µS/cm;
- Has a median value greater than the ANZECC guideline trigger values for chloride (irrigation) and sodium (irrigation); and
- Has a median value lower than the ANZECC guideline trigger value for all other monitored parameters.

2.6.2 Coal & Allied Monitoring

Receiving Waters

Controlled discharges from Dam 1N and Dam 9S are directed to Doctors Creek and Loders Creek respectively, which are tributaries of the Hunter River. Runoff from undisturbed areas and small areas of disturbed catchment is treated via sediment dams on the site. Overflows from these sediment dams discharge to Wollombi Brook and Longford Creek (a tributary of Wollombi Brook), as well as Sandy Hollow Creek, Loders Creek and Doctors Creek (which are tributaries of the Hunter River). A tabular summary of the MTW surface water quality monitoring data for watercourses is detailed in Appendix A. Sampling locations are shown in Figure 2.10. Review of the site water quality monitoring results for receiving waters indicates:

- The Hunter River upstream of the Loders Creek confluence has a median EC of 645µS/cm and a median pH of 8.0. The Hunter River downstream of the Loders Creek confluence has a median EC of 630µS/cm and a median pH of 8.1.

- Loders Creek (water quality impacted by controlled discharges under the HRSTS) has a median EC of approximately 4,200µS/cm and a median pH of 8.1. Pre-mining water quality data (BHP Ltd, 1980) at Loders Creek indicated ECs varying between 2,000µS/cm and 14,200µS/cm, with an average of 7,100µS/cm. The salinity was attributed to seepage from the Saltwater Creek coal measures which sub-crop in areas of Loders Creek (MER, 2012).
- It is difficult to determine the Doctors Creek catchment runoff water quality characteristics, as the water quality is impacted by controlled discharges under the HRSTS. The water quality monitoring results indicate a median EC of 4,695µS/cm and a median pH of 8.2;
- Longford Creek has a median EC of 288µS/cm and a median pH of 7.4;
- Sandy Hollow Creek has a median EC of 270µS/cm and a median pH of 7.7;
- Wollombi Brook has a median EC of 680µS/cm and a median pH of 7.5; and
- Salt Pan Creek has a median EC of 16,810µS/cm and a median pH of 8.1.

Site Dams

The primary saline water storages at MTW (Dam 6S, Dam 1N and Dam 9S) are routinely monitored for EC, pH and turbidity. Additionally, a comprehensive analysis of water quality in a number of saline and sediment dams is undertaken on a quarterly basis. A tabular summary of the results of the MTW site water quality monitoring program for site dams is detailed in Appendix A. Locations of site dams are shown in Figure 2.8. Review of the site water quality monitoring results for the site dams indicates:

- The primary mine water storages at MTW (Dam 1N, Dam 6S and Dam 9S) are characterised as brackish and strongly alkaline, with median ECs of approximately 7,000µS/cm and median pH values of 8.7 to 9.0;
- Water quality of sediment dams varies considerably in salinity from fresh to brackish, with median ECs of between 300µS/cm and 8,400µS/cm. The sediment dams' water quality ranges from moderately alkaline to very strongly alkaline, with median pH values between 7.9 and 9.8.

2.6.3 Water Quality Monitoring Results Analysis

Box and whisker plots have been used to graphically depict water quality in the Hunter River to illustrate the spread of data at four locations:

- Upstream of Glennies Creek;
- Upstream of Loders Creek;
- Downstream of Loders Creek; and
- Upstream of Singleton.

Figure 2.11 and Figure 2.12 show box and whisker plots for EC and Total Suspended Solids (TSS) as measured in the Hunter River from both NOW and site monitoring locations over the period 2003 to 2013. Note that the monitoring frequency of samples by MTW and NOW are different (quarterly versus daily), and therefore results are not directly comparable and are to provide an indication only. Review of the results indicates that there is a slight decrease in EC downstream of the Loders Creek confluence. Additionally, the median EC downstream of Loders Creek is lower than upstream of Glennies Creek, indicating the releases from MTW do not appear to be adversely affecting salinity in the Hunter River. TSS levels increase slightly across the Loders Creek confluence.

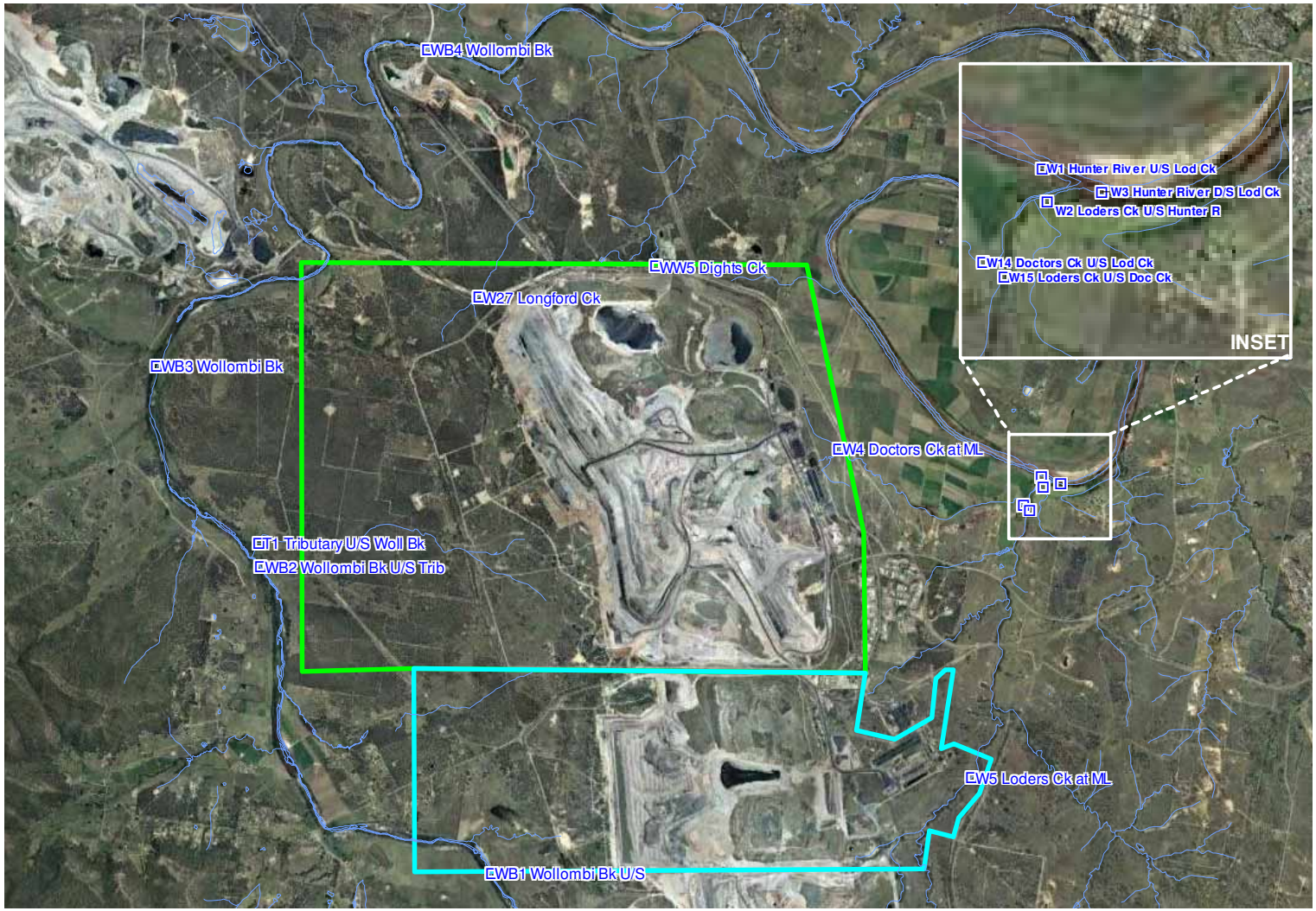


Figure 2.10 MTW Receiving Water Monitoring Locations

Table 2.5 Summary of Discrete NOW Water Quality Data - Hunter River at Singleton and Wollombi Brook at Warkworth (New South Wales Office of Water, 2011) and ANZECC Trigger Values

		ANZECC Trigger Value				Hunter River at Singleton			Wollombi Brook at Warkworth		
Parameter	**Unit**	**Irrigation**	**Livestock drinking**	**Eco-system^^**	**Recreational**	**90%ile**	**Median**	**Count**	**90%ile**	**Median**	**Count**
Aluminium as Al	mg/L	5 (LTV) 20 (STV)	5	0.055^^^^	0.2						
Arsenic as As	mg/L	0.1 (LTV) 2.0 (STV)	0.5	0.024 (As III) 0.013 (As V)	0.05						
Barium as Ba	mg/L				1						
Bicarbonate (HCO_3)	mg/L					275	221	70	232	513	9
Boron (Total)	mg/L	0.5	5	0.37	1	0.13	<LOR	38	0.13	<LOR	38
Calcium (Ca)	mg/L		1,000			50.0	37.0	70	26.0	19.9	9
Chloride as Cl	mg/L	175***			400	153	100	71	459	260	9
EC (uncompensated)	µS/cm	950***		125-2,200		820	621	687	1,172	595	64
EC (25C)	µS/cm					1,014	730	65	2,307	804	500
Iron as Fe (Soluble)	mg/L	0.2			0.3	0.121	0.004	8			
Iron as Fe (Total)	mg/L					0.711	0.035	52	0.83	0.25	6
Fluoride (Soluble)	mg/L	1 (LTV) 2 (STV)	2			0.52	0.22	39	0.39	0.39	1
Lead as Pb (Total)	mg/L	2 (LTV) 5 (STV)		0.0034		0.011	0.003	8	0.011	0.003	8
Lithium as Li	mg/L	2.5									
Magnesium as Mg	mg/L		2,000**			43.0	30.7	70	45.2	24.2	9
Manganese as Mn (Total)	mg/L	0.2 (LTV) 10 (STV)		1.9	0.1	0.155	0.057	10	0.155	0.057	10
Mercury as Hg (Total)	mg/L	0.002		0.0006		0.005	0.001	6			
Nitrite and nitrate as N	mg/L		30	0.7^^^	1	0.26	0.03	107	0.12	0.01	144
pH	pH	6.0 - 9.0		6.5 - 8^	6.5 - 8.5	8.51	8.24	483	8.08	7.56	276
Potassium as K (soluble)	mg/L					4.4	3.1	69	8.2	5.2	9
Selenium as Se (total)	mg/L	0.02 (LTV) 0.05 (STV)	0.02	0.011	0.01						
Silicon as Si	mg/L										
Sodium as Na (soluble)	mg/L	115***			300	100.3	71.6	70	265.4	171.6	9
Sulphate as SO_4	mg/L		1,000		400	80.0	38.2	70	53.8	29.0	9

		ANZECC Trigger Value				Hunter River at Singleton			Wollombi Brook at Warkworth		
Parameter	**Unit**	**Irrigation**	**Livestock drinking**	**Eco-system^^**	**Recreational**	**90%ile**	**Median**	**Count**	**90%ile**	**Median**	**Count**
Total Dissolved Solids (TDS)	mg/L		2,000*		1,000						
Total Nitrogen (Total N)	mg/L	5		0.5^		1.10	0.56	105	0.89	0.47	143
Total Phosphorus (Total P)	mg/L	0.05		0.05^		0.152	0.060	240	0.035	0.013	297
Total Suspended Solids (TSS)	mg/L					47	21	72	16	6	71
Turbidity	NTU										
Zinc as Zn (Total)	mg/L	2 (LTV) 5 (STV)	20	0.008	5	0.09	<LOR	23	0.09	<LOR	23

* Lowest recommended value.

** Cattle (insufficient information on other livestock).

*** Sensitive crops.

^ Lowland river (<150m altitude).

^^ 95 per cent of species protected.

^^^ Nitrate only.

^^^^ pH greater than 6.5.

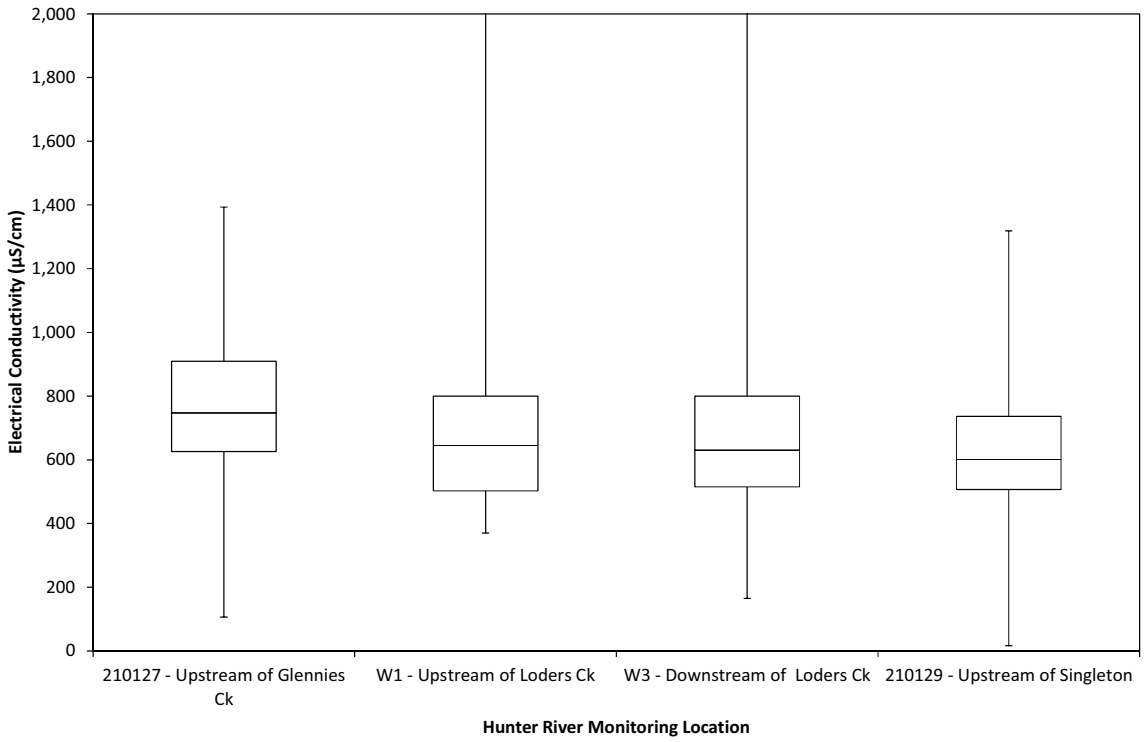


Figure 2.11 Hunter River EC Monitoring Data – Box and Whisker Plot

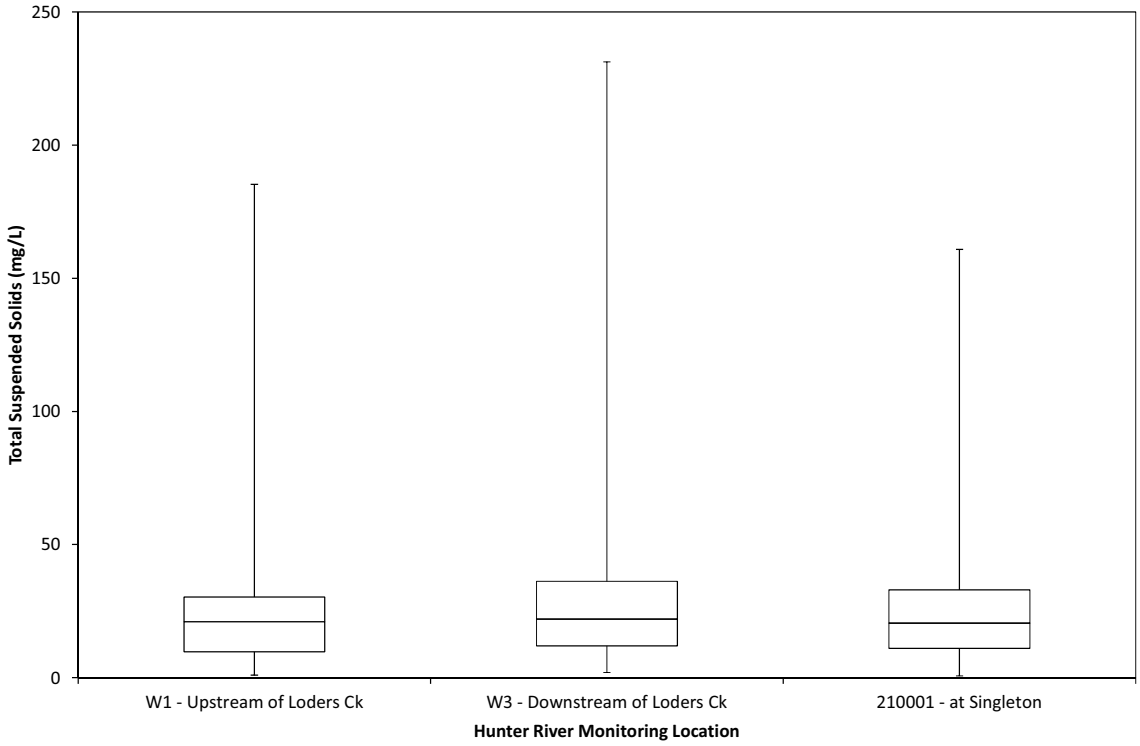


Figure 2.12 Hunter River TSS Monitoring Data – Box and Whisker Plot

3 RELEVANT LEGISLATION AND GUIDELINES

3.1 OVERVIEW

The following legislation, plans, policies and regulations are relevant to this assessment:

- *Protection of the Environment Operations Act 1997*;
- *Water Management Act 2000* and applicable Water Sharing Plans;
- State Water Management Outcomes Plan (SWMOP) and Hunter and Central Rivers Catchment Action Plan (CAP);
- Protection of the Environment Operations (Hunter River Salinity Trading Scheme) Regulation 2002; and
- National Water Quality Management Strategy: Australian Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) (refer Section 2.6).

The relevance of key legislation is briefly outlined in the following sections.

3.2 PROTECTION OF THE ENVIRONMENT OPERATIONS ACT 1997

Warkworth Mine and MTO are licensed under the *Protection of the Environment Operations Act 1997*. The existing licences (EPL 1976 for MTO and EPL 1376 for Warkworth Mine) make provision for release of water from the sites at Dam 1N and Dam 9S. Licence discharge limit conditions are the same for each EPL, as shown in Table 3.1.

Table 3.1 MTO & Warkworth Mine Discharge Conditions (EPL 1376 & 1976)

Pollutant	Unit	Limit
pH	pH units	Lower: 6.5 Upper: 9.0
Total suspended solids	mg/L	120
Volume	ML/d	100 (at each discharge location)

(NSW Government Office of Environment & Heritage, 2011)

3.3 WATER MANAGEMENT ACT 2000

3.3.1 Water Sharing Plans

The *Water Management Act 2000* applies to surface waters within the MTW area and the Hunter River itself through the following Water Sharing Plans:

1. **Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009.** Surface water in Wollombi Brook and its tributaries is regulated under this plan. Water volumes extracted from these catchments require a water entitlement (an unregulated river access licence). The plan limits annual extraction to provide for no new growth in water entitlements.
2. **Hunter Regulated River Water Sharing Plan 2003.** All water extractions from the Hunter River will be managed under appropriate Water Access Licences (WALs). MTW holds approximately 1,012 ML/a of high security units of Hunter River water shares under the MTJV Supply Scheme. Water will continue to be extracted from existing licences and therefore, there will be no cumulative impact on water supplies in the Hunter River catchments caused by the proposal.

3.4 STATE WATER MANAGEMENT OUTCOMES PLAN (SWMOP) AND HUNTER AND CENTRAL RIVERS CATCHMENT ACTION PLAN (CAP)

The SWMOP (established under the *Water Management Act 2000*) and CAP (established under the *Catchment Management Authorities Act 2003*) set out the broad targets and strategic directions for the state and for the catchment. Natural resources features to be protected and enhanced are identified, along with actions to achieve key outcomes. The proposal is consistent with the SWMOP and CAP objectives because:

- Surface disturbance is restricted to the area covered by the application (the Site). Impacts will be mitigated within MTW's water management system described in Section 3. Erosion and sediment controls for the proposal will be designed and operated in accordance with 'Managing urban stormwater: soils and construction' requirements (Landcom, 2004);
- Any extraction of water will be in accordance with licensing provisions; and
- Discharges under the proposal will only occur in accordance with the site EPL and where applicable, the Hunter River Salinity Trading Scheme (HRSTS).

3.5 PROTECTION OF THE ENVIRONMENT OPERATIONS (HUNTER RIVER SALINITY TRADING SCHEME) REGULATION 2002

The HRSTS was introduced by the NSW Government to reduce salinity levels in the Hunter River, and operates under the Protection of the Environment Operations (Hunter River Salinity Trading Scheme) Regulation 2002.

Releases of mine water to the Hunter River can be made in compliance with the conditions of an EPL and in accordance with credits purchased under the HRSTS. The HRSTS limits the quantity of salt that may be discharged through a cap and trade system that also restricts discharge to periods of high flow.

Under the HRSTS, credit holders are permitted to discharge saline water to the Hunter River on a managed basis. The aim is to maintain river salinity levels below 600µS/cm at Denman and 900µS/cm at Singleton. This is achieved through:

- Discharge scheduling that allows discharge only at times when the river flow and salinity level are such that salt can be discharged without breaching the salinity targets; and
- Sharing the allowable discharge according to licensed holdings of tradeable salinity credits.

The discharge schedule prohibits discharges during low flow periods. Discharges are regulated in proportion to credit holdings during high flow periods and unlimited discharges are permitted during flood flow periods, subject to tributary protection limits and the overarching requirement to achieve the upper limit salinity levels at Denman and Singleton.

A total of 1,000 credits are available for allocation through the scheme. Consequently, a holding of one credit entitles the owner to discharge 0.1 per cent of the total allowable discharge for the period.

If discharge of further excess water to the Hunter River system is required, under the scheme, credits may be obtained on a day to day basis through trade between licensed users, or, for long term use, through public auction.

Under the HRSTS, the Hunter River is separated into three sectors upstream of Singleton: Upper, Middle and Lower. MTW lies in the Lower Sector (downstream of Glennies Creek confluence). The HRSTS flow and river salinity thresholds for the Lower Sector are presented in Table 3.2.

Table 3.2 HRSTS Flow & River Salinity Thresholds, Lower Sector

Hunter River Flow Rate (ML/d)	Block Classification	River Target Salinity (EC)	Discharge Procedure
<2,000	Low	n/a	No discharges allowed
2,000 – 10,000	High	900µS/cm	Limited discharges allowed, controlled by salt credits and Total Allowable Discharge (TAD)
>10,000	Flood	900µS/cm	Unlimited discharges

(Protection of the Environment Operations (Hunter River Salinity Trading Scheme) Regulation 2002)

The water in the river is divided into numbered blocks. The scheme operators monitor the flow and salinity in each block, and calculate the Total Allowable Discharge (TAD) of salt to meet the salinity target. Credit holders are notified via a dedicated website of the TAD and the start and end times for each release.

MTW is currently a Licence Holder and Scheme Participant of the HRSTS. Warkworth Mine currently hold 68 credits and MTO holds 78 credits, totalling 146 credits, which entitles MTW to discharge 14.6 percent of the TAD for a given period.

4 IMPACT ASSESSMENT

4.1 OVERVIEW

The potential changes to surface water and water management during the life of the proposal that have been investigated in the following sections comprise:

- Additional water demand from external third party sources (ie neighbouring mines or the Hunter River) to meet increased operational water requirements for the proposal;
- Loss of catchment area draining to Wollombi Brook and the Hunter River due to capture of runoff within onsite storages during mining. This could potentially reduce runoff volumes to Wollombi Brook and the Hunter River;
- Change in the quality of surface runoff draining from the local site catchment to Wollombi Brook and the Hunter River;
- Adverse impacts on downstream water quality associated with possible overflows from the mine water management system;
- Increase in saline water controlled discharges (HRSTS); and
- Interference with flood flows along Wollombi Brook and the Hunter River associated with changes in the respective flood plains.

4.2 MINE SITE WATER REQUIREMENTS

A significant proportion of mine site water requirements will be sourced from water collected on the site, including rainfall runoff and groundwater inflows to the open cut pits (Year 0 and Year 3) which will be transferred to the mine water management system for recycling.

The results of the water balance modelling (see Section 6.6) show that external water may be required to meet all site demands. Total external water requirements are characterised as:

- A minimum of 140ML/a of external raw water (from the Hunter River) will be required for the life of the proposal. This is consistent with site demands of industrial use and vehicle wash of around 140ML/a which are supplied from raw water sources only;
- There is a 90 per cent chance that at least 450ML of external water will be required in any year of project life.
- A step change in external water requirement occurs in around Year 2 which is consistent with the decrease in pit inflows at MTO, and an increase in production at Warkworth Mine. External water requirement from Year 3 to Year 21 is generally consistent with:
  - A 50 per cent chance that between 1,500ML/a to 2,000ML/a of external water will be required; and
  - A 10 per cent chance that between 3,000ML/a to 3,700ML/a of external water will be required.

MTW has identified the following possible sources of additional water for the proposal, which will be negotiated on an as-needed basis when mutually beneficial:

- Water sharing with Hunter Valley Operations (directly to the north of Warkworth Mine). This strategy has been successfully adopted in the past;
- Water sharing with Bulga Coal Complex (directly to the south of MTO); and
- Water sharing with Wambo Mine.

If required, additional water licences would be sought and purchased by Coal & Allied over the life of the project to meet external water demands. As all off-site water supplies for the project would be obtained from licensed sources, there will be no adverse impact on other licensed users who will still have access to their entitlement (subject to climatic conditions and the operation of the water supply scheme).

4.3 LOSS OF CATCHMENT AREA

During active mining operations, the mine water management system will capture runoff from areas that would have previously flowed to Wollombi Brook or the Hunter River. The indicative mine plans are shown in Figure 6.4 to Figure 6.11 for Years 3 to 21. A breakdown of the catchment areas reporting to the mine storages is provided in Appendix B.

Table 4.1 shows the total catchment area captured within the MTW mine water management system over the life of the proposal, including sediment dam areas. The maximum captured Wollombi Brook area of 10.5km^2 occurs during Year 14 to Year 22 of the proposal, representing 0.56 per cent of the Wollombi Brook catchment to the confluence of the Hunter River. Note that although the catchment area of sediment dams is included in the catchment loss calculations, these sediment dams may overflow to Wollombi Brook during periods of rainfall, reducing the volume of water lost from the downstream catchment. Refer to Section 4.6.2 for further information on the Hunter River flow volume.

Table 4.1 also shows the catchment area captured in the final landform (including the South Pit void). The final landform restored the Hunter River catchment area (excluding the Wollombi Brook catchment) to 99.96 per cent of its pre-mining catchment area. The final landform captures 8.6km^2 or 0.44 per cent of the Wollombi Brook catchment to the confluence of the Hunter River.

Table 4.1 Receiving Waters Catchment Area during and after MTW Mining Operations

Mine Stage	Wollombi Brook to Hunter River confluence		Hunter River (excluding Wollombi Brook) to Singleton	
	Area (km²)	Proportion of Pre-mining Area (%)	Area (km²)	Proportion of Pre-mining Area (%)
Pre-Mining	1,888	100%	16,400	100%
Existing (2013)	1,885	99.84%	16,371	99.82%
Proposal				
Year 0	1,885	99.84%	16,371	99.82%
Year 3	1,881	99.79%	16,368	99.81%
Year 9	1,878	99.60%	16,368	99.81%
Year 14	1,878	99.44%	16,368	99.81%
Year 21	1,878	99.44%	16,368	99.81%
Final Landform	1,879	99.54%	16,394*	99.96%

Notes: * Includes South Pit final void.

4.4 SURFACE WATER QUALITY

The MTW water management plan has the following key objectives in relation to surface water quality of receiving waters:

- Preferential re-use of poor quality mine water in preference to clean water;
- Minimise the use of fresh water; and
- Protect clean water systems.

Potential impacts on surface water quality in the receiving waters will be managed by implementation of the following measures:

- MTW site water management system (detailed in Section 6.5);
- Compliance with HRSTS discharge limits (detailed in Section 6.5.8);
- Sediment and Erosion Control Plan (detailed in Section 7.3); and
- Surface water monitoring program (detailed in Section 7.5).

The results of the water balance modelling show that no uncontrolled release of saline water occurs over the life of the proposal. Excess saline water is released in accordance with the existing rules of the HRSTS. Downstream impacts on surface water quality as salinity will be in accordance with the acceptable limits under the HRSTS. Refer to Section 4.6.4 for impacts on other water quality parameters.

4.5 UNCONTROLLED OFFSITE RELEASES

The results of the water balance modelling indicate that under the current model assumptions and configuration, there is a low risk of the MTW water management system accumulating water over the 21 year project life. The results show that the system recovers well after each wet

season. The model results show no uncontrolled spills of saline water from the saline water storages.

Overflows of water from sediment dams will occur during wet periods that exceed the design standard of the sediment control system (as per the design intent). Monitoring of sediment dams' water quality will continue, as described in Section 7.5.

4.6 IMPACTS OF CONTROLLED RELEASES UNDER HRSTS

4.6.1 Overview

MTW is a current participant of the HRSTS, which provides the opportunity to discharge saline water without exceeding salt concentration limits in the Hunter River. Further details of the HRSTS are provided in Section 3.5. Under the proposal, MTW will continue to be a Scheme participant. Controlled discharges are currently made from Dam 9S at MTO, and Dam 1N at Warkworth Mine. The proposal seeks an increase in the maximum release rate at MTO to 300ML/d (currently 100ML/d); however, the release rate of Warkworth Mine will remain unchanged. The water balance has modelled a discharge rate of 200ML/d at MTO, to be conservative with regards to mine water containment performance.

Figure 4.1 and Figure 4.2 show the simulated annual controlled discharges to the Hunter River under the HRSTS from MTO and Warkworth Mine, respectively. Review of the results shows that:

- Overall, much greater volumes are discharged from MTO than Warkworth Mine, which is consistent with the capacity of the discharge structures (200ML/d at MTO and 100ML/d at Warkworth Mine) and dam volumes;
- There is a 50 per cent chance of controlled releases from MTO will not be required in any year of the life of the proposal, and small volumes of controlled discharges (100ML) will be required from Warkworth Mine in any year of the life of the proposal; and
- There is a 10 per cent chance of controlled releases from MTO of between 1,000ML to 2,000ML will be required in any year of the life of the proposal, and around 400ML from Warkworth Mine in any year of the life of the proposal.

