APPENDIX C

GROUNDWATER ASSESSMENT

WILPINJONG EXTENSION PROJECT

Groundwater Assessment

FOR

Wilpinjong Coal Pty Ltd

BY

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trading as

HydroSimulations

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1 INTRODUCTION

The Wilpinjong Coal Mine (WCM) is an existing open cut coal mining operation situated approximately 40 kilometres (km) north-east of Mudgee, near the Village of Wollar, within the Mid-Western Regional Council Local Government Area, in central New South Wales (NSW) (**Figure 1-1**).

The WCM is owned and operated by Wilpinjong Coal Pty Limited (WCPL), a wholly owned subsidiary of Peabody Energy Australia Pty Limited. Mining is currently undertaken within Mining Lease (ML) 1573 and the approved open cut and contained infrastructure area at the WCM comprises approximately 1,990 hectares (ha).

The WCM was approved under Part 3A of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) by the NSW Minister for Planning in February 2006 (Project Approval 05-0021). The mine has been operating since 2006, and is approved to produce up to 16 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal from six open cut pits, noting that Pit 3 was subdivided into Pit 3 (north) and Pit 7 (south) for internal mine planning.

This groundwater assessment will form a component of the Environmental Impact Statement (EIS) to be lodged for the Wilpinjong Extension Project (WEP) under Part 4 of the EP&A Act.

1.1 THE WILPINJONG EXTENSION PROJECT (WEP)

The WEP would include the following activities:

- open cut mining of ROM coal from the Ulan Coal Seam and Moolarben Coal Member in ML 1573 and in new Mining Lease Application areas in Exploration Licence (EL) 6169 and EL 7091;
- approximately 800 ha of open cut extensions including:
  - approximately 500 ha of incremental extensions to the existing open cut pits in areas of ML 1573 and EL 6169;
  - development of a new open cut pit of approximately 300 ha in EL 7091 (Pit 8);
- continued production of up to 16 Mtpa of ROM coal;
- continued use of the WCM Coal Handling and Preparation Plant (CHPP) and general coal handling and rail loading facilities and other existing and approved supporting mine infrastructure;
- rail transport of approximately 13 Mtpa of thermal product coal to domestic and export customers (within existing maximum and annual average daily rail limits);
- relocation of a section of the TransGrid Wollar to Wellington 330 kilovolt electricity transmission line (ETL) to facilitate mining in Pit 8;
- various local infrastructure relocations to facilitate the mining extensions (e.g. realignment of Ulan-Wollar Road and associated rail level crossing, relocation of local ETLs and services);
- construction and operation of additional mine access roads to service new mining facilities located in Pits 5 and 8;
- construction and operation of new ancillary infrastructure in support of mining including mine infrastructure areas, ROM pads, haul roads, electricity supply, communications installations, light vehicle roads, access tracks, remote crib huts, up-catchment diversions, dams, pipelines and other water management structures;
- extension of the approved mine life by approximately seven years (i.e. from approximately 2026 to 2033);
- a peak operational workforce of approximately 625 people;

- ongoing exploration activities; and
- other associated minor infrastructure, plant and activities.

More detail on the historic, approved and proposed activities at WCM is provided in Section 2 of the Main Report of the EIS.

1.2 SCOPE OF WORK

The key tasks for this assessment, while relying in part on the previous Groundwater Assessment for the Wilpinjong Mine Modification 5 (HydroSimulations, 2013) and for the original project approval (Australian Groundwater and Environmental Consultants [AGE], 2005), are:

- Characterisation of the existing groundwater resources information including review of existing and recent groundwater datasets and monitoring regimes available from the WCM and surrounding mines/projects (current Moolarben Coal Complex and Ulan Mine Complex assessments and approvals), such as:
  - water level and water chemistry data sets;
  - available geological and hydrogeological mapping, drill logs and reports pertaining to extension areas;
  - available records for licensed and un-licensed groundwater users in the vicinity of Wilpinjong;
  - any other additional results from the current groundwater investigation program or supplementary testwork and mapping; and
  - the proposed mine plan for the WEP.
- Revise the current conceptual model for the WEP area and surrounds.
- Build a new numerical groundwater flow model for the area, based on, but broader than the previous AGE (2005) model, taking in account existing and recent data.
- Calibrate the numerical model for the WEP so that it is capable of predicting potential impacts in accordance with the NSW Aquifer Interference Policy ('AI Policy').
- Model the proposed WEP during operations and post closure.
- Regional groundwater modelling of the cumulative impacts of the WEP concurrently with the neighbouring Moolarben Coal Complex and any other nearby significant users of groundwater:
  - review and assessment of groundwater licensing requirements;
  - potential WCM and cumulative impacts on alluvial and hard rock groundwater sources (including impacts of the water supply borefield on alluvial water sources);
  - potential WCM and cumulative impacts on creeks/streams (with estimation of the loss of baseflows as a result of hard rock depressurisation from mining compared with natural variations in different baseflow regimes); and
  - potential WCM and cumulative impacts on other groundwater users.
- An assessment of the potential impacts of the WEP on groundwater quality, as well as cumulative impacts on groundwater quality.
- Identification of the data and model constraints and limitations.
- Discussion of the potential impacts of climate change.
- Discussion of measures to avoid, mitigate and/or remediate potential impacts on groundwater resources.
- A recommended augmentation of the existing groundwater monitoring programme to measure potential impacts on groundwater resources, and associated auditing and complaint response measures.

- Provision of the Groundwater Assessment report and any necessary supporting data for groundwater peer review.

Analysis and assessment has been carried out with consideration of the following groundwater-related technical and policy guidelines:

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and New Zealand and Australian and New Zealand Environment and Conservation Council [ARMCANZ/ANZECC]).
- AI Policy (NSW Office of Water [NOW]), September 2012.
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]).
- NSW State Groundwater Quality Protection Policy (DLWC).
- NSW State Groundwater Quantity Management Policy (DLWC) Draft.
- NSW Groundwater Dependent Ecosystem Policy (DLWC).
- Groundwater Modelling Guidelines, namely:
    - Murray-Darling Basin Groundwater Quality. Sampling Guidelines. Technical Report No 3 (Murray-Darling Basin Commission [MDBC]); and
    - Australian National Groundwater Modelling Guidelines, published by the National Water Commission (Barnett *et al*, 2012).
- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change).

The surface water components of the assessment for the WEP, including consideration of final voids, are provided separately in the Surface Water Assessment (WRM Water & Environment, 2015) which in turn builds on previous surface water assessments.

As part of the assessment process for the WEP, an Environmental Risk Assessment was undertaken in January 2013. The following potential groundwater related issues were identified and have been considered in this assessment:

- incremental reduced base flow to creeks due to groundwater depressurisation effects;
- incremental induced leakage from creeks due to groundwater depressurisation effects;
- potential groundwater depressurisation effects on National Park and Nature Reserve;
- removal of Slate Gully and Wilpinjong Creek alluvium; and
- potential incremental and direct impacts on springs.

This Groundwater Assessment has been prepared in consideration of the AI Policy (NOW, 2012). The numerical groundwater model has been carried out and reviewed by Frans Kalf of Kalf and Associates, in consideration of the *Australian Groundwater Modelling Guidelines* (Barnett *et al*., 2012).

1.3 GROUNDWATER MANAGEMENT

The WCM is located within or near the Groundwater Management Areas (GMAs) listed in **Table 1-1**, as defined by NSW Department of Planning and Infrastructure (DPI) (formerly NOW). These are listed in order of proximity to the WCM, and are shown in **Figure 1-2**.

Table 1-1 Groundwater Management Areas Relevant to WCM

Sydney Basin – Upper Hunter GMA (which will be managed within *North Coast Fractured and Porous Rock Groundwater Sources WSP* – this is yet to be completed*.	Mine located within this proposed GMA.
'Wollar Creek Water Source' of the Goulburn Extraction Management Unit which is governed by the *Hunter Unregulated and Alluvial Water Sources WSP*, commenced 2009.	This GMA covers the alluvium to 200-300 metres (m) north and northeast of the WCM and Slate Gully area and Wollar Creek to the east.
Sydney Basin – Macquarie-Bogan GMA (within the *NSW Murray Darling Basin Porous Rock Groundwater Sources* Plan - commenced 2011).	This GMA is approximately 6 km south of the WCM.
Lachlan Fold Belt GMA (within the NSW Murray Darling Basin Fractured Rock Groundwater Sources Plan - commenced 2011).	This GMA is approximately 7 km west of the WCM.
Oxley Basin GMA (managed under both the NSW Murray Darling Basin Fractured Rock Groundwater Sources Plan and NSW Murray Darling Basin Porous Rock Groundwater Sources Plan.	Located 8 km north-west of WCM.
Liverpool Ranges Basalt GMA (managed under both the NSW Murray Darling Basin Fractured Rock Groundwater Sources Plan).	Located 21 km north-west of WCM.

* because it is still to be finalised, this area is under the *Water Act 1912*.

Of the areas within or immediately around the WCM, water resources are currently managed under one active Water Sharing Plan (WSP). The WCM and the WEP lie wholly within the boundary of the 'Wollar Creek Water Source' of the Goulburn Extraction Management Unit which is governed by the *Hunter Unregulated and Alluvial Water Sources WSP* and the *Water Management Act 2000*. Within the plan, the watercourses within the Wollar Creek Water Source are defined as "highly connected". This plan commenced in August 2009. This plan does not cover non-alluvial or hard-rock groundwater systems.

The hard-rock areas are covered by the Sydney Basin – Upper Hunter GMA which is to be governed by the *North Coast Fractured and Porous Rock Groundwater Sources WSP*; however, this WSP is currently under development by DPI Water Therefore licensing of the water take from the coal seams and adjacent hard-rock remains governed by Part 5 of the *Water Act 1912*.

Section 60 of the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* indicates that there is no unassigned total daily extraction limit water in any of the water sources covered by the plan, including the Wollar Creek Water Source.

Applications can be made for further entitlement from the fractured and porous rock aquifers around WCM, and no estimate of Unassigned Water has yet been made or declared for these due to the relevant *North Coast Fractured and Porous Rock Groundwater Sources WSP* still being under development.

1.3.1 GROUNDWATER EMBARGO ZONES

NOW currently have an embargo on groundwater resource licences in 'Coastal alluvial groundwater sources' that are not yet managed by a WSP under the *Water Management Act 2000*[1]. The alluvium near WCM, in the Wollar Creek Water Source, is a 'coastal alluvial aquifer' ('coastal' because it is part of a river system that is east of the Great Dividing Range and flows to the NSW coast), however this body of alluvium is managed under the active Hunter Unregulated and Alluvial WSP. Therefore the embargo does not apply to the area around WCM.

[1] http://www.water.nsw.gov.au/Water-management/Water-availability/Groundwater/avail_ground_embago/default.aspx

1.3.2 GROUNDWATER PRODUCTIVITY

The AI Policy establishes minimal impact considerations for 'Highly Productive' and 'Less Productive' groundwater. Based on information received from NOW (dated June 2013), 'Highly Productive' groundwater is restricted to the alluvium associated with the Wollar Creek Water Source, i.e. along reaches of Wilpinjong Creek (below the confluence with Cumbo Creek) and Wollar Creek. At its closest this is about 200-300 m northeast (downstream) of the WCM (see **Figure 1-3**). The remainder of the alluvium and hard-rock aquifer are classified by NOW as 'Less Productive' groundwater.

1.3.3 BIOPHYSICAL STRATEGIC AGRICULTURAL LAND

Biophysical Strategic Agricultural Land (BSAL) has been mapped across parts of NSW as part of the Strategic Regional Land Use Policy (SRLUP). **Figure 1-1** shows that BSAL is not mapped at the WCM. This policy is aimed at managing potential conflict between extractive and agricultural industries in defined areas of high quality agricultural land. If BSAL is present at a mine project, a 'Gateway' Assessment of groundwater may be required. BSAL mapping is relevant to 'greenfield' projects, and to 'brownfield' projects where the mine is proposed to expand beyond the existing lease area[2], as is the case here.

An investigation of soil and agricultural potential carried out for WCPL (McKenzie Soil Management, 2014) has indicated that BSAL is not present at the WCM, including within the Slate Gully extension area (Pit 8). As a result a Site Verification Certificate (SVC) has been issued by the NSW Department of Planning[3], and therefore a Gateway Assessment was not required for the WEP.

1.4 REQUIREMENTS FOR THE ENVIRONMENTAL IMPACT STATEMENT

The Secretary's Environmental Assessment Requirements (SEARs) for the WEP were issued by the DP&E on 9 December 2014 and 22 June 2015. Relevant government agencies provided input into the SEARs, including NOW (now DPI Water).

[2] http://www.mpgp.nsw.gov.au/docs/Guideline%20for%20Gateway%20Applicants.pdf
[3] SVC 6667, issued 17 October 2014.
http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6667

1.4.1 SECRETARY FOR THE NSW DEPARTMENT OF PLANNING AND ENVIRONMENT'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS

The SEARs related to groundwater are as follows:

General

REQUIREMENT	REPORT SECTION
A description of the existing environment likely to be affected by the development, using sufficient baseline data.	Section 3
An assessment of the likely impacts of all stages of the development, including any cumulative impacts, taking into consideration any relevant laws, environmental planning instruments, guidelines, policies, plans and industry codes of practice.	Sections 4-7
A description of the measures that would be implemented to mitigate and/or offset the likely impacts of the development, and an assessment of: ▪ Whether these measures are consistent with industry best practice, and represent the full range of reasonable and feasible mitigation measures that could be implemented. ▪ The likely effectiveness of these measures where relevant; and ▪ Whether contingency plans would be necessary to manage any residual risks.	Sections 2.2.2, 3.8.2 and 7
A description of the measures that would be implemented to monitor and report on the environmental performance of the development if it is approved.	Sections 2.2.2, 3.8.2 and 7

Water

▪ an assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources, having regard to the OEH's, EPA's and DPI's (NOW's) requirements.	Sections 6 and 7. See following tables for specific Agency comments.
▪ an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users; and	Sections 6 and 7.
▪ an assessment of the likely flooding impacts of the development;	Surface Water Assessment (WRM Water & Environment, 2015)

1.4.2 NSW OFFICE OF WATER'S INPUT TO SEARS

NOW also supplied comments on the EIS requirements (in a NOW document, dated 25/11/2014). This document raised general issues as follows:

▪ Details of water proposed to be taken (including through inflow and seepage) from each surface and groundwater source as defined by the relevant water sharing plan, for the proposed extension.	Sections 6.7, 6.8, and 7.1.1
▪ Assessment of any volumetric water licensing requirements (including those for ongoing water take following completion of the project).	Sections 6.7, 6.8, and 7.1.1
▪ The identification of an adequate and secure water supply for the proposed extension. Confirmation that water can be sourced from an appropriately authorised and reliable supply. This is to include an assessment of the current market depth where water entitlement is required to be purchased.	Section 7.1.1
▪ A detailed and consolidated site water balance.	WRM Water & Environment (2015)
▪ A detailed assessment against the NSW Aquifer Interference Policy (2012) using the NSW Office of Water's assessment framework.	Section 7

▪	Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, wetlands, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 7
▪	Full technical details and data of all surface and groundwater modelling, and an independent peer review.	Sections 5 and 6 and Attachment 4 of the EIS
▪	Proposed surface and groundwater monitoring activities and methodologies.	Sections 5 and 6
▪	Proposed management and disposal of produced or incidental water.	WRM Water & Environment (2015)
▪	Details surrounding the final landform of the site, including final void management (where relevant) and rehabilitation measures.	Section 2.2, Figure 2-4, WRM Water & Environment (2015) and Section 5 of the EIS
▪	Assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.	Section 6
▪	Consideration of relevant policies and guidelines.	Sections 1.3 and 1.4
▪	Assessment of whether the activity may have a significant impact on water resources, with reference to the Commonwealth Department of Environment Significant Impact Guidelines.	Sections 4.7 and 4.8 of the EIS
▪	If the activity may have a significant impact on water resources, then provision of information in accordance with the Information Guidelines for Independent Expert Scientific Committee [IESC] advice on coal seam gas and large coal mining development proposals, including completion of the information requirements checklist.	Sections 4.7 and 4.8 of the EIS
▪	A statement of where each element of the SEARs is addressed in the EIS (i.e. in the form of a table).	Section 1.4.

In addition, NOW provided the following additional comments:

Water Sharing Plans

The proposal is located within the area covered by the WSP for the Hunter Unregulated and Alluvial Water Sources 2009. The EIS is required to:

▪	Demonstrate how the proposal is consistent with the relevant rules of the Water Sharing Plan including rules for access licences, distance restrictions for water supply works and rules for the management of local impacts in respect of surface water and groundwater sources, ecosystem protection (including groundwater dependent ecosystems), water quality and surface-groundwater connectivity.	Section 7
▪	Provide a description of any site water use (amount of water to be taken from each water source) and management including all sediment dams, clear water diversion structures with detail on the location, design specifications and storage capacities for all the existing and proposed water management structures.	WRM Water & Environment (2015)
▪	Provide an analysis of the proposed water supply arrangements against the rules for access licences and other applicable requirements of any relevant WSP, including: ▫ Sufficient market depth to acquire the necessary entitlements for each water source. ▫ Ability to carry out a "dealing" to transfer the water to relevant location under the rules of the WSP. ▫ Daily and long-term access rules. ▫ Account management and carryover provisions.	Sections 2.2.1 and 7.1.1
▪	Provide a detailed and consolidated site water balance.	WRM Water & Environment (2015)

Licensing Considerations

The EIS is required to provide:

▪ Identification of water requirements for the life of the project in terms of both volume and timing (including predictions of potential ongoing groundwater take following the cessation of operations at the site – such as evaporative loss from open voids or inflows).	WRM Water & Environment (2015), Section 7.1.1
▪ Details of the water supply source(s) for the proposal including any proposed surface water and groundwater extraction from each water source as defined in the relevant Water Sharing Plan/s and all water supply works to take water.	Section 7.1.1
▪ Explanation of how the required water entitlements will be obtained (i.e. through a new or existing licence/s, trading on the water market, controlled allocations etc).	Section 7.1.1
▪ Information on the purpose, location, construction and expected annual extraction volumes including details on all existing and proposed water supply works which take surface water, (pumps, dams, diversions, etc).	Sections 2.2.1, 6.2.5 and 7.1.1
▪ Details on all bores and excavations for the purpose of investigation, extraction, dewatering, testing and monitoring. All predicted groundwater take must be accounted for through adequate licensing.	Sections 2.2.1, 6.2.5 and 7.1.1
Water allocation account management rules, total daily extraction limits and rules governing environmental protection and access licence dealings also need to be considered.	WRM Water & Environment (2015), Sections 2.2.1 and 7.1.1 and Attachment 6 of the EIS

Groundwater Assessment

To ensure the sustainable and integrated management of groundwater sources, the EIS needs to include adequate details to assess the impact of the WEP on all groundwater sources including:

▪ Works likely to intercept, connect with or infiltrate the groundwater sources.	Sections 2 and 6.2
▪ Any proposed groundwater extraction, including purpose, location and construction details of all proposed bores and expected annual extraction volumes.	Sections 2 and 6.2
▪ Bore construction information is to be supplied to the Office of Water by submitting a "Form A" template. The Office of Water will supply "GW" registration numbers (and licence/approval numbers if required) which must be used as consistent and unique bore identifiers for all future reporting.	Section 2.2.1
▪ A description of the water table and groundwater pressure configuration, flow directions and rates and physical and chemical characteristics of the groundwater source (including connectivity with other groundwater and surface water sources).	Section 3
▪ Sufficient baseline monitoring for groundwater quantity and quality for all aquifers and GDEs to establish a baseline incorporating typical temporal and spatial variations.	Section 3.8.2
▪ The predicted impacts of any final landform on the groundwater regime.	Sections 2.2 and 6.9
▪ The existing groundwater users within the area (including the environment), any potential impacts on these users and safeguard measures to mitigate impacts.	Sections 3.3, 3.6, 6.6 and 6.8
▪ An assessment of groundwater quality, its beneficial use classification and prediction of any impacts on groundwater quality.	Sections 3.9 and 3.5
▪ An assessment of the potential for groundwater contamination (considering both the impacts of the proposal on groundwater contamination and the impacts of contamination on the proposal).	Section 7.1.6
▪ Measures proposed to protect groundwater quality, both in the short and long term.	Sections 3.8.2 and 7.3.2 and GEM (2015)
▪ Measures for preventing groundwater pollution so that remediation is not required.	Sections 7.1.6 and 7.3.2
▪ Protective measures for any groundwater dependent ecosystems (GDEs).	Section 3.8.2

▪ Proposed methods of the disposal of waste water and approval from the relevant authority.	Section 2.2.1 and WRM Water & Environment (2015)
▪ The results of any models or predictive tools used.	Sections 5, 6
Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users, including information on:	
▪ Any proposed monitoring programs, including water levels and quality data.	Sections 3.8.2 and 7.3.2
▪ Reporting procedures for any monitoring program including mechanism for transfer of information.	WCPL Surface and Groundwater Response Plan
▪ An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal.	Section 7.1
▪ Identification of any nominal thresholds as to the level of impact beyond which remedial measures or contingency plans would be initiated (this may entail water level triggers or a beneficial use category).	WCPL Surface and Groundwater Response Plan
▪ Description of the remedial measures or contingency plans proposed.	Sections 3.8.2 and 7.3
▪ Any funding assurances covering the anticipated post development maintenance cost, for example on-going groundwater monitoring for the nominated period.	WCPL Water Management Plan

Groundwater Dependent Ecosystems

The EIS must consider the potential impacts on any Groundwater Dependent Ecosystems (GDEs) at the site and in the vicinity of the site and:

▪ Identify any potential impacts on GDEs as a result of the proposal including:	Section 3.8.2
▫ the effect of the proposal on the recharge to groundwater systems	Sections 4.1 and 4.3
▫ the potential to adversely affect the water quality of the underlying groundwater system and adjoining groundwater systems in hydraulic connections; and	Sections 3.9, 4 and 7.1.5
▫ the effect on the function of GDEs (habitat, groundwater levels, connectivity).	Sections 3.3, 3.6 and 7.2.3
▪ Provide safeguard measures for any GDEs.	Sections 3.8.2 and 7.2.3

1.4.3 NSW OFFICE OF ENVIRONMENT AND HERITAGE INPUT TO SEARS

The NSW Office of Environment and Heritage (OEH) provided comments on the EIS requirements (in OEH correspondence dated 18 November 2014 - #DOC14/259901-01). This document raised general issues as follows:

Water and Soils

5. The EIS must map the following features relevant to water and soils including:	
a. Acid sulfate soils (Class 1, 2, 3 or 4 on the Acid Sulfate Soil Planning Map).	McKenzie Soil Management (2015)
b. Rivers, streams, wetlands, estuaries (as described in Appendix 2 of the Framework for Biodiversity Assessment).	Sections 3.3 and 3.6
c. Groundwater	Section 3.8
d. Groundwater dependent ecosystems.	Section 3.6
e. Proposed intake and discharge locations.	Section 2.2

6. The EIS must describe background conditions for any water resource likely to be affected by the Wilpinjong Extension Project, including:	
a. Existing surface and groundwater.	Section 3
b. Hydrology (volume, frequency and quality) at proposed intake and discharge points.	Section 3.3, WRM Water & Environment (2015)
c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters.	Sections 3.3, 3.5 and 3.9
d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Sections 3.3, 3.5 and 3.9
7. The EIS must assess the impacts of the WEP on water quality, including:	
a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the Wilpinjong Extension Project protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction.	Sections 3.3, 3.5, 3.8.2, 3.9, WRM Water & Environment (2015)
b. Identification of proposed monitoring of water quality.	Sections 3.8.2 and 7.3
8. The EIS must assess the impact of the Wilpinjong Extension Project on hydrology, including:	
a. Water balance including quantity, quality and source.	WRM Water & Environment (2015)
b. Effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas.	WRM Water & Environment (2015) and Section 7.2
c. Effects to downstream water-dependent fauna and flora including groundwater dependent ecosystems.	Section 7.2
d. Impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (e.g. river benches).	WRM Water & Environment (2015)
e. Changes to environmental water availability, both regulated/licensed and unregulated/rules-based sources of such water.	Section 7.2 and WRM Water & Environment (2015)
f. Mitigating effects of proposed stormwater and wastewater management during and after construction on hydrological attributes such as volumes, flow rates, management methods and re-use options.	WRM Water & Environment (2015)
g. Identification of proposed monitoring of hydrological attributes.	WRM Water & Environment (2015) and Section 3.3

Cumulative Impact

D. The cumulative impacts from all clearing activities and operations, associated edge effects and other indirect impacts on cultural heritage, biodiversity and OEH Estate need to be comprehensively assessed in accordance with the *Environmental Planning and Assessment Act 1979.* This should include the cumulative impact of the proponent's existing and proposed development and associated infrastructure (such as access tracks etc.) as well as the cumulative impact of other developments located in the vicinity such as Moolarben Coal Project, including the effect on habitat connectivity in the area. This assessment should include consideration of both construction and operational impacts.	Sections 6.6 and 6.8

1.4.4 NSW ENVIRONMENT PROTECTION AUTHORITY INPUT TO SEARS

The NSW Environment Protection Authority (EPA) also provided comments on the EIS requirements (in EPA correspondence dated 13 November 2014). This document raised general issues as follows:

The environmental outcomes of the project in relation to water should be:

▪ There is no pollution of waters (including surface and groundwater);	Sections 7.1.5 and 7.1.6

As well, as (stating only those points relevant to groundwater):

1. Describe existing surface and groundwater quality. An assessment needs to be undertaken for any water resource likely to be affected by the proposal.	Sections 3.3 and 3.9
2. Describe any drainage lines, creeks etc. that will be impacted by the project	Sections 3.3 and 6.8
4. Describe the Project including the position of any intakes and discharges, volumes, water quality and frequency of all water discharges (e.g. surface water discharge to river, creek, groundwater, irrigation of waste water etc.)	Section 2.2.1
5. Assess the nature and degree of impact of any proposed discharges may have on the receiving environment.	WRM Water & Environment (2015)
7. Identify potential impacts on watercourses and the management/mitigation measures that will be implemented where mining activities occur in proximity to or within a watercourse.	Sections 4.1, 3.3 and 3.8.2
13. State the Water Quality Objectives for the receiving waters relevant to the proposal. Where groundwater may be impacted the assessment should identify appropriate groundwater environmental values.	Sections 3.3, 3.5 and 3.9
14. State the indicators and associated trigger values or criteria for the identified environmental values. This information should be sourced from the ANZECC (2000) Guidelines for Fresh and Marine Water Quality.	Sections 3.3, 3.5 and 3.9
15. State any locally specific objectives, criteria or targets which have been endorsed by the NSW Government.	Sections 3.3 and 3.9
16. Assess impacts on groundwater and groundwater dependent ecosystems. The assessment should be guided by the principles in the NSW State Groundwater Policy Framework Document (DLWC, 1997). Assessment and Management of Groundwater Contamination (DEC, 2007) provides guidance on assessing and managing groundwater contamination. Assess impacts against relevant water quality guidelines for: ▫ Potentially impacted environmental values and beneficial uses using local Water Quality Objectives; ▫ Contamination, such as investigation levels specified in National Environment Protection Measure Guideline on the Investigation Levels for Soil and Groundwater (EHPC, 1999).	Section 3.6, 6.6 and 7.2.3
19. Describe how predicted impacts on surface water, groundwater and aquatic ecosystems will be monitored and assessed over time, including monitoring locations, parameters and sampling frequency. The EIS should: ▫ Include a Trigger Action Response Plan (TARP) or similar management plan to identify appropriate trigger values and criteria and provide appropriate response actions if impacts are identified through the monitoring program. ▫ Identify the process for identifying any trends in the monitoring data obtained.	Sections 3.3, 3.5, 3.8 and 3.9, WRM Water & Environment (2015)

Monitoring, Assurance and Reporting Programs

1. The EIS should include a detailed assessment of any …. Water quality monitoring required during the construction phase and on-going operation of the facility to prevent or minimise any adverse environmental impacts from the development.	Sections 0 and 3.8.2
2. Appropriate baseline data requirements are to be identified as part of the EIS, to form the basis for baseline and ongoing monitoring of environmental parameters.	Sections 3.8.2, 3.3 and 3.9.2

3. It must be demonstrated that the proposed methods for monitoring are scientifically robust and statistically sound.	Sections 0, 3.8.2, 3.3 and 3.9.2
4. The EIS must also identify and describe monitoring programs, compliance assurance programs and reporting requirements and arrangements that will demonstrate the effectiveness of proposed management measures in meeting applicable requirements.	Sections 0, 3.8.2 and 7.3
5. The EIS must clearly identify what is to be monitored and audited and why. This should include identification of monitoring locations, parameters to be monitored, analysis methods, and the level of reporting. The EIS should also include information on frequency and type of audits proposed to assure compliance with applicable requirements.	Sections 0, 3.8.2, 3.3, 3.9.2 and 7.3
6. The EIS should demonstrate monitoring and audit programs are designed to best practice, to provide objective evidence regarding activities associated with the development and regard to whether these activities are adversely impacting on the environment in the short, medium and long term.	Sections 0, 3.8.2, 3.3, 3.9.2 and 7.3

Cumulative Impacts

The EIS should provide an assessment of the cumulative impacts of the project during construction and operation of the proposal with regard to…. water quality. Assessment of cumulative impacts must consider past, current and future activities in the area surrounding the project, impacts associated with internal components of this project (where relevant – e.g. a project involving construction through a precinct or similar) as well as the construction impacts of any projects recently completed.	Sections 6 and 7

1.4.5 DEPARTMENT OF ENVIRONMENT / EPBC TERMS OF REFERENCE

The Federal Department of the Environment (DoE) is responsible for administering the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

A referral including a supporting assessment of significance for each threatened species and community must be made to the DoE to obtain confirmation of whether or not a project constitutes a “controlled action”. A controlled action is a proposed development or activity that will have, or is likely to have, a significant impact on ‘matters of national environmental significance’ (MNES). Similarly, the referral is likely to require the inclusion of information on the potential impacts that the project may have upon water resources to confirm whether or not the project constitutes a controlled action. The Project was deemed a controlled action on 12 March 2015.

The EPBC Act establishes an environmental assessment and approval process for controlled actions. The Commonwealth Minister for the Environment has the power to accredit the Environmental Impact Assessment process under the NSW EP&A Act to meet the assessment requirements of the EPBC Act. On 26 February 2015, the Commonwealth Minister for the Environment reached a Bilateral Agreement with the NSW Government which accredits the NSW planning approvals system for the assessment of a Controlled Action and its impacts upon MNES. However, the ultimate approval authority remains with the Commonwealth Minister for the Environment. The Controlled Action cannot be carried out until the Minister has granted approval under section 133 of the EPBC Act.

It should be noted that the action that requires assessment under the EPBC Act relates to those aspects of the proposed Project that would include extension of open cut mining operations and consequent additional disturbance areas, and associated surface infrastructure that is necessary to support the extension of open cut mining.

The action does not include the approved WCM that has either been previously referred and determined not to be a Controlled Action or previously determined not to require referral under the EPBC Act but has received all relevant State approvals. In addition the elements of the Project which require EPBC Act approval exclude the continuation of mining operations in the open cut pits and associated activities which are currently authorised by existing approvals (including modifications and exploration activities).

The DoE has provided its requirements for the WEP (dated 16 June 2015), and the MNES relevant to this Groundwater Assessment include:

Water Resources

Impacts to the surface water quality and/or hydrology of Wollar, Wilpinjong and Cumbo Cks.	Sections 6.8 and 7.2
Impacts to Groundwater, Groundwater Users and Groundwater Dependant Ecosystems.	Section 7.1
Cumulative impacts on water resources.	Sections 6.6, 6.8, 7.1 and 7.2

Further, the assessment is to include discussion regarding a Description of the Action (i.e. the proposed development), environment including MNES, predicted impacts, avoidance and mitigation measures, and any residual effects.

2 EXISTING AND PROPOSED OPERATIONS

The following subsections describe the background to the WEP, the history of coal mining at Wilpinjong, the water licences held by WCM, as well as the current plan and schedule for the proposed WEP.

Two terms are used frequently in the following sections and are defined as:

- **Project area** – the area within and immediately around the WCM tenements; and
- **Study area** – a larger 40 x 40 km area, as shown on **Figure 1-1**, and defined as such to encompass the geological and hydrological features that might be important to the WEP and to the numerical model built for the purpose of impact assessment.

2.1 BACKGROUND

The WCM has been operating since 2006, and has had a number of Modifications approved since that time, including Modification 5 (approved in February 2014) and Modification 6 (approved in November 2014). The original approval and subsequent approved Modifications cover the areas identified in **Figure 2-1**.

The WCM extracts coal via open cut mining methods, and because the Ulan Coal Seam is quite close to the surface (within tens of metres), it therefore has one of the lowest strip ratios of any operating coal mine in NSW.

2.2 EXISTING OPERATIONS

Figure 2-2 presents a plan showing the existing development of the WCM as well as the proposed development under the WEP. This figure, along with **Figure 2-1** provides spatial context to the following subsections.

ML 1573 covers the approved mine area, with all excavated and active pits (Pits 1-6 and the newly named Pit 7, which was formerly the southern half of Pit 3) within its limits. As of the end of 2014, Pit 6 had not yet commenced, but full or partial excavation of the other pits has occurred.

Over 120 groundwater bores have been installed by WCPL within and around the WCM area, some as pumping bores (**Section 2.2.1**) and most as part of the monitoring bore network of (**Section 3.8.2**).

WCM operate a number of surface water storages and tailings dams around the site, and diversions up-gradient of the pits. A reverse osmosis (RO) plant has been installed to allow on-site treatment of waste water and subsequent discharge to Wilpinjong Creek in accordance with an Environment Protection Licence (EPL).

In July 2013, WCPL submitted an application to modify Project Approval 05-0021 under section 75W of the EP&A Act ('Modification 5') which sought upgrade of the RO Plant to a water treatment facility with the addition of pre-filtration and flocculation/dosing facilities to improve plant efficiency. Modification 5 was approved by the Planning Assessment Commission (as a delegate of the NSW Minister for Planning and Infrastructure) on 7 February 2014 however the upgrades have not yet been made. Therefore, references to RO plant in this document should also be read as water treatment facility when these upgrades are implemented in future.

Active mining is proposed to cease in Pit 2 in approximately 2022, however water and tailings storages located within the Pit 2 area would continue to be used as part of the proposed WEP (**Figure 2-1**).

Within ML1573, WCPL has approval, under the existing project approval, to re-align the lower reach of Cumbo Creek in order to mine under the current alignment. This approved realignment involves the creek, from where it crosses into WCM Pit 4 from the south moved to the west to flow over previously mined and rehabilitated areas until it reaches the northern edge of Pit 4, where it will rejoin its original course before meeting Wilpinjong Creek.

Under both Modification 5 and 6 (both approved), mining was proposed to end in 2026.

2.2.1 WATER LICENSING - USE AND DISCHARGE

Table 2-1 summarises bore licences under the *Water Act 1912* held by WCPL that are relevant to groundwater extraction (including groundwater inflow to mine workings) at the WCM. WCPL also holds a series of bore licences for monitoring boreholes at the WCM.

Table 2-1 WCM Groundwater Licences under the *Water Act 1912*

LICENCE NO.	EXTRACTION LIMIT	EXPIRY	PURPOSE
20BL173517*	2021 units (= 2021 ML/a)	10 June 2020	Excavation – Groundwater (Mining)
20BL173516*		10 June 2020	
20BL173514*		10 June 2020	
20BL173515*		10 June 2020	
20BL173513*		10 June 2020	
20BL170063	110 ML/a	18 December 2016	Water Supply Bore (GWs10)
20BL170062	110 ML/a	18 December 2011^	Water Supply Bore (GWs11)
20BL170061	110 ML/a	18 December 2011^	Water Supply Bore (GWs12)
20BL170059	110 ML/a	18 December 2016	Water Supply Bore (GWs14)

ML/a = megalitres per annum.
* WCPL have recently consolidated the five Excavation or Pit licences into this single site-wide 2021 unit entitlement.
^ WCPL is currently in consultation with DPI Water regarding the renewal of these licences.

In addition, Peabody Pastoral Holdings and WCPL jointly own a Water Access Licence (WAL 21499) for the alluvial aquifer in the Wollar Creek Water Source under the *Water Management Act 2000* with a share component of 474 units.

Pumping Bores

WCPL installed two groups of production (pumping) bores early on in the operation of the WCM.

A series of dewatering bores (named DB1-DB5 – see **Figure 2-2**) were installed into the Coal Measures in 2006 with the aim of controlling groundwater ingress into the open cut workings. After a short period of pumping (**Table 2-2**) these bores were abandoned as production bores and have been used as monitoring bores since.

Table 2-2 Groundwater Pumping Record for Dewatering Bores

	DB1	DB2	DB3	DB4	DB5
30/04/2006	0	0	0	0	0
31/05/2006	1.01	1.37	1.97	0.00	0.00
30/06/2006	0.85	2.23	4.47	2.08	1.94
30/04/2007	0	0	0	0	0
	These bores not used since				

Units are megalitres.
Data from WCM Annual Environmental Management Report (AEMR) 2007, and AEMR 2009

A series of water supply bores, known as GWs1-GWs19 and also sometimes referred to as WSB1-WSB19, were approved and planned to be installed (AGE, 2005) however only five were ever installed (GWs10-12 and GWs14-15 – see **Figure 2-2**), and this was done by 2007. These bores are believed to be screened across the Ulan Coal Seam and Marrangaroo Formation. 98 megalitres was pumped from these bores over a period of four months in 2007 (**Table 2-3**) and the bores have not been used since, mainly due to the there being an excess of water generated by other means. There remains the potential for the approved borefield of up to 19 bores to be used again in future.

Table 2-3 Groundwater Pumping Record for Water Supply Bores

	GWS10	GWS11	GWS12	GWS14	GWS15
31/01/2007	0	0	0	0	0
28/02/2007	0	0	0	0	0
31/03/2007	3.1	6.2	4.9	9.3	5.6
30/04/2007	3.3	6.5	5.8	9.2	5.5
31/05/2007	3.4	6.4	5.7	9.4	5.8
30/06/2007	0.9	1.7	1.5	2.5	1.6
31/07/2007	0	0	0	0	0
	These bores not used since				

Units are megalitres. Data from WCM AEMR 2007, and AEMR 2009

Discharge

WCM is permitted to discharge water to Wilpinjong Creek pursuant to the conditions of EPL 12425. The discharge point and conditions governing these are dealt with in the Surface Water Assessment (WRM Water & Environment, 2015).

The WEP would utilise the existing groundwater extraction licences and permitted discharge point. Discussion of the current licensed groundwater extraction volume and its sufficiency for planned WEP operations is presented in **Section 7.1.1**.

2.2.2 ON-SITE WATER MANAGEMENT

The WCM Water Management Plan (WMP) describes the management measures that are used to minimise potential impacts on water resources. The WMP incorporates five documents, of which 1, 4 and 5 are most relevant to this Groundwater Assessment:

1. the Site Water Balance;
2. the Erosion and Sediment Control Plan;
3. the Surface Water Management and Monitoring Plan;
4. the Groundwater Monitoring Program; and
5. the Surface and Ground Water Response Plan (inclusive of contingency measures required under extraction licences).

2.3 PROPOSED OPERATIONS

EL 6169 includes a number of open cut extensions, including extensions to Pits 1, 2, 5 and 6. At the cessation of mining a final void would be located in the northwestern extension of Pit 6 (**Figure 2-4)**.

EL 7091 (Slate Gully) lies to the immediate east of the approved mine on ML1573, and will be home to Pit 8, which is also labelled with 'SG' on some of the figures accompanying this report to identify it as 'Slate Gully'.

The proposal is for mining to commence in Pit 8 in approximately 2018 and ceasing in approximately 2033. As with the other areas, mining will occur via open cut methods.

Mining Lease Applications have been made for the WEP to allow mining to commence in these ELs.

After the cessation of mining in this area, a final void is proposed to remain in the southern portion of Pit 8 (see **Figure 2-4**).

2.4 NEARBY MINES

The Western Coalfield has a number of coal mining operations, of which the nearest are shown on **Figure 1-1**. Of importance to the operation at the WCM, specifically with regard to the need for a 'cumulative assessment' of groundwater impacts as required by the AI Policy, are the nearest mines (operator in brackets):

- Moolarben Coal Complex (Yancoal Australia Ltd [Yancoal]). This mine is located to the west of the WCM and extracts from the Ulan Coal Seam using both open cut and underground (longwall) methods. This mine has been operational since 2010, and occupies the area between 0 and 8 km west of Wilpinjong Pit 6, i.e. the approved Moolarben Open Cut 4, once active, will be excavated an area immediately west of the WEP Pit 6 extension.
- Ulan Mine Complex (Glencore). This mine is located 11 km to the northwest of the WCM on the other side of the Goulburn River, although the bulk of the underground mine is located 12-14 km away. Ulan Mine Complex extracts from the Ulan Coal Seam using both open cut and underground (longwall) methods. Coal mining has occurred at Ulan since the 1920s, however the current open cut and underground operations commenced in the 1980s (Mackie, 2011).
- Bylong Coal Project (Kepco Bylong Australia), located approximately 15 km to the south-east of the WCM, is in the proposal/application stage, and not yet operational.

Additionally, Bowdens Silver Project is a proposed silver mine near Lue. This is more than 25 km south of WCM.

With respect to Moolarben Coal Complex, features of that mine to consider in this study are the excavations or workings (location, depth and timing), location of discharges, and operation of borefields.

Moolarben Coal Complex is licensed to discharge to surface water at two sites (LDP1 and 2, to Bora Creek and Goulburn River respectively), and to discharge to land at three sites (LDP5, 22, and 23) (Yancoal, 2013).

Cumulative impact assessment for the WEP will consider the operation of the Moolarben Coal Complex, but not Bylong, Bowdens Silver Project or Ulan. This is because both Bylong Mine and Bowdens Silver Project are too far away and outside the Wollar Creek Water Source to be relevant to cumulative assessment.

The Ulan Mine Complex is immediately beyond the Moolarben Coal Complex. Depressurisation of the Ulan Coal Seam or overlying coal measures, resulting from the operation of the Ulan Mine, will not extend through the Moolarben area because of the depressurisation (and extraction) of the coal seam that will occur due to Moolarben's operations. Therefore, mining at Ulan will not contribute to the cumulative effects of the WCM on the local water sources.

