SPRINGVALE MINE EXTENSION PROJECT GROUNDWATER IMPACT ASSESSMENT

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TABLE OF CONTENTS

1. INTRODUCTION 7
1.1 Background 7
1.2 Site, Situation and Existing Approved Mine 7
1.3 Project description 8
1.4 Purpose of the Report 8
1.5 Structure of the report 9
1.6 Key inputs to the report 10

2. REGULATION AND BEST PRACTICE GUIDELINES 11
2.1 Commonwealth Legislation 11
2.1.1 Environment Protection and Biodiversity Conservation Act 1999 11
2.2 NSW State Legislation 11
2.2.1 Environment and Planning Assessment Act 1979 11
2.2.2 NSW Office of Water 12
2.2.3 Office of Environment and Heritage 13
2.2.4 Groundwater Dependent Ecosystems 13
2.2.5 Contingency Measures 14
2.2.6 Post Mining Mitigation Measures 14
2.3 Relevant State Policies and Guidelines 14
2.4 Water Sharing Plans 15
2.5 Licensing and Aquifer Interference Policy 15
2.6 Subsidence Constraints Analysis 15

3. EXISTING ENVIRONMENT 17
3.1 Topographical Setting 17
3.2 Historical Mining 17
3.3 Climate 17
3.3.1 Rainfall 17
3.3.2 Evapotranspiration 18
3.4 Catchment Description and Local Hydrology 20
3.5 Temperate Highland Peat Swamps on Sandstone 20
3.5.1 MU50 – Newnes Plateau Shrub Swamps (NPSS) 21
3.5.2 MU51 – Newnes Plateau Hanging Swamps (NPHS) 22
3.5.3 MU52 – Newnes Plateau Rush – Sedge Snow Gum Hollow Wooded Heath 22
3.6 Geology 23
3.6.1 Regional geology and stratigraphy 23
3.6.2 Local Geology and Stratigraphy 23
3.7 Regional Hydrogeology 26
3.8 Local Hydrogeology 27
3.8.1 Perched Groundwater System (AQ5 – AQ6) –Burralow Formation 28
3.8.2 Shallow Groundwater System (AQ4) – Banks Wall Sandstone 28
3.8.3 Deep Groundwater System (Coal Seams plus AQ1 to AQ3) 29
3.9 Environmental Values 29
3.9.1 Groundwater Users 29
3.9.2 Groundwater Dependent Ecosystems 29

4. GROUNDWATER INVESTIGATIONS 31
4.1 Existing Monitoring Network 31

4.2 Mine Modifications ... 31
4.2.1 Reduction of Mine Void Widths ... 31
4.2.2 Avoidance of Undermining Swamps ... 32
4.3 Swamp Water Level Monitoring ... 32
4.3.1 Swamp Water Level Analysis ... 33
4.3.2 Swamp Groundwater Level Interpretation ... 34
4.4 Shallow Groundwater Level Monitoring ... 34
4.4.1 Shallow Groundwater Level Analysis ... 35
4.5 Deep Groundwater Level Monitoring ... 37
4.5.1 Deep Aquifer Groundwater Level Trends ... 38
4.6 Vertical Groundwater Gradients ... 39
4.7 Recharge and Discharge ... 40
4.7.1 Perched Groundwater System ... 40
4.7.2 Shallow Groundwater System ... 40
4.7.3 Deep Groundwater System ... 40
4.8 Regional Groundwater Quality ... 40
4.9 Site Specific Water Quality ... 41
4.9.1 Swamp Water Quality Monitoring ... 41
4.9.2 Deep Groundwater Quality Monitoring ... 43
4.10 Hydraulic Testing ... 45
4.10.1 SPR26 Permeability Results ... 45
4.10.2 AP1205 Permeability Results ... 45

5. CONCEPTUAL HYDROGEOLOGY ... 47

5.1 Introduction ... 47
5.1.1 The Conceptual Hydrogeological Model ... 47
5.1.2 CSIRO Conceptual Model ... 48
5.2 Regional and Local Hydrogeology ... 48
5.2.1 Summary of Hydrostratigraphy ... 48
5.2.2 Formation Permeability ... 49
5.2.3 Vertical Connectivity between Aquifer Units ... 49
5.2.4 Recharge and Discharge ... 50
5.2.5 Groundwater Flow Direction ... 50
5.3 Subsidence Fracturing ... 51
5.3.1 Modified Mine Design to Minimise Subsidence ... 52

6. NUMERICAL MODELLING ... 53

6.1 Introduction and Context ... 53
6.1.1 Historical Context ... 53
6.2 Model Setup ... 54
6.2.1 Model Software ... 54
6.2.2 Model Grid and Active Domain ... 54
6.2.3 Model Layers ... 54
6.2.4 Model Geometry ... 55
6.2.5 Model Parameters ... 56
6.2.6 Solver Settings ... 58
6.3 Groundwater Inflow and Outflow ... 58
6.3.1 Recharge ... 58
6.3.2 Evaporation ... 58
6.3.3 Ephemeral and Perennial Creeks, and Swamps ... 59
6.3.4 Water Table at Ground Surface ... 60

6.3.5 Mine Dewatering ... 60
6.3.6 Groundwater Throughflow ... 61
6.4 Model Calibration ... 62
6.4.1 Steady-State ... 62
6.4.2 Transient Calibration ... 62
6.4.3 Transient Validation ... 65
6.5 Sensitivity Analysis ... 67
6.5.1 Steady-State Sensitivity Analysis ... 67
6.5.2 Transient Calibration Sensitivity Analysis ... 68
6.6 Model Prediction ... 68
6.6.1 Modelled Scenarios ... 68
6.6.2 Model Results ... 69
6.7 Uncertainty Analysis ... 73

7. IMPACT ASSESSMENT ... 74

7.1 Current Mining and Observed Impacts ... 74
7.1.1 Swamp Water Level Monitoring ... 74
7.1.2 Surface Water Gauging ... 75
7.2 Subsidence Assessment of Proposed Mining Plan ... 75
7.3 Predicted Groundwater Impacts ... 76
7.3.1 Predicted Groundwater Levels ... 76
7.3.2 Predicted Drawdown ... 77
7.3.3 Predicted Baseflow Impacts ... 80
7.3.4 Baseflow Impacts Uncertainty Analysis ... 88
7.3.5 Predicted Impacts on Groundwater Dependent Ecosystems ... 90
7.3.6 Gardens of Stone National Park ... 92
7.3.7 Birds Rock Flora Reserve ... 92
7.3.8 Existing Groundwater Users ... 92
7.3.9 Potential Water Quality Impacts ... 92
7.3.10 Impacts Under Climate Change Scenarios ... 92
7.3.11 Impacts of other Groundwater Related Activities ... 94
7.3.12 Aquifer Interference and Minimal Impacts Considerations ... 94
7.4 Impacts Summary ... 96

8. WATER LICENSING ... 97

8.1 Groundwater Licensing ... 97
8.1.1 Licensing Requirement ... 98
8.1.2 Groundwater Management Rules ... 99
8.1.3 Aquifer Interference Policy ... 100
8.2 Surface Water Licence ... 101
8.2.1 Licensing Requirement ... 101
8.2.2 Water Sharing Rules ... 102
8.3 Summary License Volumes ... 103

9. MONITORING AND MANAGEMENT ... 104

9.1 Monitoring of Impacts of Groundwater Extraction / Dewatering ... 104
9.2 Existing Environmental Management System ... 104
9.3 Review and Reporting ... 105

10. REFERENCES ... 107

11. GLOSSARY OF TERMS.. 109

TABLES

Table 2.1: DGRs Specific to Groundwater Resources.. 11
Table 2.2: Supplementary DGRs – Water Resources 12
Table 2.3: NSW Office of Water Requirements 13
Table 2.4: OEH Requirements for the Environmental Assessment 13
Table 3.1: Average Daily Pan A Evaporation (mm) from Bathurst Agricultural Station.................................. 18
Table 3.2: Long-term Rainfall Summary at Lidsdale (Maddox Lane), Station 63132 (mm) 19
Table 3.3: Catchment Characteristics in the Project Application Area... 20
Table 3.4: Regional Stratigraphic Summary 24
Table 3.5: Use Summary of Registered Bores Within 10 km of centre-point of Project Application Area........ 30
Table 4.1: Springvale Shrub Swamp Water Level Monitoring Details... 32
Table 4.2: Standpipe Piezometer Monitoring Points.. 34
Table 4.3: VWP Monitoring Details.. 37
Table 4.4: Groundwater Chemistry Monitoring At Springvale Swamp Sites 41
Table 4.5: Swamp Groundwater Quality Summary at Springvale Sites... 42
Table 4.6: Summary of Site Specific Permeability Data - AP1205 (Golder Associates, 2012) 46
Table 6.1: Major Hydrogeological Units in the Groundwater Model (based on stratigraphy at SPR50)............ 55
Table 6.2: Model Input Parameter – Hydraulic Conductivity and Porosity (Initial Values) 56
Table 6.3: Model Input Parameters – Permeability Change for Longwall Mines (Initial Values)....................... 57
Table 6.4: Model Input Parameters – Permeability Change for Bord and Pillar (Initial Values) 57
Table 6.5: Model Boundary Condition – Creeks and Swamps... 59
Table 6.6: Steady-State Calibration - Model Mass Balance 62
Table 6.7: Steady-State Calibration – Calibration Statistics 62
Table 6.8: Transient Calibration - Model Mass Balance 63
Table 6.9: Transient Calibration – Calibration Statistics 63
Table 6.10: Transient Calibration - Calibrated Values for Hydraulic Conductivity.. 64
Table 6.11: Model Input Parameters – Permeability Change for Longwall Mines (Calibrated)......................... 64
Table 6.12: Transient Calibration – Calibrated Values for Hydraulic Conductivity at Example Location, SPR5066
Table 6.13: Prediction Simulation – Modelled Drawdown.. 71
Table 7.1: Prediction Simulation – Cumulative Drawdown at Groundwater Works.. 78
Table 7.2: Summary of Predicted Baseflow Changes 87
Table 7.3 Predicted maximum drop in the average standing water levels within swamps/streams with respect to the water levels in December 2012 (CSIRO, 2013) 90
Table 7.4: Climate Change Scenario Baseflow Variation – End of Mining 93
Table 7.5: Climate Change Scenario Baseflow Variation – 100 Years Post Mining 93
Table 7.6: Minimal Impact Considerations: Triassic Age Narrabeen – Wianamatta Group (Fractured Rock Water Source).. 95
Table 7.7: Minimal Impact Considerations: Permian Age Illawarra Coal Measures (Fractured Rock Water Source) 95
Table 8.1: Groundwater Resource Statistics 97
Table 8.2: Predicted WAL Requirement – Sydney Basin Coxs River and Richmond River............................. 98
Table 8.3: Springvale Licence Allocations.. 99
Table 8.4: Groundwater Source Rules Summary 99
Table 8.5: Surface Water Licensing Requirements 101
Table 8.6: Management Zone Water Sharing Rules... 102
Table 8.7: Licensing Volumes Summary 103

FIGURES (compiled at end of report)

Figure 1: Site Location
Figure 2: Project Application Area
Figure 3: Historical and Proposed Mining
Figure 4: Mining Schedule
Figure 5: Regional Hydrogeology
Figure 6: Shrub and Hanging Swamp Locations
Figure 7: Groundwater Dependent Ecosystems
Figure 8: Regional Geology
Figure 9: Conceptual Hydrogeology
Figure 10: Aquifer Units
Figure 11: Carne West Swamp Long Section
Figure 12: Sunnyside Swamp Long Section
Figure 13: Sunnyside, Sunnyside East, Carne West Swamp Cross Section
Figure 14: Kangaroo Creek Long Section
Figure 15: Kangaroo Creek Swamp Cross Section
Figure 16: West Wolgan Swamp Long Section
Figure 17: East Wolgan Swamp Long Section
Figure 18: Registered Bores and Wells
Figure 19: Surface and Groundwater Monitoring Network
Figure 20: Swamp Groundwater Quality Monitoring
Figure 21: Groundwater Contours Banks Wall Sandstone
Figure 22: Groundwater Contours Burra Moko Head Formation
Figure 23: CSIRO Model Domains
Figure 24: Model Stratigraphy
Figure 25: Model Boundary Condition - Creeks and Swamps
Figure 26: Predicted Groundwater Levels in 2013 - Lithgow Seam
Figure 27: Predicted Groundwater Levels in 2013 - AQ1
Figure 28: Predicted Groundwater Levels in 2013 - AQ3
Figure 29: Predicted Groundwater Levels in 2013 - AQ4
Figure 30: Predicted Groundwater Levels in 2013 - AQ6
Figure 31: Cumulative Drawdown and Recovery - Top of Lithgow Seam
Figure 32: Cumulative Drawdown (End of Mining2026) - Lithgow Seam
Figure 33: Cumulative Drawdown and Recovery - AQ1
Figure 34: Cumulative Drawdown (End of Mining 2026) - AQ1
Figure 35: Cumulative Drawdown and Recovery - AQ3
Figure 36: Cumulative Drawdown (End of Mining 2026) - AQ3
Figure 37: Cumulative Drawdown and Recovery - AQ4
Figure 38: Cumulative Drawdown (End of Mining 2026 - AQ4
Figure 39: Cumulative Drawdown and Recovery - AQ6
Figure 40: Composite Water Table Decline (End of Mining 2026) – AQ4, AQ5, AQ6
Figure 41: Springvale Only Drawdown and Recovery - Lithgow Seam
Figure 42: Springvale Only Drawdown (End of Mining 2026) - Lithgow Seam
Figure 43: Springvale Only Drawdown and Recovery - AQ1
Figure 44: Springvale Only Drawdown (End of Mining) - AQ1
Figure 45: Springvale Only Drawdown and Recovery - AQ3
Figure 46: Springvale Only Drawdown (End of Mining at 2026) - AQ3
Figure 47: Springvale Only Drawdown and Recovery - AQ4
Figure 48: Springvale Only Drawdown (End of Mining 2026) - AQ4
Figure 49: Springvale Only Drawdown and Recovery - AQ6
Figure 50: Springvale Only Drawdown (End of Mining 2026) - AQ6

Figure 51: Time-Series Hydrograph Reporting Locations
Figure 52: Time-Series Hydrograph No APE Scenario Location 1
Figure 53: Time-Series Hydrograph Base Case Scenario Location 3
Figure 54: Time-Series Hydrograph No SV Scenario Location 5
Figure 55: Location of Phreatic Surface Cross-Sections
Figure 56: Predicted Phreatic Surface Cross-Section W-E
Figure 57: Predicted Phreatic Surface Cross-Section A-B
Figure 58: Predicted Mine Inflows
Figure 59: Predicted Groundwater Discharge to Ephemeral Swamps/Creeks
Figure 60: Predicted Groundwater Discharge to Perennial Swamps/Creeks
Figure 61: Predicted Groundwater Discharge to Perennial Swamps/Creeks
Figure 62: Predicted Groundwater Discharge to Perennial Swamps/Creeks
Figure 63: Predicted Groundwater Discharge to Perennial Swamps/Creeks
Figure 64: Baseflow Uncertainty Analysis to Ephemeral Swamps/Creeks
Figure 65: Baseflow Uncertainty Analysis to Perennial Swamps/Creeks
Figure 66: Baseflow Uncertainty Analysis to Perennial Swamps/Creeks
Figure 67: Predicted Groundwater Discharge to Perennial Swamps/Creeks
Figure 68: Baseflow Uncertainty Analysis to Perennial Swamps/Creeks
Figure 69: Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources
Figure 70: Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources

APPENDICES

Appendix A: NSW Office of Water Registered Bores
Appendix B: Swamp Groundwater Impact Case Study
Appendix C: Swamp Delineation Study
Appendix D: Swamp Borehole Logs
Appendix E: Swamp Hydrographs
Appendix F: Vibrating Wire Piezometer Hydrographs
Appendix G: VWP Installed Sensor Depth Descriptions
Appendix H: Shallow and Deep Aquifer Bore Logs
Appendix I: Swamp Water Quality Results
Appendix J: Bore 6 Groundwater Quality
Appendix K: CSIRO Numerical Modelling Report
Appendix L: Climate Affected Baseflow Plots
Appendix M: Previous Investigations
Appendix N: Piezometric Profiles
Appendix O: Minimal Impact Considerations for AIP

1. INTRODUCTION

Springvale Coal Pty Limited has commissioned RPS to prepare a groundwater impact assessment for the Springvale Mine Extension Project (the Project). The overall objective is to obtain approval for the Project which will involve the continuation of longwall mining at Springvale Mine (Springvale) beyond the current Development Consent expiry date of 28 September 2014. This study forms an appendix to the main Environmental Impact Statement (EIS) being prepared in support of the development application for the Project.

1.1 Background

The Springvale mine is owned by Centennial Springvale Pty Limited (as to 50%) and Springvale SK Kores Pty Limited (as to 50%) as participants in the Springvale unincorporated joint venture. The Springvale mine is operated by Springvale Coal Pty Limited, for and on behalf of the Springvale joint venture participants.

Springvale proposes to extend its current underground longwall mining operations to the east and the southwest of its existing operations at Springvale. Springvale is located in the Western Coalfields, approximately 15 km northwest of Lithgow and bordering the Angus Place Colliery (Figure 1) to the north. The Project will fall within Springvale's existing Colliery Holding.

Springvale's current development consent will expire on 28 September 2014, and the Applicant is seeking approval to continue mining beyond this date. Mining is expected to have advanced to Longwall (LW) 416 by this date. Therefore the development application is proposed to include LW417 to LW432 and LW501 to LW503. The locations of the proposed longwall panels, and the Project Application Area, are shown in Figure 2. The Project Application Area comprises the area within the boundary as defined on Figure 2.

The Project is a State Significant Development (SSD-5594) in accordance with Clause 8 and Schedule 1 (Item 5) of State Environmental Planning Policy (State and Regional Development) 2011. As such the Applicant will seek approval under Part 4, Division 4.1 of the Environmental Planning and Assessment Act 1979 (EP&A Act).

This study has been prepared with consideration of the Director General's Requirements (DGRs) for the Project issued on 6 November 2012 by the DP&I, the environmental assessment requirements of NSW Office of Water, Office of Environment and heritage, and the relevant legislation and guidelines.

1.2 Site, Situation and Existing Approved Mine

The administrative centre at Springvale (pit top) is accessed off the Castlereagh Highway at Lidsdale. Springvale is within the Lithgow City Council Local Government Area. The underground longwall mine is situated directly below a sandstone plateau of undulating unpopulated bushland that is part of the Newnes State Forest. The mine currently has an annual extraction limit of 3.4 million tonnes of run-of-mine (ROM) coal. Within the current approved area, LW401 to LW414 have been extracted, and LW415 is being mined currently. Mining currently occurs in accordance with the subsidence management plan for LW414 to LW418 approved on 22 October 2010 (Figure 3).

Springvale is situated adjacent to Angus Place and Clarence Collieries to the north and southeast respectively, and the abandoned Lithgow state mine to the south. Several abandoned mines and Coxs River Valley lie to the west. The Wolgan Valley is situated to the north and Newnes State Forest to the east (Figure 1). Collectively, existing land uses in the vicinity of the colliery include residential land, pastoral farming, open cut and underground coal mining, power generation and commercial forestry.

Springvale exists as an underground coal mine producing high quality thermal coal which is supplied to both domestic and international markets. Domestically, Springvale has established long term contracts with two local power stations: Wallerawang and Mount Piper. All coal is distributed to these sites via dedicated conveyors. The international market is accessed via the approved Lidsdale Siding rail loading facility, a business unit of Centennial Coal.

1.3 Project description

Springvale is seeking approval for the Project based on resource modelling completed within the Project Application Area. The current approved and proposed workings at Springvale are shown on Figure 3. The Project will continue to use existing surface and underground facilities at the Springvale Mine pit top and existing infrastructure on Newnes Plateau within Newnes State Forest in accordance with the existing development consent DA 11/92. Additionally, new facilities and modifications to existing facilities are being proposed on Newnes Plateau.

In summary, Springvale Mine is seeking approval under the provisions of Part 4.1 of the EP&A Act to:

- continue to extract up to 4.5 million tonnes per annum of run of mine coal from the Lithgow Seam underlying the Project Application Area;
- extend the life of the mine for an additional 13 years with rehabilitation to be undertaken post this period;
- develop underground access headings and roadways from the current mining area to the east to allow access to the proposed mining areas;
- undertake secondary extraction by retreat longwall mining method for the proposed longwalls LW416 to LW432 and LW501 to LW503;
- continue to use the existing ancillary surface facilities at the Springvale pit top;
- continue to manage the handling of ROM coal through a crusher and screening plant at the Springvale pit top, and the subsequent loading of the coal onto the existing overland conveyor system for despatch to offsite locations;
- continue to operate and maintain the existing ancillary surface infrastructure for ventilation, electricity, water, materials supply, and communications at the Springvale pit top and on Newnes Plateau;
- install and operate two additional dewatering bore facilities (Bores 9 and 10) on Newnes Plateau and the associated power and pipeline infrastructure, and upgrade the existing and construct two new sections of access tracks to Bores 9 and 10 facilities;
- construct a downcast ventilation borehole at the Bore 10 facility location;
- establish a mine services borehole area;
- manage predicted increase in mine inflows using a combination of direct water transfer to the Wallerawang Power Station, via the Springvale Delta Water Transfer Scheme (SDWTS), and discharge through Angus Place Colliery's licensed discharge point LDP001 and Springvale Mine's LDP009. The SDWTS will be upgraded when mine inflows to Springvale Mine and Angus Place Colliery exceed 30ML/d;
- continue to undertake exploration activities, predominately borehole drilling to refine the existing geological model;
- continue to undertake existing and initiate new environmental monitoring programmes;
- continue to operate 24 hours per day seven days per week, 52 weeks per year;
- continue to provide employment to a full time workforce of up to 310 employees;
- progressively rehabilitate disturbed areas at infrastructure sites no longer required for mining operations;
- undertake life-of-mine rehabilitation at the Springvale pit top and the Newnes Plateau infrastructure disturbance areas to create final landforms commensurate with the surrounding areas and the relevant zonings of the respective areas; and
- transfer the operational management and physical infrastructure regarding coal processing and distribution infrastructure to the proposed Western Coal Services Project.

1.4 Purpose of the Report

This report has been compiled in order to address groundwater related hazards and risks that may arise as a result of proposed Project activities and will support and form part of the EIS for the Project.

The report has also been developed and structured to address key issues specific to groundwater resources as prescribed DGRs for the Project.

The report is designed to provide sufficient information on the existing groundwater environment within the Springvale area and its immediate surrounds to enable assessment of the potential impacts of the Project on groundwater system; and any subsequent impacts on surface water, groundwater dependent ecosystems (GDEs) and existing groundwater users.

The assessment has been used to develop appropriate management and mitigation strategies which are based on the predicted impacts.

1.5 Structure of the report

This report is written such that it provides the reader with clear and concise information on the state of the groundwater environment within the Project and its immediate surrounds (study area). It aims to assess the potential impacts on groundwater levels and quality, environmental receptors and local groundwater users from the proposed Project. It also addresses all of the relevant licensing requirements, and puts forward monitoring and management methodologies to ensure that all relevant stakeholders in the Project have been considered.

The report is structured as follows:

- ***Section 2*** presents the statutory requirements and relevant legislation which is applicable to the Project in relation to groundwater. This includes the Director Generals Requirements (DGRs) the NSW Office of Water requirements and the Office of Environment and Heritage requirements which are specific to groundwater resources. It also addresses the relevant state policies and Water Management Act 2000 along with the licensing and the NSW Aquifer Interference Policy.
- ***Section 3*** reports on the existing environment within the study area. It presents the existing climatic information, catchment description (including the description of the swamps that exist within the Project Application Area), the geological setting, and the hydrogeological setting.
- ***Section 4*** expands on the existing environment setting which is presented in section 3, and goes on to explain in detail the hydrogeological investigations which have been ongoing within the Project Application Area in the recent history. It gives detail on the current monitoring network which is installed across the site and describes how this monitoring network is designed to obtain groundwater data from the separate hydrogeological systems which are present in the study area. It also presents data on the existing groundwater users in the Project Application Area. The groundwater data obtained from the monitoring network is discussed and analysed in terms of groundwater flow paths, vertical gradients, and recharge and discharge points.
- ***Section 5*** presents the conceptual hydrogeology of the Project Application Area. This chapter has been included so that the complex hydrogeological regime in the study area can be presented in a clear and logical way. It enables the reader to understand the reasons why certain hydrogeological properties have been represented in the numerical model, and consequently, provide clarity on the calibration process and the prediction phase.
- ***Section 6*** presents the groundwater numerical modeling which was undertaken by CSIRO to predict potential mining induced impacts on the groundwater system and environmental receptors. The objectives of the modeling exercise are described along with the calibration, prediction and sensitivity / uncertainty analysis phases. The impacts of climate change are also simulated in the model. Included in this section are other analyses and reports which have been carried out using 11 years of site groundwater data for the Project Application Area. These reports and case studies within the Project Application Area provide additional lines of evidence to support and complement the numerical groundwater model.
- ***Section 7*** presents the impact assessment from the Project on the surrounding groundwater environment, surface water and swamps, GDEs and regional groundwater users. The impacts of climate change are also considered in the impact assessment process.
- ***Section 8*** presents the relevant groundwater accounting and water sharing plan relevant to the Project Application Area. The licensing rules are discussed along with the relevance of

the aquifer interference approval.

- ***Section 9*** presents the groundwater monitoring, management and contingency response plans. The impacts of the Project are assessed in relation to the existing monitoring network and any potential changes or additions to this monitoring network are also discussed.
- ***Section 10*** presents the published and non-published literature which was used to inform various sections of this report.

1.6 Key inputs to the report

The key input into the assessment of impacts from the Project is the results of the COSFLOW numerical modelling that has been conducted by Commonwealth Scientific and Industrial Research Organisation (CSIRO). As has been previously described, other lines of evidence such as groundwater case studies, and additional analysis of groundwater levels has also contributed to the assessment of impacts from the Project.

The report also acknowledges the outcome of the subsidence impacts assessment, as detailed in the Subsidence Predictions and Impact Assessment (SPIA) report (MSEC, 2013), the outcomes of the Surface Water Impact Assessment (RPS, 2013a) and the Ecological Impact Assessment (RPS, 2013c).

Most of the field data used in this assessment has been collected and compiled by Springvale, CSIRO and Aurecon.

2. REGULATION AND BEST PRACTICE GUIDELINES

2.1 Commonwealth Legislation

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

Pursuant to the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act), an action that has, will have, or is likely to have a significant impact upon Matters of National Environmental Significance (MNES) is declared a "controlled action" and requires the approval of the Commonwealth Minister for Sustainability, Environment, Water, Population and Communities (SEWPaC). Approval under the Commonwealth EPBC Act is in addition to requirements under NSW State legislation.

The EBPC Act lists eight MNES that must be addressed when assessing the impacts of a proposal. Ecology investigations completed for the Project have identified that there are threatened species, ecological communities and migratory species identified as MNES within the Project Application Area.

SEWPaC have determined that the Project is a controlled action requiring assessment and approval under the EPBC Act. The Project will be assessed by accredited assessment under Part 4 of the Environmental Planning and Assessment Act 1979 (NSW) (EP&A Act) under the terms of the bilateral agreement between the Commonwealth and the NSW Government.

SEWPaC has provided assessment requirements that are integrated into the NSW State environmental assessment process. Assessment documentation required under the NSW EP&A Act process for the Project will be provided to the Commonwealth Minister to determine the Project under the EPBC Act.

2.2 NSW State Legislation

2.2.1 Environment and Planning Assessment Act 1979

The Project is a 'Major Development' as defined in State Environmental Planning Policy (SEPP) Major Development 2005, and in accordance with the Environmental Planning and Assessment Act, 1979 (EP&A Act) requires approval of the NSW Minister for Planning to proceed under Part 4 of the EP&A Act.

The Director General's Requirements (DGRs) relating to groundwater for the EIS are outlined in Table 2.1. This table also shows the relevant report section that deals with each specific requirement.

The DGRs relating to groundwater assessment for the EIS are outlined in Table 2.1. This table also shows the relevant report section that deals with each specific requirement.

Table 2.1: DGRs Specific to Groundwater Resources

DGRs Specific to Groundwater	Relevant Section of this report
Detailed assessment of the key issues and any other significant issues identified in this risk assessment, which includes a description of the existing environment, using sufficient baseline data;	Section 3 & 4
An assessment of the potential impacts of all stages of the development, including any cumulative impacts, taking into consideration relevant guidelines, policies, plans and statutes;	Section 7
A description of the measures that would be implemented to avoid, minimise and, if necessary, offset the potential impacts of the development, including proposals for adaptive management and/or contingency plans to manage any significant risks to the environment;	Section 9
Detailed assessment of potential impacts on the quality and quantity of existing surface water and ground water resources in accordance with the NSW Aquifer Interference Policy, including; • impacts on affected licensed water users and basic landholder rights; • impacts on riparian, ecological, geo-morphological and hydrological values of	Section 7, 8.1 & 8.2 Refer to Surface Water

DGRs Specific to Groundwater	Relevant Section of this report
watercourses, including groundwater dependent ecosystems and environmental flows; and • whether the development can operate to achieve a neutral or beneficial effect on water quality in the drinking water catchment, consistent with the provisions of *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011.*	Assessment Section 7.1 and 7.3 Refer to Surface Water Assessment
Identification of any licensing requirements, including existing or future Environment Protection Licences (EPLs) or Pollution Reduction Programs (PRPs), and approvals under the *Water Act 1912* and/or *Water* Management Act 2000.	Section 2, 8.1 & 8.2 Refer to Surface Water Assessment
Demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP).	Section 8.1 & 8.2
A description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo.	Section 8.1 & 8.2
A detailed description of the proposed water management system water monitoring regime, beneficial water re-use program and all other proposed measures to mitigate groundwater impacts.	Section 9

Supplementary DGRs were issued on 30 August 2013 (EPBC 2013/6881). The supplementary DGRs are presented in Table 2.2.

Table 2.2: Supplementary DGRs – Water Resources

Requirement	Where addressed
An assessment of all relevant impacts on water resources and water related values, including:	
• detailed information addressing the Independent Expert Scientific Committee Information Guidelines for Proposals Relating to the Development of Coal Seam Gas and Large Coal Mines where there is a Significant Impact on Water Resources, available at: www.environment.gov.au/coal-seam-gas-mining/pubs/iesc-information-guidelines.pdf	Water Balance: – Refer to Surface Water Assessment Impact Assessment including Risk Assessment: – Section 7 Management and Monitoring: – Section 9
• detailed information addressing the department's Water Resources Terms of Reference, currently in preparation.	N/A

2.2.2 NSW Office of Water

The NSW Office of Water (NOW) has provided a series of requirements for the EIS in addition to the DGRs (Table 2.3). These are addressed in this report according to the relevant sections identified in Table 2.3.

The NOW requirements under the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources and Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources have been addressed separately in Section 8 and have been structured around the following:

- Planned environmental water provisions.
- Water supply works approvals (considering the mine dewatering as forming a water supply work under definitions of the Water Management Act 2000 (WM Act).
- Long term average extraction limits and development of Available Water Determinations during the lifetime of the Project, and the post-mining hydrological configuration.
- Total daily extraction limits and rules governing environmental protection.
- Surface and groundwater connectivity.
- Access license dealings.

Table 2.3: NSW Office of Water Requirements

NSW Office of Water Requirement	Report Section where requirement is addressed
Adequate and secure water supply for all mine activities	Section 8
Compliance with WSP rules including rules for access licences, and distance restrictions, water quality and surface water and groundwater connectivity	Section 8
Baseline monitoring of all groundwater sources and GDEs within and adjacent to mining operation	Section 4.3
Details of groundwater sources and existing users and potential impact to users	Section 3.8, 3.9 and 7.3
Identification of GDEs, assessment for condition and water quality and quantity requirements for terrestrial and aquatic systems, diversity and abundance	Section 3.10
Description of aquifer properties, chemical characteristics and connectivity with surface water systems	Section 3 & 4
Assessment of potential effects of mining operation on groundwater quality in short and long term	Section 7.3
Predictive assessment of drawdown, inflow and potential impacts to groundwater and surface water sources, basic landholders right, licensed water users and GDEs	Section 7.3
Provide detail of groundwater extraction and water supply works including purpose, location, volumes to be extracted, and monitoring	Section 4 & 6.6
Details on management of groundwater extraction such that groundwater levels and quality do not impact GDEs and sustain ecological processes and maintain biodiversity	Section 7.3 & 9
Mitigation strategies to address adverse impacts on surface and groundwater sources and GDEs for operational and post mining phases	Section 9
Determination of critical thresholds for negligible impacts to groundwater sources and GDEs	Section 9

2.2.3 Office of Environment and Heritage

The Office of Environment and Heritage (OEH) has provided supporting documentation that concurs with the DGRs. In addition, OEH considered that the EIS should provide the details outlined in Table 2.4 regarding the provision of an offsite discharge (where required).

Table 2.4: OEH Requirements for the Environmental Assessment

OEH Requirement	Report Section where requirement is addressed
Describe quality and quantity of water produced through the mining activities	Section 4.8 & 4.9
Specify impacts of modified flow and quality on biodiversity	Section 7.3
Detail impact of quality, temperature and quality of discharged water on aquatic system	Refer to Ecological Assessment
Impact of changes to groundwater levels to vegetation	Section 7 .3
Project relationship to Regional Water Strategy	Refer to Main EIS
Mitigation strategies to address impact of mining on swamps	Refer to Surface Water Assessment Section 9

2.2.4 Groundwater Dependent Ecosystems

As outlined in the WM Act amendment, Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources, 2008, Order Schedule 1, Dictionary, Department of Water and Energy, GDEs are defined as:

'Ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.'

Risk assessment guidelines for groundwater dependent ecosystems (NSW Office of Water and the OEH, 2012), state that GDEs explicitly include any ecosystem that uses groundwater at any time or for any duration in order to maintain its composition and condition.

This report addresses the potential for the Project to impact on GDEs. The identified GDEs within the Project Application Area are discussed in Section 3.10. A specialist ecology report, included in the EIS provides more in-depth analysis of the identification process for the GDEs within the Project Application Area (RPS, 2013c).

2.2.5 Contingency Measures

Where potential impacts from the Project have been identified (refer to Section 7) this study has attempted to quantify the limits of impact and provide suitable contingency measures that could be implemented to reduce or manage potential impacts on sensitive receptors i.e. swamps, stream baseflows, GDEs and other groundwater users. The latter largely revolves around mine design measures to avoid unacceptable impacts.

Section 9 provides details of a recommended groundwater monitoring programme and includes recommendations on suitable time intervals for water level monitoring, representative sampling and associated field and laboratory analysis. Section 9 also outlines appropriate reporting procedures relevant to the long term monitoring programme and outlines a suitable mechanism for transfer of information to NSW Office of Water (NoW).

2.2.6 Post Mining Mitigation Measures

This assessment has also considered appropriate post mining mitigation measures and a series of options for the management of mitigation measures. Section 9 of this report addresses the following:

- Measures that would need to be established in order to minimise the potential impacts on the local and regional groundwater resources and surface water systems and for the ongoing management of the site following cessation of the mining phase.
- Detailed description of the measures to be put in place to ensure that sufficient resources are available to implement the proposed rehabilitation of water related impacts.

2.3 Relevant State Policies and Guidelines

This report has addressed (as applicable) policies and procedures from the relevant state policies and guidelines:

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC, 1995).
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000).
- Australian and New Zealand Guidelines for Water Quality Monitoring.
- NSW State Groundwater Policy Framework Document (DLWC, 1997).
- NSW State Groundwater Quantity Management Policy (1998).
- NSW State Groundwater Quality Protection Policy (DLWC, 1998).
- Murray-Darling Basin Groundwater Quality Sampling Guidelines. Technical Report No. 3 (MDBC).
- Barnett et al, 2012, *Australian Groundwater Modelling Guidelines*, Waterlines Report, National Water Commission, Canberra.
- Guidelines for the Assessment and Management of Groundwater Contamination (DECC, 2007).
- NSW State Groundwater Dependent Ecosystem Policy (2002).
- Risk assessment guidelines for groundwater dependent ecosystems (NSW Office of Water and OEH, 2012).

- Guidelines for Groundwater Protection in Australia (1995).
- Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (July, 2011).
- Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources (July, 2011).
- NSW Aquifer Interference Policy – Stage 1 (New South Wales (NSW) Government, September 2012).
- State Environmental Planning Policy (Major Development) 2005 (SEPP).
- Information Guidelines for Proposals Relating to the Development of Coal Seam Gas and Large Coal Mines where there is a Significant Impact on Water Resources (IESC, 2013)
- Significant Impact Guidelines for Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (Department of the Environment, 2013).