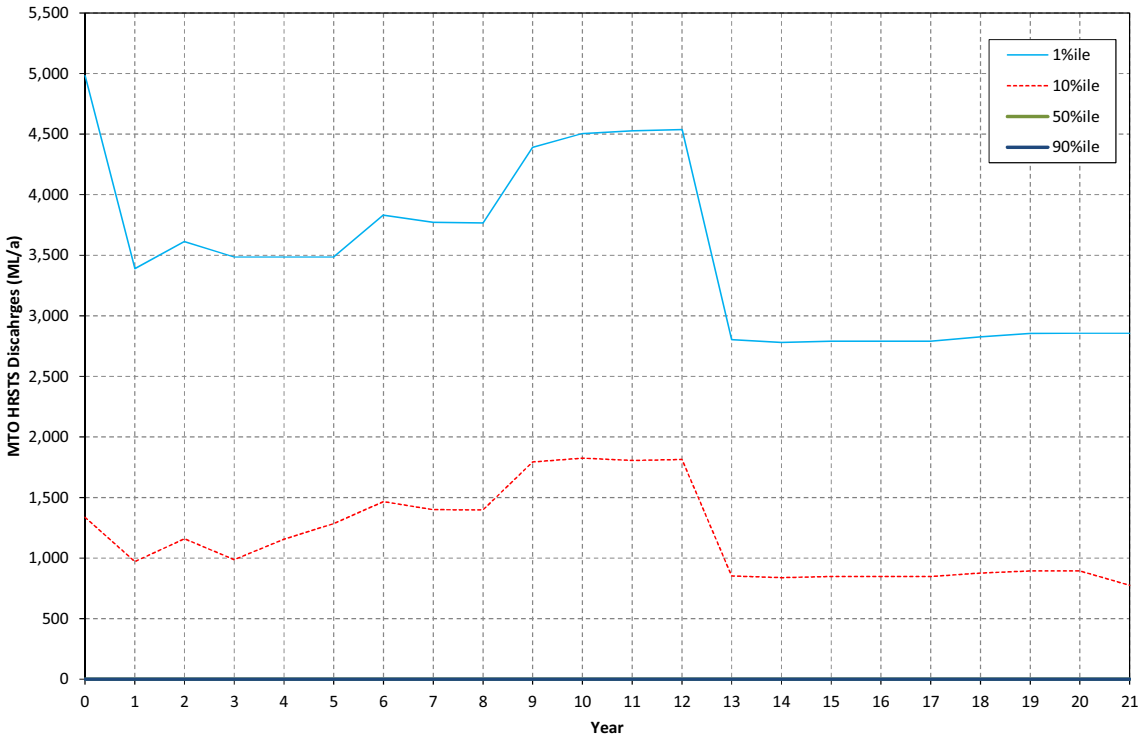


Figure 4.1 MTO Discharges to Hunter River

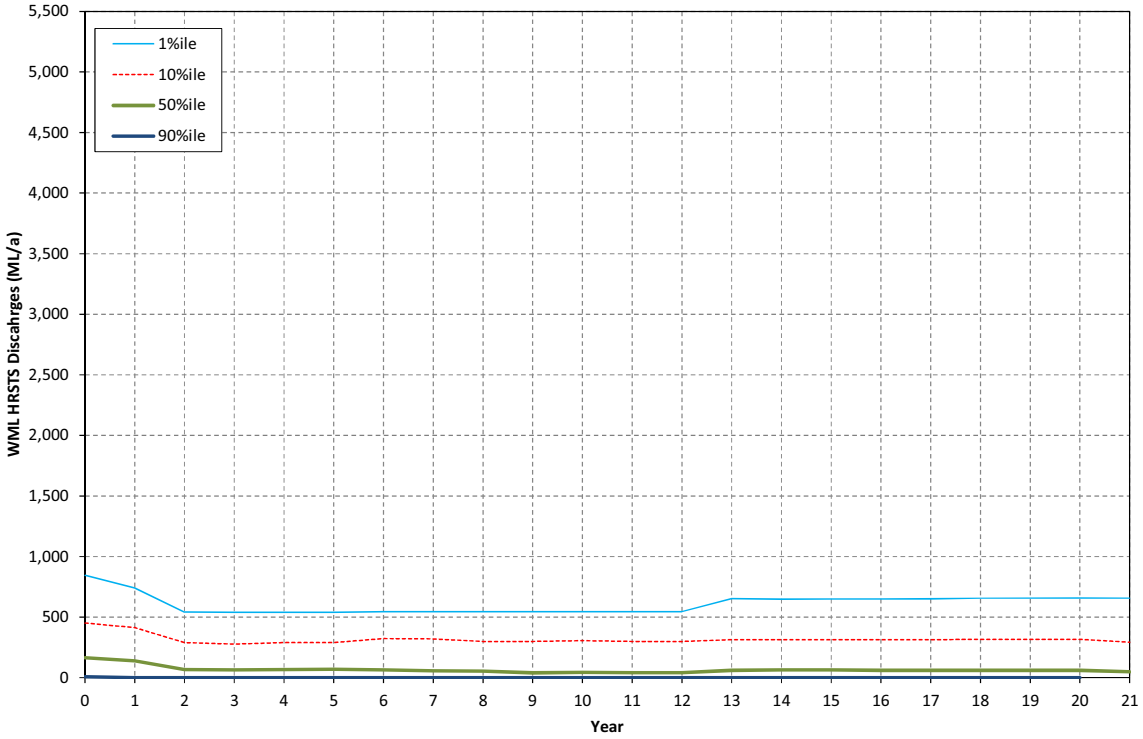


Figure 4.2 Warkworth Mine Discharges to Hunter River

Controlled releases of saline water under the HRSTS have the following potential impacts:

- Impacts on the total flow volume in the Hunter River;
- Impacts on stream condition, including bank erosion; and
- Water quality impacts.

These potential impacts are discussed in the following sections.

4.6.2 Hunter River Flow Volume

Table 4.2 shows the net impact of the MTW water management system on Hunter River flow volumes over the life of the proposal. The median runoff captured in the system is based on the captured catchment areas (see Appendix B), and the harvestable rights runoff coefficient (0.07ML/ha). The simulated median controlled discharges (HRSTS) and simulated median sediment dam overflows to the Hunter River are used to estimate the median net reduction in runoff in the Hunter River. The HRSTS discharges and sediment dam overflows offset the reduction in Hunter River flows caused by the loss of catchment area. The results show that the median annual reduction in flows to the Hunter River varies between 16 and 75ML/a during the life of the proposal, and the median annual reduction is 104ML/a post-mining. This is approximately 0.02 per cent of the median annual Hunter River discharge to Singleton (estimated from NOW's IQQM model - full development case with 2004 water sharing plan rules).

Table 4.2 Net Impact of Mine Water Management System on Hunter River Flow Volumes over Project Life

Mine Stage	Median Runoff Captured (ML/a)	Median Discharge to Hunter River (ML/a)	Median Sedimentation Dam Overflows (off-site)	Median Net Runoff Reduction (ML/a)
Year 0 (existing)	225	181	25	19
Year 3	215	81	118	16
Year 9	231	40	116	75
Year 14	246	66	151	29
Year 21	243	48	154	41
Post-Mining	104	0	0	104

Figure 4.3 shows the impact of MTW HRSTS discharges on the Hunter River flow characteristics (IQQM simulated). Flow characteristics are shown for the wettest and driest realisations (defined by the total flow in the Hunter River over the simulated 22 year period of the life of the proposal), for scenarios both with and without MTW HRSTS discharges. Note that under the rules of the HRSTS, discharges only occur when flows in the Hunter River are greater than 2,000ML/d, and a maximum total discharge rate from MTW of 300ML/d has been simulated. Results show that the impacts of HRSTS discharges on the Hunter River flow characteristics are negligible during both wet periods and dry periods.

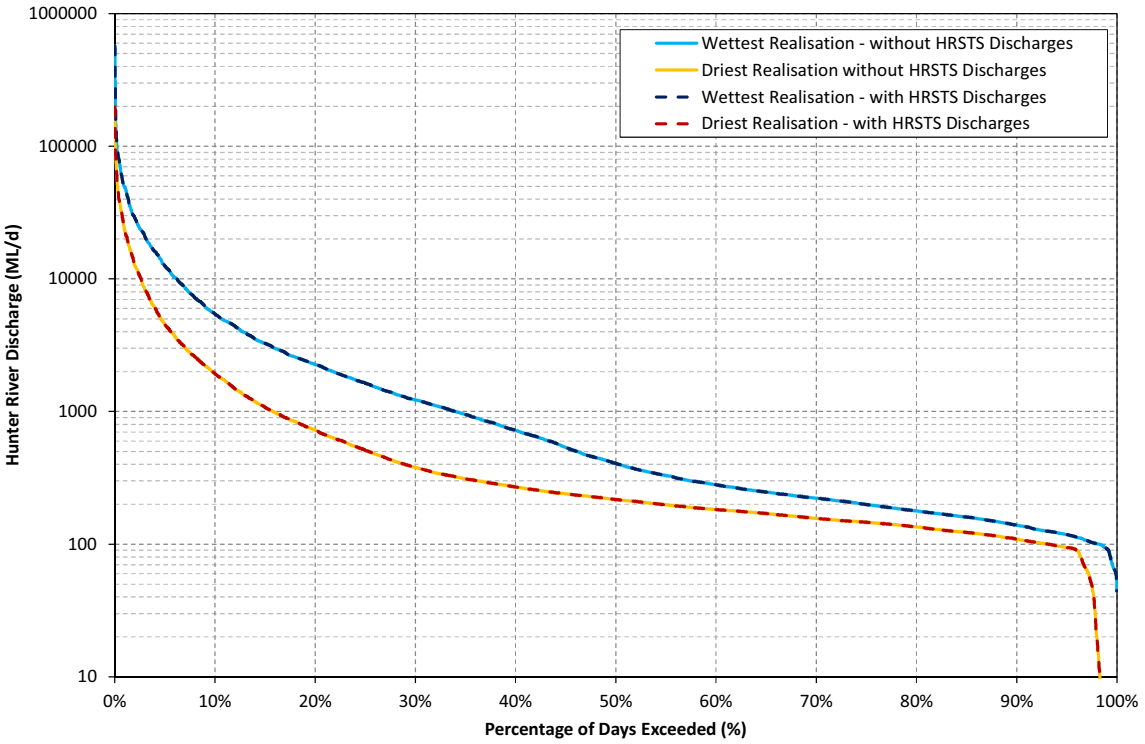


Figure 4.3 Hunter River Discharges (IQQM Simulated) Flow Characteristics – Impact of MTW HRSTS Discharges

4.6.3 Stream Condition

The proposed flow rate of the controlled discharge will be less than 300ML/d (3,500L/s) from Dam 9S to Loders Creek (increased rate of discharge from current approval), and less than 100ML/d (1,160L/s) from Dam 1N to Doctors Creek (no change to approved rate of discharge). It is possible that controlled discharges may occur at times when there is no natural flow in Loders Creek or Doctors Creek. Note that current MTW operations have discharged flows of this magnitude to Doctors Creek in the past when required and it is not expected that discharges under the proposal will have an additional impact on the stream condition of Doctors Creek to that already experienced under the current operations.

The mine directly adjacent to MTO to the south (Bulga Coal Mine (BCM)) is also currently seeking approval for an increased controlled discharge rate to Loders Creek. The Bulga Optimisation Project (Umwelt, 2014) has estimated a maximum sustainable discharge to the Loders Creek system with considerations of potential cumulative impacts of discharges from both MTO and BCM. The results of the analysis are summarised as:

- There is one area of erosion risk identified in Loders Creek downstream of MTO discharges;
- Hydraulic analysis indicates that limited the peak discharge rate to 60 per cent of the bank full capacity will most likely ensure a low risk of erosion during discharges;
- Bank full capacity in Loders Creek upstream and downstream of the Northern Dam tributary (a dam proposed in the BOP) is 23.6m^3/s and 43.4m^3/s, respectively. Therefore the maximum discharge at 60% of the bank full capacity is 14.2m^3/s (1,200ML/d) and 26.0m^3/s (2,250ML/d), respectively.

- Due to the locations of the discharge points at BCM, the BCM discharge rates are limited by the upstream creek capacities. The BCM proposed discharge rates are therefore much less than the 60% bank full flows for the downstream reaches of Loders Creek.
- The BCM proposed maximum discharge rate upstream of the Northern Dam tributary is 300ML/d; and 800ML/d downstream of the Northern Dam tributary.

The MTO and BCM combined maximum discharges rates of 600ML/d upstream of the Northern Dam tributary and 1,100ML/d downstream of the Northern Dam tributary are significantly less than the 60% bank full capacity of Loders Creek. Therefore it is considered that there is a low potential risk of erosion during discharges in Loders Creek downstream of the MTO discharge location.

As specified under the rules of the HRSTS, controlled discharges may only occur when the 'high' or 'flood' flow block is passing MTW. Therefore, controlled releases from the proposal will only occur when the Hunter River is in an increased state of flow (at least 2,000ML/d). Based on the comparatively low controlled discharge rate, it is not expected that controlled discharges would result in adverse hydraulic impacts on the Hunter River, such as increased bed and bank erosion.

4.6.4 Water Quality Impacts

Discharges under the HRSTS are controlled so that the salt concentration in the Hunter River Lower Sector (downstream of Glennies Creek confluence) does not exceed 900µS/cm. An important component of meeting the salinity goal is to discharge the salt load evenly throughout the discharge period to avoid short periods of elevated salinity in the Hunter River (DECCW, 2010).

Controlled discharges from the proposal will continue to be released in accordance with HRSTS and EPL 1376 and 1976 requirements.

Table 4.3 shows a comparison of site and NOW water quality monitoring data in the Hunter River in the vicinity of MTW, with ANZECC (2000) guideline trigger values and site water quality monitoring at the discharge dams. The comparison shows:

- Discharge dam water quality (median) is better than Hunter River water quality and the lowest recommended ANZECC guidelines trigger value for the following parameters:
  - Manganese, selenium, phosphorus (total) and zinc.
- Discharge dam water quality (median) is better than the lowest recommended ANZECC trigger value, but worse than the Hunter River water quality for the following parameters:
  - Arsenic, boron, barium, calcium, calcium carbonate, iron (filtered), potassium, lithium, magnesium, rubidium, and strontium.
- Discharge dam water quality (median) is poorer than the lowest recommended ANZECC trigger value but better than the Hunter River water quality for the following parameter:
  - Aluminium.
- Discharge dam water quality (median) is poorer than the lowest recommended ANZECC trigger value and the Hunter River water quality for the following parameters:
  - Chloride, sodium and sulphate.

It is likely that the elevated sodium and chloride concentrations are the main salt component of the salts generated on site, discharges of which are controlled by the HRSTS. The ANZECC guideline trigger value of 115mg/L for sodium and 175mg/L for chloride applies to irrigation of

sensitive crops. A trigger value of 300mg/L for sodium and 400mg/L for chloride applies for recreational use. There are no sodium or chloride trigger values for livestock drinking or ecosystem protection.

The median sulphate levels in the discharge dams exceed the ANZECC guideline trigger value for recreational use (400mg/L), and are equal to the ANZECC guideline trigger value for livestock drinking use (1,000mg/L).

As controlled discharges occur during high flow events in the Hunter River, significant dilution of discharges is expected. The 'worst case' dilution ratio for MTW discharges to Hunter River flows is 1:5 (400ML/day discharge rate to 2,000ML/day minimum flow required in the Hunter River flow for discharge under HRSTS). In the immediate vicinity of the Loders Creek confluence with the Hunter River, inside a mixing zone, contaminant concentration will be elevated compared to adjacent areas. However, secondary velocity currents induced by the nearby channel bends and turbulence induced by the riparian vegetation will promote mixing of the discharge water with the Hunter River flow. It is therefore likely that complete mixing of the discharge water with the river flow will occur within a few hundred metres of the outlet.

Table 4.3 Water Quality - Hunter River and MTW Discharge Dams

Water Quality Parameter		ANZECC (2000)	Hunter River		Discharge Dam	
		Trigger Value (Lowest)	W1 – U/S Loders Ck (Site monitoring)	At Singleton (NOW monitoring)	Dam 1N	Dam 9S
Al - Total (mg/l)	10%ile	0.055	0.33	-	0.09	0.26
	Median	(Ecosystem)	0.52	-	0.16	0.38
	90%ile		5.73	-	10.06	0.71
	N		5	-	5	9
As - Total (mg/l)	10%ile	0.013	0.001	-	0.001	0.002
	Median	(Ecosystem)	0.001	-	0.013	0.007
	90%ile		0.001	-	0.017	0.025
	N		10	-	10	13
B (mg/l)	10%ile	0.37	0.00		0.06	0.08
	Median	(Ecosystem)	0.04	<LOR	0.08	0.10
	90%ile		0.05	0.13	0.11	0.12
	N		9	38	10	13
Ba (mg/l)	10%ile	1	0.022	-	0.015	0.027
	Median	(Recreational)	0.031	-	0.033	0.051
	90%ile		0.085	-	0.114	0.085
	N		9	-	9	12
Ca - Total (mg/l)	10%ile	1,000	27		15	7
	Median	(Livestock	39	37.0	40	13
	90%ile	drinking)	44	50.0	50	17
	N		7	70	18	8
$CaCO_3$ - Total Hard (mg/l)	10%ile		77	-	502	200
	Median		163	-	590	200
	90%ile		249	-	848	200
	N		2	-	13	1
Cl- (mg/l)	10%ile	175	132		-	856
	Median	(Irrigation)	136	100	-	946
	90%ile		140	153	-	964
	N		2	71	0	3

Water Quality Parameter		ANZECC (2000)	Hunter River		Discharge Dam	
		Trigger Value (Lowest)	W1 – U/S Loders Ck (Site monitoring)	At Singleton (NOW monitoring)	Dam 1N	Dam 9S
Fe - Filtered (mg/L)	10%ile	0.2	0.03		0.02	0.01
	Median	(Irrigation)	0.12	0.004	0.05	0.01
	90%ile		0.21	0.121	0.09	0.01
	N		3	8	4	1
K - Total (mg/l)	10%ile	-	3		23	27
	Median		4	3.1	36	30
	90%ile		4	4.4	44	34
	N		7	69	5	8
Li (mg/l)	10%ile	2.5	0.002	-	0.131	0.197
	Median	(Irrigation)	0.005	-	0.275	0.212
	90%ile		0.030	-	0.358	0.294
	N		5	-	5	9
Mg - Total (mg/l)	10%ile	2,000	23		25	13
	Median	(Livestock	28	30.7	36	19
	90%ile	drinking)	35	43.0	67	25
	N		7	70	6	9
Mn - Total (mg/l)	10%ile	0.1	0.056		0.004	0.005
	Median	(Recreational)	0.110	0.057	0.008	0.011
	90%ile		0.352	0.155	0.046	0.030
	N		9	10	9	12
Na - Total (mg/l)	10%ile	115	42	-	1,306	1,720
	Median	(Irrigation)	73	-	1,800	1,860
	90%ile		80	-	1,900	2,197
	N		7	-	5	8
P - Total (mg/l)	10%ile	0.05	0.06		0.01	0.01
	Median	(Irrigation &	0.09	0.060	0.02	0.02
	90%ile	Ecosystem)	2.35	0.152	0.48	0.03
	N		6	240	6	9
Rb - Total (mg/l)	10%ile	-	0.001	-	0.043	0.048
	Median		0.002	-	0.061	0.055
	90%ile		0.004	-	0.063	0.060
	N		5	-	5	9
Se (mg/l)	10%ile	0.01	0.00	-	0.00	0.00
	Median	(Recreational)	0.00	-	0.01	0.01
	90%ile		0.05	-	0.01	0.01
	N		9	-	10	13
Si (mg/l)	10%ile	-	3.01	-	5.62	5.30
	Median		12.20	-	6.25	6.40
	90%ile		14.82	-	7.65	9.24
	N		4	-	4	5
SO_4 - Total (mg/l)	10%ile	400	26		444	730
	Median	(Recreational)	34	38.2	1,011	939
	90%ile		145	80.0	1,304	1,290
	N		8	70	10	11

Water Quality Parameter		ANZECC (2000)	Hunter River		Discharge Dam	
		Trigger Value (Lowest)	W1 – U/S Loders Ck (Site monitoring)	At Singleton (NOW monitoring)	Dam 1N	Dam 9S
Sr - Total (mg/l)	10%ile	-	0.125	-	0.316	0.382
	Median		0.380	-	0.640	0.648
	90%ile		0.490	-	0.833	0.882
	N		5	-	5	9
Zn - Total (mg/l)	10%ile	0.008 (Ecosystem)	0.005		0.005	0.005
	Median		0.005	<LOR	0.005	0.005
	90%ile		0.019	0.09	0.036	0.021
	N		10	23	10	13

4.7 FLOODING AND STREAM GEOMORPHOLOGY

The potential interactions between the proposed operations and the 1 in 100 year Average Recurrence Interval (ARI) design flood event for the Hunter River to the east and Wollombi Brook to the west has been investigated. The proposal will not result in any additional flood risk to infrastructure adjacent to the Hunter River along the eastern side of the mining lease (see Section 5).

The results of a flood study for Wollombi Brook (see Section 5) indicate that the proposal is located outside the 100 year ARI flood extent for Wollombi Brook. Hence, the proposal will not impact on flooding behaviour in Wollombi Brook and will not have any measurable effect on the geomorphology of Wollombi Brook.

4.8 WATER ALLOCATIONS

The water management system for the proposal has been designed to minimise the capture of clean runoff wherever possible.

Dams solely for the capture, containment and recirculation of mine affected water consistent with best management practice to prevent the contamination of a water source are “excluded works” and are exempt from the requirement for water supply works approvals and WALs under the Water Management Act 2000. On this basis, water captured in the site water management structures, with the exception of rainfall runoff from undisturbed natural catchments, is not subject to licensing.

The capture of runoff from undisturbed natural catchment draining to any of the proposal’s water management dams and mining areas may require a Water Access Licence (WAL). Figure 4.4 shows the clean water catchment areas requiring a WAL for runoff capture. Table 4.4 shows the estimated average volume of water captured within the water management system over the life of the proposal.

The intercepted average and maximum annual runoff has been estimated using average and maximum annual rainfalls at Jerrys Plains (Station No. 061086) of 644.5mm and 1,191.2mm respectively. A volumetric runoff coefficient of 0.108 has been used based on the runoff coefficient utilised for harvestable rights calculations at MTW (10 per cent of runoff =

0.07ML/ha = 7mm runoff. 100 per cent of runoff = 70mm. 70mm/644.5mm average annual rainfall = 10.8 per cent).

The total unregulated river access entitlement for the Hunter Unregulated and Alluvial Water Sources is 80,619 units (ML/a). The proposal is located on the boundary of the Singleton Water Source and the Lower Wollombi Brook Water Source, which have unregulated river access component shares of 960 units (ML/a) and 6,663 units (ML/a), respectively.

The predicted average annual impacts on the share components for the Singleton Water Source (67.3 ML/a) and for the Lower Wollombi Brook Water Source (10.0ML/a) under the Hunter Unregulated and Alluvial Water Sources Water Sharing Plan is approximately 8 per cent and 0.1 per cent, respectively, on an annual average basis for the life of the proposal.

MTW holds approximately 1,012ML/a of high security units of Hunter River water shares under the Mount Thorley Joint Venture (MTJV) Supply Scheme.

The total surface water entitlement (general and high security access licences) for the Hunter Regulated River water source is 151,792 units (ML/a). The proposal is located in Management Zone 2, which has an entitlement of 57,094 units (ML/a).

The MTW contiguous land holdings for the harvestable rights calculation are 4,007 ha in the Hunter River catchment and 2,667 ha in the Wollombi Brook catchment. At a harvestable right of 0.07ML/a, this equates to a volume of 280ML and 187ML in the Singleton and Lower Wollombi Brook Water Sources respectively.

Table 4.4 Surface Water Allocations

Water Sharing Plan		**Hunter Unregulated and Alluvial Water Sources**		**Hunter Regulated River**
Water Source		**Lower Wollombi Brook**	**Singleton**	**Hunter Regulated River**
Predicted annual take (ML/a)	Average	10	73	1,876
	Maximum	18	135	4,410
Predicted annual impact on water source (%)	Average	0.1	8	3.3
	Maximum	0.3	14	7.7
MTW current licences/ Harvestable Right		187 ML/a	280 ML/a	1,012 units
Additional water potentially required for the integrated operation (ML/a)	Average	0	0	864*
	Maximum	0	0	3,398*

Notes: * These volumes may be obtained from surplus mine water from nearby mining operations under water sharing agreements - refer Section 4.2.

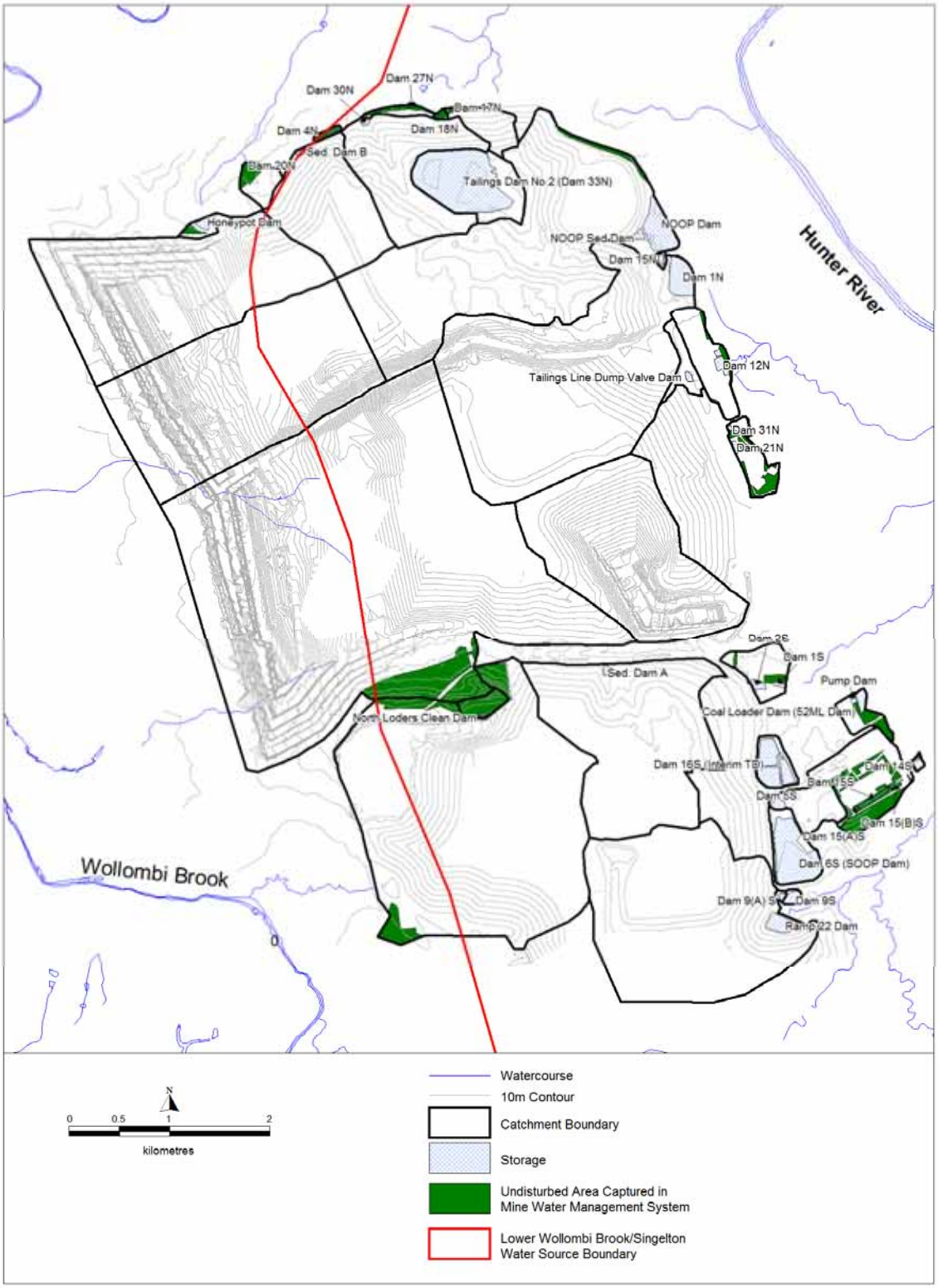


Figure 4.4 **Undisturbed Catchment Areas Requiring Water Allocation Licence for Runoff Capture**

5 FLOODING

5.1 OVERVIEW

The proposal may potentially impact on flooding in the Hunter River to the east and Wollombi Brook to the west. Since the proposal involves the advancement of mining to the west, there will be no increase in flood risk to infrastructure along the eastern side of the mining lease from the Hunter River. A desktop assessment was undertaken to assess flood levels along the Hunter River adjacent to the mine. For Wollombi Brook, a flood study was undertaken to estimate design flood levels adjacent to the mine. The methodology and results of the flood investigations are described below.

5.2 HUNTER RIVER FLOODING

Water level data for the Hunter River is available adjacent to the mine site at Mason Dieu (Station No. 210128), Long Point (Station No. 210134), Upstream Singleton (Station No. 210129) and Singleton (Station No. 210001). The locations of these stations are shown in Figure 2.4. Of these stations, only gauge levels from Long Point and Singleton can be translated into Australian Height Datum (AHD) levels. The peak levels recorded at these stations and at the two stations on Wollombi Brook (Bulga and Warkworth) for the June 2007 event are shown in Table 5.1. The June 2007 event was the largest flood event in the Hunter River at Singleton since the February 1955 event, and the third largest on record.

The minimum ground level along the eastern boundary of the MTW mining leases is approximately 50mAHD, which is about 1m higher than the maximum June 2007 flood level recorded at Long Point, located about 5km to the north-east. The proposal will not increase the Hunter River flood risk to infrastructure along the eastern side of the mining lease.

Table 5.1 Peak Recorded Levels for June 2007 Event

Station Number	River	Station Name	Peak Water Level (mAHD)
210134	Hunter River	Long Point	48.98
210001	Hunter River	Singleton	41.67
210028	Wollombi Brook	Bulga	63.48
210004	Wollombi Brook	Warkworth	56.30

5.3 WOLLOMBI BROOK FLOODING

5.3.1 Previous Flood Investigations

Two previous flood studies for Wollombi Brook have been undertaken: the first by the University of New South Wales Water Research Laboratory in April 1996 for an EIS prepared by Sinclair Knight Merz for the South Lemington open cut mine (SKM 1997), and the second by BMT WBM for Cessnock City Council in December 2010

The SKM (1997) study performed a frequency analysis on peak flood level data from the Warkworth gauge to determine design flood levels which were correlated to design discharges at Bulga. The study estimated a 100 year ARI design discharge of 2,700 m^3/s for Wollombi Brook at Bulga.

The BMT WBM (2010) study performed a flood frequency analysis (FFA) on a "synthetic" data series, which was a manipulated annual series which included gap filling and adjustment of recorded peak flow values to provide consistency in the annual flow records between the gauges. A flood frequency analysis was performed on the adjusted annual peak flows at Paynes Crossing, Bulga and Warkworth to determine the return period of a certain magnitude event. The FFA estimated a 100 year ARI design discharge of around 2,500m^3/s for Wollombi Brook at Bulga. The design flood discharges adopted for the study were based on an interactively calibrated hydrologic and hydraulic model using IFD design rainfall estimates. As the study was focussed on flood management at Wollombi Village, design discharges at Bulga using the calibrated hydrologic model have not been provided in the report.

5.3.2 Design Flood Discharges

For this study, a flood frequency analysis (FFA) of available data for the Bulga gauge was used to estimate design discharges. The available data at the Warkworth stream gauge includes a greater number of years, however the station is frequently affected by backwater flooding from the Hunter River and hence, the estimated discharges at the Warkworth gauge are unreliable. Annual recorded peak flood discharges for the Bulga gauge were available for the years 1949-1959, 1963-1987 and 2000-2013 totalling 50 years of data.

The methodology recommended in Book 4, Section 2 of Australian Rainfall and Runoff (ARR, 1998) was used to fit a Log-Pearson Type III distribution to the annual series of recorded peak flood discharges for the Bulga gauge. Figure 5.1 is a flood frequency plot for Wollombi Brook at Bulga. Design discharges estimated from the FFA are shown in Table 5.2 and are compared with the design discharges used in the SKM (1997) study, and the BMT WBM (2010) study. Discharges from this study are slightly higher than those in the BMT WBM (2010) study for the larger ARI events, and are therefore considered to be more conservative. Note that the recorded peak flood discharge for the June 2007 event at Bulga was 875m^3/s. Comparing this recorded discharge with the results shown in Table 5.2 indicates that the June 2007 event was between a five to ten year ARI event in Wollombi Brook at Bulga.

Table 5.2 Design Discharges for Wollombi Brook

ARI (years)	Design Discharge from FFA (m^3/s)	SKM (1997) Design Discharge	BMT WBM (2010) Design Discharge
5	470	600	750
10	880	1,400	1,000
20	1,400	1,900	1,500
50	2,100	2,500	2,000
100	2,700	2,700	2,500

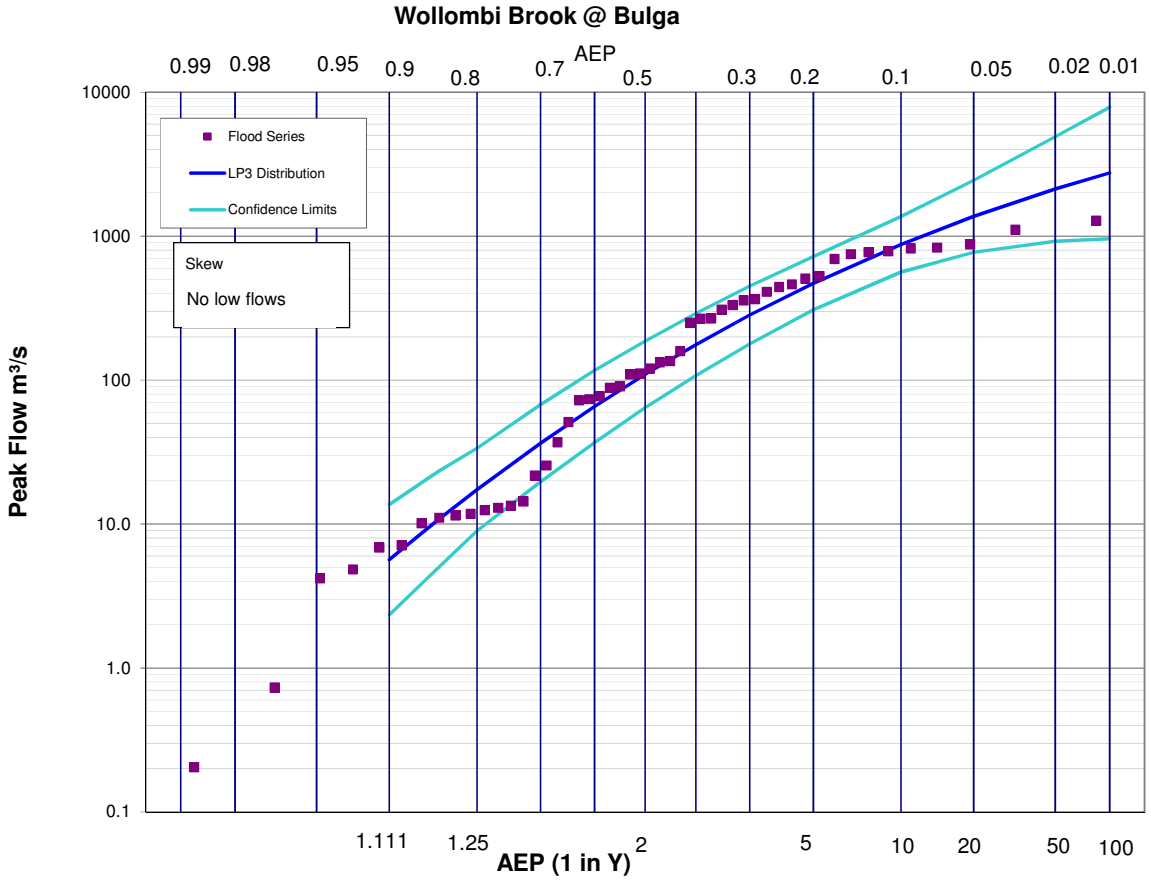


Figure 5.1 Flood Frequency Analysis Plot, Wollombi Brook at Bulga

5.3.3 Design Flood Levels

Methodology

The HEC-RAS steady state hydraulic model was used to estimate the 100 year ARI design flood levels in Wollombi Brook adjacent to the mine site. The model was calibrated to recorded flood levels and discharges for the June 2007 event.