The schedule of historic WCM and proposed WEP activities, as well as those of the other relevant coal mine operations is shown in parallel in **Figure 2-3**. This forms the basis for stresses within the historical (calibration) groundwater model as well as for the predictive modelling of impacts (described in **Sections** 5 **and** 6).

3 HYDROGEOLOGICAL SETTING

3.1 TOPOGRAPHY

Ground elevation across the greater Wollar Creek Catchment range from approximately 300 metres above Australian Height Datum (mAHD) to 725 mAHD (**Figure 3-1**). The inset of **Figure 3-1** shows higher ground topography over the existing mining lease and surrounds, including EL 7091 and the majority of EL 6169.

The regional topography shown in **Figure 3-1** is based on the Geoscience Australia Hydrologically-correct DEM (DEM-H) grid, which is built from SRTM data, combined with LiDAR data obtained for WCPL. For the purposes of **Figure 3-1** the LiDAR data has been partially modified to remove most of the mine workings and waste rock emplacements.

The valleys and lowlands associated with Wilpinjong Creek and its tributaries are bordered on the north by the Goulburn River National Park and on the south by the Munghorn Gap Nature Reserve (**Figure 1-1**). The elevation of Wilpinjong Creek as it flows along the boundary of WCM is approximately 390 to 345 mAHD.

3.2 CLIMATE

3.2.1 RAINFALL

The nearest Bureau of Meteorology (BoM) climate station to the WCM is Wollar (Barigan St), station 062032, located about 4 km east of the south-eastern corner of existing mining operations (Pit 3), and 2.5 km east of the proposed Slate Gully extension area lease.

A comparison of the rainfall data from the WCM weather station (aggregated from sub-daily to monthly) for the period from August 2011 against Wollar-Barigan St for the overlapping period (**Figure 3-2A**) shows that there are slight differences between the two records, with some periods when one received more rain than the other. Overall, across the 3.5 years of the common record, the WCM gauge received about 7 percent (%) more rainfall than the Wollar-Barigan St (BoM) gauge. Acknowledging the differences between the two, the analysis and modelling carried out for this study relies on the Wollar-Barigan St gauge because of the much greater length of that record at the BoM gauge.

Rainfall records, collected at Wollar-Barigan St since February 1901, show a long-term average (LTA) annual rainfall of 589 millimetres (mm) (**Table 3-1**). Average monthly rain records[4] (**Table 3-1**) show that the highest rainfall occurs in January (mid-summer) and the lowest in May (late-autumn). The highest monthly rainfall exceeds the lowest by about 75%.

Table 3-1 Average Monthly Rainfall (mm) at Station 062032 - Wollar (Barigan St)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
66.1	62.8	52.6	38.9	37.8	44.2	42.7	41.3	40.8	51.5	56.0	59.0	588.9

Data period 1901-2014

Table 3-2 lists the annual rainfalls associated with a range of percentile values. The median (50%) value of 596 mm is very similar to the long-term average annual rainfall (589 mm).

4 http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=062032

Table 3-2 Annual Rainfall Statistics at Station 062032 - Wollar (Barigan St)

PERCENTILE (%)	10	20	25	50	75	80	90
ANNUAL RAIN (MM)	365	444	464	596	690	743	834

Data period 1901-2014.

Information on long-term rainfall trends is provided by the Residual Mass Curve (RMC) (**Figure 3-2B**). This curve is generated by aggregating the residuals between actual monthly rainfall and long-term average rainfall for each month. The procedure is essentially a low-pass filter which suppresses the natural spikes in rainfall and enhances the long-term trends.

Given the usually slow response of groundwater levels to rainfall inputs, the RMC can be expected to correlate well with groundwater hydrographs over the long term. The groundwater levels recorded during periods of rising RMC are expected to rise while those recorded during periods of declining RMC are expected to decline.

The RMC plot using rainfall data from the Wollar station since 1901 (**Figure 3-2B**) shows that the long-term trend in rainfall in the upper Hunter catchment comprises a long period of lower than average rainfall between around 1900-1950, with severe multiple year droughts in about 1895-1902 ('Federation Drought') (not observed in this record due to Wollar record starting in 1901), the 1910-1920 period (including the very dry 1918-20 drought) and 1937-46 ('WWII Drought') (Verdon-Kidd and Kiem, 2009). This was followed by a sustained period of above average rainfall until the early 1990s, with short-lived droughts interspersed, including the intense drought of 1982-83 when unfavourable El Nino (negative SOI) and IPO conditions converged for a short period (see lower part of **Figure 3-2B**). The 'Millennium Drought' (1997-2011), which affected much of South-eastern Australia does not show a strong signature in the Wollar rainfall record, although there are dry periods during 2002-03, 2006-07 and 2009.

There were wetter episodes in the early- and mid-1950s, mid-1970s, early-1990s and 2010-12, often associated with sustained and strong La Nina events (positive SOI – see lower part of **Figure 3-2B**).

3.2.2 EVAPORATION

No site-specific evaporation data was available for locations around the WCM. This study relies on the available daily data from four stations and the SILO estimate listed in **Table 3-3**.

Table 3-3 Climate Stations Measuring Potential Evaporation

STATION	NAME	RECORD		DISTANCE TO WCM	PE
062003	Mumbil (Burrendong Dam)	1955 – 2014	64% complete	60 km	1528 mm/a
065035	Wellington Research Centre	1965 – 2005	89% complete	90 km	1805 mm/a
065034	Wellington Agrowplow	2005 - 2014	100% complete	93 km	1662 mm/a
061089	Scone SCS	1950 – 2014	88% complete	100 km	1,586 mm/a
SILO	Data Drill	1889-2015	n/a	at WCM	1638 mm/a

Data for 62003, 061089, 65035 and 65034 from BOM. Data Drill from SILO (WRM Water & Environment, 2015).
mm/a = millimetres per annum, n/a = not applicable., PE = Potential evaporation.

PE for the region is approximately 1600 mm/a, while actual evapotranspiration (AE) for the region is up to approximately 600 mm/a (BoM, 2009)[5].

For the purposes of conceptualisation and numerical modelling, a composite series of daily PE has been constructed for WCM using available daily data from the sites in **Table 3-3**. The derived sequence has been normalised to the 1638 mm/a obtained from SILO Data Drill (WRM Water & Environment, 2015).

The derived average pattern of PE is compared against rainfall in **Figure 3-2C**. This shows that there is a significant rainfall deficit (i.e. PE is higher than rainfall) for much of the year, except for a few months in winter, when rainfall is similar to PE. The excess of PE may have implications for salinity in creeks reliant on baseflow and in alluvium or groundwater discharge (shallow water table) areas (see **Sections 3.3 and 3.9**).

3.3 HYDROLOGY AND DRAINAGE

Surface water hydrology is addressed in detail in the Surface Water Assessment for the WEP (WRM Water & Environment, 2015), however details relevant to hydrogeological behaviour are presented here.

The WCM is located within the catchment of the Goulburn River which flows from west to the north and then to the southeast and east, circling the Project area to the west, north and east at a distance of between approximately 7 km to 12 km (**Figure 3-3**). The Goulburn River joins the Hunter River near Denman, some 70 km east of Wollar.

The WCM lies in the Wilpinjong Creek catchment, which is the main tributary of Wollar Creek. Wilpinjong Creek originates 6 km north or north-west of WCM (the watercourse is 12 km long upstream of WCM) in the Goulburn River National Park at an elevation of about 500 mAHD. Wilpinjong Creek rises and is fed by a number of tributary watercourses, including Murragamba Creek (which rises in the Munghorn Gap Nature Reserve upstream and southwest of WCM) From the confluence with Murragamba Creek, Wilpinjong Creek flows south-east and then east, parallel to the northern boundary of the WCM, to join Wollar Creek downstream of the WCM (2 km northeast of the proposed Pit 8), which then discharges into the Goulburn River 10 km northeast of the WCM.

According to Gilbert and Associates (2005): "Wilpinjong Creek is incised into the valley floor and forms a series of semi-permanent soaks fed primarily from drainage from the surrounding alluvial plain and colluvium which is recharged by runoff from the adjacent sandstone plateau".

Fresh water springs occur in the headwaters of the creeks within the Wollar Creek catchment. Springs with steady flow can be found at Cumbo Creek and its tributaries (e.g. Back Flat Gully, located 6km south of WCM) and Barigan Creek (Department of Infrastructure, Planning and Natural Resources [DIPNR], 2003). A number of springs were located as part of the original bore census (**Section 3.8.1**). These springs, which rise from the Triassic Narrabeen Group or the Permian coal measures to the south of the WCM, are plotted on **Figure 3-3**.

Pre-mining surface water would have drained northwards across the mining lease to Wilpinjong Creek along a series of small creeks named, from west to east (see inset on **Figure 3-3**):

- Planters Creek (Pit 6);
- Spring Creek and an un-named drainage line (Pit 5);

[5] These regional PE and AE values have been obtained from the BoM map viewer. AE is the evapotranspiration that takes place under current water supply or rainfall conditions, calculated or averaged over a large area so as to remove local variation (http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp). In areas of where shallow water table persist, the AE is likely to be closer to PE, see **Section 3.8.3**.

- Narrow Creek (Pit 1);
- Bens Creek (Pit 2 and part of Pit 1);
- Cumbo Creek (running between Pits 2 and 3, and through Pit 4); and
- an un-named drainage line through Pit 8 - Slate Gully (within EL 7091).

The creeks range from semi-perennial spring-fed streams in the south to wider ephemeral streams in the north. The largest tributary drainage feature within the mining lease is Cumbo Creek.

To the south-west of the mine is Moolarben Creek which flows north-westerly into Goulburn River, which skirts the northern boundary of the Greater Wollar Creek Catchment (**Figure 3-3**).

Table 3-4 and **Figure 3-3** present the location and detail of the river gauging stations in the region. There were a couple of government-operated gauging stations on watercourses near to the WCM, however only a single one of these is active and this is some 10 km east of WCM on the Goulburn River. The WCM operate a number of permanent gauging stations (**Table 3-4**), two on Wilpinjong Creek and a third on Cumbo Creek.

Table 3-4 River Gauging Stations

STATION	NAME	STATUS	MONITORING PERIOD	Zero Gauge (mAHD)	Area (km^2)
NSW government gauging station					
210006	Goulburn River at Coggan	Active	18/10/1912 - current	210.07	3340
210046	Goulburn River at Ulan	Inactive	9/03/1956 to 28/07/1982	27.23	159
210082	Wollar Creek U/S Goulburn R	Inactive	1/05/1969 to 25/06/1975	317.29	274
210086	Munmurra Brook at Tomimbil	Inactive	17/08/1970 to 5/07/1978	23.05	606
210092	Merriwa River at Merriwa	Inactive	13/04/1972 to5/07/1978	22.99	498
210037	Krui River at Neverfail	Inactive	14/12/1954 to 13/5/1955	22.13	689
WCM gauging station					
WILGSU	Wilpinjong Creek (upstream of WCM)	Active	mid-2007 - current	386.1*	81
WILGSD	Wilpinjong Creek (downstream of WCM)	Active	Feb 2006 - current	353 *	175
CCGS	Cumbo Creek at WCM	Active		360.5 *	70

* from elevation contours determined by LiDAR.

Figure 3-4 presents a summary of flow and water quality in creeks immediately around the WCM. Average flow along Wilpinjong Creek is about 1.9 megalitres per day (ML/d) (WILGSU) and 3.5 ML/d (WILGSD). In more recent times, flows at WILGSD have been augmented by discharge from WCPL's RO plant, the discharge from which is plotted on the upper chart in **Figure 3-4**. WCPL have a gauging station on Cumbo Creek, however it is not rated for flow (i.e. stage only).

The water quality charts on **Figure 3-4** show that:

- Electrical Conductivity (EC) (salinity) is relatively constant, between 150 and 1800 microSiemens per centimetre (µS/cm), at the upstream site and more variable (500 to 7500 µS/cm) at the downstream site;

- Salinity is generally inversely related to flow, with the consistent trend of increasing salinity in 2012-14 occurring in response to the decreasing flows (and low rainfall) of the same period.
- Salinity was high in 2006 (4500-7500 µS/cm) at WILGSD, and mining commenced in June 2006.
- pH is generally in the range 6-8, with neutral or weakly acidic conditions prevailing upstream and neutral-weakly alkaline conditions downstream. pH is less strongly correlated to flow than EC.

The difference in water quality between the upstream and downstream sites is influenced by the greater time between rainfall and flow past the gauge at the downstream site, possible increasing contribution from groundwater and greater role of evaporation at the downstream site, the presence of discharge from the RO plant since 2012, and also flows from tributaries, notably Cumbo Creek, which has older geology (Shoalhaven Group) outcropping within its catchment. With reference to the recorded in-stream salinity, OEH stated in 2006 that there was “high background salinity levels in the Bylong, Growee, Wollar” catchments, i.e. high salinity before WCM began operations.

Figure 3-5 presents flow data from gauging stations operated by NOW in the region around the WCM. The downstream-most gauge is 210006 on the Goulburn River, and all the others presented are on tributaries to the Goulburn River, including 210082 on Wollar Creek. The data presented is for the period 1980-1982, and is the common period for these gauges. Most are no longer monitored, including the Wollar Creek gauge, which was active for the period May 1980-Feburary 1995.

The flow duration curve on **Figure 3-5** shows that Wollar Creek ceases to flow about 25-30% of the time (using the data 1980-1995), while the others had more reliable flows (i.e. cease-to-flow conditions only 1-2% of the time). Based on the definition stated in the SRLUP documents (DPI, 2012) a cease to flow frequency is required to be <5%, i.e. the watercourse flowing at least 95% of the time, for an unregulated watercourse to be classified as a ‘reliable water supply’. Therefore Wollar Creek does not meet the SRLUP classification as a ‘reliable water supply’.

3.4 DESIGNATED AREAS

3.4.1 NATIONAL PARKS AND STATE FORESTS

There are a number of small State Forests in the area around WCM, as shown in **Figure 1-1**, along with National Parks.

Immediately to the south of WCM lies Munghorn Gap Nature Reserve, covering the elevated plateaus. North of Wilpinjong Creek from WCM, and extending further east, is the Goulburn River National Park. The headwaters of Wilpinjong Creek lie in this national park.

3.4.2 BIOPHYSICAL STRATEGIC AGRICULTURAL LAND

Areas of BSAL are presented on **Figure 1-1** and discussed in **Section 1.3.3**. BSAL is not relevant to the WEP.

3.4.3 CULTURALLY SIGNIFICANT SITES

There are no Culturally Significant Sites listed in the relevant WSPs (**Section 1.3**).

3.5 LAND USE

Aside from the nearby National Parks and Nature Reserves (**Section 3.4.1**), and as described in McKenzie Soil Management (2014), land use in and around the WCM "*is characterised by a combination of coal mining operations, agricultural land uses (primarily grazing) and rural residential development (evident in the local villages of Wollar, Ulan and the localities of Cumbo, Slate Gully and Araluen). The cleared grazing land is under unimproved pasture utilized by cattle and sheep. Some dryland cropping has occurred in previous decades in the north-western part of the SVC Application Area, in the vicinity of Ulan-Wollar Road*".

Within the greater Wollar Creek catchment, pasture areas have typically been used for grazing sheep, beef cattle, and horses (DIPNR, 2003), while cropping has even included small scale olive and grape plantations, as well as native plants.

WCPL is a major landholder in and around the WCM and Wollar, and manages the majority of its landholdings for agricultural production.

3.5.1 VEGETATION TYPES

A brief assessment of vegetation types, based on literature review (including Hunter Eco, 2013) and the on-going ecological assessments (Hunter Eco, 2015) at WCM is provided here. This is done in order to understand likely rooting depths and the potential for groundwater use by vegetation.

Within and immediately around the approved WCM area and the proposed WEP (i.e. extension) areas the main vegetation communities are (Hunter Eco, 2015):

- cleared Agricultural land (including much of the approved mine area as well as of the proposed Pit 5, 6 and 8 extensions);
- Shrubby White Box Woodlands;
- Narrow-leaved Stringybark and Narrow-leaved Ironbark Forest;
- Rough-barked Apple Woodlands;
- Red Ironbark Forest;
- Yellow Box and Blakely's Red Gum Woodlands, an Endangered Ecological Community (EEC); and
- on the Narrabeen Group plateaus, including the Goulburn River National Park, the dominant vegetation community is Sandstone Range Shrubby Woodlands.

3.5.2 ROOTING DEPTH

A review of a number of literature sources, including Canadell *et al* (1996), Florabank[6], Lamontagne *et al* (2005), Allen *et al* (2006) and Zolfaghar (2013) was carried out.

A compilation of reported maximum rooting depth of sclerophyllous shrubland and forest (Canadell *et al*, 1996) indicated that average for such species was 5.2 m (±0.8 m).

[6] http://www.florabank.org.au/

Specific rooting depth information for the main tree and shrub species present around the WCM is unavailable. Of the trees within the EEC, Yellow Box (*Eucalyptus melliodora*) are described as having "moderate to deep or shallow and spreading" root systems, while root systems of Blakely's Red Gum (*E. blakelyi*) are "moderate to deep" (FloraBank[7]). Based on recent research done elsewhere in the Sydney Basin, 9 m has been adopted as the likely depth to which water is accessed by these potentially deeper-rooted sclerophyllous trees (based on Zolfaghar, 2013).

A review of data in Allen *et al* (2006) provides information on the likely maximum rooting depths of grasses and agricultural crops, of which grasses are the dominant vegetation type in the cleared/grassland areas around WCM. The mean of these reported maximum rooting depth of the grasses in Allen *et al* (2006) is 1.2 m (range 0.9 to 1.5 m).

3.6 GROUNDWATER DEPENDENT ECOSYSTEMS

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- **Deep Alluvial Groundwater Systems** – occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- **Shallow Alluvial Groundwater Systems** – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- **Fractured Rock Groundwater Systems** – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and submit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- **Coastal Sand Bed Groundwater Systems** – significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).
- **Sedimentary Rock Groundwater Systems** – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

Groundwater resources in the WCM area are located mainly within the Porous and Fractured sedimentary rock groundwater systems and the small areas of alluvium located along watercourses.

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) also recognises the four Australian GDE types (Hatton and Evans, 1998) that can be found in NSW, namely:

- terrestrial vegetation;
- base flows in streams;
- aquifer and cave ecosystems; and
- wetlands.

A review of the BoM GDE Atlas[8] and relevant legislation and other literature has been conducted.

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[7] http://www.florabank.org.au/lucid/key/Species%20Navigator/Media/Html/Eucalyptus_melliodora.htm and http://www.florabank.org.au/lucid/key/Species%20Navigator/Media/Html/Eucalyptus_blakelyi.htm (accessed November, 2014)

[8] http://www.bom.gov.au/water/groundwater/gde/map.shtml

Inspection of the BoM GDE Atlas indicated that potential GDEs which access groundwater in the subsurface (rather than being reliant on the surface expression of groundwater) have not been mapped in the area immediately around WCM. Mapping of features reliant on surface expression of groundwater has been conducted. Assessment has been made of the upper Goulburn (low to moderate reliance on groundwater), Murragamba Creek (low reliance on groundwater) and Growee River (moderate reliance) (see **Figure 3-3**), but no BoM assessment has been made of Wilpinjong, Wollar or Cumbo Creeks. The only watercourses in the area mapped with a higher reliance on groundwater are those on the Palaeozoic geological units about 10 km to the west of WCM, such as Sportsmans Hollow and Rouses Creek (**Figure 3-3**).

A search of legislation (see WSPs in **Section 1.3**) was carried out to identify any High Priority GDEs in the region:

- The Hunter Unregulated and Alluvial WSP specifies a number of High Priority GDEs. The nearest of these are 130 km northeast or 155 km east.
- The NSW Murray Darling Basin WSP specifies a number of High Priority GDEs and High Priority Karst features (see **Figure 3-3**). Of these, the Cooyal Karst feature[9] is 13 km southwest of WCM, and Baileys Springs are located 16 km west of WCM. The Cooyal Karst features are likely to be in the Silurian-age Tannabutta Formation, while Baileys Springs are located in Carboniferous plutonic strata.
- Because the North Coast Fractured and Porous Rock WSP is not yet commenced, earlier documents were reviewed for information on that region. Because of this, earlier literature (*State of the Catchments 2010: Groundwater – Hunter-Central Rivers Region* [Department of Environment, Climate Change and Water {DECCW}, 2010a] and *State of the Catchments 2010: Groundwater – Central West Region* [DECCW, 2010b]) was consulted and a Geographic Information System (GIS) dataset of all currently identified High Priority GDEs was obtained from NOW. Of the GDEs likely to be defined as High Priority in that WSP, the nearest are (these are too distant from the WCM to be shown on **Figure 3-3**):
  - Wild Bull Spring, in the upper Wollar Creek catchment, and 17 km due south of WCM;
  - Wappinguy Spring, located 50 km east of WCM; and
  - Ginger Beer Springs, also located 50 km east of WCM.
- Although not defined as a 'High Priority', 'The Drip' and associated features are ecologically and culturally significant. These are located 11 km north-northwest of WCM (see **Figure 3-3**).

Most of these High Priority GDE features will not be affected by the operation or expansion of WCM. Due to the distances involved, only the Drip, Baileys Springs and the Cooyal Karst feature are located within (or on the edge) of the active area of the groundwater flow model (**Section 5.3.1**). The relevant modelling and impact assessment is presented in **Sections 6.6 and 7.2.3**.

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9 Location is approximate only, based on the information in Schedule 3 of the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011 (http://www.legislation.nsw.gov.au/viewtop/inforce/subordleg+616+2011+cd+0+N/)

Previous investigations into the nature of the 'The Drip' feature indicate that it is a perched water table, sustained by recharge up-gradient that then seeps out along the Narrabeen Group sandstone escarpment above the Goulburn River (Mackie Environmental Research [MER], 2011; Frans Kalf, pers comm.). While the area hosting the Drip is covered in the active model area, the fine-scale detail and structure of The Drip will not be captured within this regional groundwater model. Given the nature and location of the Drip, it will not be affected by groundwater drawdown from WCM.

Ecological assessments carried out for WCPL (Hunter Eco, 2013 and 2015) indicate that riparian vegetation is present along most of Wilpinjong Creek, Cumbo Creek to the south of Pit 4, along Wollar Creek and a couple of smaller creeks or drainage lines. This is typically a *typha* (bulrush) or *phragmites* (reed) type of vegetation. No groundwater dependent vegetation has been identified within the WEP open cut extension areas, including Pit 8 Slate Gully.

Typha are salt-tolerant, and tend to populate less favourable areas, i.e. although their presence is not a definite indication of more saline conditions, they are viewed as indicators of brackish to saline conditions (DIPNR, 2005).

Comparison of vegetation, rooting depth and groundwater levels within and around the WCM is provided in **Section 3.8.6**.

3.7 GEOLOGY

3.7.1 STRUCTURAL SETTING

The WCM is located in the Western Coalfield on the north-western edge of the Sydney-Gunnedah Basin, which contains sedimentary rocks, including coal measures, of Permian and Triassic age.

To the west of the site are Carboniferous igneous rocks and volcanics, marking the eastern limit of the Lachlan Fold Belt. There are relatively few occurrences of Mesozoic igneous laccoliths and Tertiary basalt plugs and sills external to the mining lease.

The only major structural features identified in the region are a number of hingelines and faults, as shown on the Western Coalfield Map (Yoo, 1998) (see **Figure 3-6**).

The hingelines are fold structures and while most of those identified by Yoo (1998) are well outside the limits of the WCM, the north-south oriented Wollar Hingeline runs through Pits 3 and 7.

Yoo (1998), Colquhuon *et al.* (1999) or Watkins *et al.* (2000) did not map any faults within the limits of the WCM. The nearest are two northwest to southeast trending faults, the Green Hills and Curra Creek Faults, which are located about 8-10 km north-northwest of the WCM.

There is no evidence of major faulting over the mining lease, although faults have been observed and mapped by WCPL, such as within the existing workings in Pit 3 (see **Figure 3-6**). Two photos of Pit 3 are included in **Appendix A**. Photo A1 shows the main fault in the centre of Pit 3, which has a displacement of about 4 m. The second fault, at the northern end of Pit 3, is more complex but much smaller (Photo A2). Based on the mapping of the Wollar Hingeline, these faults may be associated with that fault structure.

There are minor intrusions, dykes and sills in parts of the WCM lease, e.g. in Pit 4 and in the north-eastern part of Pit 3 (GeoConsult, 2014). The regional geology map **Figure 3-6** marks larger intrusions in the area around the WCM, including along Wollar Creek.

3.7.2 STRATIGRAPHIC FRAMEWORK

The stratigraphy of the Western Coalfield is presented in **Figure 3-7**. This is based on the Western Coalfield geology map (Yoo, 1998).

Mapped surface geology, shown in **Figure 3-6**, indicates that the dominant outcropping lithology over the mining lease is Permian Illawarra Coal Measures. A substantial area of outcropping Permian Shoalhaven Group (containing the Marrangaroo Conglomerate and the underlying Nile Sub-Group) hosts Cumbo Creek in the southern and south-eastern part of the existing mining area. Smaller tongues of the Triassic Narrabeen Group (Wollar Sandstone) cross the boundary of the mining lease in the more elevated portions. Rocks of the Narrabeen Group form the cliffs and plateaus of the Munghorn Gap Nature Reserve on the southern edge of the WCM and the north-south oriented ridges between Pits 1 and 5 and Pits 1 and 2 and between the existing mining area (Pit 3) and the Pit 8 Slate Gully extension (EL 7091). The same Narrabeen Group units also form the elevated ridges and plateaus of the Goulburn River National Park to the north of Wilpinjong Creek.

Figure 3-8 (from Yoo *et al*, 2001) presents a detailed stratigraphic correlation within the Illawarra Coal Measures, including the Ulan Coal Seam. The Ulan Coal Seam, which is the primary coal resource for WCM and the nearby Moolarben Coal Complex and Ulan Mine Complex, outcrops at the southern limit of the mining lease. It is subdivided into plies *a11* to *g22* over the mining lease. In the more elevated parts there are remnants of the younger Moolarben Coal Member (plies *m1* to *m4*). The Ulan Coal Seam has a dip of 1-2 degrees to the north-north-east.

A brief summary of geological unit thickness in and around the WCM area is presented in **Appendix B**. More detail on the geometry of the geological units is provided in **Section 5.3**.

3.7.3 ALLUVIUM, COLLUVIUM AND REGOLITH

Figure 3-6 shows areas of alluvium as mapped by Yoo (1998) for the Western Coalfield Map. Away from the WCM, alluvial sediments are mapped along the western part of the Goulburn River and along Moolarben Creek (**Figure 3-6**). Colluvium is evident along the edges of sandstone escarpments, especially on the northern side of Wilpinjong Creek where the landform abuts the cliffs of the Goulburn River National Park.

Recent alluvium

Based on the review and inspection of different data sources it is clear that the mapped extent of alluvium near to WCM varies depending on the source. A comparison of the extent of mapped alluvium from the Western Coalfield Map (Yoo, 1998), NOW's mapping of 'Highly Productive' alluvium (of the Wollar Creek Water Source) and local bore information was carried out and is presented in **Figure 3-9**. Also overlain on this figure are interpretations from transient electro-magnetic (TEM) geophysical surveys conducted for WCPL by Groundwater Imaging.

Figure 3-9 shows the Highly Productive alluvium of the Wollar Creek Water Source is mapped in two locations: along Wollar Creek (downstream of Wollar) and along Wilpinjong Creek between Cumbo Creek and Wollar Creek. As shown on **Figure 3-9**, no alluvium is mapped on the Western Coalfield Map in the first of these locations (Wollar Creek), and at the second, it can be seen that along Wilpinjong Creek, alluvium was mapped by Yoo (1998), although the extent and configuration of the alluvium is slightly different to the NOW mapping.

Two TEM surveys were conducted for WCPL in 2011 and 2014. The interpretations of those surveys are documented in Groundwater Imaging (2014), and the inferred extent of alluvium are shown (green hatching) on **Figure 3-9**. The TEM survey did not extend to Wollar Creek. The alluvial deposits based on TEM are generally much narrower than the other mapping, with long thin deposits along Wilpinjong Creek, Cumbo Creek, and in the northern part of Slate Gully.

Bore logs for bores (groundwater works) from the NSW Pinneena database have been analysed, and the near-surface lithology is summarised on **Figure 3-9**. Red or orange circles indicate bores at which gravel and sand (respectively) are present in the shallow subsurface, while brown circles indicate clay, and a black cross indicates no unconsolidated material or no record. Along Wilpinjong Creek (to the confluence with Cumbo Creek) and along Cumbo Creek, the distribution of crosses (no unconsolidated material) versus orange/red circles supports the TEM interpretation of a narrow alluvial body.

The Western Coalfield Map (Yoo, 1998) identifies the Quaternary-aged alluvium as silt, clay, sand and gravel. An analysis of alluvium composition at WCM is presented in **Figure 3-10**. **Figure 3-10** presents bore log information, taken from WCM exploration bores and from registered Groundwater Works bores, simplified into major lithology classes (e.g. sand, silt, clay, siltstone, shale, sandstone, coal) and then summarises the thickness for each of the classes of unconsolidated material (gravel, sand, silt, clay, soil and alluvium), with the size of the pie charts on the figure sized proportional to the total thickness of unconsolidated material (except 'soil') (and labelled with this total thickness, in metres). A cross (**x**) on **Figure 3-10** is used to identify bores at which no unconsolidated material is recorded in the shallow subsurface. The pie charts are coloured to highlight the presence of the coarser sediments ('gravel' and 'sand') and 'alluvium' (which could be coarse or fine-grained). The aim of **Figure 3-10** is to identify areas where coarser-grained deposits are present, noting that this could represent alluvium, colluvium or weathered regolith, and shows:

- Sand deposits, of up to 8 m (bore GW052223) and 27 m (bore PW1116) in the centre and on the eastern edge of the Pit 6 area. These appear to be linked to the palaeochannel interpreted from TEM surveys (which extends into Pit 6 from the northwest) (further discussion of this in the following subsection).
- A significant concentration of bores intersecting coarse sediments toward the south of Pit 5. This makes conceptual sense, as the 1:25000 topographic map of the area (Wollar 8833-2-N) shows drainage lines in the very southern part of the Pit 5 area, but disappearing to the north, which could be due to the presence of these more permeable deposits. There is no indication that this body of coarse-grained sediments continues further north in Pit 5.
- Only sporadic occurrences of sands and gravels in Pits 1, 2 and 4.
- There are indications of a channel of unconsolidated material from the middle of Pit 7 to the north, possibly into Pit 3 and toward Cumbo Creek, however there are a number of bores without any indication of unconsolidated material, suggesting that continuity might be limited or localised. There is no evidence to suggest that this material is connected through Pit 7 all the way to the alluvium of Cumbo Creek.
- In Pit 8 (Slate Gully), there are very few indications of coarse sediments in the shallow subsurface, with only a few bores showing the presence of a few metres of sand or soil, usually at the very north of Slate Gully.

Elsewhere, there are isolated bores showing coarse material, including along Wollar Creek (4 m of gravel at bore GW273100 (north of Wollar), 2 m of sand at Wollar (bore GW273101) and 7 m of sand south of Wollar (GW011258).

The conclusions from comparing the various maps and data sources are that:

- Mapping of recent alluvium from local scale investigation (analysis of TEM and bore data) will be relied on for the conceptual model, and in the numerical modelling and impact assessment. This covers Wilpinjong Creek and Cumbo Creek. In other areas, a combination of Western Coalfield (Yoo, 1998) and NOW mapping will be used (including along Wollar Creek);
- The regional geological model (**Section 5.3.2**) relies on this finding, and the resultant distribution of quaternary or recent alluvium is presented there.
- The potential for the mine to intersect areas of alluvium is discussed in **Section 7.1.8**.

Other Unconsolidated Deposits

Figure 3-6 shows mapping from the Western Coalfield geological map (Yoo, 1998). This map has been overlain with the interpreted extent of other unconsolidated deposits identified around the site. Two polygons marked on **Figure 3-9** within and to the west of WCM Pit 6 are the interpretations of two different TEM surveys – one for WCPL (open red polygon and white filled polygon), and the other for Moolarben (RPS Aquaterra, 2011) (pale red striped polygon to the west of Pit 6). The interpretation as a palaeochannel (i.e. prior drainage system) was adopted for Moolarben Coal Complex (RPS Aquaterra, 2011), with the extent based on RPS Aquaterra (2011) and TEM surveys at WCM (Groundwater Imaging, 2014). Photo A3 in **Appendix A** provides some evidence of the channel-like nature of these deposits, showing two locations at which recent workings in Pit 5 have intersected these deposits.

Not shown, but commented on in **Figure 3-9**, was a Thiel Surface Impedance Method (TSIM) survey conducted by GeoConsult (2014) in the south of Pit 5, which indicated a channel-like feature along part of the drainage line (labelled 'unnamed creek' on **Figure 3-3**). Bore logs support the presence of such a feature, which has been filled with sandy unconsolidated material.

Figure 3-10 shows the analysis of lithology at various bores (as described for recent alluvium, above). The inset on **Figure 3-10** provides detail for the area in Pit 6 and to the west, extending into the Moolarben Coal Complex area. This shows bores intersecting significant thicknesses of unconsolidated or poorly consolidated materials, with some bores showing greater than 20 m of sands and/or gravel in this area.

As for the recent alluvium, re-mapping of the unconsolidated material (channel deposits or otherwise) is presented as part of the description of the regional geological model for the WEP (**Section 5.3.2**).

3.7.4 NARRABEEN GROUP (WOLLAR SANDSTONE)

In some literature, the Wollar Sandstone is used in place of, or to describe the equivalent to, the Narrabeen Group strata in the Western Coalfield. This report will use the term 'Narrabeen Group'.

The Narrabeen Group "form cliffs, ridges and hilltops of mesa-like plateaus" (AGE, 2005) around the WCM and are thickest to the north of the WCM. Typical lithologies include pebbly to medium-grained quartz sandstone, red-brown and green mudstone and lenses of quartz conglomerate. The thickness of these deposits is typically 100-180 m.

3.7.5 ILLAWARRA COAL MEASURES

The Permian-aged Illawarra Coal Measures are comprised of a number of named units of varying lithologies (**Figure 3-8**). AGE (2005) described this group as occupying "the midslopes of the gently undulating landforms that border the drainage lines in the Project area. The measures tend to subcrop in parts of the south of the Project area. The dominant lithologies include mudstone, laminated siltstone, medium-grained quartz-lithic sandstone, lenses of polymictic conglomerate, coal, carbonaceous mudstone, rhyolitic tuff and sporadic torbanite."

Mackie (2009) states that at Ulan these Permian Coal Measures are about 145 m thick.

3.7.6 ULAN COAL SEAM

The Ulan Coal Seam is a horizon within the Illawarra Coal Measures. This is primary economic coal resource in this area, being mined at WCM, and at the nearby Ulan Mine Complex and Moolarben Coal Complex.

According to Yoo *et al* (2001) the upper section of the Ulan Coal Seam is subdivided into three plies (A, B and C), where C is the marker horizon (see **Figure 3-8**), while the lower section is subdivided into five plies (C-lower, D, E, F and G).

Based on WCM geological data, the Ulan Coal Seam is approximately 15 m thick; this is measured from the roof of the A11 ply to the floor of the G22 ply. The median aggregate thickness of the coal plies from the top of A11 to the base of G22 is 11.4 m (i.e. about 75% of the total thickness).

3.7.7 MARRANGAROO FORMATION

The Marrangaroo Formation is usually a conglomerate or sandstone in this area. Yoo *et al* (2001) describe it as fining "upward from a quartz-lithic pebbly sandstone or conglomerate to a medium- to fine-grained quartzose sandstone, and occasionally contains as series of upward-fining sandstone beds. Locally the Marrangaroo Formation is dominantly quartzose in composition grading from the granular sandstone through to pebble conglomerate." The thickness of this unit is "from 3 m to 8 m north of Ulan. At Bylong, the Marrangaroo Formation consists of fine to medium-grained, often bioturbated, lithic to quartz-lithic, well-cemented sandstone, 3 m to 5 m thick.", and Yoo *et al* (2001) stated that across the Western Coalfield it has a "thickness from 2 m to 16 m".

3.7.8 NILE SUB-GROUP

The Nile Subgroup is the basal unit of the Illawarra Coal Measures (see **Figure 3-8**). The dominant lithologies are sandstone, siltstone and claystone. Exposures of this unit (as described in Yoo *et al*, 2001) reveal that the Nile Subgroup is much finer-grained than the conglomerate/sandstone of the overlying Marrangaroo Formation.

Published data on the Nile Subgroup indicates thickness up to about 30-40 m in the Blue Mountains well to the south of WCM (Bembrick and Holmes, 1972). The thickness of the Nile Subgroup is estimated as being 10-15 m at Wilpinjong.

3.7.9 SHOALHAVEN GROUP

The Shoalhaven Group are of early Permian-age. The most obvious outcrop of the Shoalhaven Group is immediately to the south of WCM Pits 2, 4 and 7, where there is an exposure along Cumbo Creek, and a similar exposure along Wollar and Barigan Creeks, to the southeast of WCM (**Figure 3-6**).

The Shoalhaven Group strata consist of polymictic conglomerate, lithic sandstone and shale, siltstone, claystone, minor carbonate and evaporite (AGE, 2005 and Yoo *et al*, 2001).

3.7.10 PALAEOZOIC UNITS

These units form the basement of the Sydney Basin units, including the Shoalhaven Group (see previous subsection). The Shoalhaven Group unconformably overlies on a sequence of Silurian and Devonian-age metamorphic rocks and a number of Carboniferous-age granitoids. These are most obvious to the west of WCM and the Goulburn River, where they are the dominant outcropping units (**Figure 3-6**).

3.8 HYDROGEOLOGY

This section (**Section 3.8**) describes a review of literature and analysis of data with respect to:

- Groundwater use (**Section 3.8.1)**;
- Groundwater and related surface water monitoring, at WCM (**Section 3.8.2**);
- Groundwater level trends and behaviour (**Section 3.8.3**);
- Recharge processes (**Section 3.8.4**);
- Groundwater-surface water interaction (**Section 3.8.5**);
- Evapotranspiration from groundwater (**Section 3.8.6**);
- Hydraulic properties of aquifers or groundwater systems (**Section 3.8.7**); and
- Groundwater inflow to WCM open cuts and to nearby mines (**Section 3.8.8**).

Although also under the broad heading of 'hydrogeology' sections on the analysis of groundwater chemistry is presented in **Section 3.9**.

3.8.1 GROUNDWATER USE AND BORE CENSUS

Figure 3-11 shows:

- the bores identified in the WCPL bore census (see below);
- bores in the WCPL bore database (mainly monitoring but also some production bores) (**Section 2.2.1**); and
- Groundwater Works (typically bores) registered on NOW's Pinneena database (versions 10.1 and 4.1 were checked), plus data received in late 2014 from NOW following a request by HydroSimulations.

WCPL conducted a bore census of privately held bores surrounding the WCM in 2004 (for the original EIS). Specific to the WEP, in 2015 WCPL carried out a further census to confirm bore location and usage in Wollar village.

Bores on private or public land in the vicinity of the WEP include:

- one bore at Wollar Public School (20BL173431) that is used for watering recreational areas and gardens; and
- one private bore (GW063717) to the south-west of the WCM for stock and domestic use.

A number of bore censuses have been conducted at the Moolarben Coal Complex, which have established that there are only four privately owned bores within 10 km of the mine (Moolarben Coal Operations [MCO], 2015).

Based on NOW's data, there are 838 registered groundwater works within the Study Area (40x40 km) (537 of these are within the active domain of the numerical model). Many of those near to the WCM are now owned by WCPL.

Where such details are available from the NOW Pinneena database, the registered bores have a median depth of approximately 35 m (average = 39 m, maximum = 298 m).

Around the WCM, most of the groundwater usage in the area is from the Permian strata or from surficial alluvial aquifers. Groundwater is not extracted from the Triassic Narrabeen Formation as it is in areas of National Park or State Reserve.

Most of the bores in the area are not attached to a licence to extract water, e.g. are monitoring bores, or used for Domestic, Stock or Farming purposes. Based on the data search, there is a total licensed groundwater entitlement of 13,620 ML/a in this area. Additionally, there is approximately 500 ML/a of unlicensed groundwater use for stock, domestic and farming purposes, which is based on the assumption that use for these purposes is 1 ML/yr at each such bore. An approximate breakdown of the groundwater use is presented in **Figure 3-12**, which shows the breakdown first as percentages with all uses included (**Figure 3-12A**), and then, to allow more detail to be revealed, without mining as volumes (ML/a) (**Figure 3-12B**).

Approximately 10% of registered bores within the Study Area have a bore yield recorded the Pinneena database. Of these, the median bore yield is approximately 1.5 litres per second (L/s) (minimum = 0.1 L/s and maximum = 25 L/s). The distribution of recorded bore yield is presented against NOW's classification of Groundwater Productivity (**Figure 1-3**), which does not show a correlation between high bore yield and 'High' Groundwater Productivity.

3.8.2 GROUNDWATER MONITORING AT THE WILPINJONG COAL MINE

WCM's approved Groundwater Monitoring Program[10] is part of the management plans outlined in **Section 2.2.2**. As part of these management plans, a network of groundwater monitoring bores has been operated since April 2006 for the purposes of monitoring water levels and water quality. This monitoring network has been extended in recent times. Laboratory analysis is undertaken by a laboratory which has been accredited by the National Association of Testing Authorities, Australia (NATA) to undertake testing for the parameters being determined. Monitoring frequency varies from 15-minute to hourly (using data loggers) to monthly or quarterly intervals, depending on the relevant strata and proximity to mining.

Additional monitoring of production bore responses is outlined in the WCPL Surface and Groundwater Response Plan[11].

The monitoring program has been designed to:

- Enable construction, calibration and refinement of multiple iterations of groundwater modelling necessary for various rounds of approvals (e.g. AGE, 2005, HydroSimulations, 2013, and this report);
- Be used in the continued development of groundwater impact assessment criteria and investigation triggers , as set out in the Groundwater Monitoring Plan; and
- Provide input to annual reviews of groundwater monitoring data.