2.4 Water Sharing Plans

Water sharing plans (WSPs) are being progressively developed for rivers and groundwater systems across NSW following the introduction of the WM Act. These WSPs are designed to provide long-term environmental protection and sustainability of the groundwater resources as well as directing how water will be allocated and shared among the various water users. WSPs apply the goals and principles of the State Groundwater Policy at a local and regional level.

The WSPs identify the recharge component to each groundwater source or zone and direct how the recharge component will be allocated and shared among different water users. They also outline the management of local impacts, including groundwater interference, and list beneficial uses of the groundwater to be protected and occurrence of any GDEs within the groundwater source of zone.

The WSPs refer to the National Health and Medical Research Council (NHMRC) 1996 *Drinking Water Guidelines for drinking water beneficial use.* Other beneficial uses are defined by the Australian and New Zealand Environment and Conservation Council (ANZECC) 2000 Water Quality Guidelines (ANZECC, 2000).

Compliance with the requirements of the relevant water sharing plans is addressed in Section 8.

2.5 Licensing and Aquifer Interference Policy

Under the NSW Aquifer Interference Policy (AIP) (NSW Department of Primary Industries, September 2012) a water licence is required for any activity that penetrates, interferes, obstructs flow in aquifer or takes and disposes of water from aquifer during mining activity. Where the activity causes the movement of water form one part of the aquifer to another or to and from a surface water body, a licence is also required.

Licences under the Water Act 1912 will be required for installation of monitoring piezometers for the purposes of water level, groundwater quality monitoring and hydraulic testing in any aquifer underlying the study area. The WM Act 2000 includes the concept of ensuring “no more than minimal harm” for both the granting of water access licences and the granting of licences and approvals. Water access licences will not be granted unless the Minister is satisfied that adequate arrangements are in force to ensure that no more than minimal harm will be done to any water source as a consequence of water being taken under the licence. In order to address minimal harm criteria, groundwater sources have been divided into “highly productive” and “less productive” based on certain criteria which are detailed in the AIP. Compliance with the requirements of the relevant water sharing plans is addressed in Section 8.

2.6 Subsidence Constraints Analysis

A subsidence constraints analysis process was undertaken by Springvale, using mine operator Management Standard MS 004 Risk Management with the aim of:

- Identifying the known mine characteristics (such as depth of cover, geology, mining method, mining height, mine layout and percentage extraction) and the mine design criteria to be applied.

- Identifying sensitive natural and man-made features that might be at risk.
- Describing in full significant natural and manmade features and any characteristics that may be relevant in assessing potential subsidence related impacts and consequences.
- Identifying knowledge gaps and requirements to provide sufficient information to fill these knowledge gaps for either the subsidence assessment or other specialist assessments. The DGRs require an assessment of subsidence to use sufficient baseline data (MSEC, 2013).

This meeting was attended by all relevant site personnel, specialist consultants (including subsidence, groundwater, surface water, flora, fauna and archaeology), and other relevant stakeholders. Key topics discussed at the meeting are as follows:

- Depressurisation of aquifers
- Impact to surface water
- Ecological impacts
- Impacts to cliffs, rock features and Aboriginal heritage
- Infrastructure
- Far field effects
- Cumulative impacts

The topics relevant to groundwater which were discussed at the meeting have been incorporated throughout the body of this document.

3. EXISTING ENVIRONMENT

3.1 Topographical Setting

The topography of the study area comprises narrow gorges with high ridgelines and steep sided slopes of sandstone cliffs. The cliffs rise above incised valleys and hilly areas with relatively flat crests and some spurs with moderately sloped ephemeral drainage lines. Rivers and streams, such as Coxs Creek, Kangaroo Creek, the Wolgan River, Carne Creek and their tributaries are found incised into this topography.

Most of the land surface within the Project Area lies within the Newnes Plateau at elevations from 900 to greater than 1175 m AHD. The plateau forms part of the divide between the Wolgan and Coxs River catchments. It consists of a number of connecting, wide, gently undulating ridges, dissected by relatively steep–sided valleys with the floors of the creeks and gullies sited at elevations of between 960 m and 980 m AHD. Sandstone cliffs over 40 m in height can be found in the south western and north eastern corners, and along the southern boundary of the study area. In general, however, the sandstone cliffs range between 10 m and 40 m in height throughout the area.

Some swamps occur within the headwater valleys and are controlled by the flat topography and impervious shale layers. To the north, there is Sunnyside Swamp, Gang Gang Swamp and Carne Central Swamp. To the south there is Sawyers Swamp, and other unnamed swamp which occur along the tributaries of both Marrangaroo Creek and Paddys Creek.

See Figure 1 for details of the local topography.

3.2 Historical Mining

The area around Springvale has been subjected to extensive mining operations in the past which started at Fernbrook / Hermitage Colliery in 1886. A number of operations which are either active, completed or abandoned exist in the vicinity of Springvale are shown in Figure 3.

There are currently three active mines adjacent to Springvale:

- Angus Place Colliery (Angus Place) – longwall mine situated directly to the north of Springvale.
- Clarence Colliery – bord and pillar mine situated approximately 3 km to the southeast of Springvale.
- Yarraboldy open cut - open cut mine which is situated approximately 3 km to the west of Springvale.

An indicative timeline of mining operations noted above is provided on Figure 4.

3.3 Climate

The climate in the vicinity of the Newnes State Forest is classified as warm temperate with an annual rainfall of 1,097 mm recorded at the Newnes Forest Centre. Summers are mild with average maximum temperatures of 23.5°C and winters are cold with average minimum temperatures of -1.0°C. Rainfall and temperature trends are seasonally distributed with the highest rainfall and the highest temperatures occurring in the summer months, and the lowest rainfall and temperatures experienced during the winter months.

3.3.1 Rainfall

The rainfall data for the region surrounding the Project Application Area was collated.

A number of BOM stations have been identified near the Project Application Area and are listed below, in order of preference, taking into consideration locality, altitude and quality of data.

- Lidsdale (Maddox Lane), Station No. 63132 – 01/08/1959 to present.
- Portland (Jamieson St), Station No. 63071 – 01/01/1923 to present.

- Lithgow (Cooerwull), Station No. 63226 – 01/01/1878 to present.
- Sunny Corner (snow line), Station No. 63079 – 01/01/2003 to 29/02/2008.
- Wallerawang Power Station, Station No. 63176 – 01/12/1902 to 31/10/1973.
- Lithgow (Birdwood St), Station No. 63224 – 01/04/1889 to 30/06/2006.
- Lithgow (Kylie Park), Station No. 63164 – 01/09/1959 to 31/09/2009.
- Lithgow (Newnes Forest Centre), Station No. 63062 – 01/04/1938 to 30/11/1999.

The Lithgow (Newnes Forest Centre) (BOM Station No. 63062) station represents the most complete historical rainfall dataset with respect to the Newnes Plateau (elevation above 1,000mAHD). Monitoring at this station ceased in 1999.

The most complete dataset with respect to Angus Place Pit Top corresponds to the Lidsdale (Maddox Lane) (BOM Station No. 63132) station. This station is located 5km from the Springvale Pit Top. The next closest station to Angus Place Pit Top is Portland (Jamieson St) (BOM Station No. 63071); however, there are significant data gaps until 1944 and between 1993 and 2003.

Table 3.1 presents the tabulated monthly values.

3.3.2 Evapotranspiration

Daily Pan A evaporation has been recorded at the Bathurst Agricultural Station (BOM Station No. 63005) from 1966 to current. The average monthly evaporation rate is presented in Table 3.2. The annual average daily Pan A evaporation rate is 3.7 mm/day. The Bathurst Agricultural Station is the closest monitoring station to Springvale Mine and is 47km to the west.

Pan A evaporation is usually used for estimating evaporation losses from open water surfaces of sediment ponds and dams.

In forested areas, evaporation tends to be low compared to Pan A evaporation, but this is offset by increased transpiration. Analysis of flow gauging at Sunnyside Swamp on the Newnes Plateau suggest actual evaporation may be 35% of Pan A evaporation.

Table 3.1: Average Daily Pan A Evaporation (mm) from Bathurst Agricultural Station

Stat.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	6.8	5.8	4.5	2.9	1.7	1.1	1.2	1.8	2.8	4.0	5.2	6.5	3.7

Table 3.2: Long-term Rainfall Summary at Lidsdale (Maddox Lane), Station 63132 (mm)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	85.1	78.7	64.2	42.4	51.1	48.8	51.6	65.5	53.7	68.4	73.4	72.9	755.8
Lowest	8	5.6	3.8	1.2	2.6	2.6	2.7	1.8	3.4	2.4	7.6	0	329.8
5th %ile	18.8	11.6	8.7	3.1	5.6	7.7	11.4	8	11	11	13	20.4	465.4
10th %ile	24.8	17.6	14.2	6	7.4	16.5	18	16	19.6	14.6	18.7	25.7	515.1
Median	76.6	70.4	50.7	32.3	45.2	39.8	43.2	51.6	52	73.1	62.5	62.3	765.3
90th %ile	172.5	131.9	120.8	84.9	102.4	83.5	91.2	121.7	91.3	124.2	142.1	133.4	972.7
95th %ile	191.7	178.9	180.7	122.6	124.2	113.2	98.4	202.6	99.7	132.7	151.9	161.7	1165.6
Highest	213.6	270.4	270.4	202.6	131.2	228.3	214	363.8	123	228.4	164.7	217	1260.3

3.4 Catchment Description and Local Hydrology

The Project Application Area covers two adjacent sub-catchments including Wolgan River sub catchment within Northern Valley region of the Hawkesbury - Nepean Catchment and the Upper Coxs River sub-catchment. Both catchments are under the jurisdiction of Hawkesbury - Nepean Catchment Management Authority, although the Coxs River is listed within the boundary of Sydney Drinking Water Catchment (SDWC) under the SEPP. The catchment divide for these catchments runs in a northwest / southeast direction through the Project (Figure 5).

Both the Wolgan River and the Coxs Rivers are connected to watercourses and creeks within the study area that form tributaries to their respective catchments. The south-east boundary of the Project Application Area is a small section comprising the headwaters of Colo River Catchment. The main watercourse in this area is the Nine Mile Creek / Bungleboori Creek.

Spatial details of the catchments and associated watercourses are shown in Figure 5 and summarised Table 3.3 below, which is taken from RPS (2013a).

Table 3.3: Catchment Characteristics in the Project Application Area

Main Catchment	Sub-Catchment	Associated Watercourses	Sub Catchment area (ha)	% catchment area within project boundary (approx.)
Coxs River Catchment	Coxs River (5th & 6th)	Wangcol Creek (3rd), Springvale Creek (2nd), Sawyers Swamp Creek (3rd)	13,026	30%
	Marrangaroo Creek (4th)	Unnamed watercourses south of project boundary	5,495	30%
	Pipers Flat Creek (5th)	Unnamed watercourses south of project boundary	5,948	0%
Wolgan River Catchment	Wolgan River Western Branch	Wolgan River (4th and 5th)	8,526	9%
	Wolgan River Eastern Branch	Carne Creek (5th and 6th)	8,597	30%
Colo River Catchment	Nine Mile Creek/ Bungleboori Creek	Nine Mile Creek (3rd)	4,840	1%

3.5 Temperate Highland Peat Swamps on Sandstone

Temperate Highland Peat Swamps on Sandstone (THPSS) form part of the hydrological regime across the Newnes Plateau. Several of the THPSS are found across the Project Application Area and several have been undermined by longwalls already. They are listed as Endangered Ecological Communities (under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

There are two characteristic THPSS systems on the Newnes Plateau. These systems are referred to as Shrub Swamps and Hanging swamps. The locations of the THPSS across the Project Application Area on which water level monitoring is carried out are shown in Figure 6.

Shrub Swamps and Hanging Swamps can be identified separately due to differences in:

- *Hydrological regimes* – Shrub Swamps are more likely to be permanently water logged due to a more reliable groundwater source and relatively low sloping swamp base. Hanging swamps are less likely to be waterlogged due to smaller more localised perched groundwater systems and steeper slope angles on the base of the swamps.
- *Floral assemblages* – Floral assemblages within the two swamp systems vary due to the physical setting and hydrological regimes.
- *Location* – Shrub Swamps occupy the bases of valleys whereas hanging swamps develop higher up on the flanks of the valleys.

THPSS systems are dynamic evolving systems similar to all other watercourses. These systems experience natural perturbations such as erosion, slumping and piping and damage from wildfires and have a natural inherent ability to 'self-repair' following these events. The peat / sand substrate is strain tolerant and can, to an extent, adjust to these dynamic perturbations (Centennial Angus Place, 2012).

A swamp delineation study was undertaken by RPS Aquaterra in February 2013 (RPS, 2013b). The aim of the study was to use both hydrograph rainfall response trends and vegetation mapping to delineate the areas of swamps which are predominantly groundwater dependent, and those areas of swamps which are predominantly rainfall dependent. The results of this study are discussed in Section 4.3, and the full report is attached as Appendix C.

THPSS as Groundwater Dependent Ecosystems

The terrestrial ecology report (RPS, 2013c) have identified the THPSS as groundwater dependent ecosystems.

In order to define GDEs the following paragraphs have been extracted from Eamus (2009):

> *Identifying groundwater dependent ecosystems, a guide for land and water managers:*
>
> *"There are many types of GDEs, but they can all be classed into one of two types. The first class of GDE relies on the surface expression of groundwater. Swamps, wetlands and rivers are ecosystems that rely on the discharge of groundwater to the surface, either into a river or into a swamp or wetland. Rivers and streams that flow all year (perennially flowing) are generally groundwater dependent because a significant proportion of their daily flow is derived from groundwater discharging into the river course. When groundwater availability declines, river flow is reduced and swamps and wetlands may become dry, temporarily or permanently.*
>
> *The second class of GDEs rely on the availability of groundwater below the surface but within the rooting depth of the vegetation. These terrestrial ecosystems include riparian forests all across Australia, banksia woodlands of Western Australia, eucalypts on the floodplains of the Murray River and plantation forests in South Australia, Victoria and New South Wales. They all require a supply of groundwater within the root zone."*

Using the guide above, the vegetation within the Project Application Area that is dependent on sub-surface flows (i.e. have rooting zones which overlap the sub-surface water interface such as floodplain vegetation) or are located such that surface flows originate from sub-surface flows (i.e., areas of impeded drainage such as swamps, wet heaths and coastal Melaleuca sands) are all classified as GDEs.

The locations of the GDEs which have been identified across the Project Application Area are shown in Figure 7.

3.5.1 MU50 – Newnes Plateau Shrub Swamps (NPSS)

Newnes Plateau Shrub Swamps (Shrub Swamps) develop on the Newnes Plateau at altitudes in excess of 1000 m, in the bases of valleys underlain by the Narrabeen group strata. These swamps have formed in areas which are subject to water logging, which ranges from periodic to permanent. This water logging is caused by an excess rainfall supply. The rainfall eventuates as either direct rainfall recharge to the swamps via overland flow, or rainfall interflow through the upper geology. The interflow is prevented from infiltrating deep into the sandstone sediments by underlying low permeability clay / siltstone beds, bands and lenses.

Shrub Swamps have a characteristic floral assemblage which is largely a result of the physical location in the base of valleys and the hydrological regime. The bases of these swamps have characteristic low gradients resulting in low velocity surface water flows and high water retention (Centennial Angus Place, 2012). A summary of the MU50 Shrub Swamps which have been identified across the Project Application Area is:

- A total of 10 individual shrub swamps are recorded within the survey area, covering a total area of approximately 17.9 ha.
- A total of 37 individual shrub swamps are recorded within the Project Application Area,

covering a total of 41.2 ha.

The Shrub Swamps, on which water level monitoring is carried out across the Project Application Area have been classified into two broad types based on the predominant source of water supplying the swamp. The classifications have been made by Aurecon (2012) and are used to help identify water level patterns and trends. These patterns and trends are discussed in Section 4.3. The two classifications are:

- The first swamp type, '*Type A – periodically waterlogged*', generally show large and reasonably rapid variations in water level in response to significant rainfall events. The water level data for some of these swamps may also be affected by emergency discharge events from licensed discharge points. These are designated Type A* to indicate that they are potentially impacted by discharge. This helps during the analysis of hydrographs to identify the cause of any water level anomalies.
- The second swamp type, '*Type C – permanently waterlogged*', display a reasonably static water level that is relatively unaffected by climatic conditions. Since the percentage of groundwater contribution to the swamp hydrogeology will vary from swamp to swamp, there may be a range of hydrogeological conditions observed for this swamp type.

The monitoring which is undertaken on the Shrub Swamps is discussed in Section 4.1 and shown on Table 4.1.

Many swamps in the Project Application Area exhibit characteristics from both classification types. That is, one area in a swamp may be predominantly surface water fed (this is usually the more elevated up-gradient part), while another section may be predominantly groundwater fed (usually the lower reaches of the swamp which are less elevated).

3.5.2 MU51 – Newnes Plateau Hanging Swamps (NPHS)

Newnes Plateau Hanging Swamps (Hanging Swamps) develop on the Newnes Plateau at altitudes in excess of 1000 m, on the flanks of valleys underlain by the Narrabeen Group strata. The swamps have formed in areas which are subject to infrequent water logging caused by a supply of water from perched groundwater systems, direct rainfall recharge via overland flow, and indirect rainfall recharge via interflow through the surficial geology, which is similar to the recharge mechanisms of the NPSS.

These swamps have a characteristic floral assemblage which is largely a result of the physical location on the flanks of valleys and the hydrological regime. The base of hanging swamps is generally at a steeper slope angle than shrub swamps, which means that hanging swamps are less able to retain water as it discharges away along the greater slope angles. A summary of the MU51Shrub Swamps which have been identified across the Project Application Area is:

- A total of 53 individual hanging swamps were recorded within the survey area, covering a total area of approximately 29.2 ha.
- A total of 75 hanging swamps were recorded within the Project Application Area, covering a total area of 49.9 ha.

3.5.3 MU52 – Newnes Plateau Rush – Sedge Snow Gum Hollow Wooded Heath

A summary of the MU52 Heaths which have been identified across the Project Application Area is:

- A total of 3 Newnes Plateau Rush – Sedge Snow Gum Hollow Wooded Heath swamps were recorded within the survey area, covering a total area of approximately 3.17 ha.
- A total of 11 Newnes Plateau Rush – Sedge Snow Gum Hollow Wooded Heath swamps were recorded within the Project Application Area, covering a total of 47.2 ha.

3.6 Geology

3.6.1 Regional geology and stratigraphy

Springvale is situated in the south-western part of the Western Coalfields of the Sydney Basin. Strata in the Sydney Basin date from Early Permian to Late Triassic with Quaternary alluvium sediments deposited in erosional valleys. Two periods of coal deposition occurred during the Permian, with the more significant Late Permian episode resulting in widespread coal seam development across the entire Sydney Basin. The economically important Illawarra Coal Measures of the Southern and Western Coalfields were formed during this phase. Total thickness of the Illawarra Coal Measures increases towards the east, from approximately 120 m in the Lithgow area to a maximum thickness of 520 m in the northern part of the Southern Coalfield, (Palaris, 2013a).

Non coal-bearing Triassic strata directly overlie the Illawarra Coal Measures. The basal unit is the Narrabeen Group, which consists of sandstone, shale and claystone. This is overlain by the Hawkesbury Sandstone, which is overlain by the Wianamatta Shale. Economic development of the Hawkesbury Sandstone and the Wianamatta Shale has not extensively taken place in the Western Coalfield.

Structure in the Western Coalfield is relatively undeformed, with seams generally dipping at one to two degrees towards the northeast. The dominant structures are north-south trending regional scale monoclines and associated sub-parallel faults that can have throws of up to 200 m. Small scale faults, generally with throws of less than 5 m are also found. Igneous intrusions are only present in the centre and north east of the coalfield, (Palaris, 2013ab).

The regional stratigraphy is summarised in Table 3.4, which also shows estimated vertical distance to the base of each unit above the roof of the Lithgow seam at Springvale. Further discussion on the individual units is provided in Section 3.6.2 and their inclusion in the model is provided in Section 6.2.3.

3.6.2 Local Geology and Stratigraphy

The Lithgow area of the Western Coalfield occupies a unique geological position located on the edge of the Permian age coal bearing strata of the Sydney Basin. West of the coal bearing Permian strata, the sediments, meta-sediments and granitic bodies of the underlying Silurian and Devonian age rocks of the Lachlan Fold Belt dominate the surface geology. These older strata also extend beneath the coal bearing Sydney basin, (Palaris, 2013c).

The Lithgow seam at Springvale is the lowermost economic seam and is only tens of metres to 100 metres above the older basement strata. In other parts of the Sydney basin it is typical for the Permian coal bearing strata to be separated from the basement strata by many hundreds of metres. The highest stratigraphic units present at Springvale are those of the Narrabeen Group. The geology of the Project Application Area and its surrounds is shown in Figure 8.

Key units underlying the Project Application Area, as detailed in the Palaris 'Stratigraphic Setting – Angus Place and Springvale Collieries' report, (Palaris, 2013a) are described below in descending order. They are shown schematically in Figures 9A and 9B.

Burralow Formation

The upper marker unit has been correlated as the Burralow Formation. It consists of medium- to coarse-grained sandstones interbedded with fine-grained sandstone/siltstone/claystone units, the latter of which can be several metres thick. The base of the Burralow Formation is defined as the first significant fine-grained unit above the Banks Wall Sandstone. Palaris (2013a), reports that a recent study of the upper stratigraphy of Springvale indicates that there is a lithographic and topographic link between the outcrop of the Burralow Formation claystones and the location of hanging swamps.

Within the Burralow Formation a number of continuous fine grained units have been identified that act as aquitards, limiting the vertical infiltration of groundwater and resulting in a sequence of perched aquifers. These low permeability units are designated YS1 to YS6 (McHugh, 2013).

Table 3.4: Regional Stratigraphic Summary

Period/Age	Group	Subgroup	Formation	Aquifer Unit	Lithology	Average Height Above Lithgow Seam Roof at Springvale
Triassic	Wiannamatta		Narrabeen Sandstone	AQ6 / Weathered		
	Hawkesbury Sandstone					
	Narrabeen Group	Grose Subgroup	Burralow Formation	SP4/AQ5/YS6		
			Banks Wall Sandstone	AQ4		200 m
			Mt York Claystone	SP3		195 m
			Burra – Moko Head Sandstone	AQ3		
			Caley Formation	AQ3		106 m
Permian	Illawarra Coal Measures	Wallerawang Subgroup	Farmers Creek Formation	AQ2/SP2/Katoomba Seam	Katoomba coal Member, Middle River Coal Member	
			Gap Sandstone	AQ2	Sandstone	
		Charbon Subgroup	State Mine Creek Formation	AQ2	Coal, mudstone, claystone	
			Watts Sandstone	AQ2	Sandstone	
			Denman Formation	SP1	Interbedded mudstone / sandstone, claystone, mudstone	
			Glen Davis Formation	AQ1	Coal, claystone	
			Newnes Formation	AQ1	Coal, claystone	
			Irondale seam	AQ1	Coal	25 m
			Long Swamp Formation	AQ1	Interbedded sandstone and siltstone	4 m
		Cullen Bullen subgroup	Lidsdale Coal	AQ1	Coal and claystone bands	0 m
			Blackmans Flat Formation	Lithgow Seam Roof	Sandstone, conglomerate	
			Lithgow seam	AQ1	Coal, claystone	3 m
			Marrangaroo Formation	Lithgow Seam Floor	Sandstone, conglomerate	
		Nile subgroup	Gundangaroo Formation	Basement	Coal, sandstone, claystone	

Period/Age	Group	Subgroup	Formation	Aquifer Unit	Lithology	Average Height Above Lithgow Seam Roof at Springvale
			Coorongooba Creek Sandstone		sandstone	
			Mount Marsden Claystone		Claystone	
	Shoalhaven Group		Berry Siltstone			
			Snapper Point Formation			

Adapted from Adhikary & Wilkins, 2013 and Palaris, 2013.

Banks Wall Sandstone (Narrabeen Group)

The Banks Wall Sandstone consists predominantly of sandstone which is generally medium to coarse-grained. It is continuous in nature and the average thickness across the Project Application Area is 90 m. The base of the Banks Wall sandstone is defined by the presence of the first significant claystone band of the Mount York Claystone (MYC).

Mount York Claystone (Narrabeen Group)

This unit is a sequence of interbedded claystone and sandstone. The average thickness of the unit is 22 m at Springvale. Typically the unit comprises two or three discrete claystone bands, up to 4 m thick separated by sandstone / siltstone bands up to 8 m thick. The top of the unit is generally 100 m – 120 m above the Katoomba seam. The MYC is generally difficult to identify from open hole drill cuttings, but geophysical gamma logging can be used to identify the unit more accurately. The top of the unit is identified as the first significant claystone band below Banks Wall Sandstone. The base of the MYC is less distinct as additional thick claystone bands occasionally occur within the underlying Burra-Moko Head Sandstone.

The MYC is shown to be continuous across the Project Application Area where it has been identified in 101 cored and geophysically logged drill holes.

Burra-Moko Head Sandstone (Narrabeen Group)

This formation consists predominantly of sandstone. Several thick claystone bands, which are similar in nature and thickness to the bands within the MYC, are also present.

Katoomba Seam (Illawarra Coal Measures)

The Katoomba seam is generally considered to be the first occurrence of coal in the upper Permian strata. In parts of Springvale, the seam is often thin or deteriorated and may be confused with the Woodford of upper Middle River seams. The variability in the thickness and nature of the seam is not significant from a hydrogeological perspective.

The Katoomba seam is mined at Clarence Colliery, to the east of Springvale, however is not considered to be a viable mining resource at Springvale.

Denman Formation (Illawarra Coal Measures)

This is a fine grained to finely laminated unit which grades upwards into a sandstone (~4 m thick). It is consistent in thickness and nature at Springvale and is thought to inhibit vertical groundwater flow.

Lithgow Seam

The Lithgow seam is the basal seam of economic importance in the Illawarra Coal Measures in the Lithgow area. Towards the north, correlatives of the overlying Lidsdale seam are of greater economic importance. In these areas, deterioration of the true Lithgow seam may have led to some misidentification of the seam.

3.7 Regional Hydrogeology

Bish (1999) has described the sedimentary strata in the Western Coalfield as comprising a non-uniform sequence of interbedded rocks of differing grain size, lithification and strength properties. This gives rise to layers of rock with a wide range of intrinsic permeabilities and potential to either transmit or inhibit the flow of groundwater, resulting in a hydrogeological regime which can be described as complex.

The hydrogeological regime is further complicated, locally, by the effects of large mine voids, which have the potential to act as preferential flow paths between discreet aquifer units, and as groundwater repositories.

The complex nature of the groundwater system in the sedimentary deposits is in part due to the number of water bearing zones present, which range from perched water tables to layered, semi confined and leaky horizons. Groundwater flow in the Illawarra Coal Measures is typically towards the northeast. This is coincident with the dip of the main strata. Groundwater flow is primarily through fracture systems with some minor pore / primary porosity (Bish, 1999). This fracture system is the major control on groundwater flow paths, as the rocks themselves generally have low primary permeability.

3.8 Local Hydrogeology

A review of local hydrogeology was carried out by CSIRO in 2004 (Adhikary et.al., 2004).

The report bases its understanding on reviewed hydrogeological data from vibrating wire piezometer sensors and mine water make, along with time-domain reflectometer (TDR - measures the separation / delamination of rock layers) measurements and regional hydrogeological reports.

The TDR report found that five distinctive aquifers or water bearing horizons could be identified in the hydrostratigraphy underlying the study area and above the Lithgow seam. These water bearing horizons have been identified in ascending order, starting at the Lithgow Seam, as AQ1, AQ2, AQ3, AQ4 and AQ5.

Subsequent investigations (McHugh, 2011 and 2013; Palaris, 2013a) have identified a number of continuous claystone layers within the Burralow Formation consisting of medium to coarse-grained sandstones, interbedded with fine grained sandstone/siltstone/claystone units. The bottom most of these claystone layers in the Burralow Formation divides the previously identified AQ4 in two, so that now six aquifer units are identified (AQ1 to AQ6), as summarised on Table 3.4 and shown on Figures 9B and 10.

It should be noted that the term aquifer used by Adhikary et. al. is used to distinguish between relatively permeable and less permeable groups of strata. The results of permeability testing (Section 4.10) show all the formations tested to be of generally low permeability and do not in themselves represent viable aquifers in the conventional sense. A brief summary of the identified aquifers and interbedded aquitards (termed SP, or semi-permeable) is provided as follows:

- Weathered section – this is a 10 m thick layer of weathered material which is assumed to cover the top surface of the Project Application Area.
- AQ6 – This aquifer is located in the upper part of the Burralow Formation. This is a group of largely unconfined perched aquifers and only appears near the top of the Newnes Plateau. AQ6 includes a number of discrete aquitard units (YS1 to YS3) that sustain the perched aquifers.
- SP4 - A thin semi-permeable layer located in the Burralow Formation and comprises claystone (YS4) and sandstone/ siltstone.
- AQ5 – This aquifer is located in the lower Burralow Formation. AQ5 is separated from AQ4 by YS6 and also includes a continuous low permeability unit (YS5) that can result in perched conditions within the aquifer.
- YS6 – A thin semi-permeable claystone layer separates AQ4 and AQ5.
- AQ4 – This aquifer is located in the Banks Wall Sandstone (Narrabeen Group).
- SP3 - A semi-permeable claystone layer (Mt York Claystone) separates aquifers AQ3 and AQ4. The Mt York Claystone forms an effective barrier between the deep and shallow groundwater systems; it averages over 20 m in thickness and is continuous throughout the Springvale/Angus Place area.
- AQ3 - Aquifer AQ3 can be identified in the sandstone of the Burra Moko Head Formation and the Caley Formation and located below the Mt York Claystone. It is hydraulically connected with the Katoomba Seam.
- SP2 - A semi-permeable layer with coal, siltstone and mudstone is the boundary between aquifers AQ2 and AQ3. This semi-permeable layer is assumed to occur just below the Katoomba Seam.
- AQ2 – This aquifer contains sandstone with laminated siltstone and Middle River Coal Member.
- SP1 - Aquifer AQ1 is separated from aquifer AQ2 by a semi-permeable layer (SP1) located

within the Baal Bone/Denman Formation and comprises mudstone, siltstone and claystone.

- AQ1 – This aquifer is found to include Lidsdale / Lithgow Coal Seam which is hydraulically connected with the laminated siltstone (Berry Siltstone) and sandstone of the Marrangaroo Formation underneath, and the sandstone and siltstone of the Long Swamp Formation and Irondale Coal Seam above.

The permeability of the various formations is controlled by the porosity of the formation and the interconnection of the pore spaces, along with the degree of interconnective fracturing that is present. Within both the Narrabeen Group and Illawarra Coal Measures, significant primary porosity is likely to be limited and localised, with the majority of regional groundwater flow controlled by secondary fracture networks.

This series of aquifers and aquitards can be grouped together to form three basic groundwater systems underlying the Project Application area as follows:

- A perched groundwater system (AQ5 and AQ6).
- A shallow regional groundwater system, ranging from unconfined to semi-confined (AQ4).
- A deep confined groundwater system (AQ1 to AQ3, including coal seams).

The aquifer units identified above are each separated by strata of lower permeability, which behave as aquitards.

3.8.1 Perched Groundwater System (AQ5 – AQ6) –Burralow Formation

These systems comprise discontinuous, surficial systems which are hydraulically independent of the underlying regional groundwater system. The perched groundwater is generally located within the upper 100m where the Burralow Formation is present. It is derived from excess rainfall which is largely prevented from infiltrating deeper down into the regional systems due to the presence of fine grained or less permeable claystone and siltstone horizons (YS1 to YS6). The perched groundwater system produces seeps and discharge points at outcrop which are fundamental to the existence of the THPSS system across the Project Application Area (McHugh, 2013).

Longitudinal and cross sections through some of the Shrub Swamps in the Project Application Area are presented in Figures 11 to 17. The sections show how the perched aquifers of the Burralow Formation, in particular and also the Banks Wall Sandstone, are of fundamental importance to the existence of the THPSS. As well as providing direct groundwater seepage to the THPSS which overlie the Burralow Formation the perched aquifers also provide moisture that migrates down gradient to help support the THPSS within the Banks Wall Sandstone.

3.8.2 Shallow Groundwater System (AQ4) – Banks Wall Sandstone

This groundwater system is a regional system located in the Banks Wall Sandstone of the Narrabeen Group. This system generally extends to a depth of 100 m below ground surface. The aquifer zone which has been identified by CSIRO (Adhikary et. al, 2004) in the Banks Wall Sandstone is AQ4.

Most groundwater flow in this water bearing sequence is generally horizontal along bedding planes. Some vertical flow is likely to occur within the shallow groundwater system, such as the infiltration of rainfall in the upper part of the aquifer.

Bish (1999) identified that the general flow direction in the shallow groundwater system is towards the northeast, in the general formation dip direction. Recharge potentially occurs in areas of outcrop/sub-crop to the west and southwest of the study area. Discharge is inferred to occur to the northeast, where the units outcrop in the scarp of the plateau.

The shallow groundwater system is underlain by the MYC. This horizon comprises a low permeability layer that restricts infiltration downwards from the shallow groundwater system to the underlying deep groundwater system.

3.8.3 Deep Groundwater System (Coal Seams plus AQ1 to AQ3)

The deep groundwater system is located in the strata underlying the MYC, and includes the Illawarra Coal Measures, which generally lie at a depth of more than 200 m below ground surface. Most of the coal measures overlying the Lithgow seam, in this groundwater system, have low permeability characteristics. A small number of aquifer units in the system have a slightly higher permeability and represent the water bearing zones (AQ1, AQ2 and AQ3, Figures 9B and 10).

The few water bearing zones that do occur at depth in this groundwater system are typically fractured rock aquifers (with groundwater flow exploiting the secondary porosity, fracture-plane conduits). These include jointed or cleated coal seams and other localised jointed or fractured lithologies, often adjacent to faults.

3.9 Environmental Values

3.9.1 Groundwater Users

The NSW Office of Water maintains a database of registered water bores and standpipe piezometers in NSW. This database includes exploration and test boreholes that may not have been completed as permanent structures, observation / monitoring bores, and privately owned water supply bores and distinguishes bores which are currently in use or abandoned.

A search of this database identified two registered bores within 5 km of the centre-point of Project Application Area and 112 registered bores within 10 km of the centre-point of Project Application area. The locations of which are shown on Figure 18. A summary of the registered bore details for these bores is provided in Appendix A.

The following key points about two bores within 5 km of the centre point of the Project Application area are:

- The deeper bore extends to a depth of 400 metres below ground level (mbgl), and is classified as being in use by government for the conservation of water.
- This bore is installed into the Marangaroo Formation (AQ1).
- There is limited information on another bore within 5 km of the Project Application Area. It is classified as in industrial use, with no final depth recorded.

The details of 112 registered bores within 10 km of the Project Application area are presented in Appendix A. The following salient points about these bores are as follows:

- The deepest bore extends to 319.5mbgl.
- The majority of the bores range up to 20mbgl.
- The majority of the bores extract from the Banks Wall Sandstone (immediately overlying the MYC aquitard).
- Most of the bores comprise monitoring bores.
- Six bores extract from the Lithgow Seam. Only one of these is listed as a domestic bore.

A table showing the numbers and types of bores installed into each aquifer unit are presented in Table 3.5

3.9.2 Groundwater Dependent Ecosystems

An investigation into the groundwater dependent ecosystems that exist on site has been undertaken by RPS and are discussed in the terrestrial ecology report (RPS, 2013c). Further discussion on GDEs is provided in the aquatic ecology report (Cardno Ecology Lab, 2013). The locations of the GDEs within the Project Application Area are shown on Figure 7. This figure shows all of the GDEs as identified by the terrestrial ecology report. The swamps which are shown on Figure 6 include only the THPSS which are monitored across the Project Application Area.

Table 3.5: Use Summary of Registered Bores Within 10 km of centre-point of Project Application Area

Formation	Aquifer Unit	Total Number of Bores Listed	Domestic	Stock	Industrial	Monitoring Bore	Power Generation	Recreational	Conservation of Water	Other
Banks Wall Sandstone	AQ4	50	7	0	4	39	0	0	0	0
Burra – Moko Head Sandstone	AQ3	6	0	0	1	0	2	0	0	3
Caley Formation	AQ3	6	0	0	0	5	0	0	0	1
Farmers Creek Formation	Semi-permeable layer	4	3	0	0	0	0	0	1	0
Gap Sandstone	AQ3	6	1	2	0	3	0	0	0	0
Middle River Seam	AQ3	1	0	0	0	1	0	0	0	0
Katoomba Coal Seam	AQ3	3	0	1	0	1	0	0	0	1
State Mine Creek Formation	AQ2	1	1	0	0	0	0	0	0	0
Denman Formation	Semi-permeable layer	1	0	0	0	1	0	0	0	0
Newnes Formation	AQ1	3	0	1	1	1	0	0	0	0
Long Swamp Formation	AQ1	5	2	2	1	0	0	0	0	0
Lidsdale / Lithgow Seam	AQ1	7	1	0	0	5	1	0	0	0
Marangaroo Formation	AQ1	4	2	0	0	1	0	0	1	0
Berry Siltstone	Semi-permeable layer	15	9	1	1	3	0	1	0	0

4. GROUNDWATER INVESTIGATIONS

Numerous specialist hydrogeological studies have been undertaken at Springvale with the aim of quantifying mine water inflow and subsidence impacts, groundwater drawdown and depressurisation, and addressing other geotechnical and hydrogeological issues over the past number of years. A summary of some of the relevant previous investigations is presented in Appendix M.