Model Configuration

Figure 5.2 shows the location of the cross-sections used in the HEC-RAS model. A total of 23 cross-sections were used in the study. Cross-section data was based on 2m contours obtained from aerial survey undertaken by AAMHatch in September 2008. The vertical accuracy of the data is +/- 2m, which was considered adequate for this study given the significant available freeboard between estimated flood levels and the proposed pit extent.

Downstream Boundary Condition

The adopted downstream boundary condition was a fixed water level which was selected to match a selected level at the Warkworth stream gauge. A frequency analysis was performed on available peak water level data for the Warkworth stream gauge to estimate design water levels. Annual recorded peak flood levels for the Warkworth gauge were available for the years 1908-2013 (except 1953) totalling 105 years of data. The predicted water level for the 100 year ARI event from the analysis was 59.0mAHD which is slightly lower than the 59.4mAHD estimated by the SKM (1997) study. The slightly higher value of 59.4mAHD was adopted as the target starting water level at the Warkworth gauge.

Model Calibration

The HEC-RAS model was calibrated to match recorded peak discharges and water levels for the June 2007 flood event. A uniform friction loss coefficient (Manning's 'n') value of 0.045 was adopted for all cross-sections in the model based on calibration to recorded flood levels. A comparison of the recorded and calculated flood levels for the calibration event is included in Table 5.2.

Table 5.3 Recorded and Estimated Flood Levels for June 2007 Event

Water Level (mAHD)	Bulga Station	Warkworth Station
Recorded value	63.48	56.30
Estimated value	63.50	56.31

Estimated Flood Levels

Estimated flood levels for the 100 year ARI design event vary from 59.4mAHD at Warkworth to 65.7mAHD at Bulga. Note that the 100 year ARI design flood level at Bulga is about 2.2m higher than the June 2007 peak flood level (63.5mAHD). Although the estimated 100 year ARI design discharge for this study is similar to the previous SKM study (SKM, 2007), the estimated design flood level at Bulga from this study is 1.2m higher than the SKM study.

Figure 5.2 shows the 100 year ARI design flood extent and flood level at each cross-section. Note that the proposal is outside the 100 year ARI extent of flooding from Wollombi Brook. An existing levee across Salt Pan Creek prevents flood waters from Wollombi Brook entering Loders Pit at MTO.

5.3.4 Flood Impacts

As shown in Figure 5.2 the proposal is located outside the 100 year ARI design flood extent. Figure 5.3 shows a cross-section of Wollombi Brook adjacent to the proposal, indicating that the 100 year ARI design flood level is about 11m below the top of the extended pit high wall. Hence, the proposal will have no impact on flood flows, velocities or flood levels along Wollombi Brook for events up to and including the 100 year ARI flood event. For this reason, the proposal does not require measures to mitigate flood impacts on Wollombi Brook.

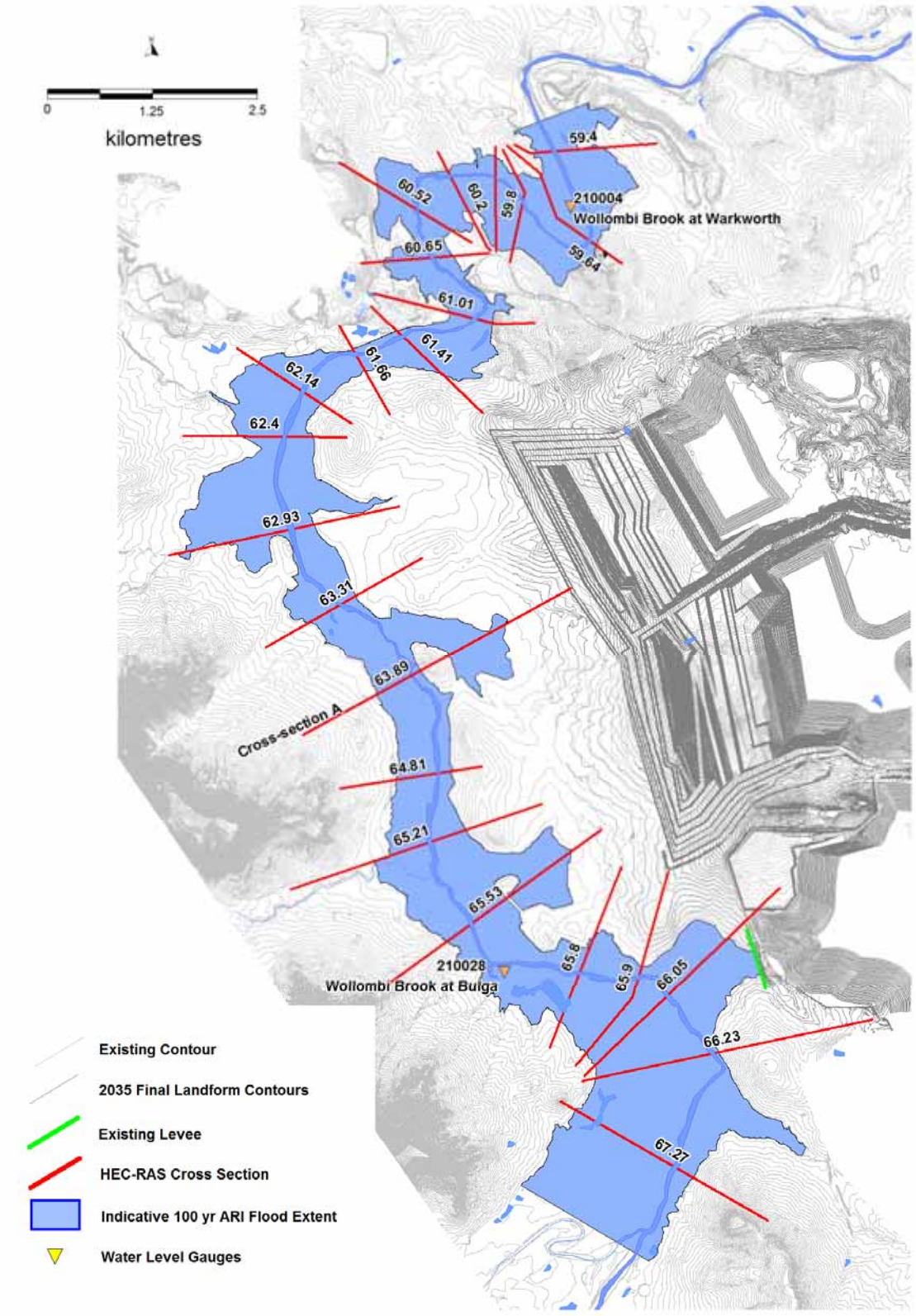


Figure 5.2 HEC-RAS Model Configuration and 100 Year ARI Design Flood Extent

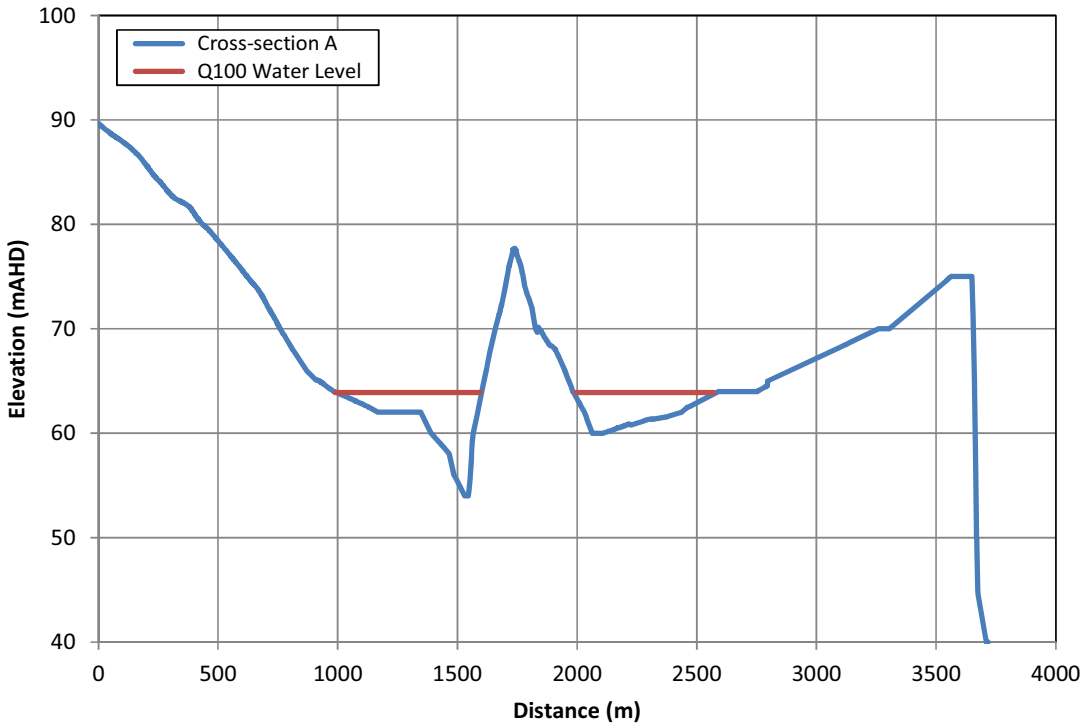


Figure 5.3 Flood Level at Cross-Section A, Adjacent to Extended Pit Highwall

6 MINE WATER BALANCE

6.1 OVERVIEW

The computer based OPSIM model was used to simulate the site water balance for the proposal. The model simulates the operations of all major components of the proposed water management system, including:

- Climatic variability – rainfall and evaporation;
- Catchment runoff;
- Controlled discharges (under the HRSTS) and uncontrolled overflows;
- Groundwater inflows; and
- Site water usage (CHPP, haul road dust suppression and stockpile dust suppression, vehicle wash).

6.2 SIMULATION METHODOLOGY

The water balance model has been run for the 'forecast' simulation methodology.

The forecast water balance results are generated by running multiple climate sequences through the model and taking a statistical representation of the results for the different climate cases modelled. These results more accurately reflect the actual performance of the system because they take into account the dynamic nature of the mine staging, groundwater inflows, and CHPP throughputs. In these runs the model configuration changes over time, to reflect the changes due to mine development.

The forecast water balance model has been run on a daily time-step for a 22 year period, corresponding to the period of operation of the proposal (21 years) plus one year of the existing system (total 22 years). The model was run for multiple climate sequences, each referred to as a "realisation". Each realisation is based on a 22 year sequence extracted from the historical rainfall data. The first of 93 realisations is based on rainfall data from 1893 to 1914. The second is based on data from 1894 to 1915, and so on. This approach provides the widest possible range of climate scenarios covering the full range of climatic conditions represented in the historical rainfall record.

The model configuration changes over the 21 year project life, reflecting changes in the water management system over time. The different stages of the mine life are linked in the model to reflect variations over time such as catchments, ROM coal production and groundwater inflows. Five different representative stages of mine life were modelled (Years 0, 3, 9, 14 and 21). Although the catchment areas will continuously change as mining under the proposal progresses, the adopted approach of modelling discrete stages will provide a reasonable representation of conditions over the 21 year period.

The operational rules and physical layout for each representative stage of mine progression are applied to a range of years given in Table 6.1.

Table 6.1 Application of Representative Mine Stage to Full Mine Life

Representative Mine Stage	Applied Range of Mine Life	Period (years)
Year 0	Year 0 – 1	2
Year 3	Year 2 – 5	4
Year 9	Year 6 – 12	7
Year 14	Year 13 – 17	5
Year 21	Year 18 - 21	4

6.3 SIMULATION OF RAINFALL RUNOFF

The OPSIM model uses the Australian Water Balance Model (AWBM) (Boughton, 2003) to estimate daily runoff from daily rainfall. The AWBM is a saturated overland flow model which allows for variable source areas of surface runoff.

AWBM 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 evapotranspiration. Simulated surface runoff occurs when the storages fill and overflow. Figure 6.1 shows a conceptual configuration of the AWBM model.

The model uses daily rainfalls and estimates of catchment evapotranspiration to calculate daily values of runoff using a daily balance of soil moisture. The model has a baseflow component which simulates the recharge and discharge of a shallow subsurface store. Runoff depth calculated by the AWBM model is converted into runoff volume by multiplying by the contributing catchment area.

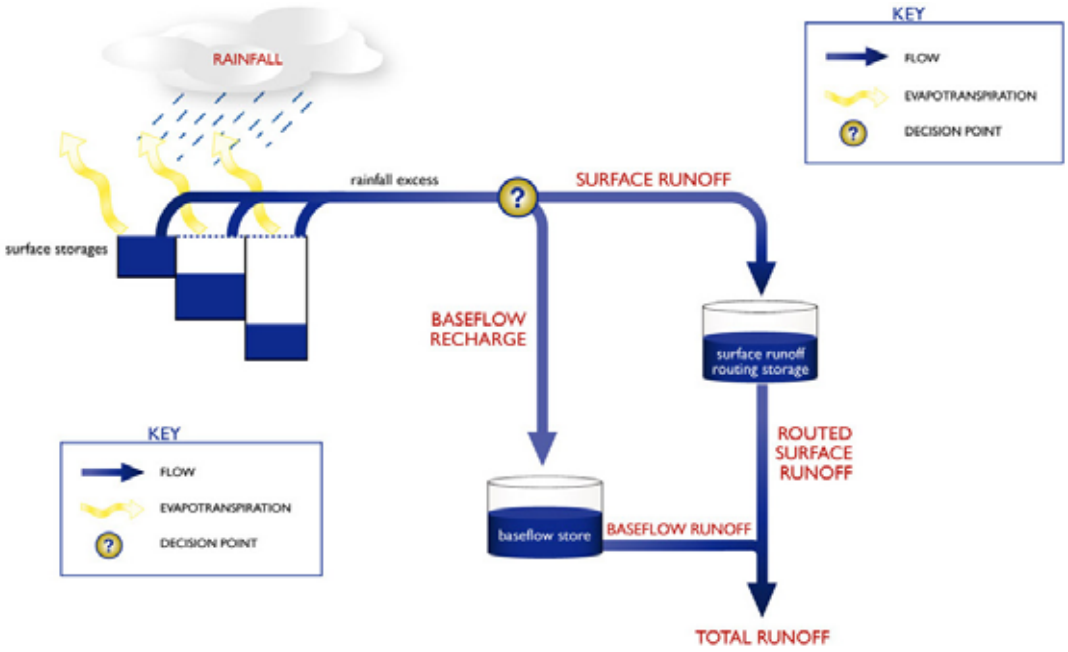


Figure 6.1 AWBM Model Configuration

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).

The AWBM model parameters selected have been derived from the previous water balance modelling undertaken at MTW (WRM, 2014). Table 6.2 presents the calibrated AWBM model parameters and long term runoff coefficients over the period 1893 to 2006.

Table 6.2 MTW Catchment Yield (AWBM) Parameters

Parameter	Natural/ Undisturbed	Cleared/ Prestrip	Mining Pit	Tailings	Rehabilitated Spoil	Unrehabilitated Spoil	Roads/Industrial/ Hardstand
A1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
A2	0.4	0.9	0.9	0.9	0.9	0.9	0.9
A3	0.4	0	0	0	0	0	0
S1	30	1	2.3	1	9.4	12.5	2.3
S2	50	11	6.9	11	94	125	6.9
S3	90	0	0	0	0	0	0
BFI	0.15	0	0	0	0.15	0.7	0
K_b	0.98	0	0	0	0.98	0.99	0
K_s	0.96	0	0	0	0.96	0.96	0
Long term Runoff Coefficient, C_v	12.5 %	40.4 %	46.1 %	40.4 %	9.9 %	7.2 %	46.1 %

6.4 WATER BALANCE MODEL CALIBRATION

The MTW OPSIM model was last updated and calibrated as part of the 2013 water balance model update (WRM Water & Environment Pty Ltd, 2014). The model was calibrated over the period May 2012 to June 2013 to the recorded total site inventory (see Figure 6.2). It was determined that the difference between recorded and simulated storage inventories in January and February 2013 is due to one or a combination of factors:

- Inaccurate recorded inventories in the pits; and/or
- Water stored in storages which are not recorded being pumped back into the recorded storage inventory system over time after rainfall events.

Nevertheless, the 2013 MTW OPSIM water balance model is considered to provide a reasonable representation of the response of the site's water management system to a range of climatic scenarios. The MTW 2013 OPSIM water balance model has been used as a basis for the proposed surface water investigations.

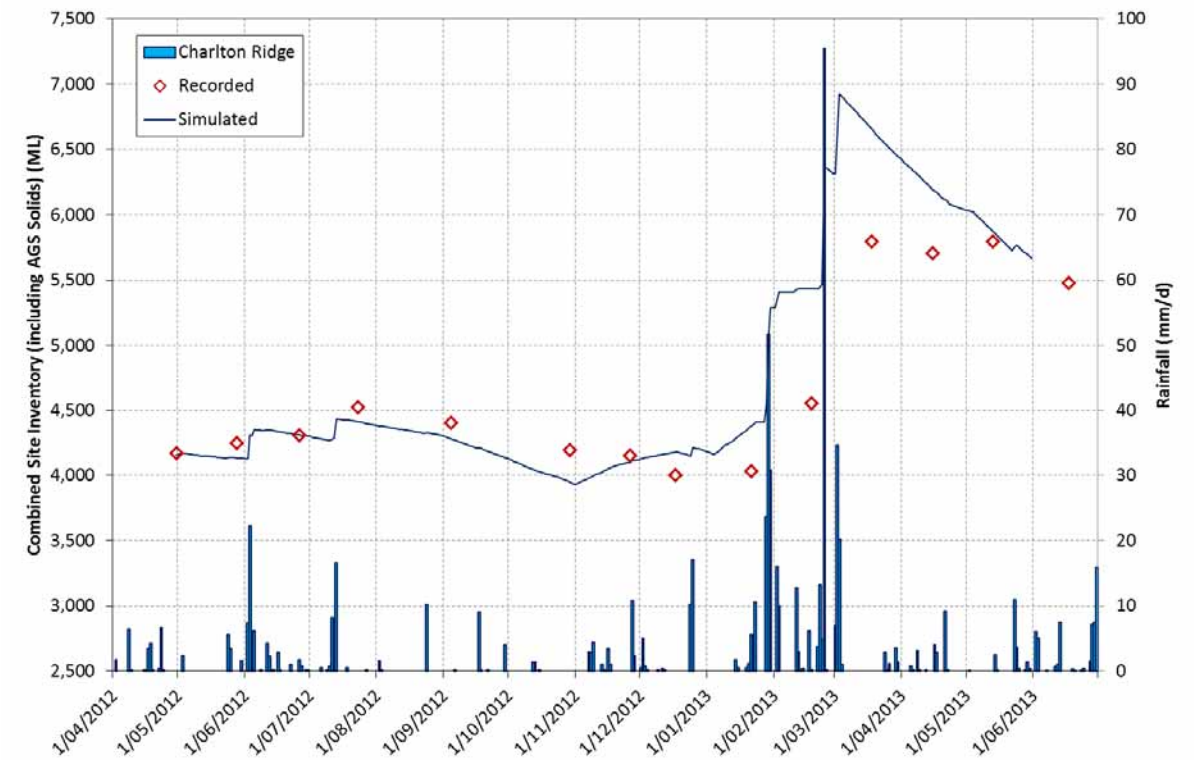


Figure 6.2 Combined Site Inventory, Recorded vs. Simulated

6.5 PROPOSED WATER MANAGEMENT SYSTEM

6.5.1 Proposed Mine Water Storages

A number of new storages or upgrades to existing storages are proposed at MTW in this proposal and are described below:

- North-Out-of-Pit Dam (NOOP Dam): Saline water storage located directly to the north of Dam 1N at Warkworth Mine. NOOP Dam has a proposed capacity of 740ML.

- SOOP Dam: Primary water storage for MTO (existing), also referred to as Dam 6S. Increase in storage capacity to 2.2GL within the same footprint.
- Ramp 22 Dam: Sediment dam situated at the current Dam 10S and Dam 11S location at MTO. Joint sediment dam with Bulga Coal Mine to the south. Runoff from both MTW and Bulga will be directed to this dam.
- Sediment Dam A: Sediment dam located at MTO to capture runoff from future spoil and rehabilitated areas. Exact location yet to be confirmed.
- Sediment Dam B: Sediment dam location at Warkworth Mine to capture runoff from future spoil and rehabilitation areas. Exact location yet to be confirmed.

Note also that a new pit/tailings storage facility (Abbey Green North) will be mined in approximately 2018 and 2019, however does not form part of this proposal. AGN is the designated tailings storage facility during Years 9 to 12.

6.5.2 Water Management System Layout and Operating Rules

The changes to the approved mine under the proposal will result in a number of potential changes to the water management system layout. The proposed water management system is shown in the schematic in Figure 6.3, with proposed changes highlighted. The mine stage layouts are presented in Figure 6.4 to Figure 6.10. Table 6.3 details the proposed OPSIM model operating rules.

The water management system will evolve as the mine develops, simulated as follows:

- Year 3: Tailings are directed to both the Centre Ramp Tailings Storage Facility (CRTSF) and AGS. Construction of the North-Out-of-Pit (NOOP) Dam is complete. Construction of Ramp 22 Dam is complete, replacing Dam 10S and 11S. Dam 32N (TD1) has been capped and rehabilitated. Dam 6N and Dam 12S have been mined out.
- Year 9: Tailings are directed to the CRTSF and Abbey Green North (AGN) TSF. Mining has been completed in Loders Pit, which has been partially backfilled. Mini-strip TSF has been rehabilitated. Sediment Dam A has been constructed. AGS is covered and rehabilitated.
- Year 14: Tailings are directed to the partially backfilled Loders Pit. CRTSF has been capped and rehabilitated. Sediment Dam B has been constructed. AGN is covered and rehabilitated.
- Year 21: Tailings Dam 2 (Dam 33N) has been capped and rehabilitated. Considerable areas of the site have now been rehabilitated.

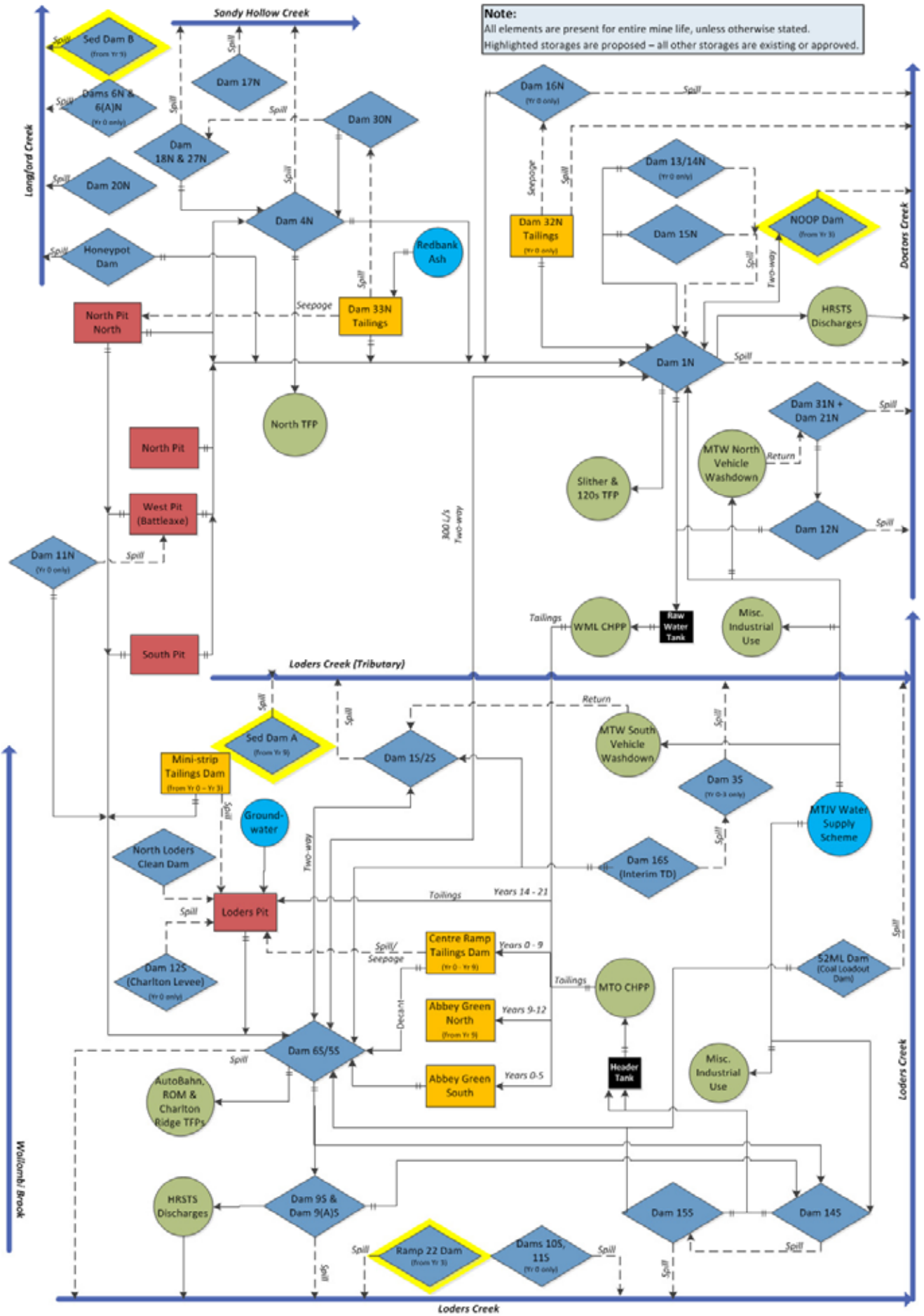


Figure 6.3 Proposed Water Management System Schematic

Table 6.3 Proposal OPSIM Model Operating Rules

Node No.	Node Name	Operating Rules
Water Supply		
161	MTJV Water Supply Scheme	▪ Supplies to the following locations as required: ▫ Dam 14S ▫ Dam 1N ▫ MTW South Vehicle Washdown ▫ MTW North Vehicle Washdown ▫ MTW South Misc. Industrial Use ▫ MTW North Misc. Industrial Use
Controlled Discharges		
311	Dam 1N HRSTS Discharge	▪ Warkworth controlled release point from Dam 1N under the following conditions: ▫ >70% of MOL capacity ▫ Maximum 100ML/d ▫ Under 'High' flows – releases so that downstream EC does not exceed 900µS/cm. ▫ Under 'Flood' flows – not limited by salts. ▪ Discharged to Hunter River via Doctor's Creek. ▪ Storage overflows to Doctor's Creek.
313	Dam 9S HRSTS Discharge	▪ Mount Thorley controlled release point from Dam 9S under the following conditions: ▫ >70% of MOL capacity ▫ Maximum 100ML/d ▫ Under 'High' flows – releases so that downstream EC does not exceed 900µS/cm. ▫ Under 'Flood' flows – not limited by salts. ▪ Discharged to Hunter River via Loders Creek. ▪ Storage overflows to Loders Creek.
Water Demands		
150	MTW North CHPP (Warkworth Mine)	▪ Supplied from Dam 1N via the Raw Water Tank ▪ Tailings directed to Abbey Green South/ CRTSF/Abbey Green North/Loders Pit – depending on stage.
250	MTW South CHPP (MTO)	▪ Supplied from the following locations (via the Header Tank): ▫ Dam 14S ▫ Dam 15S ▪ Tailings directed to Abbey Green South / CRTSF/Abbey Green North/Loders Pit – depending on stage.
181	MTW South Vehicle Washdown	▪ Supplied from MTJV Supply Scheme as per Table 6.11. ▪ 85% loss assumed. ▪ Return directed to Dam 1S/2S.
183	MTW South CHPP Miscellaneous Industrial Use	▪ Suppled from MTJV Supply Scheme as per Table 6.11. ▪ 100% loss assumed.
281	MTW North Vehicle Washdown	▪ Supplied from MTJV Supply Scheme as per Table 6.11. ▪ 85% loss assumed. ▪ Return directed to Dam 31N/21N.
283	MTW North CHPP Miscellaneous Industrial Use	▪ Suppled from MTJV Supply Scheme as per Table 6.11. ▪ 100% loss assumed.

Node No.	Node Name	Operating Rules
307	AutoBahn, ROM and Charlton Ridge Truck Fill Points (TFPs)	▪ Supplied from Dam 6S at a maximum rate of 3,481kL/d on a 'non-rain day'. ▪ Reduction in demand for days of rain. ▪ 100% loss assumed.
308	Slither and 120s Truck Fill Points (TFPs)	▪ Supplied from Dam 1N at a maximum rate of 2,320kL/d on a 'non-rain day'. ▪ Reduction in demand for days of rain. ▪ 100% loss assumed.
	North Truck Fill Point	▪ Supplied from Dam 4N at a maximum rate of 1,610kL/d on a 'non-rain day'. ▪ Reduction in demand for days of rain. ▪ 100% loss assumed.
Operational Pits		
190	Loders Pit	▪ Continuous dewatering from pit dewatering pumps (when required) at a nominal maximum rate of 100L/s. ▪ Pit dewatering directed to Dam 6S (SOOP Dam). ▪ Receives seepage from Dam 17S (Centre Ramp TD) at a rate of 12,000kL/d. ▪ Receives pumped transfers from the following locations for Years 14-21: ▫ MTW North CHPP (tailings) ▪ MTW South CHPP (tailings)Receives spillway overflows from the following locations: ▫ Mini-strip TSF ▫ Dam 12S (Charlton Levee) ▫ Dam 17S (CRTSF) ▪ Receives groundwater inflows as per Table 6.4.
290	North Pit North	▪ Continuous dewatering from pit dewatering pumps (when required) at a nominal maximum rate of 100L/s. ▪ Pit dewatering directed to Dam 4N, Dam 1N, Dam 6S. ▪ Receives seepage from Dam 33N at a rate of 50kL/d. ▪ Receives groundwater inflows as per Table 6.4.
291	West Pit	▪ Continuous dewatering from pit dewatering pumps (when required) at a nominal maximum rate of 280L/s. ▪ Pit dewatering directed to Dam 6S (SOOP Dam) or Dam 1N. ▪ Receives spillway overflows from Dam 11N.
293	South Pit	▪ Continuous dewatering from pit dewatering pumps (when required) at a nominal maximum rate of 280L/s. ▪ Pit dewatering directed to Dam 6S (SOOP Dam) or Dam 1N. ▪ Receives groundwater inflows as per Table 6.4.
295	North Pit	▪ Continuous dewatering from pit dewatering pumps (when required) at a nominal maximum rate of 100L/s. ▪ Pit dewatering directed to Dam 1N.
Water Storages		

Node No.	Node Name	Operating Rules
102	Dam 1S/2S	▪ Receives pumped transfers from the following locations: ▫ Dam 6S (SOOP Dam). ▫ Dam 16S (Interim TD). ▪ Receives return from MTW South Vehicle Washdown. ▪ Pump transfers to Dam 6S when >12ML. ▪ Storage overflows to Loders Creek Tributary.
103	Dam 3S	▪ Rehabilitated area sediment dam (clean catchment). ▪ Receives storage overflows from Dam 16S. ▪ Storage overflows to Loders Creek Tributary. ▪ Mined out from Yr 9 onwards.
104	Sediment Dam A	▪ Present for Yr 9 onwards. ▪ Storage overflows to Loders Creek tributary.
105	Dam 5S	▪ Storage overflows to Dam 6S (SOOP Dam).
106	Dam 6S (SOOP Dam)	▪ Primary mine water storage for Mount Thorley. ▪ Receives pumped transfers from the following locations: ▫ Loders Pit ▫ Mini-strip TSF ▫ Dam 1S/2S ▫ Dam 15S (South CPP) ▫ Dam 16S ▫ Dam17S (Centre Ramp TSF) ▫ Dam 1N ▫ Dam 11N ▫ North Pit North ▫ West Pit ▫ South Pit ▫ Abbey Green South ▫ Coal Loader Dam (52ML Dam) ▪ Receives storage overflows from Dam 5S. ▪ Supplies to the following locations: ▫ Dam 2S ▫ Dam 14S ▫ Dam 1N ▫ Dam 9S ▫ AutoBahn TFP ▫ ROM TFP ▫ Charlton Ridge TFP ▪ Storage overflows to Loders Creek.
107	Ramp 22 Dam	▪ Present from Yr 3 onwards. ▪ Storage overflows to Loders Creek.
109	Dam 9S	▪ Mount Thorley HRSTS controlled release point (max. 200ML/d). ▪ Receives pumped transfers from the following locations: ▫ Dam 6S (SOOP Dam) ▫ Dam 9(A)S ▪ Supplies to Dam 14S as required. ▪ Storage overflows to Loders Creek.
110	Dam 10S	▪ Present for Yr 0 only. ▪ Rehabilitated area sediment dam (clean catchment). ▪ Storage overflows to Dam 11S.