[10] WCPL Groundwater Monitoring Program (Appendix 6): Document No. WI-ENV-MNP-0006. Nov, 2014.
[11] WCPL Surface and Ground Water Response Plan (Appendix 7): Document No. WI-ENV-MNP-0006. Nov 2014.

The details of monitoring bores in the WCM network are summarised in **Table 3-5** while the locations of these bores are shown in **Figure 3-13**. In recent times WCPL have put considerable effort into collating and managing data on bore information, namely via the bore master file[12]. There remain some monitoring and production bores for which bore logs and depth information is uncertain or unavailable.

For alluvium, there are eight bores being measured monthly for water level and another five logged every 15 minutes. For coal, there are five bores being measured monthly for water level and another five logged every 15 minutes. The data-logged sites were intended to monitor short-term responses to production bores which to date have only been utilised for a very short time.

A network of production bores was drilled for dewatering (DB1-DB7) and water supply (WSB1 to WSB15). Five of the DB-series bores were pumped in May-June 2006 and all were used for water level measurement from July 2006 to April 2007. Of the WSB-series bores, only five were ever pumped (WSB10-WSB12, WSB-14-WSB15 – now identified as GWs10-12,-GWs14-15, as shown on **Figure 3-13**) and then only for a few months (March to June 2007). **Section 2.2.1** presents more detail on these.

[12] Latest version reviewed by HydroSimulations: Water Masterfile_FINAL 16012015.xlsx

Table 3-5 Summary of Groundwater Monitoring Sites

MONITORING SITE	GEOLOGY	START DATE	END DATE	FREQUENCY	LOCATION
GWa1, GWa2, GWa3, GWa4	Alluvium	20 April 2006	-	12 hours	Wilpinjong Creek
GWa7	Alluvium	14 April 2008	-	monthly	Wilpinjong Creek
GWa5	Alluvium?	20 April 2006	-	monthly	Cumbo Creek
GWa6	Alluvium	20 April 2006	-	monthly	Cumbo Creek
GWa8	Alluvium	20 April 2006	-	monthly	Wollar Creek
GWD4, GWD5, GWD6	Alluvium	No record	-	-	Wilpinjong Creek
GWa10, GWa11, GWa12, GWa14, GWa15	Alluvium	May-June 2007	-	15 minute	Wilpinjong Creek
GWc1, GWc2, GWc3	Ulan Coal	20 April 2006	-	monthly	Wilpinjong Creek
GWc4, GWc5	Ulan Coal	20 April 2006	-	monthly	Wollar Creek
GWc10, GWc11, GWc12, GWc14, GWc15	Ulan Coal	20 April 2006	-	15 minute	Wilpinjong Creek
GWD1, GWD2	Ulan Coal	No record	-	-	Pit 1
DB1, DB2	Ulan Coal	23 May 2006	1 April 2007	monthly	Pit 1
DB6, DB7	Ulan Coal	30 July 2006	1 April 2007	monthly	Pit 1
DB3, DB4, DB5	Ulan Coal	30 July 2006	1 April 2007	monthly	Pit 2 - Pit 4
PZ01 - PZ14	Coal Measures	28 April 2008	30 Dec 2011	monthly	Pit 1
PZ15 - PZ28	Coal Measures	12 Nov 2009	30 Dec 2011	monthly	Pit 1 - Pit 2
PZ29 - PZ32	Coal Measures	19 Nov 2012	-	-	adjacent Pits 3 and 4
GWa16	Alluvium	Nov-Dec 2013	-	12-hourly	Wilpinjong Creek
GWc16	Ulan Coal	Nov-Dec 2013	-	daily	Wilpinjong Creek
GWc17, GWc18	Ulan Coal	Nov-Dec 2013	-	daily	Pit 6
GWc22	Ulan Coal	Nov-Dec 2013	-	daily	Pit 4 (centre)
GWa22	Alluvium	Nov-Dec 2013	-	12-hourly	Cumbo Creek / Pit 4
GWa23	Marrangaroo Fm	Nov-Dec 2013	-	12-hourly	Pit 7 (centre)
GWc24	Ulan Coal	Nov-Dec 2013	-	daily	Pit 7 (south)
GWc25	Ulan Coal	Nov-Dec 2013	-	daily	Pit 5 (south, extension)
GWc26	Permian overburden	Nov-Dec 2013	-	daily	Wilpinjong Ck, N of Pit 6
GWc27	Permian overburden	Nov-Dec 2013	-	daily	South of Pit 2
GWc28, GWc29	Ulan Coal	Nov-Dec 2013	-	daily	Pit 8 Slate Gully - north
GWc30, GWc31	Ulan Coal ?	Nov-Dec 2013	-	daily	Pit 8 Slate Gully - south
GWa32, GWa33	Alluvium	Nov-Dec 2013	-	12-hourly	Wollar Creek
GWc32	Moolarben Coal	Nov-Dec 2013	-	daily	Wollar Creek
GWc34	Shoalhaven Grp	Nov-Dec 2013	-	daily	Wollar Creek - south
GWf1	Spoil (final landform)	2014	-	Daily (logger)	Pit 1
GWf2		2014	-	~monthly	Pit 5

A set of 28 monitoring bores[13] (PZ01 to PZ28) was drilled adjacent to Pit 1 and Pit 2 to monitor tailings dam seepage (**Figure 3-13**). The first 14 piezometers (PZ01 to PZ14) were monitored for water level, pH and EC from April 2008 to December 2011. The second group (PZ15 to PZ28) were monitored for water level, pH and EC from November 2009 to December 2011, and an additional non-routine round of monitoring of these bores was carried out on 17 April 2015. Additional bores (PZ29 to PZ32) were installed in 2012 adjacent to Cumbo Creek in Pits 3 and 4.

In November and December 2013 additional monitoring sites were installed around the WCM leases, including in the extension areas proposed as part of the WEP (GES, 2015). These sites are GWa/c16-34 (i.e. some bores monitoring alluvium, some monitoring the Permian coal measures). In 2014, two bores were installed in spoil (rehabilitated) areas (GWf1-2).

Groundwater quality sampling and water level monitoring is undertaken by WCPL in accordance with the *National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia* (ARMCANZ/ANZECC, 1995) and the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality (*ARMCANZ/ANZECC, 2000) and *Murray Darling Basin Groundwater Quality Sampling Guidelines* (MDBC, 1997). Groundwater level and quality monitoring undertaken by WCPL has primarily focused on Wilpinjong Creek, Cumbo Creek, Wollar Creek and associated alluvium.

Water quality parameters that are measured at the monitoring bores listed in **Table 3-5** are provided in **Table 3-6**. These parameters are measured in the alluvium ('GWa'), coal measures ('GWc') bores, and in the in-pit sumps.

Table 3-6 Groundwater Quality Parameters Measured at WCM

pH	Sodium (Na)	Chloride (Cl)	Copper (Cu)	Nickel (Ni)	Lead (Pb)
Electrical conductivity (EC)	Potassium (K)	Sulphate (SO4)	Zinc (Zn)	Manganese (Mn)	Arsenic (As)
Total Dissolved Solids (TDS)	Magnesium (Mg)	carbonates (HCO3, CaCO3)	Iron (Fe)	Barium (Ba)	Selenium (Se)
	Calcium (Ca)		Aluminium (Al)	Strontium (Sr)	

Groundwater inflows to the pits are monitored by recording pump volumes from the in-pit sumps. Field parameters and a suite of water quality parameters are monitored in the sumps on a quarterly basis. Additional pumping rate data has been collected on a higher frequency, with a record of daily pumping hours at individual pumps collated over the period 2012-14. In future more of the pumping data will be collected via flow meters that have recently been installed on key transfer pumps.

Additionally, there are surface water monitoring sites around the Project area, and these have relevance to understanding groundwater-surface water interaction. The locations of these main gauging sites are shown on **Figure 3-3** and **Figure 3-13**, and more detail on the data and subsequent analysis of surface water is presented in WRM Water & Environment (2015).

3.8.3 GROUNDWATER LEVELS

A review of groundwater levels from both WCM monitoring bores and other data sources, including bores registered on NOW's Pinneena database has been conducted.

Some of the NOW registered bores do not have reported/surveyed bore collar or ground surface elevations; therefore groundwater elevations are estimated from approximate ground levels (LIDAR, where available, or DEM, as per **Section 3.1**). The majority of historical data

[13] Installed depth is uncertain

from the NOW registered bores is limited to notes on levels and salinity records taken at the time of drilling or installation.

Spatial Analysis

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers. During short events of high surface flow, streams would lose water to the host aquifer, but during recession, the aquifer would discharge water slowly back into the stream from bank storage.

Based on the available groundwater level data and to gain an impression of the regional water table pattern before mining, a contour map of inferred groundwater levels (**Figure 3-14**) was prepared from:

- groundwater levels at those NOW registered bores (**Figure 3-11**) with water level information;
- data from around the great Wollar Creek catchment taken from DIPNR (2003) – this survey of water levels was done in 2001;
- measured from WCM monitoring boreholes (**Figure 3-13**); and
- topographic elevations at ‘control points’ along watercourses to provide some control on interpolation, particularly in areas where there was no groundwater level data available (marked ‘X’ on **Figure 3-14**). In essence, the assumption is that at these locations, groundwater is discharging to surface water.

The water table map in **Figure 3-14** is a composite of water levels from different dates and from different formations, including Illawarra Coal Measures and the Ulan Coal seam and from alluvium or other surficial deposits (regolith, colluvium). There are no observations from the Narrabeen Formation, mainly because in this area there is minimal development on Narrabeen Formation outcrop as much of it is National Park, State Forest or difficult to access.

On a regional scale, groundwater typically flows perpendicular to the contours (except for discrete fracture flow), so **Figure 3-14** allows the interpretation of groundwater flow patterns around WCM. In general groundwater would flow from the ridges to the natural surface drainages.

Regionally (see upper pane in **Figure 3-14**), there is a groundwater divide to the south and southwest of WCM (coincident with the Great Dividing Range), with:

- mainly westward groundwater flow toward Cooyal Creek and other creeks and springs along the western boundary of the Study Area; and
- primarily eastward groundwater flow toward the Goulburn River.

More locally (see inset on **Figure 3-14**), in the higher parts of the landscape, springs are known to occur (e.g. from the Narrabeen Formation to the south of the WCM mine areas), while Cumbo Creek, Wilpinjong Creek and Wollar Creek are the main prominent groundwater discharge features.

Discussion of the effect of the mine on local groundwater levels, in both alluvium and coal measures groundwater systems, is presented in the following sub-section on ‘Temporal Analysis of Groundwater Levels’.

Figure 3-15 presents the interpreted water table depth, based on the interpreted pre-mining water table map (**Figure 3-14**) subtracted from natural topography (**Figure 3-1**). **Figure 3-15** indicates that depth to water is likely greater on the interfluves (e.g. on the plateaus located on all sides of WCM area, and shallow water tables in the valleys. More usefully, it shows shallow water tables along Cumbo Creek, particularly just to the south of Pits 4 and 2, and along Wollar Creek. This suggests groundwater discharge in these areas, which is a behaviour identified in these catchments in DIPNR, 2003 (i.e. linked to salinity issues).

Where such details were available from the NOW Pinneena database, the median depth to water is approximately 5 m (average = 10 m) with a range in water depths from approximately 0.2 to 60 m below ground (mean = 13 m). The average and range from the database are a useful check on the calculated depth to water shown on **Figure 3-15**.

Within and around the WCM lease area, the lower reaches of Wilpinjong, Cumbo and Wollar Creeks, as well as the middle to upper reaches of Wollar and Cumbo Creeks, are likely to have groundwater within less than 2 to 5 m from the surface. In the main open cut areas associated with the WCM and WEP the depth to groundwater is more typically in the range of at least 5 m below ground surface, if not 10 m to 50 m below ground (e.g. Pit 6, Pit 4, much of Pit 3 and Pit 7 and Pit 8 [Slate Gully]).

Figure 3-16 shows minimum and maximum groundwater levels at a series of WCM monitoring bores, with this dataset extended by using Moolarben Coal Complex monitoring bores obtained from reports (e.g. RPS Aquaterra). The interpolated water levels have been clipped to show where they lie above the (measured or interpolated) base of the Ulan Coal seam (based on the revised geological model, **Section 5.3**). Where blue shading is absent, the coal seam is absent or is dry, and the difference in the blue shading in the upper and low panes shows the degree to which the wet/dry boundary can shift (based on the observed record at the bores marked.

The wet/dry boundary calculated in HydroSimulations (2013) is marked in pink, and this correlates well with the revised boundary calculated 2014 dataset of water levels used in the study). **Figure 3-16** shows that the areas to the immediate south of the WCM pits are usually dry, with an increasing degree of saturation (and confinement) occurring to the north of WCM. Minimum recorded water levels at the WCM show that the Ulan Coal Seam is dry well into Pits 1, 2 and 4, both as a result of drier meteorological conditions but also due to drawdown from mining (see following sub-section, which presents analysis of hydrographs).

Groundwater flow directions in the Ulan Coal Seam are marked on **Figure 3-16**, with a general pattern of northward and down-dip flow, with localised variations around Moolarben Coal Complex (where a groundwater divide is apparent, with flow to the north and northwest as well as to the east. The pattern of flow in the Ulan Coal seam is representative of the pattern of flow in the less permeable overlying Permian Coal Measures or underlying Marrangaroo Formation and Nile Sub-group.

Temporal Analysis of Groundwater Levels

A groundwater monitoring network (**Section 3.8.2**) has been in place at the WCM since April 2006, as illustrated in **Figure 3-13**. Many paired monitoring bores have been drilled along the Wilpinjong Creek alluvium, with a shallow bore screened in the alluvium and a deeper bore screened across the coal seam. More recently, since late 2013, a number of new bores have been drilled around the periphery of the site, in Slate Gully and along Wollar Creek (**Figure 3-13**).

For bores with sufficient record, groundwater levels around the WCM site have been investigated in detail to check for cause-and-effect responses in temporal water level changes which could result from rainfall recharge, creek dynamics, short-term dewatering/production pumping or a mining effect.

Summary bore hydrographs are shown in **Figure 3-17** (alluvial) and **Figure 3-18** (coal seam). More detailed analysis and presentation of hydrographs are included in **Appendix C**.

Based on the analysis of the hydrographs in **Figure 3-17** (and in **Appendix C**) with comparison of each other bore hydrograph against GWa1, mining effects of around1 m, but possibly up to 3 m, are considered to have occurred at the following bores:

- GWa3 at 450 m north of Pit 4, about 1 m drawdown during 2014;
- GWa6 at the northern junction of Pits 3 and 4, less than 1 m during 2014;
- a possible mining-related decline at GWa12, but it is not possible to clearly identify a mining effect;
- GWa14 at 300 m north of Pit 4, less than 1 m during 2013 (bore possibly dry); and
- Bore GWa5, not shown in **Figure 3-17** but presented in **Appendix C**, shows a clear mining effect in 2013-14, with a drawdown of 2-3 m attributable to mining at Pit 4 and/or 3. Note that it is uncertain whether this bore is actually in alluvium or regolith.

The other alluvium bore hydrographs (e.g. GWa1, GWa2, GWa4, GWa11 and GWa15) show no discernible mining effects.

Figure 3-18 shows groundwater levels in the Ulan Coal Seam or coal measures around WCM, and additional or more detailed hydrographs are presented in **Appendix C**. Initial inspection of these shows that drawdown effects from mining are far more prevalent within the coal seam than in alluvium groundwater levels. This is discussed further at the end of this section.

Inspection of **Figure 3-18** (and **Appendix C**) shows more significant drawdowns occurring in the coal seam as a result of mining at WCM. This includes drawdowns in the range of 2 m (at a number of bores) to about 20 m (at GWc12). More detailed analysis is included in **Appendix C**.

The general trend is for mining-related drawdown to be very apparent in coal seam hydrographs, typically within a few hundred metres of active mine areas, but drawdown is much less, if apparent at all, in alluvial bore hydrographs. This is due to the following properties and processes:

- Alluvial bodies not being directly connected to or intersected by the footprint of the open cut pits;
- Rock strata overlying the coal seams and underlying the alluvium serving to mitigate the drawdown response because of low vertical hydraulic conductivity; and
- Unconfined conditions and a greater aquifer storage in the alluvium than in the confined coal seams resulting in much lower head variation (drawdown) in the alluvium.

No mining-related drawdowns have been observed in any hard rock or alluvial monitoring bores in Wollar Village.

3.8.4 GROUNDWATER RECHARGE

The initial step taken in assessing the likely rainfall recharge in the Study Area was through inspection of the Report Card for the Wollar Creek Groundwater Source (NOW, 2009). This provides the information presented in **Table 3-7**, including that recharge is around 846 ML/a and that long-term average rainfall is or 658 mm/a. Note the slightly higher rainfall reported here (compared to 589 mm/a at Wollar in **Section 3.2.1**), most likely due to the Wollar gauge being in a valley, with higher rainfall occurring on the hills of the Wollar Creek catchment.

Table 3-7 Recharge to the Wollar Creek Groundwater Source

AREA	AVERAGE RAINFALL		RAINFALL RECHARGE	
(km^2)	(ML/a)	(mm/a)	(mm/a)	(% rainfall)
532	846	658*	1.6	0.2 %

This is based on average recharge to the catchment of the Wollar Creek alluvium, rather than the area of the Wollar Creek alluvium presented in NOW's GW Macro Plan GIS data.
km^2 = square kilometres

Literature review of some modelling studies carried out in the Study Area yielded the information presented in **Table 3-8**.

Table 3-8 Summary of Recharge in Adjacent Modelling Studies

RECHARGE (mm/a)	RECHARGE AS % LTA RAINFALL	COMMENT	STUDY / MINE	REFERENCE
125	19 %	Zone 1: Alluvium	WCM EIS Groundwater Model	AGE, 2005 / Heritage Computing, 2013
5	~0.7 %	Zone 2: Permian Regolith		
100	~15 %	Zone 3: Narrabeen Group		
33	5 %	Zone 4: Coal Seam Subcrop / Colluvium		
	0-2 %	Permian and Triassic hardrock outcrop	Ulan Coal Continued Operations Model	Mackie, 2009
50	7.4%	Alluvium	Moolarben Groundwater Model	RPS Aquaterra, 2011
45	6.8%	Alluvium (west)		
3	0.5%	Narrabeen Group, Jurassic formations		
20	3.1%	Illawarra Coal Measures outcrop		
0	0.0 %	'basement' (Shoalhaven Group & older formations)		

Geoscience Australia's MapConnect portal provides estimates of recharge as in **Table 3-9**.

Table 3-9 Other Published Recharge Estimates

SOURCE		RAINFALL RECHARGE	
Crosbie, 2010a.	Method of Last Resort (MOLR)	0.8 mm/a [range: 0.02 to 39.2]	0.1% rainfall [range: 0 to 5.8%]

Following the literature review, analysis of water table hydrographs, chloride mass balance and baseflow analysis was carried out using local data, and are presented below.

Water Table Fluctuation

Analysis using the water table fluctuation ('WTF') method (Scanlon *et al.*, 2002) was carried out on bores monitoring shallow aquifers, either alluvium or shallow Permian Coal Measures. The main uncertainties and assumptions associated with this method are:

- Value of specific yield (Sy) to use. The following analysis has used an expected minimum, mean and maximum Sy and compared results;

- Whether rises in the hydrograph are a result of recharge, or from other sources. For example, whether recovery was due to local pumping or the cessation of drawdown from other sources; and
- The method is best used for hydrographs which rise conspicuously and over short periods of time.

This analysis was carried out for five boreholes monitoring the Permian Coal Measures, and four monitoring alluvial deposits. The recharge calculated by this method is as follows:

- Alluvium: 63 mm/a (range 15 to 270 mm/a) or 11% long term average (LTA) rainfall (range 2.5 to 45%), noting that this probably includes influence of leakage from local watercourses, so not truly representative of *rainfall* recharge; and
- Permian: 15 mm/a (range 6 to 75 mm/a) or 2.5% LTA rainfall (range 1 to 13%).

The limited spatial extent and relatively thin geometry (vertically) of these deposits means that the potential for more infiltration is limited. This means that after heavy rain, direct rainfall and leakage of runoff from upgradient can cause the alluvium to become saturated, preventing further infiltration, in which case runoff will then occur from the alluvium. The limited spatial extent of the alluvium, and the proximity to Wilpinjong Creek (in particular) then causes the alluvium to drain relatively quickly following after high rainfall events, with a slower recession over time.

Chloride Mass Balance

The chloride mass balance method (Cartwright *et al.*, 2008) relies on a comparison of average annual rainfall, the observed chloride concentration in groundwater, and the chloride loading of local rainfall to calculate the likely infiltration recharge.

At Wilpinjong, chloride concentrations vary from about 6 to 1730 milligrams per litre (mg/L) in groundwater, with the following statistics used in calculating recharge:

Groundwater System	Chloride (mg/L)		
	5th %ile	Median	95th %ile
Alluvium	70	320	1650
Permian rock	10	365	670

The chloride loading in rainfall was sourced from Geoscience Australia's MapConnect web portal[14] which indicated local chloride loading to be approximately 6.2 kilograms per hectare per annum (kg/ha/a) (range 5-7.5 kg/ha/a). Based on the chloride in rainfall and the range for groundwater chloride, recharge calculated using this method is approximately:

- Alluvium: 2 mm/a (range 0.4 to 9 mm/a) or 0.3% LTA rainfall (range 0.1 to 1.5%); and
- Permian: 1.8 mm/a (range 0.9 to 80 mm/a) or 0.3% LTA rainfall (range 0.2 to 13%).

The recharge rate in the Permian rock seems reasonable, while the recharge to the alluvium seems slightly lower than expected. This result for the alluvium is probably skewed due to both the input of already saline groundwater from the Permian rock into the alluvium and then subsequent evaporative concentration of chloride in the alluvium itself.

[14] http://mapconnect.ga.gov.au/MapConnect/ → Groundwater

Baseflow Yield

Further discussion of groundwater-surface water interaction is provided in **Section 3.8.5**. Rainfall recharge is expected to be matched by discharges as follows:

$$\begin{aligned} Recharge &= Discharge \\ &= Baseflow\ (BF) + Evapotranspiration\ (ET) + GWabs + GW\ flow\ out \end{aligned}$$

A given estimate for baseflow (in mm/a) allows the estimation of an expected minimum recharge value (given that other discharge processes are likely to occur). EC-constrained baseflow estimates in **Section 3.8.5** suggest that baseflow is likely to be 1% of LTA rainfall. This indicates that the minimum recharge to the area as a whole would be around 1-2 mm/a.

Summary

Based on the literature review, the estimates of recharge are 0 to 5% of LTA rainfall for hard-rock and 6 to 20% for alluvium. This is a useful starting point, however analysis of field data suggests that rainfall recharge to the two main groundwater systems is probably slightly lower, in the ranges suggested in **Table 3-10**.

Table 3-10 Summary of Likely Rainfall Recharge Rates near Wilpinjong

Groundwater System	Estimated rainfall recharge [mm/a]			% rainfall
	Min	Best estimate	Max	Best estimate
Alluvium	1	10-20	100	**2-4%**
Permian rock	<0.5	5-10	75	**1-2%**

3.8.5 RIVER-AQUIFER INTERACTION

A number of techniques for assessing groundwater interaction with watercourses near to the WCM are applied in the following sections. These include comparison of groundwater and surface water levels (hydraulics), baseflow separation, and a comparison of available gauging station records.

Hydraulic Assessment

Figure 3-19 and **Figure 3-20** present groundwater level hydrographs for a set of WCM's monitoring bores which all lie close to Wilpinjong Creek. **Figure 3-19** presents information from sites to the west of, or upstream of, WCM Pit 2 (i.e. to the north of Pits 1, 5 and proposed Pit 6), while **Figure 3-20** presents information from sites to the east, or downstream of Pit 2 (i.e. locations to the north of Pits 2, 4 and 3). These groundwater level hydrographs are compared against interpolated creek water levels for Wilpinjong Creek, which are based on the measured water levels from gauge WILGSU, and interpolated based on the LiDAR elevation at a location on the creek where it lies closest to each of the monitoring bores. The analysis does not explicitly account for the effect, if any, that discharges from the RO plant may have on water levels in Wilpinjong Creek.

Figure 3-21 presents similar groundwater level information from bores near to Cumbo Creek compared against surface elevations (as a proxy for creek water levels). This figure has additional information, showing some of the geological contacts from the WCM geological model as well as the elevation of the floor of nearby WCM open cut workings.

The rainfall trend is displayed on all three figures. Bore locations are shown on **Figure 3-13**. Despite the use of LiDAR elevations there remains some uncertainty in the creek water levels used.

Figure 3-19 shows that the occurrence of gaining and losing conditions along Wilpinjong Creek vary with time. Generally weakly gaining or neutral conditions existed in the period 2007-08, followed by a decline to losing conditions that is probably due to workings in Pit 1, but could be due to the year-long decline in rainfall. Losing conditions existing until early 2010, with the reversion to close to neutral (GWa10 and GWa11) or gaining conditions (GWa1 and GWa2) until mid-2012, which was a result of sustained rainfall from 2009. After mid-2012, and relying on extrapolation of surface water levels, Wilpinjong Creek has likely reverted to losing conditions. That conditions near GWa1, which is away from active mine workings, become weakly losing indicates that this is most likely due to the consistently lower-than-average rainfall. However that the decline to losing conditions appears stronger near GWa2, GWa10 and GWa11 suggests that excavation in Pits 5, 1, 2 and 4 are likely affecting baseflow conditions.

On **Figure 3-20**, groundwater levels at GWa4 can be seen to mirror the trend in rainfall (with the exception of a couple of suspect data points in 2010). At this location, the implication is that Wilpinjong Creek was weakly losing in late 2006, becoming gaining from 2007 until early 2014 (again relying on extrapolation from earlier creek water level data). At this time groundwater levels are declining, tending toward neutral conditions. The relationship between groundwater levels and creek water levels is different at the other sites, both in terms of trend and in terms of the apparent gain-loss behaviour.

Groundwater levels at GWa12 are strongly controlled by short-term rainfall patterns rather than the longer-term rainfall trend. At GWa12 there is an apparent strongly-gaining condition after mid-2007, with notable periods after rainfall peaks (i.e. recession periods) where that behaviour is weakened. In recent times, due to the dry period Apr-2102 to Sept-2014, however there is a suggestion that a change to neutral or losing conditions in 2014 could be enhanced by workings in nearby Pit 4.

At the other two sites, GWa3 and GWa14, the relationship points to gaining conditions occurring for most of the period 2007-2011, with GWa14 suggesting neutral then losing conditions from 2011, while at GWa3, gaining conditions appear to persist, albeit more weakly, until 2014.

Figure 3-21a shows little head separation between Cumbo Creek water levels and groundwater levels monitored at GWa5. The implication from the data is that the groundwater-creek relationship is neutral in 2006 and early 2007 (a dry period), then Cumbo Creek is weakly losing from that time until 2010 (a wetter period). Although there is no creek level data presented for 2013-14, **Figure 3-21a** clearly shows the effect of nearby Pit 4 workings, with groundwater levels declining, for the first time in the record, below the interpreted riverbed level.

Figure 3-21b shows a clear downward gradient between alluvium (GWa22) and coal (GWc22) groundwater systems. It also shows that alluvium water levels are below the interpreted creek bed level, suggesting losing conditions in 2013-14. Because the groundwater level record is short, it is impossible to categorically state whether mining has affected the gain-loss behaviour of Cumbo Creek at GWa22, however given the trend in groundwater levels at GWa22 and at GWa5 (**Figure 3-21a**) it is likely that mining in Pits 3 and 4 has strengthened the losing behaviour of Cumbo Creek at this point.

Baseflow Separation and Chloride Mass Balance

Baseflow estimates from three monitoring sites are presented below. One of these is the gauging site upstream of the WCM on Wilpinjong Creek ("WILGS-U"), and the other two are the government (NOW) gauging stations GS#210082 on Wollar Creek (now inactive) and the active GS#210006 on the Goulburn River at Coggan. These three were analysed because they monitor flow (not just level), and two of these also monitor EC.

Table 3-11 Baseflow Estimation on Local Watercourses

WATERCOURSE / STATION	CATCHMENT AREA (km^2)	% BFI (from chloride mass balance) ^	% BFI (from digital filter)	BASEFLOW YIELD (mm/yr)
Wilpinjong Creek (upstream)	81	**6% (4-12%)**	25-35%	0.5 - 2
Wollar Creek # 210082	274	n/a	45-55%	1 - 3
Goulburn River #210006	3340	**14% (10-20%)**	40-50%	2 - 6

^ % BFI from chloride mass balance reported as a best estimate (min-max range in brackets).
mm/yr=millimetres per year.

Two methods have been applied to calculate baseflow:

- digital filters, such as the HYSEP method (Sloto, 1986); and
- a chloride or EC mass balance method, which constrains baseflow estimates using river salinity (EC) data, an estimate of groundwater salinity (see **Section 3.9.3**), and a record of river flows, and combines these in a mass balance approach.

As discussed in Cartwright *et al.* (2013), and based on experience elsewhere in comparing such methods, the EC-constrained estimates are more reliable and lower compared to the much higher and more uncertain estimates produced using digital filters, such as the HYSEP method. Therefore the BFI for Wilpinjong Creek and Goulburn River are more likely to be in the range estimated based on EC-constrained analysis rather than the 25-55% predicted by digital filters. Based on a comparison between the digital filter BFI and chloride mass balance BFI at Wilpinjong Creek and Goulburn River, the likely BFI for Wollar Creek is about 10-15%.

This then suggests that baseflows in this area are equivalent to about 1-3 mm/yr or approximately 0.5-1% of long-term average rainfall.

Flow Differential Using Gauged River Flows

Flow differentials, calculated based on the flow in gauge 210006 (Goulburn River) and the aggregate flow in the other ('upstream') gauging stations presented on **Figure 3-5** during a recession period of four months in mid-1982, suggest an average gain in flow of around 10 megalites per day (ML/day) or equivalent to 3 mm/a. This supports the other analysis and estimates of baseflow and recharge.

3.8.6 EVAPOTRANSPIRATION AND GROUNDWATER DEPENDENT VEGETATION

An assessment of the likelihood of vegetation accessing groundwater was made considering:

- **Figure 3-15** as a guide to the depth to the water table;
- the distribution of mapped (potential) GDEs (**Section 3.6**);
- aerial photos of the site; and
- the adopted vegetation rooting depths for trees (9 m) and grasses (1.2 m) (refer **Section 3.5.2**).

Based on the preceding review of data, no GDEs are known or likely to occur within the WCM mining lease area, with the exception of the *typha* vegetation which is present along Cumbo Creek where the creek intersects the southern boundary of planned WCM Pits 4 and 3 (see inset in **Figure 3-3**).

There are a number of significant groundwater dependent sites in the region to the north, west and south of WCM (see main map in **Figure 3-3**).

Prior to land-clearing in this area, it is more likely that trees on the flats now occupied by the WCM did access groundwater. However, as aerial photos suggest, the land occupied by the WCM and proposed to be occupied by the WEP has been cleared for some time, with the exception of Pit 7.

Trees on the Narrabeen Group plateaus surrounding the WCM might access perched groundwater, however groundwater monitoring data does not exist for these National Park/State Reserve areas.

3.8.7 HYDRAULIC PROPERTIES

Hydraulic Conductivity

Hydraulic property data has been gathered at WCM since 2005, and presented in various reports including AGE (2005) and HydroSimulations (2013). More testing has been carried out in recent times by GES, as presented in GES (2015). Additionally, adopted hydraulic property values from previous groundwater models have been compiled from studies conducted at the WCM, Moolarben Coal Complex and Ulan Mine Complex. Note in this section, and elsewhere in the report, the terms ‘permeability’ and ‘hydraulic conductivity’ are used interchangeably.

A compilation of the hydraulic conductivity data is presented in **Figure 3-22**, which presents data grouped into the hydrostratigraphic units that will be adopted in the conceptual model (see later, **Section** 4). On that figure, *kx* = horizontal hydraulic conductivity, and *kz* = vertical hydraulic conductivity. The following comments are made on this dataset:

- Alluvium and Ulan Coal seam permeabilities are generally higher than those measured in other units, except perhaps the Shoalhaven Group and older units.
- Many of the slug test results suggested Ulan Coal Seam permeabilities in the range of 0.01 m/d to greater than 1 m/d, and with peak values recorded as being up to 12 m/d (slug test) and 5 m/d (pumping test).
- Pumping tests results for the Marrangaroo Formation (a conglomerate) suggested permeabilities of up to 6 m/d, although the bulk of the slug testing suggested lower values (typically 0.01 metres per day [m/d]).
- Core testing results, for both horizontal and vertical permeability, are displayed as the median result with error bars to show the range in results. Horizontal permeabilities from core testing are typically lower than results obtained from slug or packer testing, particularly in the Illawarra Coal Measures, but to a lesser degree in the Marrangaroo Formation. This is expected, due to core testing focussing on the primary porosity of the strata (i.e. the intergranular pore space), while *in situ* testing such as packer and pumping tests accounting for flow through any secondary porosity (fractures, joints).
- GES (2015) stated that when a pumping test was conducted in pumping bore GW11 (in the Ulan Coal Seam), drawdown was quickly detected in nearby GWc11 (also in the coal seam), but no drawdown was evident in GWa11 (in the alluvium). This suggested that, in the short-term at least, there is limited connection between the Ulan Coal Seam (pumped interval) and the overlying alluvium.
- Permeabilities adopted for modelling studies follow the trends in field testing data. Commentary on model parameters was made in HydroSimulations (2013), with the general findings that the adopted horizontal permeabilities in the Moolarben model were probably high, while the anisotropy (kx/kz) applied in the Ulan model was possibly too low (although, if those models are calibrated satisfactorily, then the differences may be site-specific).

The adopted ‘best estimate’ ranges in hydraulic conductivity are tabulated in **Table 4-2** in **Section** 4.

Storage Properties

Studies conducted in the Sydney metropolitan area and elsewhere indicate a Sy of between 0.01 and 0.02 (i.e. 1-2%) is reasonable for typical Hawkesbury Sandstone (Tammetta and Hewitt, 2004). This serves as an initial estimate for the sedimentary deposits at WCM, which is in the northern part of the Sydney Basin.

Six measurements each of total porosity (n) and effective porosity on core from WCM exploration bores (PW1123, PW1127 and PW1130) were available (**Figure 3-23**). Total porosity is a theoretical upper limit for the water held in a volume of rock or soil, however effective porosity is more representative of the likely 'drainable' porosity or Sy. The results of testing for effective porosity are (the blue series on **Figure 3-23**):

- Two for the Illawarra Coal Measures (20 and 40 m above the Ulan Coal Seam respectively), where eff. porosity = 0.7 to 6%;
- Two for the Ulan Coal Seam, where eff. porosity = 0.4 to 12%; and
- Two for the Marrangaroo Formation, with eff. porosity = 0.4 (siltstone) to 9% (conglomerate).

Sy, together with porosity and specific storage (Ss), usually decreases with depth, and this trend is evident on **Figure 3-23**. The two samples from the Marrangaroo Formation (underlying the Ulan Coal Seam) exhibit a trend opposite to this – this is due to the variable lithology, with the deeper sample (60.7 mBG) being taken from conglomerate, while the slightly shallower sample (56.9 mBG) being taken from a horizon of fine-grained sandstone within the Marrangaroo Formation.

In all cases, there is significant variation in the effective (and total) porosity of each stratigraphic unit sampled (acknowledging that this is based on two samples from each).

Alluvium is expected to possess a Sy in the range of 0.03 to 0.2 (3-20%), depending on the dominance of silt/clay or sand/gravel.

AGE (2005) used storage properties as shown in **Table 3-12** in their groundwater model for WCM. This was the same model as used in HydroSimulations (2013). Some comments on these values are provided in the table, with further discussion below.

Table 3-12 Summary of Previous Model Storage Properties at WCM (AGE, 2005)

HYDROSTRATIGRAPHIC UNIT	Sy (unconfined)	Ss (confined)	Comment on Sy parameter	Comment on Ss parameter t
Alluvium	0.25 (25%)	1e-04	Probably high	
Narrabeen Group	0.1 (10%)	1e-04	High	High
Illawarra Coal Measures	0.1 (10%)	1e-04	High	High
Ulan Coal Seam	0.1 (10%)	1e-04	Probably high	OK, possibly high
Marrangaroo Sandstone	0.1 (10%)	1e-04	OK	OK, possibly high

Direct test data is not generally available for Ss. AGE (2005) stated "Aquifer storativity of the Ulan Coal Seam was determined by GeoTerra Pty Ltd (2004) to vary between $2.3x10^{-4}$ and $3.2x10^{-3}$, which for the average thickness of the coal seam of 15 m gives a Ss value of between $1.5x10^{-5}$ m^{-1} and $2.1x10^{-4}$ m^{-1}. The storativity of the Marrangaroo Sandstone was determined from the pumping tests to be $1.3x10^{-3}$. This was the justification for the adopted uniform Ss of $1x10^{-4}$ m^{-1} used in that modelling.

Model calibration parameterisations at mines in the Southern Coalfield, where the Narrabeen Group and Illawarra Coal Measures are also present, suggest that Ss is in the order of 1E-7 to 3E-5 m^{-1} for the coal seams, and about 1E-6 m^{-1} for overburden or interburden.

Good estimates of Ss can also be made based on Young's Modulus and porosity, based on calculations in Mackie (2009). Calculations for the WEP suggested that for coal, Ss generally lies in the range 5E-6 m^{-1} to 5E-5 m^{-1}, and Permian interburden from 1.7E-6 (unfractured, fresh rock) to 8E-6 (fractured rock). This is in line with Mackie's work at Ulan (MER, 2011), which stated "Specific storage estimates ranging from 1.69E-06 to 5.13E-06 m^{-1} have been calculated for a modulus range from 3.1 to 17.7 GPa. Higher specific storage values may be associated with weaker porous Triassic sandstones and the coal seams".

For the parameterisation of this model (see initial values and ranges **Table 4-2** in **Section** 4), a broad trend of decreasing Ss with depth was used, representing the concept that joints and fractures are more likely to be open nearer the surface and more likely closed due to overburden pressure at depth.

3.8.8 GROUNDWATER INFLOW TO MINES

Available Data

Groundwater inflow to the open cuts at WCM was recorded as monthly volumes for the period September 2006 to December 2011. After that the frequency of recording changed to daily records based on pumping hours and pump capacity.

The WCM AEMRs record the monthly volumes of water pumped from the main pit sump, dewatering bores and production bores. The rate of water extraction, expressed in ML/day units for the relevant measuring period, is illustrated in **Figure 3-24**. The whole-of-mine records shown on **Figure 3-24** are moving averages calculated across 6-month periods. The pit-by-pit estimates are averages for water years (2012-13 and 2013-14).

All the raw data for the volume pumped from the pits include direct rainfall and any surface runoff in addition to groundwater inflow, but exclude evaporation from the pit and from groundwater seepage faces. There is also likely to be a component of dam seepage for water that is recirculated from surface water storages and tailings dams around the site, and it is known that this was particularly the case in the period 2012-14. As a result of the high rates of recirculation between surface water storages in Pit 2 and the open cut in Pit 4 (based on the pumping hours vs pump capacity dataset), the actual groundwater inflow to Pit 4 is uncertain, and not shown on **Figure 3-24** for 2013-14, although has been estimated by comparing the site-side estimates made by WRM Water & Environment (2015) – see **Table 3-13**.

In future more accurate data should be available via flow meters that were installed at the site in 2014.

Historical Groundwater 'Take'

Bore dewatering at the northern edge of Pit 1 occurred only in May and June 2006, at the time mining commenced in Pit 1 (June 2006). The peak rate was 0.4 ML/day (averaged over a month). This rate has been incorporated into the 'sump pumping record' shown on **Figure 3-24**. The production borefield on the northern side of Wilpinjong Creek from the WCM and nearer the foothills of the Goulburn River National Park, was operated only for four months in mid-2007 at a maximum rate of 1.0 ML/day.

Figure 3-24 shows that there was a steady increase in pumping from less than 1 ML/day at the start of mining in 2006 to about 2 ML/day in 2009. Although pumping from the pit occasionally reached 4-6 ML/day (averaged over a month), the long-term average is 1.6 ML/day until 2012, then rising slightly to about 2-2.5 ML/day for the period 2013-15. The broadly increasing trend in pit dewatering volumes is generally consistent with the rainfall trend (also shown on **Figure 3-24**), although the development of more of the open cut pits at one time (see lower chart on **Figure 3-24**) is likely to be a factor contributing to the increase in overall dewatering rates in recent years. The WRM Water & Environment (2015) water balance data suggests that inflow declined to about 2.5 ML/day in late 2014.

A water year summary of available site-wide and pit-by-pit groundwater inflow is shown in **Table 3-13**. The peak inflow over a water year is about 1380 megalitres or 3.8 ML/day (in 2013-14).

Table 3-13 Measured and Inferred WCM Groundwater Inflows (ML/a)

DATE	PIT 1	PIT 2	PIT 3	PIT 4	PIT 5	PIT 6	PIT 7	TOTAL	DATA SOURCE
2006-07								254	WCPL sump pumping and dewatering data. Estimates of pit-by-pit inflow not available.
2007-08								601	
2008-09								702	
2009-10								511	
2010-11								570	
2011-12								804	
2012-13	0	1	38-54	136-273	160-453	0	0	335-780	Pumping hours for pit-by-pit and WRM water balance for site-wide total.
2013-14	0	1	890-1270	345-695	140-405	0	445	1380-1794	

Moolarben Mine

Data or records for any actual inflow to the neighbouring Moolarben Open Cuts has not been sighted by HydroSimulations. The Moolarben Underground Mine is not yet operational. Predictions of inflow from the Groundwater Assessments conducted for Moolarben (RPS Aquaterra, 2012; HydroSimulations, 2015) indicate that inflows are expected as per **Table 3-14**.

Table 3-14 Predicted Moolarben Groundwater Inflows (ML/a)

	OC1	OC2	OC3	OC4	UG1	UG2	UG4	TOTAL OC	TOTAL UG
Max	413	58	265	1819	1450	24	4466	1819	4466
Average	304	32	126	855	918	5	2452	626	1667

UG = Underground.