4.1 Existing Monitoring Network

The existing monitoring network was started in 2002 and is ongoing. Additional monitoring points are also being continually added to the network. The groundwater monitoring network is presented on Figure 19. The current monitoring network comprises the following:

- 24 standpipe piezometers that monitor water levels in 10 Shrub Swamps.
  - 4 of these have been undermined.
  - 20 of these have not been undermined.
- 14 standpipe piezometers installed into the elevated ridges between the swamps. These piezometers monitor shallow groundwater levels in the Banks Wall Sandstone aquifer.
- Water quality sampling from swamp standpipe piezometers.
- 18 individual monitoring locations are installed with fully grouted VWPs.
  - 8 of these are in impacted (undermined) areas.
  - 10 are in un-impacted areas.
- Four surface water flow monitoring stations are installed at swamp discharge points for Sunnyside Swamp, Junction Swamp, and Narrow Swamp, as well as on the Kangaroo Creek.
- Two additional surface water gauging stations have recently been installed (November 2012) on Paddy's Creek just downstream of the confluence with Pine Swamp and at Nine Mile Swamp and Gang Gang Swamp (Figure 19).

Data for groundwater and surface water monitoring at the adjacent Angus Place has also been utilised for the purposes of this groundwater impact assessment. This additional data will be used to provide better understanding of the groundwater systems in the Project Application Area.

4.2 Mine Modifications

Springvale recognises the importance of the THPSS and remains committed to ensuring minimal mining induced impacts on them. Specialist hydrogeological studies along with data from the existing monitoring network have helped inform the mine operator of several mine design modifications which have already been carried out. These mine design modifications are specifically aimed at reducing mine subsidence and related impacts to the THPSS which are situated across the Project Application Area.

4.2.1 Reduction of Mine Void Widths

Based on monitoring above reduced width longwall panels, the proposed mine design at Springvale has been modified to minimise subsidence beneath sensitive shrub swamp areas.

Site specific monitoring at Springvale has shown that a reduction in the longwall void widths from 315 m to 261 m and an increase in the chain pillar width from 45 m to 58 m will induce minimal subsidence impact to the overlying THPSS.

Consequently, the panel widths at LW416 and LW417 have been reduced. The width of the inter panel chain pillars is 58 m. The net result of these modifications is a reduction in subsidence observed at ground surface. The mine subsidence impact assessment has incorporated these modifications.

4.2.2 Avoidance of Undermining Swamps

Due to its geographical orientation which is the same orientation as the underlying LW414, Sunnyside Swamp would have been entirely undermined by the longwall panel. In order to prevent this, LW414 was stopped short before undermining Sunnyside Swamp to avoid any potential impacts to the swamp. This mine modification technique has been carried out even though it is not considered economically viable due to the high development costs and discontinuity of mining operations.

4.3 Swamp Water Level Monitoring

Details of the swamp water level monitoring, which is undertaken at Springvale, are presented in Table 4.1. All of the monitoring locations are standpipe piezometers. The standpipes are installed to maximum of 2 metres below the swamp surface and record water levels on a daily basis. The locations of the swamps are shown in Figure 6.

The borehole logs from the swamp piezometers are presented in Appendix D. Cross sections for a number of the swamps have been produced. The locations of the cross sections are presented in Figure 11 and the cross sections are presented in Figures 12 to 17. Detailed lithology of the swamps is also presented in the figures.

The monitored swamps have been separated into those which have been undermined, and those which have not been undermined. This enables any mining induced impacts to be easily identified from the hydrographs.

- Baseline Swamp Monitoring:
  - 8 of the 10 monitored Swamps at Springvale have not been undermined (Table 4.1).
- Undermined Swamp Monitoring:
  - 2 of the 10 monitored Swamps at Springvale have been undermined (Table 4.1). These comprise Junction Swamp and Sunnyside West Swamp / Heath

Table 4.1: Springvale Shrub Swamp Water Level Monitoring Details

Piezometer	Easting	Northing	Swamp Name	Undermined	Swamp Type	Monitoring Started
SS1	237766	6303509	Sunnyside Swamp	Not Undermined	Type C	12/05/2005
SS2	237783	6303571	Sunnyside Swamp	Not Undermined	Type C	12/05/2005
SS3	237485	6303838	Sunnyside Swamp	Not Undermined	Type C	12/03/2010
SS4	237791	6304398	Sunnyside Swamp	Not Undermined	Type C	12/03/2010
SS5	237782	6304627	Sunnyside Swamp	Not Undermined	Type C	12/03/2010
SW1	237778	6302277	Sunnyside West Swamp / Heath	LW413B & LW414	Type A	26/07/2007
SSE1	238668	6303143	Sunnyside East Swamp	Not Undermined	Type A	12/03/2010
SSE2	238831	6303352	Sunnyside East Swamp	Not Undermined	Type C	12/03/2010
SSE3	239064	6303558	Sunnyside East Swamp	Not Undermined	Type C	12/03/2010
CW1	239352	6303196	Carne West Swamp (lower)	Not Undermined	Type C	12/05/2005
CW2	239382	6303247	Carne West Swamp (lower)	Not Undermined	Type C	12/05/2005

Piezometer	Easting	Northing	Swamp Name	Undermined	Swamp Type	Monitoring Started
CW3	238977	6302179	Carne West Swamp (upper)	Not Undermined	Type A	14/10/2011
CW4	239070	6302377	Carne West Swamp (upper)	Not Undermined	Type A	14/10/2011
D1	235779	6302692	Junction Swamp	LW408 & LW409	Type A	10/05/2002
D2	235784	6302749	Junction Swamp	LW408 & LW409	Type A	10/05/2002
D3	235857	6302731	Junction Swamp	LW408 & LW409	Type A	10/05/2002
GW1	239814	6302877	Gang Gang West Swamp	Not Undermined	Type C	14/10/2011
GW2	240263	6303097	Gang Gang West Swamp	Not Undermined	Type C	14/10/2011
GG1	240285	6302294	Gang Gang Swamp	Not Undermined	Type C	14/10/2011
CC1	241193	6302693	Carne Central Swamp	Not Undermined	Type C	04/11/2011
BS1	241045	6301305	Bungleboori Swamp	Not Undermined	Type C	14/10/2011
BS2	240809	6300174	Bungleboori Swamp	Not Undermined	Type C	04/11/2011
BS3	242008	6301246	Bungleboori Swamp	Not Undermined	Type C	04/11/2011
MS1	238860	6299169	Marrangaroo Swamp	Not Undermined	Type C	04/11/2011

4.3.1 Swamp Water Level Analysis

Hydrographs have been produced on a swamp by swamp basis and are presented in Appendix E. The hydrographs plot swamp water level data with cumulative rainfall distribution (CRD). This enables the water level in the swamp to be directly correlated with the rainfall pattern. For the swamps which have been undermined, the start and end date of the underlying longwall panel are shown on the hydrograph also.

The following salient points can be concluded from the swamp hydrographs:

- *Type A* undermined and baseline swamps:
  - The only Shrub Swamps which have been undermined at Springvale comprise Type A swamps.
  - All of the piezometers display a rapid trend in response to rainfall. Water levels fluctuate usually by about 0.75 m, however following significant rainfall events the water level fluctuation increases to over 2 m.
  - Baseflow from aquifer recharge does not contribute significantly to the water inputs in these swamps.
  - Over the monitoring period reported (July 2007 to November 2012), the overall long term trend of the groundwater remains flat, with no gradual increase or decrease.
- *Type C* baseline only:
  - All piezometers respond to rainfall to some extent, however baseflow from groundwater recharge comprises the predominant water input into the swamps.
  - A slight rise in the water level in all swamp piezometers is observed from approximately January 2010 to November 2012.

- A continued slight drop in water levels is observed in the piezometers after November 2012.

4.3.2 Swamp Groundwater Level Interpretation

The groundwater level data from the Type C swamp areas at Springvale show a much more subdued pattern in response to rainfall events. This is expected from this swamp type as the water levels are predominantly dependent on aquifer recharge, with only minor contributions from rainfall inflows.

The water level patterns recorded in swamps which have been undermined, and those which have not been undermined show similar trends. A characteristic Type A trend and a characteristic Type C trend is identifiable from the hydrographs. These two trends remain the same whether the swamp has been undermined or not.

Due to the groundwater discharge being the predominant source of water supplying the Type C swamps, it is fair to say that these swamp types are more likely to show mining induced water level impacts. However, no mining induced fluctuations can be observed in these swamps (or the Type A swamps).

As no mining influenced water level fluctuations can be identified in any of the monitored swamps (both undermined and baseline) it is accurate to say that mining at Springvale has not led to any identifiable water level impacts on the monitored swamps, and that all undermined swamps display baseline water levels.

A more detailed breakdown of the water level trends in 4 of the swamp systems across the Project Application Area, and the adjacent Angus Place is presented in Appendix B, the *Swamp Groundwater Impact Case Study*.

4.4 Shallow Groundwater Level Monitoring

Monitoring in the shallow groundwater system (AQ4 to AQ6) underlying the Project Application Area has been ongoing since December 2005 at several ridge standpipe piezometers and since November 2011 at several VWP monitoring locations. The hydrographs of the VWPs which monitor the shallow aquifer are shown in Appendix F. The monitoring points comprise:

- 11 automatically-logged standpipe piezometers.
- 18 automatically-logged fully grouted piezometers.
- Three manually dipped standpipe piezometers currently in use.

The locations of all of these monitoring points are shown in Figures 19 and 20.

Table 4.2: Standpipe Piezometer Monitoring Points

Monitoring Point	Easting	Northing	Monitoring Frequency	Monitoring Commence Date	Monitoring Depth (mbgl)	Data recording method
RNW	235076	6304525	Every two months	20/12/2005	Unknown	Manual dip
REN	Unknown	Unknown	Every two months	20/12/2005	Unknown	Manual dip
RSE	236840	6304191	Every two months	20/12/2005	Unknown	Manual dip
RCW	Unknown	Unknown	Every two months	20/12/2005 to 29/03/2010	Unknown	Manual dip
SPR1111	240404	6303692	Daily	14/12/2011	60	Pressure transducer
SPR1112	240852	6302995	Daily	15/12/2011	50.1	Pressure transducer
SPR1113	240625	6302160	Daily	13/02/2012	60	Pressure transducer

Monitoring Point	Easting	Northing	Monitoring Frequency	Monitoring Commence Date	Monitoring Depth (mbgl)	Data recording method
SPR1109	239186	6303314	Daily	14/12/2011	60	Pressure transducer
SPR1108	241045	6301305	Daily	04/11/2011	75	Pressure transducer
SPR1107	239739	6302330	Daily	04/11/2011	55	Pressure transducer
SPR1110	238699	6302635	Daily	14/12/2011	65	Pressure transducer
SPR1101	238484	6303627	Daily	14/11/2011	84.5	Pressure transducer
SPR1106	239980	6304227	Daily	15/12/2011	85	Pressure transducer
SPR1104	239746	6303184	Daily	04/11/2011	50	Pressure transducer
RSS	238072	6303500	Every two months	01/12/2005 to 14/12/2011	Unknown	Manual Dip
			Daily	14/12/2011		Pressure transducer

The details of the VWP monitoring points which have sensors installed in the shallow aquifer system are presented in the following section.

4.4.1 Shallow Groundwater Level Analysis

Groundwater level contours in the Banks Wall Sandstone and the Burra Moko Head Formation have been produced from data collected from both the open hole standpipe piezometers and also the VWP sensors across the Project Application Area. The data used to generate the groundwater contours was taken from monitoring on 12 March 2012. The contours are discussed in the following sections and also shown on Figure 21 and Figure 22.

A summary of some of the salient information on the water levels in the shallow aquifer system is shown below. The aquifer units and formations into which each VWP sensor is installed are presented in Appendix G.

The monitoring points have been separated into those which have been undermined by longwall mining (impacted) and those which have not been undermined (baseline). Similarly, the aquifer units are described in terms of baseline aquifer units, and impacted aquifer units.

The majority of the VWP monitoring points at Springvale have been installed after November 2011 and therefore the identification of specific mining induced impacts from the hydrographs is difficult. Hydrographs have been discussed in terms of overall trends since monitoring began as this method gives a better overall view of how easily the aquifer units may be impacted by mining.

AQ6 (Baseline)

The uppermost aquifer unit in the shallow groundwater system is installed with one VWP sensor – SPR-1102 Sensor 1 (82mbgl). From approximately mid 2012 the water level in this aquifer unit at this location displays a rising trend. Prior to this date the water level displays a slight decrease from the onset of monitoring in November 2011. The highest water level observed in this sensor corresponds with the largest increase in cumulative rainfall distribution (CRD), which is also plotted on the hydrographs. At this location water levels in AQ6 appear to be responsive to rainfall events, suggesting unconfined conditions.

AQ5 (Baseline and Impact)

There are two VWP sensors installed into AQ5 at Springvale. These comprise SPR-67 Sensor 1 (35mbgl) and SPR-1102 Sensor 1 (82mbgl). Both of these sensors display quite different trend profiles. In SPR-1102 the water level remains constant from the onset of monitoring, right through to the most recent monitoring data. A very slight decrease of approximately 1 m is observed in early January 2012, however on the whole the water level remains reasonably constant at around 1010 m AHD.

On the other hand, the water level in SPR-67, while on the whole remains somewhat flat around 1080 m AHD, displays significant spikes of a maximum of approximately 15 m. After the sharp rise in water level occurs the levels recede back to the background level at 1080 m AHD. The spikes resemble those characteristic of pumping being switched on and off. It is possible that either discharge into or pumping from this aquifer unit may be occurring.

AQ4

There are 52 VWP sensors installed into AQ4 at Springvale, all of which monitor water levels in the Banks Wall Sandstone. A greater variability in the responses of the sensors compared to those installed in AQ5 and AQ6 is observed over the monitoring period.

- A significant event comprising a water level decline is observed in six monitoring locations (12 separate sensors) in this aquifer unit, these are:
  - SPR51 (early 2011, two sensors, a decline of 12 m and 30 m).
  - SPR39 (early 2006, three sensors, a decline of 60 m and 70 m).
  - SPR38 (early 2006, three sensors a decline of 1.5 m, 1 m and 1 m. Reaches the lowest point in around mid 2007 before all showing a continued rise).
  - SPR37 (January 2010, two sensors a decline of 4 m and 5 m, before all sensors show a continued rise).
  - SPR33 (December 2009, two sensors, a decline of 25 m and 35 m).
- A continued overall downward trend is observed in 17 sensors.
- A continued overall upward trend is observed in 12 sensors.
- An overall flat trend is observed in six sensors.
- A correlation between the CRD pattern and water level can be made in 15 sensors which include the following:
  - SPR-26, in the only sensor installed at this monitoring point.
  - SPR-37, in all three sensors.
  - SPR-38, in all three sensors.
  - SPR-49, in one sensor at 50mbgl.
  - SPR-50, in one sensor at 30mbgl.
  - SPR-64, in all three sensors.
  - SPR-1102, in one sensor at 160mbgl.
  - SPR-1103, in two sensors at 151 and 178mbgl, respectively.
- REN and RCW do not show any major change in groundwater level over the monitoring period which ranges from December 2005 – April 2010 (RCW) and December 2005 – present (REN).
- RNW and RSE show slight decreases in groundwater level from approximately June 2006 – June 2008, with the water level stabilizing for the rest of the monitoring period.
- RSS shows a slight and gradual rise in water level from the commencement of monitoring in December 2005 until a continuous monitoring instrument was installed in December 2011.

Summary of water levels observed in AQ4 – AQ6

The upper aquifer unit (AQ6) in this groundwater system displays unconfined conditions, and is responsive to rainfall. An increase in water level is observed from approximately mid-2012.

In the lower aquifer unit (AQ4), the potential correlation between CRD and the water levels observed in 15 sensors suggests unconfined conditions at some locations in this aquifer unit. Other sensors in this unit do not respond to CRD, suggesting confined / semi-confined conditions and the degree of variation in water level behaviour between aquifer units increases with increasing depth into the aquifer system.

4.5 Deep Groundwater Level Monitoring

As part of the network of deep groundwater monitoring locations across the Project Application Area, a number of fully grouted VWPs have been installed into the horizons underlying the MYC. These VWPs monitor pore water pressures in the deeper aquifer units underlying the MYC. At each of the monitoring points, sensors are also installed into the shallow aquifer units overlying the MYC.

The monitoring points comprise fully grouted VWP transducers which log data on a daily basis. Data is downloaded every two months. The salient details regarding these monitoring points are shown in Table 4.3, and are as follows:

- 18 individual monitoring locations are installed with fully grouted VWP transducers.
- The number of transducers installed at each location ranges from 1 to 9 sensors.
- Additional VWP monitoring locations continue to be installed on site.
- The earliest VWP began recording in July 2002, the most recent monitoring point included in the report data was installed in November 2011.
- The monitoring points record pore water pressures at different horizons from AQ1 through to AQ6.

The hydrographs for these monitoring points are presented in Appendix F. The discussion and analysis of the groundwater levels from these monitoring points is presented in Section 4.5.1. More detail on the specific formations and aquifer units into which each sensor is installed is presented in Appendix G.

Table 4.3: VWP Monitoring Details

Monitoring Point	Easting	Northing	Monitoring Frequency	Monitoring Commence Date	Number of Piezometers installed	VWP setting depth (mbgl)
SPR-26	237060	6301251	Twice Daily	18/07/2002	2	73, 353
SPR-29	237791	6301016	Daily	04/03/2003	1	382
SPR-33	237575	6304545	Twice Daily	10/07/2004	4	80, 160, 280, 336
SPR-34	237573	6303655	Daily	06/07/2004	2	270, 359
SPR-35	237618	6302778	Daily	13/07/2004	1	310
SPR-36	239357	6303496	Twice Daily	18/11/2005	8	35, 75, 130, 146, 274, 320, 376, 389
SPR-37	239074	6300367	Twice Daily	13/02/2006	8	110, 135, 165, 187, 260, 320, 350, 405
SPR-38	240061	6298330	Twice Daily	29/12/2005	8	80, 100, 135, 190, 230, 300, 355, 370
SPR-39	236846	6304550	Twice Daily	18/12/2005	8	80, 140, 155, 240, 270, 340, 374, 380
SPR-48	237217	6304198	Daily	28/11/2007	8	30, 50, 70, 90, 110, 140, 170, 200
SPR-49	237245	6303199	Daily	09/06/2008	8	30, 50, 80, 110, 150, 200, 250, 295
SPR-50	238290	6304151	Daily	01/12/2007	8	30, 50, 70, 90, 110, 140, 170, 200
SPR-51	237957	6303240	Daily	05/06/2008	7	30, 90, 150, 190, 230, 310, 350
SPR-64	238420	6299864	Daily	22/09/2009	8	30, 100, 150, 200, 270, 310, 370, 390
SPR-66	239824	6301994	Daily	30/09/2009	8	35, 80, 130, 180,

Monitoring Point	Easting	Northing	Monitoring Frequency	Monitoring Commence Date	Number of Piezometers installed	VWP setting depth (mbgl)
						230, 290, 348, 372
SPR-67	238709	6302283	Daily	28/09/2009	8	35, 50, 70, 90, 110, 160, 200, 260
SPR-1102	241235	6304180	Daily	07/11/2011	9	82, 125, 151.5, 160, 292, 300, 312, 380, 407
SPR-1103	241430	6302983	Daily	08/11/2011	9	138, 151.5, 178.5, 258.5, 290, 313.8, 326.5, 381.5, 407

4.5.1 Deep Aquifer Groundwater Level Trends

The deep aquifer system at Springvale comprises all of the aquifer units underlying the MYC. This is a confined aquifer system and the water level is represented by the potentiometric surface. The salient points from the hydrographs installed in this aquifer system are separated into each of the identified aquifer units below.

An overall summary of the predominant trends observed in this aquifer system is given at the end of this section. Monitoring points are located across the Project Application Area in both mined and unmined areas (previous sections have described these as baseline and impacted areas). However, due to the confined nature of the deep aquifer system this method of description has not been used in this section.

AQ3

There are 28 sensors installed into AQ3 at 13 separate monitoring locations across the Project Application Area. Monitoring began in one sensor in late 2004, monitoring in the remainder began in early 2006 – mid 2008. The main trends observed are as follows:

- A continued downward trend is observed in 14 separate sensors across 9 monitoring locations (SPR-35, SPR-37, SPR-38, SPR-39, SPR-48, SPR-49, SPR-51, SPR-64 and SPR-67). The trend starts at the onset or monitoring, and continues through until the most recent monitoring data. The magnitude of the drop ranges from a minimum of approximately 10 m in SPR-64 Sensor 2, to a maximum drop of approximately 70 m in SPR-51 Sensor 2.
- An overall flat trend is observed in eight sensors across five separate monitoring locations (SPR-1102, SPR-1103, SPR-37, SPR-67 and SPR-36). The water levels recorded in each of these sensors ranges from 885 mAHD in SPR-1103 to a maximum of 1100 mAHD in SPR-37.
- A continued rising trend is observed in six sensors across three separate monitoring locations (SPR-64, SPR-66, SPR-1102). The overall rising trend ranges from 15 m in SPR-1102 Sensor 3 to a maximum rise of 60 m in SPR-64 Sensor 1.

AQ2

There are 5 sensors installed into AQ2 at 5 separate monitoring locations. Monitoring began in two locations in early 2004 (SPR-33 and SPR-34), another sensor was initiated in early 2006 (SPR-36). Monitoring began at the final two locations in mid-2008 (SPR-49 and SPR-51). The main trends observed are as follows.

- A continued downward trend which begins from the onset of monitoring is observed in 5 sensors across five separate monitoring locations (SPR-33, SPR-34, SPR-36, SPR-49 and SPR-51). The drop in water level ranges from 30 m in SPR-49 to a maximum drop of 94 m in SPR-51.
- No overall flat trend is observed in any of the sensors installed in AQ4.
- No overall upward trend is observed in any of the sensors installed in AQ4.

AQ1

There are 19 sensors installed into AQ1 at 11 separate monitoring locations. Monitoring began in this aquifer unit in early 2003 in two locations (SPR-26 and SPR-29). The other monitoring points were added in mid-2004, early 2006, late 2009 and the most recent sensors were initiated in late 2011 in SPR-1102 and SPR1103. A summary of the main trends observed in this aquifer unit are as follows.

- A continued downward trend which begins at the onset of monitoring is observed in nine sensors across seven monitoring locations (SPR-26, SPR-29, SPR-33, SPR-34, SPR-36, SPR-37 and SPR-38). The drop in water level ranges from 20 m in SPR-38 Sensor 5 to a maximum drop of 128 m in SPR-33 sensor 2.
- An overall flat trend is observed in six sensors across four separate monitoring locations (SPR-38, SPR-64, SPR-1102 and SPR-1103). The constant levels in these sensors range from a minimum level of 822 mAHD in SPR-1102 to a maximum level of 925 mAHD recorded in SPR-38.
- An overall rising trend is observed in four sensors in three separate locations (SPR-36, SPR-64, SPR-66). The rise in water level ranges from 15 m in SPR-66 Sensors 1 and 2, to a rise in 45 m in SPR-36 sensor 5.

Interpretation of Water Levels observed in AQ1 – AQ3

All of the aquifer units in this groundwater system display confined conditions. Temporal changes are not observed in the hydrographs. The predominant water level trend across the three aquifer units in this groundwater system is downward. This is not unexpected due to the legacy of mining. Some variable trends have been identified however, the dominant trends are downward due to mining of the Lithgow seam in this aquifer system. The depressurisation impacts are spread spatially across the Project Application Area, even at monitoring locations which are away from the active mining area. This is also expected, as depressurisation impacts are generally seen across a wider spatial area in a confined system compared to a non-confined system.

4.6 Vertical Groundwater Gradients

Extensive analysis of vertical hydraulic gradients has been undertaken at Springvale by CSIRO. The ongoing and historical mining at the site has resulted in some groundwater level impacts to certain hydrogeological units. Selected VWP pressure profiles for three VWPs located within the Project Application Area (SPR36, SPR37 and SPR66) are presented on Figure N1 (Appendix N). The location of the VWPs within the Project Application Area is shown on Figure 19. All three VWPs are located within the proposed Angus Place longwall panels and SPR36 is located in close proximity of the existing mined longwall panels of the adjacent Springvale Mine.

From Appendix N the key trend that is apparent is the separation of responses to mining above and below the MYC and the lack of propagation of impacts through the MYC.

When plotted against depth the various piezometer pressures should generally plot on or close to a 45 degree line (shown as a dashed blue line) assuming the saturated sequence is hydraulically connected and in a state of equilibrium. Any significant variation from the 45 degree (hydrostatic) line can indicate either dynamic stresses on the system (recharge/abstraction) or multiple systems that are behaving independently. Some minor variations can be expected due to formation stratification and the MYC itself could reasonably be expected to separate two relatively disconnected hydrodynamic systems.

As well as depth variations, the hydrostatic profiles presented in Appendix N, also show temporal variation with the three separate traces.

The profiles generally show piezometric pressures measured above the MYC to fall on or close to the hydrostatic line. Below the MYC the profiles show significant depressurisation, with variable piezometric levels and responses depending on individual formation permeabilities. Deeper levels within or close to the Lithgow Seam show variable trends ranging from pressure recovery to depressurisation depending on the location of the piezometer to active mining. Even away from active mining areas significant responses are apparent within the Deep Groundwater System.

4.7 Recharge and Discharge

The recharge and discharge regime of the aquifers underlying the study area are discussed in this section under the three main groundwater systems which have been identified underlying the Project Application Area.

4.7.1 Perched Groundwater System

Recharge to the Perched Groundwater System across the Project Application Area occurs predominantly via two methods, these being:

- Recharge via rainfall
- Recharge via leakage from surface water/swamps.

Recharge via rainfall occurs when significant precipitation falls directly on or near rocky outcrop areas.

Recharge from surface water seepage occurs beneath swamps and creeks when the swamps/creeks are saturated or flowing and the shallow or perched water table is below the water level in the surface water feature.

Discharge from the Perched Groundwater System occurs via discharge to surface water flows and swamps, evapotranspiration, and leakage to the underlying Shallow Groundwater System.

4.7.2 Shallow Groundwater System

The primary mode of recharge to the Shallow Groundwater System is by direct recharge where the aquifer outcrops or sub-crops beneath the upper weathered section. Recharge is also likely to include vertical seepage from the Perched Groundwater System, this method of recharge is inhibited by the presence of lower permeability bands / horizons. These clay and siltstone bands are deposited throughout the upper sections of the aquifer and act as a barrier, retarding direct vertical flow from rainfall to the underlying layers. Discharge from the shallow groundwater system occurs as seeps from the cliff face towards the north and north-northeast of the Project.

4.7.3 Deep Groundwater System

Recharge to the deep groundwater system underlying the MYC occurs in the sub crop zone to the west and southwest of the mining area where the coal seams outcrop or sub-crop.

The Katoomba seam which is part of the deep groundwater system is sometimes used as a stratigraphic marker to locate the approximate depth of an aquitard which is thought to occur just below the seam. This aquitard separates the Lower Triassic and Upper Permian aquifer units.

Discharge from the deep groundwater system is expected to occur further to the northeast, well outside the Project Application Area.

4.8 Regional Groundwater Quality

The regional water quality in the underlying aquifers in the vicinity of the Project Application Area has been reported to be ‘generally good to moderate’. pH values range across the rock units, with waters in the Narrabeen Group tending towards neutral and waters in the Illawarra Coal Measures varying through slightly acidic to slightly alkaline. Consistently, the Narrabeen Group has better quality waters (Bish, 1999). The difference in quality between the various rock units depends on the geological matrix of the rock, residence time, and distance from recharge point.

Trace metal concentrations (i.e., iron and manganese) are highly variable across the Coxs River Catchment, particularly in the Illawarra Coal Measures (Bish, 1999).

Historical analyses of mine water discharged from discharge points at adjacent mines show that the discharged water is slightly alkaline and low in salinity. Some changes in surface water quality as a result of mine water discharge into the Wolgan River have been recorded. The pH of the water was recorded to become more neutral and the salinity of the water increased.

4.9 Site Specific Water Quality

The overall water quality monitoring programme comprises water quality sampling at several locations across the Project Application Area.

The summary of groundwater quality monitoring network includes the following:

- Samples are taken on a monthly basis from 11 monitoring points in the swamps on the Springvale Project Application Area (at Sunnyside Swamps and Carne West Swamps, with limited monitoring at Marangaroo Swamp). The water quality sampling began in February 2011. Additional sampling locations are continually incorporated into the water quality sampling programme as new standpipe piezometers are drilled and installed.
- Full suite of parameters are collected and tested from Bore 6 (and Bore 940 on Angus Place) dewatering bore. Field readings of pH, temperature and electrical conductivity are taken at each sampling event.

4.9.1 Swamp Water Quality Monitoring

The water samples from the swamps at Springvale are analysed for a range of parameters on a monthly basis which include:

- Free chlorine,
- total chlorine,
- hardness as $CaCO_3$,
- Hydroxide Alkalinity as $CaCO_3$,
- Carbonate alkalinity as $CaCO_3$,
- Bicarbonate Alkalinity as $CaCO_3$,
- total Alkalinity as $CaCO_3$,
- SO_4,
- Chloride,
- Calcium,
- Magnesium,
- Sodium,
- Potassium,
- Aluminium (dissolved),
- Copper,
- Lead,
- Zinc,
- Iron,
- Chromium,
- Aluminium (total),
- Manganese (total),
- Zinc (total),
- Iron (total),
- Nitrite as N,
- Nitrate as N,
- Nitrite & Nitrate as N,
- total Kjeldahl Nitrogen as N,
- total Nitrogen as N,
- Total Phosphorus as P,
- total Organic Carbon,
- Oil & Grease,
- Phenols (total).

The locations of the swamp water quality monitoring points are shown in Figure 19. Table 4.4 presents the details of the current water quality monitoring programme at Springvale.

Table 4.4: Groundwater Chemistry Monitoring At Springvale Swamp Sites

Piezometer	Easting	Northing	Associated Swamp	Monitoring Commencement Date
SS1	237766	6303509	Sunnyside Swamp	22/02/2011
SS3	237783	6303571	Sunnyside Swamp	18/05/2011
SS4	237791	6304398	Sunnyside Swamp	22/02/2011
SS5	237782	6304627	Sunnyside Swamp	22/02/2011
SSE3	239064	6303558	Sunnyside East Swamp	22/02/2011
CW1	239352	6303196	Carne West Swamp	22/02/2011

Piezometer	Easting	Northing	Associated Swamp	Monitoring Commencement Date
CW2	239382	6303247	Carne West Swamp	22/02/2011
SSE1	238668	6303143	Sunnyside East Swamp	12/06/2012
SSE2	238831	6303352	Sunnyside East Swamp	12/06/2012
CC1	241193	6302693	Carne Central Swamp	12/06/2012
MS1	238860	6299169	Marangaroo Swamp	12/06/2012

A summary of the minimum, maximum and average pH, EC and DO results are presented in Table 4.5. The full results of the swamp groundwater quality analyses undertaken across the Springvale Project Application Area are presented in Appendix I.

Table 4.5: Swamp Groundwater Quality Summary at Springvale Sites

Monitoring Point	Swamp Name	pH min – max, [Av.], (med)	EC (µS/cm) min – max, [Av.]	DO (mg/L) min – max, [Av.]
SS1	Sunnyside	4.59 – 6.65 [5.90] (6.08)	23 – 82 [40] (23)	3.13 – 10.34 [7.55] (3.13)
SS3	Sunnyside	5.00 – 6.76 [6.21] (6.40)	33 – 85 [63.31] (61.5)	3.05 – 10.04 [7.06] (7.46)
SS4	Sunnyside	5.23 – 6.21 [5.76] (5.74)	27 – 86 [51.53] (50)	3.61 – 9.47 [6.87] (6.48)
SS5	Sunnyside	4.49 – 5.82 [5.23] (5.25)	17 – 41 [28.16] (29)	2.6 – 10.46 [6.87] (7.08)
SSE3	Sunnyside East	5.18 – 6.03 [5.61] (5.58)	20 – 55 [37] (37)	2.8 – 9.18 [5.62] (5.39)
CW1	Carne West Swamp (lower)	3.95 – 5.30 [4.89] (4.9)	15 – 30 [19.95] (19)	4.42 – 10.57 [7.72] (7.64)
CW2	Carne West Swamp (lower)	4.15 – 5.71 [5.14] (5.24)	12 – 28 [17.74] (17)	4.53 – 10.39 [7.49] (7.56)
SSE1	Sunnyside East	No Data	No Data	No Data
SSE2	Sunnyside East	5.54 – 5.92 [5.68] (5.59)	36 – 39 [37.67] (38)	4.66 – 9.08 [6.87] (6.87)
CC1	Carne West Swamp	6.14 – 6.48 [6.33] (6.36)	66 – 90 [75] (69)	8.32 – 9.1 [8.71] (8.71)
MS1	Marangaroo Swamp	5.57 – 6.08 [5.84] (5.87)	33 – 50 [40.33] (38)	6.00 – 8.25 [7.13] (7.13)
Site wide*	-	4.49 – 6.76 [5.03] (5.03)	15 – 90 [34.27] (32.95)	2.6 – 10.57 [6.24] (6.31)

* Average of averages, median of medians.

The water quality results are consistent with swamp environments in that the EC (salinity) is characteristic of rainwater or shallow perched systems recharged by natural precipitation or immediate rainfall runoff. The water, from a salinity perspective, is high quality (low salinity) as a consequence of the short residence time characteristics of the swamp groundwater (15 – 90 µS/cm), and is well within ANZECC default trigger levels for highland streams environments (for 95% Freshwater Ecosystem Protection for SE Australia (Upland Rivers)).

The swamp groundwater quality results exhibit pH levels (4.49 – 6.76) which are more acid than the ANZECC default trigger levels (6.5 to 7.5). However, these values are not atypical of swamps where stagnant or slow moving water conditions and biological activity give rise to mildly acidic water quality conditions, indicating natural background pH in this area that is below the ANZECC default trigger levels.

Dissolved oxygen (DO) values were highly dependent on temperature, salinity, biological activity. The ANZECC (2000) guidelines for Freshwater Ecosystem Protection for SE Australia (Upland Rivers) show DO (% saturation) range from 90 to 120 % for surface water streams and rivers. The project site swamps range in DO values of 2.6 – 10.6% suggesting active biological decay of vegetable material is taking place in the immediate subsurface causing depletion in available oxygen. This is further corroborated by the low pH conditions observed in the swamps water quality data. These conditions are consistent with similar swamp environments.

The major cations and anion concentrations replicate the high water quality characteristics (low salinity) indicated in the EC results. Bicarbonate concentrations, when compared with chloride concentrations, dominate the swamp water signature. As such, the water quality reflects limited exposure deep saline waters of the Permian sequence and the lower pH conditions within the swamp environment.

Acid pH groundwater conditions are often accompanied by elevated dissolved metals concentration since such metals are more soluble under acidic conditions. This is indicated in the results of swamp groundwater sampling in Appendix I where zinc and copper concentrations are present at concentrations above the ANZECC default trigger levels. It is noted that this is not atypical of groundwater within the Triassic and Permian sequences in the Sydney Basin and surrounding sedimentary systems.

Nutrient concentrations (as reflected in Kjeldahl Nitrogen, nitrate and nitrite) are considered to be within normal background conditions within swamp environments where biological activity and decay are prevalent.

The concentrations of the indicator parameter, “Oil and Grease”, are below the standard laboratory practical quantification limits (PQL) indicating the swamp water shows no evidence of being impacted by anthropomorphic hydrocarbons.

Through the duration of the monitoring period, temporal changes show a relationship to rainfall and seasonal affects, but do not show any discernible trends outside of these natural phenomena.

While Sunnyside swamp was not directly undermined by longwall mining, its immediate surrounds to the east, the south and the west have been undermined. The lack of discernible swamp water level effects would strongly infer that subsidence impacts (if present) are unlikely to impact water quality in the swamps.