Node No.	Node Name	Operating Rules
111	Dam 11S	▪ Present for Yr 0 only. ▪ Rehabilitated area sediment dam (clean catchment). ▪ Receives storage overflows from Dam 10S. ▪ Storage overflows to Loders Creek.
112	Dam 12S (Charlton Levee)	▪ Present for Yr 0 only. ▪ Storage overflows to Loders Pit.
113	Dam 9(A)S	▪ Rehabilitated area sediment dam. ▪ Pump transfers to Dam 9S. ▪ Storage overflows to Loders Creek.
114	Dam 14S	▪ Receives pumped transfers from the following locations: ▫ Dam 6S (SOOP Dam) ▫ Dam 9S ▫ MTJV Water Supply Scheme (as required) ▪ Supplies to Header Tank as required. ▪ Storage overflows to Dam 15S.
115	Dam 15S (South CHPP)	▪ Receives overflows from Dam 14S. ▪ Supplies to Header Tank as required. ▪ Pump transfers to Dam 6S when >10ML. ▪ Storage overflows to Loders Creek.
116	Dam 16S (Interim TD)	▪ Pump transfers to Dam 2S or Dam 6S to maintain empty. ▪ Storage overflows to Dam 3S.
117	Dam 17S (Centre Ramp TSF)	▪ Receives pumped transfers from the following locations for Years 0-9: ▫ MTW North CHPP (tailings) ▫ MTW South CHPP (tailings) ▪ Seeps to Loders Pit at a rate of 12,000kL/d. ▪ Storage overflows to Loders Pit (no spillway). ▪ Rehabilitated from Yr 14 onwards.
118	Coal Loader Dam (52ML Dam)	▪ Pump transfers to Dam 6S to maintain empty. ▪ Storage overflows to Loders Creek Tributary.
119	Loders Pit North Clean Water Dam	▪ Clean water catchment. ▪ Storage overflows to Loders Pit.
191	Mini-strip TSF	▪ Supplies to Dam 6S as required. ▪ Storage overflows to Loders Pit.

Node No.	Node Name	Operating Rules
201	Dam 1N	▪ Primary mine water storage for Warkworth. ▪ Warkworth HRSTS controlled release point (max 100ML/d). ▪ Receives pumped transfers from the following locations: ▫ Dam 6S ▫ Dam 4N ▫ North Pit North ▫ North Pit ▫ West Pit ▫ South Pit ▫ Dams 13/14/15N ▫ NOOP Dam ▫ Dam 16N ▫ Dam 32N ▫ Dam 33N ▫ MTJV Water Supply Scheme ▪ Receives storage overflows from Dams 13/14/15N. ▪ Supplies to the following locations: ▫ MTW North CHPP & miscellaneous industrial use via Raw Water Tank ▫ NOOP Dam ▫ Slither and 120s TFPs ▪ Transfers to Dam 6S @ 300L/s when > 240ML. ▪ Storage overflows to Doctor's Creek.
204	Dam 4N	▪ Receives pumped transfers from the following locations: ▫ North Pit North ▫ Dam 27N ▫ Honeypot Dam ▫ Dam 30N ▪ Pump transfers to Dam 1N to maintain empty. ▪ Supplies to North Pit TFP. ▪ Storage overflows to Sandy Hollow Creek.
205	Sediment Dam B	▪ Present for Yr 9 onwards. ▪ Storage overflows to Longford Creek.
206	Dam 6N	▪ Present for Yr 0 only. ▪ Clean water catchment. ▪ Receives storage overflows from Dam 6(A)N. ▪ Storage overflows to Longford Creek.
207	Abbey Green South	▪ Tailings storage facility. ▪ Receives pumped transfers from the following locations for Years 0-5: ▫ MTW North CHPP (tailings) ▫ MTW South CHPP (tailings) ▪ Pump transfers to the following locations at a nominal rate of 100L/s: ▫ Dam 6S ▫ Capped and rehabilitated from Yr 9 onwards.
208	Abbey Green North	▪ Present for Yr 9 onwards. ▪ Receives pumped transfers from the following locations for Years 9-12: ▫ MTW North CHPP (tailings) ▫ MTW South CHPP (tailings) ▪ Capped and rehabilitated from Yr 14 onwards.

Node No.	Node Name	Operating Rules
211	Dam 11N	▪ Present for Yr 0 only. ▪ Clean water catchment. ▪ Pump transfers to Dam 6S (SOOP Dam) to maintain empty. ▪ Storage overflows to West Pit.
212	Dam 12N	▪ Receives pumped transfers from Dam 31N (CC8). ▪ Supplies to Raw Water Tank as required. ▪ Storage overflows to Doctor's Creek.
215	Dams 13/14/15N	▪ Supplies to Dam 1N as required. ▪ Storage overflows to Dam 1N. ▪ (Dams 13N & 14N not present from Yr 3 onwards)
216	Dam 16N	▪ Present for Yr 0 only. ▪ Receives seepage from Dam 32N (Tailings Dam 1). ▪ Pump transfers to the Dam 1N to maintain empty. ▪ Storage overflows to Doctor's Creek.
217	Dam 17N	▪ Rehabilitated area sediment dam (clean catchment). ▪ Storage overflows to Sandy Hollow Creek.
218	Dam 18N	▪ Storage overflows to Dam 27N.
220	Dam 20N	▪ Clean water catchment. ▪ Storage overflows to Longford Creek.
227	Dam 27N	▪ Receives storage overflows from the following locations: ▫ Dam 18N ▫ Dam 30N ▪ Pump transfers to Dam 4N at a rate of 25L/s to maintain empty. ▪ Storage overflows to Sandy Hollow Creek.
228	NOOP Dam	▪ Present from Yr 3 onwards. ▪ 2-way transfer with Dam 1N. ▪ Storage overflows to Doctors Creek.
230	Dam 30N	▪ Receives storage overflows from Dam 33N (Tailings Dam 2). ▪ Transfers to Dam 4N to maintain empty (50L/s). ▪ Storage overflows to Dam 27N.
231	Dam 31N (CC8) + Dam 21N	▪ Pump transfers to Dam 12N at a rate of 70L/s. ▪ Receives return from MTW North Vehicle Washdown. ▪ Storage overflows to Doctor's Creek,
232	Dam 32N (Tailings Dam 1)	▪ Present for Yr 0 only (rehabilitated from Yr 3 onwards). ▪ Seeps to Dam 16N at a rate of 50kL/d. ▪ Pump transfers to Dams 1N to maintain empty. ▪ Storage overflows to Doctor's Creek.
233	Dam 33N (Tailings Dam 2)	▪ Seeps to North Pit North at a rate of 50kL/d. ▪ Receives moisture in ash from Redbank Power Station at a rate of 68kL/d. ▪ Pump transfers to Dams 1N to maintain empty. ▪ Storage overflows to Dam 30N.
306	Dam 6(A)N	▪ Clean water catchment. ▪ Storage overflows to Dam 6N.
381	Honeypot Dam	▪ Pump transfers to Dam 1N to maintain empty. ▪ Storage overflows to Longford Creek.
Receiving Waters		

Node No.	Node Name	Operating Rules
174	Loders Creek (including Tributary)	▪ Receives controlled HRSTS discharges from Dam 9S. ▪ Receives storage overflows from the following locations: ▫ Sediment Dam A ▫ Dam 1S/2S ▫ Dam 3S ▫ Dam 6S (SOOP Dam) ▫ Dam 9S ▫ Dam 9(A)S ▫ Ramp 22 Dam ▫ Dam 11S ▫ Dam 15S (South CPP) ▫ Coal Loader Dam (52ML Dam)
175	Wollombi Brook	▪ Not linked to MTW water management system.
176	Hunter River	▪ Receives controlled releases from the following locations: ▫ Dam 1N (via Doctors Creek) ▫ Dam 9S (via Loders Creek)
275	Doctor's Creek	▪ Receives controlled HRSTS discharges from Dam 1N. ▪ Receives storage overflows from the following locations: ▫ Dam 1N ▫ Dam 12N ▫ Dam 16N ▫ Dam 31N (CC8) + 21N ▫ Dam 32N ▫ NOOP Dam
276	Longford Creek	▪ Receives storage overflows from the following locations: ▫ Dam 6N/6(A)N ▫ Honeypot Dam ▫ Sediment Dam B ▫ Dam 20N
277	Sandy Hollow Creek	▪ Receives storage overflows from the following locations: ▫ Dam 4N ▫ Dam 17N ▫ Dam 27N

6.5.3 Groundwater Inflows

Groundwater inflows into the proposed operation are not expected to be significant. The groundwater impact assessment (AGE 2014a, AGE 2014b) has predicted total groundwater inflow rates to Warkworth Mine and MTO from two sources: Permian inflows and spoil inflows. The predicted inflows from spoil to the open cut pits include rainfall runoff baseflow and seepage from tailings dams, both of which are already simulated in the surface water balance model. Comparison of the surface water balance estimates and the groundwater model estimates indicate flows are of the same order of magnitude. However, the surface water balance model simulates rainfall runoff baseflow on a daily basis whereas the groundwater model uses annual average rainfall. Therefore the spoil inflow estimates from the surface water balance model are considered more suitable for the purposes of the surface water balance modelling than the spoil inflows from the groundwater model.

The Permian inflows to the open cut pits were reduced to account for evaporation from the pit faces and the entrained moisture losses due to mining. These water losses were estimated as follows:

- Evaporation from the open cut pits was based on pit face lengths estimated from the indicative mine plans and actual coal seam heights (36m at Warkworth, and 21m at Mount Thorley). An evaporation rate of 2.63mm/d was adopted based on a Morton's Lake Average rate of 3.8mm/d, an evapotranspiration factor of 0.99 and a shading factor for deep pits of 0.7.
- The entrained losses due to mining were calculated from production schedule and an assumption that the raw feed to the CHPP has a moisture content of 5 per cent.

At Warkworth Mine, the losses from coal moisture entrainment and evaporation resulted in a predicted nil 'pumpable' Permian groundwater inflows for the life of the project. This is consistent with the existing operation, which has very little groundwater inflow. At MTO, groundwater inflows occur for Years 1 to 5. After Year 6, inflows are nil as mining has finished and Loders Pit has been filled in.

The groundwater inflow rates were averaged over the years covered by each mine state, as detailed in Table 6.4.

Table 6.4 Adopted Groundwater Inflows (ML/a)

Year	Warkworth	Mount Thorley
Year 0 (2 years)	0	186
Year 3 (4 years)	0	10
Year 9 (7 years)	0	0
Year 14 (5 years)	0	0
Year 21 (4 years)	0	0
Total	**0**	**413 ML**

An uncertainty analysis of the groundwater model inputs was undertaken (AGE, 2014) to put potential error bars around predictive results. The predictive groundwater model simulation for the uncertainty analysis showed 95th percentile worst case inflows resulted in an increase of 'pumpable' Permian groundwater inflows by 157ML/a in Year 15. This equates to approximately 2.6% of the total inflows to MTW (refer Table 6.13), and is therefore not expected to greatly impact on the performance of the MTW water management system. It is likely that the only significant impact of increased groundwater inflows of this magnitude on the site water balance would be to reduce the external water requirement by an equal amount.

6.5.4 Catchments and Land Use Classifications

The changes in the physical layout are represented in the indicative mine plans given in Figure 6.4 to Figure 6.11 for Years 3, 9, 14 and 21 respectively. Catchment areas (separated by the different land use types) reporting to the mine site storages are provided in Appendix B.