3.8.9 GROUNDWATER PRODUCTIVITY

NOW classify groundwater systems as 'Highly Productive' and 'Less Productive'. The AI Policy (NSW DPI, 2012) states that a groundwater source will be defined as Highly Productive *'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.'

NOW has classified the alluvium associated with Wilpinjong Creek and Wollar Creek as 'Highly Productive'. However, the available data indicates that this current classification is not valid. This statement is made in the context of the recorded lithology and thickness of alluvium (**Section 3.7.3**), the fact that no bores intersecting the declared 'Highly Productive" alluvium along Wollar Creek or Wilpinjong Creeks has a recorded bore yield of >5 L/s in the Pinneena bore database (**Section 3.8.1**) and the distribution of groundwater salinity (**Section 3.9**). Notwithstanding, these formations have been conservatively assessed as 'highly productive' in accordance with DPI Water's classification.

3.9 GROUNDWATER CHEMISTRY

This section characterises the groundwater quality at and around the WCM using existing regional and local data, for the purpose of assessing potential impacts of the WEP.

Reporting requirements in relation to groundwater quality are listed in the SEARs and related documents, a summary of which is provided in **Section 1.4.1**. Potential impacts to water quality are assessed in relation to the minimal impact consideration from the NSW AI Policy (NOW, 2012) are listed in **Table 3-15**.

Table 3-15 Water Quality Minimal Impact Considerations Relevant to the WEP (AI Policy)

GROUNDWATER SOURCE	MINIMAL IMPACT CONSIDERATION
Alluvial groundwater	a) Any changes in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. c) Redesign of a highly connected surface water source that is defined as a "reliable water supply" is not an appropriate mitigation measure to meet considerations 1 (a) and 1 (b) above d) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank of 100m vertically beneath (or the three dimensional extent of the alluvial water source – whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". e) Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".
Less productive porous and fractured rock	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. 2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

3.9.1 GROUNDWATER ENVIRONMENTS

Groundwater investigations carried out by AGE (2005) and HydroSimulations (2013 and this report) identify six aquifer systems or groundwater environments in the vicinity of the WCM:

- Quaternary and Tertiary alluvium/colluvium along drainage lines;
- Elevated sandstone plateaus of the Triassic Narrabeen Group;
- Illawarra Coal measures and Lower Narrabeen Group (Overburden);
- Ulan Coal Seam;
- Marrangaroo Conglomerate (separated from the Ulan Coal Seam by a thin siltstone layer in places but otherwise hydraulically connected with Ulan Coal Seam) and the Nile Sub-Group; and
- Shoalhaven Group.

For the purposes of the AI Policy and the region's WSPs, the aquifers are divided into two primary water sources; a) the alluvial aquifer system (primarily associated with Wilpinjong Creek and Wollar Creek), and b) porous rock groundwater system (dominated by the Permian Illawarra Coal Measures near the mine). The following discussion on groundwater quality uses the same subdivision.

3.9.2 GROUNDWATER QUALITY MONITORING

Wilpinjong Mine maintains an extensive groundwater monitoring network comprising 92 monitoring bores as shown in **Table 3-16**. Water quality monitoring has been carried out at selected sites since April 2008. Specific bore details, dates of operations and monitoring frequencies are shown in **Table 3-5**, and bore locations are shown in **Figure 3-13**.

Table 3-16 Summary of the Groundwater Quality Monitoring Network

AREA	ALLUVIUM	PERMIAN COAL MEASURES	TOTAL BORES
Wilpinjong Creek	GWA01, GWA02, GWA03, GWA04, GWA07, GWS10A, GWS11A, GWS12A, GWS14A, GWS15A, GWA16, GWA09, GWA14, GWA10, GWA11, GWA12, GWA15	GWC01, GWC02, GWS10CS, GWS11CS, GWS12CS, GWS14CS, GWS15CS, GWC26, GWC16, GWC10, GWC11, GWC12, GWC14, GWC15	31
Cumbo Creek	GWA05, GWA06	GWC03	3
Wollar Creek	GWA08, GWA32, GWA34	GWC04, GWC05, GWC32, GWC34	7
Near Mine Pits 4, 5, 6, 7 & 8	GWA22, GWA33	GWC17, GWC25, GWC20, GWC19, GWC35, GWC22, GWC33, GWC31, GWC18, GWC28, GWC29, GWC30, GWC24, GWC35, GWC21, GWC23	18
South of the mine		GWC27	1
Tailings facilities		PZ01 – PZ32	32
Number of bores	24	68	**92**

3.9.3 GROUNDWATER QUALITY

Beneficial Use

Figure 3-25 shows the ranges in groundwater EC (µS/cm) for 1064 field and laboratory measurements, arranged according to aquifer type and area. EC increases in proportion to the total dissolved ions in a water sample and is a commonly used proxy for water quality. Also shown are thresholds for groundwater use categories as recommended in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).

Groundwater quality within and surrounding the WEP is highly variable but generally poor, with most groundwater suitable only for livestock and irrigation of some salt tolerant crops. Groundwater in some areas is too saline for livestock. The highest groundwater salinity is associated with the alluvium along Wilpinjong, Wollar and Cumbo Creeks where groundwater EC exceeds 8000 µS/cm at GWa01, GWa07, GWa11A, GWa16, GWa05, GWa06 and GWa33. Groundwater in the alluvium has a higher average salinity than the underlying coal measures.

Groundwater pH is near neutral with 90% of all 1064 measurements between pH 6.2 and pH 7.9. The lowest recorded groundwater pH is pH 4.5 at in coal measures at GWc27, well to the south of active mining.

Surface water quality is also typically poor. The Hunter River Water Quality Objectives (OEH, 2006) notes that the surface water quality in the area of "uncontrolled streams" that includes the WEP is "often inadequate to support most of the desired environmental values, particularly for healthy aquatic ecosystems, for swimming and drinking, and for irrigation of moderately salt-tolerant crops." Included in this is the "high background salinity levels of… Wollar" Creek, which is on the down-gradient side of the WEP.

The highest recorded salinity values have been identified at Cumbo Creek to the South of Pit 4, Wilpinjong Creek near Pit 6, and in Wilpinjong Creek northeast of Slate Gully. The lowest recorded salinity values are found in Wilpinjong Creek between Pit 1 and Pit 4 and in Wollar Creek.

The discussion above indicates that the groundwater in the vicinity of the WEP would have a somewhat limited range of beneficial uses with most groundwater suitable only for livestock and irrigation of some salt tolerant crops.

Groundwater Chemistry

Groundwater chemistry is characterised according to the abundances and types of dissolved ions in a water sample. The proportions of dissolved ions in the water often reflects the origin of the water and interactions with aquifer materials (dissolution and precipitation of minerals). These attributes can be useful in classifying groundwater types and placing constraints on conceptual models for groundwater movement.

The major ion chemistry of 129 groundwater samples is shown in a piper plot in **Figure 3-26**. A Piper plot uses two tri-linear plots to represent proportions of major cations (lower-left: Na^{+} + K^{+}, Ca^{2+}, Mg^{2+}) and anions (lower-right: HCO_3^{-} + CO_3^{2-}, Cl, SO_4^{2-}). Each analysis is then projected onto a third rhombohedral (upper) plot illustrating the overall water type.

The following groundwater types and spatial relationships are noted:

- There is a large range in major ion chemistry particularly amongst groundwater samples from the Illawarra Coal Measures. At least five main types or end-member compositions are apparent, with a spread of compositions between (numbered list corresponds to classes on **Figure 3-26**):
    1. **Sodium chloride dominant**; for example, groundwater in alluvium at GWa02, GWa10 and GWa16, and in coal measures at GWc01 and GWc29.
    2. **Sodium bicarbonate dominant**; for example, groundwater in coal measures at GWc02, GWc05, GWc12, GWc14, GWc16, GWc28, and GWc32.
    3. **Mixed cation sulphate**; for example, groundwater in alluvium at GWA04, GWa05, GWa08 and GWa22 and in coal measures at GWc11, GWc18, GWc22 and GWc24.
    4. **Mixed cation chloride bicarbonate**; for example groundwater in coal measures at GWc20, and GWc35.
    5. **Calcium chloride type**; this groundwater type is noted at only one location, GWc33, northwest of Pit 6.
- There is no clear spatial relationship between the hydrochemical types, apart from the overall tendency for groundwater within the alluvium to be higher in salinity (and in trace metals). Rather, groundwater chemistry is highly heterogeneous.

One characteristic that is not apparent in Piper diagrams is that potassium is notably higher in concentration in groundwater within the coal measures (on average) than groundwater in alluvium. This is clearly seen in **Figure 3-27** and indicates that saline groundwater in the alluvium is chemically distinct from the coal measures.

Trace Metals

The concentrations of trace metals in 131 groundwater samples are summarised according to groundwater environment in **Figure 3-28**. Dissolved metal concentrations are slightly higher in the alluvium groundwater, on average, than groundwater in the coal measures. The difference is more distinct for aluminium and manganese concentrations, which are an order of magnitude higher in alluvium groundwater than in coal measures. The increase in trace metal concentration with salinity (or EC) is to be expected as a result of evaporative concentration of ions. The observed ranges in metal concentrations are considered typical for groundwater in the area and reflect baseline conditions.

Temporal Changes in Groundwater Quality

Summary plots of the long-term in EC in the alluvium and coal seam are presented in **Figure 3-29**. This plot shows the longest records from the WCM, and key points include:

- Not only is the salinity in alluvium typically higher than in the coal seam, it is far more variable. The variability is due to the interaction between the shallow alluvial groundwater with rainfall, runoff and evaporation;
- Trends in GWa5 and GWa6 reflect the rainfall residual curve, with generally increasing EC in dry periods and decreasing EC in wetter periods; and
- That there is no discernible trend in salinity that indicates that mining at WCM is having a negative effect on groundwater salinity.

Individual time series plots of EC and pH for all groundwater monitoring sites are shown in **Appendix D**. These time series plots include smoothed trend lines using the LOWESS method (a locally-weighted polynomial regression) to identify underlying trends in the data. The following temporal trends are noted:

- Most monitoring bores in alluvium (with a long monitoring record) show a steady increase in EC from approximately mid- to late-2013. The percentage increase is variable between locations but exceeds 100% in some bores (e.g. GWa01, GWa04, GWa06, GWa16). Increasing EC trends are also noted in some bores screened within the coal measures (e.g. GWc02, GWc03, GWc28).

- The increase in EC appears to coincide with the onset of a particularly dry period, during which rainfall recharge was limited and evaporative concentration of salts would occur. The increase also coincides with the start of mining at Pits 3 and 7. However the change in salinity is considered to reflect climatic influence and not mining impact because an increasing EC trend is apparent in bores that are well distant from the mine and/or up-gradient from the mine, precluding a mining cause.

- A decreasing EC trend is noted in a small number of monitoring bores (e.g. GWS12CS, GWc19, GWc22, GWc31, GWa11).

- Groundwater pH remains relatively stable around near neutral values. Groundwater pH at GWc16 and GWc35 declines sharply from high values (>10) to near neutral values several months after installation of the bore. This probably reflects the influence of grout from the installation which dissipates over time.

Monitoring of the Tailings Facilities

The seven tailings dams at WCM are shown on **Figure 2-1**. A total of 28 piezometers (PZ01 to PZ28 - **Figure 3-13**) were installed at the tailings dams ('TD') to monitor groundwater level and groundwater quality. Time series plots of EC and pH for the PZ-series piezometers are shown in **Figure 3-30** (TD1 and 2) and **Figure 3-31** (TD3 and 4). Individual plots are presented in **Appendix D**.

Figure 3-30 and **Figure 3-31** present pH and EC monitoring results from the monitoring piezometers near to the each pair of tailings facilities along with the long–term rainfall trend, and the EC and pH from "baseline" bores selected in relation to distance from the tailings dams within the alluvial and coal units. A selection of these bores that were still accessible (only two near TD3 and 4) were tested again in early 2015 as a check on the medium-term operation of the tailings dams. More detailed commentary on these figures follows below, but in general, there is no evidence of a solute breakthrough at the down-gradient PZ bores that would indicate a medium- to long-term issue with the tailings dams.

Figure 3-30 suggests no issue regarding groundwater pH near to TD1 and TD2. The PZ bores show slightly higher values than those indicated by the alluvium or coal baselines, however almost all fall within the acceptable range of 6.5-8. The initial readings in PZ6 (pH = 10) and PZ10 (pH = 9) were outside this acceptable range but are found while the sensors are likely calibrating, and subsequent data was below pH 8, so this early time data was ignored.

Figure 3-30 also suggests that, other than the initial readings in PZ6, there were no concerns regarding EC near TD1 and TD2. The readings generally fall below the coal baseline, and almost always fall below the alluvium baseline.

Figure 3-31 shows that the groundwater pH measured in the PZ bores near TD3 and TD4 generally lies within the acceptable range of 6.5-8, including the two readings from 2015 (pH 7.3 and 7.6), suggestive of no medium-term issue around TD3 and 4. Apparent acidic conditions were found in a single reading at PZ28, which may be anomalous, and in three consecutive readings at PZ16 in 2011, which suggests that these low pH readings (pH = 5.1-5.4) were correct. However, in both of these bores, the pH returned to 6.5 and 7 respectively following the brief period of lower readings. This suggests that there may have been some short-term observable effect possibly related to the tailings dams, but possibly unrelated.

The EC data on **Figure 3-31**, including the 2015 data, indicates no long term issues with salinity around TD3 and 4. The high readings in PZ21 in 2010-2011 correspond with the operation of TD3 and TD4, and potentially indicate short-term effects from those tailings dams, particularly in relation to the decline from late 2011 (the end of TD4) to early 2015. Although the EC at this bore (and infrequently at PZ18) was higher than other PZ bores, the EC of 6000-8000 microseconds per centimetre (µS/cm) recorded during that time is similar to the baseline alluvium EC, and therefore not out of character with conditions at WCM. The most recent EC readings, including those at PZ21, are <2000 µS/cm, indicating that any effects, whether due to the tailings dams or not, were short-lived and are not affecting the potential for longer-term beneficial use.

4 HYDROGEOLOGICAL CONCEPTUAL MODEL

This section synthesizes or integrates the conclusions and analysis described in previous sections.

A conceptual model of the groundwater regime was described in AGE (2005) and Heritage Computing (2013), including reference to the data incorporated within that model:

- Western Coalfield Geological Mapsheet (Yoo, 1998);
- Dubbo 1:250,000 Geological Mapsheet SI/55-04 (Colquhuon *et al*, 1999);
- Gulgong 1:100,000 Geological Mapsheet Watkins *et al* (2000);
- NSW WSPs and GW Macro Plan mapping (NOW);
- WCPL exploration (geological) data, bore logs and downhole geophysics;
- TEM geophysics commissioned by WCPL in 2011 and 2014 (Groundwater Imaging, 2014);
- NOW Pinneena Groundwater Works database (both v4 and v.10.1) records;
- Bore censuses conducted by WCPL in 2004 and 2015;
- Previous hydrogeological assessments undertaken for the WCM and nearby mines (i.e. GeoTerra, 2004; AGE, 2005; GeoTerra Pty Ltd, 2005; Merrick, 2005; Wilton and Dundon, 2008; RPS Aquaterra, 2011; MER, 2009);
- Piezometric data from groundwater monitoring programs undertaken at the WCM and surrounding mines (e.g. RPS Aquaterra, 2011); and
- Groundwater investigation testwork (e.g. pumping tests) commissioned by WCPL (e.g. GeoTerra Pty Ltd, 2004; GeoTerra Pty Ltd, 2005; Merrick, 2005).

Based on the above data, and consistent with the relevant WSPs, the data supports two distinct groundwater systems:

- <u>Porous Rock groundwater system</u>: primarily the Illawarra Coal Measures; and
- <u>Alluvial groundwater system</u>: associated primarily with Wilpinjong and Wollar Creeks.

These two broad groundwater systems are broken down further into hydrostratigraphic layers. The hydrostratigraphic framework for the WCM area is shown in **Table 4-1**. This is essentially an extension of that presented in AGE (2005) and HydroSimulations, 2013).

Table 4-1 Conceptual Hydrostratigraphic Framework for WCM

LAYER	HYDROSTRATIGRAPHIC UNIT	AGE	INDICATIVE THICKNESS [m]
1	Alluvium, colluvium, other unconsolidated deposits and weathered zone/regolith	Recent to Tertiary	Typically 3-15, up to 50
2	Narrabeen Group (upper)	Triassic	50
3	Narrabeen Group (lower)	Triassic	25
4	Illawarra Coal Measures (upper)	Permian	
5	Illawarra Coal Measures (middle) [includes the Moolarben Coal Member]	Permian	20 to 50
6	Ulan Coal Seam	Permian	10 to 15 *
7	Marrangaroo Formation / Nile Sub-group	Permian	20 to 25
8	Shoalhaven Group, older units	Permian - Palaeozoic	50

* total coal ply thickness (i.e. excluding partings or interburden).

The key geological features of the WCM area are:

- elevated sandstone plateaus of the Narrabeen Group;
- a thin veneer of recent alluvium/colluvium along Wilpinjong Creek and alluvium along Cumbo Creek and Wollar Creek. Alluvial bodies are quite narrow (laterally) near to WCM;
- unconsolidated deposits in the western portions of the WCM. Near to and within the Moolarben Coal Complex this represents a coarse-grained lithology almost 60 m deep;
- overburden, consisting of the Permian Illawarra Coal Measures, including the Moolarben Coal Member, which is a secondary economic coal resource;
- Ulan Coal seam (the primary economic coal resource);
- Marrangaroo Sandstone and underlying Nile Sub-Group; and
- Shoalhaven Group and older units acting as the 'basement'.

Alluvial deposits are associated with Wilpinjong and Cumbo Creeks in the WCM area, along Wollar Creek to the east of Pit 8 (Slate Gully) and Moolarben Creek about 4 km to the south-west of the WCM area. Colluvial deposits are evident Wilpinjong Creek and the Goulburn River National Park.

A prior drainage system and/or some other process has resulted in coarse-grained deposits which are deposited through WCM Pit 6 and to the west, through the Moolarben Coal Complex lease. These sediments are generally not coincident with modern drainage lines.

None of the identified groundwater systems are significant aquifers. The most permeable units are the Ulan Coal Seam, alluvium and Marrangaroo Formation (Marrangaroo Conglomerate), while the sandstones of the Narrabeen Group are of lower permeability. The Illawarra Coal Measures include low permeability mudstones and siltstones.

Sketches of the pre-mining, operational (during mining) and post-mining hydrogeological conceptual models are illustrated in **Figure 4-1**.

4.1 RECHARGE AND DISCHARGE

Recharge to the groundwater systems would occur primarily from rainfall and runoff infiltration, and lateral groundwater flow especially from the elevated Narrabeen Group to the alluvium of Wilpinjong Creek. Seepage faces would be expected along the cliff faces bordering Wilpinjong Creek after rainfall events, and perched water tables might be sustained at high elevations due to the presence of occasional mudstone/siltstone beds between the sandstone layers. Although groundwater levels are sustained by rainfall recharge, they are controlled by topography, geology and surface water levels in local drainages. Local groundwater tends to mound beneath hills but mounding is expected to be slight to the south of the WCM area because sub-cropping coal seams are dry there. Areas of alluvium and where sandier soils are present, such as in the upper parts of Pit 5 and Pit 7, are likely to accept more infiltration (recharge) than areas where clayey soils or bare rock are present.

Wilpinjong Creek and Cumbo Creek are conceptualised as gaining systems under natural conditions. Groundwater, under natural conditions, is expected to discharge upwards from the Permian rocks to the alluvium associated with Wilpinjong Creek. Loss by evapotranspiration (ET) is likely along the riverine corridor where the water table is nearer the ground surface (where it is usually less than 2 or 3 m below ground level).

During mining the water table will be lowered in the vicinity of active open cut pits. In most of the open cut areas, the intention is to fill the void left after mining with spoil or waste rock. Spoil and waste rock is likely to be more permeable than the native strata (Hawkins, 1998 and Mackie, 2009), hence there would be increased rainfall infiltration into and through areas of spoil emplacement, causing the water table to rise, or 'mound', within spoil and waste emplacement areas over time. A review of groundwater level data from bore GWf1, installed in 2014 in the spoil in the northern part of Pit 1 (see **Figure 3-13**) indicates a slow recovery of groundwater levels at this location, with water levels only 2 m above the former floor of the pit. The recovery is likely hampered by the presence of nearby open workings in adjacent Pits 2 and Pit 5, but it is expected that water levels will recover once workings move away, and possibly recover to levels above the pre-mining water table.

Groundwater sourced from the coal measures and the spoil or waste emplacements will discharge into the open cut pits. Some reduction in creek baseflow and groundwater upflow would be expected. At times, or in some reaches, the natural upward groundwater gradient could be reversed, to downward flow, from the alluvium to the Permian strata.

The proposed WEP mine plan proposes to have three final voids left after mining; one at the southern end of Pit 8, one on the western edge of Pit 2 (the existing Pit 2 West dam), and one in the north-western corner of Pit 6 (**Figure 2-4**). The latter two will be closest to a watercourse, being proximal to and south of Wilpinjong Creek. Furthermore, the Pit 6 void is likely to be adjacent to the approved void in Moolarben Open Cut 4. Depending on the location of the voids located in the north of the mine in relation to surrounding spoil emplacement areas and local climate, it is likely that the final voids will form lakes ('void lakes'), and that these will act as hydraulic sinks into the long-term. This is due to evaporation from the open water surface maintaining the lake stage at a level below surrounding water table levels. Where close to watercourses, this may result in removal of some baseflow contribution to watercourses, or even a persistent losing condition in the vicinity of the lake.

4.2 HYDRAULIC PROPERTIES

Eight active layers are conceptualised in **Table 4-1** for the purpose of numerical modelling. The thicker stratigraphic formations (Narrabeen Group and Illawarra Coal Measures) are split into multiple layers in recognition of their vertical hydraulic gradients and the need to represent the target coal seam as separate model layers.

Indicative permeabilities and storage properties for the main stratigraphic units, based on field testing and model calibration at WCM and neighbouring mines are summarised in **Table 4-2**.

Table 4-2 Indicative Hydraulic Properties of Hydrostratigraphic Units

UNIT	HYDROGEOLOGY (at WCM)	Hydraulic Conductivity k [m/d]		Storage Properties	
		Horizontal (k_H)	Vertical (k_V)	Sy	Ss (m^{-1})
Recent alluvium	Unconfined aquifer	1 (0.1 to 10)	0.1	3.0E-02 (clayey) 2.0E-01 (coarse)	--
Unconsolidated sand and gravel deposits (colluvium, prior channels)	Unconfined aquifer	5.0E-01	5.0E-02	5.0E-02	--
Regolith	Unconfined aquifer	0.1 to 1	5.0E-02	3.0E-02	--
Narrabeen Group	Unconfined aquifer	5.0E-02	1.0E-04	1.0E-02	5.00E-06
Illawarra Coal Measures	Unconfined aquifer	1E-03 to 1E-02	5.0E-05	1.0E-02	3.00E-06
Ulan Coal Seam	Leaky confined aquifer	1	2.0E-02	5.0E-02	2.00E-05
Marrangaroo Formation / Nile Sub-Group	Leaky confined aquifer	2.0E-02	1.0E-05	3.0E-02	2.00E-05
Shoalhaven Group	Confined aquifer	1.0E-04	1.0E-06	5.0E-03	1.00E-06
Palaeozoic units	Confined aquifer	1.0E-03	1.0E-05	1.0E-02	5.00E-06

These hydraulic property values have been used to assign initial permeability values in the numerical groundwater model. The construction of the groundwater model is discussed in **Section** 5, with calibration presented in **Section 5.6**.

4.3 HYDROGEOLOGICAL BEHAVIOUR OF WASTE AND SPOIL EMPLACEMENT

As stated in **Section** 4, Hawkins (1998) and Mackie (2009) indicate that spoil and waste rock are more permeable that the undisturbed strata. Based on review of that literature, the likely properties are presented in **Table 4-3**, including additional recharge due to the enhanced permeability allowing greater recharge.

Table 4-3 Hydraulic Properties of Spoil

k_h [m/d]	k_v [m/d]	Sy	Recharge
1	1	0.2	5% rainfall

k_h, k_v and Sy values are based on Hawkins (1998) and Mackie (2009).

5 GROUNDWATER MODELLING

5.1 APPROACH TO MODELLING

The groundwater impact assessment for the WEP EIS is a regional groundwater model developed based on the analysis and conceptualization presented in the preceding sections. . Model predictions, presented in **Section** 6, are made on the basis of a 'calibrated' numerical model, which is capable of simulating observed groundwater levels with reasonable accuracy.

The following sections describe the model build and inputs, as well as the results of this 'history-matching' process, which has been conducted against steady-state and transient groundwater levels (see **Section 3.8.3**). The calibration has been undertaken with the benefit of 'observed' mine inflow data (**Section 3.8.8**).

The Moolarben Coal Complex, located to the west of the WCM Pit 6, has been included within the numerical model for assessment of the cumulative impacts. The Ulan Mine Complex does not warrant inclusion due to its location on the opposite side of the Moolarben Coal Complex.

5.2 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001) as well as the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). Under the earlier MDBC modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. That earlier guide (MDBC, 2001) describes this model type as follows:

> *"Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies."*

Under the more recent (Barnett *et al.*, 2012) guidelines, this model would be classified as a Confidence Level 2 groundwater model, with the following key indicators (based on Table 2-1 of Barnett *et al.*, 2012):

- Rainfall and evaporation data are available for the site (Level 3);
- Groundwater head observations and bore logs are available and with a good coverage around the WCM and Moolarben Coal Complex, but without spatial coverage throughout the model domain (Level 2);
- Streamflow data and baseflow estimates available at a few points (Level 2);
- Seasonal fluctuations reasonably replicated in many parts of the model domain (Level 2, possibly 3);
- Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable (Level 3); and
- Suggested use is for prediction of impacts of proposed developments in medium value aquifers (Level 2).

A more complete assessment of Model Confidence is presented as **Appendix E** (again, based on Table 2-1 of Barnett *et al.*, 2012).

Numerical modelling has been undertaken using GIS and a range of Fortran and Visual Basic (6 and .Net) utilities and Python scripts in conjunction with MODFLOW-USG (Version 1.2), which is distributed by the United States Geological Survey (USGS). MODFLOW-USG is a relatively new version of the popular MODFLOW code (McDonald and Harbaugh, 1988) developed by the USGS. MODFLOW is the most widely used code for groundwater modelling and is presently considered an industry standard.

MODFLOW-USG represents a major revision of the MODFLOW code, in that it uses a different underlying numerical scheme: control volume finite difference (CVFD), rather than traditional MODFLOW's finite difference (FD) scheme. 'USG' is an acronym for Un-Structured Grid, meaning that MODFLOW-USG supports a variety of structured and unstructured model grids, including those based on cell shapes including prismatic triangles, rectangles, hexagons, and other cell shapes (Panday *et al.*, 2013). The CVFD method also means that a model cell can be connected to an arbitrary number of adjacent cells, which is not the case with a standard FD scheme. These features relieve a range of traditional MODFLOW's limitations, the key ones being:

- "It is difficult to refine the grid resolution in areas of interest; and
- Grid column and row widths can be variably spaced in order to focus grid resolution, but the added resolution must be carried out to the edges of the grid." (Panday *et al*, 2013).

In regional-scale models such as that developed for the WEP, these two limitations place severe practical limitations on modelled spatial resolution in key areas of interest (such as within and around simulated mines and surface water features), and on the spatial extent of the model. These are the key reasons, alongside the reduced total cell count (**Section 5.3.3**) and consequent reduction in model run times and disk space requirements achieved here, for applying MODFLOW-USG in this case.

MODFLOW-USG is a three-dimensional model able to simulate saturated flow in confined and unconfined conditions and can handle desaturation and re-saturation of multiple hydrogeological layers without the "dry cell" problems of traditional MODFLOW. This is pertinent to models which simulate layers, such as surficial regolith, which frequently alternate between unsaturated and saturated, as well as the depressurisation and desaturation that occurs above coal mine longwalls, such as those at Moolarben. Traditional versions of MODFLOW can handle depressurisation and desaturation to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by "dry" cells, which can interfere with the simulation of various processes and also cause model instability. Desaturation and re-saturation of model cells can be simulated using only one method in MODFLOW-USG Version 1.2 as distributed by the USGS: the Upstream Weighting method of MODFLOW-NWT (Niswonger et al, 2011).

The 'beta' version of MODFLOW-USG ('USG-beta') is developed by MODFLOW-USG's primary author, Sorab Panday, and is distributed with the popular Graphical User Interface (GUI) for MODFLOW, 'Groundwater Vistas'. USG-beta includes a range of enhancements, of which some are important in simulating mining-related processes, e.g. transient material properties (TVM – **Section 5.4.6**), hence the groundwater model developed for this groundwater assessment uses the USG-beta software. The USGS version of MODFLOW-USG will gradually incorporate the 'beta' enhancements over time as new USGS versions of the code are released.

5.3 MODEL GEOMETRY

5.3.1 MODEL EXTENT

The maximum extent of the groundwater model for the WEP is the same as the 'Study Area' shown on many figures accompanying this report (e.g. **Figure 1-1**). This area is 40 x 40 km. Based on the conceptualisation, need for inclusion of Moolarben Coal Complex as part of the cumulative impact assessment, and practical considerations for modelling, the adopted active model domain is an irregular polygon of 1046 km^2, as shown in **Figure 5-1**.

The active domain is centred on the WCM, and includes the full extent of neighbouring Moolarben Coal Complex and the Wilpinjong and Cumbo Creek catchments. The active domain also includes most of the upper Goulburn catchment except for tributaries flowing in from the north (e.g. through the Ulan Mine Complex area, from around Green Hills and the Munmurra River) and most of the Wollar Creek catchment except the headwaters south of Barigan).

The shortest distance from any part of the proposed WEP to the nearest edge of the active model domain is 9 km.

5.3.2 MODEL LAYERING

The model domain is discretised into eight (8) layers, as per the conceptual framework described in **Section** 4.

A revised mine-scale geological model, specifically focussed on mapping the Ulan Coal seam ply elevations and thicknesses, was provided by WCPL to HydroSimulations. Using this as a basis, a regional geological model was constructed relying on the following:

- Outcrop geological mapping, including:
  - Western Coalfield map (Yoo, 1998);
  - TEM interpretation (Groundwater Imaging, 2014 and GeoConsult, 2014, as discussed in **Section 3.7.3**); and
  - analysis of bore records (e.g. as presented in **Section 3.7.3**);
- Topographic elevation data (**Section 3.1**):
  - WCM LiDAR data; and
  - Geoscience Australia's Hydrologically-correct DEM (DEM-H);
- 3D geological data:
  - Digitised from Western Coalfield map (Yoo, 1998), specifically the Ulan Coal seam structure contours from that mapping;
  - Digitised from Moolarben model studies (RPS Aquaterra, 2011); and
  - Depth of regolith mapping from the recently published National Soil and Landscape dataset (Commonwealth Scientific and Industrial Research Organisation [CSIRO], 2014).

Representative model cross-sections are displayed in **Figure 5-2** (west to east) along northing 6,419,000 (MGA) and **Figure 5-3** (north-south) along easting 775,600 (MGA). The cross-sections pass through the active WCM open cuts and proposed Slate Gully open cut (Pit 8). On these cross-sections the recent alluvium, other unconsolidated deposits and regolith have been treated as separate units, however as stated in **Section** 4, these will be simulated within a single layer in the groundwater model.

The geological cross-sections in **Figure 5-2** and **Figure 5-3** show that strata dip to the east and to the north (i.e. an overall north-east dip), and illustrates the existence of the Narrabeen Group on the plateaus. These figures show the relative thickness of the Ulan Coal Seam and the other Permian and Triassic units. Recent alluvium is present only in narrow deposits.

Figure 5-2 indicates that the Shoalhaven Group is present approximately 100-200 m below ground surface in the vicinity of Wollar Creek, although much shallower in the south of that catchment and also near Cumbo Creek, even outcropping in those areas where the Illawarra Coal Measures, including the Ulan Coal seam are absent. The Shoalhaven Group is deeper below ground under the Narrabeen Group plateaus. Below this is about 1,000 m of Permian Rylstone Volcanics which lie unconformably over Ordovician rocks. To the west (**Figure 5-2**) the Shoalhaven Group is absent, and Palaeozoic strata are present at surface.

5.3.3 MODEL GRID

The use of MODFLOW-USG (**Section 5.2**) allows the use of unstructured or irregular mesh. For the WEP, a Voronoi-based mesh has been adopted, which has the advantage of being both irregular but maintaining the property that a line connecting adjacent cell-centres is perpendicular to the shared cell boundary.

The model domain is discretised into a maximum of 56,430 cells for each layer. The mesh is shown in **Figure 5-1**. MODFLOW-USG precludes the need to have layers being fully extensive across the model domain, so some model layers have less than 56,430 cells present, depending on the presence or absence of certain hydrogeological units, e.g. the Narrabeen Formation, layers 2 and 3, have only 21,803 cells present, while the Illawarra Coal Measures and Marrangaroo Formation (layers 4-7) have 48,003 cells present. There are a total of 347,038 cells in the model.

The Voronoi mesh was generated using the proprietary HydroAlgorithmics (2014a) software 'AlgoMesh', which provides significant control over the mesh generation process, and can export MODFLOW-USG files, in addition to other formats. The following general approach was taken when using AlgoMesh:

- A regular square grid of cells were enforced in the WEP's proposed open cut areas, rotated in line with the mine plan and schedule provided by WCPL. The angle of rotation for model cells in each pit is customised to the plan for that pit or part thereof.
- A regular hexagonal grid of cells was enforced within the alluvium and within Moolarben Coal Complex's historical and proposed open cut mine pits.
- A regular square grid of cells was enforced within the Moolarben Coal Complex's historical and proposed underground (longwall) mine areas. The model cells are rotated to follow the alignment of the longwalls in each of these areas.
- Polylines along mapped rivers and creeks was used to ensure the mesh conformed to mapped drainage networks, and to enforce variable spatial detail along streams (e.g. greater detail along streams closest to the WEP).
- Model grid resolution in key areas of interest is as follows:
  - 70 m in most WCM open cut pit areas;
  - 80 and 100 m in Moolarben longwalls and 100 m in Moolarben open cut areas;
  - 20 m in the area between Pit 4 and Pit 3, which is the area of the mine lease through which Cumbo Creek flows;
  - 30 m regular hexagonal grid in alluvium near to WCM (Wilpinjong Creek, Wollar Creek and Cumbo Creek); and
  - 100 m regular hexagonal grid in alluvium in areas away from the WCM.
- Maximum cell dimension is about 1 km in areas away from mines and watercourses.

5.4 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain and boundaries shown in **Figure 5-1** have been selected to incorporate the significant hydrological processes identified in the conceptual model (**Section** 4), including features such as watercourses that could be affected by mining. Following is a detailed description of each of the modelled boundary conditions.

5.4.1 RECHARGE

Spatially and temporally variable groundwater recharge rates were applied to the groundwater model. These zones are based on the outcropping geology (**Figure 5-4**) and are listed below. The list also presents the modelled average recharge rate (in mm/a, based on the analysis in **Section 3.8.4**) and also expresses this as a proportion of average rainfall:

1. Alluvium 20 mm/a [3.4% of average rainfall];
2. Other unconsolidated deposits 15 mm/a [2.5% of average rainfall];
3. Narrabeen Group 8 mm/a [1.4% of average rainfall];
4. Illawarra Coal Measures / Shoalhaven Grp 6 mm/a [1 % of average rainfall]; and
5. Palaeozoic units 12 mm/a [2 % of average rainfall].

Additional recharge zones are defined during the predictive phase of model simulations for spoil infiltration (5% of average rainfall) and for direct rainfall to final voids (i.e. open water) (100% of rainfall).

The MODFLOW Recharge (RCH) package is used to simulate diffuse rainfall recharge.

Temporal variation in rainfall recharge has been calculated based on a water balance calculated on a daily timestep and accounting for runoff, soil moisture deficit and recharge based on inputs of rainfall and PE. This is based on the Penman-Grindley method of soil moisture accounting (Finch, 1994), and calibrated against other recharge estimates (**Section 3.8.4**), and measured stream flow and estimated baseflow at the WIL-GSU stream gauge operated by WCPL (**Sections 3.3 and 3.8.5**). The average recharge as calculated across the catchment was about 7 mm/a (equivalent to 1.2% of rainfall), and this is considered quite well constrained by the analysis in Sections **Section 3.8.4 and 3.8.5**. The daily estimates of recharge were then lumped to provide estimates of the recharge in each model stress period. The resulting recharge sequence, specified as a multiplier of the long-term average recharge is shown on **Figure 5-5** (i.e. where 1 = long-term average recharge). This calculation suggests that recharge fell to zero in 2014.

Recharge (infiltration) to the alluvium and other unconsolidated units might be higher than indicated here, however the small area and relatively thin geometry (vertically) of these deposits means that the potential for more infiltration is limited. This means that after heavy rain, direct rainfall and runoff from upgradient can cause the alluvium to become saturated, preventing further infiltration, in which case runoff will then occur from the alluvium. The limited spatial extent of the alluvium, and the proximity to Wilpinjong Creek (in particular) then causes the alluvium to drain relatively quickly immediately after high rainfall events.

5.4.2 EVAPOTRANSPIRATION FROM GROUNDWATER

The MODFLOW Evapotranspiration (EVT) package was used to simulate ET from the groundwater system. Maximum potential rates were set from the water balance as described above for recharge. Long-term average PE is about 1600 mm/a at Wilpinjong (**Section 3.2.2**), with the water balance model used for estimating recharge indicating that on average about 490 mm/a of evaporation occurs in the soil zone during or immediately after rainfall events, leaving about an average of 1110 mm/a (almost 4 mm/d) of 'excess PE' available to make a demand on shallow groundwater via evaporation or transpiration. The evaporation multiplier on **Figure 5-5** is based on the calculated 'excess PE' for each model stress period and expressed as a multiple of the calculated average.

ET is applied uniformly using MODFLOW's linear function in the EVT package. Topographic elevation is used as the 'evaporation surface' at which MODFLOW will simulate ET at the specific rate. Extinction depths, which is where the simulated rated of ET falls to zero, were set to 1.2 m and 9 m below ground for grasses (or bare ground) and trees, as described in **Section 3.5.2**. The spatial distribution of trees and grasses was based on the *Land Use of Australia* (v4) dataset (Australian Bureau of Statistics [ABS], 2006).

5.4.3 WATERCOURSES

The watercourses in the area, including the Wilpinjong, Cumbo, Murragamba, Moolarben and Wollar Creeks, but also the Goulburn River, are established using the MODFLOW "River" package, most of them set in model Layer 1 (denoted by blue cells in **Figure 5-4**). The River package allows water exchange in either direction between the stream and the aquifer if specified. For the main watercourses (listed above) the river stage elevations are set as transient, based on the rainfall for a particular model stress period, so that river stages can vary between zero (i.e. gaining only) and 2.5 m depth of water above the riverbed (where a non-zero depth allows both baseflow and leakage from watercourse to aquifer). For un-named or minor watercourses, the stage has been set to the elevation of the base of the rived bed (i.e. zero water depth) so that these creeks are gaining only.

The river conductances have been set proportional to estimated reach lengths in each river cell, and range from 15 to 40 square metres per day (m^2/d). This is approximately equal to a vertical hydraulic conductivity for the riverbed material in the range 0.01 to 0.5 m/d, depending on model cell size, and assuming an average channel width of 5 m. Because model cells are smaller nearest the mine areas (**Figure 5-1**), this means that the effective vertical permeability for the riverbed material tends toward the higher end, i.e. 0.05 to 0.5 m/d, around the WCM and Moolarben Coal Complex.

5.4.4 REGIONAL GROUNDWATER FLOW

The model edges are 'no-flow' by default, however general head boundaries (GHB) specified where regional groundwater flow is likely to enter or leave the active model area in the following layers, restricted to where the relevant hydrogeological unit is present:

- Layer 2 (Narrabeen Formation) – GHBs located mainly around the northern, eastern and parts of the southern model boundaries;
- Layer 4 (Coal Measures) – GHBs set along the northern, eastern and southern model boundaries;
- Layer 6 (Ulan Coal Seam) – GHBs set around the north and east, but not along the southern boundary given the likely 'dry' condition of the seam in that area (**Figure 3-16**); and
- Layer 8 (Shoalhaven Group or Palaeozoic strata) – GHBs extensive around the model boundary.

Figure 5-4 shows the total distribution of these GHBs. The elevation of the GHBs has been guided by the interpolated water levels in **Figure 3-14** and **Figure 3-16** and altered during calibration. The GHBs are specified with constant ('time-invariant') heads, as per the recommendation in the Groundwater Modelling Guidelines (Barnett *et al.*, 2012).

5.4.5 GROUNDWATER USE

Licensed NOW groundwater extraction bores were not included in the model. WCPL's production and dewatering bores were included in the model, and were simulated using the 'Well' package. The locations of these ("GWs" and "DB" series bores) are shown in **Figure 3-13** and the pumping rates are based on the information in **Table 2-2** and **Table 2-3** (**Section 2.2.1**). Note that only the five of the 19 approved production bores have been installed and pumped to date. These approved bores may be relied on again in future, and so there is scope to simulate pumping from these in the predictive modelling.

5.4.6 MINE WORKINGS

Dewatering

The MODFLOW "Drain" package has been used to represent open cut mining at the WCM, as well as at Moolarben. Invert levels are progressively lowered to the floor of the coal seam, and are set to 0.1 m above the base of layers for the mined seam as well as, in the case of open cut areas, in any layers overlying the mined seam. The drain conductance value (50 m^2/day) was determined during calibration.

Backfill and Rehabilitation

Typically the mine plan had information for each cell, specifying the progress of excavation on a 6-12 monthly schedule, followed by the annual progress of the spoil dumping (infilling) process. The likely higher permeability of the spoil was simulated by altering the permeability and storage properties from their host values using the MODFLOW-USG Time-Variant Materials (TVM) package (HydroAlgorithmics, 2014b). The hydraulic properties applied to simulate the spoil are presented in **Table 5-1**.

Table 5-1 Hydraulic Properties Applied to Spoil in the Groundwater Model

kh [m/d]	kv [m/d]	Sy	Ss [m^{-1}]	Recharge	ET
1	1	0.2	5.0e-4	5% rainfall	no change

kh, kv and Sy values are based on Hawkins (1998) and Mackie (2009).