4.9.2 Deep Groundwater Quality Monitoring

Bore 6 (Springvale)

Groundwater quality samples are taken from the Springvale’s current dewatering bore, *Bore 6*. The discharge from this borehole is pumped via the Springvale-Delta Water Transfer Scheme (SDWTS) to Wallerawang power station where it is used as part of the plant cooling system.

Groundwater is also pumped from the underground workings to the surface by the existing Bore 940 dewatering borehole at the adjacent Angus Place Colliery (Angus Place). Discharged water from this borehole is also pumped to Wallerawang Power Station using the SDWTS.

Water quality sampling and testing from Bore 6 (and Bore 940 on Angus Place) was started in January 2010. In the initial stages of sampling (January 2010 – February 2011) samples were analysed for a full range of parameters quarterly. After this date a full suite of parameters were analysed approximately fortnightly. The full suite of analysis comprises 75 parameters. The full list of parameters is presented in Appendix J.

A summary review of Springvale groundwater data (Bore 6) is provided below.

- pH, Cations and Anions:
  - *pH* – min: 6.95, max: 8.5, average: 7.61 (ANZECC guideline value: 6.5 to 7.5 for surface water; no trigger level for groundwater).
  - *Anions* - the groundwater is a high bicarbonate - low chloride water quality.
  - *Cations* - the groundwater is a high magnesium - low sodium water quality.
- Consistent exceedance above the ANZECC water quality guidelines in:
  - *Electrical Conductivity* – min: 698 µS/cm, max: 1210 µS/cm (ANZECC guideline value: 350 µS/cm).
  - *Chlorine (total)* – min: 0.01 mg/L, max: 0.3 mg/L (ANZECC guideline value: 0.003 mg/L).

  - *Aluminium (filtered)* – min: 0.08 mg/L, max: 0.56 mg/L (ANZECC guideline value: 0.055mg/L).
  - *Copper (filtered)* – min: 0.002 mg/L, max: 0.024 mg/L (ANZECC guideline value: 0.0014 mg/L).
  - *Zinc (filtered)* – min: 0.015 mg/L, max: 0.124 mg/L (ANZECC guideline value: 0.008).
- Some intermittent slight exceedances in Turbidity, pH, Lead (filtered) and Cadmium.
- The concentrations of the indicator parameter, “Oil and Grease”, are below the standard laboratory practical quantification limits (PQL) indicating the dewatering bore water are not impacted by anthropogenic hydrocarbons.
- All other parameters sampled remain below the ANZECC guideline values, or below the laboratory PQL.
- As such, all other parameters measured in the groundwater monitoring programme for the dewatering Bore 6 Springvale is considered to be typical background values (or better) for Permian coal seam aquifers.
- Temporal variations in deep groundwater quality data do not show any discernible longterm trends.

Bore 940 (Angus Place)

For comparison purposes, a summary of the salient details of the water quality monitoring data for Bore 940 over the three year monitoring period is shown below:

- pH Cations and Anions:
  - *pH* – min: 6.82, max: 8.18, average: 7.20 (ANZECC guideline value: 6.5 to 7.5 for surface water; no trigger level for groundwater).
  - *Anions* -the groundwater is distinctly a high bicarbonate - low chloride water quality.
  - *Cations* - the groundwater is distinctly a high magnesium - low sodium water quality.
- Consistent exceedance above the ANZECC water quality guidelines in:
  - *Electrical Conductivity* – min: 610 µS/cm, max: 950 µS/cm (ANZECC guideline value: 350 µS/cm).
  - *Chlorine (total)* – min: 0.01 mg/L, max: 0.26 mg/L (ANZECC guideline value: 0.003 mg/L).
  - *Copper (filtered)* – min: 0.002 mg/L, max: 0.019 mg/L (ANZECC guideline value: 0.0014mg/L).
  - *Zinc (filtered)* – min: 0.013 mg/L, max: 0.062 mg/L (ANZECC guideline value: 0.008 mg/L).
- Occasional exceedance above the ANZECC water quality guidelines in:
  - Arsenic (filtered) – min: 0.014 mg/L, max: 0.062 mg/L (ANZECC guideline value: 0.008 mg/L).
- The concentrations of the indicator parameter, “Oil and Grease”, are below the standard laboratory practical quantification limits (PQL) indicating the dewatering bore water are not impacted by anthropogenic hydrocarbons.
- All other parameters sampled remain below the ANZECC guideline values, or below the laboratory PQL.
- As such, all other parameters measured in the groundwater monitoring programme for the dewatering Bore 6 Angus Place is considered to be typical background values (or better) for Permian coal seam aquifers.
- Temporal variations in deep groundwater quality data do not show any discernible longterm trends.

Not unexpectedly, the salient details of the water quality monitoring for Bore 6 over the three year monitoring period are very similar to those of Bore 940.

Summary

In summary, the water quality sampling and testing carried out on the deep groundwater system (Lithgow coal seam aquifer) at Springvale (and at the adjacent Angus Place) indicates that the water is largely on the better quality end of groundwaters typical of Permian coal measures in NSW and Queensland, that is, it is generally good quality (low-moderate EC/salinity, ranging from 610 to 1210 µS/cm).

The pH values of these the deep groundwaters range from 6.82 to 8.50, and are therefore classified as mildly acid through to mildly alkaline. For comparison, the ANZECC guideline values of 6.5 to 7.5 provide an indication of guideline values for *surface water* (no trigger level for groundwater have been set). Again these values are not atypical for groundwater from similar coal seams in NSW and Queensland.

Elevated dissolved metals concentrations are common within the Sydney Basin groundwater systems. In particular, copper and zinc concentrations in excess of ANZECC guideline values, are typically recorded within the aquifers and aquitards of the basin.

All other parameters measured in the groundwater monitoring programme for the dewatering bores on Angus Place and Springvale are considered to be within the lower end of the range typical background values for Permian coal seam aquifers.

Temporal variations in swamp and deep groundwater quality data do not show any discernible trends outside of rainfall and seasonal affects.

4.10 Hydraulic Testing

Permeability testing has been undertaken on the stratigraphic units underlying the neighbouring Angus Place Colliery and is considered to be indicative of the equivalent units underlying Springvale. For the purposes of this report it should be noted that the terms 'hydraulic conductivity' and 'permeability' are used synonymously.

Packer injection testing, using pneumatic packer equipment, was carried out at borehole on:

- SPR26 on Springvale in June and July 2002 (Golder Associates, 2002).
- AP1205 in Angus Place in July and August 2012 (Golder Associates, 2012).

4.10.1 SPR26 Permeability Results

A geotechnical and hydrogeological investigation was undertaken by Golder Associates in 2002 (Golder Associates, 2012). In this investigation permeability tests were carried out on a number of horizons underlying Springvale. The salient points regarding the permeability testing are as follows:

- 12 discrete in-situ permeability tests were carried out in SPR-26 in June and July 2002.
- A variety of permeability tests comprising packer testing, falling and rising head tests and pumping tests were carried out.
- The highest permeability of 0.17m/day (2.0×10^{-6} m/s) was recorded in the Banks Wall Sandstone. The test zone ranged from 70.61mbgl to 76.71mbgl.
- The lowest permeability of 2.6×10^{-4}m/day (3.0×10^{-9} m/s) was recorded in the 'floor rock'. The test zone ranged from 361.61mbgl to 367.71mbgl.
- Permeability results from the Lithgow / Lidsdale Coal Seam indicate a permeability of 5.0×10^{-7} m/s.

4.10.2 AP1205 Permeability Results

A number of horizons were tested at this location at Angus Place, and permeability values for each horizon tested are shown in Table 4.6.

Other salient points regarding the permeability testing are as follows:

- 10 discrete in-situ permeability tests were carried out in AP1205 in July and August 2012.

- The test type comprised constant rate Lugeon Tests using a double pneumatic packer tool, also known as a packer test.
- Permeabilities values range from less than 1.0 x 10^{-2} to 5 x 10^{-2}m/day (1.2 x 10^{-7} to 5.8 x 10^{-7} m/s).
- The permeability results show that out of the 10 tests, all formations tested were of low permeability and display tight to very tight rock mass characteristics.
- Packer equipment leakage issues mean that these data should be considered with caution (i.e. they are indicative values).

Table 4.6: Summary of Site Specific Permeability Data - AP1205 (Golder Associates, 2012)

Monitoring Point	Depth Tested	Formation	Calculated Permeability (m/day)	Rockmass Condition*
AP1205	99.9 – 110.93	Banks Wall Sandstone	< 1.0x10^{-2}	Very tight
	139.5 – 150.0	Banks Wall Sandstone	< 1.0 x 10^{-2}	Very tight
	158.8 – 168.0	Banks Wall Sandstone	< 1.0 x 10^{-2}	Very tight
	178.18 – 189.0	Mt York Claystone	< 1.0 x 10^{-2}	Very tight
	241.0 – 252.0	Caley Formation	< 1.0 x 10^{-2}	Very tight
	277.5 – 290.35	Farmers Creek Formation	< 1.0 x 10^{-2}	Very tight
	323.5 – 336.07	Denman Formation	1.0 x 10^{-2}	Tight
	352.0 – 363.1	Denman Formation and Newnes Formation	< 1.0 x 10^{-2}	Very tight
	363.2 – 375.0	Long Swamp Formation	1.0 x 10^{-2}- 5 x 10^{-2}	Tight
	387.5 – 398	Lidsdale / Lithgow Coal Seams	1.0 x 10^{-2}	Very tight

5. CONCEPTUAL HYDROGEOLOGY

5.1 Introduction

In order to grasp the fundamentals of the current hydrogeological regime underlying the Project Application Area, the development of a robust, simple and realistic conceptual model is essential for a higher level understanding of the key driving elements within a dynamic groundwater system. For this reason, a conceptual hydrogeological model has been developed for the Project.

5.1.1 The Conceptual Hydrogeological Model

The conceptual hydrogeological model (CHM) for the Project Application Area, described below, is a simplified representation of the real system, identifying the most important geological units and hydrogeological processes, while acknowledging that the real system is geologically and hydrogeologically more complex. The prime purpose of the CHM is that it provides a descriptive and graphic presentation (Figures 9A & 9B) of the groundwater system of the Application Area in a clear and logical way, that is easy to understand for all stakeholders.

The conceptual model typically forms the basis for the computational groundwater flow and impact estimation model (Section 6). However, the CHM presented in this report for the Project Application Area described below has been developed independently and in parallel to that of the CSIRO (Adhikary and Wilkins, 2013a) numerical model (refer Section 5.1.2). The CHM is based on observations and analyses of monitoring data acquired to date (described in Section 4) and on previous investigations.

It should be noted that the CHM presented herein, and that upon which the CSIRO model has been founded are in agreement. Without a fully developed hydrogeological conceptual model the execution of numerical modelling properties may be implemented incorrectly, giving way to future calibration problems or system shortfalls.

Key elements of the conceptual hydrogeological model as described below are presented graphically on Figures 9A & 9B.

Figures 9A & 9B present the perched, shallow and deep groundwater systems. Longwall mining leads to localised disruption of the deep groundwater system as well as subsidence induced changes in overlying strata. The magnitude of influence on overlying strata declines with increasing height above the mined coal seams. Due to the multiple layers of aquitards and aquifers in overlying strata there is minimal change to the perched system that supports hanging swamps and perched and shallow system that supports shrub swamps.

The key elements illustrated in these drawing are described in the sections which follow and in summary:

- Stacked and segregated groundwater systems recharged by rainfall – locally in the case of perched and shallow systems and regionally in the case of the deeper systems.
- Deep regional flow essentially isolated from the shallow and perched groundwater systems;
- Perched water systems supported on low permeability aquitard layers.
- Shrub swamps fed partially by groundwater originating from the perched groundwater systems and partially from surface water run-off.
- The Mount York Claystone acting as a significant regional aquitard isolating the shallow and perched groundwater systems from the deep groundwater system.
- The deep interbedded and interbanded aquitard (mudstones) and aquifer (sandstone and coal) units present beneath the Mt York Claystone strongly influence the deep regional groundwater flow pattern at depth.
- Groundwater flow is dominated by both porous media flow (dominantly horizontal) and to a much lesser extent, fracture flow associated with the joint, fracture and fault conduits.
- Variably enhanced groundwater flow through the lithological pile affected by subsidence induced permeability zones.
- Extensive aquifer interference in the Deep Groundwater System aquifers due to

depressurization and subsidence-induced goaf formation, collapse and fracturing affects.

- Shallow formation sagging, induced by subsidence, gives rise to enhanced horizontal permeability in the Shallow Groundwater System (permeability enhancements decreasing closer to the ground surface).
- Disconnected vertical permeability enhancements are inferred in the shallow surface zones.

5.1.2 CSIRO Conceptual Model

To aid in the assessment of impacts, a numerical groundwater model has been developed by CSIRO to predict the groundwater impacts associated with longwall extraction at Springvale and Angus Place; the model is discussed in detail in Section 6. The purpose of the model was to assess potential impacts on local and regional hydrogeology and to assess the potential cumulative impacts with the extensive network of past, present and proposed mining operations on the regional groundwater system.

Section 2 of the CSIRO modelling report (Appendix K) provides a technical description of how key physical elements are implemented and represented within the numerical model, and provides justification for the adoption of the specific model parameters that were required to undertake the modelling assessment.

The following sections provide a discussion of the key hydrogeological elements and their various interactions and dependencies, and are consistent with the CSIRO conceptualisation (Adhikary and Wilkins, 2013a).

5.2 Regional and Local Hydrogeology

The local and regional hydrogeology is discussed in Sections 3.7 and 3.8, and the conceptualisation is displayed graphically in Figure 9A & 9B. The groundwater system underlying the Project Application Area is relatively complex with multi-layered units of variable permeability resulting in a number of discrete groundwater flow systems. The already complex system is further compounded by the effects of large mine voids due to historical mining in the vicinity of the Project Application Area, and the alteration of formation hydraulic properties due to mining and mine subsidence. This section provides an overview of the different hydrogeological components and their interaction which contribute to the overall hydrogeological regime underlying the Project Application Area.

5.2.1 Summary of Hydrostratigraphy

A number of key hydrostratigraphic units have been identified through past investigations. The investigation and delineation of these units is discussed in Section 3.8 and is presented graphically on Figure 9A and 9B.

As described in Sections 3.6 to 3.8, and Table 3.4, the stratigraphic sequence is divided into a series of horizontally layered and bedded, highly laminated and flat-lying sedimentary layered lithologies, forming a complex layered sequence of less-permeable and more-permeable horizons.

For the purposes of this assessment, the more permeable units are referred to as aquifers (AQ1 to AQ6) and are separated by less permeable or semi-permeable horizons (SP1 to SP4). The bottom most aquifer unit (AQ1) directly overlies the Lithgow Seam, which in turn is underlain by low permeability siltstone and sandstones, which comprise the hydrogeological basement in the sequence (SP0).

This sequence is further subdivided into two groundwater systems, which are separated by the Mount York Claystone (SP3) and in the natural environment, are largely independent of each other. The Shallow Groundwater System, above the Mount York Claystone includes AQ4, AQ5 and AQ6, while the Deep Groundwater System comprises the Lithgow Seam, AQ1, AQ2 and AQ3. Further descriptions of these units are provided in Section 3.8. The vertical hydraulic profiles presented in Appendix N and discussed in Section 4.6, illustrate the hydraulic disconnection between these two systems across the Mt York Claystone.

A third groundwater system is present locally overlying the *Shallow Groundwater System*. This system is referred to as the *Perched Groundwater System*, and comprises multiple localised and perched water tables that are located above the regional water table, on a series of low permeability bands, beds and lenses within the Burralow Formation. The perched aquifers are generally limited to topographically elevated areas (e.g. ridges) and are completely reliant on rainfall to sustain them through direct recharge. The perched aquifers drain laterally (horizontally) and feed the hanging swamp systems that are found on the flanks of the valleys in the area and the majority of shrub swamps in the valley bases (as identified by McHugh, 2013).

The regional water table is generally represented within AQ6 across most of the Project Application Area where this unit is present, or the next stratigraphic sequence when AQ6 is absent such as within the larger valley areas on the edge of the plateau.

The shallow groundwater system is generally consistently saturated below the regional water table (although it is noted that where these units outcrop on the edge of the plateau or in the larger valleys, local desaturation and phreatic surfaces may develop due to groundwater discharge). In the Deep Groundwater System, depressurisation due to past mining operations has resulted in areas of localised desaturation at the top of the aquifer units, notably within AQ1 and at the top of AQ3, resulting in multiple phreatic surfaces and a hydraulic discontinuity between the units.

5.2.2 Formation Permeability

The total permeability of the various formations is controlled by the porosity of the formation and the interconnection of the pore spaces (primary porosity), and the degree of interconnective fracturing that is present (secondary porosity). Within both the Narrabeen Group and Illawarra Coal Measures, primary porosity is likely to be limited and localised, with the regional groundwater flow being controlled by bedding and, to a lesser extent, secondary fracture networks.

The permeability of the Narrabeen Group and the Illawarra Coal Measures is generally low. Hydraulic packer testing results (Section 4.10) indicate the permeability of the formations to be of the order of $5x10^{-2}$m/day or less Earlier testing (Golder Associates, 2002) found similar results for the Lithgow Seam ($1.7x10^{-2}$m/day) but elevated permeabilities in the Banks Wall Sandstone ($1.7x10^{-1}$m/day).

A regional study of the Coxs River catchment (Bish, 1999), suggests that the bulk permeabilities may be higher and of the order of up to 0.9m/day for fractured Narrabeen Group and 0.35m/day for Illawarra Coal Measures. Indicative permeability for coal seams in the vicinity of the Project Application Area is reported as 2m/day (Bish, 1999).

The permeability of coal measures is often higher than the surrounding formations due to the development of pervasive and dense micro-fracturing (referred to as cleats) within the coal seam. Coal seam permeability can often be one to two orders of magnitude higher than the siltstones, claystones, shale and sandstone units which comprise the coal measures. However, testing at Springvale has indicated that this is not the case and in general formation permeabilities appear much lower than regional values for the Narrabeen Group and Illawarra Coal Measures.

Due to the bedded and laminated nature of the formations, groundwater flow is predominantly horizontal, and often occurs within, or along the boundaries between stratigraphic layers (beds, bands or units). This means that effective rock mass vertical permeability is significantly lower than horizontal permeability (typically by multiple of 10 to 100 times lower).

5.2.3 Vertical Connectivity between Aquifer Units

The three groundwater systems identified within the Project Application Area (perched, shallow and deep) display independent hydraulic behaviours. This is most evident in the Perched Groundwater System which is hydraulically isolated above the regional water systems (shallow and deep) by a series of lower permeability claystone and mudstone layers in the Burralow Formation overlying the Banks Wall Sandstone.

These lower permeability layers are a predominant factor in the formation of the hanging swamps and shrub swamps and also are the main reason that the swamp system remains largely hydraulically disconnected from the underlying regional groundwater systems. The hydraulic cycle associated with the perched groundwater system is driven predominantly by rainfall.

Each of the identified aquifer units (AQ1 to AQ6) are separated by low permeability units (termed semi-permeable in the CSIRO report). These low permeability units impede the vertical flow of water between the aquifers. The most substantial of these units, the MYC, is significant enough that the Shallow and Deep Groundwater Systems display independent head profiles (Section 4.6).

Even within each of the aquifer units, the horizontally layered nature of the lithological systems will also act to impede vertical groundwater flow. Within the largely unconfined AQ6, stratification will result in the aquifer becoming increasingly confined with depth.

The natural vertical segregation between the aquifer units can be compromised by mining operations which have been ongoing in the region. Mining operations can create the potential for vertical preferential flow paths due to either the physical excavation of horizons, and due to the connective vertical fracturing of overlying strata due to subsidence. However, the connective vertical fracturing is not predicted to propagate as high within the sequence as the MYC, and the main enhancement of vertical permeability and associated impacts will be constrained to the Deep Groundwater System (Figure 9A & 9B). This is discussed further below in Section 5.3.

5.2.4 Recharge and Discharge

Recharge to the surficial perched aquifer system is predominantly sourced from rainfall infiltration. Rainfall recharge can be separated into two predominant types which give rise to the two swamp classifications across the Project Application Area. The first rainfall infiltration type is direct recharge. This comprises direct overland flow to the swamp systems following a rainfall event, and also direct infiltration onto the swamp surface. The second type of recharge occurs via through-flow in the surficial deposits. Rainfall infiltrates the upper horizons of the Burralow Formation until it is largely prevented from further vertical flow by lower permeability deposits such as claystone or siltstone lenses. This flow them becomes predominantly horizontal and travels laterally along the lenses before discharging into the hanging swamp systems along the valley flanks or shrub swamps in valley bases.

Recharge to the Shallow Groundwater System in the Banks Wall Sandstone occurs via indirect rainfall infiltration through the surficial weathered deposits the Burralow Formation. Given the stratification of the system recharge is likely to be slow and convoluted, with the exception of areas beneath valley floors where the Burralow Formation is absent and the water table is close to ground surface.

Recharge to the Deep Groundwater System underlying the MYC occurs predominantly where the aquifers outcrop to the west and southwest of the Project Application Area on the flanks of the plateau.

Regional groundwater discharge is likely to occur down gradient (to the northeast) where the various aquifers “daylight” in the scarps and bluffs of the plateau. Smaller local discharge will also occur via baseflow and evapotranspiration where shrub swamps and creeks are a surface expression of the local water table.

5.2.5 Groundwater Flow Direction

Groundwater monitoring results indicate that the regional and local groundwater flow direction in the Deep Groundwater System and deeper parts of the Shallow Groundwater System (AQ4 and AQ5) is from southwest to northeast, consistent with the regional dip of the stratigraphic units. Within the water table aquifer (AQ6) groundwater flow is more likely to be an expression of surface topography.

Current and historical mining of the Lithgow Seam (and other coal seams) in the Project Application Area has resulted in significant dewatering and depressurisation in the surrounding coal measures, with the coal seams and underground workings acting as a groundwater sink, and underdrain to the overlying lithologies of the Illawarra Coal Measures. Localised changes to groundwater flow direction due to dewatering extraction can be observed at site. This can be seen in the groundwater contours presented in Figures 21 and 22. Data from the adjacent Angus Place has also been used to create these groundwater contours in both the unconfined Banks Wall Sandstone (Shallow Groundwater System) and the confined Burra Moko Head Formation (Deep

Groundwater System). The data for the groundwater contours have been derived from vibrating wire piezometers installed within the relevant formations.

The groundwater contours in the Banks Wall Sandstone (Figure 21) show a general northerly to northeasterly flow direction, with some localised variation that may be due to differing VWP installation depths and variable vertical hydraulic gradients within the units. Groundwater levels are generally elevated in the vicinity of the existing mining operations at Springvale, indicating a local groundwater divide, with water levels dropping off to the north and east away from the existing mining areas. This area of elevated groundwater coincides with a topographic high and a surface drainage divide.

Groundwater heads within the Burra Moko Head Sandstone (Figure 22) are generally 120 m to 140 m lower than those in the Banks Wall Sandstone in the vicinity of the existing Springvale longwall panels. The lowest groundwater elevations in the Burra Moko Head Sandstone are consistent with the more recent longwall activity as observed at SPR-51. There appears to be propagation of these impacts to the northeast in AP11PR and AP1104.

The location of the depressed groundwater levels in the Burra Moko Head Sandstone coincide with the groundwater high in the Banks Wall Sandstone, indicating that the depressurisation is not transferred through the MYC.

5.3 Subsidence Fracturing

Longwall mining results in the complete collapse of the goaf area behind the advancing longwall shearer. This collapse results in the successive upwards transfer of stresses, with subsequent subsidence and deformation of the overlying strata that result in changes to the natural hydraulic properties of the formations. The extent and propagation of these deformations can directly influence groundwater inflow to the underground mine and the propagation and magnitude on groundwater impacts away from the mined area. Subsidence fracturing can result in the hydraulic connection of aquifers that had previously been isolated from the area of mining (Figure 9B). The deformation and propagation of subsidence and fracturing above the longwall panel has been the subject of numerous investigations. In general, a number of zones are expected to develop above the longwall panel as described in the Subsidence Predictions and Impact Assessment report for the Springvale Project (MSEC, 2013) described below. Information on the permeability of each zone has also been included using the ACARP C18016 study (Adhikary and Wilkins, 2012). The zones are depicted in Figure 9A and Figure 9B.

- *Caved* or *Collapsed Zone* comprising loose blocks of rock detached from the roof and occupying the cavity formed by mining. This zone can contain large voids and consequently the permeability within this zone is very high. At Springvale, the Caved Zone is expected to propagate approximately 9 m above the Lithgow seam.
- *Disturbed* or *Fractured Zone* comprising in-situ material lying immediately above the caved zone which have sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation. In this zone, connective vertical fractures and bed separation provide a direct hydraulic connection with the Collapsed Zone. Both the horizontal and vertical permeability are significantly enhanced. The Fractured Zone, including a transition zone is predicted to propagate approximately 140 m above the roof of the Lithgow Seam, which would take it into the base of AQ3.
- *Constrained* or *Aquiclude Zone* comprises confined rock strata above the disturbed zone which have sagged slightly but, because they are constrained, have absorbed most of the strain energy without suffering significant fracturing or alteration to the original physical properties. Some bed separation or slippage can be present as well as some discontinuous vertical cracks, usually on the underside of thick strong beds, but not of a degree or nature which would result in connective cracking or significant increases in vertical permeability. Some increases in horizontal permeability can be found. Weak or soft beds in this zone may suffer plastic deformation. The presence of discontinuous vertical fracturing and bed separation in this zone results in an increase in horizontal permeability with lesser or no increase in bulk vertical permeability. There is generally no direct hydraulic connection with the Collapsed Zone. The Constrained Zone is predicted to propagate to approximately 240 m to 250 m above the roof of the Lithgow Seam. The base of the MYC is approximately

in the middle of the Constrained Zone.

- *Surface Zone* comprises unconfined strata at the ground surface in which mining induced tensile and compressive strains may result in the formation of surface cracking or ground heaving. The Surface Zone may also experience bed separation resulting in enhanced horizontal permeability. Shallow surface cracking can also occur but this is generally limited to the upper 10 m to 15 m and is not in hydraulic connection with the deeper continuous fracturing.

In the groundwater model (Adhikary and Wilkins, 2013b) these zones and their respective changes in hydraulic parameters are implemented through the use of a ramp function that applies changes to the permeability above the longwall that diminish with height above the longwall. The application of the ramp function is discussed in more detail in Section 6.2.5 and in the CSIRO report (Appendix K).

5.3.1 Modified Mine Design to Minimise Subsidence

In order to minimise subsidence beneath sensitive THPSS areas such as Sunnyside East and Carne West swamps, Springvale have opted to adjust mine plans by narrowing the longwall (void) widths and increasing the chain pillar (support) widths. The narrower void width and increased support results in a reduction in subsidence impacts observed at the ground surface and will also act to reduce potential impact on the swamps.

The adoption of the 261 m (260.9 m) wide panel for LW416 and LW417 will result in a 16 to 20% reduction in total subsidence at surface compared to the standard 315m wide panels.

Centennial Coal considers modified mine design to minimise subsidence as the prime method for impact mitigation. Mining under key environmental and ecologically sensitive areas (including sensitive creeks and swamps) is also minimised to reduce impacts to negligible levels.

6. NUMERICAL MODELLING

6.1 Introduction and Context

As part of the impact assessment, a numerical groundwater model has been developed for the Project Application Area, and surrounding area. The model has been constructed to a level consistent with groundwater modelling guidelines and has been subject to 3rd party review. The overall objective of the groundwater modeling, undertaken by CSIRO (2013), was to assess the potential impacts of the Project on the groundwater environment, specifically with regard to the following:

- Predicted mine inflow (and dewatering) rates
- Regional changes in groundwater levels during mining and after mine closure
- Changes in baseflow contributions to surface watercourses and swamps
- Potential impacts on any existing groundwater users and GDEs.

To enable these predictions, a regional numerical model has been constructed that can examine synergistic impacts from underground operations across the area (Appendix K). The model was subjected to transient calibration against the observed impacts of recent mining in the model area and subsequently used for impact predictions, including uncertainty analysis.

The numerical model has been constructed with the capacity to carry out mining simulation to enable the reliable prediction of groundwater inflow rates to the mine. These inflow rates are part of the water balance important for understanding the proposed mine development scenarios.

Important information related to the groundwater systems under stress conditions already exists and this has been considered at the conceptual and numerical model development stages. These lines of evidence include the following:

- Case study reports on swamp water level responses to longwall progression, and rainfall
- Specific hydrograph analysis of both the swamp water levels, and the regional water levels in the shallow aquifer system
- Vertical pressure gradients
- Extent of drawdown as a result of current operations.

6.1.1 Historical Context

- The numerical computer code selected for the assessment of mining related impacts on groundwater and associated environmental values was COSFLOW. COSFLOW was developed as a joint project with CSIRO, Japan Coal Energy Center (JCoal) and New Energy and Industrial Technology Development Organization (NEDO). It is a continuum model. In the application at Angus Place, it has been configured to couple fluid flow through a porous medium with rock deformation as well as flow-only.
- The use of COSFLOW at Springvale and Angus Place dates back to 2004 when a research program was initiated which sought to assess and predict local geomechanical and water inflow impacts of mining the Lithgow Coal Seam. Because the model couples mechanical deformation and fluid flow, it was more broadly used to understand the effect of mining and consequent subsidence on the local groundwater flow systems. On the basis of the pre-existing body of work undertaken as part of the research projects at Springvale and Angus Place, COSFLOW was chosen to undertake the groundwater impact assessment for this study.
- The intent of the impact modelling assessment is primarily to predict, in a responsible yet conservative way, what groundwater impacts might be expected into the future, during mining and post mining, and what implications these impacts might impute with regard to existing water users, GDEs, the environment in general, and more broadly evaluate the implications to the WSP and water licensing requirements, and AIP.

6.2 Model Setup

6.2.1 Model Software

COSFLOW is a numerical model code developed by the CSIRO to simulate multi-component, multi-phase fluid and heat flow coupled with Cosserat elasto-plasticity. In essence, COSFLOW is a coupled geotechnical and groundwater model and has the capacity to simulate either subsidence and fracture propagation, or groundwater flow, or both.

As alluded to above, there have been a series of applications of COSFLOW at the Springvale Mine as part of the Australian Coal Association Research Program (ACARP) since early 2000. These previous studies have focussed on calibration and prediction of coupled *mechanical deformation* and *fluid flow*. The results of these studies are summarised in Adhikary and Wilkins, (2012) and Guo et. al. (2007).

For this Project, the COSFLOW model was used in a single component, groundwater flow capacity mode.

The model simulates both unsaturated and saturated groundwater flow via a fully implicit solution to Richards's equation, written in terms of pore pressure. As such, COSFLOW is capable of simulating multiple phreatic surfaces, and therefore is considered appropriate for the Springvale groundwater system (see Section 5 for discussion of the CHM).

Mechanical deformation was not directly coupled to prediction simulations presented in this groundwater impact assessment and summarised herewith; however, the results from recent previous studies at Springvale were used to inform the choice of the ramp function (see Section 6.2.5) that is used to alter the permeability of the rock around the mined region (as would be anticipated in and above the goafed area of the stratigraphy).

6.2.2 Model Grid and Active Domain

COSFLOW is a finite element code based on quadrilateral elements. The mesh density is variable, and in the central region of the Springvale model, the mesh has higher refinement compared to that at the edge of the model. The element edge length is amended in areas of refinement such that there is a smooth transition in element size.

The extent of the model is 30km by 30km and the grid is located between 221000mE, 6288000mN and 251000mE, 6318000mN. The coordinate system of the model is MGA94 and the entire model domain is active in the numerical simulation. This model is referred to in the CSIRO report as the '*mini-regional scale model*' (Figure 23). The full modelling report is presented in Appendix K.

To provide boundary conditions to the eastern edge of the model, a second larger model was also prepared (Figure 23). The extended model is also referred to in the CSIRO report as the '*regional scale model*'. The extended model is 60 km by 40 km and consists of a coarser model grid. The extended model grid is located between 220000mE, 6285000mN and 280000mE, 6325000mN and has square elements of 1000m everywhere.

The element size is about 50 m of the 'mini regional scale model' in the central region of the model, the location of active mining, and in the vicinity of the swamps and streams, which are a focus of the impact assessment. The element size at the boundary of the model domain was 1000 m. In total, in plan, there are 45,000 quadrilateral elements.

It is noted that nodes were also placed at each piezometer location and strings of nodes (as line segments) added to define rivers and swamps prior to generation of the mesh. The objective of this approach to assign model nodes at each point of interest was to minimise interpolation.

6.2.3 Model Layers

As presented in Section 3.8 (Table 3.4), there are multiple hydrogeological units considered in the CHM. These have been incorporated into the COSFLOW model using 20 layers. Accordingly, the COSFLOW model consists of 900,000 elements in total.

The model comprises two hydrogeological unit types (refer Figure 10):

- Aquifers (model prefix ‘AQ’).
- Semi-Permeable Units (model prefix ‘SP’).

Table 6.1 presents a summary of the layers used in the COSFLOW model. It is noted that some hydrogeological units were represented by more than one model layer. Additional layers were included in the model for the purpose of improving vertical discretisation rather than differentiation due to change in assumed hydraulic properties of these aquifers.

The top of each model layer and the thickness at location SPR50 is presented in Table 6.1 and Figure 10. Further detail of the model geometry is presented in Section 6.2.4 and Appendix K.

Table 6.1: Major Hydrogeological Units in the Groundwater Model (based on stratigraphy at SPR50)

Hydro-geological Unit	Top of Model Layer (mAHD)	Layer Thickness (m)[1]	Hydrogeological Description	Stratigraphic Units
Weath	1160	10	Regolith	N/A
AQ6	1150	60	Sandstone	Narrabeen Group sandstone
SP4	1090	10	Siltstone/Claystone	Burralow Formation, Claystone (YS4), Sandstone/Siltstone
AQ5	1080	25	Sandstone	Burralow Formation
YS6	1055	2	Claystone	Claystone (YS6)
AQ4 (2 layers)	1053	88	Sandstone	Banks Wall Sandstone
SP3	965	25	Claystone	Mount York Claystone
AQ3	940	95	Sandstone	Burra Moko Head Sandstone, Caley Formation
KAT	846	~1	Coal	Katoomba Seam
SP2	845	~4	Siltstone/Claystone	
AQ2	842	47	Siltstone/Coal	Middle River Coal Member
SP1	795	10	Siltstone/Claystone	Baal Bone/Denman Formation
AQ1	785	35	Sandstone	Long Swamp Formation, Newnes Formation
LTH (3 layers)	740	~10	Coal	Lithgow Seam
SP0	490	250	Sandstone/Siltstone/ Claystone	‘Nile’ Group

1. Layer thickness is variable and units are not continuous throughout model domain. This is discussed further in Section 6.1.4.

6.2.4 Model Geometry

The elevation of the various model layers were derived by CSIRO from the geological model prepared by Palaris (2013ab). The geological model was based on the extensive database of borehole and geophysical logs in the Western Coalfields.

Figure 24 presents the hydrogeological units represented in the model. The cross-sections presented in Figure 24 were extracted directly from the CSIRO modelling report (see Appendix K).

It is noted from Figure 24 that the elevation and thickness of each hydrogeological unit is variable. It is also identified that all units are assumed to exist within the model domain, as a continuous layered profile, except where the surface topography is such that the profile has been eroded. Where particular hydrogeological units have been eroded, these layers have been vertically truncated to a minimum thickness and relevant hydraulic properties adjusted to represent the remaining unit.

6.2.5 Model Parameters

An extensive program of research has been undertaken by the CSIRO to collate hydrogeological information at Springvale, including packer testing laterally adjacent the main headers and into the collapsed goaf at various angles. Details of these investigations are presented in Guo et.al., 2007. Section 4.10 summarises the results of testing data obtained during other investigations.

Initial values for hydraulic conductivity, vertical to horizontal anisotropy and porosity were determined by the CSIRO based on the conceptual model (see Appendix K). Table 6.2 presents these values. During calibration, the values presented in Table 6.2 were adjusted, including implementation of the amendment to hydraulic properties to account for alteration due to mining.

It is noted that the COSFLOW model is formulated based on intrinsic permeability, expressed in millidarcys (md), rather than hydraulic conductivity values. This is due to COSFLOW being written to simulate multiple phases as well as different fluid types (other than water).

The conversion between permeability (millidarcys; md) and hydraulic conductivity (metres per second, m/s) is as follows:

- 1 md = 9.64 x 10^{-9} m/s.