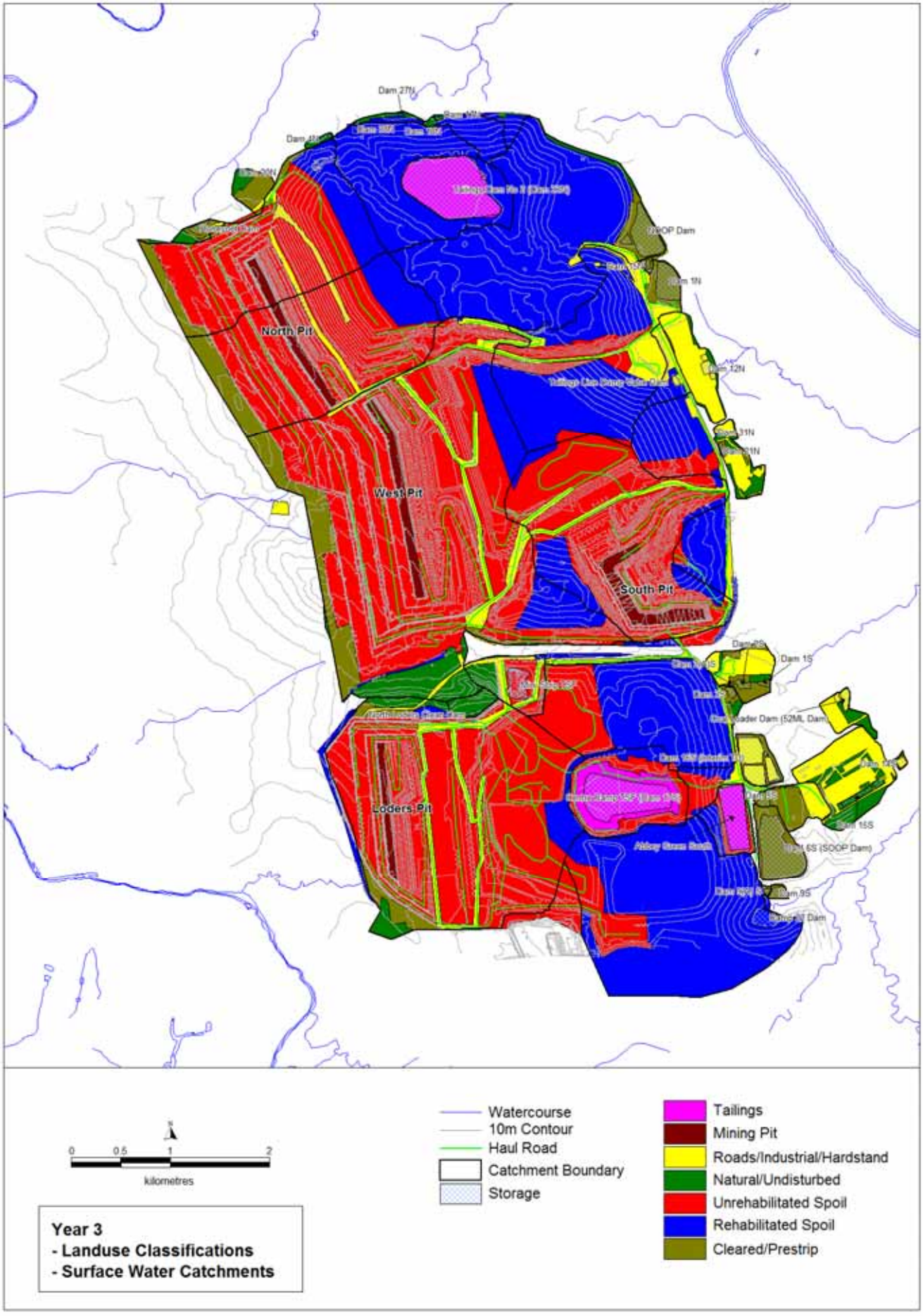


Figure 6.4 MTW Surface Catchments & Land Use Classifications – Year 3

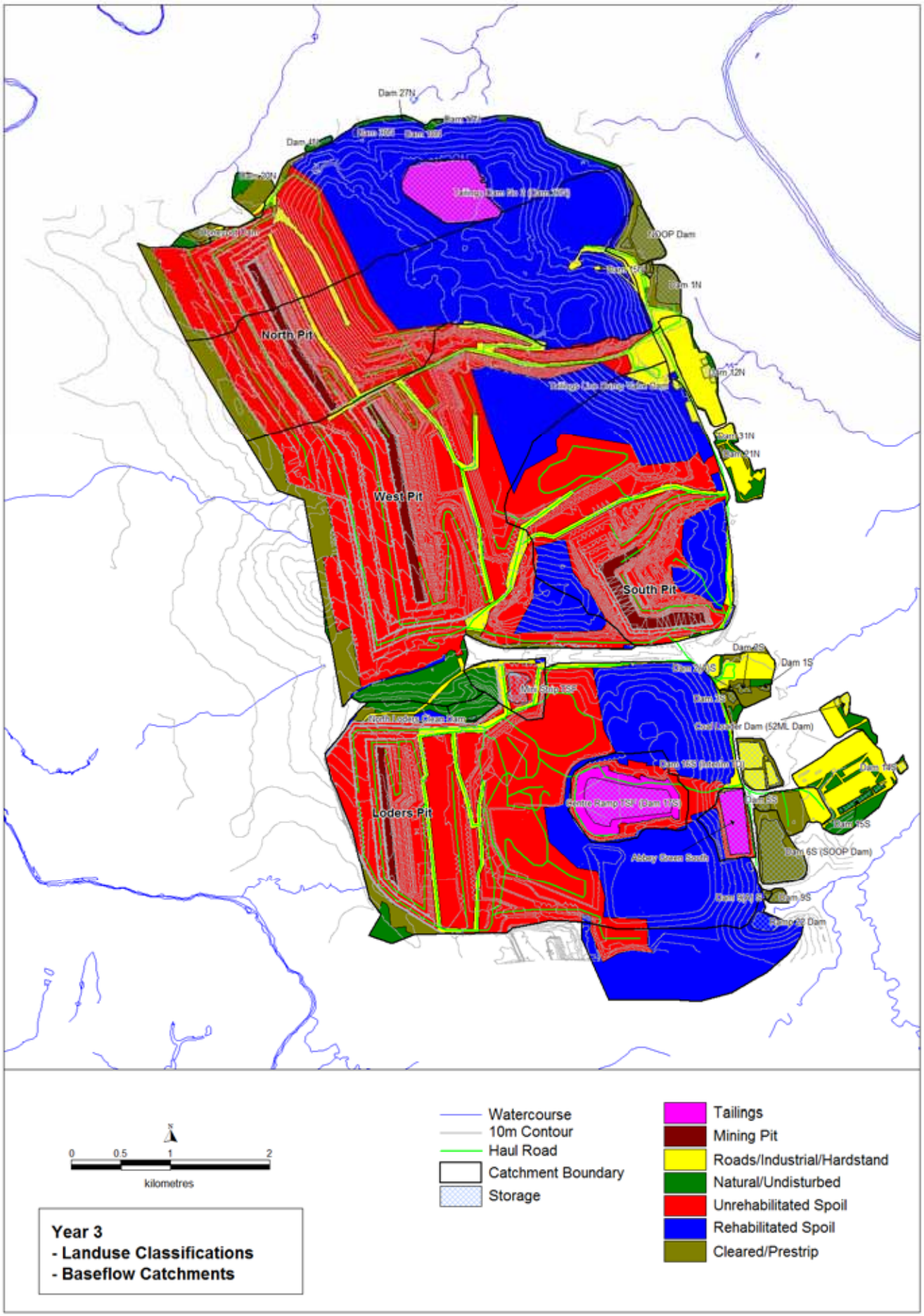


Figure 6.5 MTW Baseflow Catchments & Land Use Classifications – Year 3

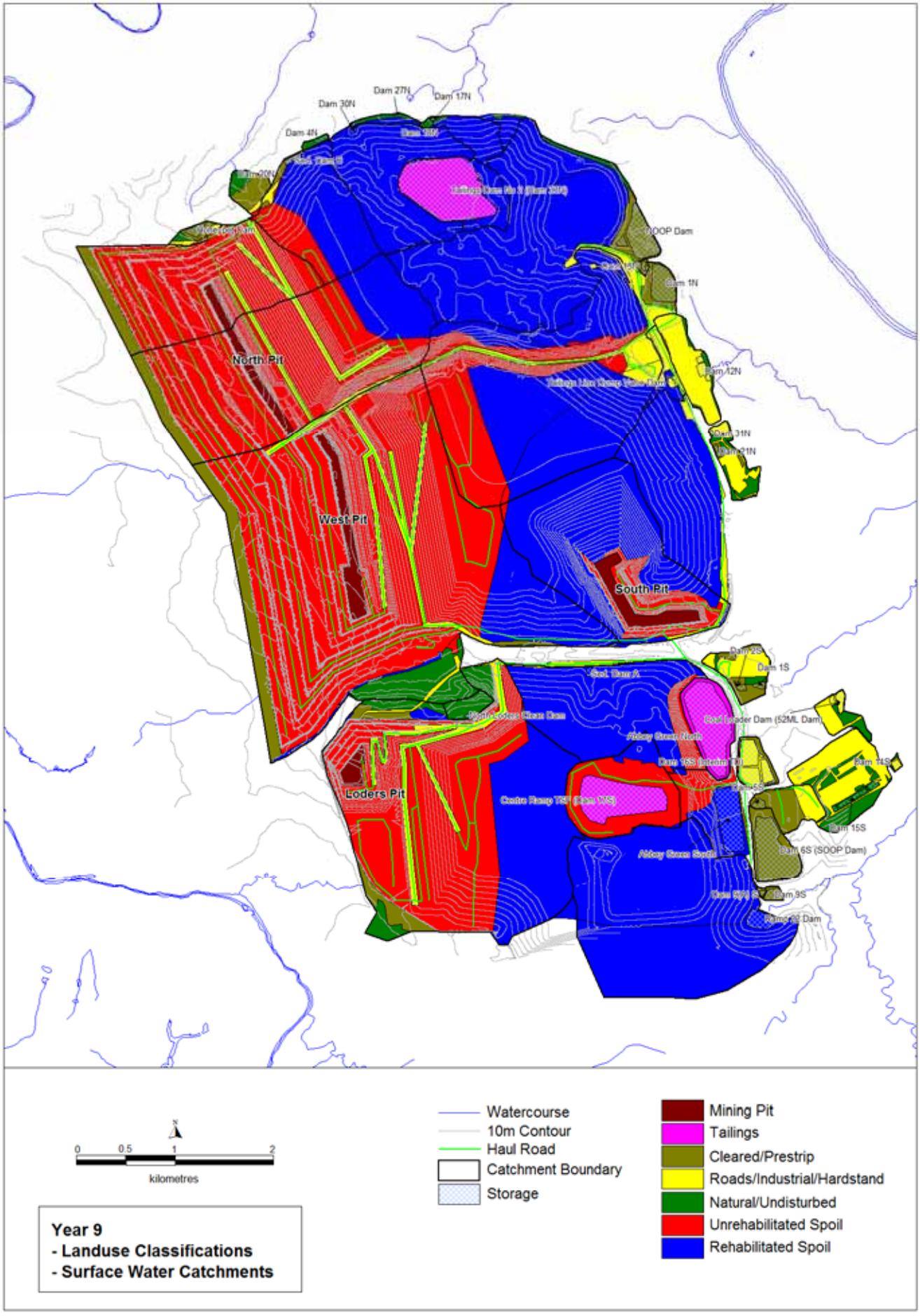


Figure 6.6 MTW Surface Catchments & Land Use Classifications – Year 9

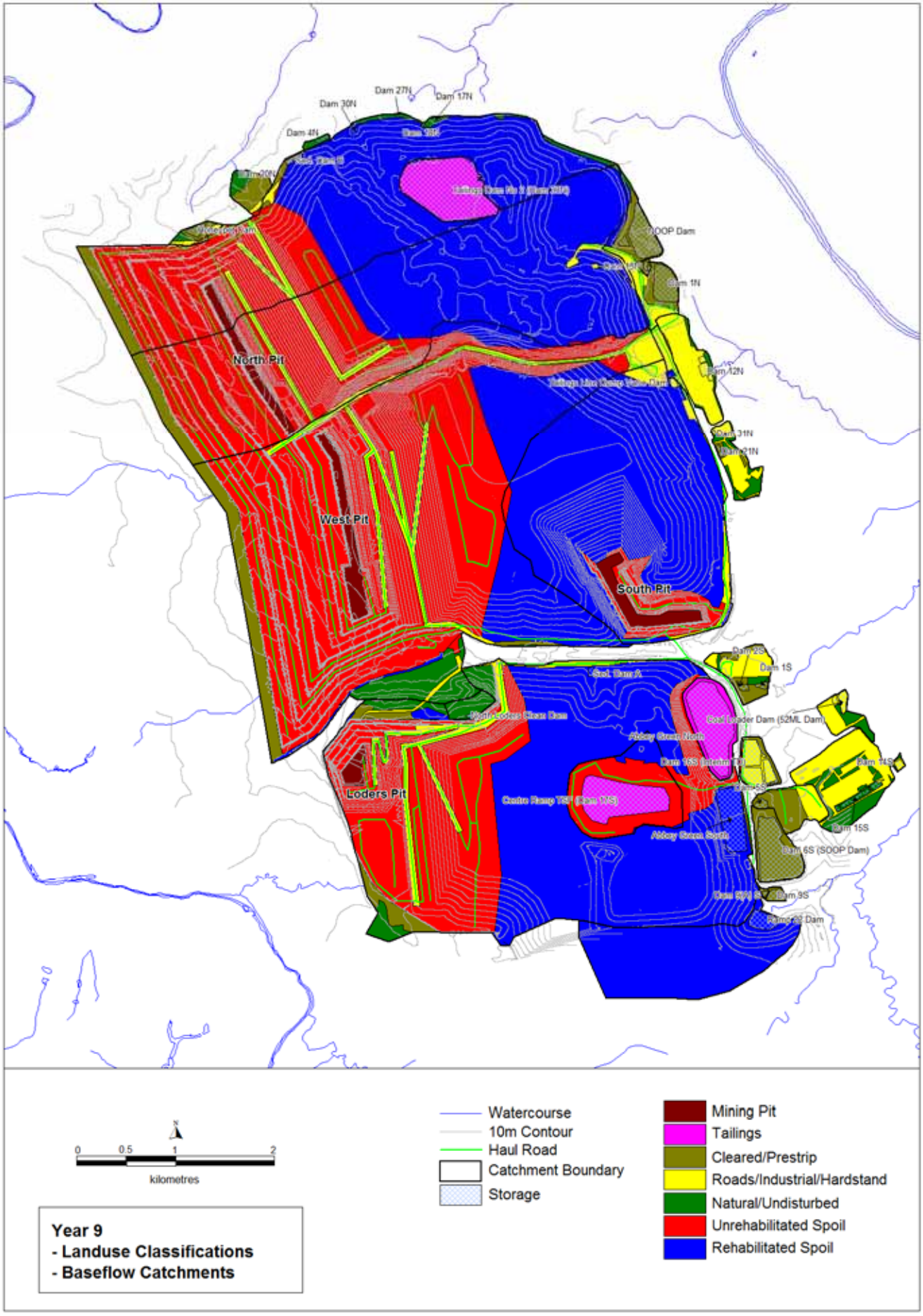


Figure 6.7 MTW Baseflow Catchments & Land Use Classifications – Year 9

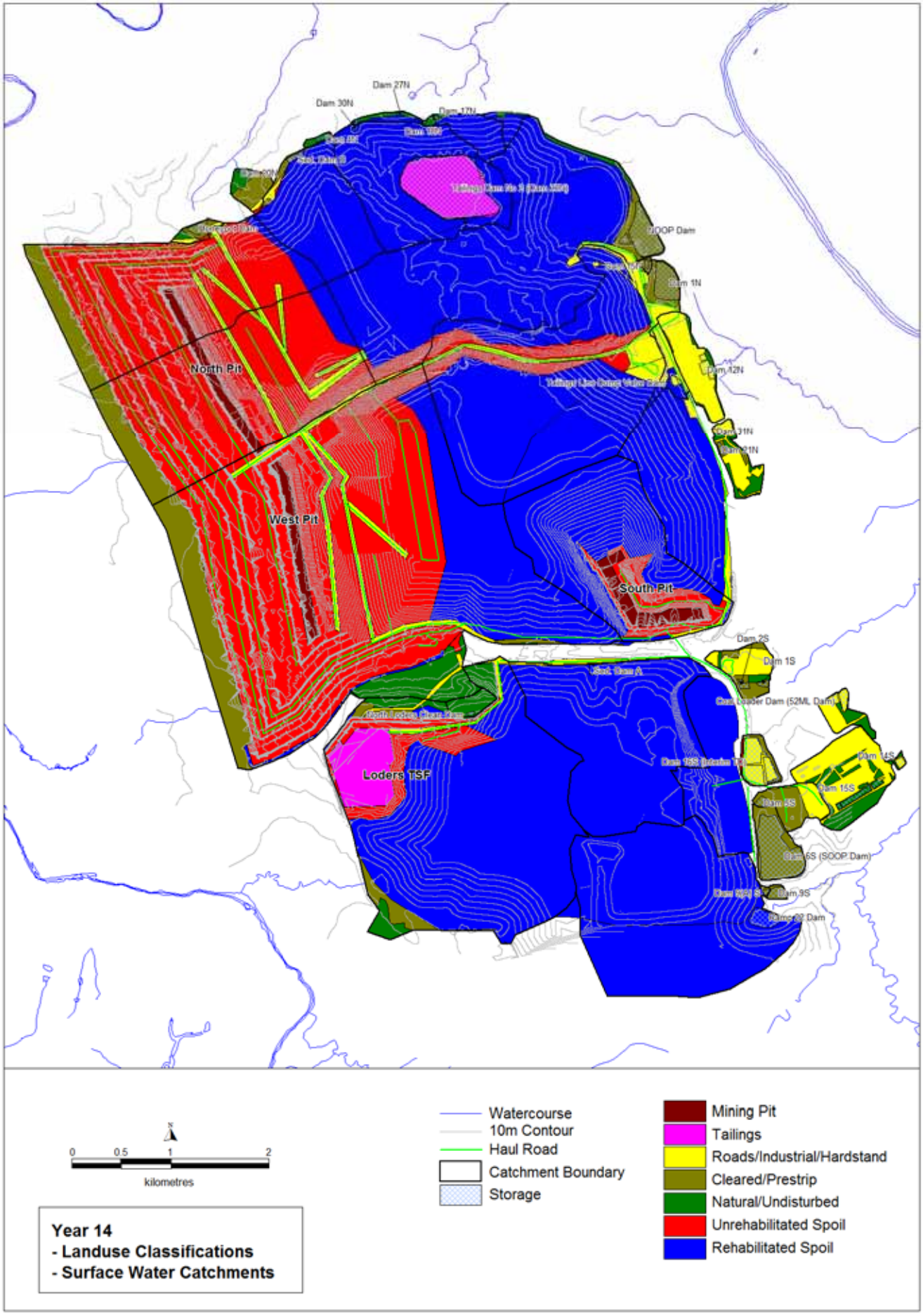


Figure 6.8 MTW Surface Catchments & Land Use Classifications – Year 14

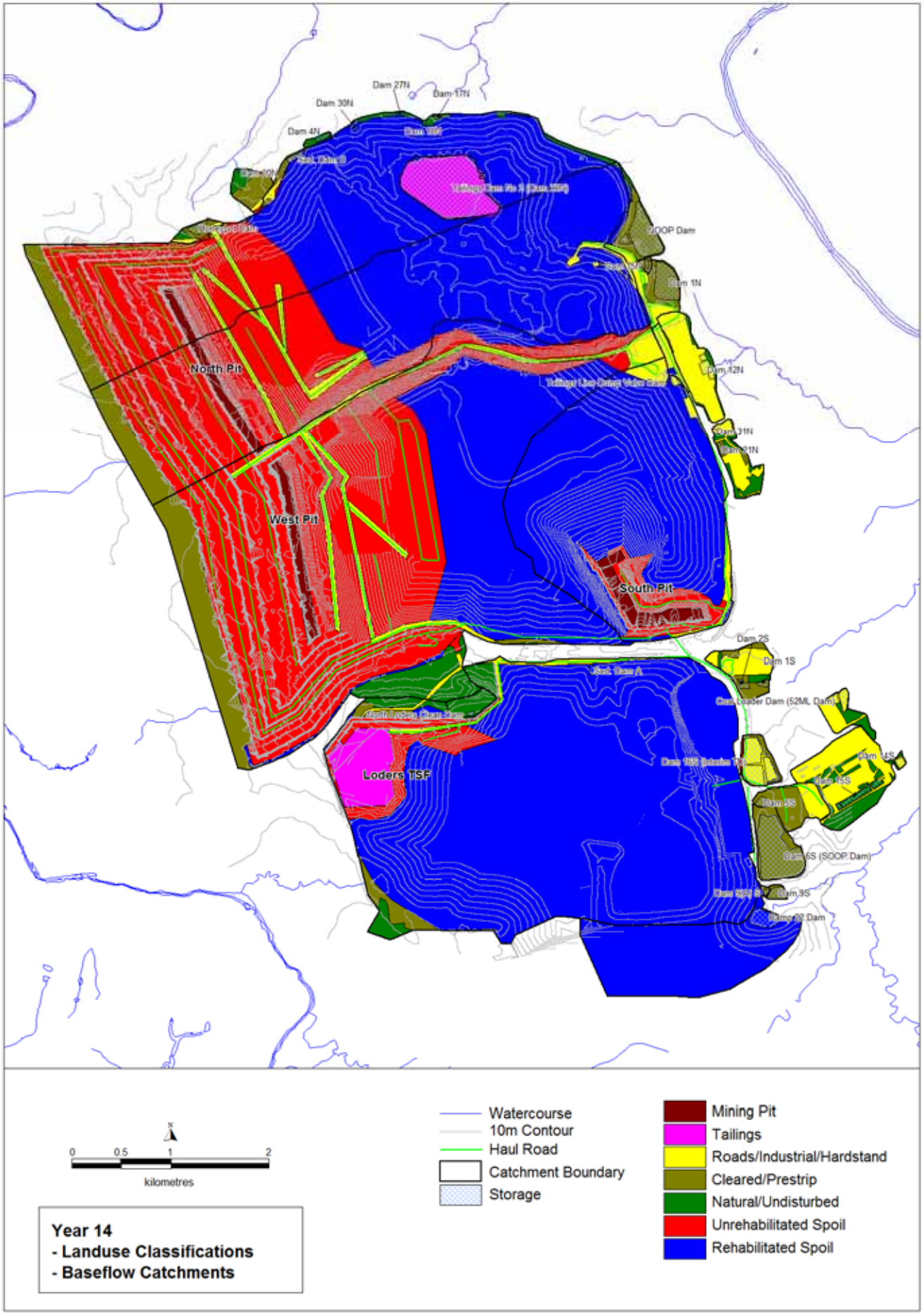


Figure 6.9 MTW Baseflow Catchments & Land Use Classifications – Year 14

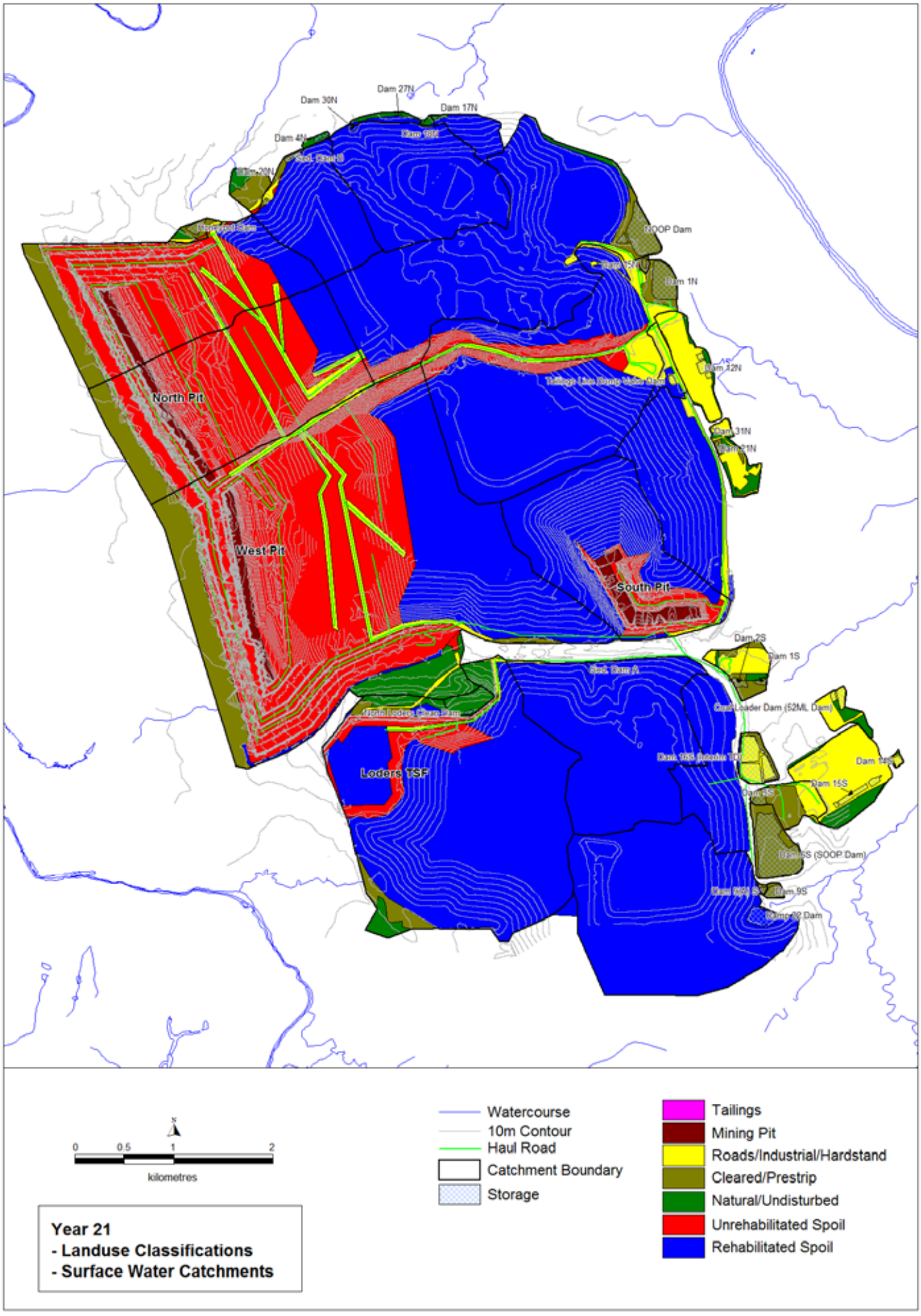


Figure 6.10 MTW Surface Catchments & Land Use Classifications – Year 21

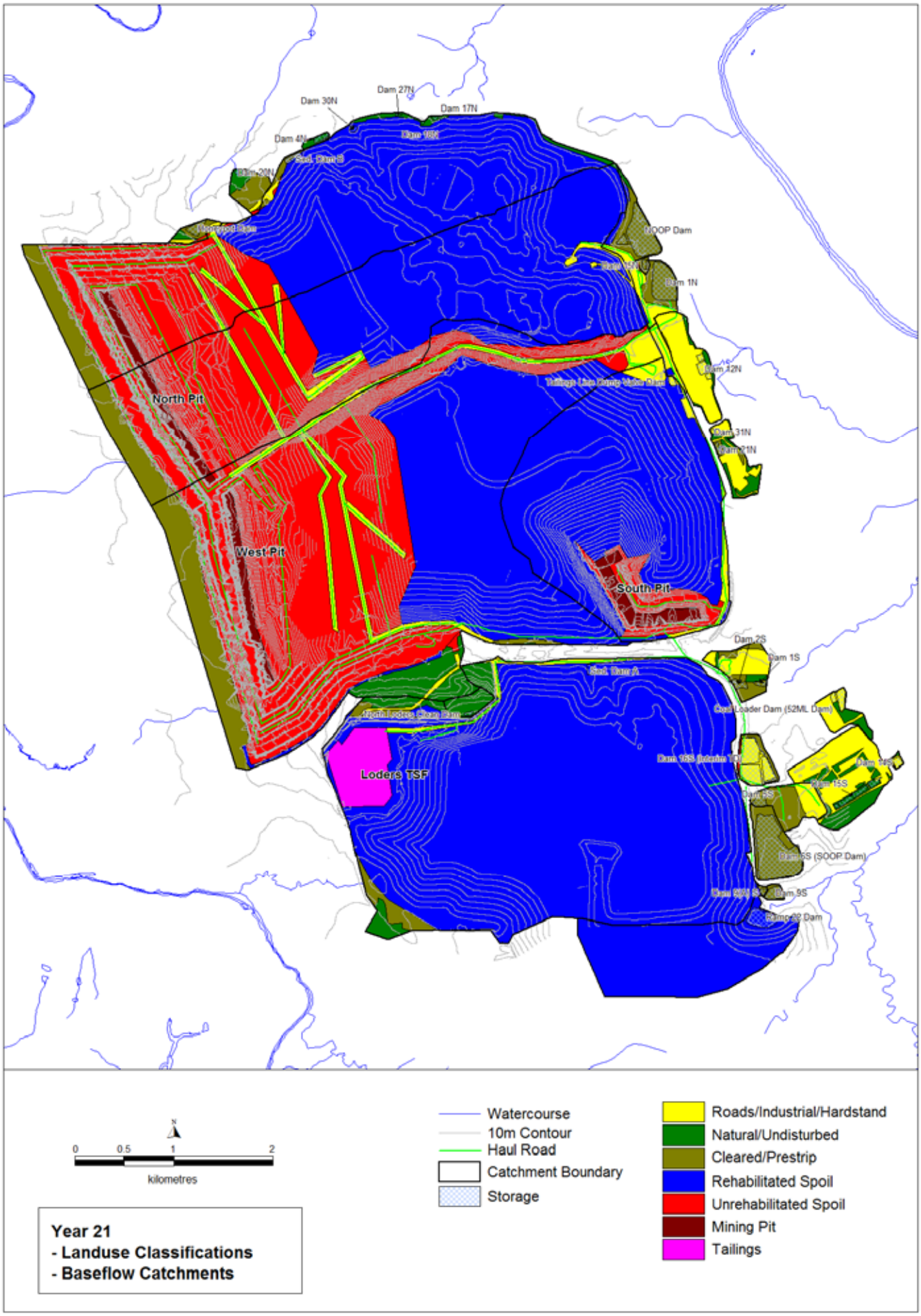


Figure 6.11 MTW Baseflow Catchments & Land Use Classifications – Year 21

6.5.5 Water Quality

An estimate of salinity generation rates for each land use type and water source (raw water, groundwater) has been made based on the MTW water quality monitoring program (refer Section 2.6.2). It is proposed to adopt the salinity generation rates shown in Table 6.5.

Table 6.5 MTW Salinity Generation Rates

Land Use Classification / Salt Source	Salinity Generation Rate (µS/cm)	Basis
Natural/Undisturbed	300	Wollombi Brook, Dam 11N
Cleared/Prestrip	1,500	Dam 12S, Dam 6N
Mining Pit	15,000	Assumed same as groundwater salinity
Unrehabilitated Spoil	4,000	Dam 1N, Dam 6S
Rehabilitated Spoil	600	Dam 30N
Roads/Industrial/Hardstand	3,000	Dam 15S
Tailings	10,000	Dam 1N, Dam 6S
MTJV Raw Water Supply	650	Hunter River
Groundwater	15,000*[a]	(AGE, 2014a)

Notes: *[a] Average water quality of alluvial aquifers in Mount Thorley area, samples taken from 1993 to 2013 indicates an EC of between 931 to 27,800µS/cm.

6.5.6 Water Demands

CHPP

The MTW coal preparation facilities consist of two plants:

- Warkworth Mine CPP (North Plant); and
- MTO CPP (South Plant).

MTW has provided forecast total washed and unwashed coal throughputs and production rates. Based on the provided production schedule and the 2013 plant characteristics (WRM, 2014), plant moisture balances for each of the North CHPP and South CHPP have been determined and are shown in Table 6.6 to Table 6.9.

Note that 0.5 Mtpa of coal bypass will be produced for the life of the proposal. It is assumed that the bypass coal has negligible water requirements and therefore does not impact the site water balance.

Table 6.6 Warkworth Mine CPP (North Plant) – Year 0

Item	Mtpa (wet)	t/day (wet)	Total Moisture (%)	Dry Solids (t/day)	Moisture (kL/d)
Raw Feed	9.22	25,254	5.5	23,865	1,389
Product Coal	6.59	18,056	8.8	16,467	1,589
Tailings	4.79	13,133	83.1	2,219	10,913
Coarse Rejects	2.22	6,029	14.1	5,179	850
			Process Plant Makeup Requirement		**11,963**
			Plant yield (wet)		71.5 %
			Plant yield (dry)		69.0 %
			Fine/coarse split (dry)		30 %
			Water use (L/ROM tonne (wet))		474

Table 6.7 Warkworth Mine CPP (North Plant) – Year 3 to Year 21

Item	Mtpa (wet)	t/day (wet)	Total Moisture (%)	Dry Solids (t/day)	Moisture (kL/d)
Raw Feed	9.52	26,093	5.5	24,568	1,435
Product Coal	6.81	18,655	8.8	17,014	1,642
Tailings	4.95	13,569	83.1	2,293	11,276
Coarse Rejects	2.27	6,229	14.1	5,351	878
			Process Plant Makeup Requirement		**12,361**
			Plant yield (wet)		71.5 %
			Plant yield (dry)		69.0 %
			Fine/coarse split (dry)		30.0 %
			Water use (L/ROM tonne (wet))		474

Table 6.8 MTO CPP (South Plant) – Year 0

Item	Mtpa (wet)	t/day (wet)	Total Moisture (%)	Dry Solids (t/day)	Moisture (kL/d)
Raw Feed	7.92	21,688	4.8	20,647	1,041
Product Coal	5.63	15,418	7.6	14,246	1,172
Tailings	2.62	7,165	73.2	1,920	5,245
Coarse Rejects	1.90	5,198	13.8	4,480	717
			Process Plant Makeup Requirement		**6,093**
			Plant yield (wet)		71.1 %
			Plant yield (dry)		69.0 %
			Fine/coarse split (dry)		30.0 %
			Water use (L/ROM tonne (wet))		281

Table 6.9 MTO CPP (South Plant) – Year 3 to Year 21

Item	Mtpa (wet)	t/day (wet)	Total Moisture (%)	Dry Solids (t/day)	Moisture (kL/d)
Raw Feed	9.45	25,901	4.8	24,658	1,243
Product Coal	6.72	18,413	7.6	17,014	1,399
Tailings	3.12	8,557	73.2	2,293	6,263
Coarse Rejects	2.27	6,207	13.8	5,351	857
			Process Plant Makeup Requirement		**7,276**
			Plant yield (wet)		71.1 %
			Plant yield (dry)		69.0 %
			Fine/coarse split (dry)		30.0 %
			Water use (L/ROM tonne (wet))		281

Haul Road Dust Suppression

A dry day haul road watering rate of 3.5mm/d was determined based on the average recorded rate over the 2013 period (WRM, 2014). This rate has been adopted and applied to the varying watered haul road length as the mine develops, with an assumed watered width of 20m. The resultant average dust suppression water requirements are presented in Table 6.10. Estimates of haul road lengths were based on indicative mine plan information as presented in Figure 6.4 to Figure 6.11.

Table 6.10 Estimated Haul Road Dust Suppression Requirements

Mining Stage	Dust Suppression Area (ha)	Maximum Daily Dust Suppression (kL/d)*	Yearly Average Dust Suppression (ML/a)**
Year 0	199	6,962	1,623
Year 3	185	6,478	1,510
Year 9	174	6,106	1,423
Year 14	140	4,910	1,144
Year 21	136	4,770	1,107

* For a non-rainfall (<0.1 mm) day.
** Based on long term average including rainfall days.

Miscellaneous Industrial Demand and Vehicle Washdown

The miscellaneous industrial use and the vehicle washdown are sourced directly from the MTJV raw water pipeline. Usage is metered; however the breakdown of industrial use and vehicle washdown is not available at Warkworth Mine. The MTW 2013 water balance update (WRM, 2014) estimated the usages and return rates at the north and south workshops and vehicle washdown locations.

The average rates over 2012/13 were estimated as follows:

- South vehicle washdown 53kL/d (8kL/d return, 45kL/d loss)
- South workshop misc. industrial use 151kL/d (100 per cent loss)

- North vehicle washdown — 53kL/d (8kL/d return, 45kL/d loss)
- North workshop misc. industrial use — 59kL/d (100 per cent loss)

These usages have been assumed to vary based on plant throughput. A return rate of 15 per cent has been adopted for vehicle washdown.

Demand Summary

Table 6.11 shows a summary of demands over the life of the proposal.

Table 6.11 Summary of Demands (ML/a)

Demand	2014	2017	2023	2028	2035
CHPP gross (net)*[a]	6,591 (2,466)	7,168 (2,731)	7,168 (2,731)	7,168 (2,731)	7,168 (2,731)
Haul Road Dust Suppression*[b]	1,623	1,510	1,423	1,144	1,107
Misc. Industrial Use & Vehicle Washdown – gross (net)*[a]	135 (126)	146 (136)	146 (136)	146 (136)	146 (136)
Total – gross (net)*[a]	**8,349 (4,215)**	**8,824 (4,377)**	**8,737 (4,290)**	**8,458 (4,011)**	**8,421 (3,974)**

*[a] Net rates include return.
*[b] Long term average (dependant on rainfall). Based on haul road lengths of 92.6km, 87.2km, 70.1km and 68.1km for 2017, 2023, 2028 and 2035 year indicative mine plans respectively.

6.5.7 Proposed Sediment Dams

Conceptual sediment dam locations have been proposed based on the indicative mine plans and are shown in Figure 6.4 to Figure 6.11. The locations and sizes of the sediment dams are conceptual for inclusion in the water balance modelling and will be refined and confirmed through detailed design and incorporated into the MTW Water Management Plan (WMP).

Sizing of the proposed sediment basins has been undertaken in accordance with the Blue Book (DECC, 2008) requirements for Type D basins. Adopted sediment dam sizes are shown in Table 6.12. Note that the pump rates shown in Table 6.12 are based on a 5 day management period. To reduce these required pumping rates, the guidelines specify adjustment factors to the 5-day volumes for alternate management periods as 85 per cent for 2 days, 125 per cent for 10 days, and 170 per cent for 20 days.

A summary of the assumptions and parameters adopted for the concept sizing of the sediment basins is as follows:

- The catchment areas used to size each sediment dam are the maximum area draining to a dam at any time during the mine life;
- Type D basin (for dispersive soils);
- Design rainfall: duration of disturbance >3 years, 90th percentile, 5 day rainfall depth (for standard receiving waters) = 42.8mm;
- Volumetric runoff coefficient C_v = 0.69;
- Sediment storage zone = 50 per cent of settling zone; and
- Maximum 5m storage depth.

Table 6.12 Proposed Sediment Dam Sizing

Sediment Dam	Catchment Area (ha)*	5-Day Volume (ML)	5-Day Pump Out Rate (L/s)
Sediment Dam A	238	105	244
Sediment Dam B	102	45	105

Notes: * Maximum catchment area reporting to sediment dam over project life.

6.5.8 Hunter River Salinity Trading Scheme

To model future HRSTS discharges from MTW, a Hunter River streamflow and water quality time series was obtained from NOW's IQQM model (full development case with 2004 water sharing plan rules) for the period 16/09/1892 to 30/6/2007. The modelling rules for HRSTS discharges are based on Hunter River stream flow and salinity, and discharge dam volumes and salinity (refer Appendix C).

It is assumed that the number of salt credits held by MTW is not a limitation to releases. Historically there have been sufficient credits available for trade.

The proposal includes an upgrade to the approved discharge point at MTO (Dam 9S) to increase the maximum discharge rate to 300ML/d. The maximum discharge rate at Warkworth Mine (Dam 1N) will remain at 100ML/d.

Controlled releases to the Hunter River under HRSTS are allowed at MTO when the combined inventory of Dam 6S + Dam 9S is greater than 1,500ML, and at Warkworth Mine when the inventory of Dam 1N is greater than 220ML. This ensures that water is not being released at times when the on-site inventory is low and water retention is a key objective.

6.6 WATER MANAGEMENT SYSTEM PERFORMANCE ASSESSMENT

6.6.1 Overview

Key surface water issues for the proposal include:

- Potential for uncontrolled spills from the saline water dams;
- Potential to impact on production due to in-pit water accumulation; and
- Potential for inadequate supplementary water supply from external sources to meet mine-site demands for production and dust suppression.

An assessment of the impacts of the proposal's mine water management system has been undertaken using the water balance model, against the following key performance indicators:

- Mine water inventory: the risk of accumulation (or reduction) of the overall mine water inventory at the proposal, and the associated volumes;
- External water requirements: the risk of requiring imported external water to supplement on-site mine water supplied and the reliability of water supply;
- Uncontrolled spillway discharges: the risk of uncontrolled discharges from the site storages to receiving waters; and
- Overall site water balance.

6.6.2 Interpretation of Results

Water balance results have been analysed in two ways:

- By mine stage – the results for each climatic realisation are averages over the duration of each mine stage (results presented in Section 6.6.3); and
- Annual statistical results – a statistical analysis is performed on an annual basis as a percentile (results presented in Sections 6.6.4 to 6.6.8).

The modelling methodology of a forecast simulation is described in Section 6.2. In interpreting the results of the water balance assessment, it should be noted that the results provide a statistical analysis of the water management system's performance over the 21 years of mine life, based on 93 realisations with different climatic sequences. The 50th percentile probability represents the median results, the 10th percentile represent 10 per cent exceedance and the 90th percentile results represent 90 per cent exceedance. There is an 80 per cent chance that the result will fall within the 10th and 90th percentiles and a 98 per cent chance the result will fall between the 1st and 99th percentiles. Importantly, note that a percentile trace shows the percentile chance of a particular value on each day, and ***does not*** represent continuous results from a single model realisation e.g. the 50th percentile trace does not represent the model time series for median climatic conditions.

6.6.3 Overall Site Water Balance

A water balance for one of the 93 modelled realisations is presented in Table 6.13, averaged over each stage of modelled mine life. The results are presented in Table 6.13 to allow a direct comparison of inflows, outflows and overall water balance between each of the mine stages for the average of all climate realisations for each mine stage. It should be recognised that the following items are subject to climatic variability:

- Rainfall runoff;
- Haul road dust suppression;
- Evaporation;
- External water requirement;
- Controlled releases; and
- Site releases/spills.

The results for the mine stage averages over all climatic realisations show that over the life of the proposal:

- External raw water supply is required in every stage of mine life, with the greatest amount required in Year 21;
- The largest demand from the water management system is due to the CHPP (includes fine tailings moisture retention, product coal and rejects moisture);
- Total mine water demand (including CHPP makeup, dust suppression and miscellaneous industrial use and vehicle washdown) ranges between approximately 4,000ML/a to 4,400ML/a, with the highest demand in Year 3;
- No overflows from the saline water storages occurred in the simulation period; and
- The combined spill volumes from the sediment dams is highest in Year 14 (316ML/a), which corresponds to the stage with the highest rainfall yield, and ranges between 91ML/a and 316ML/a for the remaining stages.

Table 6.13 MTW Average Water Balance for Each Mine Stage over all Climatic Realisations

Process	Volume (ML/a)				
	Year 0 (2 years)	Year 3 (4 years)	Year 9 (7 years)	Year 14 (5 years)	Year 21 (4 years)
INFLOWS					
Rainfall Runoff	3,524	3,846	4,111	4,210	4,278
Groundwater	186	10	0	0	0
External Raw Water Requirements	1,251	1,807	1,720	1,519	1,803
ROM moisture	877	978	978	978	978
Redbank Power Station	25	25	25	25	25
Total Inflows	**5,873**	**6,665**	**6,833**	**7,016**	**7,084**
OUTFLOWS					
Evaporation	495	656	751	607	817
Fine tailings moisture retention	1,774	1,965	1,965	1,965	1,965
Haul road dust suppression	1,644	1,533	1,471	1,195	1,171
Misc. ind. demand & vehicle wash	126	136	136	136	136
Product coal moisture	1,008	1,110	1,110	1,110	1,110
Coarse rejects moisture	572	633	633	633	633
HRSTS Discharges	561	453	548	369	366
Offsite Sediment Dam Releases	91	214	240	316	315
Offsite Saline Dam Releases	0	0	0	0	0
Total Outflows	**6,253**	**6,679**	**6,803**	**6,274**	**6,450**
Change in Site Water Inventory	***-380***	***-14***	***+30***	***+742***	***+634***

6.6.4 Pit Storage Characteristics

An assessment of pit inventory characteristics has been undertaken to determine the likelihood of water inundating the pit, which could impact production. A forecast assessment has been used.

Figure 6.12 shows the predicted probability of the modelled total in-pit storage volume. A build-up of water in the active pits generally occurs when the out-of-pit storages are too full to accept additional pit water, or the catchment runoff draining to the pit is greater than the dewatering pump capacity.

Figure 6.13, Figure 6.14, Figure 6.15 and Figure 6.16 show the predicted probability of the modelled in-pit storage volume as a percentage of days for North Pit, West Pit, South Pit and Loders Pit, respectively. The assessment of in-pit inventory shows that:

- There is a one per cent chance of total in-pit volume up to 1,900ML at any year of project life;
- There is a 10 per cent chance of total in-pit volume up to 400ML at any year of project life;
- All individual pits are considered to have a low probability of pit inundation, and are likely to accumulate volumes of up to 900ML only in extreme climate conditions.

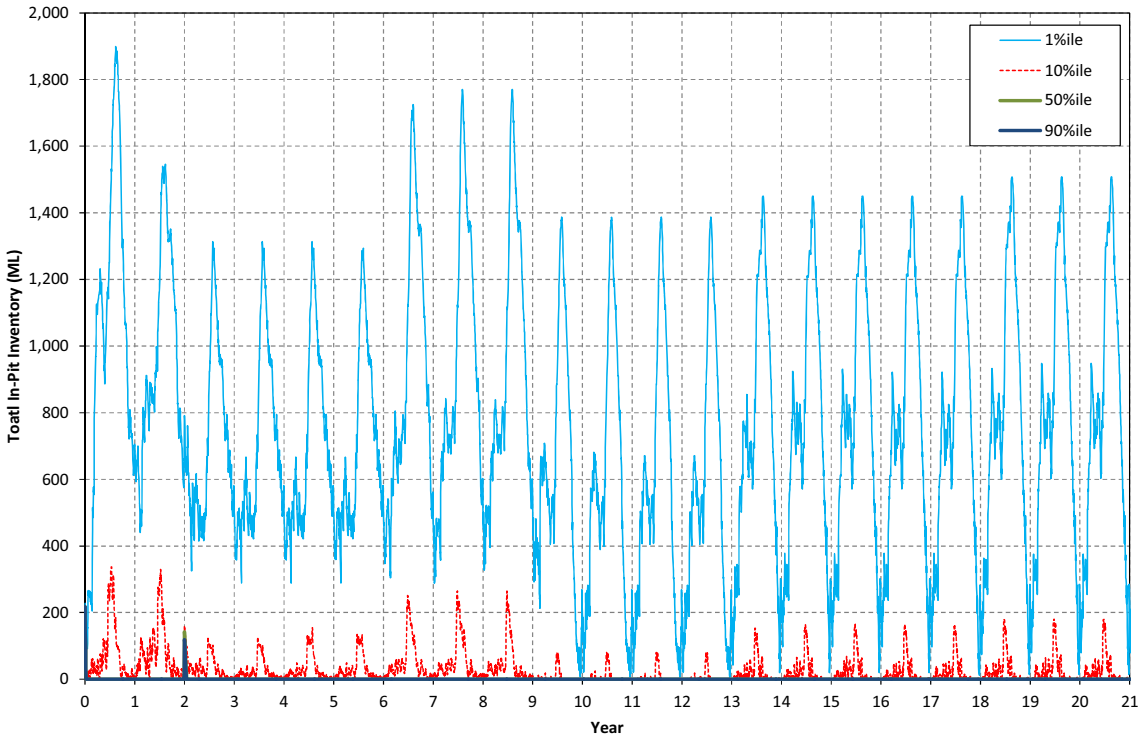


Figure 6.12 Total In-Pit Storage Inventory (ML)