The likely higher infiltration characteristics of the spoil were accommodated by allocating enhanced rainfall recharge (5% of rainfall) using the MODFLOW RCH package (see **Section 5.4.1**). Vegetation rooting depths (in the MODFLOW EVT package) were not modified to simulate changed vegetation characteristics.

Topography was not altered in response to the proposed final rehabilitated landform.

The implementation of longwall mining and final voids are discussed as part of the predictive modelling (**Section 6.2**).

5.5 MODEL VARIANTS AND TIMING

Both steady-state and transient model phases have been developed, as summarised below, with the detailed model/mining schedule presented as **Figure 2-3**:

Steady-state model of pre-mining conditions.	Period to January 2006. Model stress period 1
Transient model of the transition from pre-mining to the current state of the WCM mine.	January 2006 to end 2014. Model stress periods 2-22.
Transient predictive model extending to and beyond the proposed end of mining, simulating both the proposed mining period and the recovery period (**Section** 6).	Early 2015 to 2300. Model stress periods 23-76.

Due to the relative speed and functionality of the MODFLOW-USG model, all these are included within a single model run, i.e. steady state in stress period 1, followed by historical transient simulation leading into the transient predictive phase.

5.6 MODEL CALIBRATION

As described in the previous section, calibration was carried out using a single calibration model, which had the flexibility to utilise both steady state and transient phases.

Both automated calibration, using PEST software (Doherty, 2010), and manual ('trial and error') calibration techniques were used to 'history match' simulated groundwater levels and volumetric flows against the observed data.

Calibration was carried out by altering various model inputs, notably the aquifer parameters (permeability and storage properties) and comparing the model output against multiple target types, i.e. modelled versus observed groundwater levels, mine inflow and baseflow.

The changes to hydraulic properties were carried out considering the distribution of measured data and also considering literature values and the values used in previous modelling at Wilpinjong, Moolarben and Ulan (see **Section 3.8.7**).

In the transient model, a total of 697 groundwater level targets were set at a total of 177 sites, covering WCPL monitoring bores, Moolarben monitoring bores, and relevant NOW registered bores. For the purpose of calibration, these bores were assigned weightings between zero (unreliable) to 1 (very reliable) in order to account for data quality. Of the total number of groundwater level targets, three were rated as zero, and 531 were rated as 1. The remaining observations were either set with a weighting of 0.3 (Moolarben monitoring bores) or 0.1 (suspect data, but not considered completely unreliable).

Additionally calibration was carried out against volumetric flow targets, specifically against:

- Estimated WCM pit inflow for 2006-2011 and 2012-2014 (see **Section 3.8.8**); and
- Baseflow on Wilpinjong Creek, Wollar Creek and Goulburn River (derived in **Section 3.8.5**).

5.6.1 MODEL VERIFICATION

Model verification is sometimes performed after calibration, and sometimes after the initial modelling study. Barnett *et al* (2012) state "*Choosing not to use some data, and reserving it for verification, is a good idea in principle, but may not make the best use of available data*. A formal model verification was not carried out for this study. The full historical period of mining and all known available data were used in the calibration phase. Verification will be carried out via future periodic reviews. This is considered appropriate modelling practice.

5.6.2 CALIBRATION AGAINST OBSERVED DATA

Groundwater Levels

The ability of the model to replicate observed groundwater levels has been assessed in a number of ways: comparison of all data on an X-Y chart, comparison of hydrographs and checks on the spatial distribution of groundwater levels.

A summary of the model's ability to replicate observed groundwater levels across all parts of the model and across all layers is shown in **Figure 5-7**. **Figure 5-7A** presents that groundwater level data classed by monitoring group, e.g. groups for the Wilpinjong Alluvium observation bores and one for the Wilpinjong Coal observation bores. **Figure 5-7B** presents the same dataset grouped by model layer (i.e. hydrostratigraphic unit), e.g. all alluvium monitoring sites as one group, be they part of the WCM monitoring network or the Moolarben monitoring network or from some other network. These X-Y charts or 'scattergrams' of simulated versus measured heads demonstrate good agreement across the whole range of measurements, with the exception of a number of outliers, many of which are from the Moolarben monitoring network, which has been relied on much less than the WCM monitoring network (see discussion of targets in **Section 5.6**).

Both charts on **Figure 5-7** illustrate that there is no significant bias toward overestimating or underestimating groundwater levels. However, it could be that hydraulic conductivity around Moolarben is generally too high, given the modelled 'shallow' head gradient of the Moolarben data compared to the 1:1 line on the X-Y chart, i.e. the range in the modelled heads for the Moolarben bore network is less than the range in the observed data.

On the scale of **Figure 5-7**, it is evident that targets in the alluvium are generally very well matched (in both **Figure 5-7A** and **B**). The targets in the Ulan Coal Seam and other Coal Measures at WCM are clustered quite evenly around the 1:1 line, and almost all within +/- 10 m error. This is considered a good result in this porous/fractured rock environment.

Model calibration can be quantified by a number of statistics as described in Middlemis *et al.* (2001) and Barnett *et al.* (2012). The results for the WEP groundwater model, as calculated for the unweighted targets (i.e. all data) and weighted targets, are presented in **Table 5-2**.

The key statistics are 0.2-0.4 mRMS and 2.6%-5.6% sRMS[15], which is well below the target 10% sRMS suggested in the older MDBC flow model guidelines (MDBC, 2001).

Table 5-2 Summary Statistics of Transient Model Performance

CALIBRATION STATISTICS	VALUE - UNWEIGHTED	VALUE - WEIGHTED
Number of Data (n)	697	531
Root Mean Square (RMS) (m)	0.4	0.22
Scaled Root Mean Square (sRMS) (%)	5.6%	2.6%
Mean residual (m)	-0.4	-0.3
Mean absolute residual (m)	5.3	3.0

[15] sRMS = scaled Root Mean Squared error, where the scaling is performed by dividing the RMS by the range of the observed head values.

Comparison of modelled and observed hydrographs was also used to calibrate the model. A selection of these hydrographs is presented in **Figure 5-8**, while a larger selection is presented in **Appendix H**. Bore locations are shown on **Figure 3-13**. The first two charts on **Figure 5-8** are from nested alluvium and coal measure monitoring bores, located immediately north of approved WCM mine areas, while the third and fourth charts show pairs (not nested) of hydrographs from Slate Gully and near Wollar.

The upper chart on **Figure 5-8** presents hydrographs for GWc11 (Ulan Coal Seam) and GWa11 (alluvium) which are located close to Wilpinjong Creek and approximately 300 m north of Pit 2. The model does a reasonable job of simulating the prolonged drawdown due to the excavation of Pit 2 from 2007 to about 2010 in GWc11. The observed GWa11 hydrograph stays steady, despite excavation of nearby open cuts, and the model simulates this well.

The second chart on **Figure 5-8** presents hydrographs for GWc15 and GWa15 which are located 250 m north of Pit 3. The model does a good job of simulating the short-term drawdown in GWc15 from pumping at nearby WCPL production bores (in early 2007), but then underestimates the recovery in GWc15 in 2008-09. The drawdown due to extraction from Pit 3 from 2012-14 is quite well represented by the model, although the timing is out by about 6 months. The observed GWa15 hydrograph stays steady, despite the mine-related activities, and the model simulates this steady behaviour.

The third chart on **Figure 5-8** presents hydrographs for GWc29 and GWc31 which are located within Slate Gully (the proposed Pit 8). The model does a good job of simulating the baseline groundwater level in these areas, as well as the decline at GWc29 (also at GWc28 – see **Appendix H**), which is likely related to recent workings in Pit 3 and/or Pit 7. Groundwater levels at GWc30 (see **Appendix H**) are not as well represented – this bore is located very near a north-south trending fault, and groundwater levels proved difficult to match.

The last chart on **Figure 5-8** presents hydrographs for GWc4 and GWc5 which are located along Wollar Creek; GWc5 near the town of Wollar and GWc4 is 3.5 km to the north nearer the confluence with Wilpinjong Creek. The model does a reasonable job of simulating the baseline groundwater level in both bores, although is generally about 3 m too low at both. The modelled GWc5 does not show the same variability as the observed series, suggesting that in reality the coal measures that GWc5 is better connected to surface than in the model. The modelled GWc4 hydrograph shows what appears to be drawdown due to both dry weather and mining from 2013, where the observed series does not show that.

The following brief comments are made regarding hydrographs in **Appendix H**:

- Amplitudes and overall base levels are generally well represented for most alluvium monitoring bores along Wilpinjong Creek, e.g. GWa1, GWa2 (in the west) through GWa10, GWa12 and east to GWa7. Bores with weaker matches to observed amplitudes include GWa11, GWa14.
- Alluvium groundwater levels are reasonably matched on Wollar Creek (GWa8 and GWa32), with modelled levels within a couple of metres of observed.
- Groundwater levels along Cumbo Creek are generally well represented in both the alluvium (GWa5, GWa6, GWa22) and coal measures (GWc3, GWc22), although the recent drawdown due to Pits 3 and 7 seen in GWa5 is not replicated to the full degree by the model. This is possibly due to uncertainty about whether this bore is actually screened in the alluvium or in regolith or Permian strata at this location. Model results were checked for the underlying Permian strata at this location, and those groundwater levels did exhibit drawdown similar to the observed record.

- Drawdown due to mining at Coal Measure or Ulan Coal Seam bores along Wilpinjong Creek is generally well-represented by the model (e.g. GWc16, GWc17, GWc26 in the west of the WCM, through GWc2, GWc10, DB1, DB2 in the centre of the WCM area and east to GWc14, GWc15). The model replicates much of the magnitude of drawdown observed in many other bores that monitor the Ulan Coal Seam, although sometimes the timing of the drawdown is out by a period of 6-12 months. Also, the model sometimes overestimates the early groundwater levels (2006) compared to observed, e.g. GWc2, GWc3, even though the groundwater levels are well represented from 2007-onward.
- The recent observed data at Slate Gully monitoring bores GWc28, GWc29 and GWc31 is well matched by the model, while at GWc30 it is not.
- Groundwater levels in the Coal Measures are reasonably matched in the Wollar Creek catchment (e.g. GWc5, GWc32, GWc4), although the modelled drawdown is greater than observed.
- Groundwater levels modelled in coal measures bores located to the south of the mining area are reasonable, with a better fit between modelled and observed water levels in some bores, e.g. GWc24, GWc27 (noting some suspect data in that record), and in other bores the match is weaker (GWc25).
- Groundwater levels in the ‘PZ’ series of bores, installed to monitor seepage around the tailings dams, are generally well represented, although the observed data appears to show either quicker recovery in groundwater levels after mining and/or a greater connection between groundwater at this location and the tailings dam (or Pit 2 water storage).

Maps of modelled groundwater levels are presented for the water table (**Figure 5-9**) and Ulan Coal Seam (**Figure 5-10**), for which maps produced from observed data are available for comparison in **Figure 3-14** and **Figure 3-16** respectively. These figures show that the model replicates to a reasonable level the general pattern of groundwater flow. **Figure 5-10** also shows that the model replicates the pattern of wet-dry areas of the Ulan Coal Seam that have been observed or inferred along the southern edge of the WCM.

Mine Inflow / Groundwater Make at Wilpinjong

Simulated pit inflows were calibrated against the ‘observed’ or inferred inflow that were discussed in **Section 3.8.8**. **Figure 5-11** compares the modelled and observed inflow to the WCM open cuts, noting that these results are reflective of true groundwater inflow to the pits. Because the surface water storages at WCM have been known to leak back to active voids, and have been simulated as such in the model, the modelled inflow shown here is based on a model run without any simulated surface water storages. The source of this inflow is therefore either recharge to host rock or spoil areas, and not runoff or water ‘recirculated’ through the water storages.

The modelled inflow compares favourably with the much of the observed data, and is generally slightly higher than the recent estimates derived by WRM Water & Environment (2015). The average modelled inflow for the period 2006-2014 is 2.25 ML/day, while the average of the observed data is 1.8 ML/day.

Mine Inflow / Groundwater Make at Moolarben

No observed inflow data is publically available from the Moolarben open cuts, and the Underground areas have not yet commenced. As a result, the WEP model has been compared against previously modelled inflows for the Moolarben mine (taken from RPS Aquaterra, 2012 and Dundon Consulting, 2015). This is to ensure a degree of consistency with previous assessments.

The comparison in **Table 5-3** indicates that compared to the previous modelling for Moolarben, the WEP model underestimates inflow to the underground mines, but over-estimates inflow to the open cuts. The total average inflow is a good match.

Table 5-3 Comparison of Modelled Inflow (ML/a) at Moolarben

Mine Area	WEP Groundwater Model	Previous Modelling
Open Cuts 1-4	980	630
Underground 1, 2, 4	970	1670
Total	**1950**	**2290**

Baseflow

Baseflow estimates have been extracted from model budget files, and comparison with 'calculated' baseflow (based on observed flow data – see **Section 3.8.5**) is made at Wilpinjong GS-U gauging station. Modelled baseflow for the period 2012-14 is <0.5 ML/day, compared to calculated baseflow of 0.1-0.2 ML/day.

Baseflow at other gauging stations is not easy to compare given that the model only includes part of the catchments, however the following rough comparison was made for Wollar Creek. Baseflow on Wollar Creek, for the period 1980-1995, is estimated at between 1 and 2.5 ML/day (of an average total flow of 10 ML/day). Modelled net baseflow is approximately 0 to 6 ML/day, with an average of 3 ML/day.

Modelled baseflow is therefore possibly slightly high, but is in the right order of magnitude. It is likely that the modelled representation of baseflow could potentially be improved with the (future) use of the Stream (STR/SFR) package because the Stream package limits the leakage of flow from the watercourse to the underlying aquifer according to the flow accumulated from upstream. This would be considered in any future model reviews or augmentations.

5.6.3 TRANSIENT WATER BALANCE

The water balance across the entire model area is summarised in **Table 5-4** for the calibration period.

Table 5-4 Simulated Water Balance for the Transient Model (2005-2014)

Component	**Groundwater Inflow (Recharge)** [ML/day]	**Groundwater Outflow (Discharge)** [ML/day]
Rainfall Recharge	28.0	0
Rivers	18.1	11.8
Evapotranspiration	0	38.7
Mine inflow	0	2.5
Pumping Wells	0	0.03
Regional Boundary Flow	5.7	0.2
Groundwater Storage	16.0	14.5
TOTAL	**67.7**	**67.7**
Discrepancy (%)	<0.1%	

source: C:\HydroSim\WIL006\Model\Processing\ModelMassBalance.xlsx

The total modelled inflow (recharge) to the regional groundwater system is approximately 68 ML/day, comprising mainly rainfall recharge (42%) and leakage from local rivers and creeks into the shallow groundwater systems (28%) and release from groundwater storage (24%). Evapotranspiration is the largest discharge (57%), with baseflow (17%) and mine inflow to both the WCM and active Moolarben open cuts (4%) being more minor components. WCPL's historical pumping at various production wells (see **Section 2.2.1**) constitutes a very small part of the water balance when averaged across the calibration period.

5.6.4 CALIBRATED MODEL PARAMETERS

The adopted values for rainfall recharge were not changed during calibration, and are listed in **Table 5-5** expressed as mm/yr and as % of average rainfall (same as in **Section 5.4.1**).

Table 5-5 Modelled Recharge Parameters

ZONE	OUTCROP GEOLOGY	**Recharge** [mm/yr]	Recharge % LTA rainfall
1	Alluvium	20	3.4
2	Other unconsolidated deposits	15	2.5
3	Narrabeen Group	8	1.4
4	Illawarra Coal Measures,	6	1
5	Palaeozoic units	12	2
	Spoil Zones	30	5

Table 5-6 summarises the hydraulic and storage properties for the modelled hydrostratigraphic units (i.e. model layers and units) at the end of the transient calibration. The values for k_H and k_V are consistent with field estimates listed in **Section 3.8.7**, as shown on **Figure 5-6**. Maps in **Appendix G** show the distribution of the parameter zones.

Table 5-6 Hydraulic Conductivity and Storage Parameters

ZONE	LAYER	FORMATION	K_H (m/day)	K_V (m/day)	S_S (m^{-1})	Sy (-)
1, 12	1	Regolith	2.20E-01 to 2.5E-01	1.00E-01	1.00E-03	0.02 to 0.03
10	1	Alluvium	7.00E+00	1.50E-01	1.01E-03	0.08
20	1	Tertiary, palaeochannel	2.00E+00	4.00E-01	1.02E-03	0.12
2	2	Narrabeen Group	5.00E-03	2.00E-04	6.00E-06	0.02
3	3	Narrabeen Group	5.00E-02	1.00E-06	5.00E-06	0.019
4	4	Permian Coal Measures	1.92E-03 to 3.0E-02	8.49E-05 to 5.0E-03	4.00E-06	0.007
5	5	Permian Coal Measures	2.04E-03	1.04E-05	3.00E-06	0.006
6	6	Ulan Coal seam	1.6E-01 to 1.6E+00	4.00E-02	8.00E-06	0.013
7	7	Nile / Marrangaroo	1.80E-01	1.00E-04	2.70E-06	0.015
8, 28	8	Shoalhaven Group	5.00E-04 to 1.0E-03	1.00E-06 to 3.0E-04	1E-06 to 2E-06	0.005 to 0.008
9	8	Palaeozoic deposits	5.00E-03	1.00E-04	4.50E-06	0.01
11	2 to 8	Intrusion	5.00E-04	1.00E-06	1.00E-06	0.01
25	4 to 7	Fault - impermeable	2.00E-03	5.00E-04	6.00E-06	0.02
29	4 to 7	Fault - permeable	1.50E+01	8.00E-01	8.00E-06	0.02

5.7 ASSESSMENT OF MODEL PERFORMANCE AND LIMITATIONS

As described in the sub-sections in **Section 5.6**, the numerical model developed to support the WEP EIS is capable of replicating historical groundwater level and groundwater inflow data. The model is parameterised with recharge, permeability and aquifer storage inputs that are appropriate for the hydrostratigraphic units represented, and reasonably constrained by available observed data. The model is considered appropriate for use in subsequent predictive scenarios, especially considering the primary outputs of the predictive modelling are estimates or predictions of groundwater level and groundwater inflow behaviour.

Limitations associated with the WEP groundwater model are provided in the following section, in line with the recommendations of the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012).

5.7.1 MODEL LIMITATIONS

There is uncertainty in formation elevations and thicknesses away from the Project area and away from the other mines from which data has been used. This is particularly to the east and north of the WCM, where there is little by way of subsurface data. The WEP geological model has been extrapolated on the basis of seam and formation dip, outcrop geology and topographic data.

Some water level records, particularly those which are 'time-of-drilling' water levels from the NSW bore database, used to provide some calibration targets and to infer groundwater flow directions, are low quality. In general, they provide snapshot information at the time of construction of a bore and the data span many decades. In particular, the vertical head distribution away from the Project area is not known.

A substantial dataset of hydraulic property measurements has been obtained via packer tests, pumping tests and core lab analysis at WCM. There is often a substantial range in these properties. Due to the size of the groundwater model and uneven spatial distribution of these measurements, one or two 'representative' values of horizontal and vertical hydraulic conductivity have typically been applied across hydrostratigraphic units. This is a simplification of the more complex and varied nature of these properties in reality.

While the use of MODFLOW-USG has allowed the use of quite fine model resolution in many areas of interest, the scale of model cells (30-100 m laterally around the WCM, and variable vertically) limits the ability to accurately simulate some behaviours and features, particularly where hydraulic gradients are steep, such as near to open cut pits.

Although MODFLOW-USG (beta) is capable of simulating unsaturated conditions, the focus in this study has been on the saturated part of the groundwater system. Nevertheless, MODFLOW-USG will report groundwater heads (equivalent to negative pore pressures) in dry portions of model layers.

There is imperfect matching of observed groundwater levels due to a number of factors. These are inconsistencies and instability in deep groundwater pressures, model scale (see previous point), imperfect representation of hydraulic properties in a model, and well as the inability to represent the complexity of subsurface systems, particularly those in fractured rock.

A number of geological faults are included in the current model. The model does not include other structural features except to the extent that they determine formation thicknesses observed in exploration holes, and more structures may be encountered by future mining at WCM, despite the effort put into exploration and geophysical surveys. There is uncertainty as to their size, scale, vertical persistence, locations of smaller structures and whether they would act as barriers or conduits to flow. Geological structures are more likely to compartmentalise aquifers and thereby localise drawdown effects and limit pit inflows. Where possible the known structures are included, in the model geometry and sometimes as different permeability zones. Ignoring such structures would probably lead to predictions of pit inflow that are an overestimation and to conservative estimates of environmental effects.

A formal sensitivity analysis has not been carried out (although the calibration processes investigates the sensitivity of various model predictions to different model parameters). A formal analysis is not warranted here because the WCM has been operating for a decade and has an extensive network of groundwater monitoring bores (in the coal seam and the alluvium), surface water monitoring sites, and reasonable records and estimates of groundwater inflow. The calibration of the model to both observed groundwater levels and fluxes, i.e. baseflow separation estimates and inflow to the pits, means that the hydraulic conductivity-to-recharge relationship is relatively well constrained. The degree to which the model matches historical fluxes and the long record of groundwater level data (**Section 5.6.2**) gives confidence in the predictions made using the model and which are described in following sections of this report.

6 PREDICTIVE MODEL SCENARIO ANALYSIS

The following section outlines the predictive scenarios run to inform the assessment of project-specific and cumulative impacts and effects on the groundwater system of the WEP and nearby mines. It also includes a description of the methods and features implemented in the predictive phase of modelling that were not part of the historical or calibration phase, and presents the outputs of the modelling.

6.1 MODELLING APPROACH

Three main predictive model scenarios were run:

1. A 'No-mining' or 'Null' run (as per Barnett *et al*, 2012), without any past or future mining. Hereafter referred to as the 'Null' run or condition.
2. The 'Cumulative run', i.e. a run with the proposed WEP mine plan and schedule, as per **Section 2.2**, **Figure 2-2**, **Figure 2-3**, and **Figure 2-4**, as well as the current and approved mining activities at the neighbouring Moolarben Coal Complex. The schedule is shown in **Figure 2-3**, and has been derived from publicly available documents related to:
   - Moolarben Stage 1 Modification (MOD3 MP 05_0117);
   - Moolarben Stage 2 (MP 08_0135); and
   - Moolarben UG1 Optimisation (Dundon Consulting, 2015).
3. A 'no WCM/WEP' scenario, which is the same as Scenario #2, but without the operation of the WCM or WEP.
4. The 'WEP borefield' scenario. This is the same as Scenario #2, but with run to test the potential effects of pumping at the WCM/WEP borefield should this be required in future (**Section 6.2.5**).
5. 'Climate change' scenario, simulating a drier climate (see **Section** 8).

Comparison of these three runs then allows project-specific and cumulative impact assessment to be carried out.

All models used the calibrated historic period, as described in **Section** 5, as a run-in precursor to the predictive simulation period. The exception was the 'Null' run that did not include any historical or future mining in the area.

6.2 MODEL IMPLEMENTATION

This section outlines the key processes that require simulation for the predictive scenarios.

6.2.1 SPOIL AND WASTE EMPLACEMENT

Typically the WEP open cut mine plan had information for each cell, specifying the annual progress of excavation followed by the progress of the spoil dumping (infilling) process. The same information for Moolarben open cuts is available or has been assumed (usually waste emplacement occurs 1-2 years after mining). The infill process was simulated as described below.

The likely higher permeability of this spoil was altered from the host value using the MODFLOW-USG Time-Varying Materials (TVM) package (HydroAlgorithmics, 2014b). The hydraulic properties applied to simulate the spoil are presented in **Table 6-1**.

Table 6-1 Hydraulic Properties Applied to Spoil in the Groundwater Model

kh [m/d]	kv [m/d]	Sy	Ss [m^{-1}]	Recharge	ET
1	1	0.2	5.0e-4	5% rainfall	no change

kh, kv and Sy values are based on Hawkins (1998) and Mackie (2009).

The likely higher infiltration characteristics of the spoil were accommodated by allocating enhanced rainfall recharge (5% of rainfall). No change to either the rate or depth to which evapotranspiration can occur (in the MODFLOW EVT package) was implemented.

Topography was not altered in response to the proposed final rehabilitated landform.

6.2.2 VOID LAKES

After completion of the mine pit excavation in each pit of the WCM all pit Drain cells were deactivated and replaced with spoil, except for the Final Voids (currently proposed for Pit 6, Pit 2 and Pit 8 - **Sections 2.2** and **4.1**, plus the proposed Final Voids at Moolarben). Hydraulic properties of the cells representing the void were modified to the properties shown in **Table 6-2** which effectively simulated open air and allowed the potential development of an open body of water (void lake).

Table 6-2 Hydraulic Properties used to Simulate Void Lake in Groundwater Model

kh [m/d]	kv [m/d]	Sy	Ss [m^{-1}]	Recharge
1000	1000	1	as host	100% rainfall

The representation is relatively simplistic, however is common practice and is deemed appropriate for the purpose of estimating water level recovery and lake filling. The process for fully simulating lake levels has been done using both this groundwater model and WRM Water & Environment's surface water model, which incorporates open water evaporation and direct rainfall (relying on the lake level-volume-surface area relationships) and runoff. The process was therefore an iterative one, involving model results being passed between HydroSimulations and WRM Water & Environment. The lake levels presented in WRM Water & Environment (2015) should be treated as the final.

6.2.3 LONGWALL MINING (MOOLARBEN)

In addition to the open cut mining that is already in progress, Yancoal (Moolarben) are approved to conduct longwall mining in three areas: Moolarben UG1, UG2 and UG4.

The underground mining and associated dewatering (groundwater inflow) was simulated in the predictive model using MODFLOW Drain (DRN) package. These Drain boundary conditions are set within the mined coal seam. Modelled Drain elevations were set to 0.1 m above the base of the worked seam. These Drain cells were applied wherever workings occur, and were progressively added to simulate the development of roadways and the extraction of the panels over time in the transient model. Drain conductance was set to 500 m^2/day.

Development headings and roadways were simulated using Drains that were activated from the planned opening of those roadways until the end of mining in that area, i.e. some main roadways would be open for much of the life of the mine, while some, particularly those in UG4, would only be open for a short period. Hydraulic properties for roadways were changed in the seam only using the TVM file; Kh = 20 m/d, Kv = 0.2 m/d, Sy = 0.4. Ss was left unchanged.

To simulate longwall extraction and the resultant subsidence and fracturing that occurs above the longwall, the hydraulic parameters were changed with time in the goaf and overlying fractured zones during the extraction of each longwall panel (refer to Section 5.2.2 of RPS Aquaterra, 2012 or Section 7.2 of Dundon Consulting, 2015). The fracture height model and method for enhancing permeability used here was similar to that used in Dundon Consulting (2015). This included enhancing storage properties and horizontal and vertical hydraulic conductivities within the mined seam, the 'caved zone' and the 'fractured zone' (see Ditton and Merrick, 2014).

6.2.4 CUMBO CREEK RE-ALIGNMENT

The re-alignment of the lower reach of Cumbo Creek was approved under earlier project approvals for WCM (see **Section 2.2** and **Figure 2-4**). To simulate this, the River cells which simulate the existing alignment of Cumbo Creek through Pit 4 will be inactivated at the relevant time (planned for 2026-27) and the River cells along the new alignment (shown on **Figure 5-4**) will be activated at that time. In the absence of detailed design information, the properties of the new River cells along the alignment are the same as those for existing River cells (**Section 5.4.3**).

6.2.5 WILPINJONG COAL MINE (WEP) PRODUCTION BORES

Based on initial predictive modelling, a future shortfall in water available to WCPL for operational demands was predicted as a possible occurrence (WRM Water & Environment, 2015). A single predictive scenario has been run to investigate the likely outcome of operating the 19 water supply bores described in **Section 2.2.1** (five of which were used historically, as per **Table 2-3**). Pumping rates for the scenario are outlined in **Table 6-3** (from WRM Water & Environment, 2015).

Table 6-3 Potential Water Make-up Requirements for WEP Borefield

Water Year	Annual Demand (ML/a)	
	1% likelihood	All other likelihoods
2015/16	0	0
2016/17	0	0
2017/18	0	0
2018/19	0	0
2019/20	0	0
2020/21	0	0
2021/22	156	0
2022/23	182	0
2023/24	382	0
2024/25	503	0
2025/26	424	0
2026/27	207	0
2027/28	13	0
2028/29	0	0
2029/30	0	0
2030/31	24	0
2031/32	44	0
2032/33	128	0

The location of the 19 bores is shown on **Figure 2-2**. As with the bores in the historical or calibration phase, the MODFLOW-USG 'WEL' package has been used to simulate the operation of these bores. The total extraction rate has been spread equally between the 19 bores which are all simulated as screening the Ulan Coal Seam.

6.2.6 MOOLARBEN DEWATERING / PRODUCTION BORES

Part of Moolarben's proposed activities include the operation of a borefield. Based on RPS Aquaterra (2012), this is to include up to 17 bores pumping from the Ulan Coal Seam. The locations used in the WEP model are from RPS Aquaterra (2012), and are summarised in **Table 6-4**. These locations are concentrated around the Moolarben UG4 underground area.

Table 6-4 Moolarben Production Bore Locations as Modelled for the WEP

Bore	Easting	Northing	Bore	Easting	Northing
M13	765467.7	6425540.7	M9	763939.8	6430346.0
TB52A	764840.5	6425956.4	M8	763943.8	6430956.8
M3	765830.0	6426204.1	TB105	763957.7	6431610.6
TB179	764703.0	6426597.0	PZ103A	762450.2	6429258.9
M12	763821.1	6427624.1	M7	763680.1	6432039.5
M11	763832.4	6428537.4	M6	763146.2	6432226.4
M2	765433.2	6427231.1	M5	763641.2	6432811.5
M10	763842.9	6429333.1	M4	762128.4	6430763.8
			M1	761460.9	6429743.7

These production bores have been simulated using the WEL package. The total extraction rate, and the schedule of extraction, for these wells is based on Table 5.9 in RPS Aquaterra (2012), and is typically 2.5-3 ML/day across the borefield. The total extraction rate has been spread equally between the 17 bores. Because the development of the Moolarben Mine has been slower than initially anticipated, the schedule of pumping in RPS Aquaterra (2012), which indicated that pumping would start in 2012, has been pushed back three years in this WEP Groundwater Model, i.e. in line with the modelled development of the Moolarben longwall areas shown in **Figure 2-3**.

6.2.7 MODEL PERFORMANCE

The predictive models (including the historical period) take approximately 70 minutes to run. For the impact scenario #2 (simulating the proposed WEP and the Moolarben operation) the overall mass balance error was <0.01%, with no time steps reporting mass balance errors above 0.01%.

6.3 MINE SCHEDULE

The proposed cessation of mining under the WEP plan is in 2033 (**Figure 2-2**). This is a 7 year extension on the currently approved mine life. **Figure 2-3** shows the development of the WCM / WEP alongside the development of the neighbouring Moolarben open cuts and underground areas.

6.4 WATER BALANCE

Simulated water balances for the whole model area are examined in **Table 6-5** for the period 2005 until 2033 (the end of mining), compared with a no-mining case (the "null" scenario).

At the end of mining, the water balance (**Table 6-5**) totals about 62 ML/day, and is dominated by the infiltration of rainfall as the main source of recharge (45%) and evapotranspiration as the main discharge mechanism (54%).

There is no significant difference in component recharge rates between the mining scenario and the null scenario, although the modelled recharge has increased (by 1.5 ML/day) in the mining scenario due to the enhanced permeability and infiltration recharge associated with spoil areas at WCM and Moolarben (**Section 4.3**). There is a mild increase in leakage from watercourses (0.2 ML/day).

Table 6-5 Modelled Groundwater Balance at the End of Mining

Component (ML/day)	Model package	Inflow (Recharge)		Outflow (Discharge)	
		NO MINING	MINING	NO MINING	MINING
Rainfall Recharge	RCH	26.2	27.7	0	0
Evapo-transpiration	EVT	0	0	35.4	33.6
Rivers and Creeks	RIV	12.5	12.7	9.0	8.5
Mine	DRN	0	0	0	4.6
Production Bores	WEL	0	0	0	1.8
Regional Groundwater Throughflow	GHB	5.6	6.5	0	0
Change in Storage	LPF	10.4	15.2	10.0	13.4
TOTAL		55	62	55	62

By the end of mining, the average mine inflow (WCM and Moolarben) is about 4.6 ML/day. As a result of this, there are minor reductions in groundwater discharge to the rivers (0.5 ML/day), an approximate 1.8 ML/day reduction in evapotranspiration and groundwater storage has declined by about 1.6 ML/day.

6.5 PREDICTED PIT INFLOW

The time-varying pit inflow predicted by the model is illustrated in **Figure 6-1**, and tabulated in **Table 6-6**. Recommendations for licensing are discussed in **Section 7.1.1**.

Pit inflows have been conservatively predicted using model runs without the operation of the Moolarben Coal Complex borefield, as pumping from the Moolarben borefield would reduce the total inflow to the WCM.

Inflow to the whole WCM is predicted to have peaked in 2014-15 (3.9 ML/day or about 1420 ML/a). Inflows are predicted to be steady at about 3 ML/day (or 1050-1100 ML/a) until a short peak in 2018-19 (3.5 ML/day or 1269 ML/a). This peak would be a result of simultaneous workings in all eight WEP pits including early workings in Pit 8 (Slate Gully). After that the model predicts lower inflows through the remaining mine life to 2033.

Table 6-6 Predicted Annual Pit Inflows (ML/a)

YEAR	PIT 1	PIT 2	PIT 3	PIT 4	PIT 5	PIT 6	PIT 7	PIT 8	TOTAL PIT INFLOW
2015-16	40	1	357	157	464	0	23	0	1043
2016-17	29	2	346	209	454	49	25	0	1113
2017-18	26	3	283	246	382	124	40	0	1104
2018-19	21	4	261	168	273	151	27	363	1269
2019-20	17	82	217	64	151	162	34	278	1004
2020-21	8	57	213	0	98	165	27	144	712
2021-22	7	7	245	0	118	223	5	97	701
2022-23	7	0	263	0	57	230	0	19	576
2023-24	7	0	270	0	85	242	0	144	748
2024-25	7	0	131	0	50	354	0	71	612
2025-26	7	0	0	0	1	370	0	51	430
2026-27	7	0	5	78	0	398	0	46	533
2027-28	7	0	9	316	0	321	0	46	699
2028-29	7	0	71	331	0	314	0	31	753
2029-30	7	0	45	113	0	309	0	26	500
2030-31	9	0	0	0	0	334	0	15	359
2031-32	9	0	0	0	0	391	0	1	401
2032-33	20	0	0	0	0	243	0	0	263
2033-34	10	0	0	0	0	0	0	0	10

The main reason for the predicted lower inflows later in the mine life is that much of the future mining will occur in areas away from Wilpinjong Creek, i.e. workings in Pits 1, 2, 5 and 7 will continue to the south, up-gradient toward areas where the Ulan Coal Seam is near to or above the water table (**Figure 2-2**). Additionally, mining in Pit 8 is likely to be drier than in other pits because Slate Gully does not have as large a groundwater catchment (or surface water catchment) as most of the other pits.

Under the scenario in which pumping of the WCM/WEP borefield is required, groundwater inflow to the pits is predicted to decline by about 15-20%, although there is no change in the maximum predicted annual inflow. The implication of that is that the borefield would not be 100% efficient because the production bores will be capturing some groundwater that would have made its way into the pits.

6.6 PREDICTED GROUNDWATER LEVELS

A set of hydrographs and maps are presented in this section to outline the effects of the WCM mine both in time and space.

6.6.1 GROUNDWATER LEVEL HYDROGRAPHS

The hydrographs presented here show drawdown or groundwater level at a series of sites selected to show representative drawdown within and around the WCM. Bore locations are shown on **Figure 3-13**.

Figure 6-2 presents drawdown hydrographs for two sites within the WEP open cut areas; one in Pit 6 (at bore GWc17) and the second in the middle of Pit 8 (Slate Gully). Both hydrographs show that cumulative activities (WEP + Moolarben, the WCM/WEP-only and the WEP borefield scenarios) produce about 45 and 22 m of drawdown respectively at these sites. There is no difference between these scenarios due to the position of these sites within the middle of WEP open cuts. In the case of the approved WCM, drawdown at GWc17 (in Pit 6) would the same as modelled for the WEP (i.e. no incremental drawdown due to the WEP), while there would be some drawdown in the middle of Slate Gully due to the approved WCM (approximately 5 m), but not the >20 m predicted for the WEP (i.e. incremental drawdown of about 15 m).

Figure 6-3 presents groundwater level hydrographs for three sites around the WEP; A) one between GWc33 and Wilpinjong Creek (between Pit 6 and Wilpinjong Creek), B) one at GWc15/a15 (nested site north of Pit 3) and C) one at GWc32/a32 (nested site north of Wollar). Groundwater levels (not drawdown) are shown here to illustrate the head separation that exists between the coal seam and overlying alluvium.

Figure 6-3A, for the location near Pit 6, shows that despite significant drawdown in the Ulan Coal seam (up to 60 m in 2030-33 due to cumulative effects, and about 50 m in the 'no WCM/WEP run, i.e. showing the effect of Moolarben operations), there is much less drawdown in the surficial deposits near Wilpinjong Creek. Drawdown is predicted to be up to 2.1 m in these surficial deposits as a result of cumulative effects, and 0.8 m as a result of operation of the WCM/WEP. The operation of the WEP borefield (see **Section 6.2.5**) is not predicted to have any further affect, beyond that of the proposed WEP mining, on the surficial deposits at this location, and while it is predicted to have a small increase in the rate of drawdown in the coal seam (in the mid-2020s), it is not predicted to result in further drawdown within the coal seam.

Figure 6-3B, for the location near Pit 3, shows an upward gradient from the coal seam to the alluvium in the pre-mining period. Following mining, a significant drawdown will develop in the coal seam, with perched conditions developing in the surifical deposits. The model predicts drawdown of up to 45 m in the coal seam as a result of the WEP, while it is predicted that Moolarben Mine would, by 2040-45, cause about 10-12 m drawdown in the coal seam at this location. There is predicted to be minimal drawdown (0.1 m) in the alluvium at this location. The WEP borefield is predicted to have no further effect on the alluvium, and is predicted to cause an additional 3-4 m drawdown in the coal seam in this area.

Figure 6-3C, showing the model hydrographs near Wollar and Wollar Creek, presents a similar picture to the previous hydrographs, i.e. drawdown in the coal seam (up to 4 m) with minimal drawdown (<0.05 m) in the surficial alluvium. Because of the transmissive nature of the Ulan Coal seam, the model predicts that, in the (hypothetical) absence of the WCM, mining at Moolarben would eventually cause a drawdown of about 1 m in the coal seam at this location. As this site is located 1.6 km east from the nearest WEP open cut (Pit 8), peak drawdown is predicted to occur in 2050-55 which is after mining has ceased.

Figure 6-4 presents modelled drawdown or groundwater level hydrographs for three sites; one in the headwaters of Spring Creek (just south of Pit 5 – see **Figure 3-3**), one site, a hypothetical spring, in the Goulburn River National Park to the north of WCM, and at bore GWa7, which is located in the alluvium on Wilpinjong Creek, downstream of WCM and near to the confluence with Wollar Creek.

Figure 6-4A presents drawdown in the headwaters of Spring Creek, and shows that some drawdown within the coal seam about 1 m), followed by enhanced recovery of water levels in the seam due to increased recharge on the nearby spoil areas. The model predicts no change in groundwater levels perched in the Narrabeen Group.

Figure 6-4B presents groundwater levels at a site in the Goulburn River National Park and 1.8 km north of Pits 2 and 4. As with **Figure 6-4A**, this shows no change in groundwater levels in the perched Narrabeen Group, but up to 25 m drawdown in the Ulan Coal Seam as result of activities at WCM/WEP and Moolarben.

Figure 6-4C presents groundwater levels at GWa7, downstream of the WEP. This hydrograph shows that water levels in the alluvium at this location are largely unaffected by mining operations under the proposed WEP plan (maximum predicted drawdown <0.1 m).

6.6.2 SPATIAL EXTENT OF DRAWDOWN

Figure 6-5 and **Figure 6-6** presents modelled groundwater drawdown in the Ulan Coal Seam (model layer 6) and water table respectively. Drawdown is presented for cumulative activities (calculated from Scenarios #1 and #2) and for those activities specific to the WCM (WEP) (Scenarios #2 and #3). The drawdown has been calculated at the end of 2033, corresponding to the end of mining.

Figure 6-5 shows that the pattern of drawdown in the Ulan Seam is similar under both cumulative and Wilpinjong-only scenarios, i.e. drawdown spreads to the east, west and north, but not to the south. This is due to the modelled (and observed) condition of the coal seam being less saturated, and eventually dry, to the south of the WCM mine (or absent in some areas). **Figure 6-5** also shows that the cone of depressurisation within the coal seam is quite extensive due to the relatively high permeability (K_H = 1 m/d [**Section 5.6.4**]). **Figure 6-5B** shows the predicted drawdown in the Ulan Coal Seam due to the WEP is predicted to be about 25 m (northern end of Pit 3), where the 25m drawdown contour is more extensive due to the combined operation with Moolarben (**Figure 6-5A**), with extensive drawdown developed around the Moolarben Underground Mine (UG4 and its associated borefield). Note that **Figure 6-5** may not show the modelled maximum drawdown in most areas, especially where backfilling of spoil and rehabilitation is proposed to take place well before 2033.

Figure 6-6 presents the calculated drawdown in the water table at the end of mining in 2033. **Figure 6-6** shows that drawdown in the water table is laterally quite restricted compared to the drawdown in the coal seam (**Figure 6-5**). The drawdown contours are located throughout, and are bunched around the edge of, the WCM/WEP and Moolarben open cuts. The inset (**Figure 6-6C**) shows that drawdown of 1-2 m is predicted to develop in some areas away from the open cut pits, but these areas are not extensive, and are typically not directly under the creeks or the mapped 'potential GDE'. The modelled drawdown contours do no intersect the nearby spring (from the bore census) mapped to the south-west of Pit 7.