Table 6.2: Model Input Parameter – Hydraulic Conductivity and Porosity (Initial Values)

Hydrogeological Unit	Horizontal Hydraulic Conductivity (m/s)	Vertical Hydraulic Conductivity (m/s)	Porosity
Weath	$1x10^{-6}$	$3x10^{-7}$	0.15 to 0.20
AQ6	$1x10^{-7}$	$9x10^{-9}$	0.05 to 0.20
SP4	$9x10^{-11}$	$9x10^{-11}$	0.05 to 0.15
AQ5	$1x10^{-7}$	$9x10^{-9}$	0.05 to 0.20
YS6	$9x10^{-11}$	$9x10^{-11}$	0.05 to 0.15
AQ4	$1x10^{-7}$	$9x10^{-9}$	0.05 to 0.20
SP3	$9x10^{-11}$	$9x10^{-11}$	0.05 to 0.15
AQ3	$1x10^{-7}$	$9x10^{-9}$	0.05 to 0.20
KAT	$5x10^{-8}$	$2x10^{-8}$	0.05 to 0.10
SP2	$9x10^{-12}$	$9x10^{-12}$	0.05 to 0.15
AQ2	$1x10^{-7}$	$9x10^{-9}$	0.05 to 0.20
SP1	$9x10^{-12}$	$9x10^{-12}$	0.05 to 0.15
AQ1	$1x10^{-7}$	$9x10^{-9}$	0.05 to 0.20
LTH Seam	$9x10^{-8}$	$5x10^{-8}$	0.05 to 0.10
LTH Floor	$5x10^{-8}$	$9x10^{-9}$	0.05 to 0.15
SP0	$4x10^{-10}$	$4x10^{-10}$	0.05 to 0.10

From Table 6.2, the initial values for hydraulic conductivity are:

- Aquifers (horizontal $1x10^{-7}$ m/s; vertical $1x10^{-9}$ m/s; anisotropy 1:16).
- Aquitards (horizontal $9x10^{-11}$ to $9x10^{-12}$ m/s; vertical $1x10^{-11}$ to $1x10^{-12}$ m/s; anisotropy 1:1).

The hydraulic properties presented in Table 6.2 were applied homogeneously in each model layer.

RAMP Function

A ramp function was applied in mining regions to account for the change in hydraulic properties due to mining in overlying strata. It is noted that the parameters used to describe the ramp function were adjusted during model calibration.

The ramp function used in model calibration and prediction simulations presented in this report was based on the following. Further detail is presented in Appendix K. In the below, ΔK is log change in permeability, where x is height above coal seam and h is height of the mined seam and H being height of potential change above the coal seam.

$$\Delta K = 0 \;\; for \;\; x < -h$$
$$\Delta K = m \;\; for \; -h \le x \le 0$$
$$\Delta K = M - \frac{(M-m)x}{H} \;\; for \; 0 < x < H$$
$$\Delta K = m \;\; for \;\; x \ge H$$
$$where$$
$$\Delta K = \log_{10}\left(\frac{K_{final}}{K_{initial}}\right)$$

It is noted that a width dependence was also added to the above ramp function definition wherein the *M* parameter was substituted with *M_315* and *H* was substituted with *H_315*. Further detail is presented in Appendix K.

Table 6.3 presents the initial values adopted for the various parameters of the ramp function for the longwall mines. Table 6.4 presents the values adopted for the ramp function for Bord and Pillar mines. It is noted that the M_315 and *m* values, described below, are $\log_{10}$.

The ramp function utilised in the model simulations presented in this report is different to that presented in Guo et. al., 2007, which was derived from coupled deformation simulations following model calibration to extensometer and limited lateral packer-testing.

As nominated in the CSIRO model report, attached in Appendix K, a coupled model approach could not be used for this study due to the requirement for very high model mesh density, in plan, as well as much higher vertical discretisation. The model grid required to adopt a coupled modelling approach was implausible due to computation time. Accordingly, a simpler mesh was adopted and modelling undertaken using flow component only.

Table 6.3: Model Input Parameters – Permeability Change for Longwall Mines (Initial Values)

Material		H_315	h	M_315	m
		Height of Ramp Function (315m wide panel) (m)	Depth below seam floor of permeability change (m)	Maximum value for permeability change (315m wide panel)	Minimum value for permeability change, ΔK
Aquifer	$P_{vertical}$	230	50	1 to 3	0.25
	$P_{horizontal}$	230	50	3 to 7	0.75
Semi-Permeable	$P_{vertical}$	230	50	2.5 to 4	0.25
	$P_{horizontal}$	230	50	8 to 12	0.75

From Table 6.3, the minimum change in horizontal permeability is $10^{0.75} = 5.6$ and the minimum change in vertical permeability is $10^{0.25} = 1.8$.

Table 6.4: Model Input Parameters – Permeability Change for Bord and Pillar (Initial Values)

Material		H	h	M	m
		Height of Ramp Function (m)	Depth below seam floor of permeability change (m)	Maximum value for permeability change	Minimum value for permeability change, ΔK

Material		H	h	M	m
Aquifer	$P_{vertical}$	10	2	0.1	0
	$P_{horizontal}$	10	2	0.3	0
Semi-Permeable	$P_{vertical}$	10	2	1.5	0
	$P_{horizontal}$	10	2	4	0

In addition to the permeability change values presented in Table 6.3, there is also an amendment to account for the width of longwall panels, where it has been found that mine inflows from narrow longwalls are smaller than those from wider panels.

As well, there is a time-series amendment to the permeability values for goaf region presented in Table 6.3 wherein 80 days after mining, the ramp function is modified to simply the M_315 parameter multiplied by 0.5. This replaces the ramp function presented above and is referred to as the ‘goaf permeability’. One further modification is with respect to conductance of seepage nodes within the mined regions to account for reduced permeability and reduction in surface area due to the roof collapsing post-active mining. As presented in Appendix K this was another calibration factor, C.

6.2.6 Solver Settings

As mentioned previously, COSFLOW is based on a fully implicit solution of Richards’ equation and uses an adaptive time-step methodology. A head convergence tolerance of 0.1 m was adopted in all of the model simulations undertaken by the CSIRO. Due to the adoption of a fully implicit solution scheme, the solution is mathematically unconditionally stable and as such model mass balance error is eliminated.

6.3 Groundwater Inflow and Outflow

6.3.1 Recharge

During steady-state and transient calibration, a long-term average rainfall rate of 3 mm/day was used. During transient validation (2006-2012), three-monthly average data obtained from the Newnes Plateau was used.

Rainfall recharge to the model was applied at 5% of the rainfall rate identified above. Rainfall recharge was distributed uniformly across the model domain. An exception to this is perennial and ephemeral creeks and swamps. A higher recharge rate is applied to these nodes, as discussed in Section 6.3.3.

It is highlighted that seepage boundary conditions were also applied to all surface nodes. If a surface node became fully saturated then excess rainfall recharge was discarded.

During prediction simulations, a constant rainfall rate of 3 mm/day was adopted and rainfall recharge set to 5% of this rate, or 0.15 mm/day.

6.3.2 Evaporation

During steady-state (pre-mining) calibration, a fixed rate of maximum evaporation, ET_{max}, of 3.7 mm/day was adopted. This was based on the average annual daily evaporation rate from the Bathurst BOM station (Station No. 063005).

For transient calibration (2000-2006) and validation (2006-2012), a three-monthly stress period was used from the Bathurst BOM station. It is noted that ET_{max} is used directly in COSFLOW and as such there is no Pan A factor applied to the values adopted.

In COSFLOW, evaporation is governed by an exponential function wherein evaporation decreases approximately linearly from the near surface to near the extinction depth. The function is non-linear at the extremes. The extinction depth in COSFLOW was set at 5 m and this extinction depth was used for all simulations presented in the report.

During prediction simulations, ET_{max} was set at a constant rate of 3.7 mm/d.

6.3.3 Ephemeral and Perennial Creeks, and Swamps

Figure 25 presents the location of perennial and ephemeral creeks and swamps implemented in the numerical model. Table 6.5 presents a summary of the boundary condition type applied to each of these waterbodies. It is noted that not all waterways are represented in the numerical model, and this can be considered in a subsequent revision of the model, however, it is highlighted that seepage boundary conditions exist for all surface model nodes. As such, in topographic lows, these seepage boundaries operate in the same way as ephemeral boundaries, presented in Table 6.5, except for the rainfall and ET assumption described above.

Further detail is presented in Appendix K.

Table 6.5: Model Boundary Condition – Creeks and Swamps

Notation	Creek or Swamps	Boundary Condition Type
CA1 to CA5	Carne Creek	Perennial
CW	Carne West Swamp	Ephemeral
GGSE	Gang-Gang Swamp East	Perennial
GGS	Gang-Gang Swamp	Perennial
KC1	Kangaroo Creek	Perennial
KC2	Kangaroo Creek	Ephemeral
KAS	Kangaroo Swamp	Ephemeral
LAM	Lamb Creek	Ephemeral
LOS	Long Swamp	Perennial
MER	Marangaroo Creek	Perennial
NMS	Nine-Mile Swamp	Perennial
PDY	Paddys Creek	Ephemeral
PIS	Pine Swamp	Perennial
TRS	Tri-Star Swamp	Ephemeral
TWG	Twin-Gully Swamp	Ephemeral
SSS	Sunnyside Swamp	Perennial
WOL	Wolgan River	Perennial

Ephemeral Creeks

Outflows from COSFLOW for ephemeral creeks are managed using a seepage boundary condition in accordance with the following equation:

$$Q = -AC(P - P_s) \ for \ P > P_s$$

$$Q = 0 \ for \ P < P_s$$

wherein the above equation P_s is the seepage pressure (Pa), which was set to 0 Pa for ephemeral creeks; A is the area of the creek (m^2) and C is the creek-bed conductance ($ms^{-1}Pa^{-1}$) and was set to $1x10^{-10}$ $ms^{-1}Pa^{-1}$ (equivalent to 0.085 m^2/d, assuming a 1m thick creek-bed).

The configuration of the equation is such that there is only outflow from the groundwater domain.

It is noted that a recharge rate of 3.7 mm/day, being 123% of the steady-state recharge in the model elsewhere, is applied to nodes that have been set to act as ephemeral creeks. The purpose of this change is to exactly match ET at these nodes. Rainfall recharge applied elsewhere in the model is set at 5% of the rainfall rate of 3 mm/day, as outlined in Section 6.3.1.

Further details are provided in Appendix K.

Perennial Creeks

Inflows and outflows from COSFLOW for perennial creeks are represented using a seepage boundary condition according to the following:

$$Q = -AC(P - P_r)$$

where P_r is the staging pressure (expressed in Pa), which was set at 2000 Pa for perennial creeks (equivalent to a staging height of 0.2 m); A is the area of the creek (m^2) and C is the creek-bed conductance ($ms^{-1}Pa^{-1}$) and was set to $1x10^{-10}$ $ms^{-1}Pa^{-1}$ (equivalent to 0.085 m^2/day, assuming a 1 m thick creek-bed).

As configured, an increasing differential pressure between P_r and P in the above equation leads to an increasing inflow to the groundwater system. The rate of inflow into the groundwater system, where the near surface becomes unsaturated is, however, reduced by the relative permeability function. As discussed in the CSIRO model report (Appendix K), the relative permeability function represents the decrease in unsaturated hydraulic conductivity as a function of capillary suction.

It is noted that whilst there is no transition to a unit gradient-based flux, as is the case with MODFLOW when the water table falls below the bottom of the creek or river, there is an absolute upper limit to influx in the COSFLOW formulation due to the maximum negative pore pressure being set at -100,000 Pa (equivalent to a -10 m head). This, however, is unlikely to be reached in a model simulation due to the relative permeability function being such that the unsaturated hydraulic conductivity becomes extremely low with maximum negative pore pressures.

The recharge rate applied to perennial creeks is 3.7 mm/day, as presented in Section 6.3.1, such that this is balanced by withdrawal by the ET function. Rainfall recharge elsewhere in the model is set at 5% of the rainfall rate.

Swamps

Swamps are implemented in the numerical model as either perennial or ephemeral seepage boundary conditions. The configuration of these boundary conditions is as per that presented above for perennial creeks or ephemeral creeks except that staging pressure, P_s, for perennial swamps is set at 0 Pa rather than 2000 Pa for perennial creeks.

Table 6.7 provides a summary of the boundary condition type with respect to each surface waterway or swamp.

6.3.4 Water Table at Ground Surface

COSFLOW uses a seepage boundary condition at ground surface such that a positive pore pressure is dissipated. Accordingly, the phreatic surface cannot rise above ground surface.

The seepage boundary condition is implemented in accordance with the following:

$$Q = -AC(P - P_s) \; for \; P > P_s$$

$$Q = 0 \; for \; P < P_s$$

where P_s is the seepage pressure (Pa), which was set to 0 Pa; A is the exposed area (m^2) and C is the conductance ($ms^{-1}Pa^{-1}$) and was set to $1x10^{-10}$ $ms^{-1}Pa^{-1}$.

As noted in the CSIRO model report (Appendix K), the circumstance where a phreatic surface rises to ground surface is quite unlikely due to inclusion of ET in the model.

6.3.5 Mine Dewatering

Other coal mines surrounding the Project Application Area were included in the groundwater impact model so as to address the requirement from the Aquifer Interference Policy (NSW Office of Water, 2012) and DGRs for the Project with respect to assessment of cumulative impact.

Detailed schedules of both Angus Place and Springvale Collieries are known. Proposed schedules of surrounding mines were also included in the model simulation, to the fullest practical extent.

In addition to the existing and proposed longwalls at Springvale, the following mines have been included in the model (refer to Section 3.2 for all of the local mining activities):

- Angus Place (Bord and Pillar, Longwalls)
- Angus Place East (Proposed Longwalls)
- Baal Bone (Longwall)
- Clarence (Bord and Pillar, Longwalls)
- Commonwealth (Bord and Pillar)
- Eastern Main (Bord and Pillar)
- Fernbrook – Hermitage (Bord and Pillar)
- Folly (Open Cut)
- Invincible (Bord and Pillar)
- Johnsdale (Open Cut)
- Kerosene Vale (Open Cut)
- Lithgow State (Bord and Pillar)
- Newport (Open Cut)
- Oakey Park (Bord and Pillar)
- Pinedale (Open Cut)
- Renown (Bord and Pillar)
- Steel Works (Bord and Pillar)
- Wallerawang (Bord and Pillar)
- Vale of Clwyd (Bord and Pillar).

Dewatering of mines, where active, was achieved through seepage boundary conditions in accordance with the following:

$$Q = -AC(P - P_s)$$

where P_s is the seepage pressure, which was set to 0 kPa; *A* is the area exposed in the model (m^2), *C* is the conductance ($ms^{-1}Pa^{-1}$), which was calculated directly from surrounding rock permeability. It is noted that a correction factor is applied in the goaf region, as per below:

$$C\_goaf = 10^c * C\_face$$

where *C* is a calibration parameter and *C_face* is conductivity of material surrounding the seepage node. Further detail on modification of the model simulation due to mining-induced changes is presented in Section 6.2.5.

Further detail of mine plans and schedules adopted in the model is presented in Appendix K.

6.3.6 Groundwater Throughflow

As outlined in Section 6.2.2, an extended model, using a much coarser grid, was used to calculate the pore water distributions. The extended model consisted of no-flow boundaries on all sides and was executed in steady-state mode with rainfall recharge, ET and seepage boundary conditions (creeks and swamps) all activated.

The pore water pressure distributions were then extracted at the appropriate location and applied to the ‘mini-regional scale’. The ‘mini-regional scale’ model was then executed in steady-state prior to commencement of model calibration.

6.4 Model Calibration

6.4.1 Steady-State

The COSFLOW model was calibrated in steady-state mode to pressure levels that have been interpreted as representative of pre-mining conditions (circa 1950).

As indicated in the CSIRO model report, there was limited data at the Springvale and Angus Place Collieries prior to 2000 as compared to the much longer period of mining activity in the region.

Accordingly, some VWP pressure levels from more recent times were used to supplement the steady-state calibration dataset, where it could be established that those levels were not impacted by mining. Further detail is presented in the CSIRO modelling report.

The mass balance of the steady-state calibration model is presented in Table 6.6.

Table 6.6: Steady-State Calibration - Model Mass Balance

Boundary Type	Inflow (ML/day)	Outflow (ML/day)
Rainfall Recharge	126.8	
Evapotranspiration		96.7
Swamps and Rivers	5.2	14.5
Seep through Top of Model (removal of excess rainfall from surface once saturation has occurred)		0.0
Groundwater Throughflow (Net)		20.7
TOTAL	132.0	131.9
	ERROR (%)	0.14%

Table 6.7 presents a summary of the calibration statistics for the steady-state simulation.

Table 6.7: Steady-State Calibration – Calibration Statistics

Calibration Statistic		Value
Residual Mean Square Error	RMS	23.1m
Scaled Residual Mean Square Error	SRMS	5.5%

From Table 6.7, the SRMS (Scaled Root Mean Square) error is 5.5%. As outlined in Australian Groundwater Modeling Guidelines (Barnett et. al., 2012), a target SRMS of about 5% to 10% is considered to be an indicator of an appropriate fit. The RMS error of 23.1 m is somewhat high, however, for the observed head difference between the Burralow Formation (top of the model) and the Lithgow Seam (bottom of the model), this error is not unacceptable.

It is highlighted though that there are not many shallow measurement points in this dataset.

Further detail of steady-state calibration is presented in Appendix K.

The calibrated values of hydraulic parameters are presented in Table 6.10 below.

6.4.2 Transient Calibration

The transient calibration consisted of simulation of mining activity at the Springvale and Angus Place Collieries from interpreted pre-mining levels through to December 2006. Activity at surrounding mines was also included in the transient calibration. The surrounding mines, included in the simulation, although not all active, are summarised in Section 6.3.5 above.

The transient calibration dataset comprised observed groundwater pressure levels obtained from the VWP networks at both Springvale and Angus Place Collieries. It is noted that the dataset comprised observed values at a single point in time, at December 2006 or thereabouts.

Where observation values at December 2006 were interpreted as unreliable due to mechanical deformation, significant impact due to mining (readings fluctuating randomly) or other issues, a surrogate value from the monitoring dataset was selected. If a suitable value could not be identified, the monitoring location was not included.

The mass balance (average flows) of the transient calibration model is presented in Table 6.10.

Table 6.8: Transient Calibration - Model Mass Balance

Boundary Type	Average Inflow (ML/day)	Average Outflow (ML/day)
Rainfall Recharge	125.8	
Evapotranspiration		98.3
Swamps and Rivers	5.2	14.6
Seep through Top of Model		0.0
Groundwater Throughflow (Net)		20.6
Mine Inflow		3.7
Storage (Net)	6.2	
TOTAL	137.2	137.2
	ERROR (%)	0.0%

The results of time-series predicted groundwater elevations against observed elevations are presented in Appendix B of the CSIRO model report, including transient validation results discussed below.

Table 6.9 presents a summary of the transient calibration statistics.

Table 6.9: Transient Calibration – Calibration Statistics

Calibration Statistic		Value
Residual Mean Square Error	RMS	28.8 m
Scaled Residual Mean Square Error	SRMS	6.9%

From Table 6.9, the SRMS is 6.9%. As indicated in Section 6.4.1, an SRMS of about 5% to 10% is considered to be an indicator of a satisfactory fit to observed levels. The RMS error of 28.8 m is somewhat high, however, is not unacceptable.

Mine Inflows

The comparison between predicted mine inflows and observation during the transient calibration simulation is presented in Section 6.4.3, together with output from the transient validation simulation. Further detail is presented in Appendix K.

Baseflow in Sunnyside Swamp

The comparison between predicted baseflow to Sunnyside Swamp and observation during the transient calibration is presented in Section 6.4.3, together with output from the transient validation simulation. Further details are presented in Appendix K.

Calibrated Values of Hydraulic Parameters

Table 6.10 presents the calibrated values for hydraulic parameters for each model layer.

COSFLOW is based on solution of the Richards Equation. This includes both unsaturated and saturated groundwater flow. As such the porosity and volumetric water content function describe storage characteristics of the groundwater system rather than parameters such as specific yield and specific storage. Further detail of the adopted relationship between capillary suction and volumetric water content, expressed in terms of % saturation, is presented in the CSIRO model report.

Table 6.10: Transient Calibration - Calibrated Values for Hydraulic Conductivity

Unit	Hydrogeological Description	Porosity	Horizontal Permeability (md)	Vertical Permeability (md)	Horizontal Conductivity (m/s)	Vertical Conductivity (m/s)
Weath	Regolith	0.15	200	25	1.9E-06	2.4E-07
AQ6	Sandstone	0.1	25	2.5	2.4E-07	2.4E-08
SP4	Siltstone/Claystone	0.1	1.00E-03	1.00E-03	9.6E-12	9.6E-12
AQ5	Sandstone	0.1	30	2	2.9E-07	1.9E-08
YS6	Claystone	0.1	1.00E-03	1.00E-03	9.6E-12	9.6E-12
AQ4	Sandstone	0.1	30	2	2.9E-07	1.9E-08
SP3	Claystone	0.1	1.00E-02	1.00E-02	9.6E-11	9.6E-11
AQ3	Sandstone	0.1	80	8	7.7E-07	7.7E-08
KAT	Coal	0.1	2.5	2.5	2.4E-08	2.4E-08
SP2	Siltstone/Claystone	0.1	5.00E-05	5.00E-05	4.8E-13	4.8E-13
AQ2	Siltstone/Coal	0.1	80	8	7.7E-07	7.7E-08
SP1	Siltstone/Claystone	0.1	5.00E-06	5.00E-06	4.8E-14	4.8E-14
AQ1	Sandstone	0.05	2	0.5	1.9E-08	4.8E-09
LTH	Coal	0.1	2.5	2.5	2.4E-08	2.4E-08
SP0	Sandstone/Siltstone/ Claystone	0.05	5.00E-02	5.00E-02	4.8E-10	4.8E-10

From Table 6.10, the calibrated values for hydraulic conductivity for sandstone range between $1x10^{-6}$ m/s and $1x10^{-7}$ m/s, with a horizontal to vertical anisotropy of 10:1. The calibrated values for claystone and siltstone layers range between $4.8x10^{-10}$ m/s and $4.8x10^{-14}$ m/s, with a horizontal to vertical anisotropy of 1:1. The calibrated values for claystone and siltstone are low to very low.

From Table 6.10, the calibrated values for porosity for sandstone range from 5% to 10%. The porosity for siltstones and claystones is 10%. The porosity of the weathered layer is 15%.

Table 6.11 presents the calibrated values for the ramp function that represents permeability change associated with longwall mines. The initial values adopted for the ramp function for Bord and Pillar mines, as presented in Table 6.4, were not adjusted during model calibration.

The ramp function is presented in Section 6.2.5 and acts on the horizontal and vertical hydraulic conductivity values in Table 6.12 to modify the calibrated values by multiplying by the ramp value. The ramp value is height dependent. In Table 6.13, the minimum ramp value for horizontal permeability is $10^{0.75}$ = 5.6 and is $10^{0.25}$ = 1.8 for vertical permeability.

Table 6.11: Model Input Parameters – Permeability Change for Longwall Mines (Calibrated)

Material		H_315	h	M_315	m
		Height of Ramp Function (315m wide panel) (m)	Depth below seam floor of permeability change (m)	Maximum value for permeability change (315m wide panel)	Minimum value for permeability change
Aquifer	$P_{vertical}$	230	50	2.1	0.25
	$P_{horizontal}$	230	50	6.2	0.75
Semi-Permeable	$P_{vertical}$	230	50	3.7	0.25
	$P_{horizontal}$	230	50	11.2	0.75

Table 6.14 presents an example of the implementation of the ramp function at location SPR50. It is a simplified example of how the ramp function works and is based on estimated mid-point elevations of the various layers from the borehole log at SPR50. In the model, the ramp function is

implemented in a more sophisticated manner where variable layer elevation heights and layer thicknesses are taken into account.

In addition there is a modification due to consolidation of the goaf, as well as a modification to seepage nodes within excavated areas to account for reduction in permeability and surface area in the mined region as outlined in Section 6.2.5 and 6.3.5.

There are two sets of modified hydraulic conductivities presented in Table 6.14, active permeability and goaf permeability. It is noted that the angle of draw is not considered in the groundwater model. The ramp function is applied directly above the mine footprint. The ramp value for 'active permeability' is applied to model elements immediately after mining up until 80 days after mining. From 80 days after mining until the end of model simulation, the ramp value changes to 'goaf permeability'. The goaf permeability is simply the M_315 parameter multiplied by 0.5, where the 0.5 factor was derived from calibration. As outlined in the CSIRO model report, the temporal variation in ramp value represents consolidation of the goaf following mining.

From Table 6.12, the 'active permeability' values applied to model elements following mining is quite large. For SP1, by way of example, the 'active permeability' ramp value is $1.4\text{x}10^{10}$ horizontally and is 1,100 vertically. This results in a modified value of horizontal hydraulic conductivity for SP1 being $6.6\text{x}10^{-4}$ m/s and the vertical hydraulic conductivity being $5.1\text{x}10^{-11}$ m/s. After 80 days, the modified horizontal hydraulic conductivity of SP1 is $6.7\text{x}10^{-9}$ m/s and the vertical hydraulic conductivity is $1.7\text{x}10^{-12}$ m/s.

The values of the ramp function parameters presented in Table 6.11 are higher than that presented in the calibrated hydrogeological response for Springvale Colliery presented in the ACARP C18016 study. However, the combined effect of the higher ramp value and relatively low calibrated values for hydraulic conductivities of aquitards layers offset each other in the most part, although the ramp function is not applied outside of the defined mining areas.

6.4.3 Transient Validation

A transient validation simulation was also prepared. This simulation encompassed the period 2006 to 2012. During that period, baseflow monitoring at Sunnyside Swamp commenced, including installation of shallow piezometers at the periphery. Also, an extended dataset of mine inflows was obtained. The model predictions are presented with respect to each of these observation datasets.

Baseflow to Swamps

For the period prior to 2006, rainfall recharge to the model was constant; therefore baseflow in Sunnyside Swamp was relatively constant. The variation between 2006 and 2012 reflects the response of the shallow groundwater system to seasonal fluctuation. It is noted that rainfall recharge to the swamp itself was held constant during that time. Observed baseflow in Sunnyside Swamp has been estimated to be 0.0934 ML/day. Baseflow in Sunnyside Swamp has been predicted during model simulation to be 0.1 ML/day and therefore compares favourably.

Based on the calibrated results, through the period 2001 to 2012, no decline in baseflow in Sunnyside Swamp was predicted in the model simulation. This period is associated with continuous mining activity.

Observed shallow groundwater level monitoring data in the vicinity of Sunnyside Swamp and Carne West is presented in Appendix K. The date of these observations is January 2012. The simulated groundwater level at equivalent time is also presented.

From Appendix K, there is reasonable agreement between observed and simulation levels. The RMS error of these observations is quite small in comparison to that of the whole model.

Mine Inflows

Predicted mine inflow against observed data is presented in Appendix K. Observation data exists for the period between 2004 and 2012.

From Appendix K, the observed inflow rate at Springvale is 120 L/s in January 2004 and is about 200 L/s in January 2012. Predicted inflows at equivalent times are 60 L/s and 200 L/s respectively. As noted in the CSIRO model report, there is significant month-to-month variability

Table 6.12: Transient Calibration – Calibrated Values for Hydraulic Conductivity at Example Location, SPR50

Unit	Elevation (m AHD)[a]	Height Above Seam (m)[a]	n[b]	Kh (m/s)	Kv (m/s)	RAMP (Horiz)	RAMP (Vert)	Modified Kh (m/s)	Modified Kv (m/s)	RAMP (Horiz)	RAMP (Vert)	Modified Kh (m/s)	Modified Kv (m/s)
						Active Permeability				**Goaf Permeability**			
Weath	1155	410	0.15	1.9E-06	2.4E-07	5.6	1.8	1.1E-05	4.3E-07	5.6	1.8	1.1E-05	4.3E-07
AQ6	1120	375	0.1	2.4E-07	2.4E-08	5.6	1.8	1.4E-06	4.3E-08	5.6	1.8	1.4E-06	4.3E-08
SP4	1085	340	0.1	9.6E-12	9.6E-12	5.6	1.8	5.4E-11	1.7E-11	5.6	1.8	5.4E-11	1.7E-11
AQ5	1067.5	322.5	0.1	2.9E-07	1.9E-08	5.6	1.8	1.6E-06	3.4E-08	5.6	1.8	1.6E-06	3.4E-08
YS6	1054	309	0.1	9.6E-12	9.6E-12	5.6	1.8	5.4E-11	1.7E-11	5.6	1.8	5.4E-11	1.7E-11
AQ4_Node1	1030	285	0.1	2.9E-07	1.9E-08	5.6	1.8	1.6E-06	3.4E-08	5.6	1.8	1.6E-06	3.4E-08
AQ4_Node2	985	240	0.1	2.9E-07	1.9E-08	5.6	1.8	1.6E-06	3.4E-08	5.6	1.8	1.6E-06	3.4E-08
SP3	950	205	0.1	9.6E-11	9.6E-11	7.7E+01	4.2E+00	7.4E-09	4.1E-10	1.9E+01	2.7E+00	1.8E-09	2.6E-10
AQ3_Node1	915	170	0.1	7.7E-07	7.7E-08	1.5E+02	5.4E+00	1.1E-04	4.2E-07	2.3E+01	2.9E+00	1.8E-05	2.2E-07
AQ3_Node2	890	145	0.1	7.7E-07	7.7E-08	5.8E+02	8.6E+00	4.5E-04	6.6E-07	4.2E+01	3.5E+00	3.2E-05	2.7E-07
AQ3_Node3	865	120	0.1	7.7E-07	7.7E-08	2.3E+03	1.4E+01	1.8E-03	1.1E-06	7.5E+01	4.3E+00	5.8E-05	3.3E-07
KAT	847.1	102.1	0.1	2.4E-08	2.4E-08	6.0E+03	1.9E+01	1.5E-04	4.6E-07	1.1E+02	5.0E+00	2.7E-06	1.2E-07
SP2	844	99	0.1	4.8E-13	4.8E-13	5.0E+06	1.6E+02	2.4E-06	7.9E-11	3.3E+03	1.4E+01	1.6E-09	7.0E-12
AQ2	818.5	73.5	0.1	7.7E-07	7.7E-08	2.9E+04	3.2E+01	2.2E-02	2.5E-06	2.2E+02	6.2E+00	1.7E-04	4.8E-07
SP1	790	45	0.1	4.8E-14	4.8E-14	1.4E+10	1.1E+03	6.6E-04	5.1E-11	1.4E+05	3.4E+01	6.7E-09	1.7E-12
AQ1	762.5	17.5	0.05	1.9E-08	4.8E-09	6.1E+05	9.1E+01	1.2E-02	4.4E-07	8.3E+02	9.8E+00	1.6E-05	4.7E-08
LTH	740	-5	0.1	2.4E-08	2.4E-08	5.6	1.8	1.4E-07	4.3E-08	5.6	1.8	1.4E-07	4.3E-08
SP0	550	-195	0.05	4.8E-10	4.8E-10	1	1	4.8E-10	4.8E-10	1	1	4.8E-10	4.8E-10

a. Midpoint of model layer;

b. n is Porosity.

in mine inflow, however, the rate of increase is well matched.

From Appendix K, the observed inflow rate at Angus Place is about 50 L/s in January 2006 and is about 125 L/s in January 2012. Predicted inflows at equivalent times are 60 L/s and 130 L/s respectively. Again, mine inflows are reasonably matched by model predictions.

Change in Water Storage

Appendix K presents the change in water content within each model layer for the period 1996 through to 2012. The change in water content is calculated based on the difference from the steady-state (pre-mining) water content.

From Appendix K, there is a decrease in water content in the upper weathered layer of 2%, with a distinct change in the rate of change in water content from 2006 to 2012. It is interpreted that this is associated with transient rainfall recharge being applied in the model 2006 to 2012 whereas constant recharge is applied in the period prior to 2006. The rate of change in water content of AQ6 also decreases between 2006 to 2012 compared to pre-2006. The maximum change in water content occurs in SP3 (Mount York Claystone), where the simulated change is 3%.

6.5 Sensitivity Analysis

A number of sensitivity analyses were undertaken during model calibration. This included sensitivity analysis with respect to steady-state (pre-mining) calibration as well as transient calibration (2000-2006).

6.5.1 Steady-State Sensitivity Analysis

The sensitivity of the steady-state calibration was evaluated with respect to:

- Horizontal and Vertical Permeability (0.5 and 2.0 horizontally, 0.1 and 10 vertically)
- Rainfall (85% and 115%)
- ET (0.5 and 2.0 extinction depth, 0.5 and 2.0 ET_{max})
- Riverbed Conductance (0.1 and 10).

The results of sensitivity analyses were presented in the CSIRO modelling report (Appendix K) with respect to calibration statistics, expressed as RMS error, and baseflow to Sunnyside Swamp.

The sensitivity of horizontal and vertical permeability was evaluated individually with respect to each model layer. Analysis indicates the steady-state calibration was insensitive to changes in horizontal and vertical permeability of model layers except for SP3 (MYC) and SP1 (Siltstone/Claystone associated with the Baal Bone/Denman Formation).

For layer SP3, the increase in vertical permeability by a factor of 10 increased the RMS error from 23.09 m to 33.59 m. For layer SP1, the increase in vertical permeability by a factor of 10 increased the RMS error from 23.09 m to 28.02 m.

There was essentially no change in predicted baseflow in Sunnyside Swamp due to changes in horizontal and vertical permeability.

The sensitivity of the steady-state calibration to changes in input parameters for rainfall was found to be negligible with respect to model RMS error. An increase in rainfall recharge to the model of 15%, however, led to an increase in baseflow in Sunnyside Swamp of 12%. A decrease in rainfall of 15% led to a decrease in baseflow in Sunnyside Swamp of 12%.

For ET, an increase in ET_{max} by a factor of 2.0 led to a decrease in predicted baseflow in Sunnyside Swamp of 11%. Similarly, a decrease in ET_{max} by a factor of 0.5 led to an increase in predicted baseflow of 12%. For ET extinction depth, a decrease by a factor of 0.5 led to an increase in baseflow of 23% and for an increase by a factor of 2.0 there was a decrease in baseflow of 10%. Changes to ET_{max} and extinction depth were insensitive with respect to RMS error.

The sensitivity of steady-state calibration to changes in ‘riverbed’ conductance was found to be insensitive with respect to RMS error. An increase in ‘riverbed’ conductance by a factor of 10 led to an increase in baseflow in Sunnyside Swamp of 8%. Conversely, a decrease in riverbed conductance by a factor of 0.1 led to a decrease in baseflow of 36%.

6.5.2 Transient Calibration Sensitivity Analysis

The sensitivity of the transient calibration was evaluated with respect to modification of ramp function parameters as follows:

- Maximum Change in Permeability, *M_315*
- Modification Factor for Panel Width, *a*
- Goaf Permeability Factor, *b*
- Seepage Node conductivity factor, *c*.

The results of sensitivity analyses were evaluated with respect to predicted mine inflows.

Analysis indicates that an increase in *M_315* from 6.2 to 6.3 leads to an increase in mine inflows of 7%. Similarly, a decrease in *M_315* from 6.2 to 6.1 leads to a decrease in mine inflows of 7%. Sensitivity analysis implies that mine inflows are quite sensitive to the adopted maximum change in permeability. This is due, in part, to the calibrated values of hydraulic conductivity for SP layers. It is noted that the maximum change in permeability due to *M_315* values is $\log_{10}$.

Results indicate that mine inflows are sensitive to the modelled value for panel width dependence, '*a'*. Analysis presented in the CSIRO model report indicates that, for Springvale a decrease in 'a' from 0.75 to 0.5 leads to an increase in mine inflow of 4%. Conversely an increase in 'a' from 0.75 to 1.0 leads to a decrease in mine inflow of 5%.

Analysis indicates that the goaf permeability multiplier, '*b*', has a significant effect on mine inflows. The calibrated value of '*b*' is 0.5; however, if '*b*' was 0.8, mine inflow would be 43% higher. This is due mostly because of the large ramp values presented in Table 6.13.

Results indicate that the goaf conductance modification exponent '*c*' is also quite sensitive. The conductance of the seepage boundary condition that represents mine dewatering is calculated based on the permeability of surrounding elements. As outlined in Section 6.3.5, this conductance is modified to account for reduction in permeability and surface area available for water to enter the open mine area due to collapse of the roof following active mining. The calibrated value for the goaf conductance modification exponent, '*c*' is -4. If '*c*' is -2, namely the modification to goaf conductance is 100 times smaller, this leads to an increase in mine inflow of 46%.

In summary, the sensitivity analysis indicates that mine inflows are quite sensitive to the adopted value of the ramp function as a result of its influence on calibrated values of hydraulic conductivity for SP layers, which are quite low.

6.6 Model Prediction

6.6.1 Modelled Scenarios

New Mining – Cumulative Impact

The prediction simulation was executed from January 2012 through to December 2032. Following this, all the mines noted in Section 6.3.5 were assumed to be flooded and groundwater recovery was simulated from December 2032 to 2383.