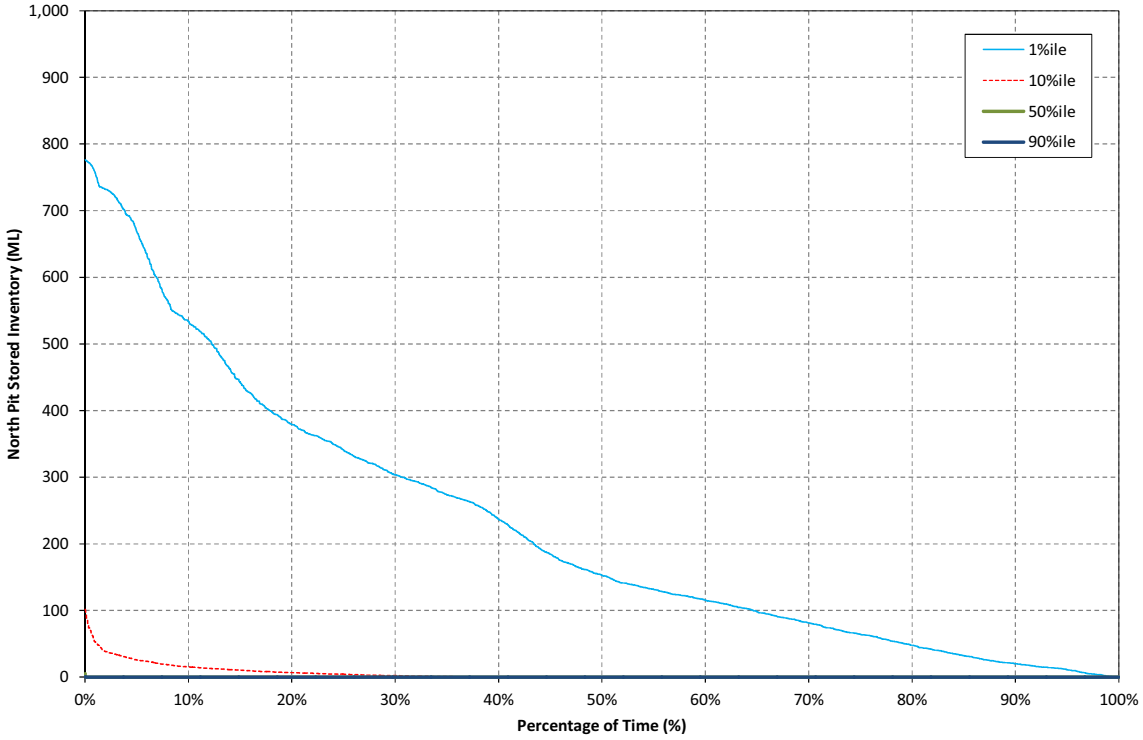


Figure 6.13 North Pit Inundation Characteristics

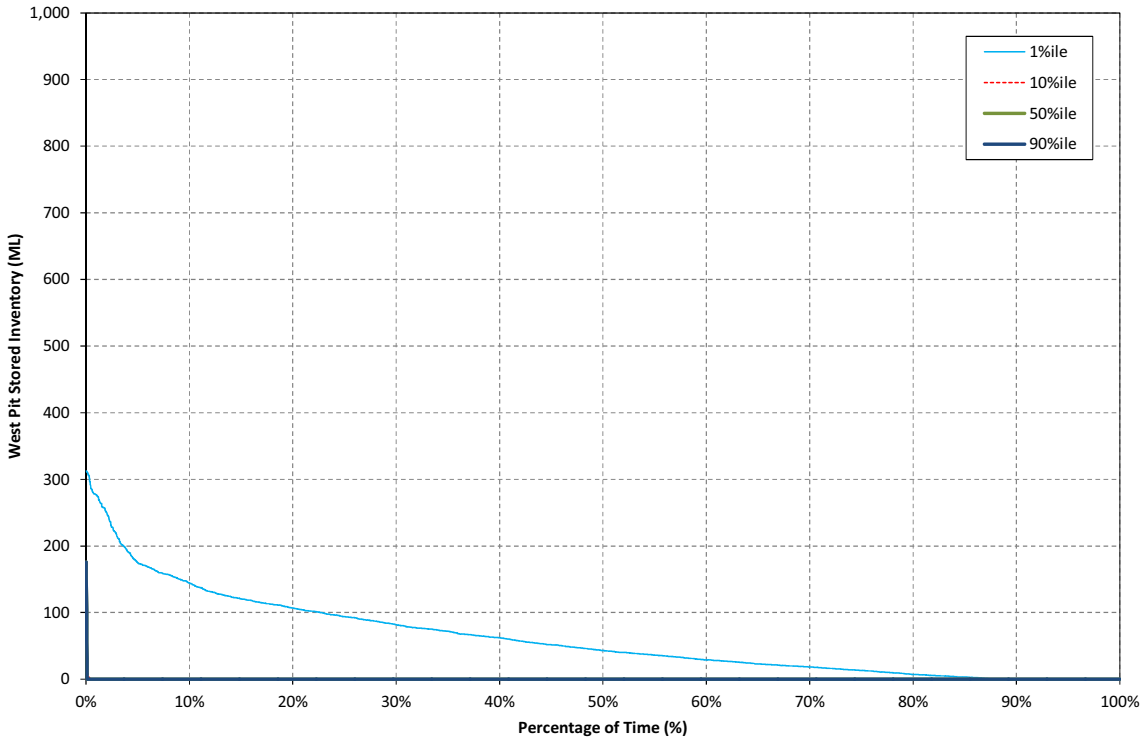


Figure 6.14 West Pit Inundation Characteristics

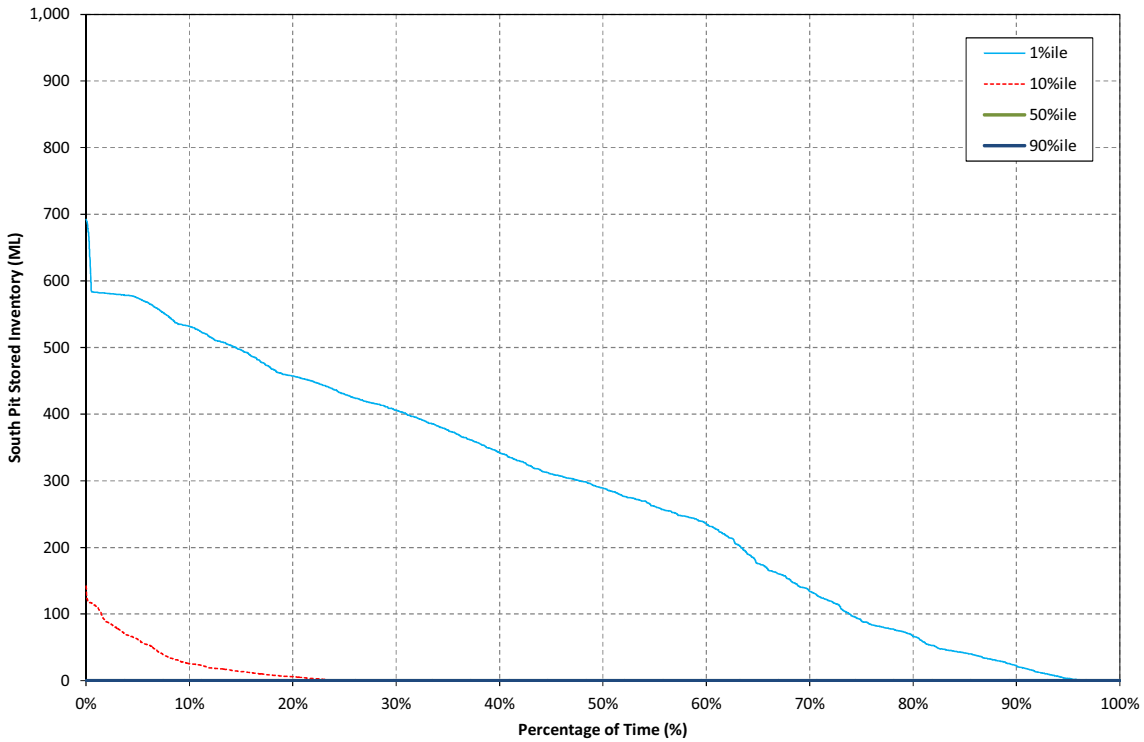


Figure 6.15 South Pit Inundation Characteristics

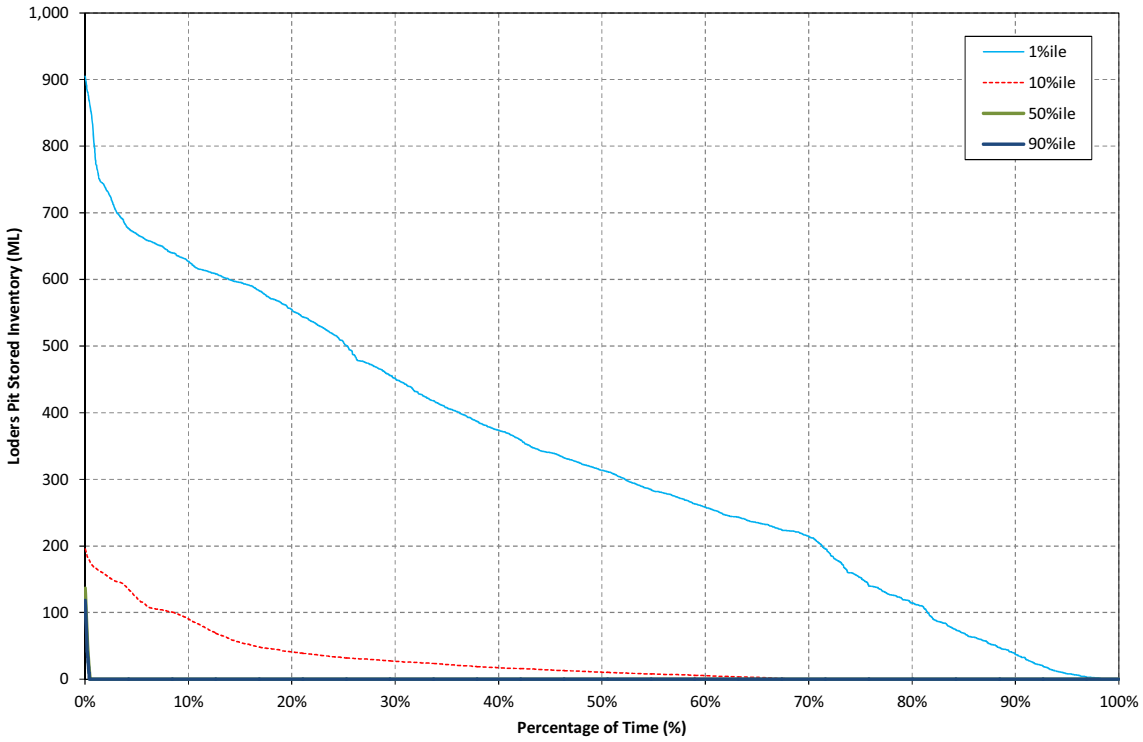


Figure 6.16 Loders Pit Inundation Characteristics

6.6.5 Out-of-Pit Storage Characteristics

A forecast assessment has been undertaken to estimate the future out-of-pit water inventory. The out-of-pit water storages included in the analysis are the four main saline water storage dams on site (existing and proposed):

- Dam 6S (SOOP Dam);
- Dam 9S;
- Dam 1N; and
- NOOP Dam (proposed).

Figure 6.17 shows the predicted probability of the modelled total out-of-pit storage inventory. The combined capacity (to spillway) of the four primary saline water storages is 2,621ML (prior to construction of NOOP Dam), and 3,363ML including the NOOP Dam capacity. The results show that:

- Consistent with the in-pit inventory results, the water management system is not at risk of accumulating water over the life of the project and is able to recover prior to each subsequent wet season;
- The total out-of-pit inventory:
  - Has a one per cent chance of reaching at least 2,000ML in Years 0 to 2, and at least 2,500ML in any year after that;
  - Has a 10 per cent chance of reaching between 1,500ML to 2,500ML in any year;

- Has a 50 per cent chance of reaching an inventory of at least 300ML in any year;
- Has a 90 per cent chance of reaching an inventory of at least 0ML to 100ML in any year (equivalent to a 10 per cent chance of not exceeding approximately 0ML to 100ML in any year).

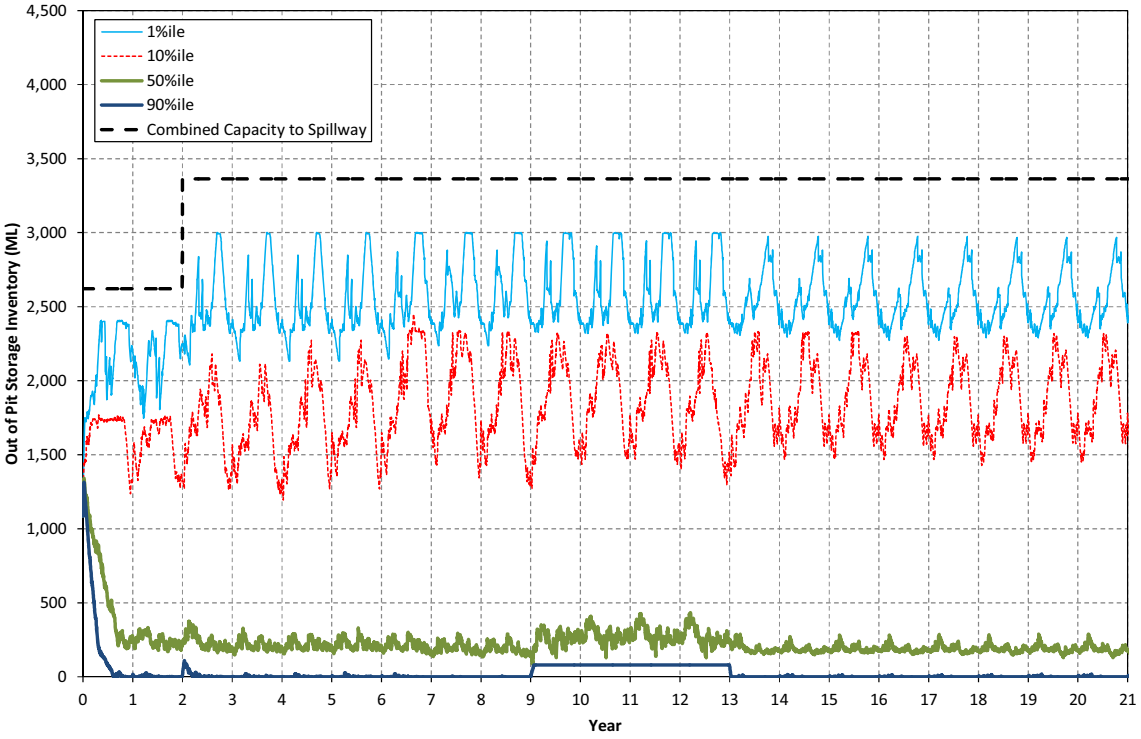


Figure 6.17 Out-of-Pit Water Inventory

6.6.6 Controlled HRSTS Discharges to Hunter River

The potential for controlled releases under the proposal has been assessed using a forecast assessment simulation. The predicted probability of the annual controlled discharges from MTO and Warkworth Mine are provided in Figure 6.18 and Figure 6.19 respectively. The results show that:

- Overall, much greater volumes are discharged from MTO than Warkworth Mine, which is consistent with the capacity of the discharge structures (200ML/d at MTO and 100ML/d at Warkworth Mine) and dam volumes;
- There is a 50 per cent chance of controlled releases from MTO will not be required in any year of the life of the proposal, and small volumes of controlled discharges (100ML) will be required from Warkworth Mine in any year of the life of the proposal; and
- There is a 10 per cent chance of controlled releases from MTO of between 1,000ML to 2,000ML will be required in any year of the life of the proposal, and around 400ML from Warkworth Mine in any year of the life of the proposal.

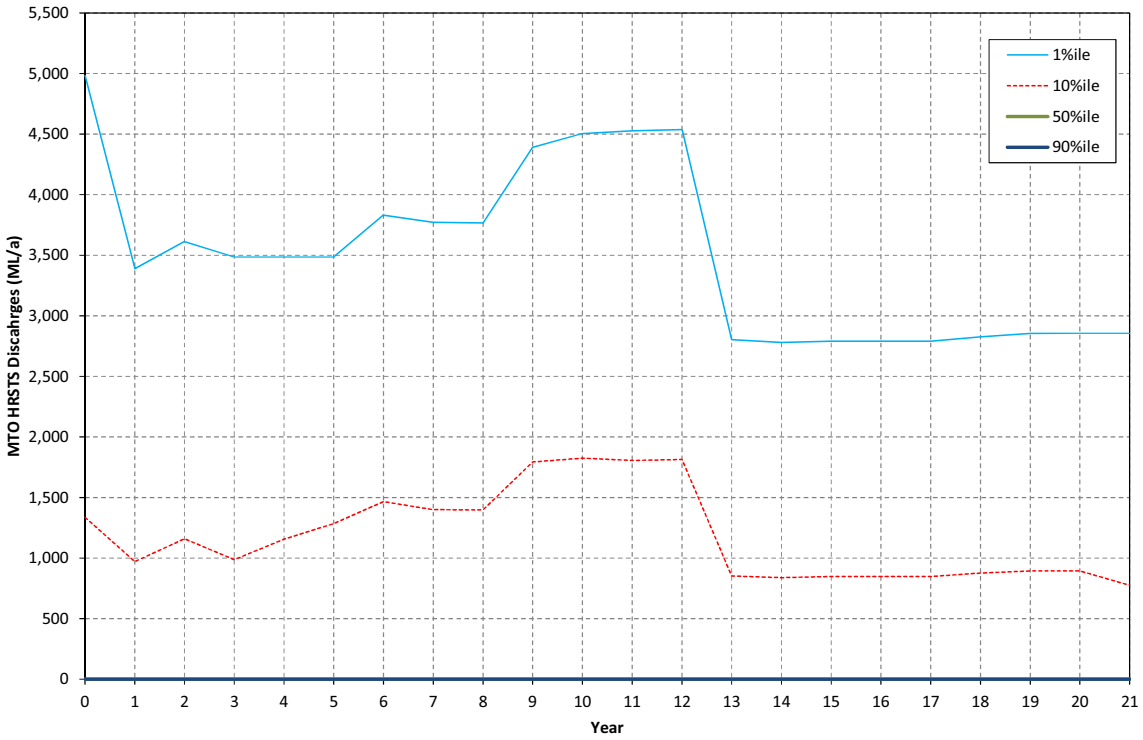


Figure 6.18 MTO Discharges to Hunter River

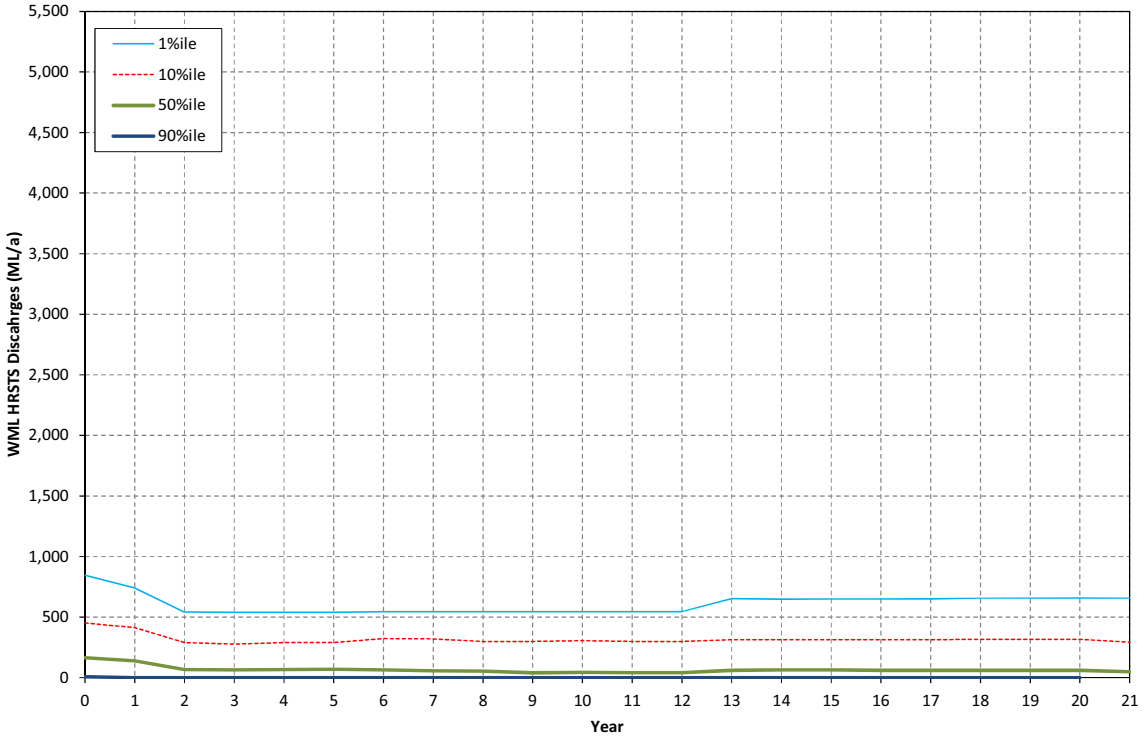


Figure 6.19 Warkworth Mine Discharges to Hunter River

6.6.7 External Water Requirements

For the purposes of current investigations, the term 'external water requirements' represents the amount of imported water from external third party sources, such as the Hunter River (or other sources such as water sharing agreements with nearby mine sites) that is required to sustain the nominated design production rate and associated operational demands for the proposal. The simulation of the water management system assumes that any shortfall in water captured onsite is made up from imported water – that is, during dry periods imported water is used to ensure that all operational demands are met. Note that the current MTJV allocation is 1,012ML/a (at 100 per cent Available Water Determination (AWD)).

This potential requirement for external water supply has been assessed using a forecast assessment simulation. The predicted probability of annual external water requirement is provided in Figure 6.20. The results show that:

- A minimum of 140ML/a of external raw water (from the Hunter River) will be required for the life of the proposal. This is consistent with site demands of industrial use and vehicle wash of around 140ML/a which are supplied from raw water sources only;
- There is a 90 per cent chance that at least 450ML of external water will be required in any year of project life.
- A step change in external water requirement occurs in around Year 2 which is consistent with the modelled decrease in groundwater inflows at MTO, and an increase in production. From Year 3 onwards the external water requirements are generally consistent with:
  - A 50 per cent chance that between 1,500ML/a to 2,000ML/a of external water will be required; and
  - A 10 per cent chance that between 3,000ML/a to 3,700ML/a of external water will be required.

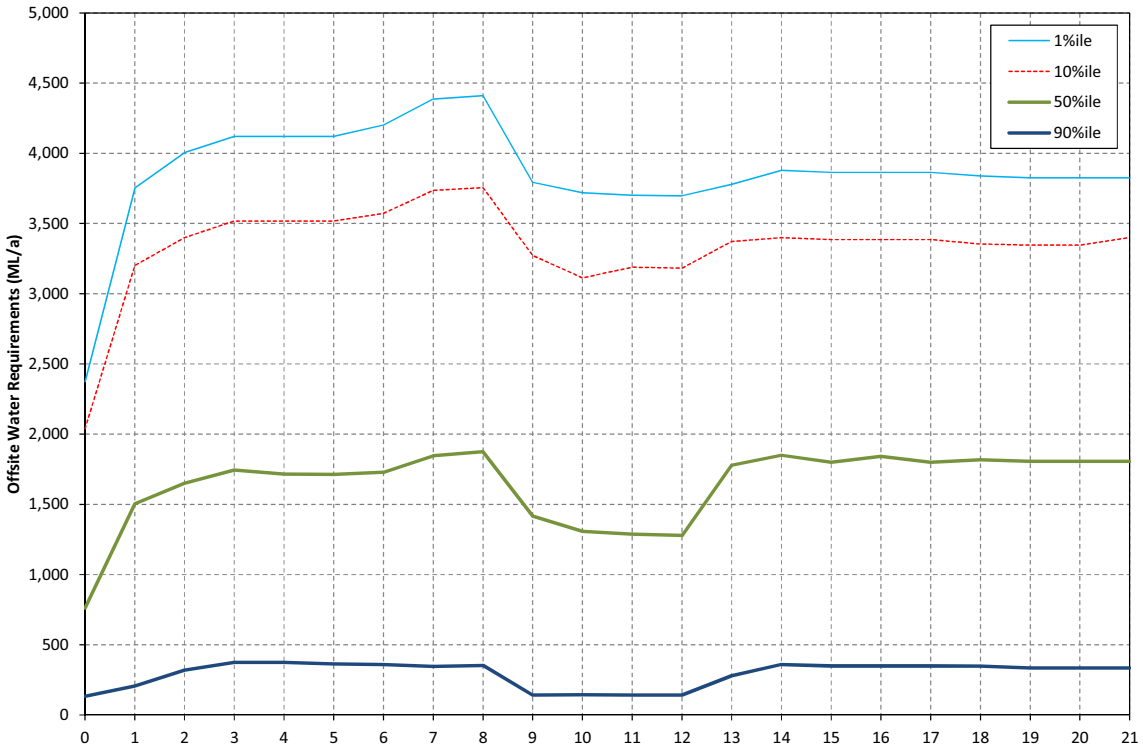


Figure 6.20 MTW External Water Requirements

6.6.8 Uncontrolled Offsite Discharges

Expected discharges from the proposal have been assessed on the basis of simulated spillway overflows from site storages to receiving waters. The assessment includes storages which have the ability to discharge via a spillway into the receiving waters, including saline dams and sediment dams. No saline water discharges were simulated for the life of the project. Figure 6.21 shows the sediment dam offsite overflows, assessed using a forecast simulation. Results show that sediment dam overflows increase over the life of the proposal, consistent with the increase in rehabilitation of spoil areas and diversion of these areas offsite.

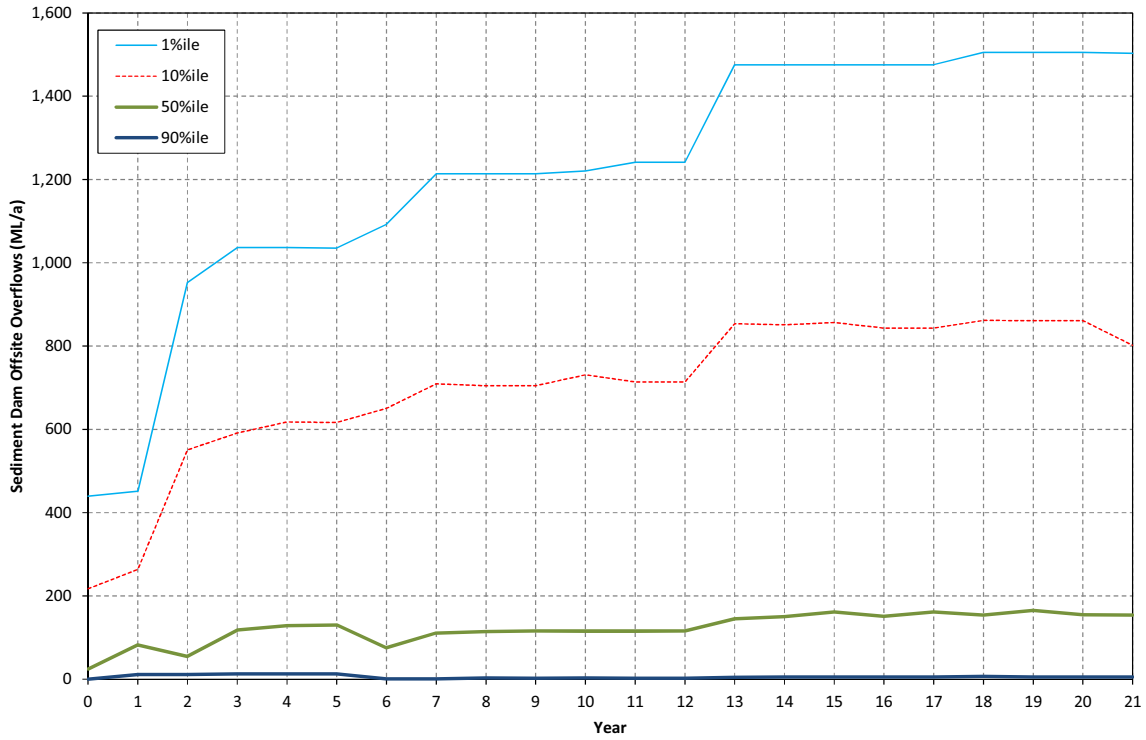


Figure 6.21 Sediment Dam Offsite Overflows (ML/a)

6.7 FINAL LANDFORM STORAGE AND WATER QUALITY BEHAVIOUR

6.7.1 Overview

The behaviour of the MTW final voids has been simulated to assess the long term accumulation of water and salts. Two final voids will remain: North Pit and West Pit final voids at Warkworth mine, as well as a depression at MTO at the location of the partially backfilled Loders Pit, which is proposed to be used for tailings storage.

6.7.2 Groundwater Behaviour

Figure 6.22 shows the estimated groundwater inflows to the Warkworth final void and Loders depression (AGE, 2014), and outflows. An iterative methodology was used to achieve agreement between the surface water model and groundwater model. The groundwater inflows from the spoil to the void are initially quite high, and decrease sharply. This is a result of the capping of tailings dams which used to seep to the void. The groundwater inflows from spoil then reach an equilibrium which is essentially rainfall runoff baseflow through the spoil piles. Note that water seeps out of the Loders depression, some of which flows to the Warkworth Void and some flows to the Wollombi alluvium. The potential impact on the Wollombi alluvium is discussed further in the AGE (2014) Groundwater Impact Assessment.

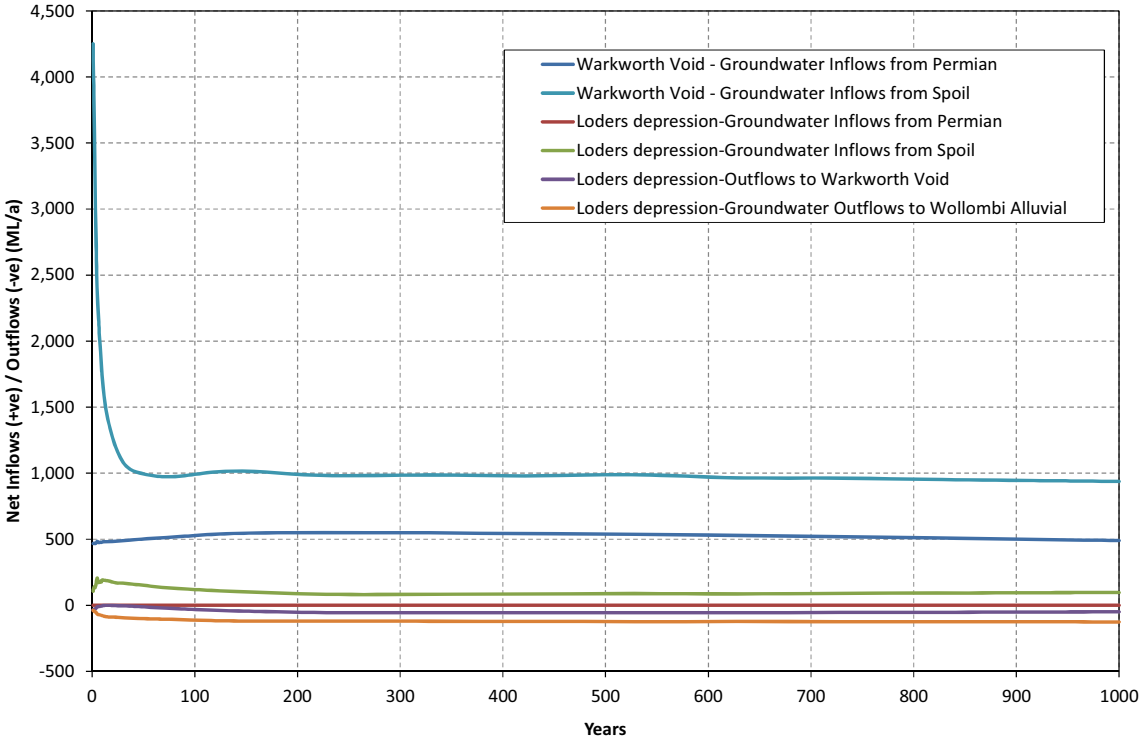


Figure 6.22 Final Void Groundwater Inflow/Outflow (AGE, 2014)

6.7.3 OPSIM Model Configuration

The final landform configuration and contributing catchment area are shown in Figure 6.23. Following mine closure, there are no further operational demands and all infrastructure and mine water storages are rehabilitated. The water balance and final equilibrium water level of the final void is dependent on the rainfall and runoff entering the void, evaporation loss from the void, and the inflow or outflow of groundwater. Permanent drainage of spoil dumps will be constructed on the eastern (low-wall) side to minimise capture of surface runoff in the final void. The model was run for a period of 1,000 years, using looped Data Drill rainfall and evaporation. The following assumptions were made with regards to salinity:

- Permian groundwater inflow salinity at both Warkworth mine and MTO: 10,000µS/cm, based on the average of bore water quality monitoring for Permian groundwater at the mines.
- Spoil groundwater inflow salinity (including water seeping from tailings dams and rainfall runoff baseflows through the spoil pile): 9,000µS/cm, based on measurement at the pit face of the spoil seepage water quality.
- Rainfall runoff surface flow salinity for rehabilitated spoil: 600µS/cm, based on median water quality measured in Dam 30N which has a rehabilitated spoil surface runoff catchment.

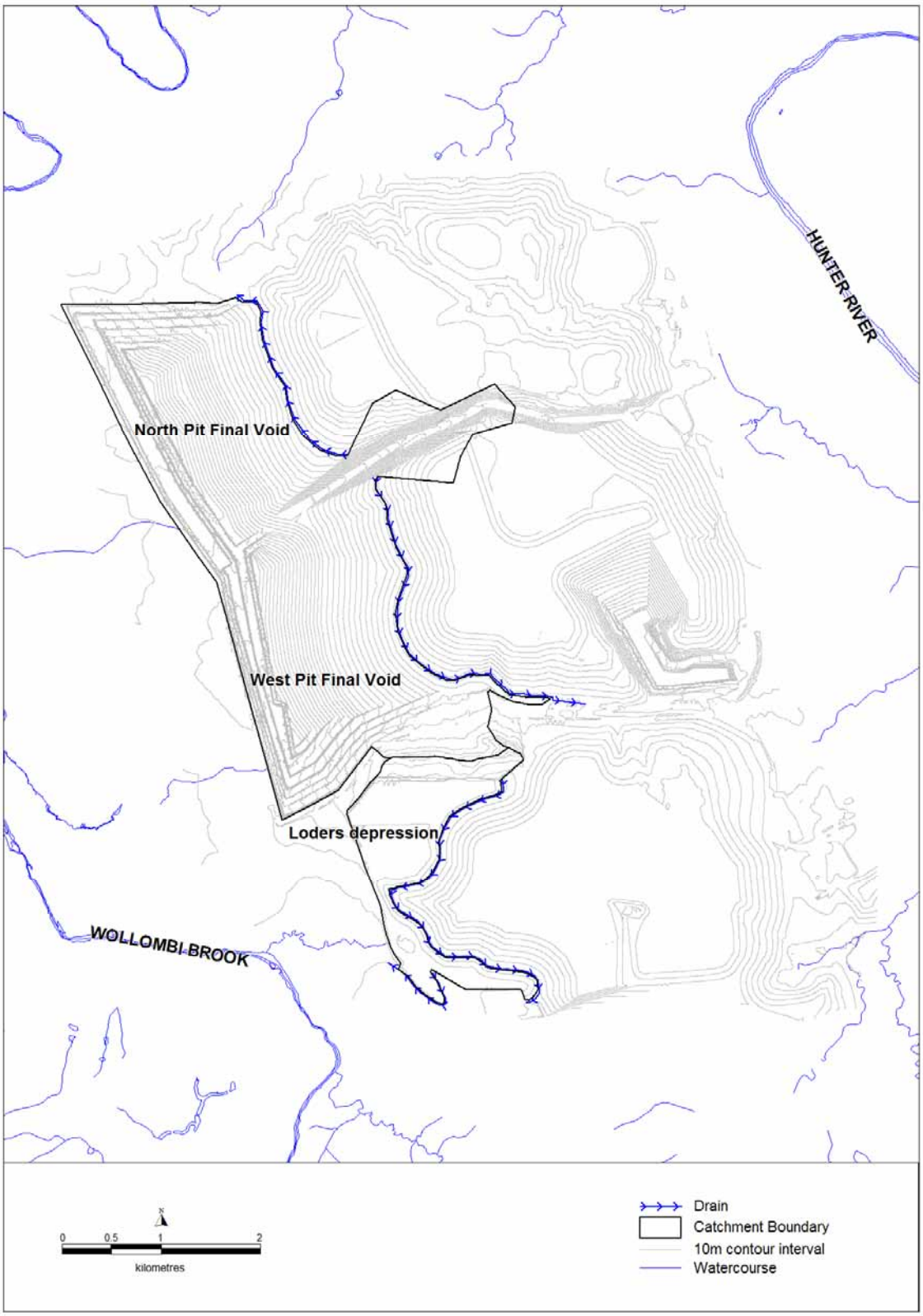


Figure 6.23 MTW Final Landform Catchment Plan

6.7.4 OPSIM Model Results

Figure 6.24 shows the simulated Warkworth final void water level and salinity as EC. The final void water level increases until it reaches equilibrium of inflows and outflows at approximately 20m AHD. This is approximately 54m below the crest level of the void. The salinity increases at a rate of approximately 30µS/cm per year, reaching 30,000µS/cm over the modelled 1,000 year period. This is due to the concentration of salts from evaporation.