6.7 PREDICTED INDUCED FLUX FROM ALLUVIUM

The groundwater flux between the hardrock and alluvium in the Wollar Creek Water Source has been calculated using ZoneBudget for MODFLOW-USG (based on Harbaugh, 1990). The results are presented as hydrographs of change in flux on **Figure 6-7** and a summary of the annualised fluxes is provided in **Table 6-7**. These takes are for the WEP operation only.

Table 6-7 Predicted Take from Wollar Creek Alluvium

PERIOD	EFFECT OF WCM		WITH WEP BOREFIELD	
	Mean	Max	Mean	Max
Operational period (2015-2033)	138	170	140	171
Post-mining (2033-2040)	125	142	126	143
Post-mining (2040-2300)	103	146	104	147

units are ML/a.

The predicted take from other bodies of alluvium is negligible, including around near Cooyal and pockets of alluvium on the Goulburn River.

6.8 PREDICTED BASEFLOW EFFECTS

Predicted changes in baseflow and natural river leakage from 2015 onwards have been assessed for relevant reaches of Wilpinjong Creek, Wollar Creek, Cumbo Creek and the Goulburn River. The reaches are defined as follows:

- 'Wilpinjong Creek (upper)' is the reach upstream of WEP Pit 6.
- 'Wilpinjong Creek (lower)' is the next downstream reach to the confluence with Wollar Creek.
- 'Wollar Creek (mid)' is the reach between the model boundary and the confluence with Wilpinjong Creek. Wollar (upper) is outside the model domain.
- The 'tributary to the Goulburn' is the un-named drainage line located 6 km to the east of Wollar and Wollar Creek.
- The 'Goulburn' reach is the Goulburn River from the west of WCM, north past the Drip and extending to the east of the model domain.

River-aquifer exchanges have been compared for transient simulations under the Null condition (Scenario #1), the WEP with Moolarben (i.e. Cumulative, Scenario #2 with the WEP (Scenario #3 and #4).

Figure 6-8 presents the hydrograph of the modelled change in river-aquifer flux for WCM/WEP only and as a result of cumulative effects. Only the main watercourses around WCM are presented. **Table 6-8** summarises the average baseflow capture for the watercourses in the area, for both the mining period 2015-2033 and post-mining.

Table 6-8 Summary of Predicted Baseflow Capture

Watercourse	Reduction in Baseflow					
	Cumulative Effect		WEP only		WEP with Borefield	
	During mining	Post-mining	During mining	Post-mining	During mining	Post-mining
Wilpinjong (upper)	0.082	0.123	0.002	0.001	0.002	0.001
Wilpinjong (mid)	0.242	0.252	0.167	0.150	0.170	0.152
Murragamba and Moolarben Creeks	0.125	0.187	0.001	0.001	0.001	0.000
Cumbo Creek	0.074	0.017	0.068	0.013	0.068	0.013
Slate Gully	0.013	0.027	0.011	0.025	0.011	0.026
Wollar (mid)	0.011	0.010	0.009	0.008	0.009	0.008
Wollar (lower)	0.001	0.002	0.001	0.002	0.001	0.002
Trib to Goulburn	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Goulburn	0.092	<0.001	0.007	0.010	0.007	0.010
Cooyal	0.0032	0.0010	0.0	0.0	0.0	0.0

units in ML/day.

Wilpinjong Creek (the reach adjacent to the WCM) and Cumbo Creek are the two creeks predicted to be most affected by the WCM/WEP. The baseflow time series (**Figure 6-8**) shows that during periods of higher flow, the baseflow capture is predicted to be higher than during low flow periods. The hydrographs indicate that baseflow capture will continue for some time after the cessation of mining, especially along Wilpinjong Creek.

Effects on Slate Gully are predicted to be minimal, despite the proposed development of the Pit 8 open cut through this drainage line. This is because Slate Gully is ephemeral, and rarely carries baseflow.

For context, peak baseflow loss predicted in HydroSimulations (2013) for the (at that time) Approved WCM and for the Modification 5 mine plan was 0.48 ML/day for Wilpinjong Creek and Cumbo Creek. The peak predicted baseflow loss for those two watercourses in this study is 0.47 ML/day. The findings in this study are therefore consistent with the conclusions reached in the previous groundwater assessments to the WCM.

6.9 POST-MINING RECOVERY

Groundwater levels for the end of the simulated post-mining (“recovery”) period have been extracted from the MODFLOW-USG model. The modelled (and arbitrary) recovery period is the year 2300, i.e. approximately 270 years after the proposed end of mining at the WCM.

The hydrographs in **Figure 6-2**, **Figure 6-3** and **Figure 6-4** show the predicted recovery of water levels in the post-mining phase. For the open cut areas themselves, recovery begins as mining of adjacent areas moves away and the enhanced recharge due to spoil emplacement begins to wet up the backfilled material. In the case of GWc17, this is somewhat near to the final void in Pit 6, so recovery is slowed by the presence of a hydraulic sink in that void (**Section 6.9.1**). However the hydrograph from the middle of Pit 8 (away from the final void in the south of Pit 8) is predicted to recover back to within about 3 m of natural levels (**Figure 6-2**).

Figure 6-3 shows that the model predicts about 80% recovery of groundwater levels in the Ulan Coal Seam by 2300 for the two sites nearer the WEP open cuts (near GWc33 and at GWC15). Shallow (perched) groundwater levels are essentially unaffected, as discussed in **Section 6.6.1**. Away from the open cuts (as in the last hydrograph on **Figure 6-3**), the predicted drawdown in the Ulan Coal Seam (and surficial deposits) is smaller than near to the pits and the recovery of groundwater levels in the coal measures is more complete. Similar patterns are seen on **Figure 6-4**.

Maps showing the difference in modelled pre-mining and end of recovery water levels are presented for the Ulan Coal seam (**Figure 6-9**) and water table (**Figure 6-10**).

Figure 6-9 shows that a residual drawdown is predicted to exist in 2300 in the Ulan Coal Seam. This is predicted to be in the order of 10 m around WEP Pit 6, and around Moolarben Open Cut 4. Final voids (**Section 6.9.1**) are the cause of this. In other parts of the WCM area, the residual drawdown is predicted to be about 5 m, and 2 m for the northern part of Slate Gully (Pit 8). As in **Section 6.6.2**, the residual cone of depression extends northward, as well as east and west, and not to the south of WCM due to the unsaturated nature of the coal seam to the south.

The model also predicts that drawdown will persist in the water table (**Figure 6-10**) for a long period after mining, due to both cumulative effects (**Figure 6-10A**) and due to WEP activities only (**Figure 6-10B**). In some areas (e.g. the northern parts of Pits 1, 2 and 4), the water table is predicted to recover more than in others (e.g. southern parts of Pit 6, 5, 1, 7 and 8), as well as around the northern part of Pit 6 (near a proposed final void). To the south of the WCM the coal seam is unsaturated, so there is very little throughflow into the mined areas from the south. This means that recovery in the southern parts of the pits is slow, while because of the dip to the north and the proximity of the northern parts of the pits to the main drainage lines, the predicted rate of recovery is greater in the north of the open cuts.

6.9.1 FINAL VOIDS

Within the post-mining ("recovery") period of the predictive scenarios, the MODFLOW-USG model has been configured to simulate the development of void lakes, located in the final voids in Pits 6, 2 and 8 (**Figure 2-4**). The method to simulate these is discussed in **Section 6.2.2**. The predicted lake levels and lake salinities are presented in WRM Water & Environment (2015) – the WRM Water & Environment predictions account for more of the processes that affect lake water levels (i.e. runoff, open water evaporation and direct rainfall, as well as considering groundwater flow derived from this groundwater model).

Salinities in the voids are predicted to increase over 100-200 years, up to about 17,000 µS/cm (Pit 6) and 70, 000 µS/cm (Pit 2) [WRM Water & Environment, 2015].

The predicted lake levels have been provided by WRM Water & Environment and assessed by HydroSimulations to understand the likely interaction between the voids and the groundwater system:

- Pit 6 void: this void is predicted to be a net inflow system and long-term hydraulic sink. There is a short period in 2041-47 in which water levels in the void are predicted to recover more quickly than in the surrounding spoil and where outflow is predicted to be about 10 cubic metres per day (m^3/d) (peak 40 m^3/d), but after that the model indicates that a sink will develop.
- Pit 2 void: this void is predicted to be a net inflow system and long-term hydraulic sink. There is a short period in 2034-37 in which water levels in the void are predicted to recover more quickly than in the surrounding spoil and where outflow is predicted to be about 70 m^3/d (peak 100 m^3/d), but after that the model indicates that a sink will develop.

- Pit 8 void: this is predicted to be a net outflow system. This void is situated at the very southern end of Pit 8, where the saturated thickness of the Ulan Coal Seam is relatively low. Long-term outflow from this void will flow to the north or west, and is predicted to be about 70 m^3/d. Much of this volume will be derived from runoff and rainfall (i.e. low salinity), and not from groundwater inflow.

The previous points suggest that a plume of saline groundwater will not form from the Pit 2 and Pit 6 voids. Pit 8 will allow some outflow, however the potential for salts to accumulate is limited due to the limited groundwater flux predicted to enter the base of this void.

The void water levels in Pit 2 and Pit 6 are expected to reach an equilibrium within approximately 100 years. The maximum void water levels are expected to be well below the crest of the void (WRM Water & Environment, 2015).

Pit 8 would not maintain a final void lake of any significant volume and would frequently be dry (WRM Water & Environment, 2015).

7 IMPACTS ON THE GROUNDWATER RESOURCE

7.1 POTENTIAL IMPACTS ON GROUNDWATER

This assessment focuses on the criteria specified by the minimal impact considerations of the AI Policy, and includes:

- Licensable takes of water (and their partitioning);
- Intersection of or proximity to alluvial deposits;
- Water table drawdown;
- Pressure head drawdown; and
- Groundwater quality impacts.

7.1.1 LICENSABLE TAKES OF WATER

Table 7-1 presents the groundwater licensing summary for the WCM. This is based upon predictive model runs #2 and #3 simulated water balance changes in response to the WEP.

Table 7-1 Groundwater Licensing Summary

PERIOD	YEARS	ALLUVIUM	HARD ROCK
		Wollar Creek Water Source	Sydney Basin – Upper Hunter
During Mining	2015-2033	171	1099
Post-mining	2033-2045	143	0
Post-mining	2045-2100	147	0

C:\HydroSim\WIL006\Model\Processing\zonebudget_usg\[WilpV2TR25_USGzbud_GMAlicensing.xlsx]GWPartitioning_Timeseries

The predicted takes from the alluvium associated with the Goulburn River, the Sydney Basin – Macquarie Bogan and Oxley Basin (Jurassic deposits) GMAs are negligible.

As stated in **Section 2.2.1**, WCPL currently holds several groundwater extraction licences:

- Peabody Pastoral Holdings and WCPL jointly own WAL 21499 for 474 units (i.e. 474 ML/a) units from the alluvium of the Wollar Creek Water Source; and
- WCPL hold five *Water Act 1912* licences (20BL173517, 20BL173516, 20BL173514, 20BL173515 and 20BL173513), with a consolidated entitlement of 2021 units (i.e. 2021 ML/a) from the Permian formations (covering the Sydney Basin – Upper Hunter GMA).

Based on the predictive modelling, WCPL currently hold sufficient licence entitlement to cover the modelled groundwater 'take' from the alluvial and hard-rock groundwater sources.

7.1.2 CHANGES IN HYDRAULIC PROPERTIES

There would be a change in hydraulic properties over the mine footprint where spoil infills the excavation down to the floor of the mined coal seam. As spoil would have a higher permeability than any natural material in this area, with the possible exception of alluvium, there would be associated reductions in hydraulic gradients in accordance with Darcy's Law. As one increases, the other must decrease to maintain the same flow. The flattening of the hydraulic gradient in the spoil material is evident in the spacing of the contours to the south of the pit lakes in **Figure 6-9** and **Figure 6-10**.

Rainfall recharge is expected to be higher in the spoil than in any natural local material, and may even result in recovery of water levels in some areas beyond natural levels.

7.1.3 CHANGES IN GROUNDWATER FLOW

As mining progresses, the open cut voids will act as a groundwater sink, resulting in groundwater discharge to the voids (**Section 7.1.4**). This discharge will result in a cone of depressurisation and cause a temporary change in groundwater flow direction, often reversal of direction, until mining is completed and the aquifer system recovers to a new equilibrium.

The maximum regional drawdown due to mining are expected within model Layer 6 (Ulan Coal Seam). **Figure 6-5** shows the predicted drawdown magnitude and pattern for the Ulan Coal Seam, for the WEP (**Figure 6-5b**) and cumulative impacts (**Figure 6-5a**). Drawdowns are naturally restricted from developing to the south by the outcropping of the Shoalhaven Group and/or naturally unsaturated nature of the Ulan Coal Seam. However, they propagate readily to the north. The extent of the predicted drawdown is greater than in previous assessments for WCM (e.g. AGE, 2005), due to both changes in parameters (hydraulic conductivity, storage and recharge), as well as a change in modelling software (MODFLOW-96 in AGE, 2005 compared to MODFLOW-USG for this assessment).

Groundwater levels in the Ulan Coal Seam and overlying Coal Measures are expected to recover after mining, with the enhanced recharge to spoil or waste emplacement areas likely to assist in this regard.

Two of the three proposed final voids, those in the north of Pits 6 and 2, will act as groundwater sinks into the long-term. No impacts to groundwater quality are expected during this time as a result of water quality within those final voids. The remaining void, in the southern part of Pit 8, is likely to act as a ‘flow through’ system’ due to its position near the top of a groundwater catchment and the naturally unsaturated nature of the coal seam in this area. Minimal groundwater flow will gather or pass through this void, however it is likely to collect rainfall and runoff, and this will either evaporate or leak into the adjacent or underlying groundwater system.

Depressurisation of the Ulan Coal Seam and coal measures will result in induced downward flux from (or reduced upward flux to) nearby alluvium. The maximum volume of this is stated in **Section 7.1.1**. The predicted ‘take’ from the alluvium within the Wollar Creek Water Source is consistent with that estimated in previous assessments, and WCPL already hold licence sufficient to meet the take this source.

7.1.4 PIT INFLOWS

Up to the end of mining, there would be a continuous discharge of water from the groundwater system into the mining voids. The predictive modelling reported in **Section 6** demonstrates that pit inflow is expected to vary between approximately 0.5 and 4.55 ML/day from 2015 until the proposed cessation of mining in 2033. The future peak annual inflow is predicted to be 3.3 ML/day (1188 ML/a) in 2018-19, which is less than the simulated historical peak for WCM (about 1420 ML/a occurring in 2014-15).

These rates are the total groundwater takes, and do not account for subsequent evaporation at seepage faces or pools and sumps in the floor of the pit that would reduce the volume that would require management in the operational water management system. These volumes are estimated in WRM Water & Environment (2015).

7.1.5 CHANGES IN GROUNDWATER QUALITY

There is not expected to be any long term degradation of the quality of the groundwater resource at the WCM. This is partly because the background water quality in the surrounding groundwater and local watercourses is relatively poor, i.e. high background salinity (OEH, 2006).

No groundwater quality impact is expected from groundwater interactions with the final void water in Pit 6 and Pit 2 as these would remain as groundwater sinks in the long term. Pit 8 would not maintain a final void lake of any significant volume and would frequently be dry (WRM Water & Environment, 2015), therefore it would also have no groundwater quality impact.

This conclusion is supported by monitoring at the WCM. **Figure 3-29** to **Figure 3-31** show the EC of groundwater at bores around the site, including adjacent to now-inactive tailings facilities. Many bores, particularly those in the shallow sediments, have recorded short-term spikes in water quality indicators, however across the longer-term pH remains within the acceptable 6.5-8 range and EC shows no discernible rising trend in response to mining at WCM, noting again that this catchment is noted for its naturally high salinity.

7.1.6 GEOCHEMISTRY

Potential acid drainage at the WCM is managed in accordance with the plans documented in Section 4.0 of Geo-Environmental Management (GEM, 2015) These plans cover the following components:

- Potential acid-forming (PAF) material separation procedures;
- PAF material storage procedures; and
- Monitoring of surface water and groundwater for the control of PAF materials.

Monitoring results from the WCM indicate that the waste rock management methods have been successful in controlling or negating effects on groundwater and surface water bodies (GEM, 2015).

Recent geochemical investigation undertaken and presented in GEM (2015) were consistent with the conclusions of earlier assessments (e.g. EGi, 2005 at Wilpinjong, and EGi, 2008 at Moolarben), i.e. that:

- "Overburden and interburden materials from the Wilpinjong Coal Project were expected to be non-saline and, apart from a small quantity of PAF/LC *[potentially acid forming/low capacity]* material occurring in the floor rock of the G Seam, the bulk of this material was expected to be NAF *[non-acid forming]."*
- Fresh overburden and interburden is likely to be non-sodic and that some of the weathered and alluvial materials may be slightly to moderately sodic.

The similarity between the approved WCM and proposed WEP mean that, based on groundwater monitoring results and the assessment by GEM, it is expected that existing management practices alongside recommendations by GEM (2015) with respect to waste rock and coal rejects, would be sufficient to maintain adequate control over ARD risk on-site.

In consideration of the above, it is expected there would be negligible impacts to groundwater quality (either directly or via final pit voids) as a result of PAF material.

GEM (2015) indicated that there is a risk of Molybdenum (Mo) and Selenium (Se) being mobilised from waste rock under neutral (non-acidic) conditions.

7.1.7 POTENTIAL IMPACTS ON REGISTERED PRODUCTION BORES

An assessment of drawdown on privately-owned bores, i.e. on non WCPL-controlled land, have been assessed. Many of the bores around WCM are on property owned by WCPL or Peabody Pastoral Holdings. Bores on private or public land in the vicinity of the WEP include:

- one bore at Wollar Public School (20BL173431) that is used for watering recreational areas and gardens; and
- one private bore (GW063717) to the south-west of the WCM for stock and domestic use.

The groundwater modelling results indicate that only a single registered bore is predicted to experience drawdown greater than 2 m as a result of the WEP operation. This bore is owned by Wollar Public School (20BL173431). The bore is screened in the Shoalhaven Group, which is relatively low-yielding. The bore is 60 m deep, with approximately 40-50 m of available drawdown. The maximum predicted drawdown is 6 m, meaning that the bore is unlikely to go dry because of the WEP.

A number of bore censuses have been conducted at the Moolarben Coal Complex, which have established that there are only four privately owned bores within 10 km of the mine (MCO, 2015). The WEP is not predicted to result in any appreciable increase to drawdowns at these private bores.

The predictions for the remainder of the 537 registered groundwater works within the active model domain indicate no simulated drawdown in excess of the AI Policy criterion of 2 m. **Appendix I** presents a list of the bores and the modelled WEP-specific and cumulative drawdown at each. For the sake of brevity, this list includes only those bores for which the predicted WEP-specific drawdown is >0.1 m.

A series of springs were identified during the previous bore census (locations shown on **Figure 3-3**). Based on the analysis of modelled drawdown (**Section 6.6**), these springs are unlikely to be affected by mining.

7.1.8 INTERSECTION OF ALLUVIUM

The AI Policy states that mining activities are not allowed to occur within 200 m laterally or 100 m vertically of either ‘Highly Productive’ or ‘Less Productive’ alluvium if that alluvium is associated with watercourses that are both ‘highly connected surface water’ and classified as a ‘reliable water supply’.

While the unregulated watercourses of the Wollar Creek Water Source are ‘highly connected’ (NSW Department of Water and Energy, 2009) they are do not meet the definition of ‘reliable water supply’ (**Section 3.3**). Despite this, the assessment of this issue for the WEP is that:

- None of the WEP expansion areas, including Pit 8, come within 200 m laterally of mapped alluvium associated with ‘highly connected’ watercourses.
- None of the WEP expansion areas, including Pit 8, are within 100 m vertically of mapped alluvium associated with ‘highly connected’ watercourses.
- Therefore, this consideration or rule is not breached by the proposed WEP mine plan.

7.2 POTENTIAL IMPACTS ON SURFACE WATER BODIES

The modelled patterns of drawdown for the Ulan Coal Seam and water table are shown in **Figure 6-5**, **Figure 6-6**, **Figure 6-9** and **Figure 6-10**. These show that while there is substantial reduction in potentiometric head in the aquifers of the deeper groundwater system due north and northeast/northwest of the WCM area, there is no significant reduction in groundwater levels simulated in the alluvium. This finding of the model is supported by observed groundwater level data at the alluvial monitoring bores (**Figure 3-17**) which show little, if any, mining effect in the alluvium in spite of substantial reduction in groundwater pressure in deeper layers as mining progresses, and therefore in line with the conceptual model of the connection between the mined seam and shallow sediments (**Section 4**).

The predictive simulation in **Section 6.8** demonstrates that the net reduction in baseflow to the watercourses is expected to be small and, furthermore, is consistent with estimates of baseflow capture for the approved WCM (HydroSimulations, 2013). The effects of baseflow capture on flows in watercourses is assessed by WRM Water & Environment (2015).

7.2.1 CHANGES IN WATER QUALITY

There are not expected to be any changes in the quality of groundwater as a consequence of mining, other than possible freshening over the mine footprint due to higher rainfall infiltration rates through spoil.

No groundwater quality impact is expected from groundwater interactions with the final void water (**Section 7.1.6**). Therefore, it is unlikely the water quality of any surface water body would be impacted via final void water migration through groundwater.

As described in **Sections 3.8.3** and **3.9.3**, evidence is that there is only limited connection between the coal seam and coal measures and the alluvium of the Wilpinjong and Wollar Creeks. This restricts the flux between mine voids (including final voids) to the surrounding groundwater and surface water bodies. Given no changes to groundwater quality are expected, and the limited connection to Wilpinjong Creek or Wollar Creek, it is unlikely that the water quality of any surface water body would be impacted by seepage.

Given the localised disturbance of open pit mining, and the modelling and demonstration of minimal changes in groundwater and surface water quality through the 10-year history of groundwater monitoring at WCM, no effects on water quality of the Wilpinjong Creek, Cumbo Creek and Wollar Creek are anticipated.

7.2.2 CHANGES IN WATER BALANCE

Numerical modelling has allowed quantification of the relative magnitudes of the major components of the water balance. Pre-mining recharge is dominated by rainfall (48%) and river leakage (23%), while discharge is dominated by evapotranspiration (64%) and baseflow to rivers and creeks (16%). End of mining recharge is expected to be dominated by rainfall (45%) and river leakage (20%), while discharge should be dominated by evapotranspiration (54%) and baseflow to rivers and creeks (14%). Discharge to the mines is estimated to be about 3% (WCM only, compared to 7% for both WCM and Moolarben) of the water budget at the end of mining.

These figures indicate that mining would have a relatively minor effect on the water balance.

7.2.3 EFFECTS ON SURFACE ECOSYSTEMS

Given the localised disturbance of open pit mining, and the demonstration of limited, if any, changes in groundwater levels in the alluvium and other shallow deposits, only minimal effects on surface ecosystems, are anticipated in relation to mining-induced changes to the water system. This includes the typha vegetation mapped within Wilpinjong and Cumbo Creeks (**Section 3.6**).

High Priority GDEs as defined in the relevant WSPs (**Section 3.6**, **Figure 3-3**) are too distant from the WCM and WEP to be affected by drawdown from the mine.

The relevant WSPs do not list any Culturally Significant Sites in the vicinity of the WCM.

Modelling of drawdown indicates that the mining or production bore extraction proposed as part of the WEP is not expected to have any discernible effect on any perched groundwater or springs in the National Park or Munghorn Gap Nature Reserve (i.e. in the Triassic Wollar Sandstone / Narrabeen Group).

7.3 PROPOSED GROUNDWATER MONITORING PROGRAMME

The existing groundwater monitoring network for the mine is summarised in **Section 3.8.2** and measured water quality parameters are listed in **Table 3-6**. Since the commencement of mining, WCPL have extended the monitoring network considerably, including at Wollar and around the proposed Slate Gully (Pit 8) area.

7.3.1 MONITORING PIEZOMETERS

The existing network is considered adequate for providing information on the dynamics of the groundwater hydraulics and offers an adequate basis for groundwater model calibration and verification.

Water level measurements should be continued as outlined in **Table 3-5**, with renewed monitoring of water levels at PZ20-21 on a 6-monthly frequency. The collar elevation of these bores should be surveyed.

WCPL have recently installed two bores in spoil emplacement areas: GWf1 in Pit 1 and GWf2 in Pit 5. Continued monitoring of these bores is recommended. Such data are useful in providing information on the recharge rates through spoil, spoil permeabilities, and to validate modelling assumptions and predictions. In the future, it would be useful to install and monitor an additional bore in the spoil/final landform north of the proposed Pit 8 final void (assuming that GWc31 will be removed by mining).

7.3.2 GROUNDWATER QUALITY

The groundwater monitoring network is currently sampled for water quality on a regular basis, Samples for laboratory analysis should continue to be undertaken at a NATA accredited laboratory. Water quality data should be evaluated as part of the AEMR processes and should aim to identify any potential mining related impacts.

Testing of field parameters in monitoring bores should continue. Groundwater quality monitoring should continue to sample for the parameters outlined in **Table 3-6**: HydroSimulations agree with GEM's (2015) recommendation that molybdenum (Mo) be added to the groundwater monitoring program.

Monitoring of field parameters at PZ20-21 should continue on a 6-monthly frequency. An annual sample for laboratory analysis from PZ20 or PZ21 would provide a useful baseline, in combination with data from GWa/c10-11, against which to assess any interaction between the Pit 2 final void and the adjacent groundwater system after the end of mining.

7.3.3 HYDRAULIC PROPERTY MEASUREMENTS

Several iterations of groundwater modelling have been carried out for WCM, and calibration of these has been considered acceptable. However, core sampling and testing should be conducted during appropriate WCPL drilling within or near the WCM area, where practicable, to determine aquifer properties within the natural rock strata, e.g. effective porosity, horizontal permeability and, particularly, for vertical permeability. A reasonable dataset of horizontal permeability data throughout the WCM area is available (**Section 3.8.7**), however vertical permeability data for the Ulan Coal and overlying coal measures would be useful to constrain and validate model parameters and guide any future groundwater assessments.

7.3.4 MINE WATER BALANCE

Monitoring of inflow

There remains scope to improve measurement of groundwater inflows to the pits. It is recommended that runoff diversions be maintained and upgraded/extended for the WEP to reduce the runoff component in the pits. Estimates of non-runoff components of the water balance have been based on pumped hours and more recently, metered rates. The recent metering requires calibration, or confirmation of calibration. Any efforts that can reduce inflow from non-groundwater sources would be helpful in constraining estimates of groundwater 'take' be made, including the minimisation of runoff into the pits and reducing the potential for recirculation of water from surface water storages back into adjacent open cut workings.

As has been carried out for both 2013-14 and 2014-15, water balances should continue to be conducted regularly, accounting for all monitored volumes and should be reported in the AEMR, as per the conditions of earlier approvals.

The water balance should be regularly reviewed to confirm groundwater transmission characteristics and modelling predictions. Monitoring results which indicate anomalous mine water seepage should be investigated. If anomalous seepage is detected, WCPL should notify and consult with the relevant regulator regarding further courses of action.

Borefield to meet future shortfall

Predictive scenario #4 (**Section 6.1**) simulated the operation of the WCM/WEP borefield to assess the effects of the mine operation as a whole should the borefield be required. This scenario is envisaged in the case that there is a potential short-fall in inputs in the site water balance compared to the operational requirements. The modelling suggested that the borefield would be about 80-85% efficient; e.g. pumping the borefield at 100 megalitres per year (ML/yr) would cause a reduction in groundwater inflow to the pits of about 15-20 ML/yr, therefore yielding a total of 80-85 ML/yr to the volume of water available for operations. This has been considered by WRM Water & Environment and should be considered for future operations.

8 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on groundwater are projected to be negative in some places on earth, but positive in others. In the Netherlands, for example, beneficial effects are anticipated (Kamps *et al*., 2008). There it is expected that coastal water tables will rise, but evapotranspiration will reduce in response to the adaptation of vegetation to higher levels of carbon dioxide. Modelling shows more pronounced seasonal water table fluctuations by accounting for vegetation feedback mechanisms (Kamps *et al*., 2008). Plants are expected to have a lower water demand under higher carbon dioxide levels due to production of more biomass, increased leaf area index, and a shorter time to reach the saturation point for carbon demand (Kamps *et al*., 2008). In New Hampshire, United States of America, on the other hand, negative effects on the water table are expected due to the onset of spring recharge two to four weeks earlier (Mack, 2008). This shift will allow a longer period for evapotranspiration prior to summer, at which time groundwater availability is likely to decrease.

The modelling of climate change effects needs to take into account complex vegetation and hydrologic feedback mechanisms, coupled surface water and groundwater interactions, and inter-annual temporal variations. Few modelling studies have been conducted so far. Hunt *et al*. (2008) reported on the difficulties to be overcome in doing comprehensive modelling using the integrated GSFLOW software (MODFLOW plus PRMS).

Order of magnitude estimates can be found by ignoring feedback mechanisms and changing the currently calibrated rain infiltration percentages. However, more intense rainfall events would be expected to increase fast runoff and lead to a reduction in infiltration. This should be taken into account to allow for short-term temporal variations.

Two sources of projected changes in rainfall have been reviewed:

- NarClim (NSW / ACT Regional Climate Modelling)[16] for the 'Central West' area.
- Climate Change in Australia[17] ['CCiA'] for the 'Eastern Australia' region.

Table 8-1 presents the median projection for change in rainfall from these sources for 2030 (i.e. approximate end of mining) and longer-term projection for 2080/90. Scenarios relying on low carbon emissions have not been considered because the moderate ('RCP4.5') or higher emissions ('RCP8.5') scenarios being more likely (CSIRO and BoM, 2014).

These rainfall projections are somewhat similar, at least on an annual basis, for 2030, but quite variable for the 2080/2090 forecast, as described in **Table 8-1**. NarClim projections are suggestive of a wetter climate, while 'CCiA' projections favour a drier climate.

[16] http://www.climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM
[17] http://www.climatechangeinaustralia.gov.au/en/

Table 8-1 Climate Change Projections – Percentage Change in Rainfall

PERIOD	2030		2080	2090	
	NarClim	'CCiA' RCP 4.5	NarClim	'CCiA' RCP 4.5	'CCiA' RCP 8.5
Summer	-1.1	-2.0	13.2	-2.0	4.0
Autumn	14.7	-4.0	13.5	-7.0	-8.0
Winter	-4.2	-3.0	5.4	-10.0	-16.0
Spring	-7.6	-2.0	-5.8	-10.0	-16.0
Annual	**0.2**	**-1**	**7.6**	**-7.0**	**-10.0**

Baseline for NarClim = 1990-2010 period; baseline for CCiA projections = 1986-2005 period.

These changes in rainfall are predicted to result in changes in rainfall recharge similar to:

- NarClim 'recharge scenario': 0.6% in 2030, increasing to 22.8% in 2080.
- CCiA 'recharge scenario': -3% in 2030, falling to -25.5% in 2090.

These recharge projections are based on experience and literature, with a general rule being that changes in rainfall are typically magnified 2-4 times when converted to rainfall recharge ('rainfall elasticity in recharge'), as described in Barron *et al* (2012). Note that the CCiA 'recharge scenario' uses the mean from the RCP4.5 and RCP8.5 projected change in rainfall for 2090 (**Table 8-1**).

For the WEP, HydroSimulations have conducted a single transient predictive simulation for rainfall recharge altered according to the drier of the projections, i.e. CCiA recharge scenario.

The effect of the postulated climate change has been assessed for the simulated WEP mine groundwater inflow. It was found that the average reduction in inflow over the remaining life of the WCM/WEP would be about <1%, given that there is only a small change in average rainfall by 2030 (**Table 8-1**), and the WEP proposal is for mining until 2033. The recharge scenario based on NarClim projections, were it to be run with the groundwater model, would produce a very similar result. In the short-term, climate variability, rather than climate change, will govern whether rainfall is similar to the long-term average or not.

The Surface Water Assessment (WRM Water & Environment, 2015) has considered the implications of climate change on the behaviour of the final void.

9 CONCLUSIONS

The initial groundwater assessment for the WCM was conducted by AGE in 2005. The WCM has been operating since its subsequent approval, i.e. for 10 years, with an extension in the amount of monitoring conducted and the amount of data available.

The available data supports two groundwater systems:

- shallow groundwater system – associated with alluvium and regolith; and
- deeper groundwater system, including:
    - the Ulan Coal Seam; and
    - low permeability fractured rock/coal measures of the overlying Illawarra Coal Measures and underlying Nile Sub-group and Shoalhaven Group.

Mining commenced in 2006 and there is strong hydrographic evidence of mining effects on the deeper groundwater system. Discernible effects on the shallow alluvial groundwater system are only observed at a select few bores (definitely one, possibly up to four). Based on strong evidence from hydrographic data and field observations, the conceptual model suggests that there is expected to be:

- minimal loss of groundwater yield to/from surface stream systems (i.e. Wilpinjong Creek and Wollar Creek); and
- limited potential for reduction of groundwater yield to other groundwater users, especially for any bores located in the shallow (alluvial) groundwater system.

These observations are consistent with the conclusions of the numerical model, described below.

As would be expected, a lateral hydraulic gradient towards the open pit has developed, and groundwater flow would continue to move toward the pit as mining progresses.

An assessment against the AI Policy Minimal Harm Considerations is presented in **Table 9-1** and **Table 9-2**, with some additional discussion following those tables. This is based on both data analysis, conceptualisation and numerical modelling.

Table 9-1 Summary of AI Policy Assessment – Wollar Creek Alluvium

Aquifer	Alluvium associated with the Wollar Creek Water Source (*Hunter Unregulated and Alluvial Water Sources WSP* – Goulburn Extraction Management Unit)
Category	Highly Productive

Level 1 Minimal Impact Consideration	Assessment
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: high priority groundwater dependent ecosystem; or high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	The relevant Water Sharing Plan is the 'Hunter Unregulated and Alluvial Water Sources' (2009). There are no Culturally Significant Sites in the Study Area listed in the WSP. Hence there are no known risks of mine development to such sites. There are no High Priority GDEs listed in this WSP in the Study Area. There is minimal risk of drawdown at current water supply works in excess of the drawdown criterion within the alluvial deposits. **Level 1 minimal impact consideration classification.**
Water pressure A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	There is minimal risk of drawdown at current water supply works in excess of the criterion within the alluvial deposits. **Level 1 minimal impact consideration classification.**
Water quality	Mining-induced changes to the hydraulic properties and depressurisation of the coal-bearing strata in the Wilpinjong Mine area may result in mixing of potentially chemically different groundwater between surficial and deeper units. However, it is considered unlikely that this will result in changes to the beneficial uses of groundwater in the naturally saline alluvial deposits. The risk of water quality impacts decreases with distance from the mine footprint. **Level 1 minimal impact consideration classification.**

Table 9-2 Summary of AI Policy Assessment – Fractured and Porous Rock

Aquifer	Sydney Basin – Upper Hunter GMA (*North Coast Fractured and Porous Rock Groundwater Sources WSP* – not yet commenced)
Category	Less Productive

Level 1 Minimal Impact Consideration	Assessment
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: high priority groundwater dependent ecosystem; or high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	The relevant Water Sharing Plan is the 'North Coast Fractured and Porous Rock Groundwater Sources WSP' (not yet commenced). There are no Culturally Significant Sites in the Study Area listed in the WSP. Hence there are no known risks of mine development to such sites. There are no High Priority GDEs listed in this WSP in the Study Area. There is a likely risk of drawdown in excess of the water supply work drawdown criterion within the Permo-Triassic strata (at one private bore). **Level 2 minimal impact consideration classification.**
Water pressure A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	Likely risk of drawdown in excess of the criterion within the Permo-Triassic strata (at one private bore). **Level 2 minimal impact consideration classification.**
Water quality	Mining-induced changes to the hydraulic properties and depressurisation of the strata in the Wilpinjong Mine area may result in mixing of potentially chemically different groundwater between overlying and underlying units. However, it is considered unlikely that this will result in changes to the beneficial uses of groundwater in the Permo-Triassic rock units. The risk of water quality impacts decreases with distance from the mine footprint. **Level 1 minimal impact consideration classification.**

Furthermore, based on groundwater modelling, there is expected to be:

- a future pit inflow averaging about 1.9 ML/day for the period 2015-2033, ranging between approximately 0.7 and 4.55 ML/day;
- substantial reduction in potentiometric head in the aquifers of the deeper groundwater system to the north and northeast of the WCM (WEP) area;
- minimal drawdown (approximately 1 m) in the aquifers of the shallow alluvial groundwater system along Wilpinjong Creek and less around Wollar Creek;
- negligible impact on access to water in known registered production bores licensed to external parties. There are no privately-owned bores predicted to experience >2 m drawdown related to the activities of the WEP. There is only one state-owned registered bore, located at the Wollar Public School, predicted to experience >2 m drawdown related to the activities of the WEP;
- no effect on the High Priority GDEs identified in this region. There are two sets of karst features (13 and 16 km away respectively) and the Wild Bull springs, located about 17 km south of the WCM. As the mine is not in close proximity to GDEs identified as High Priority, the minimal harm considerations of the AI Policy would not be infringed by the WEP;

- no effect on any High Priority Culturally Significant Sites in this area, as the relevant legislation does not identify any in the vicinity;
- no discernible effect on any perched groundwater or springs in the National Park or Munghorn Gap Nature Reserve (i.e. in the Triassic Wollar Sandstone / Narrabeen Group);
- loss of groundwater discharge (or baseflow capture) to surface stream systems is predicted to be minimal on Wilpinjong Creek and negligible for Wollar Creek;
- minimal loss of groundwater discharge (or baseflow capture) to Cumbo Creek, which is approved to be relocated as part of the existing/approved WCM;
- no discernible deterioration in groundwater quality as a result of mining, including in the long-term;
- slow recovery of the groundwater system over several decades to a new equilibrium in which two of the final void pit lakes (Pits 2 and 6) would act as hydraulic sinks in the local groundwater system, and where the remaining final void (Pit 8) may frequently be dry but with the possibility of it acting as flow-through system (mainly transmitting incident rainfall and runoff); and
- at equilibrium, natural groundwater flow direction is expected to be restored to a dominant northerly direction through the mine footprint toward Wilpinjong Creek, with the exception of around the Pit 2 and Pit 6 final voids.

As the *North Coast Fractured and Porous Rock Groundwater Sources WSP* has not yet commenced, the interception and use of groundwater at the mine remains managed and licensed under Part V of the *Water Act, 1912*. WCPL holds five Groundwater Licence with a consolidated allocation of 2021 ML/yr for the excavation. Licences were originally issued in 2006 and have recently been renewed in 2015 and remain valid until June 2020. The predicted peak groundwater take from the Permian strata (approximately 1100 ML/a - **Table 7-1**) is below the current licensed rate of 2021 ML/yr. No additional licensing for the Permian strata is required.

WCPL also hold existing licences to cover extraction of 474 ML/yr of take from the alluvium of the Wollar Creek Water Source. This is more than sufficient to cover the predicted take from the alluvium (**Table 7-1**). No additional licensing for the alluvial deposits is required.

These effects are consistent with previous assessments undertaken in 2005 (AGE) and 2013 (HydroSimulations). And relevant to the currently-approved WCM. There are no material changes to the key assessment outcomes and the incremental effects of the WEP, compared with the approved WCM, are therefore considered to be minimal, with the main differences being that:

- drawdown will persist for slightly longer due to the proposed increase in mine life (2026 to 2033);
- the cone of depression will extend further east, through Wollar, as a result of the development of Pit 8 (Slate Gully); and
- a slight increase in baseflow capture from Wollar Creek as a result of the proposed extension into Pit 8.

Cumulative impact assessment has been undertaken with the groundwater model developed for the WEP, with explicit simulation of the neighbouring Moolarben Coal Complex deemed necessary. No other mines require modelling.

With respect to baseflow capture from watercourses, there is predicted to be little change between the WEP-specific and cumulative effects on creeks that run through or east of the WCM, such as Cumbo Creek and Wollar Creek. The WEP is predicted to result in a negligible amount of baseflow capture from the Goulburn River (up to 0.007 ML/day), while this is predicted to rise to about 0.092 ML/day as a result of cumulative effects with Moolarben. Similar patterns of increase between the WEP-specific and cumulative effects are predicted in the Murragamaba and Moolarben Creeks (in the middle of the Moolarben tenements) and on Cooyal Creek to the south. The cumulative effect on creeks such as Moolarben Creek, the Goulburn River and Cooyal Creek would be similar under the proposed WEP plan or the approved WCM plan. Cumulative effects on surface water flow are considered in the Surface Water Assessment for the WEP (WRM Water & Environment, 2015).

With respect to drawdown at neighbouring bores, the minimal harm considerations of the AI Policy specify 2 m of drawdown as the threshold. There is a single state-owned bore at Wollar Public School that is predicted to experience >2 m mining related drawdown from the WEP. A number of bore censuses have been conducted at the Moolarben Coal Complex, which have established that there are only four privately owned bores within 10 km of the mine (MCO, 2015). The WEP is not predicted to result in any appreciable increase to drawdowns at these private bores.

The WEP is anticipated to have no effect on water quality in Wilpinjong Creek, Cumbo Creek and Wollar Creek and therefore would not contribute to any potential cumulative water quality impacts on these streams.

Based on the assessment presented above, and in consideration of the IESC Information Guideline Requirements and the Significant Impact Guidelines 1.3 (Commonwealth of Australia, 2013), the action (as defined in **Section 1.4.5**) would not result in significant changes to the quantity or quality of water available to third party users or the environment.

Accordingly, the action would not have a significant impact on water resources.

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APPENDIX A - SITE PHOTOS

Site photos showing structural features

Site photos

Photo A1

Photo in centre of Pit 3, looking west. Shows fault intersected in this pit.