This simulation accounts for the proposed extension at the Angus Place as well as the proposed extension at the Springvale Colliery (LW416 – LW432, LW501 – LW503).. The simulation therefore accounts for the potential cumulative impact of both projects occurring simultaneously. Other mines, outside of Angus Place and Springvale Collieries are already included in the model simulation.

The prediction simulation is based on:

- Mining at Angus Place is completed: the remainder of LW970 is mined; APLW980, and so on through to APE_19 (December 2032).
- Mining at Springvale is completed: LW415 is mined, and so on through to LW503

(Dewatering is maintained until 2032).

- Mining at Clarence is completed (December 2027).

This simulation is referred to in the CSIRO (2013) model report as "*Base case*" (Appendix K).

New Mining – Springvale Only

A prediction simulation was executed from January 2012 to 2032 as per that above, with recovery simulation from 2032 through to 2383.

The *Springvale Only* case is based on:

- Mining at Angus Place is not completed: mining and dewatering ceases after completion of AP_LW_900_west (May 2015).
- Mining at Springvale as per this proposed Project is completed: LW415 is mined, and so on through to LW503 (February 2025).
- Mining at Clarence is completed (December 2027).

This simulation is referred to in the CSIRO (2013) model report as *"No new APE".*

No New Mining

To allow comparison between the simulations, a no new mining case was developed. Aside from the change to mine plans, all other boundary conditions and model parameters were kept the same.

The *No New Mining* case is based on:

- Mining at Angus Place is not completed: mining and dewatering ceases after completion of AP LW900W (May 2015).
- Mining at Springvale is not completed: mining and dewatering ceases at the end of LW415 (July 2013).
- Mining at Clarence is completed (December 2027).

This simulation is referred to in the CSIRO (2013) model report as "*No new*".

6.6.2 Model Results

Model results are presented initially with respect to modelled change to the groundwater levels within the various aquifers and semi-permeable layers. The predicted mine inflows are then presented. Finally, the modelled change to groundwater contribution to surface water creeks and swamps is presented.

The cumulative change and the change due to the Project only are presented with respect to each of type of model results.

Simulated Groundwater Levels

The predicted groundwater levels in 2013 are presented in Figures 26 to 30 with respect to:

- Lithgow Seam (LTH) (refer Figure 26).
- AQ1 (refer Figure 27).
- AQ3 (refer Figure 28).
- AQ4 (refer Figure 29).
- AQ6 (refer Figure 30).

These groundwater levels represent current conditions prior to commencement of the proposed extension at Angus Place.

The groundwater levels presented in Figures 26 to 30 were calculated from groundwater pressures that were extracted from COSFLOW model. It is noted that only saturated pressures were used. The extents of various aquifers are also presented in Figures 26 to 30 where relevant.

The predicted cumulative change in groundwater pressure (referred to herein as drawdown) is presented in Figures 31 to 40. Results were prepared with respect to: Lithgow Seam (LTH), AQ1, AQ3, AQ4 and AQ6. Model results were generated at the following time-periods:

- At 2015 (2 years after commencement of proposed extension at Springvale).
- At 2020 (7 years after commencement of proposed extension at Springvale).
- At 2026 (end of mining, 13 years after commencement of proposed extension at Springvale).
- At 2083 (70 years after completion of proposed extension at Springvale).
- At 2183 (170 years after completion of proposed extension at Springvale).
- At 2383 (370 years after completion of proposed extension at Springvale).

It is noted that cumulative change in groundwater pressures were calculated based on a difference in groundwater pressure extracted from the COSFLOW model between current conditions in 2013 and future conditions incorporating all neighbouring mines as well as proposed extension at Angus Place as well as Springvale, "New Mining – Cumulative Impact".

Figures 41 to 50 present the change in groundwater pressure due to the Springvale Project only. The predicted change in groundwater pressure were calculated based on the difference in pressure between the "New Mining – Springvale Only" and the "No New Mining" simulations presented above, at equivalent times. The recovery simulations are also presented in Figures 30 to 50.

Time-series water level hydrographs were also prepared. Figure 51 presents the location of these model output locations and the hydrographs are presented in Figure 52 through 54. It is noted that these locations do not correspond to actual piezometer locations; rather they were selected as representative locations above the proposed mining areas.

Time variant hydrograph plots are a useful graphical presentation tool, used to highlight the comparisons in the distribution of response times among sites and between aquifers as a result of an induced stress. The time variant plots presented in this report are simulated responses from the numerical model. They show simulated water level responses as a result of the proposed mining between 2013 and 2023. Simulation of the water levels ends at the year 2093.

Simulated water level fluctuations are observed in all horizons during the mining period. The magnitude of these fluctuations decreases with increasing distance above the Lithgow seam. Furthermore, the magnitude of decline of the water levels in the horizons above the MYC are notably less than those observed from the horizons underlying the MYC and the impacts below the MYC due to inflows to the goaf and fracture zone are not transferred above the MYC.

The water level decline that can be observed above the MYC, particularly in AQ6, is attributed to enhanced horizontal permeability due to bed separation and increased lateral flow of groundwater away from topographically elevated areas.

Increased storage in AQ4 and AQ6 may account for the slight decline in water level from these aquifer units.

As expected, the largest decline in piezometric level is observed in the top of the Lithgow seam. Similarly, the largest recovery in water level is also observed in this horizon. Recovery of this water level commences when Angus Place stops mining. While the water levels in this horizon display the largest decline during the mining period, the simulation shows that this water level returns to above the pre-mining level. (As mining has been ongoing at Springvale for a number of years, the simulated recovery of water level in the Lithgow seam to above that recorded in 2013 more than likely represents the recovery of the water level to natural conditions before monitoring began).

In summary:

- The largest decline is observed in the Lithgow Seam, followed by largest recovery.
- The onset of recovery in Lithgow Seam begins once Angus Place stops mining.
- Large fluctuations in water levels are observed at the base of AQ2 and Base of AQ3 during active mining. These fluctuations recover to natural conditions.
- A small decline simulated in AQ4 and AQ6 during the mining period. Here the water levels do not recover to pre mining levels and may be a result of increased storage in these aquifer

units.

Table 6.16 presents a summary of the results of model prediction simulations.

Table 6.13: Prediction Simulation – Modelled Drawdown

Time Period	Lithgow Seam (LTH)	AQ4	AQ6
2 years after commencement of the Project	Cumulative drawdown is 50m maximum; eastern boundary is 0.5 to 2 m; northern boundary is 0.5 m Isolated drawdown is 50 m maximum; less than 0.5 m on eastern boundary; 2 to 5 m on northern boundary.	Cumulative drawdown is 0.5 m or less. Isolated drawdown is less than 0.5 m.	Cumulative drawdown is 5 m maximum. Isolated drawdown is 5 m maximum and is contained within the Project Application Area.
7 years after commencement of the Project	Cumulative drawdown is 150m at maximum; eastern boundary is 50 to 100 m; northern boundary is 50 to 100 m. Isolated drawdown is less than 150 m; eastern boundary is 50 m; northern boundary is 20 to 50m.	Cumulative drawdown is up to 5 m. Isolated drawdown is less than 0.5 m.	Cumulative drawdown is 10 m maximum. Isolated drawdown is 10 m maximum and is contained within the Project Application Area
End of mining, 13 years after commencement of the Project	Cumulative drawdown is 150m at maximum; eastern boundary is 50 to 100 m; northern boundary is 50 to 100 m. Isolated drawdown is 15 0m at maximum; eastern boundary is 50 to 100 m; northern boundary is 50 m.	Cumulative drawdown is 5m. Isolated drawdown is up to 2m.	Cumulative drawdown is 10m maximum. Isolated drawdown is 10m and is contained within the Project Application Area.
70 years after completion of the Project	Cumulative recovery is 150 m maximum; 50 m at eastern and 50 to 100 m at northern boundary.	Cumulative recovery is 10 m maximum.	Cumulative drawdown is 10 to 15 m within the Project Application Area
170 years after completion of the Project	Cumulative recovery is 200 m maximum; 50 to 100 m at eastern and northern boundary.	Cumulative recovery is 10 m maximum.	Cumulative drawdown is 10 to 15 m within the Project Application Area.
370 years after completion of proposed extension at Angus Place Colliery.	Cumulative recovery is greater than 200 m; 50 to 100 m at eastern and northern boundary.	Cumulative recovery is 1 0m maximum.	Cumulative drawdown is 10 to 15 m within the Project Application Area

It is noted in Figure 31 that the effect of drawdown extends beyond the model boundary. The potential implication of this was evaluated through an additional simulation wherein the fixed pressure boundaries were substituted for seepage boundaries (equivalent to General Head Boundaries in MODFOW). Results indicated no significant difference in the location of the 2 m drawdown contour, therefore completed simulations (based on fixed pressure boundaries) were retained.

Figure 55 presents the location of several cross-sections that are used to illustrate the temporal change in phreatic surfaces (water table in unconfined aquifer). Figure 56 presents the modelled phreatic surfaces through the existing longwall panels at Springvale. Figure 57 presents the modelled phreatic surfaces through the proposed extension at Springvale.

From Figure 56 and 57, model predictions indicate that several phreatic surfaces develop during mining:

- An unsaturated zone develops through the Lithgow Seam (LTH) and AQ1 by the end of mining at 2033, however, does not extend into the SP1 aquitard. The lateral extent of this zone is limited to the footprint of the existing and proposed longwalls. The unsaturated zone is dissipated by 2083.

- An unsaturated zone is predicted to have existed at the top of AQ3 prior to the commencement of mining in the region. There is an expansion of the unsaturated zone by the end of mining at 2033, and decrease during recovery. The unsaturated zone also extends into the base of SP3 (MYC), as discussed in CSIRO (2013). The lateral extent of the unsaturated zone extends westerly beyond the footprint of the proposed longwalls. In Figure 57, the unsaturated zone is dissipated by 2133. In Figure 56, an unsaturated zone remains post-mining.
- An unsaturated zone is predicted to have existed at the top of AQ4 prior to the commencement of mining in the region. The extent of this unsaturated zone is more pronounced in Figure 56 compared to Figure 57. As illustrated in Figure 56, the top of AQ4 is saturated below topographic valleys, in places, however, not in all topographic valleys. During mining, there is minimal change in the extent of the unsaturated zone in Figure 56 and Figure 57.
- An unsaturated zone is also predicted to exist at the top of AQ5 prior to the commencement of mining in the region. The extent of the unsaturated zone is predicted to have also extended into the base of the aquitard SP4. During mining, the extent of the unsaturated zone is predicted to increase slightly and post-mining, the extent remains slightly greater than predicted pre-mining conditions.
- The near-surface water table in AQ6 in Figure 56 and Figure 57 exists at approximately 15 to 30mbgl. In topographic valleys, the near-surface water table coincides with ground level. During mining, the phreatic surface in AQ6 is predicted to decline below topographic ridges, however, there is minimal change in predicted phreatic surface in topographic valleys.

Mine Inflows

Groundwater inflows to the proposed Springvale extension are presented on Figure 58. The plot shows both the predicted instantaneous inflows to the longwall panels as well as cumulative inflows over the life of mining.

Inflows are predicted to range from 137 L/s (11.84 ML/day) at the commencement of mining of LW416 in 2013, increasing steadily to 217 L/s (18.75 ML/day) in mid-2022 during the extraction of LW429. From that time inflows are predicted to tail off again to around 195 L/s (16.85 ML/day) at the end of mining.

The predicted inflows are consistent with observed inflows to the existing Springvale underground which are generally of the order of 150 to 200 L/s (13 to 17 ML/day).

For comparison, inflows are shown for both prediction runs: with Springvale only, and cumulative scenario. The predicted inflows from the two runs match very closely and show no significant differences in inflows over the life of the Springvale extension due to interference drawdown.

Cumulative inflows are predicted to be of the order of 68,700 ML (68.7 GL) over the life of mine, with an average inflow rate of 188 L/s (16.2 ML/day) or 5,900 ML/annum.

The mine water demand is approximately 1.5 ML/day and excess water will need to be disposed of.

Baseflow to Swamps

The predicted baseflow impacts to the swamps are discussed in Section 7.3.3.

Coxs River

The Coxs River was not specifically included in the numerical model; however, as outlined in Section 6.3.3, seepage boundary conditions exist on all surface nodes. As such, baseflow contribution to surface water can be assessed at any surface point in the model. .

To evaluate the potential impact of proposed mining on the Coxs River, the predicted change in groundwater level in surface nodes along the alignment of the River was extracted from the model. A comparison was made between the Springvale only simulation and the simulation with no ongoing mining (“No New Mining”) simulation between 2015 and 2033. Modelling presented in Appendix K indicates that the change in groundwater level between 2015 and 2033 along the alignment of the Coxs River is less than 0.01m (1cm).

Due to configuration of the boundary condition as a ‘seepage’ condition, if the groundwater elevation at the surface node exceeds ground surface level then this water is removed from the model dependent on the model element area and assumed conductance. If there is baseflow contribution to Coxs River, then this is reflected by a decline in groundwater level. It can therefore be asserted that the combined impact of the Angus Place Springvale mine extension projects does not result in a reduction in groundwater contribution at this location.

6.7 Uncertainty Analysis

Uncertainty analysis was run in the model with respect to climate change scenarios.

Climate Change scenarios have been assessed for cumulative impacts (existing and proposed projects). Climate change has been addressed in four scenarios by increasing and decreasing rainfall and evaporation by a value of 15%. The adoption of the 15% variation of rainfall and evaporation has been undertaken following the National Water Commissions report entitled “Climate Change Impact on Groundwater Resources in Australia” (Barron et al, 2011), which identified the annual rainfall as the most important climate parameter. The adoption of these scenarios is discussed further in Appendix K (CSIRO Report).

The effects of climate change will be felt most acutely in features that are strongly influenced by rainfall and at Springvale and Angus Place this will be within the swamp systems. The implication of this is presented in Section 7.3.10.

7. IMPACT ASSESSMENT

This section contains a summary of the potential groundwater related impacts of the Project on the built and natural environment, including the subsequent period of post-mining recovery.

The main effect of the underground longwall mining upon the groundwater regime occurs due to changes in bulk rock mass permeability in the area immediately above the mine, caused by the fracturing associated with subsidence, and the subsequent pumping of groundwater that enters the mine as a consequence. Details of these mechanisms, and the quantification of the effects on rock mass permeability, have been provided in Section 5.3 and Appendix K. Mining related subsidence is also discussed in MSEC (2013). The subsidence induced fracturing, and associated extraction of groundwater via mine dewatering, has a number of effects on the hydrogeological system during mine operations that have been evaluated as part of the impact assessment. These are summarised as follows:

- Impacts on groundwater levels within the Permian hard rock strata (Illawarra Coal Measures) and shallow groundwater during and after completion of mining
- Impacts on watercourses and surface water features in the vicinity of the proposed development during and after completion of mining
- Impacts on existing groundwater users
- Impacts on groundwater dependent ecosystems
- Impacts on water quality – including mine inflows and its management
- Variation of predicted impacts under differing climate change scenarios.

These impacts also have potential to endure long after mining has ceased and the groundwater system rebounds and attains a new equilibrium under the altered hydrogeological regime.

The CSIRO groundwater model, discussed in Section 6 and presented in Appendix K, has been used to predict both the cumulative impacts of the Project with other existing and proposed mining operations, as well as the incremental impacts that are directly attributable to the Project.

In addition to the predictive modelling, the Project Application Area has a long history of mining and a comprehensive network of groundwater and surface water monitoring locations has been established. The observed impacts of past longwall mining activity are presented as verification of the predicted model impacts.

7.1 Current Mining and Observed Impacts

Mining has been ongoing at Springvale since 1995, and as such there is substantial data that can be used to ascertain and quantify past impacts associated with longwall mining and use these observed impacts as a reality check against predicted model impacts that the extension project may have on the environment.

7.1.1 Swamp Water Level Monitoring

The monitoring of swamp water levels is discussed in Section 4.3. A number of the monitored swamp systems, above both Springvale and the neighbouring Angus Place, have already been undermined, including the following:

- West Wolgan Swamp
- Narrow Swamp
- East Wolgan Swamp
- Sunnyside Swamp
- Junction Swamp.

While Sunnyside Swamp at Springvale was not directly undermined by longwall mining, its immediate surrounds to the east, the south and the west have been undermined.

RPS completed a study in November 2012 (RPS, 2012) to assess whether any impacts attributable to the undermining of the swamps could be ascertained based on swamp hydrographs and groundwater level trends. The locations of the swamp monitoring piezometers are presented in Figure 18 and the swamp hydrographs are presented in Appendix E.

All of the swamps which were included in this study have a significant history of water level monitoring, are located away from licensed discharge points (to minimize potential for conflicting information), and have been either undermined by longwall extraction or were in very close proximity to extracted longwall panels (Figure 3). The selected swamps included both groundwater and rainfall dependent swamp types. As such the swamps outlined above are considered to be representative of all swamp types that have potential to be impacted by the proposed mining operations.

The results of the 2012 study showed that no water level impacts that could be attributed to past or present mining operations (subsidence-related impact or depressurisation) were observed. Rather, the water levels in the swamps showed a strong correlation to cumulative rainfall trends, and this was found to be the driving factor. The full report is provided in Appendix B.

7.1.2 Surface Water Gauging

As well as monitoring shallow groundwater levels in the vicinity of the swamps, surface water flows are also monitored at a number of gauging stations (Figure 19). Surface water flows are discussed in more detail in the Springvale Colliery Surface Water Impact Assessment (RPS, 2013).

As with the swamp water levels, trends in the surface water gauging are found to be influenced by climatic trends and seasonal variations. High flows in all the monitoring locations are generally experienced in the months of November and December, whilst periods of low flows are variable from one location to another. No impacts due to longwall extraction and subsidence were observed.

7.2 Subsidence Assessment of Proposed Mining Plan

A subsidence impact assessment has been undertaken for the 'Springvale Mine Extension Project' (MSEC, 2013) and is included in the EIS document.

The proposed mine design at Springvale has been modified to minimise subsidence beneath sensitive shrub swamp areas (refer to Section 9). The panel width at LW416 and LW417 has been reduced from 315 m to 261 m. The width of the inter panel chain pillars has also been increased from 45 m to 58 m. The net result of these modifications is a reduction in subsidence observed at ground surface. The mine subsidence impact assessment has incorporated these modifications.

Mining is predicted to cause maximum of 1.65 m of subsidence above longwall extraction areas. The subsidence is divided into conventional subsidence away from geological structures, and localised increased subsidence in the vicinity of geological structures (presented in brackets below). The predicted maximum cumulative subsidence for the various longwall panels are as follows:

- LW416 to LW423 – 1.2 m (1.45 m)
- LW424 to LW432 – 1.35 m (1.65 m)
- LW501 – 1.35 m
- LW502 and LW503 – 1.65 m.

Based on the predicted maximum strains calculated by the subsidence study it is likely that some shallow fracturing will occur in the uppermost bedrock, beneath the surface soils/regolith. It has been observed in previous studies, that the depth of fracturing and dilation of the uppermost unit, resulting from longwall mining, is generally less than 10 to 15 m (Mills, 2007).

This shallow fracturing will, in general terms, enhance shallow permeability, favouring infiltration of rainfall and surface water to the ground, and recharging the shallow aquifers hence reducing available runoff during rain events. In no case is it expected that the infiltrated water will be lost to deeper aquifers since the fracturing will be only superficial (upper most 10 to 15 m) and disconnected, and is isolated from the deeper zones of connective vertical fracturing (Section 5.3). It is likely that any infiltrated flow will re-emerge to the surface further downstream and with some degree of delay, contributing to prolong the base flow contribution to the watercourses (Mills, 2007). Further, the MYC, at approximately 200mbgl, acts as an impermeable vertical flow boundary preventing leakage to deeper aquifers. Enhanced permeability associated with this shallow fracturing also tends to be short lived, as any surface cracking would tend to be naturally filled with sediment during subsequent flow events.

No reduction in surface flows or shallow groundwater levels resulting from shallow subsidence fracturing are observed as a result of historical longwall extraction at the site. While subsidence is predicted at ground surface, resulting in enhanced shallow permeabilities, direct connective fracturing between the longwall goaf and the perched and shallow groundwater systems are not anticipated, therefore the risk of a significant fracture occurring and affecting swamp water levels and flows is considered unlikely.

Increased inflows from the Deep Groundwater System to the underground workings through connective fracturing in the Collapsed and Fractured Zones will occur, as has been simulated in the groundwater modelling predictions.

For further discussion regarding the potential impacts of subsidence on surface water flows, refer to the Surface Water Impact Assessment (RPS, 2013a).

7.3 Predicted Groundwater Impacts

7.3.1 Predicted Groundwater Levels

Predicted groundwater levels prior to the commencement of mining of the proposed extension (LW416 to LW432, plus LW501 to LW503) are presented on Figures 26 to 30. Water levels are presented at five key horizons that can be used to gauge the propagation of impacts away from the area of active mining as follows:

Deep Groundwater System

- Lithgow Seam - Maximum groundwater impacts in terms of depressurisation and propagation of drawdown are predicted within the mined seam
- AQ1 is located immediately above the Lithgow seam
- AQ3 is located directly below the Mt York Claystone.

Shallow Groundwater System.

- AQ4 is located immediately above the Mt York Claystone and will allow assessment of the propagation of dewatering or depressurisation through this regional confining layer.

Perched Groundwater System

- AQ6 is the uppermost aquifer in the model. The node at the base of AQ6 is also the uppermost consistently saturated node in the vicinity of the project area and is considered to be representative of the water table over most of the modelled area in the vicinity of the proposed development. The base of AQ6 is therefore the layer most relevant to assessing impacts on the swamps and other surface water features. The perched groundwater system that exists within AQ6 (YS1 to YS3) has not been represented in detail in the model as that level of complexity cannot be adequately represented in a regional scale model. Instead the vertical anisotropy has been represented by bulk aquifer parameters. YS4 and YS6 have been included in the model and represent the upper and lower bounds of AQ5.

From the piezometric and water table contours presented on Figures 26 to 30, and with reference to Section 5.2.5, it is apparent that the initial groundwater levels are considerably impacted by current and historical mining operations.

Initial water levels in the Lithgow Seam (Figure 26) are at or near the base of the seam in the active Springvale and Angus Place mining areas. Across the current mining areas water levels are depressed at around 770 to 850 mAHD. Within the proposed extension areas pre-mining water levels reach a maximum of around 910 mAHD in the southern extension area and 930 mAHD in the eastern area. Outside of the influence of existing operations the groundwater gradient is generally to the northeast.

Initial water levels in AQ1 show a similar pattern to those in the Lithgow Seam and are presented on Figure 27. Within the area of past and current mining operations water levels are depressed to 790 to 860 mAHD, with fairly steep hydraulic gradients to the east, south and west. Initial water levels in AQ3 still show the effects of the historical and current mining operations (Figure 28), however, water levels are significantly higher than in AQ1 and the Lithgow Seam. Water levels range from around 940 to 1000 m across the current and proposed mining areas. Water levels in AQ4 (Figure 29) are relatively uniform across the Project Application Area ranging from 1040 to 1080 mAHD. Variations outside these levels appear to be more closely related to topography than with past mining operations. The more uniform water levels across the area of current and proposed mining may be related to relatively uniform elevation of the plateau in that area.

Initial shallow water levels for AQ6 in the Shallow Groundwater System are presented on Figure 30. Initial water levels range from 1060 to 1100 mAHD. The water level contours and flow directions are closely constrained by topography. No mining related impacts are evident.

It is noted that at the top of some of the aquifer units the aquifers are unsaturated in places, in these areas the lack of continuous saturation means that the various units become hydraulically disconnected.

7.3.2 Predicted Drawdown

Predicted drawdown at the end of mining at Springvale are discussed in detail in Section 6.6.2 and are summarised on Table 6.13. Plots of groundwater drawdown are presented on Figure 31 to 40. The drawdown includes the cumulative impacts of all concurrent approved and proposed (Springvale plus Angus Place) mining operations in the vicinity of Springvale.

The isolated or incremental drawdown due to the proposed Project only is shown on Figures 41 to 50. The incremental drawdown attributable to the proposed longwalls only have been derived from the difference between prediction runs with Springvale longwalls and prediction runs without Springvale longwalls.

The predicted drawdown in groundwater levels under the various simulated scenarios will have corresponding impacts on the built and natural environment. Particularly groundwater interaction with surface water flow (baseflow), groundwater dependent ecosystems, and other groundwater users. The predicted impacts resulting from groundwater drawdown are discussed in the following sections.

There are 114 registered groundwater bores identified within a 10 km radius of the Springvale and Angus Place Collieries. Figure 18 presents the locations of these groundwater bores.

The predicted cumulative drawdown at each of these groundwater bores is presented in Table 7.1. The cumulative drawdown includes the impact of neighbouring mines as well as the proposed longwalls at Angus Place and Springvale.

From Table 7.1, the predicted impact at each of the identified surrounding groundwater works is less than 2 m at the end of mining, except for nine bores (as shown in bold). From Table 7.1, model predictions indicate recovery of groundwater levels by 2083 at all locations.

The nine bores with a predicted cumulative impact of more than 2 m at the end of mining have a drilled depth of more than 120mbgl. Review of the PINNEENA database indicates that:

- GW105734 is a dewatering well (no screen information in PINNEENA)
- GW102728 is an exploration borehole (no screen information in PINNEENA).
- GW108187 is a monitoring piezometer (screened between 30 and 197mbgl).
- GW109766 is a monitoring piezometer (no screen information in PINNEENA, potentially a VWP).
- GW109783 is a monitoring piezometer (no casing details in PINNEENA, potentially a VWP).
- GW109767 is a monitoring piezometer (no screen information in PINNEENA, potential a VWP).
- GW108185 is a monitoring piezometer (screened from 0 to 295mbgl, potentially a VWP).

- GW109336 is a monitoring piezometer or dewatering well (screened between 313.5 and 319.5mbgl).
- GW109337 is a dewatering well or exploration borehole (no screen information in PINNEENA).

As such, none of the identified impacted works are utilised for water supply purposes for non-mining applications and as such the predicted impacts are not considered significant.

Table 7.1: Prediction Simulation – Cumulative Drawdown at Groundwater Works

Name	Depth (m)	Easting (m)	Northing (m)	Cumulative Drawdown (m) – 2033	Cumulative Drawdown (m) – 2083	Cumulative Drawdown (m) – 2233
GW110706	1.1	242424	6295519	-0.1	-0.1	-0.1
GW110707	1.4	242590	6295589	-0.2	-0.2	-0.2
GW110704	1.6	241550	6296992	0.1	0.1	0.1
GW110705	1.7	241839	6297076	0.0	0.0	-0.1
GW101299	3.8	233679	6294345	-0.1	-0.2	-0.2
GW100625	4.1	236219	6297109	-0.1	-0.1	-0.1
GW101294	4.3	233679	6294345	-0.1	-0.2	-0.2
GW067397	4.5	237222	6292575	-0.1	-0.1	-0.2
GW067395	5	237153	6292819	-0.1	-0.1	-0.2
GW011892	5.4	232547	6296341	0.0	0.0	0.0
GW067398	5.5	237283	6292515	-0.1	-0.1	-0.2
GW101293	5.9	233679	6294345	-0.1	-0.2	-0.2
GW067396	6	237158	6292750	-0.1	-0.2	-0.2
GW100627	6	236219	6297109	0.0	0.0	0.0
GW100628	6	236219	6297108	-0.1	-0.1	-0.1
GW100629	6	236219	6297109	-0.1	-0.1	-0.1
GW100638	6	236219	6297109	0.0	0.0	0.0
GW101297	6	233679	6294345	-0.1	-0.2	-0.2
GW109263	6	230188	6302354	0.5	-3.7	-3.8
GW101301	6.8	233679	6294345	-0.1	-0.2	-0.2
GW067399	7	237310	6292626	-0.1	-0.1	-0.2
GW101292	7.2	233679	6294345	-0.1	-0.2	-0.2
GW103224	7.6	238275	6293738	0.0	-0.3	-0.4
GW100632	9	236219	6297109	0.0	0.0	0.0
GW100633	9	236219	6297109	0.0	0.0	0.0
GW101302	9	233679	6294345	-0.1	-0.2	-0.2
GW109260	9	231949	6301451	0.2	0.2	0.0
GW100631	10.5	236219	6297109	0.0	0.0	0.0
GW100639	10.5	236219	6297109	0.0	0.0	0.0
GW103223	10.5	238309	6293688	0.0	-0.3	-0.4
GW100636	11	236219	6297109	0.0	0.0	0.0
GW101303	11	233679	6294345	-0.1	-0.2	-0.2
GW101300	11.8	233679	6294345	-0.1	-0.2	-0.2
GW100626	12	236218	6297109	0.0	0.0	0.0

Name	Depth (m)	Easting (m)	Northing (m)	Cumulative Drawdown (m) – 2033	Cumulative Drawdown (m) – 2083	Cumulative Drawdown (m) – 2233
GW100637	12	236219	6297109	0.0	0.0	0.0
GW101295	12	233679	6294345	-0.1	-0.2	-0.2
GW110162	12	228445	6304250	0.0	0.0	0.0
GW110480	13	229530	6301968	0.0	0.0	0.0
GW100634	13.8	236219	6297109	0.0	0.0	0.0
GW109264	14.3	229631	6302170	0.1	-0.1	-0.1
GW109265	14.9	229380	6301983	0.0	0.0	0.0
GW060428	15	231162	6296889	0.0	0.0	0.0
GW055053	15.2	232063	6295156	0.0	0.0	0.0
GW100718	15.2	236219	6297108	0.0	0.0	0.0
GW110481	15.8	229166	6301605	-0.1	-0.1	-0.1
GW100635	16	236219	6297109	-0.1	-0.1	-0.1
GW105294	16	230337	6307811	0.1	0.0	0.0
GW105295	16	230239	6307853	0.1	0.0	0.0
GW104218	17.3	234134	6292824	-0.4	-1.0	-1.0
GW109262	17.4	230234	6301697	0.0	0.0	0.0
GW101304	18	233679	6294345	-0.1	-0.2	-0.2
GW109261	18	229804	6301348	-0.1	-0.1	-0.1
GW054416	18.3	237937	6293005	0.0	0.0	0.0
GW057399	18.3	231850	6296322	0.1	0.1	0.1
GW053081	18.6	232056	6295434	0.1	0.1	0.1
GW100630	21	236219	6297109	-0.1	-0.1	-0.1
GW110483	21	229149	6303041	0.1	-0.1	-0.1
GW055055	21.3	232064	6296050	0.0	0.0	0.0
GW072713	21.3	228517	6302704	0.0	0.0	0.0
GW104220	21.3	234173	6292798	-0.5	-1.1	-1.1
GW047900	21.9	236486	6292225	0.0	0.0	0.0
GW101296	23.2	233679	6294345	-0.1	-0.2	-0.2
GW110161	27.5	228450	6304254	0.0	0.0	0.0
GW101985	30	242017	6296554	-0.1	-0.1	-0.1
GW106646	30	243458	6294098	0.0	-0.2	-0.4
GW057365	30.5	232726	6296408	0.0	0.0	0.0
GW058108	30.5	232570	6296465	0.0	0.0	0.0
GW060112	31.4	232058	6294416	0.0	0.0	0.0
GW110482	33	229153	6303045	0.1	-0.1	-0.1
GW058554	33.5	232465	6296524	0.0	0.0	0.0
GW054781	38.1	232468	6296401	-0.1	-0.1	-0.1
GW102428	38.1	232196	6294111	-0.1	-0.1	-0.1
GW104221	38.6	234133	6292824	-0.4	-1.0	-1.0
GW072919	40	238298	6293735	0.0	-0.5	-0.6
GW109845	42	243780	6293856	0.0	-0.3	-0.4
GW101461	45	228708	6301415	0.0	0.0	0.0

Name	Depth (m)	Easting (m)	Northing (m)	Cumulative Drawdown (m) – 2033	Cumulative Drawdown (m) – 2083	Cumulative Drawdown (m) – 2233
GW050996	45.7	230232	6299638	0.0	0.0	0.0
GW107329	48	230020	6307333	0.2	-2.7	-3.5
GW068505	48.8	237290	6292088	-0.1	-0.1	-0.1
GW100967	50	232631	6294136	0.0	0.0	0.0
GW109307	55	237496	6292948	0.0	0.3	0.3
GW062815	56.7	228910	6302101	-0.1	-0.1	-0.1
GW053046	58.5	229846	6306997	0.2	-1.5	-1.9
GW110484	59	229722	6302884	1.1	-13.1	-13.3
GW109844	60	243657	6293783	-0.1	-0.4	-0.6
GW110485	66.6	229732	6301994	0.0	-0.3	-0.3
GW102427	68.5	231521	6299797	0.0	0.0	-0.2
GW103238	68.5	231463	6299286	0.2	0.2	0.2
GW039443	70	231952	6297312	0.2	0.2	0.2
GW102426	70	231546	6299829	0.0	0.0	-0.2
GW105433	72	238303	6293824	0.0	-3.1	-3.4
GW105434	72	238319	6293795	0.0	-2.7	-2.9
GW105435	72	238313	6293760	0.0	-2.5	-2.7
GW109842	72	243605	6293745	-0.1	-0.4	-0.6
GW109843	72	243684	6293872	0.0	-0.4	-0.6
GW109022	78	241744	6293080	0.2	-1.1	-1.6
GW058348	99.3	236477	6292534	0.3	0.3	0.3
GW105064	104	230354	6307750	0.4	-10.0	-12.8
GW105734	120	244009	6294415	**3.6**	-21.3	-28.5
GW030862	146	232011	6305423	0.7	-1.2	-9.5
GW102728	156.5	244489	6294414	**3.1**	-24.8	-30.7
GW108187	197	245529	6295851	**3.8**	-33.3	-37.2
GW109766	258	246343	6299273	**15.4**	-1.5	-2.3
GW109783	271.9	242072	6293481	**3.9**	-7.3	-14.5
GW109767	273.6	242638	6296368	**13.1**	-20.3	-29.6
GW108185	295	246570	6301610	**6.8**	-2.4	-24.9
GW109336	319.5	237342	6296562	**22.5**	-17.7	-27.7
GW109337	400	237489	6300778	**24.4**	-101.7	-124.6

7.3.3 Predicted Baseflow Impacts

Baseflow impacts have been determined for a number of priority swamps and creeks, as shown in Figure 20 of the CSIRO report (Appendix K). The focus has been placed on swamps and creeks that either directly overlie the proposed longwalls or are in close proximity to them.

Three of the Newnes Plateau Shrub Swamps are listed as protected under the Federal Environment Protection and Biodiversity Act 1999, these are; *East Wolgan Swamp, Narrow Swamp* and *West Wolgan Swamp*. As these swamps have already been undermined by the current approved longwall operations at Springvale and Angus Place, they have not been specifically included in the modelling assessment. However, all three swamps are part of the regular swamp monitoring and have been shown to have not been impacted by mining.

The creeks and swamps that have been represented in the model are presented on Table 6.7. Of these swamps those which directly overlie or are immediately adjacent to the proposed Springvale longwalls are:

- Carne West Swamp
- Carne Creek (reaches 1 to 5)
- Gang Gang Swamp South
- Gang Gang Swamp East
- Nine Mile Swamp
- Pine Swamp
- Paddy's Creek
- Marrangaroo Creek
- Sunnyside Swamp.

The locations of these swamps are presented on Figure 6.

Potential impacts to Coxs River have been determined by the change in groundwater levels along the line of the river, as discussed in Section 6.6.

Potential baseflow impacts on surface water features within the Project Application Area are associated with subsidence related fracturing and bed separation, which can result in enhanced shallow permeability and lowering of shallow groundwater levels. This has been simulated in the model by applying elevated horizontal permeability in accordance with the ramp function as discussed in Section 6.2.5. Reduced groundwater levels result in reduced groundwater discharge (baseflow) to the surface water features. Given the large depth of cover at Springvale, no direct connective cracking with the goaf (the surface fracturing is only superficial, 10-15 m depth), or subsequent draining or dewatering of surface water features is expected.

Predicted baseflows are presented on Figures 59 to 63, for each surface water feature listed above, three plots are presented. The scenario nomenclature has been kept consistent with that used in the CSIRO modelling for ease of cross-referencing with the modelling report. The scenarios presented are as follows:

- *No New Projects* – this scenario predicts baseflow in the surface water features assuming that all approved projects are completed and no new projects (neither Springvale nor Angus Place extension projects) are implemented. This scenario represents the baseline against which potential impacts can be assessed.
- *Springvale Only* (No New APE) - this scenario predicts baseflow in the surface water features assuming that all approved projects are completed and that the Springvale extension only is implemented. This scenario assesses the baseflow impacts that are attributed to the Springvale extension only.
- *Cumulative* (Base Case) – this scenario predicts baseflow in the surface water features assuming that all approved and proposed projects are completed. The scenario assesses cumulative baseflow impacts from both the Springvale and Angus Place extensions.