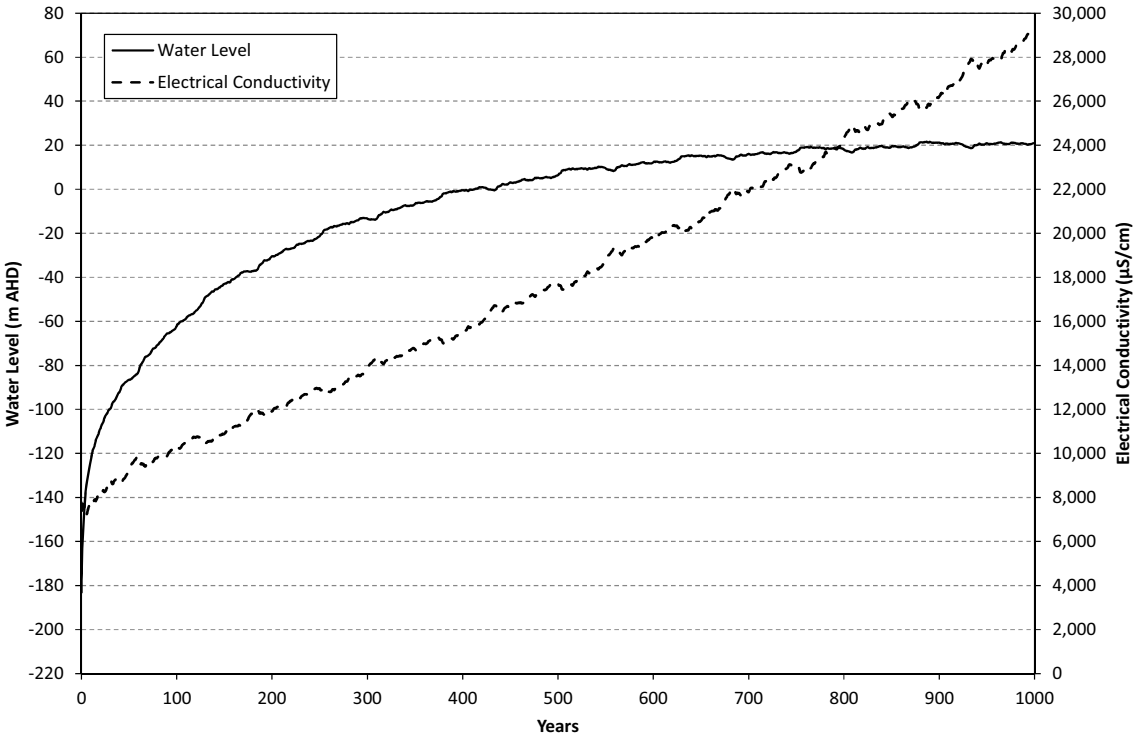


Figure 6.24 Warkworth Final Void Water Level and Salinity

Figure 6.25 and Figure 6.26 shows the Loders depression water level and stored volume, respectively. The depression stores water for approximately the first 100 years, and thereafter is mostly empty, with a lake forming at times for periods of up to 10 years in response to large rainfall events. The maximum water level reached is approximately 67m AHD (1,300ML) in the first 100 years, and thereafter approximately 64m AHD (500ML). This is approximately 3m and 6m lower than the crest level respectively. Note that a level of 67m AHD and 64m AHD equates to approximately 45% and 20% of the capacity of the depression, respectively.

Figure 6.27 shows the Loders depression salinity as a monthly average. A monthly average has been presented as the model shows artificial large spikes in EC when there are very small water volumes stored in the void. Figure 6.27 also shows the 90th percentile, median and 10th percentile ECs over the period when the depression is regularly emptying (100 to 1000 years). The results show a median EC of 3,000µS/cm, and 90th percentile EC of 8,000µS/cm.

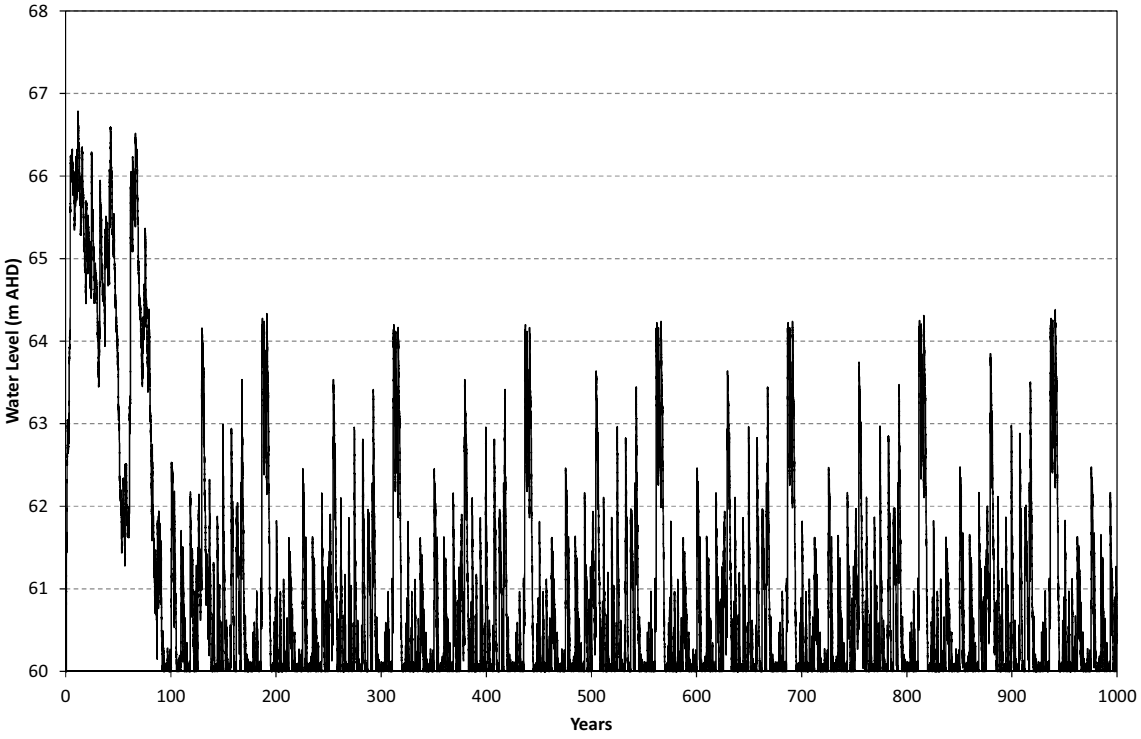


Figure 6.25 Loders Depression Water Level

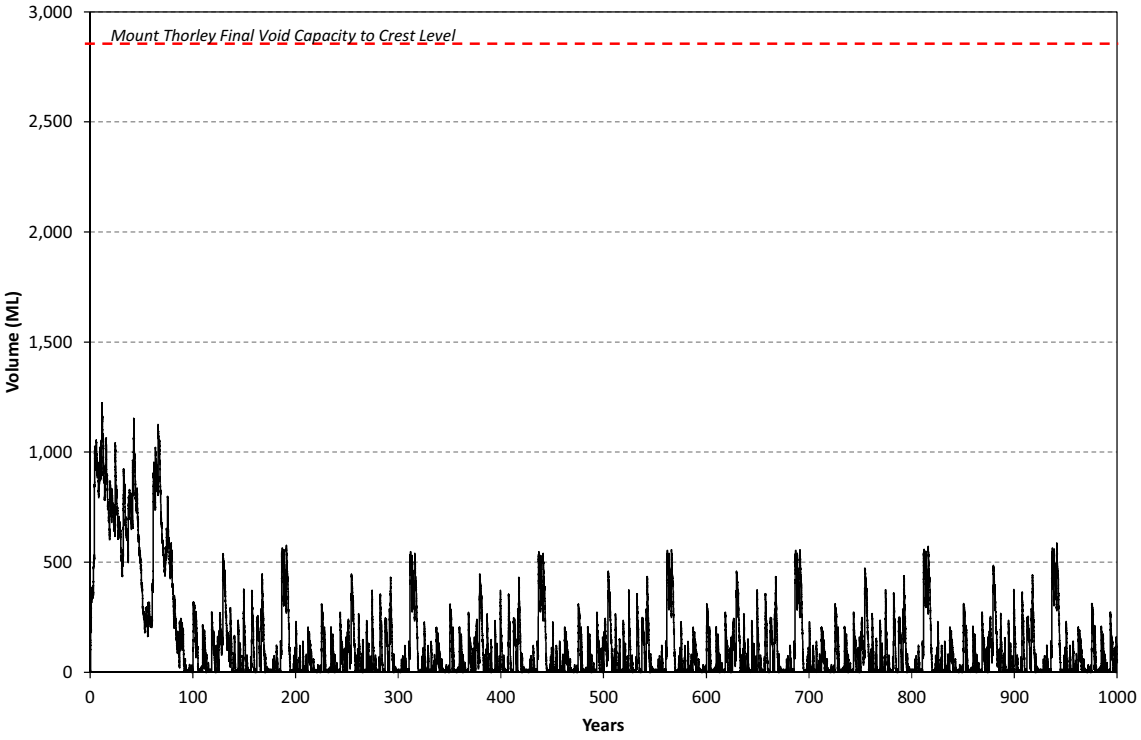


Figure 6.26 Loders Depression Stored Volume

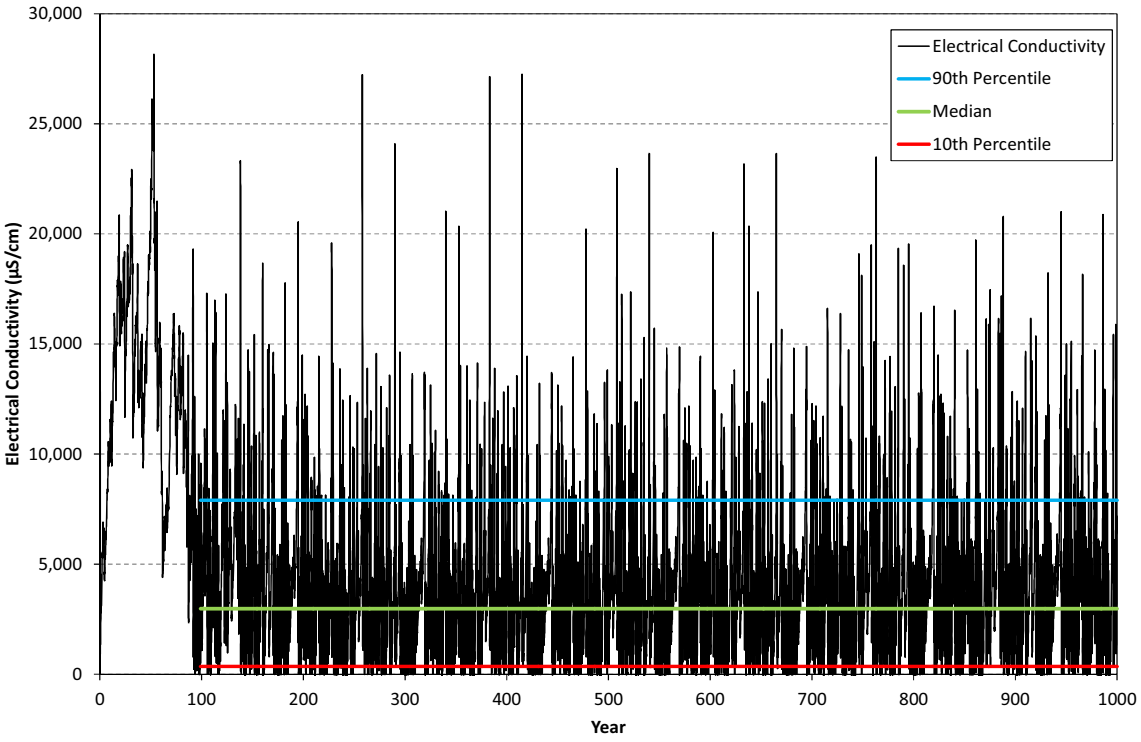


Figure 6.27 Loders Depression Salinity (Monthly Average)

6.8 MINE WATER BALANCE SUMMARY

The forecast results of the mine water balance model show that there is a step change in external water requirements which occurs in around Year 2, consistent with the increase in CHPP throughput and decrease in groundwater inflows to Mount Thorley. From Year 3 onwards the external water requirements are generally consistent:

- There is a 50 per cent chance that between 1,500ML/a to 2,000ML/a of external water will be required; and
- There is a 10 per cent chance that between 3,000ML/a to 3,700ML/a of external water will be required.

Note that the current MTJV allocation is 1,012ML/a (at 100 per cent Available Water Determination (AWD)).

Note that Tailings Dam 2 (Dam 33N) will remain uncapped until the contract with Redbank Power Station to accept ash expires in 2031. The Year 21 mine layout (Figure 6.10) shows the TD2 as rehabilitated, however the water balance model assumes it is uncapped for the life of the mine. Rainfall runoff on the TD2 contributes less than 100ML/a to the water balance in an average rainfall year (45ha catchment area x 658mm/a long term average annual rainfall x 40% long term volumetric runoff coefficient), which is 1.4% of the Year 21 total inflows of around 7,100ML/a (refer Table 6.13). The effect of capping the TD2 on the water balance model results will reduce the external water requirements by approximately 100ML/a for the Year 21 mine

stage only, which are estimated at 1,800ML/a on average (note that the year 21 mine stage is modelled as the final 4 years of the project life). Therefore this assumption is not considered to have a significant impact on the water balance model results.

The results of the water balance modelling indicate a low probability of pit inundation, and no offsite uncontrolled release (overflows) from saline storages.

HRSTS discharges will be required for site water management, with the following discharge characteristics:

- Overall, much greater volumes are discharged from MTO than Warkworth Mine, which is consistent with the capacity of the discharges structures (200ML/d at MTO and 100ML/d at Warkworth Mine) and dam volumes;
- There is a 50 per cent chance that controlled releases from MTO will not be required in any year of the life of the proposal, and small volumes (100ML) will be discharged from Warkworth Mine in any year of the life of the proposal; and
- There is a 10 per cent chance that controlled releases from MTO of between 1,000ML to 2,000ML will be required in any year of the life of the proposal, and around 400ML from Warkworth Mine in any year of the life of the proposal.

6.9 ADAPTIVE MANAGEMENT OF MINE WATER BALANCE

The model results presented above represent the application of the adopted mine water management system rules over the mine life, regardless of climatic conditions. In reality, there are numerous options for adaptive management of the mine water management system to accommodate climatic conditions. For example, temporary adjustments to pumping arrangements could be made to accommodate very wet or dry periods. These alternative management approaches would be used to reduce the risks to the project associated with climatic variability.

7 MITIGATION MEASURES

7.1 OVERVIEW

Surface water at the Site is managed in accordance with MTW's WMP which was prepared in consultation with NOW and the NSW Environment Protection Authority. The impacts of the proposal on surface water resources will be mitigated through the implementation of the following measures to be documented in the revised site Water Management Plan:

- A mine site water management system to control the flow and storage of water of different qualities across the site;
- A sediment control plan to reduce sediment loads from disturbed area runoff; and
- A surface water monitoring program to continually assess environmental impacts and ensure that the site water management system is meeting its objectives of managing impacts on receiving waters.

An overview of each of these management measures are provided in the following sections.

7.2 MINE WATER MANAGEMENT SYSTEM

A key objective of the MTW mine water management system is to minimise the risk of uncontrolled releases from mine site storages. To achieve this objective, operation of the mine water management system will be based on the following principles:

- Diversion of clean surface water runoff away from areas disturbed by mining activities;
- Operation of the mine water management system to ensure no uncontrolled releases of mine water from the site;
- Collection of potentially sediment-affected runoff in sediment dams for treatment prior to release from site;
- Transfer of groundwater and seepage inflows to the open cut pits to the mine water system for reuse;
- Collection of contaminated water from industrial areas for treatment in an oil and grease separator prior to recycling in the mine water management system; and
- Minimisation of fresh water usage by recycling water from the mine water system before taking additional water from external sources.

Details of the operation of the mine water management system are provided in Section 6.5.

An important component of the mine water management system will be to ensure that contingency measures are in place to accommodate either a surplus or deficit of water on site. Appropriate water licences or external sources will be obtained to meet the potential shortfall in water during dry conditions. Mine operations will also be planned to ensure that mining can continue during extended wet periods when water may accumulate in the open cut mining areas.

The site water management plan will detail reporting and action procedures to identify any lack of compliance with objectives and a process for implementing corrective actions.

7.3 EROSION AND SEDIMENT CONTROL PLAN

The design of sediment control measures for the proposal will be based on the principle of ensuring that runoff from disturbed areas is separated from clean area runoff and collected in sediment dams for treatment. Design of proposed erosion and sediment control measures will be based on the recommended design standards in the following guidelines:

- Managing Urban Stormwater, Soils and Construction (Landcom, 2004); and
- Managing Urban Stormwater, Soils and Construction, Volume 2E Mines and Quarries (DECC, 2008).

Proposed sediment dam sizes and locations are detailed in Section 6.5.7.

7.4 DRAINAGE OF FINAL LANDFORM

The rehabilitated overburden east of mining operations will be drained using the approach currently adopted at MTW which is based on:

- Topsoiling and revegetation of the finished landform;
- Construction of contour drains across the batter slope to minimise the potential for rilling and gullying of the finished landform;
- Collection of inflows from contour drains in rock chutes which flow downslope; and
- Flows from rock chutes are directed to sediment basins prior to release from site.

7.5 SURFACE WATER MONITORING PROGRAM

The existing MTW surface water monitoring program is described in Section 2.6.2.

The surface water monitoring locations and frequencies of the receiving waterways are considered appropriate to identify any changes in water quality associated with the proposal.

The site dam watering monitoring program will be updated to include additional locations as new dams are constructed:

- Saline storages: EC, pH and TSS will be monitored on a monthly basis. A comprehensive analysis will be undertaken annually.
  - NOOP Dam.
- Sediment dams: EC, pH and TSS will be monitored on a monthly basis. A comprehensive analysis will be undertaken annually.
  - Ramp 22 Dam;
  - Sediment Dam A; and
  - Sediment Dam B.

8 CONCLUSION

The proposed surface water management system has been developed in conjunction with the mine planning and operational teams to develop a surface water management system that has minimal impacts on surface water resources. The proposed surface water management system is a continuation of the current surface water management system, and the results of the surface water impact assessment indicate that the impacts of the proposal on surface water resources are unlikely to be significantly different to the existing approved operations.

The forecast results of the mine water balance model show that there is a step change in external water requirements which occurs in around Year 2, consistent with the increase in CHPP throughput and decrease in groundwater inflows to Mount Thorley. From Year 3 onwards the external water requirements are generally consistent:

- There is a 50 per cent chance that between 1,500ML/a to 2,000ML/a of external water will be required;
- There is a 10 per cent chance that between 3,000ML/a to 3,700ML/a of external water will be required; and
- There is a one per cent chance that between 3,700ML/a to 4,500ML/a of external water will be required.

Note that the current MTJV allocation is 1,012ML/a (at 100 per cent Available Water Determination (AWD)).

The results of the water balance modelling indicate a low probability of pit inundation, and no offsite uncontrolled release (overflows) from saline storages.

HRSTS discharges will be required for site water management, with the following discharge characteristics:

- Overall, much greater volumes are discharged from MTO than Warkworth Mine, which is consistent with the capacity of the discharges structures (200ML/d at MTO and 100ML/d at Warkworth Mine) and dam volumes;
- There is a 50 per cent chance that controlled releases from MTO will not be required in any year of project life, and small volumes (100ML) will be discharged from Warkworth Mine in any year of project life;
- There is a 10 per cent chance that controlled releases from MTO of between 1,000ML to 2,000ML will be required in any year of project life, and around 400ML from Warkworth Mine in any year of project life; and
- There is a one per cent chance that between 3,000ML to 4,500ML from MTO will be discharged in any year of mine life; and 500ML to 800ML of discharges from Warkworth Mine in any year of project life.

There is a maximum reduction of 0.56 per cent of the Wollombi Brook catchment to the Hunter River, and a maximum reduction of 0.19 per cent of the Hunter River (not including Wollombi Brook) during mining. Post-mining, the reduction in catchment area is 0.44 per cent and 0.04 per cent for Wollombi Brook and the Hunter River respectively. There is a median net runoff reduction to the Hunter River of up to 75ML/a during mining, and up to 104ML/a post-mining.

MTW currently undertakes an extensive surface water monitoring program, which will continue to be implemented for the proposal. Monitoring includes on site dams (both saline and sediment), receiving waters (upstream and downstream Hunter River, Wollombi Brook and their tributaries), and additional monitoring which is undertaken during periods of controlled release under the HRSTS. Additional saline storages and sediment dams constructed as part of the proposal will be monitored in accordance with the current monitoring program.

If required, additional water licences would be obtained from licensed sources, and therefore there will be no adverse impact on other licensed users who will still have access to their entitlement (subject to climatic availability and the operation of the water supply scheme).

Overall, the impacts of the Project on surface water resources are unlikely to be significantly greater than those of the existing mining operation.

9 REFERENCES

AGE, 2014a — *Mount Thorley Operations 2014, Groundwater Impact Assessment,* Australasian Groundwater & Environmental Consultants, March 2014.

AGE, 2014b — *Warkworth Continuation 2014, Groundwater Assessment,* Australasian Groundwater & Environmental Consultants, March 2014.

ANZECC, 2000 — *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* Australia and New Zealand Environment and Conservation Council, Canberra, October 2000.

ARR, 1998 — *Australian Rainfall and Runoff, A Guide to Flood Estimation,* Revised Edition, Institution of Engineers, Australia, 1998.

BHP Ltd, 1980 — *Saxonvale coal mine development: environmental impact statement,* prepared by Environmental Engineering Section, Central Engineering Division, Broken Hill Proprietary Co. Ltd., 1980.

BMT WBM, 2010 — *Wollombi Flood Study Review and Model Upgrade,* prepared by BMT WBM for Cessnock City Council, December 2010.

Boughton, 2003 — *Calibrations of the AWBM for Use on Ungauged Catchments,* Technical Report 03/15, Cooperative Research Centre for Catchment Hydrology, December 2003.

Coal & Allied, 2012 — *Mount Thorley Warkworth Operations Pty Ltd – Water Management Plan*, Coal & Allied, 2012.

DECC, 2008 — *Managing Urban Stormwater: Soils and Construction – Volume 2E Mines and Quarries,* June 2008.

DECCW, 2008 — *Hunter River Salinity Trading Scheme: 2008-09 performance,* NSW Department of Environment, Climate Change and Water, February 2010.

Jeffrey et al, 2001 — Jeffrey, S.J., Carter, J.O., Moodie, K.M and Beswick, A.R, *'Using spatial interpolation to construct a comprehensive archive of Australian climate data',* Environmental Modelling and Software, Vol. 16/4, pp 309-330, 2001.

Landcom, 2004 — *Managing Urban Stormwater: Soils and Construction – Volume 1, 4th edition,* Landcom, March 2004.

MER, 2012 — *Bulga Coal Management Assessment of Groundwater Related Impacts Arising from the Proposed Bulga Open Cut Optimisation*

Project, prepared by Mackie Environmental Research, Draft report, September 2012.

Morton, 1983 — Morton, F.I., 1983, *'Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology',* Journal of Hydrology, Vol. 66, No. 1-4, pp. 1-76.

Rio Tinto, 2013 — *Mount Thorley Warkworth 2012 Annual Review,* Rio Tinto, March 2013.

SKM, 1997 — *'Flooding in Wollombi Brook',* South Lemington Open Cut Mine Environmental Impact Statement, Volume 1, Appendix K.

Umwelt, 2014 — *Environmental Impact Statement - Bulga Optimisation Project Surface Water Assessment,* prepared for Bulga Coal Management Pty Ltd by Umwelt (Australia) Pty Limited, Newcastle, April 2013.

WRM, 2014 — *Mount Thorley Warkworth Water Balance Model Update 2013,* prepared for Rio Tinto Coal Australia Pty Limited by WRM Water & Environment Pty Ltd, January 2014.

APPENDIX A

SUMMARY OF MTW WATER QUALITY MONITORING PROGRAM RESULTS

Water Quality Parameter		Hunter River		Loders Creek			Doctors Creek		Longford Creek	Sandy Hollow Creek	Wollombi Brook		Saltpan Creek
		W1	W3	W2	W5	W15	W4	W14	W27	WW5	Wollombi_ Brook	Wollombi_ Brook Upstream	SP1
Al - Total (mg/l)	10%ile	0.33	0.11	0.56	0.06	0.08	0.13	0.56	3.33	6.60	0.04	-	-
	Median	0.52	1.11	1.20	0.33	0.25	0.28	3.66	14.70	6.60	0.05	-	-
	90%ile	5.73	15.65	1.52	8.76	2.86	0.47	8.59	30.54	6.60	0.05	-	-
	N	5	6	3	5	5	3	4	3	1	2	0	0
As - Total (mg/l)	10%ile	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.001	-	-
	Median	0.001	0.001	0.001	0.002	0.002	0.004	0.002	0.004	0.002	0.001	-	-
	90%ile	0.001	0.003	0.002	0.006	0.003	0.006	0.008	0.006	0.004	0.001	-	-
	N	10	9	4	12	6	3	6	4	3	9	0	0
B (mg/l)	10%ile	0.00	0.03	0.03	0.05	0.02	0.06	0.02	0.04	0.03	0.02	-	-
	Median	0.04	0.04	0.04	0.08	0.07	0.08	0.05	0.05	0.04	0.05	-	-
	90%ile	0.05	0.06	0.04	0.09	0.14	0.14	0.08	0.05	0.04	0.06	-	-
	N	9	9	4	10	5	3	6	3	3	8	0	0
Ba (mg/l)	10%ile	0.022	0.021	0.027	0.064	0.012	0.153	0.018	0.061	0.069	0.055	-	-
	Median	0.031	0.032	0.034	0.086	0.071	0.220	0.048	0.089	0.082	0.098	-	-
	90%ile	0.085	0.126	0.039	0.130	0.110	0.244	0.108	0.107	0.112	0.251	-	-
	N	9	9	4	11	5	3	6	3	3	8	0	0
Ca - Total (mg/l)	10%ile	27	24	37	18	25	11	13	5	13	12	-	-
	Median	39	39	50	78	49	20	35	6	15	14	-	-
	90%ile	44	49	105	119	113	22	65	10	17	15	-	-
	N	7	8	6	7	7	3	5	5	2	3	0	0
$CaCO_3$ - Total Hard (mg/l)	10%ile	77	86	336	392	140	584	38	41	-	109	-	-
	Median	163	230	560	1,111	210	584	88	41	-	109	-	-
	90%ile	249	266	944	1,830	1,506	584	138	41	-	109	-	-
	N	2	3	3	2	3	1	2	1	0	1	0	0
Cl- (mg/l)	10%ile	132	140	-	3,231	2,407	1,830	515	25	-	180	-	-
	Median	136	144	-	3,275	2,675	1,830	515	34	-	191	-	-
	90%ile	140	147	-	3,319	2,943	1,830	515	42	-	201	-	-
	N	2	2	0	2	2	1	1	2	0	2	0	0
EC Field (uS/cm (25TRef))	10%ile	440	450	600	1,726	2,180	1,200	620	200	162	368	437	6,786
	Median	645	630	800	7,270	4,840	5,760	3,305	288	270	764	600	16,810
	90%ile	890	890	1,082	12,570	8,108	16,024	11,620	390	442	1,060	923	24,880
	N	90	81	85	135	88	37	26	31	32	138	18	15
EC Lab (uS/cm (25TRef))	10%ile	810	533	470	4,200	646	25,320	535	-	-	746	-	-
	Median	810	845	1,135	4,200	6,770	25,320	4,695	-	-	830	-	-
	90%ile	810	7,240	5,925	4,200	10,978	25,320	9,475	-	-	886	-	-
	N	1	84	84	1	85	1	56	0	0	3	0	0
Fe - Filtered (mg/L)	10%ile	0.03	0.05	0.01	0.04	0.01	0.02	0.05	0.32	0.59	0.05	-	-
	Median	0.12	0.22	0.02	0.13	0.03	0.02	0.23	0.35	1.71	0.06	-	-
	90%ile	0.21	0.22	0.02	1.85	0.12	0.02	2.21	2.73	2.82	1.12	-	-
	N	3	3	2	6	3	2	3	3	2	5	0	0
K - Total (mg/l)	10%ile	3	3	4	15	8	26	7	6	7	4	-	-
	Median	4	4	4	27	14	45	19	7	7	5	-	-
	90%ile	4	4	5	34	25	71	32	10	8	6	-	-
	N	7	7	2	7	6	3	5	5	2	3	0	0
Li (mg/l)	10%ile	0.002	0.004	0.005	0.019	0.017	0.048	0.012	0.005	0.005	0.002	-	-
	Median	0.005	0.006	0.005	0.088	0.037	0.093	0.037	0.007	0.005	0.004	-	-
	90%ile	0.030	0.039	0.007	0.140	0.053	0.107	0.207	0.013	0.005	0.005	-	-
	N	5	6	3	5	5	3	4	3	1	2	0	0
Mg - Total (mg/l)	10%ile	23	14	23	26	41	143	15	3	11	16	-	-
	Median	28	28	29	317	136	205	29	7	13	18	-	-
	90%ile	35	36	34	418	388	243	94	7	15	19	-	-
	N	7	7	3	7	6	3	5	5	2	3	0	0
Mn - Total (mg/l)	10%ile	0.056	0.003	0.050	0.038	0.016	0.011	0.011	0.030	0.025	0.227	-	-
	Median	0.110	0.108	0.114	0.073	0.081	0.012	0.092	0.047	0.052	0.428	-	-
	90%ile	0.352	0.766	0.130	0.313	0.416	0.037	0.298	0.050	0.098	2.030	-	-
	N	9	9	4	10	5	3	6	3	3	8	0	0
Na - Total (mg/l)	10%ile	42	40	67	480	362	2,226	107	19	21	102	-	-
	Median	73	66	88	2,380	896	3,970	563	26	28	104	-	-
	90%ile	80	80	106	2,794	2,590	5,274	1,111	38	35	110	-	-
	N	7	7	3	7	6	3	5	5	2	3	0	0
P - Total (mg/l)	10%ile	0.06	0.07	0.06	0.05	0.04	0.14	0.13	0.04	0.15	0.02	-	-
	Median	0.09	0.19	0.11	0.06	0.07	0.20	0.88	0.13	0.16	0.02	-	-
	90%ile	2.35	2.62	0.15	0.17	0.10	0.36	3.89	0.27	0.16	0.02	-	-
	N	6	6	3	4	4	3	5	4	2	2	0	0
pH Field	10%ile	7.5	7.6	7.4	7.9	7.4	7.8	7.3	6.9	7.1	7.0	7.2	7.5
	Median	8.0	8.1	8.0	8.2	8.0	8.7	8.1	7.4	7.7	7.4	7.6	8.1
	90%ile	8.4	8.4	8.3	8.6	8.4	9.0	8.6	7.8	8.1	8.0	8.0	8.6
	N	89	80	85	133	88	37	26	31	32	137	18	15
pH Lab	10%ile	7.6	7.7	7.5	7.9	7.3	8.3	7.3	6.8	-	8.0	-	-
	Median	7.6	8.2	8.1	8.0	8.1	8.8	8.2	6.8	-	8.0	-	-
	90%ile	7.6	9.0	8.9	8.1	8.9	9.3	8.7	6.8	-	8.0	-	-
	N	1	86	87	2	85	2	56	1	0	1	0	0
Rb - Total (mg/l)	10%ile	0.001	0.001	0.002	0.010	0.002	0.007	0.003	0.007	0.018	0.003	-	-
	Median	0.002	0.002	0.003	0.014	0.006	0.008	0.007	0.024	0.018	0.003	-	-
	90%ile	0.004	0.009	0.004	0.025	0.011	0.008	0.019	0.038	0.018	0.004	-	-
	N	5	6	3	5	5	3	4	3	1	2	0	0
Se (mg/l)	10%ile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-	-
	90%ile	0.05	0.07	0.00	0.01	0.55	0.01	0.11	0.01	0.00	0.01	-	-
	N	9	8	4	10	5	3	6	3	3	8	0	0
Si (mg/l)	10%ile	3.01	4.01	10.60	0.16	0.20	0.43	0.07	2.89	5.50	5.95	-	-
	Median	12.20	14.50	13.00	2.65	1.11	1.26	0.16	10.63	5.50	7.04	-	-
	90%ile	14.82	15.60	16.20	4.97	4.75	2.09	10.43	18.37	5.50	8.13	-	-
	N	4	5	3	4	4	2	3	2	1	2	0	0
SO_4 - Total (mg/l)	10%ile	26	21	32	274	232	713	28	4	20	2	-	-
	Median	34	32	35	550	1,300	1,001	33	9	29	5	-	-
	90%ile	145	186	37	2,099	2,516	1,288	850	24	34	13	-	-
	N	8	6	2	10	4	2	5	4	3	9	0	0
Sr - Total (mg/l)	10%ile	0.125	0.163	0.384	0.379	0.177	1.564	0.139	0.102	0.190	0.207	-	-
	Median	0.380	0.351	0.400	1.600	0.550	1.820	0.510	0.129	0.190	0.231	-	-
	90%ile	0.490	0.487	0.520	3.244	2.862	2.604	0.959	0.171	0.190	0.254	-	-
	N	5	6	3	5	5	3	4	3	1	2	0	0
TSS (mg/L)	10%ile	5	8	10	4	3	8	15	3	19	2	5	5
	Median	21	22	21	14	14	35	54	43	45	6	5	10
	90%ile	65	61	59	97	80	78	110	129	94	18	9	20
	N	88	80	84	129	83	36	25	30	32	135	14	13
Turbidity (NTU)	10%ile	17.0	22.0	42.2	3.9	240.0	-	100.0	-	-	-	-	-
	Median	17.0	22.0	55.0	3.9	240.0	-	100.0	-	-	-	-	-
	90%ile	17.0	22.0	67.8	3.9	240.0	-	100.0	-	-	-	-	-
	N	1	1	2	1	1	0	1	0	0	0	0	0
Zn - Total (mg/l)	10%ile	0.005	0.005	0.003	0.005	0.005	0.007	0.006	0.005	0.017	0.004	-	-
	Median	0.005	0.022	0.005	0.007	0.008	0.012	0.026	0.018	0.025	0.005	-	-
	90%ile	0.019	0.064	0.006	0.030	0.042	0.013	0.134	0.043	0.173	0.005	-	-
	N	10	9	4	12	6	3	6	4	3	9	0	0

N = Number of samples

Note: The value of analytes analysed in a concentration below the detection limit were replaced for the value of the detection limit.