Photo A2

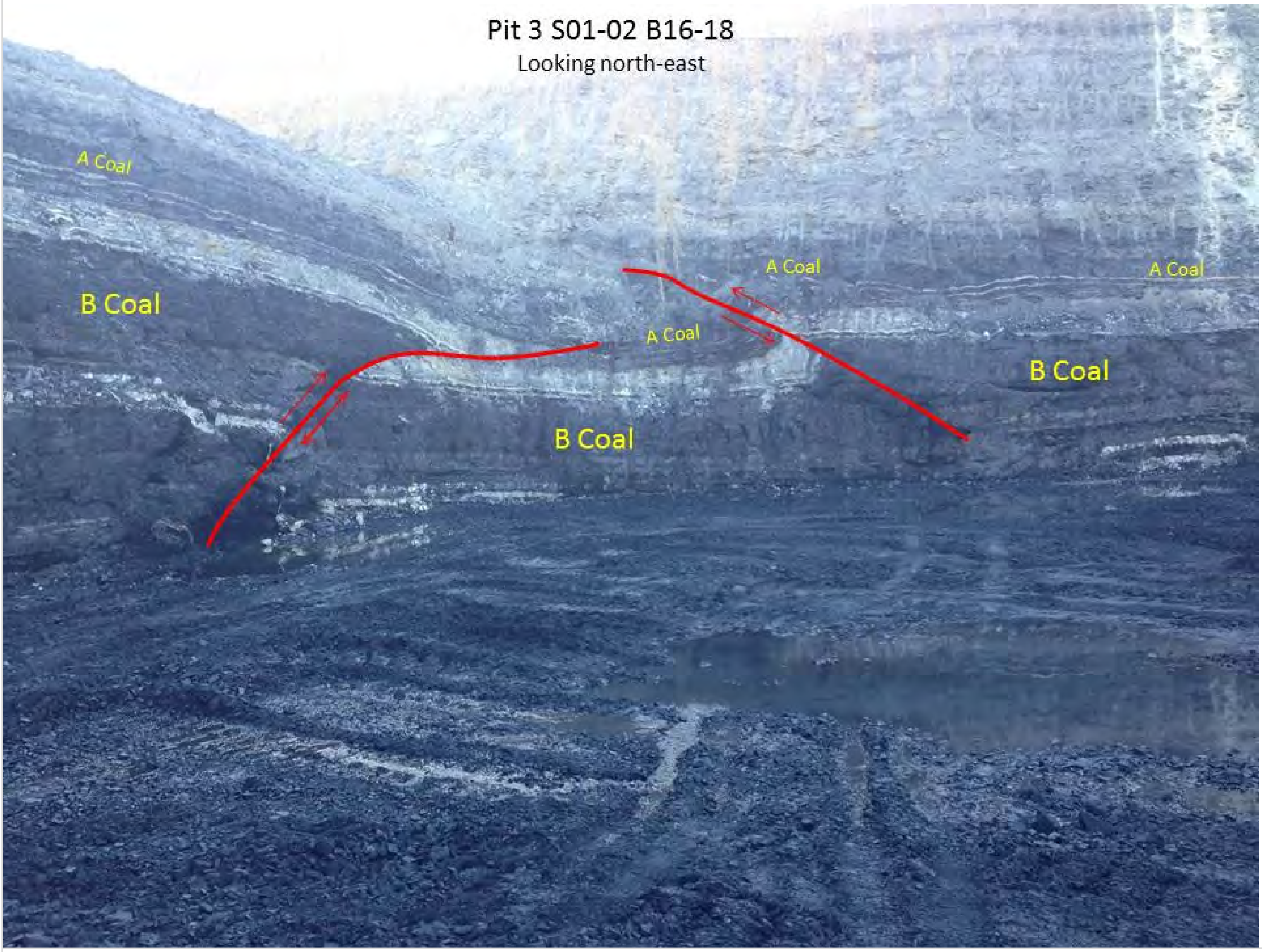


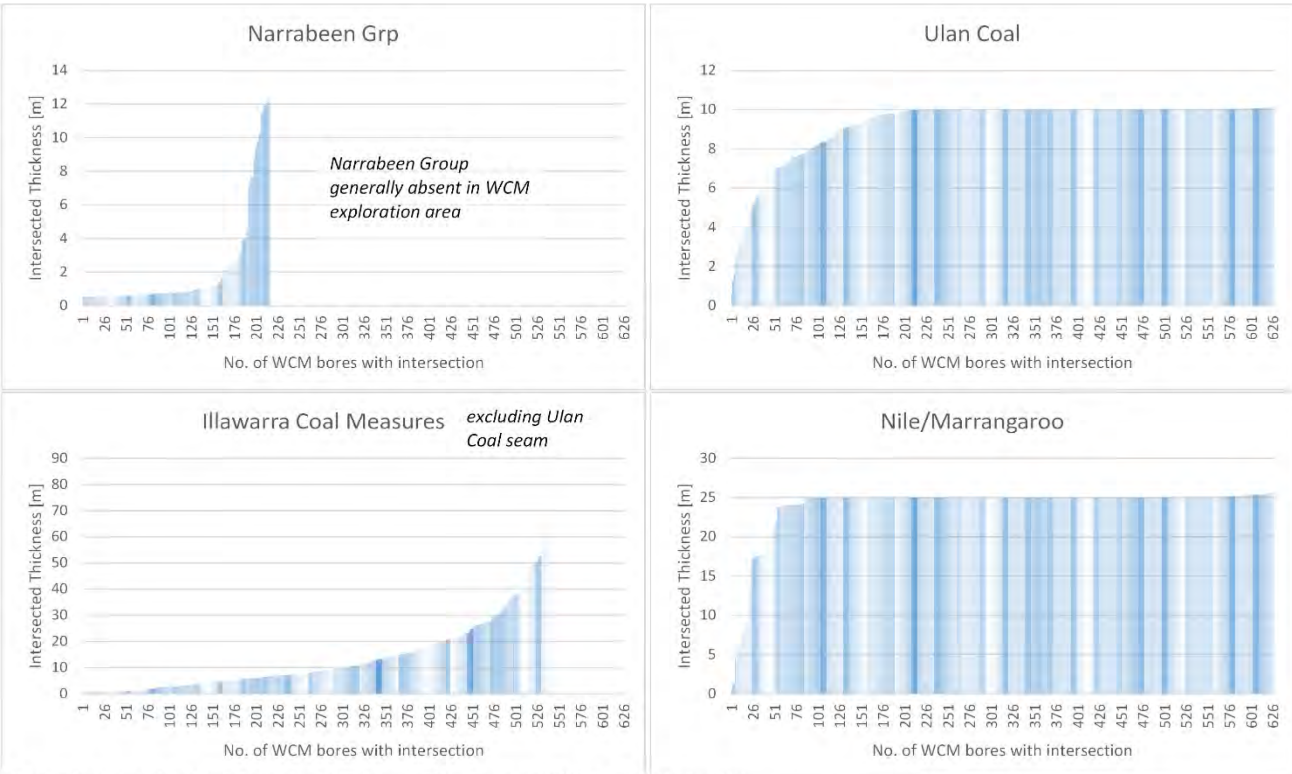
Photo in Pit 3, looking north-east. Shows other main fault structure intersected in this pit.

Photo A3

Photo from Pit 5, looking south-west. Shows palaeochannel features, which are also observed near Moolarben Mine, entering the Pit 5 footprint, after passing through the Pit 6 footprint.

APPENDIX B – STRATIGRAPHIC THICKNESS

Summary of stratigraphic thickness from WCM bores and site-scale geological model



this analysis completed by intersecting WCM exploration bores with WCPL geological model.

APPENDIX C – GROUNDWATER LEVELS

Groundwater level hydrographs from WCM monitoring bores

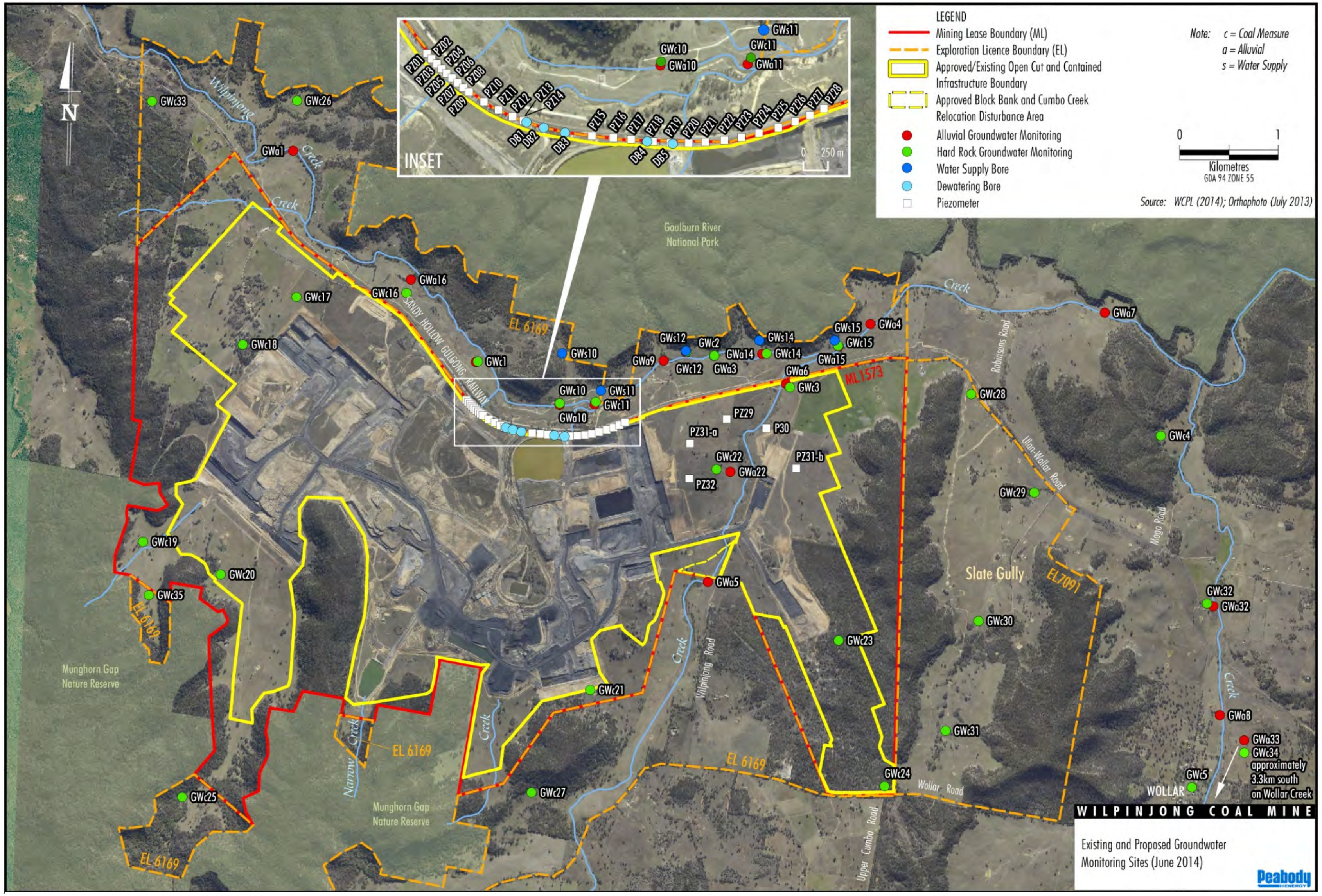


Figure C-1. Existing and Proposed Groundwater Monitoring Sites (June 2014) C:\HydroSim\WIL006\Tech\WaterLevel\2014\WEP_GroundwaterHydrographs%20AppendixC.docx

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Appendix C: Groundwater Level Hydrographs

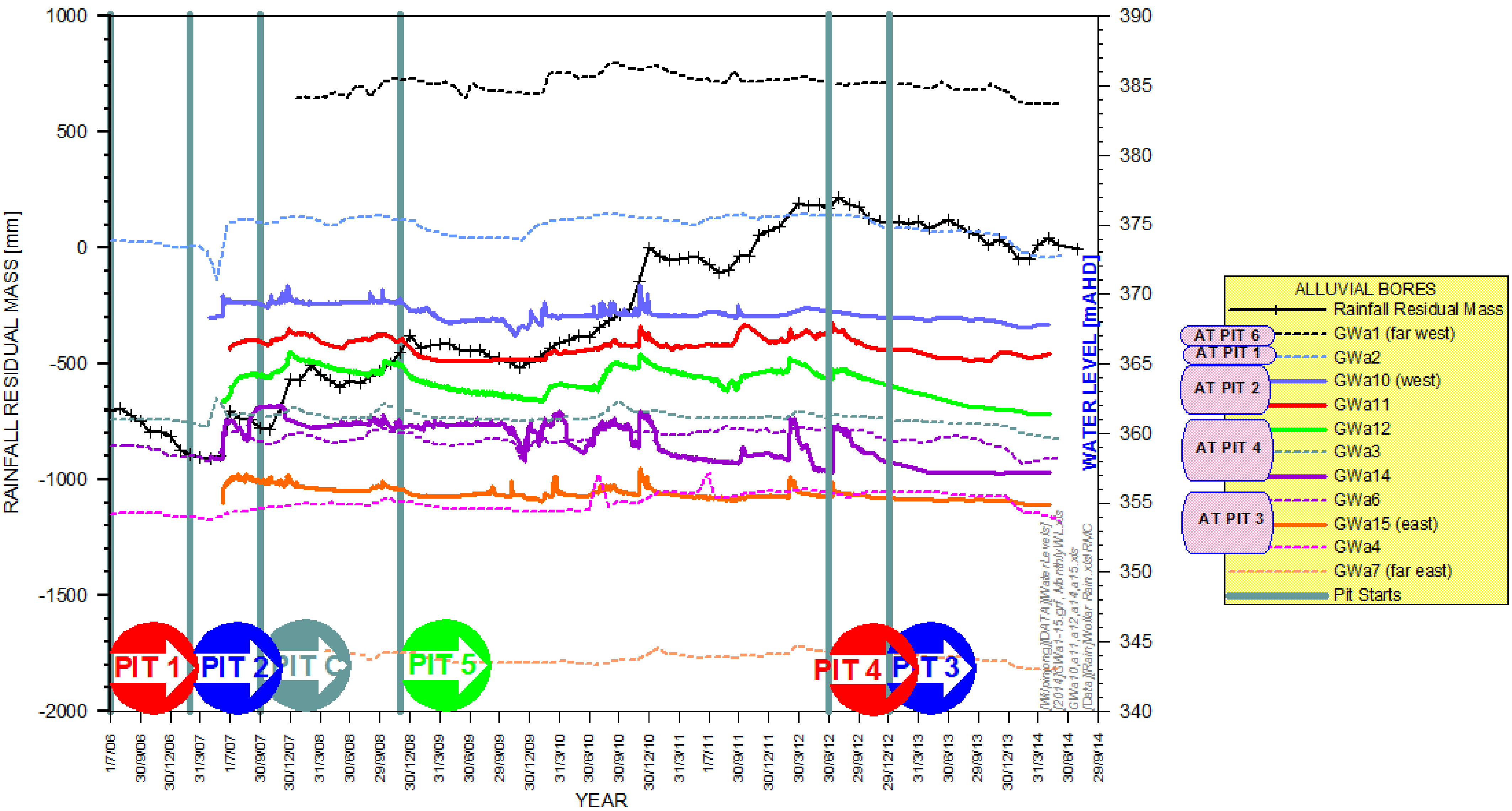


Figure C-2. Transition in Alluvial Bore Groundwater Levels from West to East along Wilpinjong Creek

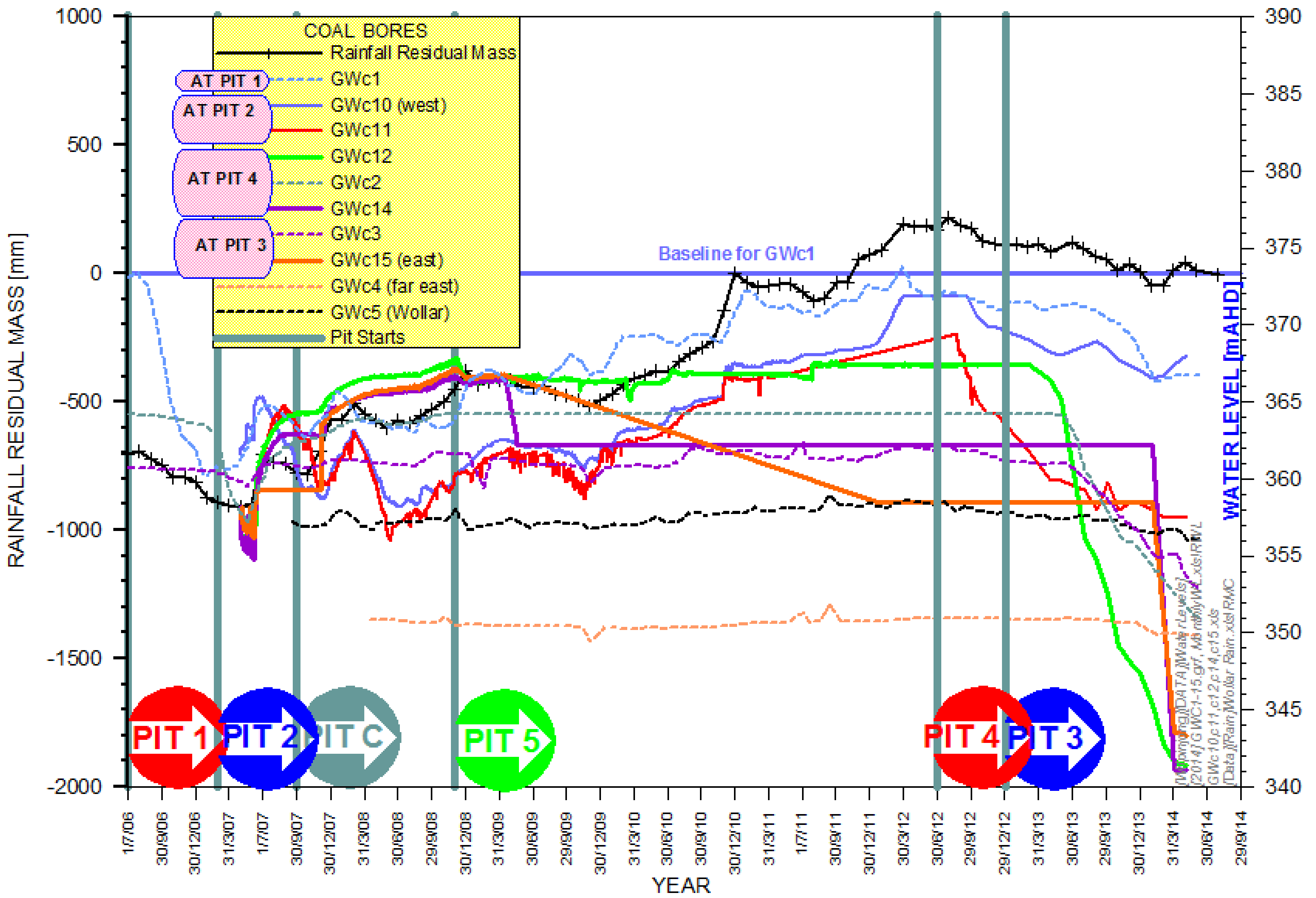


Figure C-3. Transition in Coal Bore Groundwater Levels from West to East along Wilpinjong Creek

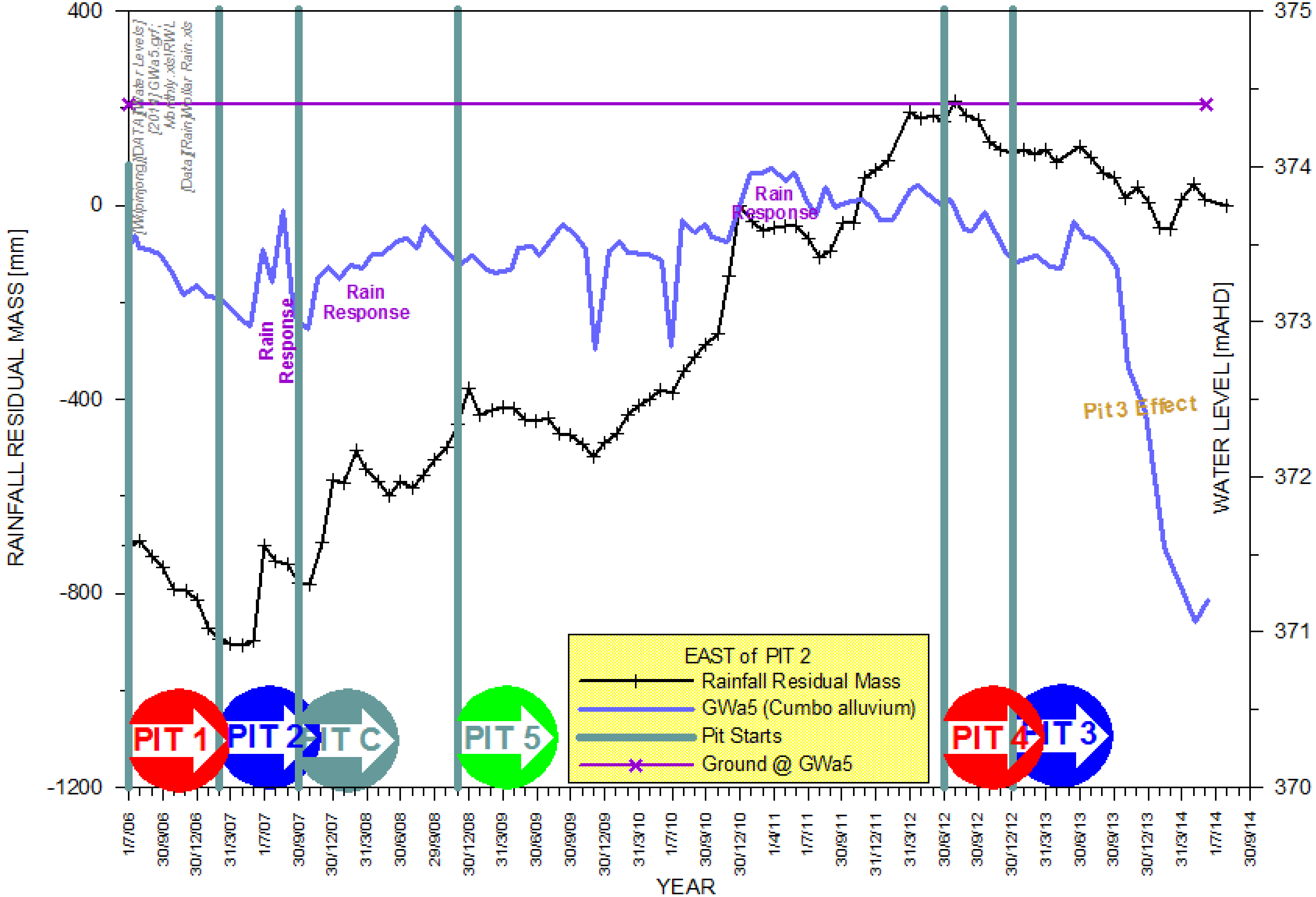


Figure C-4. Alluvial Groundwater Hydrograph at GWa5 between Pit 2 and Pit 3, adjacent to Cumbo Creek

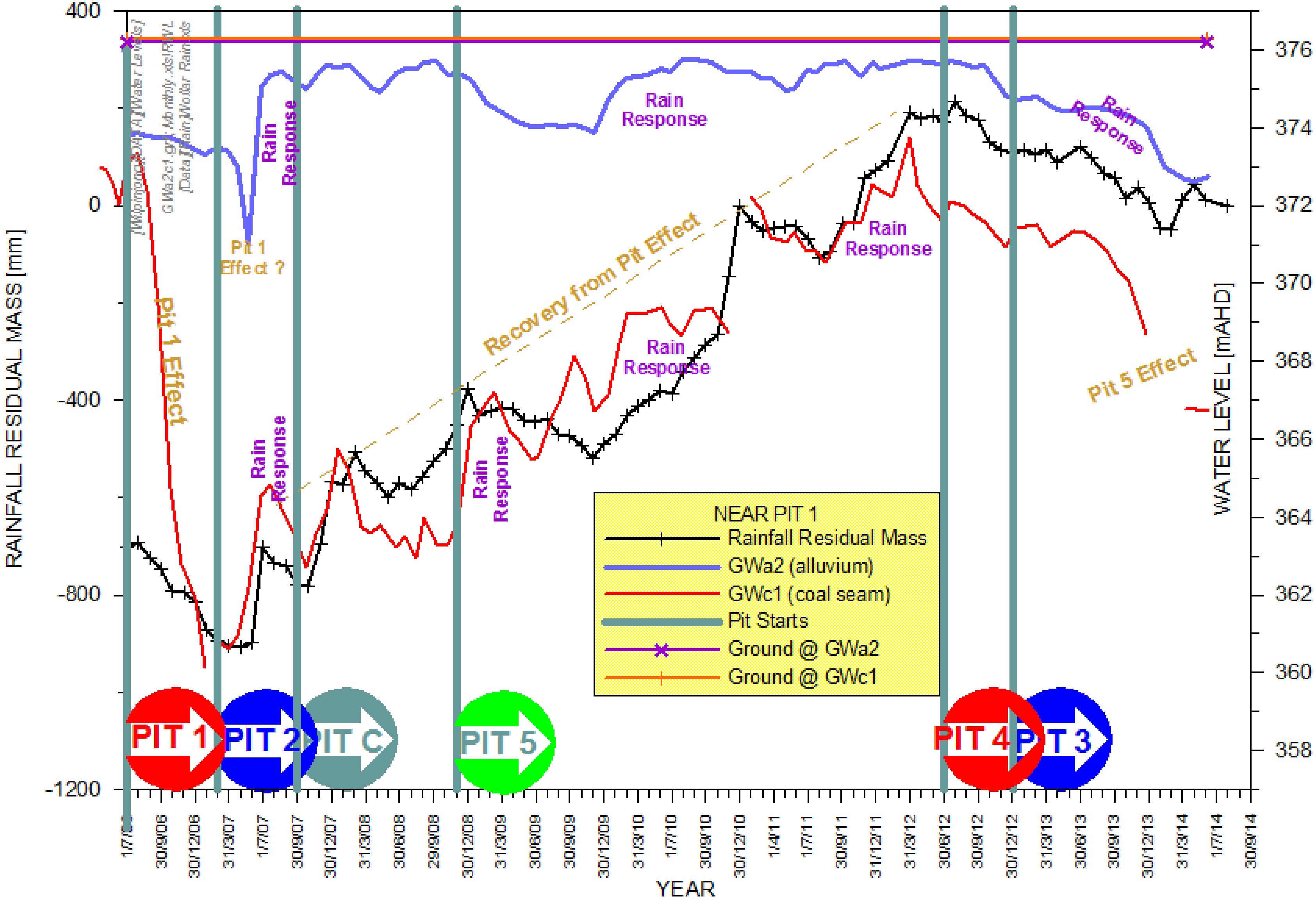


Figure C-5. Groundwater Hydrographs at GWa2 and GWc1 at 0.3 km North-West of Pit 1

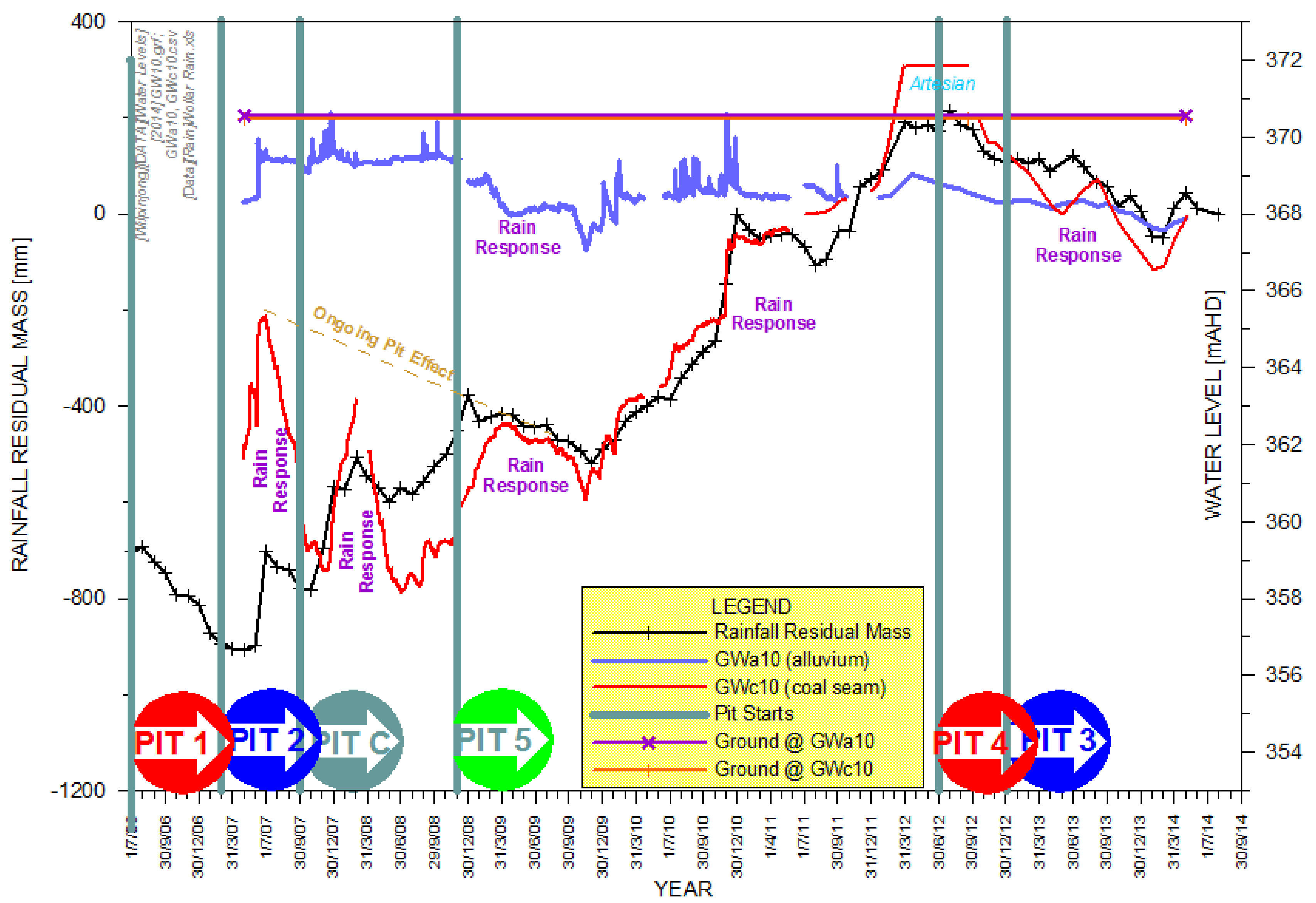


Figure C-6. Groundwater Hydrographs at GWa10 and GWc10 at 0.3 km North-East of Pit 1