Predicted baseflows are presented for both mining and post mining periods. Predicted baseflows are presented for both mining and post mining periods. It is noted, however, that predicted changes to very small groundwater contributions lead to a large % change; however, obviously, if modelled groundwater contribution is low for a particular swamp or surface watercourse then the surface feature is not particularly groundwater dependent. It is highlighted that the majority of the predicted change to baseflow is due to conservative assumption in regard to RAMP function being applied through to ground surface. Modelled baseflow impacts, of either decreasing or increasing baseflow, are not supported by extensive historical observation record.

Carne West Swamp

Carne West Swamp location is shown on Figure 6 and lies above proposed longwalls LW417 and LW418. Carne West is a Type A Shrub Swamp in its upper reaches and a Type C swamp in the lower reach, the swamp discharges to the northeast to Carne Creek. Predicted baseflows for

Carne West Swamp are shown on Figure 59. Under the No New scenario Carne West Swamp is a gaining swamp and baseflow contributions are predicted to remain relatively consistent at around 0.02 ML/day.

As the swamp is undermined by the Springvale longwall panels, the associated increase in horizontal conductivity in the shallow aquifer due to bed separation results in increased groundwater flow to the swamp driven by the higher heads in the surrounding aquifer than are present in the swamp. If groundwater levels were below the level of the swamp then the opposite response would be observed, with the increased hydraulic conductivity resulting in increased leakage from the swamp. The predicted increase happens very rapidly in two increments that coincide with the extraction of longwall panels LW417 and LW418.

Groundwater contribution to baseflow is predicted to increase to around 0.086 ML/day at the start of 2015 following the passing of the two longwall panels. Following this increase there is a gradual regression with predicted baseflows remaining above 0.05 ML/day at the end of mining, a residual increase of 155% from predicted baseline conditions at the same time. No significant variation is observed between the Springvale only (No New APE) and cumulative (Base Case) scenarios.

Overall the predicted impact at Carne West Swamp is a positive increase in baseflow.

Post mining the baseflows are predicted to stabilise at around 0.0409 ML/day, around double the predicted baseline value of 0.02 ML/day.

Carne Creek (reaches 1 to 5)

Carne Creek has been divided into a number of reaches for the purposes of this assessment.

CA1 is the Carne Creek main branch, this branch of the creek lies to the east of all proposed developments and flows south to north (Figure 4). Branches CA3 to CA5 ultimately discharge to CA1 via CA2. CA2 likewise, is located to the east of the proposed longwalls and is not under mined by any existing or proposed operations. Direction of flow is from south to north. Branch CA3 connects Gang Gang Swamp South and Gang Gang Swamp South East and drains northeast to CA2. The upper portion of CA3 overlies LW 422. Reach CA4 connects Carne West Swamp with CA2, draining to the northeast. CA4 overlies or is in close proximity to longwalls LW419 to LW422. Reach CA5 is the western branch of Carne Creek. CA5 runs across longwalls LW415 to LW419 and drains northeast to CA2.

Under baseline conditions, all of the Carne Creek Reaches are predicted to be gaining streams.

Reach CA1 (Figure 60)

Reach CA1 of Carne Creek shows average baseline baseflow value of the order of 4.64 ML/day over the duration of mining at Springvale. Predicted baseflows under the No New APE scenario decline below baseline predictions from around 1/5/2014 after the completion of LW416. Flows continue to gradually decline until the completion of LW423 and remain at around 0.0312 ML/day below the baseline values. Following the end of mining at the Clarence Bord and Pillar operation there is a noticeable recovery of baseflow levels in both the No New and No New APE scenarios.

Cumulative baseflow impacts show an even greater decline in predicted baseflow. The cumulative baseflow shows significant variation but at the end of mining at Springvale is approximately 0.1 ML/day below the baseline value, showing that approximately 30% of the baseflow reduction is attributable to the Springvale extension. Baseflow in the cumulative (Base Case) scenario begins to show a recovery following the completion of the Angus Place extension.

Post mining baseflows are predicted to recover to slightly above baseline values. [Note – basecase rebounds to well above baseline – need to check data/model inputs in subsequent report revisions].

Reach CA2 (Figure 61)

Reach CA2 displays a very similar response to CA1. Baseline baseflow predictions have an average of 1.156 ML/day during the proposed Springvale development, increasing to over 1.2 ML/day following the completion of the Clarence Bord and Pillar Operation.

Baseflow predictions for the Springvale extension (No New APE scenario) show a decline from baseline values from the commencement of the Springvale extension until the end of LW423 in

May 2018. Following this, the predicted baseflow remains at around 0.08 to 0.09 ML/day below the baseline value.

Increased baseflow reduction under the cumulative (Base Case) scenario, results in a decline to around 0.96 ML/day at the end of mining at Springvale, or around 0.2 ML/day below baseline predictions, approximately 44% of which is attributable to the Springvale extension.

Post mine the Springvale only scenario rebounds to approximately 0.067 ML/day above the predicted baseline value of 1.332 ML/day. Under the cumulative scenario predicted baseflows remain below the baseline.

Reach CA3 (Figure 62)

Reach CA3 displays significantly less baseflow contribution than CA1 and CA3, although it is also considerably smaller. Baseline baseflow predictions range from around 0.0452 to 0.0465 ML/ day over the period of Springvale extension extraction.

Baseflow predictions for the Springvale extension show a significant increase in baseflow coinciding with the extraction of LW422, and to a lesser extent with LW421. Predicted baseflow increases more than 2-fold to 0.164 ML/day from November 2016 to August 2018, and then continues to increase at a more subdued rate throughout the remainder of the Project. At the end of mining the predicted baseflow to Reach CA3 is at around 0.182 ML/day, more than three times greater than the baseline prediction at the same point in time. As discussed for Carne West Swamp, the predicted increase in baseflow is a result of increased horizontal hydraulic conductivity in the shallow aquifer allowing greater volumes of groundwater to discharge to the swamps where the predicted groundwater heads are above the heads in the swamp.

Overall the predicted impact at Reach CA3 of Carne Creek is a positive increase in baseflow of around 0.1346 ML/day. At the end of mining at Springvale there is no discernible difference between the Cumulative and Springvale only scenarios, indicating that the entire impact may be attributed to the Springvale extension.

Post mining baseflows are predicted remain well above the predicted baseline values at around 0.196 ML/day, approximately 0.147 ML/day above the predicted baseline value.

Reach CA4 (Figure 63)

Reach CA4 shows a similar response to Reach CA3 but the response is more subdued. Baseline predictions (No New Scenario) show a gradual increase in baseflow of 0.194 to 0.198 ML/day over the period of proposed mining.

Under the Springvale (No New APE) extraction scenario, predicted baseflows follow baseline predictions and show a series of three increases, concurrent with the commencement of longwalls LW419, LW420 and LW421, from November 2015 to January 2017. There is an initial rapid increase to around 0.234 ML/day which is followed by a more gradual increase over the remainder of mining to 0.251 ML/day. This represents an increase of 0.0536 ML/day over the baseline prediction at that time.

Overall the predicted impact on Reach CA4 of Carne Creek is a positive increase in baseflow of around 0.0536 ML/day increasing to around 0.066 ML/day post mining. At the end of mining at Springvale there is no discernible difference between the Cumulative and Springvale only scenarios, indicating that the entire impact may be attributed to the Springvale extension.

Reach CA5 (Figure 63)

The predicted baseline baseflows at Reach CA5 are initially stable at around 0.258 to 0.260 ML/day, baseline values then decline steadily to around 0.232 ML/day at the end of mining at the Clarence Colliery. Following the completion of the Clarence Bord and Pillar operation there is a slight recovery in baseflows to around 0.236 ML/day, after which they remain relatively stable.

Predicted baseflow impacts due to the Springvale extension commence immediately with the extraction of LW416. Baseflows increase to around 0.340 ML/day followed by a decline to 0.268 ML/day, at which point there is another increase in baseflow associated with the commencement of LW419 in November 2015, this time to around 0.308 ML/day. Following this time, the predicted baseflow declines over the remainder of the Springvale mining operation. The predicted baseflow values drop below the baseline level of around 0.255 ML/day during 2017 and by the end of mining have declined to around 0.120 ML/day.

Under the cumulative prediction scenario (Base Case), a sharp drop in baseflow is observed at the commencement of the Angus Place extension, this drop is subsequently masked by an increase in baseflow due to mining of LW419 at Springvale. The rate of baseflow decline is greater along Reach CA5 under the cumulative scenario and by the end mining at Springvale baseflows have declined to 0.0771 ML/day. More than 70% of the cumulative decline is attributable to Springvale.

Post mining baseflows are predicted to recover but still remain below the predicted baseline values by around 0.05 ML/day. Predicted baseflows under the cumulative scenario remain even lower at around 0.195 ML/day.

Gang Gang Swamp South

Gang Gang Swamp South location is shown on Figure 6, the swamp lies above proposed longwalls LW420, LW421 and LW422. Gang Gang Swamp South is a Type C shrub swamp and discharges to the northeast to Reach CA3 of Carne Creek. Predicted baseflows for the swamp are shown on Figure 63. Under the baseline (No New) scenario Gang Gang Swamp South is a losing swamp with negative baseflow (leakage) of the order of -0.055 ML/day.

Predicted baseflow impacts due to the Springvale extension occur with the commencement of LW420. Following the extraction of LW420, Gang Gang Swamp South changes from a losing swamp at -0.055 ML/day to a gaining swamp at 0.048 ML/day, an increase of 0.103 ML/day. Following this point there is steady regression of baseflow. During 2018 the swamp is predicted to revert back to a losing system, and by the end of mining the swamp is predicted to have a negative baseflow (leakage) of -0.058 ML/day, slightly less than the relevant baseline value of -0.055 ML/day.

Overall the net impact is positive in terms of increased baseflow, however at the end of mining there is predicted to be reduced baseflow to the swamp. At the end of mining at Springvale there is no discernible difference between the Cumulative and Springvale only predicted baseflows for Gang Gang Swamp South, indicating that the entire impact may be attributed to the Springvale extension.

Post mining Gang Gang Swamp South remains a losing swamp but recovers to slightly greater baseflow than the baseline predictions.

Gang Gang Swamp Southeast

Gang Gang Swamp Southeast location is shown on Figure 6, the swamp lies above proposed longwalls LW420, and LW421. Gang Gang Swamp Southeast discharges to the northeast to Reach CA3 of Carne Creek. Predicted baseflows for the swamp are shown on Figure 63. Under the baseline (No New) scenario Gang Gang Swamp East is a losing swamp with negative baseflow (leakage) of the order of -0.055 ML/day.

Under the Springvale extraction (No New APE) scenario, there is a slight reduction in leakage from the swamp associated with the mining of LW420, although there is an increase in groundwater flow to the swamp the net result is still negative with baseflow losses reducing from -0.052 to -0.029ML/day. Following this baseflows regress towards baseline values until the start of extraction of LW422 in August 2017. Following the commencement of LW422 there is a significant increase in leakage (negative baseflow) which gradually diminishes towards the end of mining. At the end of mining at Springvale, baseflows have declined by more than three orders of magnitude to around -0.185 ML/day, 0.141 ML/day below the equivalent baseline value of -0.044 ML/day.

Under the cumulative (Base Case) scenario there is no significant difference between predicted baseflows at the end of mining.

Post mining Gang Gang Swamp Southeast is predicted to remain significantly below baseline predictions by approximately 0.15 ML/day.

Nine Mile Swamp

Nine Mile Swamp is located to the east of the proposed Springvale and Springvale South longwall panels (Figure 7), but is not directly undermined by either. The upper reach of the swamp is undermined by the underground development heading. Nine Mile Swamp drains to the east at the confluence with Pine Swamp. Predicted baseflows for the swamp are shown on Figure 69.

Under the predicted baseline (No New) scenario, Nine Mile Swamp is predicted to be a gaining swamp with a groundwater contribution of around 0.0135 ML/day at the commencement of the Springvale extraction. Baseline baseflow values then gradually increase to the end of mining at SPC to a value of 0.015 ML/day.

Under the Springvale extraction (No New APE) scenario baseflow are predicted to increase above baseline levels following the commencement of LW424 extraction in July 2018 to a maximum of approximately 0.0169 ML/day in 2022, after which they start to gradually decline. At the end of mining at Springvale baseflows are predicted to be 0.0168 ML/day, a total of 0.0017 ML/day greater than baseline predictions.

At the end of mining there is no significant variation between the Springvale extraction and Cumulative model predictions.

Post mining baseflows are predicted to remain marginally above the predicted baseline value of 0.016ML/day.

Pine Swamp

Pine Swamp is located above Springvale southern longwall panels LW424, LW425 and LW426 (Figure 6). Pine Swamp drains to the northeast. Predicted baseflows for the swamp are shown on Figure 66. Baseline baseflow values from the No New prediction scenario range from 0.0884 to 0.0896 ML/day and remain relatively constant.

From the Springvale prediction scenario (No New AP) it is evident that predicted baseflow significantly increases during the extraction of longwalls LW424, LW425 and LW426. The predicted increase happens very rapidly in three increments that coincide with the commencement of the longwall panels. The maximum predicted increase is to around 0.229 ML/day after the start of LW426. Following this increase there is then a steady decline to around 0.2 ML/day at the end of mining where predicted baseflows remain well above the baseline value of 0.090 ML/day. The overall impact on baseflows at end of mining is positive.

From the Base Case scenario there is no indication of cumulative impacts with the proposed Angus Place extension.

Post mining the baseflows are predicted to remain at around 0.06 ML/day above the predicted baseline value.

Paddys Creek

Paddys Creek is located along the southeastern margin of the proposed Springvale southern longwalls (Figure 6) and drain to the northeast. Predicted baseflows are shown on Figure 66.

Baseline baseflow prediction from the No New scenario shows Paddys Creek to be a gaining stream with a baseflow contribution of around 0.1641 to 0.1645 ML/day. Under the no new scenario there is a slight decline in baseflow from 2023 to 2028, followed by a recovery to above 2013 levels following the completion of mining at the Clarence Colliery. This indicates the influence that the Clarence Colliery has on baseflows in Paddy's Creek.

Under the Springvale prediction (No New APE) scenario there is a gradual decline in predicted baseflow from 0.1642 ML/day at the commencement of the Springvale extension, to around 0.1632 ML/day prior to LW424 extraction. A sequence of drops and rises occur associated with the extraction of LW424, LW425 and LW426. At the end of mining there is a very minor reduction in baseflow of around 0.0014 ML/day that is attributable to the Springvale extension.

At the end of mining at Springvale there is no material difference in baseflow predictions between the Springvale extraction and cumulative extraction scenarios.

Post mining baseflows are predicted to rebound to above the predicted baseline value by around 0.01 ML/day.

Marrangaroo Creek

Marangaroo Creek starts above longwall panel LW429 in the Springvale southern area, then crosses above LW430 and runs above the end of longwalls LW431 and LW432 before draining to the southwest (Figure 6). Baseflow predictions are presented on Figure 70. Under baseline baseflow predictions (No New scenario) Marrangaroo Creek is a gaining stream with a relatively uniform baseflow contribution averaging 0.775 ML/day during the Springvale extraction period. Following the completion of mining operation at Clarence Colliery there is a gradual recovery (increase) in baseflow.

Following the commencement of extraction of the Springvale extension longwall panels under the Springvale mining scenario (No New APE) there is a gradual decline in predicted baseflow rates to a low of around 0.703 ML/day in 2022. Following this there is a slight recovery towards the end of Springvale extraction with a predicted baseflow of around 0.736 ML/day at the end of mining, equivalent to a decline of 0.042 ML/day from predicted baseline values.

Until the end of mining at Springvale, there is no substantial difference between the Springvale extraction and the cumulating model scenarios. Post mining however, predicted baseflow rates start to decline again with the cumulative scenario declining at a marginally greater rate than the Springvale extraction scenario.

Post mining baseflows are predicted to continue a slight decline and then rebound. Long term baseflows remain approximately 0.027 ML/day below the predicted baseline value.

Sunnyside Swamp

Sunnyside Swamp is located between the approved Springvale longwall panels LW413A and LW415. Longwall mining was stepped around the swamp, and the swamp is not undermined by any approved or proposed longwalls (Figure 6). Sunnyside Swamp is a Type C Shrub Swamp, and drains northwards into the Wolgan River. Predicted baseflows are presented on Figure 70.

Under baseline predictions (No New Scenario), baseflows in Sunnyside swamp show a minor increase until 2016 when they start to decline, and continue declining beyond the end of the propose Springvale extension. During the period of the Springvale extension longwall extraction, predicted baseline baseflow values range from 0.110 to 0.107 ML/day.

Under the Springvale extraction predictions (No New APE scenario) predicted baseflow follows a similar trend to the baseline prediction, however, the decline post 2016 is greater and at the end of mining baseflow is predicted at around 0.105 ML/day. The predicted baseflow impact at end of mining is a decline of 0.001 ML/day.

During the period of Springvale extraction, there is no significant difference, between the Springvale extraction and Cumulative extraction scenarios.

Long term baseflows post mining are predicted to remain marginally below the predicted baseline value.

Coxs River

Impacts to Coxs River have been determined in the model by assessing the change in head at nodes along the alignment of the river. The comparison shows that between 2015 and 2033, along the alignment of the Coxs River the decline in shallow water level is predicted to be less than 0.01 m. Therefore no significant changes to existing groundwater/surface water interactions will be induced.

The maximum extent of predicted drawdown at end of mining is presented in Figures 39, 41, 49 and 51 for both isolated and cumulative drawdown within the Lithgow Seam and in AQ1. In all cases these impacts are not predicted to reach the Coxs River, and consequently no baseflow loss or loss of surface flow will be induced at Coxs River.

No predicted impacts on baseflow to creeks within the Coxs River catchment are predicted due to the proposed extension at Springvale.

Baseflow Impacts Summary

The predicted impacts on baseflows as a result of longwall extraction at Springvale are varied. Predicted impacts range from positive (increased baseflow, or reduced net leakage) to negative (decreased baseflow, or increased leakage). As previously discussed the predicted increased baseflow as a result of the undermining by a longwall results from bed separation effects and enhanced horizontal permeability, which allows increased groundwater flow to the swamp or creek.

This effect only occurs where the shallow water table is naturally above the level of the swamp. Where the water table is below the level of the swamp the increased permeability will result in increased leakage from the swamp.

The magnitudes of the predicted impacts are summarised on Table 7.1. This table compares the difference between baseline baseflow predictions (No New Scenario) and Springvale only predictions (No New APE Scenario) for the respective time period. In most instances the impacts increase towards the end of mining or remain relatively constant, where there is a significant impact identified prior to end of mining, these have been identified as the maximum predicted impact (e.g. Carne West Swamp, Gang Gang Swamp South and Marrangaroo Creek, Table 7.1).

Losses of baseflow in terms of volume for water accounting purposes are discussed separately in Section 8.

Of the creeks that have been included in predictive modelling, Paddys Creek, Marrangaroo Creek and three reaches of Carne Creek (CA1, CA2 and CA5) are predicted to have a decline in baseflows at the end of mining. The predicted declines at Paddy's Creek, Marrangaroo Creek and Reach CA1 and CA2 of Carne Creek are less than 7.6% compared to predicted baseline conditions and are unlikely to have a material impact. Predicted declines at reach CA5, however, are more significant at -49%. However, as the creeks are ephemeral and flow only after prolonged or significant rainfall events (as opposed to the uniform rainfall applied during the model prediction) the differences in observed or recorded flows are unlikely to be noticeable. Carne Creek as a whole is predicted to have only a minor net loss of 0.049 ML/day at the end of mining, so the predicted baseflow losses at CA2 and CA5 are unlikely to be transferred downstream.

Although not explicitly included in the modelling, a number swamps are observed to coincide with creeks that are simulated in the model. This is the case for Carne Creek reaches CA2 and CA5, and Paddys Creek. Reach CA2 of Carne Creek coincides with the lower half of Carne Central Swamp, the swamp occupies approximately 10% of the reach and some of the 7.5% baseflow losses may be derived from the swamp. Approximately 25% of reach CA5 is occupied by Sunnyside East Swamp and a portion of the 30% baseflow losses may be derived from the swamp.

Of the simulated swamps only Sunnyside Swamp, Gang Gang Swamp South and Gang Gang Swamp Southeast are predicted to decline in baseflow. The predicted decline at Gang Gang Swamp South and Sunnyside Swamp is only -5.8% and -1.3% respectively at end of mining, which is unlikely to be noticeable.

The predicted decline of approximately 300% of baseflow at Gang Gang Swamp Southeast is more significant. The swamp is a losing swamp and leakage is predicted to increase significantly. However, past evidence indicates that swamps such as these can be self-healing and the predicted losses are unlikely to be experienced to the full extent.

No impacts on baseflow are predicted at Coxs River.

Overall a net decline in baseflow of 0.1246 ML/day is predicted due to Springvale only. The predicted cumulative impact of both the Springvale and Angus Place projects proceeding is a decline of approximately 4.7% of net baseline baseflow.

Table 7.2: Summary of Predicted Baseflow Changes

Surface Water Feature	Average Baseline Baseflow – during mining (ML/day)	Maximum Predicted Change – Springvale during mining – Springvale Only (ML/day)	Difference at End of Mining from Baseline – Springvale Only (ML/day)	Difference at End of Mining from Baseline – Cumulative (ML/day)	Residual Difference at 100 years post Mining from baseline – Cumulative (ML/day)
Carne West Swamp	0.0200	+0.066	+0.0312	+0.0312	+0.0206
Carne Creek Reach CA1	4.6418	-	-0.0328	-0.1006	+0.3713
Carne Creek Reach CA2 (incorporates the lower reach of Carne Central Swamp)	1.1560	-	-0.0881	-0.1992	-0.2570

Surface Water Feature	Average Baseline Baseflow – during mining (ML/day)	Maximum Predicted Change – Springvale during mining – Springvale Only (ML/day)	Difference at End of Mining from Baseline – Springvale Only (ML/day)	Difference at End of Mining from Baseline – Cumulative (ML/day)	Residual Difference at 100 years post Mining from baseline – Cumulative (ML/day)
Carne Creek Reach CA3	0.0462	-	+0.1346	+0.1344	+0.1393
Carne Creek Reach CA4	0.1967	-	+0.0536	+0.0534	+0.0557
Carne Creek Reach CA5 (incorporates Sunnyside central Swamp)	0.2512	-	-0.1165	-0.1599	-0.2423
Carne Creek Total	6.2919		-0.0492	-0.2729	0.0670
Gang Gang Swamp South	-0.0549	+0.1037	-0.0032	-0.0035	-0.0199
Gang Gang Swamp Southeast	-0.0652	-	-0.1673	-0.1676	-0.1693
Nine Mile Swamp	0.0146	-	+0.0017	+0.0017	+0.0006
Pine Swamp		-	+0.1072	+0.1072	+0.0605
Paddys Creek (incorporates Paddy's Creek Swamp)	0.1644	-	-0.0014	-0.0015	+0.0022
Marrangaroo Creek	0.7750	-0.0730	-0.0422	-0.0441	-0.2572
Sunnyside Swamp	0.1085	-	-0.0014	-0.0016	-0.0076
Net#	7.2543	-	-0.1246	-0.3441	-0.3031

- excludes Carne Creek Total.

7.3.4 Baseflow Impacts Uncertainty Analysis

Previous studies undertaken by CSIRO (Guo et al., 2007) suggest that in coal mining environments represented by stratified rocks, fractures tend to only reach all the way to the ground surface when the longwall width to depth of cover ratio is greater than about 0.75. At Springvale Mine the depth of cover is generally of the order of 350 to 420 m (MSEC, 2013), with the exception of LW501 to LW503 where the depth of cover ranges from 190 to 310 m. The proposed longwall panel voids at Springvale are all reduced from 316 to 261 m wide to protect sensitive swamp areas.

Given the conservative nature of the adopted ramp function in terms of predicting high permeability changes up to ground surface, uncertainty analyses were conducted whereby modelling runs were undertaken using two truncated ramp functions as described below and presented in Appendix K.

The two additional ramp functions applied are as follows:

- Truncated Ramp 1.
  - The ramp function is truncated to zero for heights above 230 m above the Lithgow Seam so that there are no permeability changes in the upper strata. The magnitude of changes in horizontal and vertical permeability for heights below 230 m is assumed to be the same as in the base case.
- Truncated Ramp 2.
  - For heights above 230 m above the Lithgow Seam the ramp function acts only on the vertical permeability component, while the horizontal component is maintained at the in situ value. The magnitude of change in vertical permeability is assumed to be the same as in the base case.

The uncertainty analysis has been undertaken for the cumulative, or *Base Case*, scenario, where all existing approved and proposed (Springvale and Angus Place) mines are included. The results of the two runs with the truncated ramp functions are compared with those from the cumulative (Base case) scenario in Figures 63 to 68.

Of particular interest to note is the absence of the large predicted increases in baseflow observed at a number of the swamps and creeks, notably; Pine, Gang Gang South and Carne West Swamps, and Reaches 3, 4 and 5 of Carne Creek. This is due to the lack of shallow bed separation and increased horizontal permeability under the truncated ramp scenarios.

Changes in predicted impacts under the truncated scenarios are as follows:

Carne West Swamp

Under both the truncated ramp 1 and truncated ramp 2 scenarios, no significant impacts are predicted at Carne West Swamp either during or post mining.

Carne Creek (reaches 1 to 5)

Predicted baseflow to Reaches 1 and 2 of Carne Creek are more or less identical to the cumulative (base case) scenarios.

Post mining rebound in predicted baseflow volumes are similar for all scenarios at Reach 2 while the truncated ramp 1 scenario lags behind at Reach 1.

Reaches 3, 4 and 5 of Carne Creek do not display the increased baseflow under the truncated ramp scenarios as were predicted under the base case scenario. Reach 4 shows a minor decline in base flow that is more pronounced under the truncated ramp 1 scenario. Reach 5 shows a more significant decline in baseflow over the life of mining that is more pronounced under the truncated ramp 2 scenario. Towards the end of mining the predicted baseflow under the base case and truncated ramp 2 scenarios merge.

Reaches 3 and 4 show only minor baseflow changes post mining while reach 5 shows significant rebound.

Gang Gang Swamp South

Gang Gang Swamp South displays no significant baseflow change under the truncated ramp 1 scenario either during or post mining. Under the truncated baseflow 2 scenario there is slightly increased leakage during mining with no significant recovery post mining.

Gang Gang Swamp Southeast

Gang Gang Swamp Southeast shows no significant baseflow impacts under the truncated ramp 1 scenario and much reduced impacts under the truncated ramp 2 scenario, with no substantial recovery post mining.

Nine Mile Swamp

Under both the truncated ramp 1 and truncated ramp 2 scenarios, no significant impacts are predicted at Nine Mile Swamp either during or post mining.

Pine Swamp

Under both the truncated ramp 1 and truncated ramp 2 scenarios, no significant impacts are predicted at Pine Swamp either during or post mining. Only a very minor baseflow increase and subsequent decline is predicted under the truncated ramp 2 scenario.

Paddys Creek

Predicted baseflow at Paddys Creek under the truncated ramp scenario are similar to those of the base case predictions. Towards the end of mining however, under the base case scenario there is a slight rebound in baseflow volumes which is less obvious in the truncated ramp scenarios. Post mining the difference becomes more pronounced with very little baseflow recovery under the truncated ramp scenarios.

Marrangaroo Creek

Baseflow predictions under all scenarios show a similar steady decline until around 2022 at which point the predicted baseflow starts to fluctuate. The fluctuations result in a net increase in baseflow under the basecase scenario, a net decrease in baseflow under the truncated ramp 2 scenario and a slightly reduced baseflow under the truncated ramp 1 scenario. All scenarios then continue to decline but with the truncated ramp 1 scenario at a reduced rate and the base case scenario at an increased rate, towards the truncated ramp 2 predictions. Post mining baseflow under all scenarios ultimately recover to similar levels.

Sunnyside Swamp

Under both the truncated ramp 1 and truncated ramp 2 scenarios, no significant impacts are predicted at Sunnyside Swamp either during or post mining.

Water Levels

Predicted changes in swamp and creek water levels (with respect to predicted level in December 2012) are compared against basecase prediction on Table 7.3.

In general, the application of the truncated ramp functions results in reduced impacts in terms of predicted decline in water levels at the swamps and creek simulated.

Table 7.3 Predicted maximum drop in the average standing water levels within swamps/streams with respect to the water levels in December 2012 (CSIRO, 2013)

Swamps and streams simulated in this study	Base Case (m)	Truncated Ramp 1 (m)	Truncated Ramp 2 (m)
CA2 (includes Carne Central Swamp)	0.103	0.095	0.110
Carne West Swamp	Small head increase	0.000	0.000
Carne Creek Total	Small head increase	Small head increase	Small head increase
Gang Gang Swamp South East	0.364	0.005	0.052
Gang Gang Swamp South	0.030	0.000	0.043
Kangaroo Swamp	0.095	0.000	0.051
Kangaroo Creek Total	0.037	0.066	0.055
Lamb Creek	0.047	0.006	0.022
Long Swamp	0.017	0.000	0.000
Marrangaroo Creek	0.020	0.011	0.019
Nine Mile Swamp	Small head increase	Small head increase	Small head increase
Paddy's Creek	Small head increase	0.002	0.004
Pine Swamp	Small head increase	No change	No change
Tri-Star Swamp	0.081	0.011	0.079
Twin Gully Swamp	0.051	0.003	0.035
Sunnyside Swamp	0.013	Small head increase	Small head increase
Wolgan River Total	0.050	0.017	0.030

7.3.5 Predicted Impacts on Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) are discussed in detail in the EIS and the specialist ecologist report (RPS, 2013c). The ecology report identifies three different types of GDE's within the Project Application Areas, these being:

- Newnes Plateau Shrub Swamp
- Newnes Plateau Hanging Swamp
- Newnes Plateau Rush – Sedge Snow Gum Hollow Wooded Heath.

It is considered that all or parts of these vegetation communities may potentially be GDEs (RPS, 2013c). The mapped swamps are shown on Figure 40 along with predicted water table decline at the end of mining. The hanging swamps are associated with the perched aquifer system and are not associated with the regional water table. Of the shrub swamps, it should also be noted that not all of the shrub swamps are groundwater dependent, and, of those that are, it is likely only the lower reaches (e.g. the lower reach of Carne West Swamp) that are truly reliant on groundwater baseflow.

Shrub Swamps that are located near areas of predicted water table decline include:

- Sunnyside east Swamp
- Carne West Swamp
- Gang Gang Swamp Southeast
- Gang Gang Swamp South
- Pine Swamp
- Paddys Creek Swamp
- Marrangaroo Creek Swamp.

A decline in the water table beneath those reaches of swamps that are reliant on groundwater can have the potential implication of changes to groundwater baseflow to, or leakage from these swamp systems. A detailed assessment of the predicted baseflow impacts has been undertaken and is discussed in Section 7.3.3 and summarised on Table 7.2.

As the shrub swaps exist over multiple aquifers a composite water table decline for AQ4, AQ5 and AQ6 has been compiled and is presented on Figure 40. The predicted water table decline beneath the shrub swamps is predicted to range from negligible to <0.5m with the greatest water level declines predicted to occur beneath elevated ridges and the upper reaches of the swamps where the swamps are generally above the water table and not reliant on groundwater.

It should also be noted that the reliance of the shrubs swamps on groundwater from the perched aquifer system is due to the lateral groundwater flow along the low permeability aquitards (YS1 to YS6) and not the absolute water level within each aquifer. The predicted water level decline within the perched aquifer system is due to bed separation effects that result in increased storage and increased horizontal hydraulic conductivity. In many cases the decline in water table has meant a corresponding increase in groundwater baseflow to the swamps (Section 7.3.3) and not a decrease. These predictions are, however, conservative due to the assumed RAMP function being applied through to ground surface in the groundwater model. Historical observation at GDEs has not identified impact to water levels in NPSS due to depressurisation of the Illawarra Coal Measures or subsidence-related impacts.

Predicted baseflow changes at shrub swamp locations are provided on Table 7.1. The swamps predicted to have significant reductions in baseflow at the end of mining include:

- *Carne Central Swamp*, as represented by Reach CA2 in the model. The Carne Central Swamp may be impacted by of portion of the 0.199 ML/day baseflow losses predicted for Reach CA2. No recovery of baseflow impacts is predicted post mining.
- *Sunnyside Central Swamp*, as represented by Reach CA2 in the model. Sunnyside East Swamp may be impacted by a portion of the 0.16ML/day baseflow losses predicted for Reach CA5. Post mining baseflow losses are predicted to increase for Reach CA5.
- *Gang Gang Swamp Southeast* is predicted to have a baseflow loss of 0.168 ML/day at the end of mining. The baseflow losses increase marginally post mining.

Other, potentially less significant baseflow losses are predicted for:

- *Paddys Creek Swamp*, as represented by Paddys Creek in the model. Paddy's creek Swamp may be impacted by a portion of the 0.0015 ML/day baseflow losses predicted for Paddy's Creek. No recovery of the losses is predicted post mining.
- *Gang Gang Swamp South* has predicted baseflow losses of 0.0035 ML/day at the end of mining increasing to 0.02 ML/day post mining.
- *Sunnyside Swamp* has a predicted baseflow loss of 0.0016 ML/day at the end of mining with

a long term decline of 0.0076 ML/day.

The maximum predicted decline in average water levels within the swamps as a result of the water table decline and baseflow changes is provided in Table 7.3 (extracted from Adhikary and Wilkins, 2013b) with a maximum average water level decline of 0.36 m observed at Gang Gang Swamp South East and 0.10 m at reach CA2 of Carne Creek. The remainder of the predicted declines in average water levels are less than 0.1 m and are not expected to have any material impact on GDEs.

7.3.6 Gardens of Stone National Park

The Gardens of Stone National Park covers 15,000 hectares and joins Wollemi National Park on the northern part of Newnes Plateau and is part of the Greater Blue Mountains World Heritage Area. The park is situated approximately 6 to 8 km to the north of the Project Application Area, and borders the neighbouring Angus Place Mine boundary.

No significant drawdown in either the perched or shallow aquifer systems is anticipated in this area, and accordingly no detrimental groundwater related impacts as are anticipated. Potential impacts to swamp related flora are discussed under Section 7.3.5.

7.3.7 Birds Rock Flora Reserve

The Birds Rock Flora Reserve is situated within the Newnes State Forest to the north of the Project Application Area and within the neighbouring Angus Place Colliery boundary. As there is no known phreatophytic vegetation species or GDEs within the reserve no detrimental groundwater related impacts are anticipated.

7.3.8 Existing Groundwater Users

Section 7.3.2 and Table 7.1 summarises the predicted groundwater drawdown at known groundwater works in the vicinity of the Project. However, it is not believed that any of these points are reliant on groundwater supply, the majority being either exploration holes or standpipe piezometers for monitoring purposes.

The only known groundwater use in the study area is for mining supply. In these instances groundwater is taken incidentally as a by-product of mining and the operations are understood to operate with a water surplus. The similarity between the predicted mine inflows for Springvale only and the cumulative (base case) scenarios, as discussed in Section 7.3.2 and shown on Figure 65, show that no substantial interference is anticipated between the two projects that would result in a significant reduction in groundwater inflows.

No detrimental impacts are anticipated on any other groundwater users in the area.

7.3.9 Potential Water Quality Impacts

No change in water quality is expected as a result of the proposed development. Groundwater inflows to the underground operations are expected to remain consistent with current inflow water quality at around 700 to 1000 µS/cm as discussed in Section 4.9. No deterioration of quality of groundwater inflows have been observed due to current mining operations, and consequently none are predicted due to the proposed development.

Similarly no detrimental impacts to groundwater quality are expected within the shallow groundwater aquifer or within the swamps. Consistent with historical mining at Springvale, no deterioration in groundwater quality has occurred.

7.3.10Impacts Under Climate Change Scenarios

Baseflow predictions under wet and dry climate scenarios are compared to the predicted baseflows of the cumulative impacts (all mines) Scenario. The predicted variations from cumulative impact predictions are provided in Table 7.2 for predicted baseflows at end of mining and in Table 7.3 for predicted baseflow at 100 years post mining. Plots of baseflow under the climate change scenarios are provided in Appendix L.

When rainfall recharge is reduced by 15% the baseflow in all the watercourses is reduced and conversely when rainfall infiltration is increased by 15% the baseflow in all the watercourses increases by a similar volume. At the end of mining, the magnitude of the changes varies widely from ±3% at Reach CA3 of Carne Creek up to ±74% at Reach CA5. At 100 years post mining, the magnitude of the variations increases in almost all cases and ranges from ±4% at reaches CA3 and CA4 to ±330% at reach CA5.

The total variation of baseflow impacts at end of mining are predicted to be ±6%, and at 100 years post mining are predicted to be ±10%.