Water Quality Parameter		Saline Storage								Sediment Dam / Clean Water Storage				
		Dam 1N	Dam 11N	Dam 25N	Dam 6S	Dam 9S	Dam 12S	Dam 15S	Dam 2S	Dam 6N	Dam 27N	Dam 30N	Dam 1S	Dam 3S
Al - Total (mg/l)	10%ile	0.09	0.91	19.60	0.09	0.26	0.51	0.21	-	0.28	-	0.09	0.18	2.71
	Median	0.16	14.90	26.00	0.47	0.38	18.00	0.37	-	0.28	-	0.09	0.48	3.89
	90%ile	10.06	25.86	36.72	1.33	0.71	62.04	1.15	-	0.28	-	0.09	5.85	4.83
	N	5	8	3	9	9	5	7	0	1	0	1	7	4
As - Total (mg/l)	10%ile	0.001	0.001	0.002	0.021	0.002	0.003	0.002	-	0.002	-	0.001	0.005	0.002
	Median	0.013	0.004	0.004	0.026	0.007	0.005	0.011	-	0.002	-	0.002	0.008	0.005
	90%ile	0.017	0.007	0.009	0.030	0.025	0.015	0.026	-	0.002	-	0.002	0.010	0.009
	N	10	8	3	10	13	8	15	0	1	0	2	12	4
B (mg/l)	10%ile	0.06	0.04	0.05	0.07	0.08	0.02	0.01	-	0.10	-	0.05	0.03	0.05
	Median	0.08	0.05	0.06	0.08	0.10	0.05	0.07	-	0.10	-	0.05	0.05	0.05
	90%ile	0.11	0.07	0.08	0.09	0.12	0.05	0.09	-	0.10	-	0.05	0.05	0.06
	N	10	8	3	9	13	7	13	0	1	0	1	11	4
Ba (mg/l)	10%ile	0.015	0.077	0.127	0.098	0.027	0.118	0.025	-	0.247	-	0.070	0.013	0.043
	Median	0.033	0.129	0.197	0.104	0.051	0.225	0.057	-	0.247	-	0.070	0.049	0.068
	90%ile	0.114	0.270	0.200	0.117	0.085	0.358	0.099	-	0.247	-	0.070	0.133	0.091
	N	9	7	3	7	12	8	14	0	1	0	1	11	4
Ca - Total (mg/l)	10%ile	15	3	4	11	7	2	10	-	4	-	9	8	4
	Median	40	5	5	13	13	3	12	-	4	-	11	20	4
	90%ile	50	11	8	16	17	16	16	-	4	-	13	39	5
	N	18	6	3	9	8	5	9	0	1	0	2	8	4
$CaCO_3$ - Total Hard (mg/l)	10%ile	502	17	88	199	200	5	53	-	-	-	142	169	47
	Median	590	56	88	199	200	5	115	-	-	-	142	506	47
	90%ile	848	95	88	199	200	5	177	-	-	-	142	842	47
	N	13	2	1	1	1	1	2	0	0	0	1	2	1
Cl- (mg/l)	10%ile	-	107	81	856	856	585	863	-	1,280	-	65	316	262
	Median	-	377	159	928	946	585	913	-	1,280	-	91	942	401
	90%ile	-	587	342	1,060	964	585	963	-	1,280	-	117	1,708	651
	N	0	3	3	9	3	1	2	0	1	0	2	3	4
EC Field (uS/cm (25TRef))	10%ile	3,790	156	297	5,122	4,956	190	2,465	1,372	8,269	278	484	595	2,066
	Median	7,260	220	478	6,140	7,460	460	4,895	2,190	8,385	351	581	1,230	3,560
	90%ile	8,725	2,591	1,417	7,392	8,729	2,212	7,860	5,670	8,501	594	899	7,010	5,285
	N	110	18	6	24	112	99	106	17	2	10	8	106	18
EC Lab (uS/cm (25TRef))	10%ile	737	193	-	-	7,857	177	7,950	-	-	-	-	2,445	-
	Median	6,440	255	-	-	7,950	383	7,950	-	-	-	-	2,785	-
	90%ile	8,875	1,787	-	-	8,008	589	7,950	-	-	-	-	3,125	-
	N	120	4	0	0	4	2	1	0	0	0	0	2	0
Fe - Filtered (mg/L)	10%ile	0.02	0.61	-	-	0.01	0.73	0.02	-	-	-	-	0.03	0.09
	Median	0.05	0.79	-	-	0.01	0.79	0.05	-	-	-	-	0.09	0.10
	90%ile	0.09	3.25	-	-	0.01	2.96	0.25	-	-	-	-	0.13	0.11
	N	4	3	0	0	1	3	3	0	0	0	0	4	2
K - Total (mg/l)	10%ile	23	3	2	23	27	9	18	-	36	-	9	10	8
	Median	36	8	4	25	30	20	29	-	36	-	10	14	11
	90%ile	44	30	7	28	34	34	35	-	36	-	11	40	17
	N	5	7	3	9	8	5	9	0	1	0	2	8	4
Li (mg/l)	10%ile	0.131	0.008	0.009	0.169	0.197	0.008	0.074	-	0.418	-	0.012	0.004	0.016
	Median	0.275	0.016	0.015	0.177	0.212	0.017	0.169	-	0.418	-	0.012	0.007	0.022
	90%ile	0.358	0.076	0.023	0.204	0.294	0.134	0.273	-	0.418	-	0.012	0.021	0.038
	N	5	8	3	9	9	5	6	0	1	0	1	6	4
Mg - Total (mg/l)	10%ile	25	3	6	26	13	2	9	-	15	-	14	0	5
	Median	36	5	7	32	19	10	21	-	15	-	20	17	8
	90%ile	67	56	14	39	25	58	44	-	15	-	25	131	9
	N	6	7	3	9	9	5	9	0	1	0	2	8	4
Mn - Total (mg/l)	10%ile	0.004	0.005	0.050	0.003	0.005	0.038	0.005	-	0.002	-	0.018	0.015	0.014
	Median	0.008	0.059	0.088	0.006	0.011	0.120	0.009	-	0.002	-	0.018	0.047	0.027
	90%ile	0.046	0.106	0.158	0.214	0.030	0.199	0.018	-	0.002	-	0.018	10.137	0.036
	N	9	6	3	9	12	7	13	0	1	0	1	10	4
Na - Total (mg/l)	10%ile	1,306	26	115	1,340	1,720	29	992	-	2,220	-	82	70	361
	Median	1,800	37	203	1,450	1,860	51	1,580	-	2,220	-	114	346	530
	90%ile	1,900	770	386	1,594	2,197	526	2,032	-	2,220	-	145	1,413	923
	N	5	7	3	9	8	5	9	0	1	0	2	8	4
P - Total (mg/l)	10%ile	0.01	0.03	0.26	0.01	0.01	0.05	0.03	-	0.05	-	0.06	0.30	0.05
	Median	0.02	0.17	0.26	0.02	0.02	0.20	0.07	-	0.05	-	0.06	0.66	0.09
	90%ile	0.48	0.72	0.59	0.05	0.03	0.51	0.09	-	0.05	-	0.06	0.94	0.12
	N	6	8	3	7	9	4	5	0	1	0	1	5	4
pH Field	10%ile	8.4	7.8	7.8	8.7	8.4	7.4	8.6	8.4	9.8	7.6	7.9	8.0	8.9
	Median	8.7	8.1	8.4	9.0	8.8	8.1	8.9	8.9	9.8	7.9	8.3	8.8	9.2
	90%ile	8.9	9.0	8.7	9.1	9.0	8.7	9.1	9.2	9.8	9.1	8.9	10.0	9.5
	N	109	17	6	24	111	98	105	17	2	10	8	88	18
pH Lab	10%ile	7.7	7.0	-	-	8.7	7.1	9.0	-	-	-	-	8.0	-
	Median	8.7	7.1	-	-	8.7	7.7	9.0	-	-	-	-	9.1	-
	90%ile	9.0	8.1	-	-	8.7	7.9	9.0	-	-	-	-	9.3	-
	N	123	3	0	0	1	3	1	0	0	0	0	20	0
Rb - Total (mg/l)	10%ile	0.043	0.020	0.027	0.035	0.048	0.008	0.015	-	0.002	-	0.005	0.005	0.014
	Median	0.061	0.036	0.042	0.041	0.055	0.053	0.036	-	0.002	-	0.005	0.007	0.018
	90%ile	0.063	0.063	0.065	0.042	0.060	0.127	0.050	-	0.002	-	0.005	0.027	0.019
	N	5	7	3	9	9	5	6	0	1	0	1	6	4
Se (mg/l)	10%ile	0.00	0.01	0.01	0.01	0.00	0.00	0.00	-	0.01	-	0.01	0.00	0.01
	Median	0.01	0.01	0.01	0.01	0.01	0.00	0.01	-	0.01	-	0.01	0.00	0.01
	90%ile	0.01	0.01	0.01	0.02	0.01	0.01	0.03	-	0.01	-	0.01	0.01	0.02
	N	10	7	3	9	13	7	13	0	1	0	1	11	4
Si (mg/l)	10%ile	5.62	0.28	-	3.38	5.30	4.62	1.97	-	-	-	-	1.46	17.80
	Median	6.25	20.90	-	6.85	6.40	4.70	5.10	-	-	-	-	2.05	17.80
	90%ile	7.65	37.30	-	13.81	9.24	46.22	6.70	-	-	-	-	3.97	17.80
	N	4	5	0	4	5	3	6	0	0	0	0	4	1
SO_4 - Total (mg/l)	10%ile	444	12	53	784	730	43	279	-	1	-	33	32	242
	Median	1,011	34	131	869	939	67	789	-	1	-	53	164	346
	90%ile	1,304	224	202	924	1,290	435	923	-	1	-	73	864	586
	N	10	6	3	10	11	5	12	0	1	0	2	8	4
Sr - Total (mg/l)	10%ile	0.316	0.096	0.212	0.934	0.382	0.110	0.170	-	0.644	-	0.528	0.223	0.177
	Median	0.640	0.145	0.258	1.180	0.648	0.160	0.370	-	0.644	-	0.528	0.280	0.248
	90%ile	0.833	0.529	0.336	1.460	0.882	0.721	1.348	-	0.644	-	0.528	1.928	0.349
	N	5	8	3	9	9	4	7	0	1	0	1	7	4
TSS (mg/L)	10%ile	5	22	124	9	8	21	15	14	5	22	5	7	12
	Median	17	54	513	41	18	91	36	56	7	46	9	36	36
	90%ile	114	150	1350	136	88	1042	163	605	8	50	25	251	80
	N	118	19	6	24	110	99	105	17	2	5	7	104	18
Turbidity (NTU)	10%ile	4.9	13.1	-	-	7.9	780.8	140.0	-	-	-	-	-	-
	Median	17.4	62.0	-	-	22.0	2080.0	140.0	-	-	-	-	-	-
	90%ile	135.0	1292.4	-	-	47.4	3064.0	140.0	-	-	-	-	-	-
	N	46	3	0	0	47	3	1	0	0	0	0	0	0
Zn - Total (mg/l)	10%ile	0.005	0.005	0.026	0.005	0.005	0.008	0.005	-	0.005	-	0.005	0.005	0.009
	Median	0.005	0.044	0.054	0.005	0.005	0.028	0.013	-	0.005	-	0.005	0.005	0.020
	90%ile	0.036	0.089	0.096	0.006	0.021	7.458	0.027	-	0.005	-	0.005	0.029	0.021
	N	10	8	3	10	13	8	15	0	1	0	2	12	4

N = Number of samples
Note: The value of analytes analysed in a

APPENDIX B

MTW CATCHMENT AND LAND USE CLASSIFICATION TABLES

Table B. 1 Year 0 Catchment Areas and Land Use Classifications (ha) - Surface component

Storage	Land Use							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
AGS	1.3			4.8	0.4	14.3	5.8	**26.7**
52ML Dam			4.1		8.7			**12.8**
Dam 10S	2.8			48.9			0.9	**52.6**
Dam 11N			53.7					**53.7**
Dam 11S	0.7			0.1				**0.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 12S	64.3		7.9		5.9			**78.1**
Dam 14S			0.4		1.0			**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16N	2.1		7.6	63.9			1.0	**74.7**
Dam 16S	4.9					12.5		**17.4**
Dam 17S (CRTSF)				11.9	14.2	29.2	24.9	**80.2**
Dam 18N				1.0				**1.0**
Dam 1N	14.1			58.0	21.3		103.6	**197.0**
Dam 1S/2S	10.1		2.2		15.6			**27.9**
Dam 20N	8.5		3.8		0.8			**13.0**
Dam 27N			0.5	5.1				**5.6**
Dam 30N	11.3			91.7				**103.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 32N (TD1)	1.2			40.7				**41.9**
Dam 33N (TD2)	2.4			13.1		45.9		**61.4**
Dam 3S	7.4		1.5	141.9	6.2		25.8	**182.8**
Dam 4N			1.9					**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6N	1.9		7.0		0.1			**9.1**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.9			0.0				**0.9**
Dam 9S	2.4							**2.4**
Dams 13,14,15N	12.3			146.3	4.0		2.1	**164.8**
Honeypot Dam	6.8		35.8		4.0			**46.7**
Loders Pit	8.2	12.7	8.1	3.3	25.1		347.7	**405.2**
Mini Strip TSF			7.4	0.3	11.2		15.7	**34.6**
North Loders Clean Dam			8.9					**8.9**
North Pit	49.3	6.2	5.0	10.9	9.0		148.1	**228.6**
North Pit North	20.9	5.4		8.5	9.7		124.9	**169.4**
South Pit	0.2	7.4	1.2	37.7	15.6		272.5	**334.6**
West Pit	25.5	19.2	74.7	18.0	35.0		462.8	**635.1**
Grand Total	**302.3**	**50.9**	**262.2**	**706.1**	**273.8**	**101.9**	**1,535.8**	**3,233.6**

Table B. 2 Year 0 Catchment Areas and Land Use Classifications (ha) - Baseflow component

Storage	Land Use							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
AGS	1.3			4.8	0.4	14.3	5.8	**26.7**
52ML Dam			4.1		8.7			**12.8**
Dam 10S	1.2			0.9				**2.1**
Dam 11N			53.7					**53.7**
Dam 11S	0.7			0.1				**0.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 12S	64.3		7.9		5.9			**78.1**
Dam 14S			0.4		1.0			**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16N	2.1		0.8				1.0	**4.0**
Dam 16S	4.9					12.5		**17.4**
Dam 17S (CRTSF)				3.4	9.0	29.2	14.7	**56.4**
North Loders Clean Dam			8.9					**8.9**
Dam 1N	14.1			0.7	5.7		0.6	**21.0**
Dam 1S/2S	10.1		2.2		15.6			**27.9**
Dam 20N	8.5		3.8		0.8			**13.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 32N (TD1)	1.2			40.7				**41.9**
Dam 33N (TD2)						45.9		**45.9**
Dam 3S	3.1		1.5		0.3			**4.9**
Dam 4N			1.9					**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6N	1.9		7.0		0.1			**9.1**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.9			0.0				**0.9**
Dam 9S	2.4							**2.4**
Dams 13,14,15N	7.8			0.5	1.4		0.9	**10.7**
Honeypot Dam	6.8		35.8		4.0			**46.7**
Loders Pit	14.2	12.7	8.1	297.2	47.6		423.4	**803.1**
Mini Strip TSF			7.4	0.3	11.2		15.7	**34.6**
North Pit	55.5	6.2	5.8	233.8	14.5		152.9	**468.7**
North Pit North	32.6	5.4	7.3	179.2	9.7		124.9	**359.1**
South Pit		7.4	0.1	114.8	27.1		307.9	**457.3**
West Pit	25.0	19.2	76.4	24.5	45.8		535.2	**726.1**
Grand Total	**301.4**	**50.9**	**263.6**	**900.9**	**294.8**	**101.9**	**1,583.0**	**3496.9**

Table B. 3 Year 3 MTW Catchment Areas and Land Use Classifications (ha) – Surface component

Storage	Land Use							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
AGS	1.3			6.4	0.2	14.7	5.0	**27.6**
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	5.5				11.9			**17.4**
Dam 17S (CRTSF)				9.1		51.8	26.0	**87.0**
Dam 18N			0.8	0.2				**1.0**
Dam 1N	13.3			149.8	34.0		35.3	**232.4**
Dam 1S/2S	10.1		2.2		15.6			**27.9**
Dam 20N	8.2		3.8		0.7		0.3	**13.0**
Dam 27N			2.5	3.0				**5.6**
Dam 30N			0.0	103.0				**103.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 33N (TD2)				16.4		45.0		**61.4**
Dam 3S	3.3		1.5	118.2	3.2		49.3	**175.5**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A) S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honeypot Dam	3.8		2.1		0.4		0.5	**6.8**
Loders Pit	17.4	11.2	15.6	19.0	32.8		381.2	**477.1**
Mini Strip TSF			7.4	0.5	10.2		16.3	**34.3**
NOOP Dam	17.7		4.2	264.0	4.5		0.1	**290.5**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	22.8	12.2		30.7	10.6		183.2	**259.4**
North Pit North	15.7	6.0	0.4	38.7	10.7		159.1	**230.5**
Ramp 22 Dam	0.3			267.9			33.8	**302.0**
South Pit		18.5		37.4	17.7		227.3	**300.9**
West Pit	53.4	20.4	35.8	55.4	42.9		522.6	**730.5**
Grand Total	**220.2**	**68.2**	**122.1**	**1120.1**	**291.1**	**111.5**	**1640.1**	**3572.9**

Table B. 4 Year 3 MTW Catchment Areas and Land Use Classifications (ha) – Baseflow component

Storage	Runoff Set							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
AGS	1.3			6.4	0.2	14.7	5.0	**27.6**
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	5.5				11.9			**17.4**
Dam 17S (CRTSF)				9.1		51.8	26.0	**87.0**
Dam 1N	13.3			0.7	7.7		0.0	**21.8**
Dam 1S/2S	10.1		2.2		15.6			**27.9**
Dam 20N	8.2		3.8		0.7		0.3	**13.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 33N (TD2)				1.7		44.3		**46.0**
Dam 3S	3.1		1.5		0.3			**4.9**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honeypot Dam	3.8		2.1		0.4		0.5	**6.8**
Loders Pit	17.9	11.2	15.5	287.5	41.9		476.5	**850.5**
Mini Strip TSF			7.4	0.5	10.1		16.3	**34.3**
NOOP Dam	18.5			2.5	2.5			**23.5**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	22.8	12.2	0.4	306.8	16.3		183.7	**542.2**
North Pit North	15.7	6.0	8.3	220.5	10.7		159.1	**420.3**
Ramp 22 Dam				123.2			14.3	**137.5**
South Pit		18.5	0.3	156.8	32.3		246.8	**454.8**
West Pit	53.5	20.4	35.8	108.6	60.2		554.5	**832.9**
Grand Total	**221.0**	**68.3**	**123.1**	**1224.7**	**306.5**	**110.8**	**1683.1**	**3737.5**

Table B. 5 Year 9 MTW Catchment Areas and Land Use Classifications (ha) – Surface component

Storage	Land Use							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
AGN						36.7	0.9	**37.6**
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	3.0				12.1		0.7	**15.8**
Dam 17S (CRTSF)				9.1		29.2	46.8	**85.1**
Dam 18N			0.8	0.2				**1.0**
Dam 1N	13.3			229.4	34.2		116.7	**393.6**
Dam 1S/2S	8.6		1.9		12.9			**23.4**
Dam 20N	8.2		3.8		0.7		0.3	**13.0**
Dam 27N			2.5	3.0				**5.6**
Dam 30N			0.0	103.0				**103.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 33N (TD2)				16.4		45.0		**61.4**
Dam 4N			1.9					**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A) S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honeypot Dam	3.8		1.1		1.4		0.5	**6.8**
Loders Pit	17.2	7.0	22.6	143.9	37.4		287.2	**515.3**
NOOP Dam	17.7		4.2	264.9	4.4			**291.2**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	15.3	13.2		50.9	17.6		244.6	**341.6**
North Pit North	14.9	6.1			12.0		158.4	**191.4**
Ramp 22 Dam	0.3			300.7			0.3	**301.3**
Sed. Dam A				133.8	1.0		16.4	**151.2**
Sed. Dam B	2.8			72.9	1.5		25.1	**102.3**
South Pit		18.0		171.9	2.7		44.4	**237.0**
West Pit	40.0	22.3	35.1	81.1	42.2		587.7	**808.4**
Grand Total	**174.7**	**66.6**	**117.8**	**1581.5**	**275.8**	**110.9**	**1530.1**	**3875.1**

Table B. 6 Year 9 MTW Catchment Areas and Land Use Classifications (ha) – Baseflow component

Storage	Runoff Set							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
AGN						36.7	0.9	**37.6**
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	3.0				12.1		0.7	**15.8**
Dam 17S (CRTSF)				9.1		29.2	46.8	**85.1**
Dam 1N	13.3			0.8	7.7		0.0	**21.8**
Dam 1S/2S	8.6		1.9		12.9			**23.4**
Dam 20N	8.2		3.8		0.7		0.3	**13.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 33N (TD2)				1.7		44.3		**46.0**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honeypot Dam	3.8		1.1		1.4		0.5	**6.8**
Loders Pit	18.9	7.0	22.6	471.8	42.5		321.0	**883.8**
NOOP Dam	17.7		0.8	2.5	2.5			**23.5**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	15.4	13.2	0.4	327.9	22.5		245.1	**624.4**
North Pit North	17.7	6.1	7.9	254.7	13.5		183.6	**483.4**
Ramp 22 Dam				137.5				**137.5**
South Pit		18.0		381.4	18.1		45.6	**463.0**
West Pit	40.1	22.3	35.2	175.5	60.4		702.8	**1036.3**
Grand Total	**194.0**	**66.6**	**119.5**	**1763.2**	**290.0**	**110.1**	**1547.2**	**4090.5**

Table B. 7 Year 14 MTW Catchment Areas and Land Use Classifications (ha) – Surface component

Storage	Land Use							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	3.0				12.1		0.7	**15.8**
Dam 17N			0.8	18.4				**19.2**
Dam 18N			0.8	0.2				**1.0**
Dam 1N	13.3			296.8	34.2		49.3	**393.6**
Dam 1S,2S	8.6		1.9		12.9			**23.4**
Dam 20N	8.2		3.8	0.1	0.7		0.2	**13.0**
Dam 27N			2.5	3.0				**5.6**
Dam 30N			0.0	103.0				**103.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 33N (TD2)				16.4		45.0		**61.4**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A) S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honeypot Dam	3.8		1.1		1.4		0.5	**6.8**
Loders Pit	17.1		22.6	376.4	9.3	42.2	47.8	**515.3**
NOOP Dam	17.7		4.2	340.9	5.7		10.0	**378.6**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	28.9	12.8		11.5	23.8		249.9	**326.9**
North Pit North	29.0	6.8		10.9	13.4		217.1	**277.2**
Ramp 22 Dam	0.3			301.0			0.0	**301.3**
Sed. Dam A				235.3	0.8			**236.1**
Sed. Dam B	2.8			97.6	1.4		0.4	**102.3**
South Pit		18.5		172.2	2.7		43.6	**237.0**
West Pit	68.8	20.5	35.1	181.2	44.7		601.8	**952.2**
Grand Total	**248.8**	**58.6**	**118.6**	**2165.3**	**258.8**	**87.2**	**1221.3**	**4158.8**

Table B. 8 Year 14 MTW Catchment Areas and Land Use Classifications (ha) – Baseflow component

Storage	Land Use							
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	Grand Total
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	3.0				12.1		0.7	**15.8**
Dam 1N	13.3			0.8	7.7		0.0	**21.8**
Dam 1S/2S	8.6		1.9		12.9			**23.4**
Dam 20N	8.2		3.8	0.1	0.7		0.2	**13.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 33N (TD2)				1.7		44.3		**46.0**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.6			0.3				**0.9**
Honeypot Dam	3.8		1.1		1.4		0.5	**6.8**
Loders Pit	17.8		22.6	861.9	14.3	42.2	47.8	**1006.5**
NOOP Dam	17.7		0.8	2.5	2.5			**23.5**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	29.0	12.8	0.4	364.1	30.1	0.3	260.4	**697.1**
North Pit North	31.8	6.8	7.9	290.0	14.8	0.4	217.5	**569.2**
Ramp 22 Dam				137.5				**137.5**
South Pit		18.5		382.8	18.1		43.6	**463.0**
West Pit	68.9	20.5	35.2	342.0	62.9		650.6	**1180.1**
Grand Total	**247.0**	**58.6**	**119.5**	**2383.8**	**273.2**	**87.2**	**1221.3**	**4390.4**

Table B. 9 Year 21 MTW Catchment Areas and Land Use Classifications (ha) – Surface component

Storage	Runoff Set							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	3.0				12.1		0.7	**15.8**
Dam 17N			0.8	18.4				**19.2**
Dam 18N			0.8	0.2				**1.0**
Dam 1N	13.3			296.8	34.3		49.3	**393.7**
Dam 1S/2S	8.6		1.9		12.9			**23.4**
Dam 20N	8.2		3.8	0.1	0.7		0.2	**13.0**
Dam 27N			2.5	3.0				**5.6**
Dam 30N				164.4				**103.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honeypot Dam	3.8		1.1		1.4		0.5	**6.8**
Loders Pit	17.1		22.6	375.1	9.2	42.2	47.9	**514.1**
NOOP Dam	17.7		4.2	340.8	5.7		9.9	**378.6**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	29.1	14.3		30.1	23.8		229.8	**327.1**
North Pit North	28.9	10.4		33.1	13.5		191.3	**277.1**
Ramp 22 Dam	0.3			300.8			0.0	**301.2**
Sed. Dam A				237.0	0.8			**237.8**
Sed. Dam B	2.8			97.6	1.4		0.4	**102.3**
South Pit		18.5		172.2	2.7		43.5	**237.0**
West Pit	68.8	19.5	35.1	249.5	44.7		534.5	**952.1**
Grand Total	**248.9**	**62.7**	**118.6**	**2336.1**	**258.9**	**42.2**	**1108.0**	**4159.3**

Table B. 10 Year 21 MTW Catchment Areas and Land Use Classifications (ha) – Baseflow component

Storage	Land Use							Grand Total
	Cleared/ Prestrip	Mining Pit	Natural/ Undisturbed	Rehab. Spoil	Roads/ Industrial/ Hardstand	Tailings	Unrehab. Spoil	
52ML Dam			4.1		8.7			**12.8**
Dam 12N	0.4		3.0		28.4			**31.7**
Dam 14S			0.4		1.0			**1.4**
Dam 15N	1.4							**1.4**
Dam 15S			20.3		38.6			**58.9**
Dam 16S	3.0				12.1		0.7	**15.8**
Dam 1N	13.3			0.7	7.7		0.0	**21.8**
Dam 1S/2S	8.6		1.9		12.9			**23.4**
Dam 20N	8.2		3.8	0.1	0.7		0.2	**13.0**
Dam 31N + 21N	1.5		7.2		11.2			**20.0**
Dam 4N			1.9	0.1				**1.9**
Dam 5S	14.1				7.8			**21.9**
Dam 6S	26.9							**26.9**
Dam 9(A)S	0.6			0.3				**0.9**
Dam 9S	2.4							**2.4**
Honey Pot Dam	3.8		1.1		1.4		0.5	**6.8**
Loders Pit	17.8		22.6	909.8	14.1	42.2		**1006.5**
NOOP Dam	17.7		0.8	2.5	2.5			**23.5**
North Loders Clean Dam			8.9					**8.9**
North Pit Mid	29.1	14.3	0.4	382.8	30.1	0.3	240.3	**697.2**
North Pit North	31.7	10.4	7.9	358.2	14.9	0.5	191.7	**569.3**
Ramp 22 Dam				137.5				**137.5**
South Pit		18.5		382.8	18.1		43.6	**463.0**
West Pit	68.9	19.5	35.2	410.3	63.0		583.2	**1180.0**
Grand Total	**231.7**	**62.7**	**119.5**	**2586.8**	**273.2**	**42.5**	**1060.2**	**4392.9**

APPENDIX C

MODELLING OF RELEASES UNDER THE HRSTS

The following approach to the HRSTS modelling was adopted:

1. Hunter River Streamflow time series – simulated streamflow data was obtained from NOW's IQQM model (full development case with 2004 water sharing plan rules) for the period 16/09/1892 to 30/6/2007.
2. Salinity –Recorded salinity data was obtained for the Hunter River at Singleton (#210129) from the PINEENA database, covering the period February 1993 to October 2009. Based on the recorded historical data, a relationship between streamflow and water quality was developed. EC's for 'High' flows only (2,000 – 10,000ML/d) were plotted against flow rates and a logarithmic trend line fitted to the data, giving salinity as a function of flow rate.
3. The salinity function was then applied to get a Hunter River flow and EC time series at Singleton which was used in OPSIM as the reference node.
4. In OPSIM, controlled discharges were simulated using an Environmental Transfer (ETN) node with two 'rules' for discharge. Rule 1 limits the volume of discharges based on the flow rates in the Hunter River, as shown in Table C. 1. Rule 2 limits the salt load discharged based on the salinity in the Hunter River and the discharge dams (Dam 9S and Dam 1N), as shown in Table C. 2.

Table C. 1 HRSTS Rule 1 (Volume Limit Rating)

Hunter River Qref (ML/d)	Site Discharge Qmax (ML/d)	Apply Rule 2	Comment
0	0	x	No site discharges allowed when Hunter River flows are <2,000 ML/d.
2,000	0	x	
2,000	100	✓	When Hunter River flows are 2,000 – 10,000 ML/d, up to 100 ML/d can be discharged from each discharge location, with salinity restrictions as per 'Rule 2'.
10,000	100	✓	
High	100	✓	When Hunter River flows are >10,000 ML/d, up to 100 ML/d can be discharged from each discharge location, with salinity restrictions as per 'Rule 2'.

Where:

- Qref is the reference volume [ML/d] (in this case, the Hunter River).
- Qmax is the discharge limit [ML/d] for Qref. At Warkworth Mine, this rate is 100ML/d. At MTO, this rate is 200ML/d.

Table C. 2 HRSTS Rule 2 (EC Rating)

Method	Cr (µS/cm)	K Value	Comment
K + Cr	0	900	If the EC in the Hunter River is zero, the concentration in the Hunter River can inrease by up to 900µS/cm due to discharges under the HRSTS.
K + Cr	900	0	If the EC in the Hunter River is 900µS/cm, the concentration in the Hunter River cannot increase due to discharges under the HRSTS.

Where:

- Cr is the concentration at the Reference Node (in this case, the Hunter River).
- K is the concentration increase (linearly interpolated between the specified values and the limiting transfer concentration is calculated as K+Cr).

In addition, discharges do not occur when the inventory in the source dams is below a nominal threshold, as follows:

- Dam 1N - if the volume in Dam 1N is less than 220ML (70 per cent of maximum operating volume)
- Dam 9S – if the combined volumes in Dam 9S and Dam 6S is less than 1,500ML (70 per cent of maximum operating volume).

Note that it is assumed that the number of salt credits held by MTW is not a limitation to releases. Historically there have been sufficient credits available for trade.



EMM
EMGA Mitchell McLennan

www.emgamm.com

SYDNEY
Ground Floor, Suite 1, 20 Chandos Street
St Leonards NSW 2065
T 02 9493 9500 F 02 9493 9599

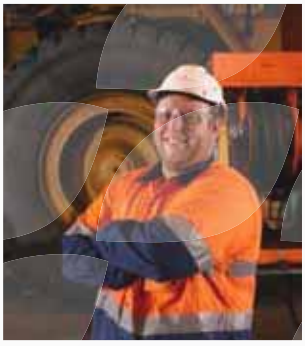
NEWCASTLE
Level 5, 21 Bolton Street
Newcastle NSW 2300
T 02 4927 0506 F 02 4926 1312

BRISBANE
Suite 1, Level 4, 87 Wickham Terrace
Spring Hill Queensland 4000
T 07 3839 1800 F 07 3839 1866















COAL & ALLIED
Managed by Rio Tinto Coal Australia