Table 7.4: Climate Change Scenario Baseflow Variation – End of Mining

Swamp/Creek	**Base Case (ML/d)**	**Baseflow Variation under High Rainfall (ML/day)d)**	**% Variation**	**Baseflow Variation under Low Rainfall (ML/day)**	**% Change**
Nine Mile Swamp	0.017	0.007	43%	-0.008	-43%
Carne West Swamp	0.050	0.004	8%	-0.004	-8%
Gang Gang Southeast	-0.225	0.011	5%	-0.01	-5%
Gang Gang South	-0.061	0.019	32%	-0.02	-33%
Marrangaroo Creek	0.728	0.098	14%	-0.1	-14%
Paddy’s Creek	0.163	0.009	6%	-0.009	-6%
Pine Swamp	0.192	0.011	6%	-0.011	-6%
Sunnyside Swamp	0.104	0.008	7%	-0.007	-7%
Carne Creek 1	4.506	0.127	3%	-0.125	-3%
Carne Creek 2	0.947	0.068	7%	-0.066	-7%
Carne Creek 3	0.181	0.006	3%	-0.006	-3%
Carne Creek 4	0.251	0.009	4%	-0.008	-3%
Carne Creek 5	0.068	0.051	74%	-0.05	-74%
Total	**6.921**	**0.428**	**6.2%**	**-0.424**	**6.1%**

Table 7.5: Climate Change Scenario Baseflow Variation – 100 Years Post Mining

Swamp/Creek	**Base Case (ML/d)**	**Baseflow Variation under High Rainfall (ML/day)d)**	**% Change**	**Baseflow Variation under Low Rainfall (ML/day)**	**% Change**
Nine Mile Swamp	0.016	0.009	54%	-0.009	-60%
Carne West Swamp	0.041	0.005	14%	-0.006	-15%
Gang Gang Southeast	-0.221	0.014	6%	-0.015	-7%
Gang Gang South	-0.069	0.029	43%	-0.033	-47%
Marrangaroo Creek	0.633	0.156	25%	-0.173	-27%
Paddy’s Creek	0.172	0.015	9%	-0.017	-10%
Pine Swamp	0.151	0.013	9%	-0.014	-9%
Sunnyside Swamp	0.089	0.011	12%	-0.011	-13%
Carne Creek 1	5.083	0.252	5%	-0.273	-5%
Carne Creek 2	1.047	0.121	12%	-0.125	-12%
Carne Creek 3	0.189	0.007	4%	-0.007	-4%
Carne Creek 4	0.259	0.011	4%	-0.011	-4%
Carne Creek 5	0.026	0.083	320%	-0.086	-330%

Swamp/Creek	Base Case (ML/d)	Baseflow Variation under High Rainfall (ML/day)d)	% Change	Baseflow Variation under Low Rainfall (ML/day)	% Change
Total	**7.416**	**0.726**	**9.8%**	**-0.78**	**10.5%**

7.3.11 Impacts of other Groundwater Related Activities

The Project also includes the installation of a ventilation shaft, service boreholes, and dewatering service bores (Bore 9 and Bore 10) that will be drilled between the underground workings and the ground surface. Bore 9 and Bore 10 will both consist of 4 individual boreholes. Bore 10 will be located in close proximity to Nine Mile Swamp.

Previous service bores on site have been installed using blind boring, mud rotary drilling methods to minimise any potential mixing of different quality water between aquifers. On completion of drilling the service bores are cased and grouted over their full length. The grouting of the service bores will prevent the possibility of shallow aquifers draining to deeper aquifer or the underground and will also prevent any cross contamination of aquifers of differing water quality.

Due to the use of mud rotary drilling methods there will be no significant inflows to the service bores during drilling. No significant groundwater impacts are anticipated as a result of the installation and operation of these service bores.

7.3.12 Aquifer Interference and Minimal Impacts Considerations

With regard to potential impacts on groundwater, this section summarises the analysis carried out for this report of two aspects of the AIP policy requirements, namely water source classification and minimal impact consideration. Where considerations of the Water Sharing Plan, water accounting and licensing are concerned, these matters are considered in Section 8.

Water Source Classification

The AIP defines ‘water sources’ into two primary categories, namely, “highly productive” (HPWS) and “less productive” (LPWS). HPWS groundwater is defined in the Policy as a groundwater source (alluvial, coastal sands, porous rock or fractured rock) that is *declared* in the Regulations *and* will be based on the following criteria:

a) has total dissolved solids of less than 1,500 mg/L, and

b) contains water supply works that can yield water at a rate greater than 5 L/sec.

Categories of less productive groundwater sources are alluvial, porous rock or fractured rock. Categories for highly productive groundwater sources are alluvial, coastal sands, porous rock and fractured rock.

It is highlighted that Sydney Basin Richmond River water source is categorised by the NSW Office of Water as a HPWS and the Sydney Basin Coxs River water source is categorised as LPWS.

The AIP provides thresholds for key minimal impact considerations for each of the HPWS and LPWS sources. These thresholds deal with water table and groundwater pressure drawdown as well as groundwater and surface water quality changes. The Policy provides for an adaptive management approach to the minimal impact considerations which involves regularly reviewed and updated, if required, based on scientific information and experience during implementation

The baseline groundwater quality sampling program comprises sampling Project piezometers located in the Project Application Area and installed across the following hydrogeological units:

Fractured Rock Water Sources:

Lithgow Coal Seam (Illawarra Coal Measures)	Fractured Rock Water Source
Narrabeen-Wianamatta Group	Fractured Rock Water Source

Minimal Impact Considerations

The AIP requires that, for each of the water sources (in this case, the 2 LPWS), groundwater sources within the potential regional influence of a Project, defined thresholds for key minimal impact be considered. These thresholds deal with two key potential impacts:

- Water table and groundwater pressure (level) drawdown changes
- Groundwater quality changes.

An analysis of the thresholds for key minimal impact considerations defined in the Table 1 of the AIP policy (NSW Office of Water, 2012) has been carried out for each of the groundwater sources potentially impacted by the Project. The outcome of this analysis is presented in summary presented below and in detail in Appendix O.

Table 7.6: Minimal Impact Considerations: Triassic Age Narrabeen – Wianamatta Group (Porous and Fractured Rock Water Source)

Category	Water Source	Water Table (WT)	Water Pressure (WP)	Water Quality (WQ)
Porous and Fractured Rock water sources	**Triassic Sedimentary Rocks**	**Consideration WT-1:** The predicted cumulative drawdown in the water table (unconfined) areas of the Triassic (AQ6 aquifer) at the end of mining is presented in Figure 40. There are 3 projects (no large-scale groundwater users) in the vicinity of the project so the predicted drawdown is representative of cumulative impact. The maximum predicted WT drawdown is 15 m under the ridgelines, with no predicted drawdown of the WT along the drainage alignments inside of the Project Application Area boundary There are no water supply works in the Triassic inside of the Project Application Area boundary and as such cumulative impact on any water supply work is less than 2m.	**Consideration WP-1:** The Triassic (AQ6 aquifer) at the end of mining is not a confined aquifer inside/outside of the proposed Project Applicable Area boundary. As such, the Water Pressure Criterion does not apply.	**Consideration WQ-1a:** The Triassic Sediments Sandstone are characterised as fresh to brackish. Mining activity will not change the beneficial use of this groundwater source inside/outside of the Project Application Area boundary.
		Consideration WT-2: Does not apply as the activity does not trigger the requirement	**Consideration WP-2.** Does not apply as the activity does not trigger the requirement	**Consideration WQ-2:** Does not apply as the activities do not trigger the requirement.

Table 7.7: Minimal Impact Considerations: Permian Age Illawarra Coal Measures (Porous and Fractured Rock Water Source)

Category	Water Source	Water Table (WT)	Water Pressure (WP)	Water Quality (WQ)
Porous and Fractured Rock water sources	**Permian age Illawarra Coal Measures Water Source**	**Consideration WT-1:** The Illawarra Coal Measures Water Source is not unconfined (WT) inside of the Project Application Area. As such, the Water Table Criterion does not apply.	**Consideration WP-1:** The predicted cumulative drawdown in the Permian at the end of mining is presented in Figure 36. There are 3 projects in the vicinity of the project so the predicted drawdown is representative of cumulative impact of these projects. The maximum predicted drawdown is 150 m within the Project	**Consideration WQ-1a:** The Illawarra Coal Measures Water Source are characterised as relatively fresh. Mining activity will not change the beneficial use of this groundwater source outside of the Project Application Area.

Category	Water Source	Water Table (WT)	Water Pressure (WP)	Water Quality (WQ)
			Application Area. There are no water supply works in the Permian except for the dedicated mine dewatering bores which supply water to the Wallerawang power station (the water is not used for potable or irrigation water supplies). Cumulative impact on any water supply works outside of the Project Application Area boundary is less than 2 m.	
		Consideration WT-2: Does not apply as the activity does not trigger the requirement	**Consideration WP-2.** Does not apply as the activity does not trigger the requirement	**Consideration WQ-2:** Does not apply as the activities do not trigger the requirement.

The AIP has adopted an adaptive management approach to the minimal impact considerations which means they will be regularly reviewed and updated, if required, based on scientific information and experience during implementation.

7.4 Impacts Summary

Monitoring of swamp water levels and surface water gauging has shown, over the life of the current mining operations (Section 4), that no impacts to the swamps or surface water flows have occurred as a result mining to date at either the Springvale or Angus Place Collieries. Given the similarities of the proposed development with past operations, there is no reason to believe that the results of the proposed mining activities will cause any impacts where none have previously been observed.

The groundwater impact model (Adhikary and Wilkins, 2013b) presented in Appendix K predicts that some minor impacts to the shallow groundwater and baseflow will occur. However, it is considered that the groundwater modelling results are conservative, particularly in respect to the predicted impacts to baseflows. The model assumes dilation of horizontal 'plies' will occur through to ground surface, however, this has not been observed in the field. In any regard, the model is not able to replicate the self-healing nature of the creeks and swamps and as such, it is conservative, over-predicting the magnitude of potential impacts.

The assessment of cumulative impacts has been undertaken throughout the modelling assessment as a matter of course and the results presented are of cumulative impacts between the proposed Springvale project and existing approved projects, and the proposed Springvale project and existing approved projects plus the proposed extension at Angus Place. Cumulative impacts are observed to some degree, most notably post mining at Springvale when recovery within the Lithgow Seam is delayed until mining at Angus Place is completed, and also with the Clarence Colliery where predicted baseflows at nearby swamps and creeks are predicted to increase (recovery) slightly at the end of the Clarence mining operation.

No other significant groundwater related impacts are anticipated.

8. WATER LICENSING

The Project Application Area lies within the *Greater Metropolitan Region Water Sharing Plan* (WSP) and as such, any groundwater extraction, incidental take, baseflow reduction or activities that have the potential to impact surface water and groundwater will be subject to conditions and management in accordance with the WSP:

- The dewatering water, arising from groundwater inflows to the underground mine, will require a Water Access Licence (WAL)
- The net baseflow impacts (losses) will require a Surface Water Licence.

8.1 Groundwater Licensing

The Project Application Area is straddles the boundary of the Sydney Basin Coxs River Groundwater Source and the Sydney Basin Richmond Groundwater Source, which both lie within the Greater Metropolitan Region WSP.

Water sharing plans are being progressively developed for rivers and groundwater systems across New South Wales following the introduction of the WM Act. These plans protect the health of rivers and groundwater while also providing water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through separation of land and water (NSW Office of Water, 2012).

The Sydney Basin Coxs River Groundwater Source has a geological boundary to the west where it contacts with the Coxs River Fractured Rock. The eastern boundary is marked by the Blue Mountains Range (NSW Office of Water, 2012).

The Sydney Basin Richmond Groundwater Source is bounded by the main arm of the Grose River to the south, Blue Mountains Range to south-west, Wolgan River to the northwest, Colo River to the north and Hawkesbury River to the east. Much of this groundwater source is covered by national parks with bore distribution constrained to the eastern areas of Kurrajong and Grose Vale (NSW Office of Water, 2012).

The Project Application Area location in relation to the Water Sharing Plan Region and the Groundwater Source Catchment is shown in Figure 69.

Under the licensing provisions of the WSP a WAL is required. WALs entitle the licence holder to specified shares in the available water within a particular water management area (the share component) and to take water at specified times, rates or circumstances from specified areas or locations (the extraction component).

WALs are required under the WM Act (unless an exemption applies) where any activity causes:

- The removal of water from a water source
- The movement of water from one part of an aquifer to another part of an aquifer
- The movement of water from one water source to another water source.

WALs may be granted to access the available water governed by a water sharing plan and, where necessary, licence applications will be assessed in accordance with the Aquifer Interference Policy.

This water licence would authorise both the taking of a volume of water from the aquifer and the work or activity that causes this water to be taken. Conditions relating to the management of aquifer interference activities would therefore be placed on the water licence itself.

Table 8.1 displays the groundwater statistics for the Sydney Basin Coxs River and Richmond Groundwater Source as shown on the WSP report card.

Table 8.1: Groundwater Resource Statistics

Parameter	Sydney Basin Coxs River	Sydney Basin Richmond
Area	528.95 km^2	1,978.39 km^2
Recharge	31,312 ML/year	127,878 ML/year
Planned Environmental Water	14,204 ML/year	106,775 ML/year

Parameter	Sydney Basin Coxs River	Sydney Basin Richmond
(volume of groundwater proposed to be preserved for the environment)		
Long-term Average Annual Extraction Limit (LTAAEL)	17,108 ML/year	21,103 ML/year
Groundwater Basic Landholder Rights	454 ML/year	1,623 ML/year
Total Licensed Groundwater Entitlement	6,926 ML/year	15,923 ML/year
Unassigned Water	9,728 ML/year	3,557 ML/year

8.1.1 Licensing Requirement

As the mining activity is taking groundwater (through the occurrence of mine inflows), a water licence is required under the WM Act (2000).

In Section 6.6.2, it was determined that the predicted maximum average rate of mine inflows will be 18.75 ML/day, which is predicted to occur around 2022. As there is not a facility within the COSFLOW model to output the relative proportion of modelled mine inflow obtained from each of the two groundwater sources, the division was applied as follows:

- Up to 2015 (40% Coxs River; 60% Richmond River)
- 2015 to 2012 (reduces at constant rate Coxs River; remainder, Richmond River)
- 2021 to 2032 (remainder, Coxs River; reduces at constant rate, Richmond River)
- After 2032 (30% Coxs River; 70% Richmond River)

It is noted that output from the groundwater model was translated into daily input for use in the site surface water balance as well as the regional water balance. Further detail on the water balance for Springvale is presented in RPS (2013a).

Table 8.2 presents the predicted WAL requirement, together with the relative proportion, as %, obtained from each source.

Table 8.2: Predicted WAL Requirement – Sydney Basin Coxs River and Richmond River

Year	Total (ML/yr)	Sydney Basin Coxs River (ML/yr)	(%)	Sydney Basin Richmond River (ML/yr)	(%)
2013	5,122	3,073	60%	2,049	40%
2014	4,567	2,740	60%	1,827	40%
2015	4,968	2,909	59%	2,059	41%
2016	5,240	2,670	51%	2,570	49%
2017	5,715	2,332	41%	3,383	59%
2018	5,699	1,958	34%	3,741	66%
2019	6,101	1,649	27%	4,452	73%
2020	6,420	1,382	22%	5,038	78%
2021	6,598	1,479	22%	5,119	78%
2022	6,737	1,869	28%	4,868	72%
2023	6,482	1,893	29%	4,589	71%
2024	6,276	2,026	32%	4,251	68%
2025	6,019	2,121	35%	3,898	65%
2026	5,457	1,695	31%	3,762	69%
2027	5,112	1,530	30%	3,582	70%
2028	4,846	1,452	30%	3,395	70%
2029	4,555	1,366	30%	3,189	70%

Year	Total (ML/yr)	Sydney Basin Coxs River (ML/yr)	(%)	Sydney Basin Richmond River (ML/yr)	(%)
2030	4,336	1,301	30%	3,036	70%
2031	4,179	1,254	30%	2,925	70%
2032	4,032	1,210	30%	2,822	70%
2033	3,863	1,159	30%	2,704	70%
2034	3,706	1,112	30%	2,594	70%
2035	3,548	1,064	30%	2,484	70%
2036	3,400	1,020	30%	2,380	70%
2037	3,233	970	30%	2,263	70%

From Table 8.2, the maximum predicted take is 3,073ML/y from the Sydney Basin Coxs River and occurs in 2013. The maximum predicted take from the Sydney Basin Richmond River is 5,119ML/y and occurs in 2021.

Current Licence Allocations

Current groundwater licence allocations held by Springvale are summarised in Table 8.2. The current groundwater licence allocation of 3,885 ML/year from the Sydney Basin Coxs River Groundwater Source and 5,958 ML/year from the Sydney Basin Richmond Groundwater source are sufficient to meet the modelled maximum extraction rate and as such, no additional groundwater licenses are required.

Table 8.3: Springvale Licence Allocations

Current Licence	Sydney Basin Coxs River	Sydney Basin Richmond
Shaft 3 – Ventilation (10BL601863)*	3,300 ML/year	-
Bore 6 (10BL603519)*	-	5,958 ML/year
Collector System (10BL602017)*	585 ML/year	-

* Issued under Water Act 1912 and in the process of being converted under Water Management Act 2000.

8.1.2 Groundwater Management Rules

The WSP also sets out management rules for the operation of aquifer interception activities. The groundwater management rules that pertain to the Sydney Basin Coxs River and Sydney Basin Richmond Groundwater Sources are provided in Table 8.3.

Table 8.4: Groundwater Source Rules Summary

Subject	Sydney Basin Coxs River	Sydney Basin Richmond
Total Licensed Groundwater Entitlement	6,926 ML/year	15,923 ML/year
Access Rules		
To minimise interference between neighbouring bores	No water supply works (bores) to be granted or amended within the following distances of existing bores: 400 m from an aquifer access licence bore on another landholding, or 100 m from a basic landholder rights bore on another landholding, or 50 m from a property boundary (unless written consent from neighbour), or 1,000 m from a local or major water utility bore, or 200 m from a NSW Office of Water monitoring bore (unless written consent from NSW Office of Water).	

Subject	Sydney Basin Coxs River	Sydney Basin Richmond
Granting of bores near GDEs	No water supply works (bores) to be granted or amended within the following distances of high priority Groundwater Dependent Ecosystems (GDEs) (non Karst) as identified within the plan: 100 m for bores used solely for extracting basic landholder rights, or 200 m for bores used for all other access licences. The above distance restrictions for the location of works from high priority GDEs do not apply where the GDE is a high priority endangered ecological vegetation community and the work is constructed and maintained using an impermeable pressure cement plug from the surface of the land to a minimum depth of 30m. No water supply works (bores) are not to be located within the following distances from these identified features: 500 m of high priority karst environment GDEs, or a distance greater than 500 m of a high priority karst environment GDE if the Minister is satisfied that the work is likely to cause drawdown at the perimeter of the high priority karst GDE, or 40 m of a river or stream or lagoon (3rd order or above), 40 m of a 1st or 2nd order stream, unless drilled into underlying parent material and slotted intervals commence deeper than 30 m (30 m may be amended if demonstrate minimal impact on base flows in the stream), or 100 m from the top of an escarpment.	
Trading Rules		
INTO groundwater Source	Not permitted	
WITHIN groundwater source	Permitted subject to local impact assessment	
Conversion to another category of access licence	Not permitted	

8.1.3 Aquifer Interference Policy

The Aquifer Interference Policy (AIP) explains the water licensing and approval processes and requirements for aquifer interference activities. It assists proponents of aquifer interference activities in preparing the necessary information and studies to be used in the assessment of the proposed activity. The AIP also forms the basis of the assessment and subsequent advice provided by the NSW Office of Water for the assessment of the proposed activity under the Environmental Planning and Assessment Act 1979 (NSW Office of Water, 2012).

It is important to note that the AIP defines an aquifer as any type of saturated geological formation irrespective of permeability or water quality. This differs to the 'traditional' definition of an aquifer as being a groundwater system of sufficient permeability such that it can yield productive volumes of water.

The AIP adopts the following definition of an aquifer interference activity from the WM Act 2000:

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

The Policy specifies that the volume of water taken from a water source(s) as a result of an activity is required to be predicted prior to Project approval and that approval will not be granted unless adequate arrangements are in force to ensure that no more than minimal harm will be done to an aquifer or its dependent ecosystems.

Minimal harm criteria are specified in the AIP for highly productive and less productive groundwater sources.

Aquifer Interference Approval

Under the AIP, an aquifer interference activity requires:

- The necessary volumetric WALs.
- A separate aquifer interference approval.

An aquifer interference approval confers a right on its holder to carry out specified aquifer interference activities at a specified location or area.

Under section 91F of the WMA, it is an offence to carry out an aquifer interference activity without an aquifer interference approval. An aquifer interference activity includes the penetration, interference or obstruction of flows within an aquifer or to take or dispose of waters from an aquifer.

However, section 91F of the WMA does not currently apply. Section 88A provides that Part 3 of Chapter 3 (including section 91F) applies to each part of the State or each water source and each type or kind of approval that relates to that part of the State or that water source that is declared by proclamation. In essence, the AIP applies, however the approvals framework has not been finalised.

A framework for the implementation of the AIP has been produced by NoW (October 2013) and this report addresses the key issues in this draft document (Section 7.3.12).

8.2 Surface Water Licence

The Project Application Area lies across the boundary of two River Management Zones; the Wywandy River Management Zone of the Upper Nepean and Upstream Warragamba Water Source, and the Colo River Management Zone of the Hawkesbury and Lower Nepean Water Source. Both Water Sources are situated within the Greater Metropolitan Region WSP.

Under the WSP for the Greater Metropolitan Region Unregulated River Water Sources any take of surface water / baseflow as a result of depressurisation of deeper aquifers will require a surface water licence.

8.2.1 Licensing Requirement

Baseflow impacts will require licensing under the surface water allocation.

The predicted baseflow impacts and surface water licensing requirements have been divided by water management zone and water body on Table 8.5.

Table 8.5: Surface Water Licensing Requirements

	During Mining		**Post Mining (0 to 50 years)**		**Long Term (100 to 200 years)**	
	Average (ML/yr)	**Max (ML/yr)**	**Average (ML/yr)**	**Max (ML/yr)**	**Average (ML/yr)**	**Max (ML/yr)**
Wywandy River Management Zone						
Marrangaroo Creek	11.163	21.573	56.753	65.860	52.088	63.651
Totals	**11.163**	**21.573**	**56.753**	**65.860**	**52.088**	**63.651**
Colo River Management Zone						
Nine Mile	-0.340	0.032	-0.239	-0.169	-0.379	-0.294

Carne West Swamp	-13.507	-0.031	-8.384	-7.626	-7.544	-7.530
Carne Creek	-8.410	65.822	6.866	17.293	-52.701	-31.959
Gang Gang South East Swamp	37.142	61.168	63.192	64.001	59.246	60.423
Gang Gang South Swamp	-7.738	1.512	8.448	9.693	3.657	5.492
Paddys Swamp	0.352	0.708	-0.082	0.353	-2.239	-1.436
Pine Swamp	-24.404	0.010	-25.302	-22.337	-22.144	-22.101
Sunnyside Swamp	0.275	0.543	1.146	1.303	1.236	1.249
Totals	**-16.630**	**129.765**	**45.646**	**62.511**	**-20.867**	**3.844**

The maximum predicted long term loss (100 to 200 years) of baseflow within the Wywandy River Management Zone is 63.65 ML/year and that for the Colo River Management Zone is 3.84 ML/year.

It is noted that model predictions are an upper bound for licensing requirement due to the conservative assumption in regard to the RAMP function applied through to ground surface.

8.2.2 Water Sharing Rules

The WM Act provides for a system of assessment and licensing and approvals relating to the equitable take of water from water sources, in addition to works and activities occurring within or affecting these water sources. The WSP sets out Water Sharing Rules that operate under these water management principles. The Water Sharing Rules that pertain to the Wywandy River and Colo River Management Zones are provided in Table 8.5.

Table 8.6: Management Zone Water Sharing Rules

Subject	Wywandy River	Colo River
Total surface water entitlement	273.3 ML/year (43.47% used for irrigation purposes)	2887.3 ML/year (85.71% used for irrigation)
Access Rules		
Cease to Pump	A Class users must cease to pump when flows are at or less than 2 ML/day B Class users must cease to pump when flows are at or less than 6 ML/day C Class users must cease to pump when flows are at or less than 14 ML/day	A Class users must cease to pump when flows are at or less than 24 ML/day B Class users must cease to pump when flows are at or less than 11 ML/day
Commence to Pump A Class users only	Users may commence when flows are greater than 4 ML/day	Users may commence when flows have exceeded 24 ML/day for 24 hours
Reference Point	Coxs River at Wallerawang Power Station (flow gauge 212054)	Colo River at Upper Colo (flow gauge 212018)
Trading Rules		
Trading INTO the management zone	Not permitted	Not permitted if the trade will increase the total licensed entitlement for the zone. Not permitted into or above reaches declared a “wild river”
Trading WITHIN the management zone	Permitted, subject to assessment	Not permitted into or above reaches declared a “wild river”, permitted elsewhere subject to assessment

Subject	Wywandy River	Colo River
Conversion to High Flow Access Licence	Not permitted.	Not Permitted

8.3 Summary License Volumes

Table 8.7 provides a summary of the licence requirements for Springvale.

Table 8.7: Licensing Volumes Summary

Management Zone	Licence Type	Activity	Occurrence of Maximum Volume	Maximum Total Annual Volume (ML/year)
Sydney Basin Coxs River Groundwater Source	Water Access Licence	Mine Inflows	In 2013	3,073
Sydney Basin Richmond Groundwater Source	Water Access Licence	Mine Inflows	In 2021	5,119
Wywandy River Management Zone	Surface Water Licence	Baseflow Reduction	50 years Post Mining	65.9
Colo River Management Zone	Surface Water Licence	Baseflow Reduction	During Mining	129.7

9. MONITORING AND MANAGEMENT

9.1 Monitoring of Impacts of Groundwater Extraction / Dewatering

The current monitoring network which exists across the Project Application Area is described in Section 4.3 to 4.5 of this report. The monitoring network is designed to provide detailed data on each identified aquifer unit in the three groundwater systems underlying the Project Application Area, namely:

- The perched groundwater system
- The shallow regional groundwater system
- The deep confined groundwater system.

It is recommended that the current groundwater monitoring network is maintained.

As mining progresses to the east, and then to the south the potential exists for some of the existing monitoring points to be mined out as a result of the Project. Any monitoring points which become mined out should be reinstated as close to the original monitoring point as possible. This may involve the installation of monitoring points in the chain pillars between the longwall panels.

Furthermore, the monitoring network should be expanded, prior to commencement, to ensure that adequate spatial coverage of the entire Project Application Area is achieved such that early warning of impacts in excess of those predicted are detected (particularly positioned to detect potential adverse impacts to GDE's). This expansion should include:

- The installation of a number of VWP monitoring points in the south and south east of the Project Application Area where the proposed LWs are located. The locations of the VWPs should be planned to ensure that they are installed in the chain pillars of the long walls so that they will not be mined out. VWPs should be set to record daily.
- The addition of a number of open hole standpipe piezometers screened in the shallow groundwater system. These should be equipped with automatic loggers to record on a daily basis.
- The installation of additional standpipe piezometers in Marangaroo Swamp and Bungleboori swamp.
- The installation of additional flow monitoring locations at the THPSS. The flow monitoring locations should be incorporated into those swamps which already have piezometers installed. This ensures that the overall hydraulic cycle at the monitored swamp can be monitored.
- The extension of the regional monitoring network to include monitoring of the water bores identified in the NOW registered bores list. Emphasis should be directed to the east and northeast, outside of the Project Application Area boundary where drawdown impacts are predicted to occur.
- Water quality sampling from the Banks Wall Sandstone both up-gradient and down-gradient of the Project Application Area.

9.2 Existing Environmental Management System

Springvale has a firm commitment to minimising the impact of its operations on the local environment and community, and has a comprehensive Environmental Management System (EMS) in place to fulfil this commitment. This EMS has been developed in accordance with the Centennial Coal Environmental Management System Framework.

The EMS has been developed and implemented to ensure the effective management of environmental aspects and impacts and compliance with regulatory requirements while providing a means for continued improvement in the environmental performance at Springvale. The EMS incorporates a number of environmental management plans that are designed to assist in meeting community and regulatory expectations. The two management plans which are applicable to groundwater are the following:

- Environmental Monitoring Program

- Newnes Plateau Shrub Swamp Management Plan
- Surface Water Management System
- This management plan aims to coordinate the management of all surface water and groundwater within the Project Application Area.

As part of the relevant management plans performance measures and indicators have been designed to provide a link between monitoring data and the response triggers (triggers) that determine whether mining related impacts are occurring on the *THPSS*. Management actions are implemented if trigger levels are exceeded.

All triggers have been developed through statistical analysis of pre-mining monitoring data with post mining monitoring data used to determine whether trigger thresholds have been exceeded. Trigger values are dynamic and are reviewed and updated as more monitoring data are collected and added to the dataset. Trigger values have been defined for the following:

- Subsidence
- Flora.

No trigger values have been defined for groundwater, surface water or stream flow on the THPSS. The site water management plan should be updated to include water level triggers, where appropriate, on these systems. These triggers should relate to a percentage of saturated thickness. Should the groundwater levels observed in the swamp piezometers (in the surficial perched groundwater systems) exceed predicted drawdown by 20% or more for any consecutive three month period, allowing for typical climatic variation, then the monitoring data should be referred to an appropriately qualified hydrogeologist for review. The reviewer should assess the data to establish the necessity and reasons for it, and should recommend an appropriate response action plan for implementation, in consultation with the NSW Office of Water.

The proposed trigger of an exceedance by 20% is relative. For a predicted water level reduction of 10 m a 20% exceedance would equate to an observed drawdown of 1.2 m.

The response action plan *may* involve one of more of the following:

- Artificial discharge to impacted swamp
- Continuation of pumping and dewatering, with more regular monitoring
- No change to the operations.

Due to the natural variation in groundwater level and quality over time, a trigger level based on a specific water level or a specific groundwater quality concentration is not considered suitable.

Groundwater levels will vary across the Project Site in response to normal climatic variation. There will also be seasonal variation in groundwater quality due to natural changes in groundwater recharge over time. It is therefore recommended that the assessment is made based on the variation of levels and quality from the baseline range, together with the results of on-going monitoring program and in context with the predicted magnitude of variation due to the Project.

9.3 Review and Reporting

The existing monitoring and management plan for the THPSS systems should be updated to reflect the above monitoring recommendations. The collated monitoring data should be subjected to an annual review by an approved, experienced hydrogeologist in order to assess the impacts of the Project on the groundwater environment, and to compare any observed impacts with those predicted from groundwater impact modelling (Adhikary and Wilkins, 2013b, presented in Appendix K).

It is also recommended that, in accordance with industry best practice (Barnett *et al.*, 2012) a modelling post audit should be carried out following the excavation of the second longwall panel which roughly equates to two years following the initiation of mining of the proposed LW panels. Following this review, if necessary, the Project model should be re-calibrated and confirmatory forward impact predictions made in relation to the Project.

Further post-audits should be carried out at five-yearly intervals throughout the remainder of the Project, and at any other time should inflows or impacts vary significantly from predictions.

Should any review or post-audit indicate a significant variance from the model predictions with respect to groundwater levels, then the implications of such variance should be assessed and appropriate response actions implemented in accordance with the protocols described in the appropriate management plan.

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11. GLOSSARY OF TERMS

- Archaeology - the scientific study of human history, particularly the relics and cultural remains of the distant past.
- Aquifer - rock or sediment capable of holding and transmitting groundwater.
- Baseflow - the portion of streamflow that comes from the sum of deep subsurface flow and delayed shallow subsurface flow.
- Bore - a well, usually of less than 20 cm diameter, sunk into the ground and from which water is pumped.
- Catchment - the entire land area from which water (e.g. rainfall) drains to a specific water course or waterbody.
- Concentration - the amount of a substance, expressed as mass or volume, in a unit volume of air.
- Clay - very fine-grained sediment or soil (often defined as having a particle size less than 0.002 mm (2 microns) in diameter).
- Claystone – general term for a clastic sedimentary rock composed primarily of clay-sized particles (less than 1/256 millimetre in diameter).
- Confined aquifer – A confined aquifer lies between two aquitards. The hydraulic head in a confined aquifer lies above the base of the upper confining layer.
- Drawdown - the difference between the water level observed during pumping and the non-pumping water level (static water level or static head).
- Ecosystem - – a functional unit of energy transfer and nutrient cycling in a given place, it includes all the relationships within the biotic community and between the biotic components of the system.
- Electrical conductivity (EC) - the ability of a substance (either solid, liquid or gas) to transmit electricity – an indicator of salinity.
- Environmental Assessment - a formal description of a project and an assessment of its likely impact on the physical, social and economic environment. The Environmental Assessment is used as a vehicle to facilitate public comment and as the basis for analysing the project with respect to granting approval under relevant legislation.
- Ephemeral (waterbody) - is a wetland, spring, stream, river, pond or lake that only exists for a short period following precipitation.
- Evaporation - the loss of water as vapour from the surface of a liquid that has a temperature lower than its boiling point.
- Evapotranspiration - the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere.
- Groundwater - all waters occurring below the land surface; the upper surface of the soils saturated by groundwater in any particular area is called the water table.
- Groundwater Dependent Ecosystem (GDE) – Ecosystems defendant on current groundwater conditions.
- Groundwater discharge - an area on the surface that intersects a groundwater aquifer, allowing it to discharge to the surface.
- Heavy metals - normally trace metals which occur in ore deposits and may be environmentally hazardous.
- Hydraulic conductivity (K) - the rate of flow of water in an aquifer through a cross section of unit area under a unit hydraulic gradient, at the prevailing temperature. Usually expressed in units of metres per second or metres per day.
- Hydraulic Testing – Tests conducted on aquifers that provide an understanding of the physical properties.
- Hydrology - the study of water, particularly its movement in streams, rivers, or underground.

- In-Situ - a term used to describe material (e.g. rocks, minerals, fossils, etc.) prior to transport.
- Intermittent – flows periodically, irregularly.
- Longwall mining – Underground mining of coal seams. Longwall shearer has a face of 300m or more and rotating drum that moves mechanically back-and-forth across a coal seam.
- Longwall goaf – The open area left behind the longwall where coal has been extracted, will collapse.
- Monitoring - systematic sampling and, if appropriate, sample analysis to record changes over time caused by impacts such as mining.
- Mudstone – general term for a fine grained sedimentary rock whose original constituents were clays or muds. Grain size is up to 0.0625 mm (0.0025 in) with individual grains too small to be distinguished without a microscope.
- Overburden - subsoil and decomposed rock overlying the main rock body that is not suitable for use in the final product.
- Perennial (waterbody) - is a stream or river (channel) that has continuous flow in parts of its stream bed all year round during years of normal rainfall.
- Perched Groundwater - groundwater accumulated at an elevation above the regional aquifer water level usually above a low-permeability unit or strata.
- Permeability - a material property relating to the ability of the material to transmit water.
- pH - a measure of the degree of acidity or alkalinity of a solution; expressed numerically (logarithmically) on a scale of 1 to 14, on which 1 is most acid, 7 is neutral acid, and 14 is most basic (alkaline).
- Piezometer - a hole drilled and fitted specifically for the monitoring of groundwater levels and water quality.
- Piezometric level
- Phreatic surface
- Recharge - the addition of water to an aquifer.
- Recovery - the difference between the water level during the recovery period following pumping and the maximum drawdown when pumping stops.
- Rehabilitation - the progressive formation of a landform after quarrying and its stabilisation with grasses, trees and/or shrubs.
- Riparian - pertaining to or situated on the bank of a river or creek.
- Runoff - the portion of the rainfall falling on a catchment area that flows from the catchment past a specified point.
- Salinity – degree of salt content of water.
- Sand - sediment comprising particles in 0.063mm to 2mm size range.
- Sandstone - general term for sedimentary rock with grain size from 0.063mm to 2mm - grains may be minerals or rock fragments.
- Sediment - naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported.
- Siltstone - - general term for clastic sedimentary rock primarily composed of silt sized particles, defined as grains 1/16 - 1/256 mm.
- Steady State Flow – Steady state flow occurs when, at any point in a flow field, the magnitude and direction of the flux are constant with time.
- Topography - the physical relief and contour of a region.
- Throughflow - the horizontal movement of water in the subterranean environment.
- Tributary - a stream or river that flows into a larger river or lake.
- Vibrating Wireline Piezometers – Transducer that converts water pressure to a measureable frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil.

- Water level - the upper limit of the saturated zone within an unconfined rock mass, generally at atmospheric pressure. For confined aquifers the water level is represented by the pressure head of the confined zone.
- Water quality - degree of the lack of contamination of water.