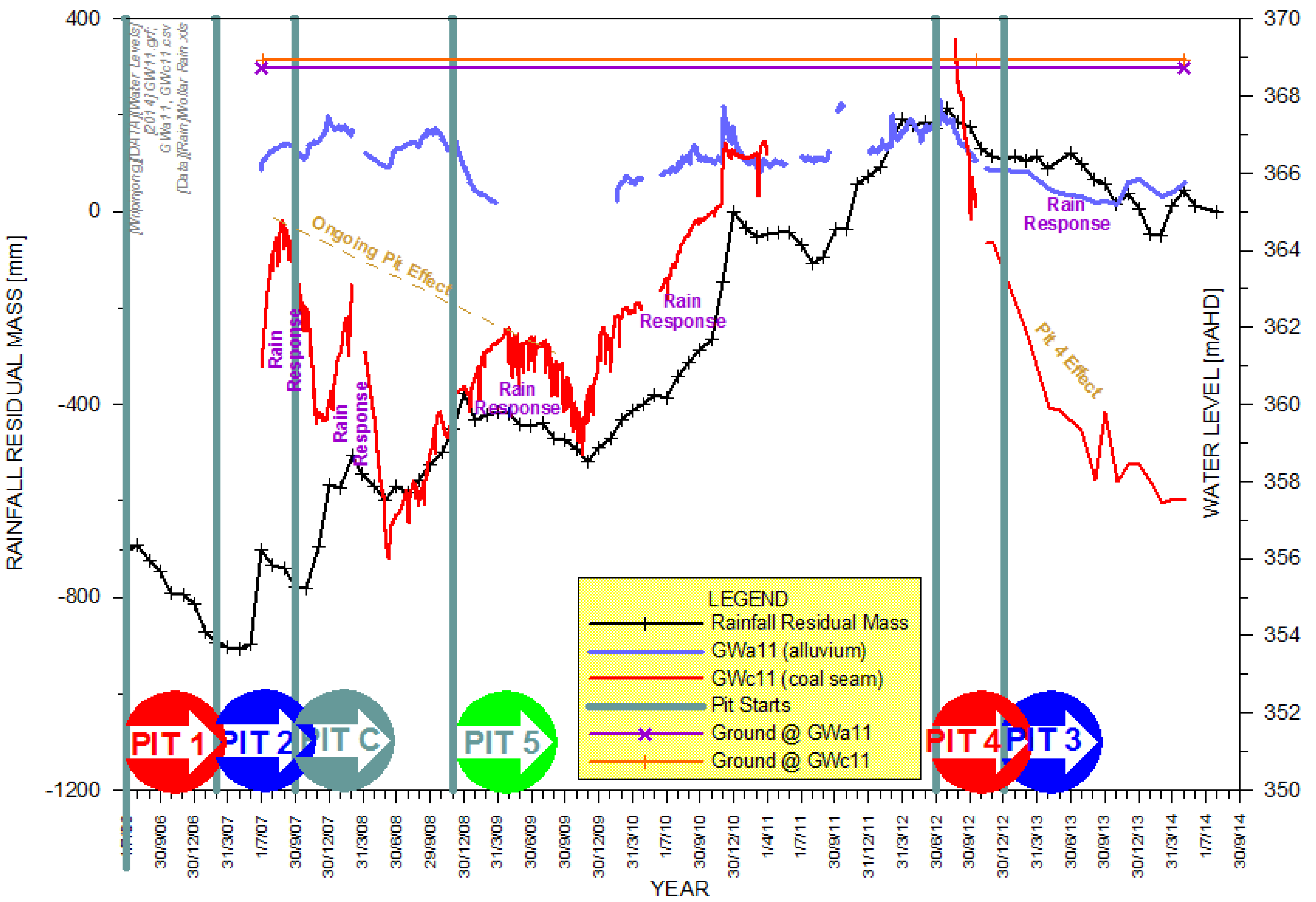


Figure C-7. Groundwater Hydrographs at GWa11 and GWc11 at 0.3 km North of Pit 2

Appendix C: Groundwater Level Hydrographs

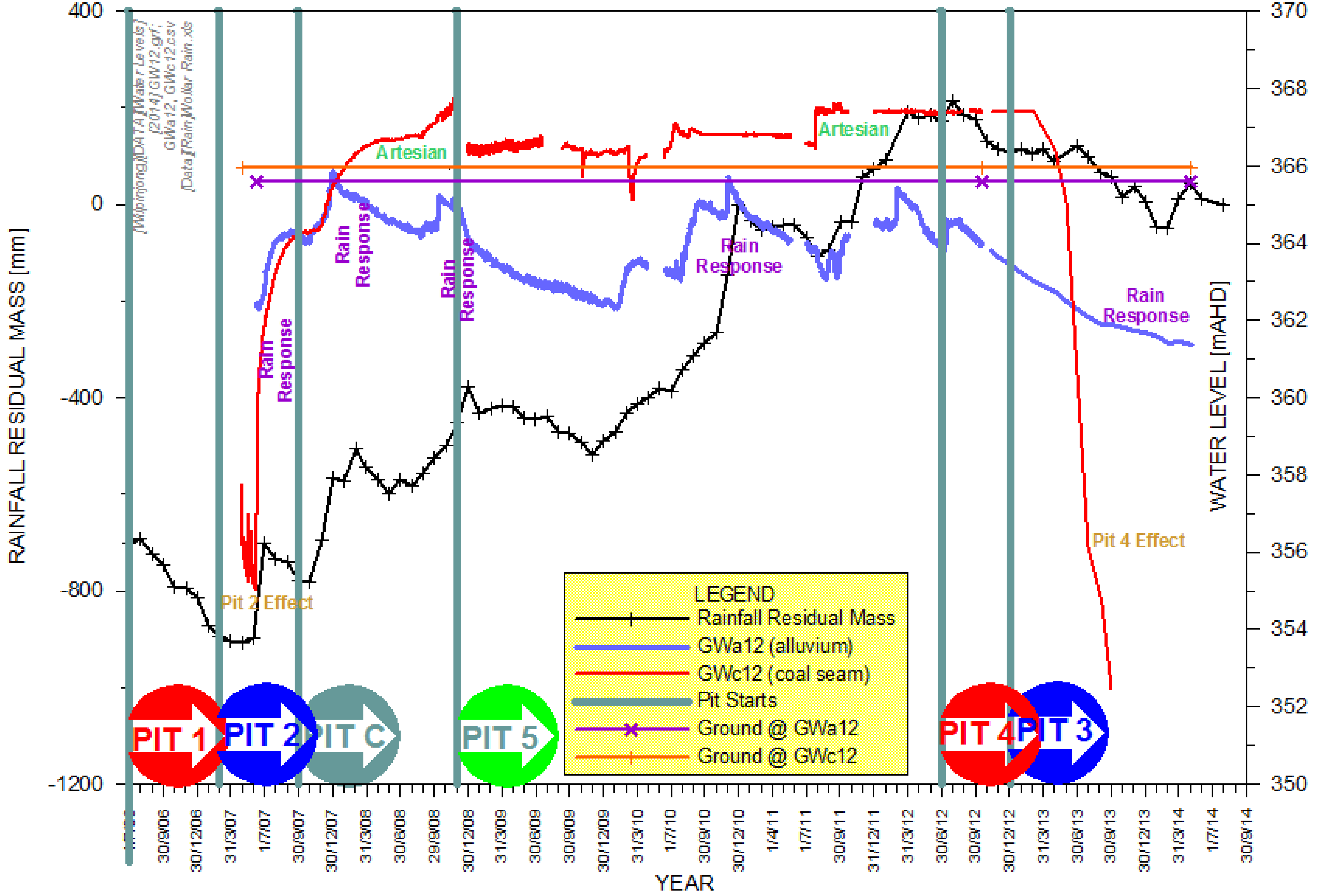


Figure C-8. Groundwater Hydrographs at GWa12 and GWc12 at 0.5 km North of Pit 4

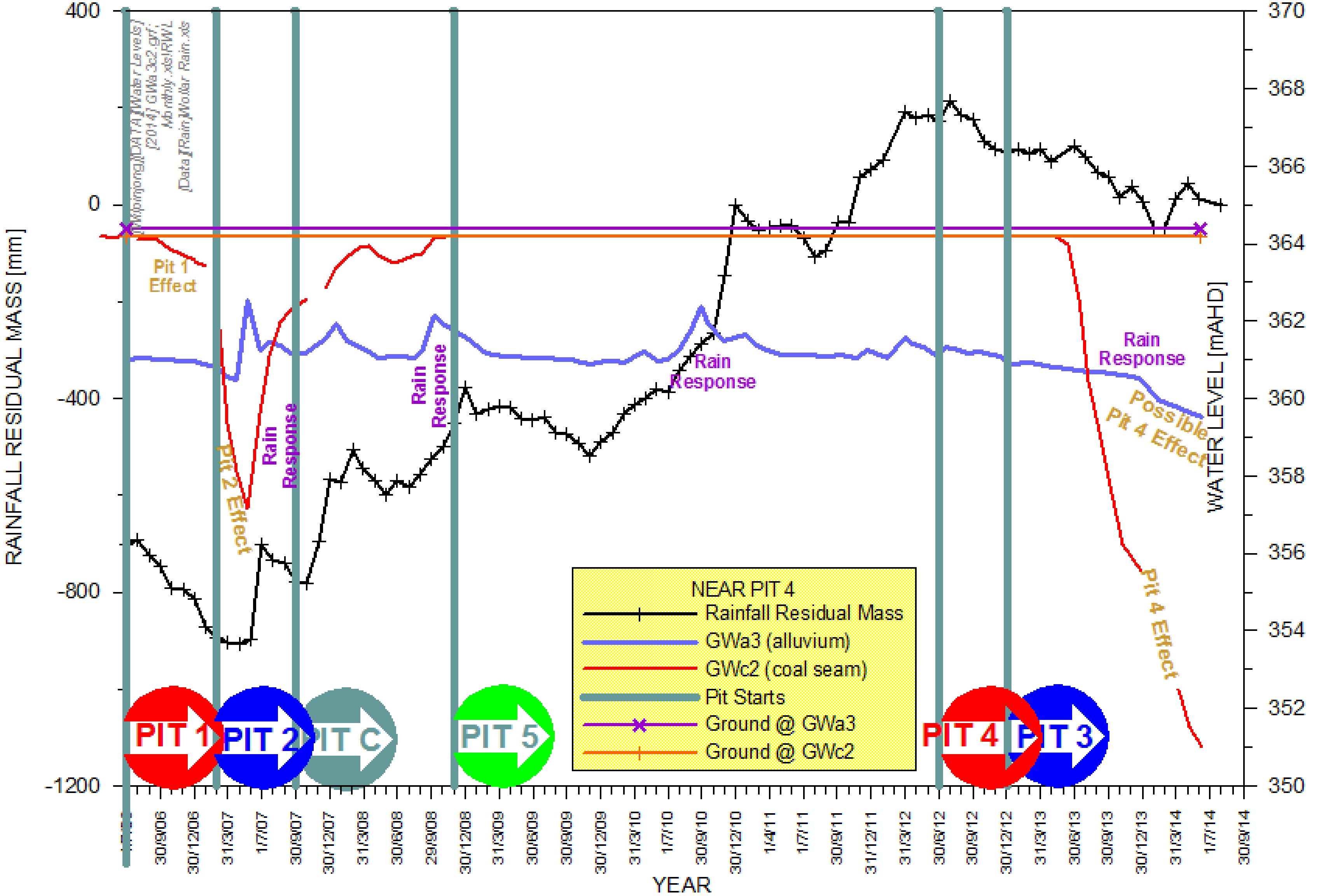


Figure C-9. Groundwater Hydrographs at GWa3 and GWc2 at 0.45 km North of Pit 4

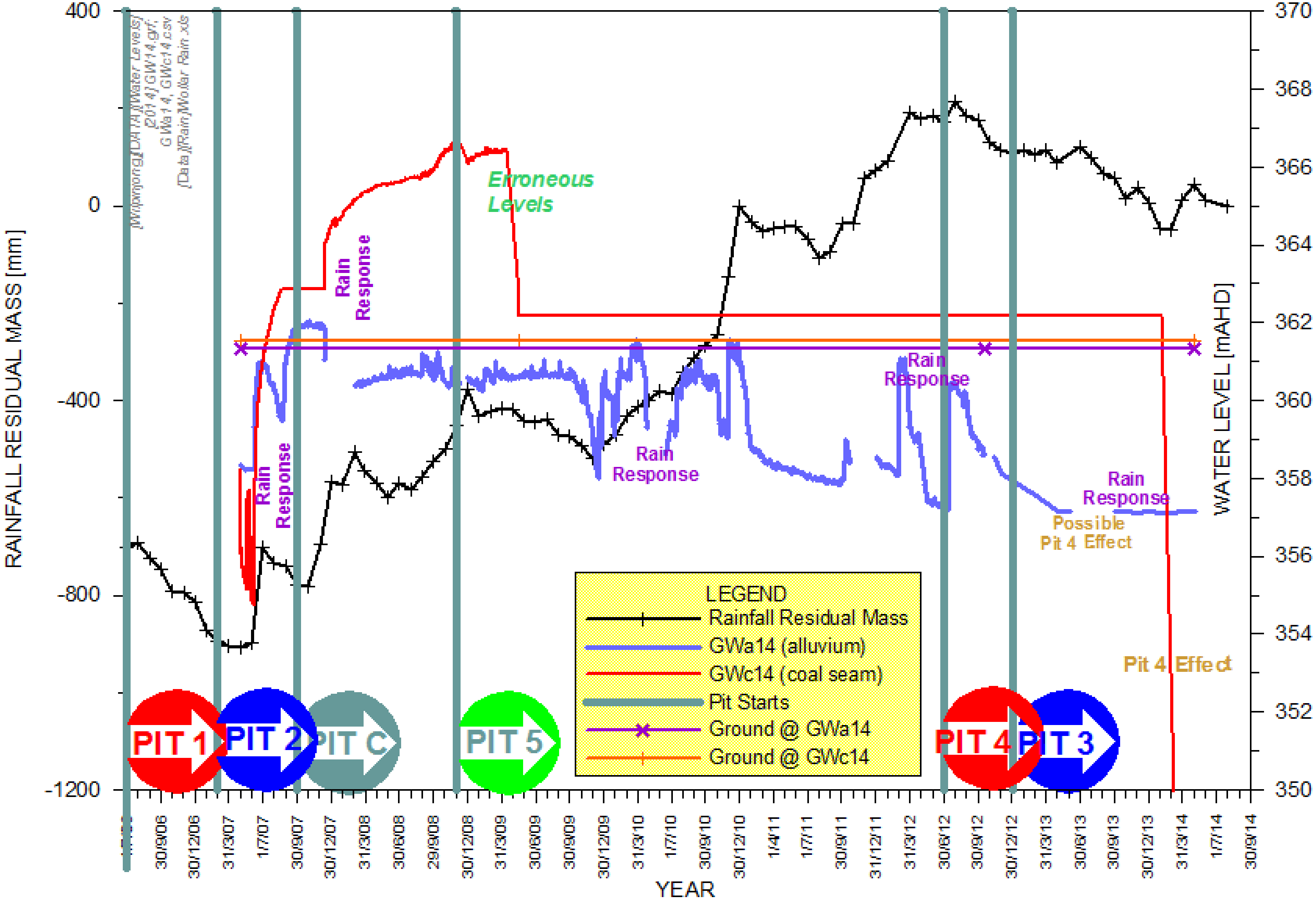


Figure C-10. Groundwater Hydrographs at GWa14 and GWc14 at 0.3 km North of Pit 4

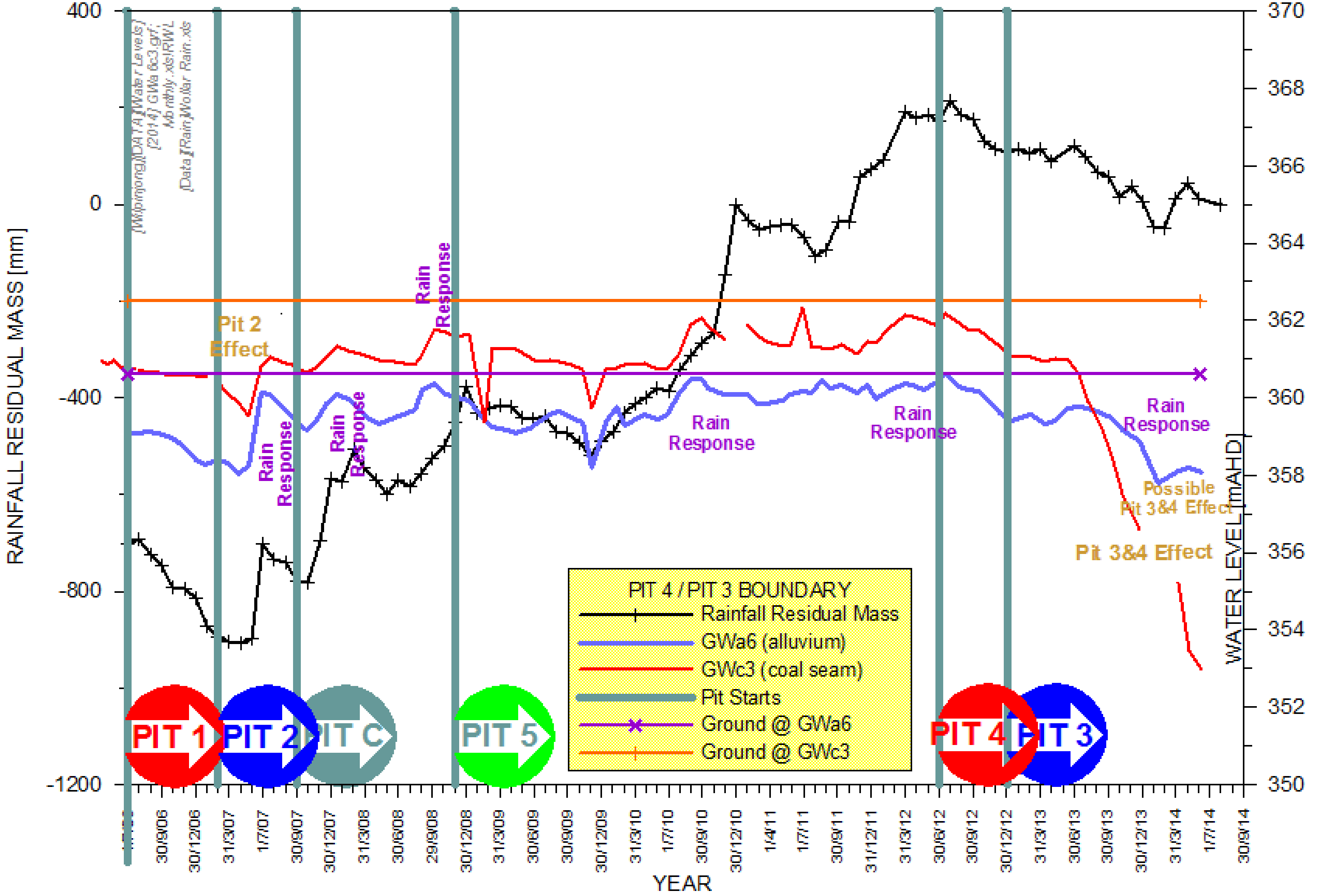


Figure C-11. Groundwater Hydrographs at GWa6 and GWc3 at Northern Junction of Pits 3 and 4, adjacent to Cumbo Creek

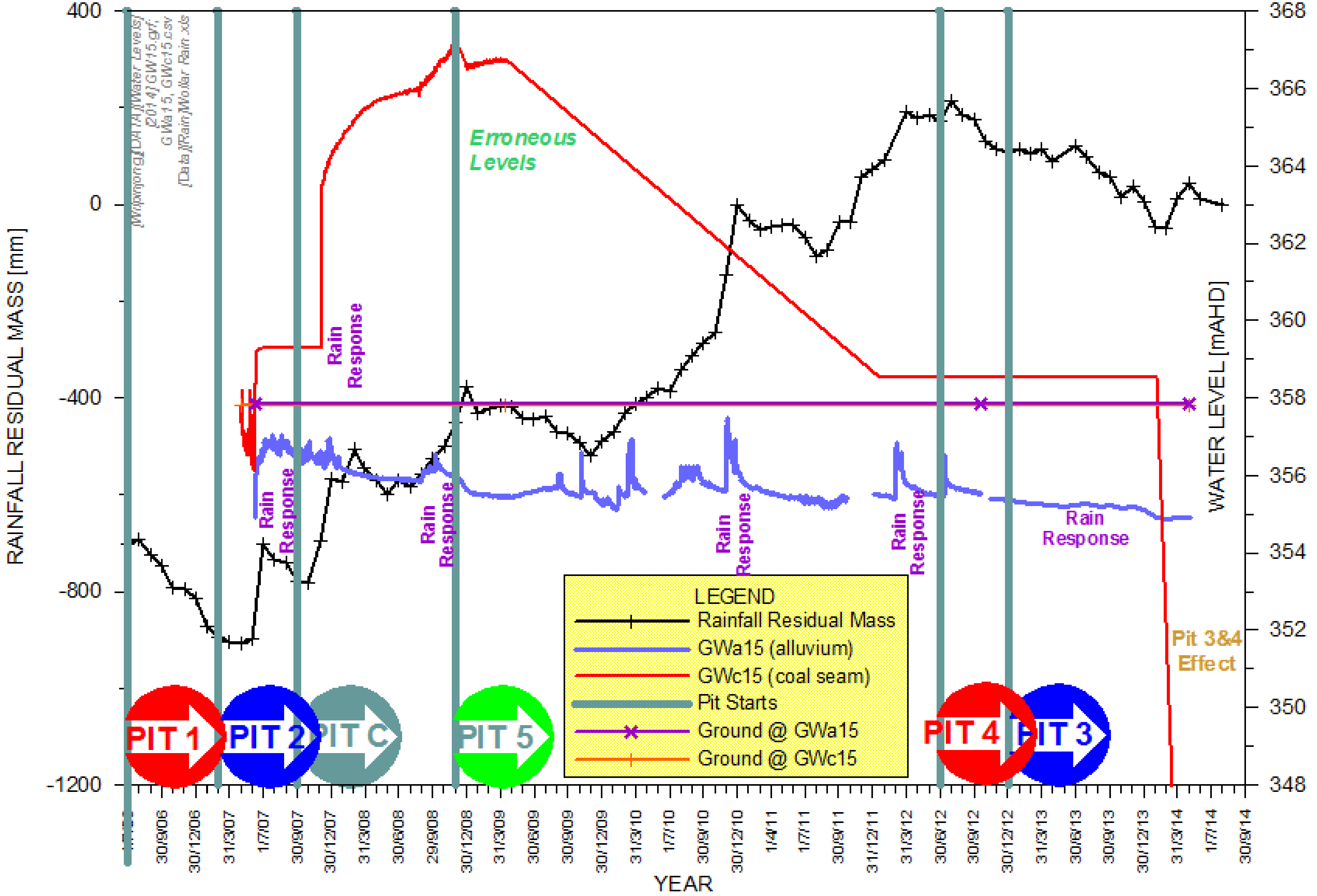


Figure C-12. Groundwater Hydrographs at GWa15 and GWc15 at 0.2 km North of Pit 3

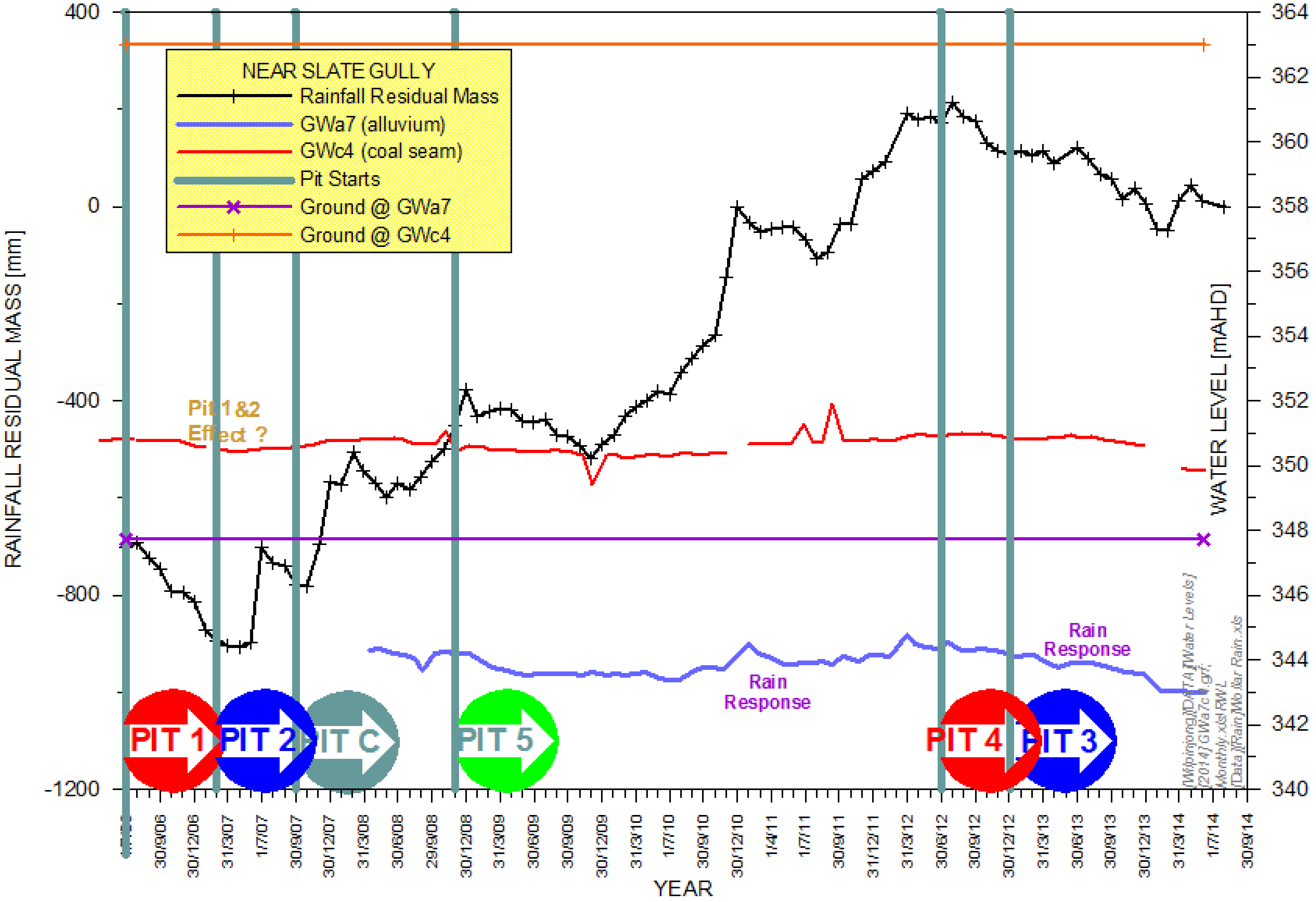


Figure C-13. Groundwater Hydrographs at GWa7 and GWc4 near the Confluence of Wilpinjong Creek and Wollar Creek

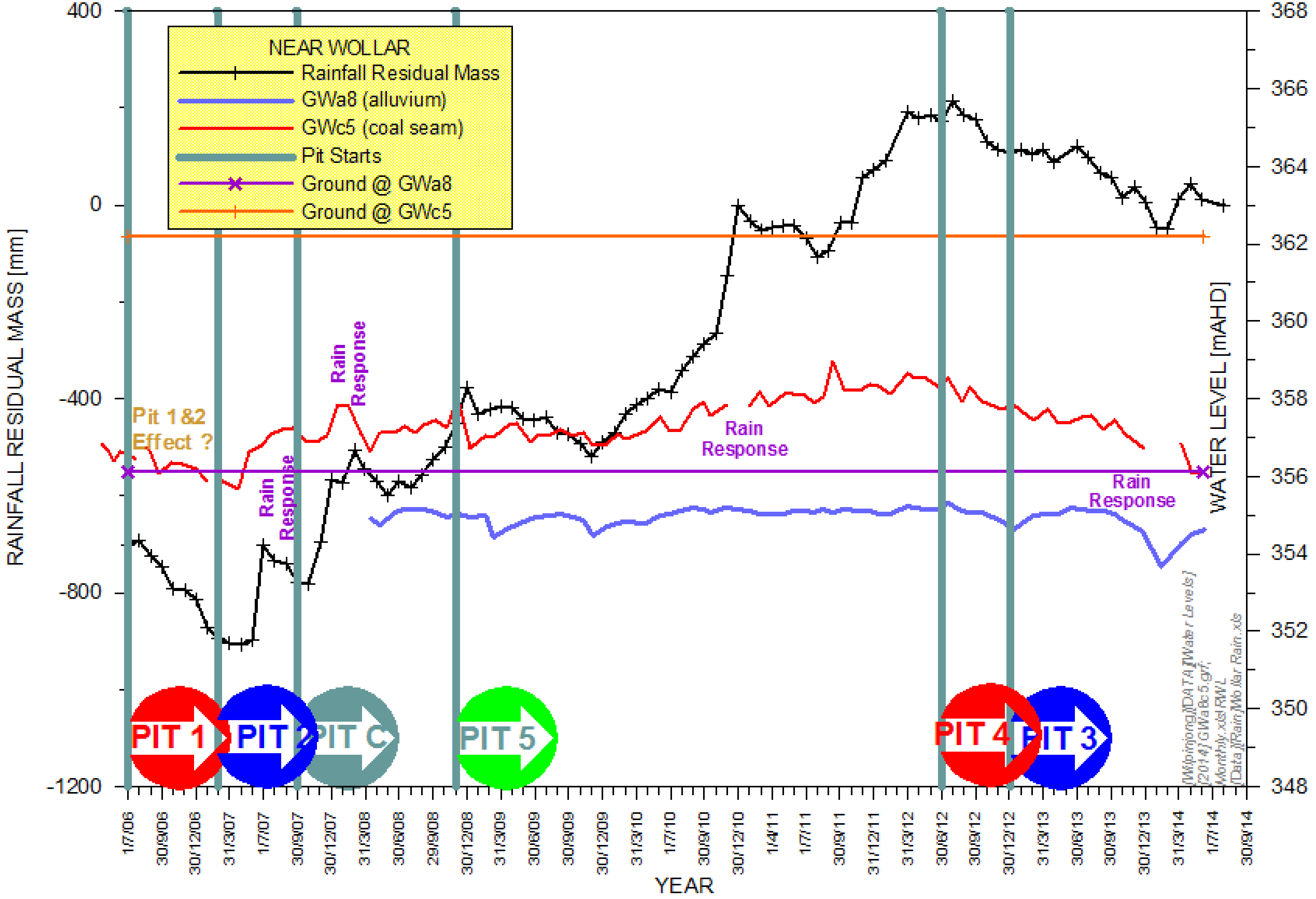
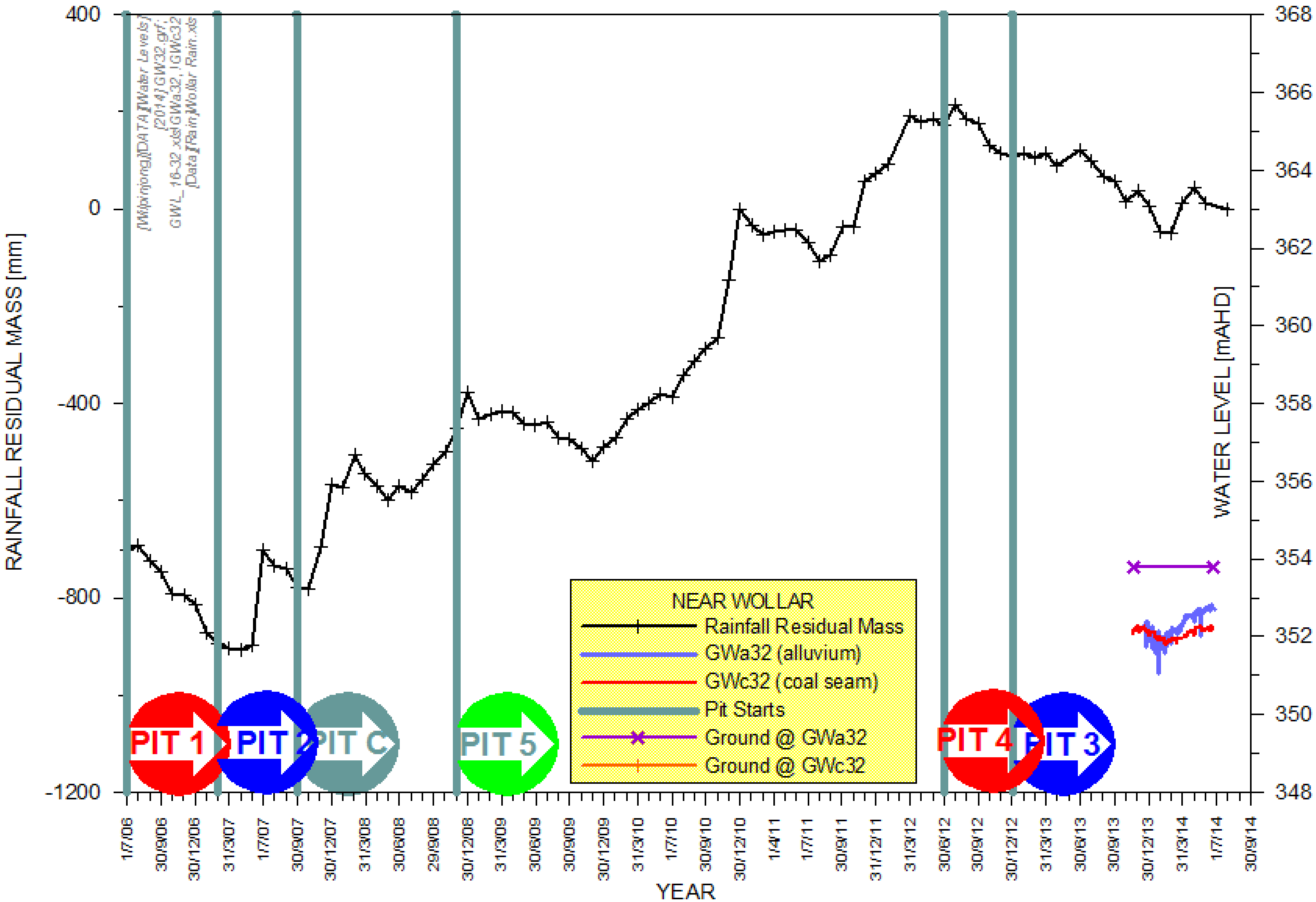


Figure C-14. Groundwater Hydrographs at GWa8 and GWc5 near Wollar



FigureC-15. Groundwater Hydrographs at GWa32 and GWc32 adjacent to Wollar Creek

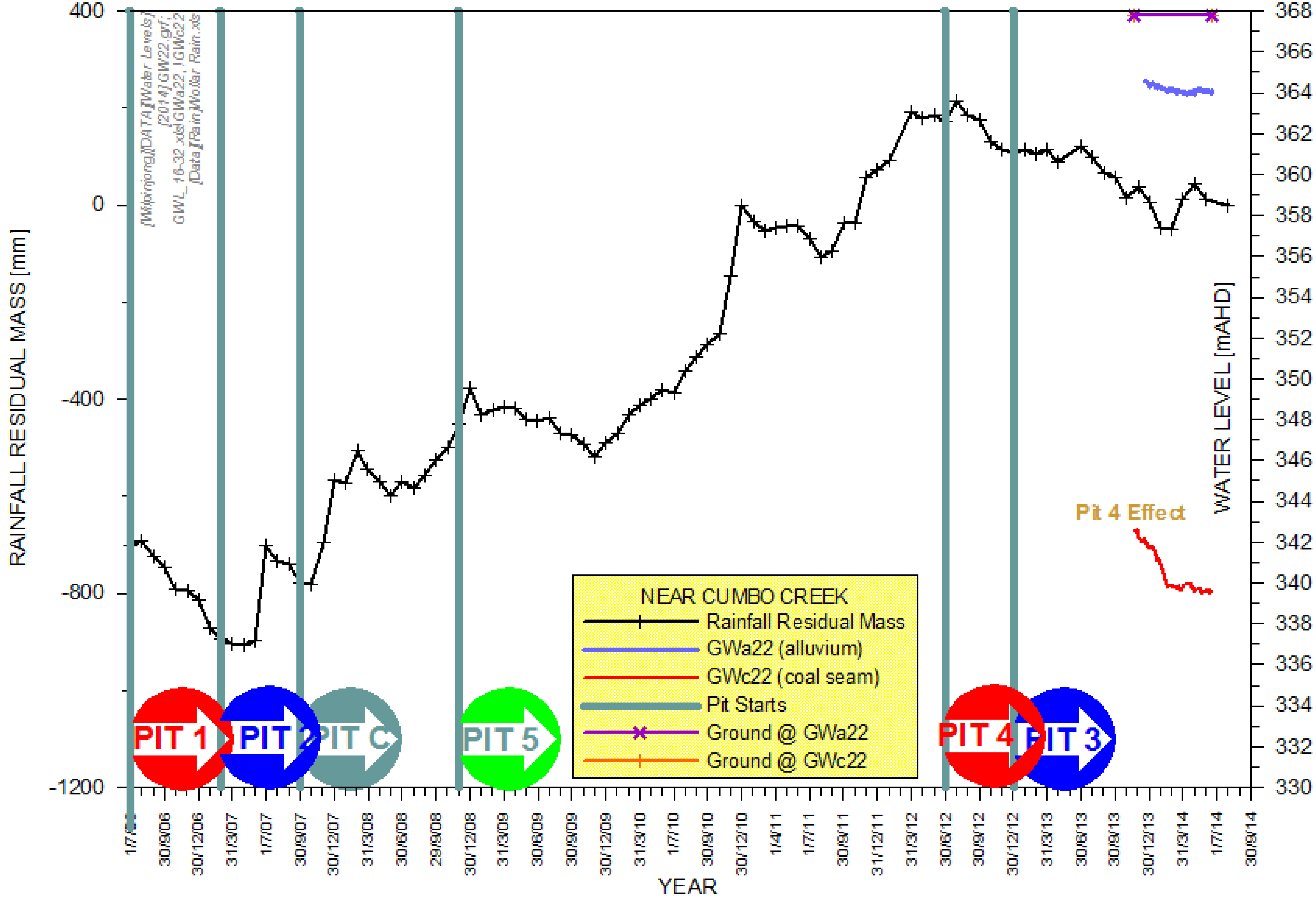


Figure C-16. Groundwater Hydrographs at GWa22 and GWc22 adjacent to Cumbo Creek

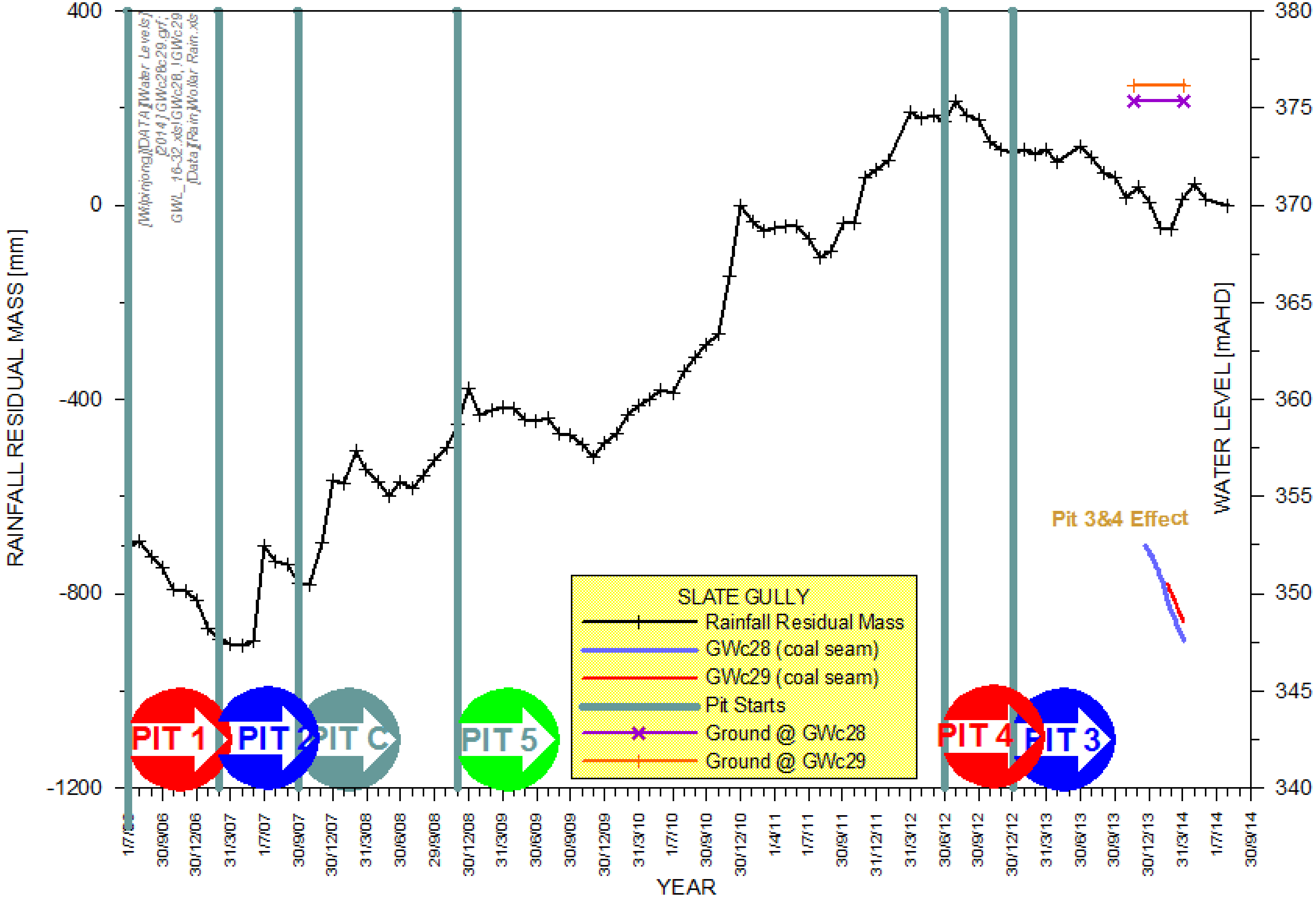


Figure C-17. Groundwater Hydrographs at GWc28 and GWc29 in Slate Gully

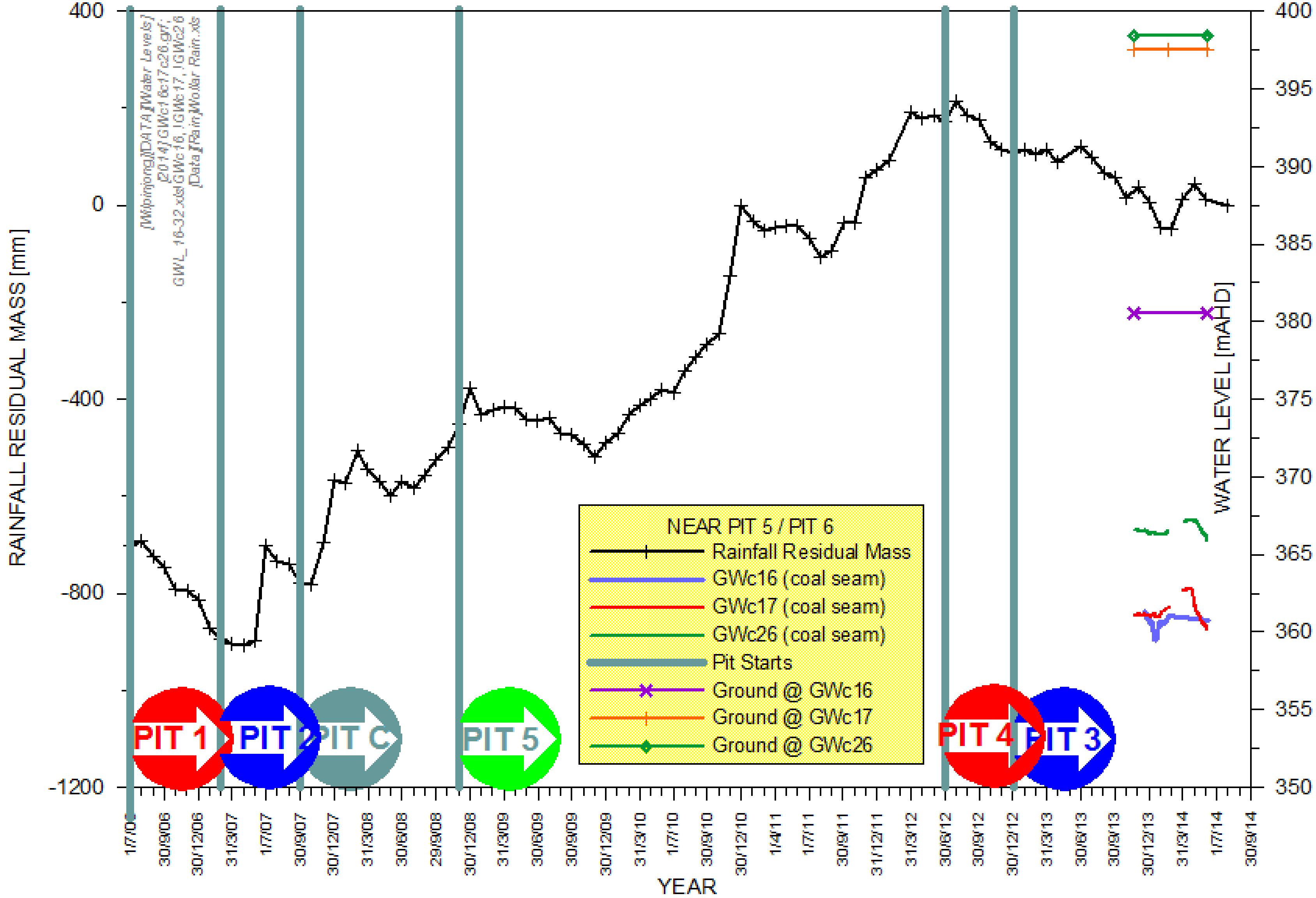


Figure C-18. Groundwater Hydrographs at GWc16, GWc17 and GWc26 at Pit 6 and North of Pit 5

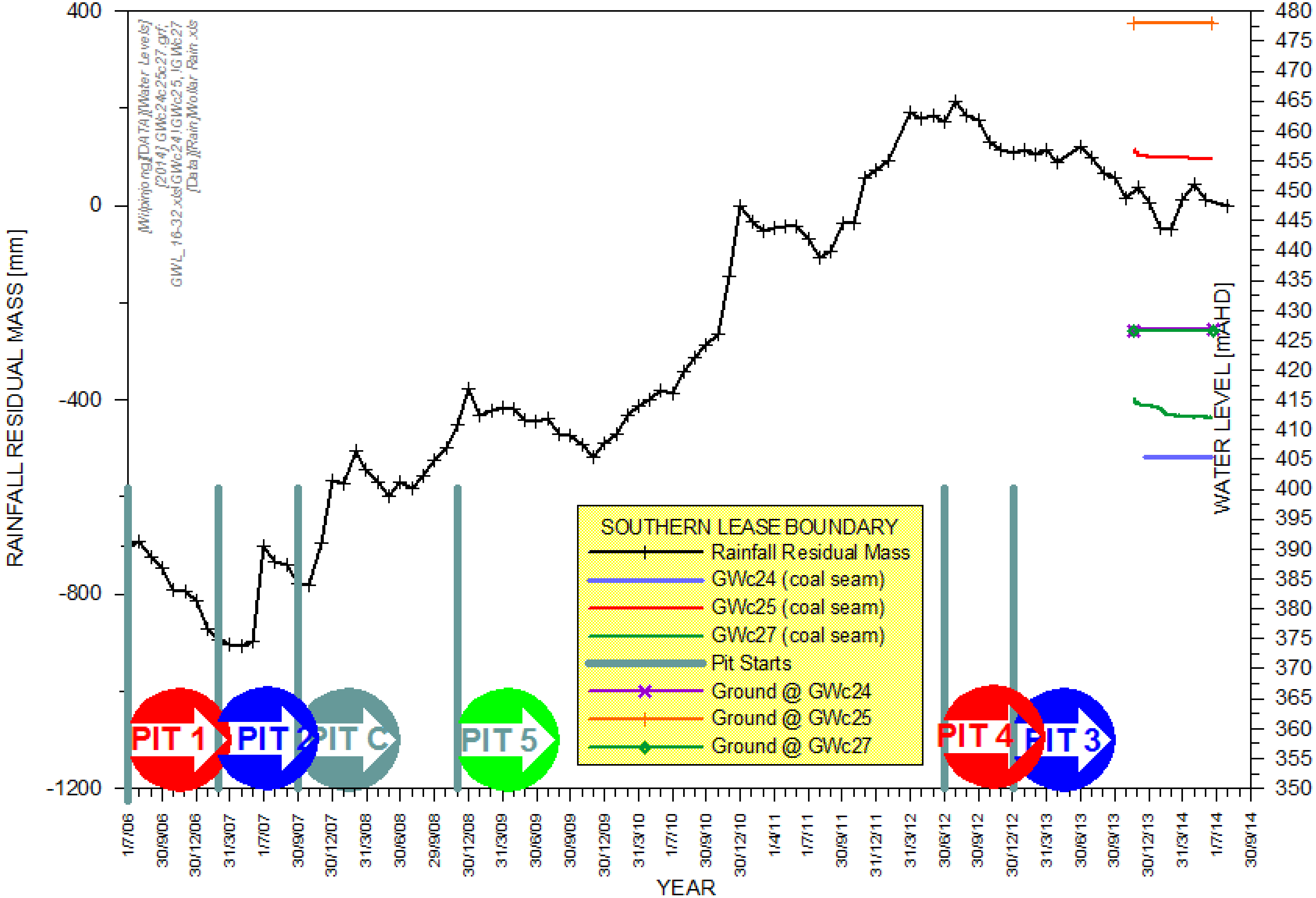


Figure C-19. Groundwater Hydrographs at GWc24, GWc25 and GWc27 at the Southern Lease Boundary

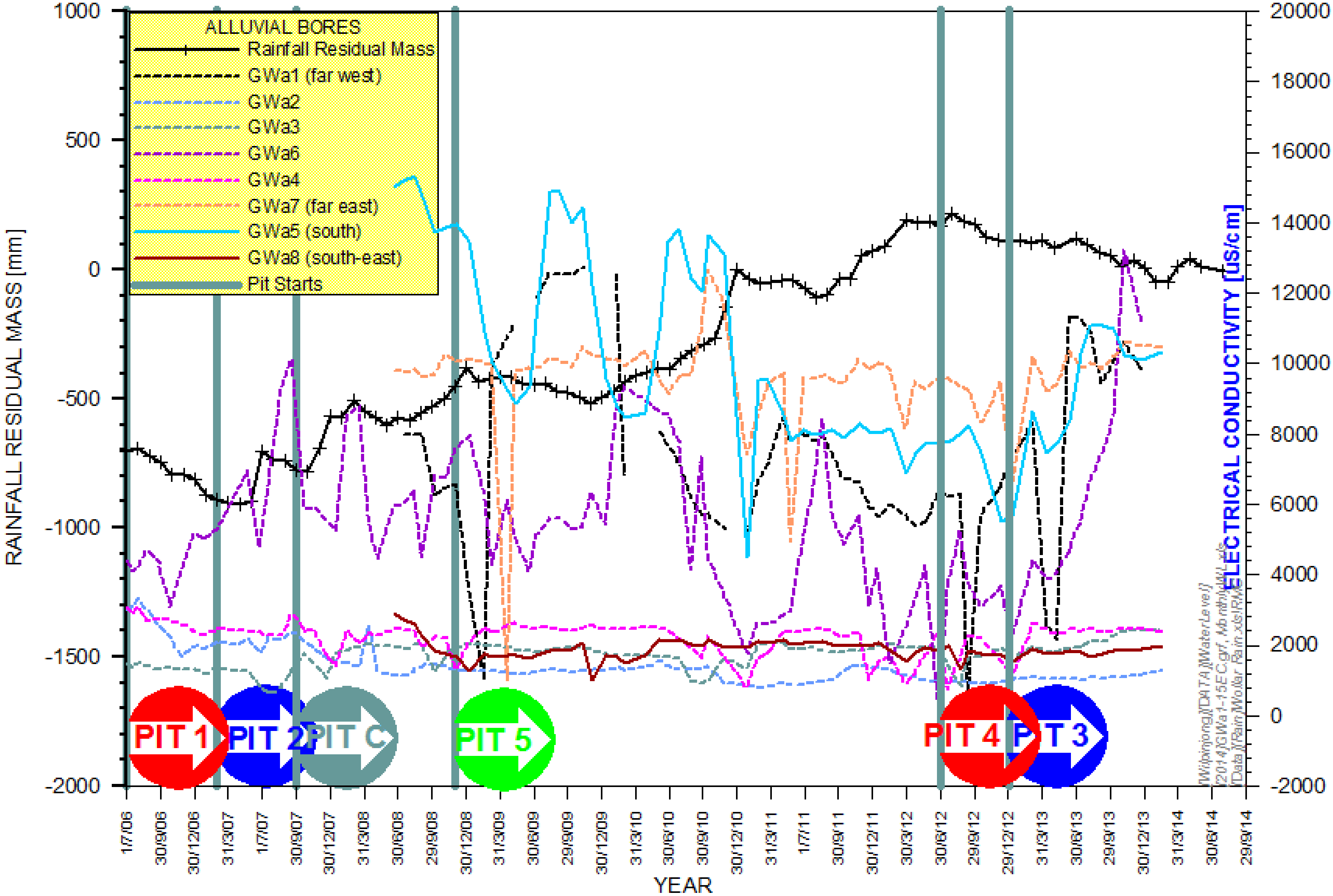


Figure C-20. Electrical Conductivity Temporal Variations in Alluvium (µS/cm)

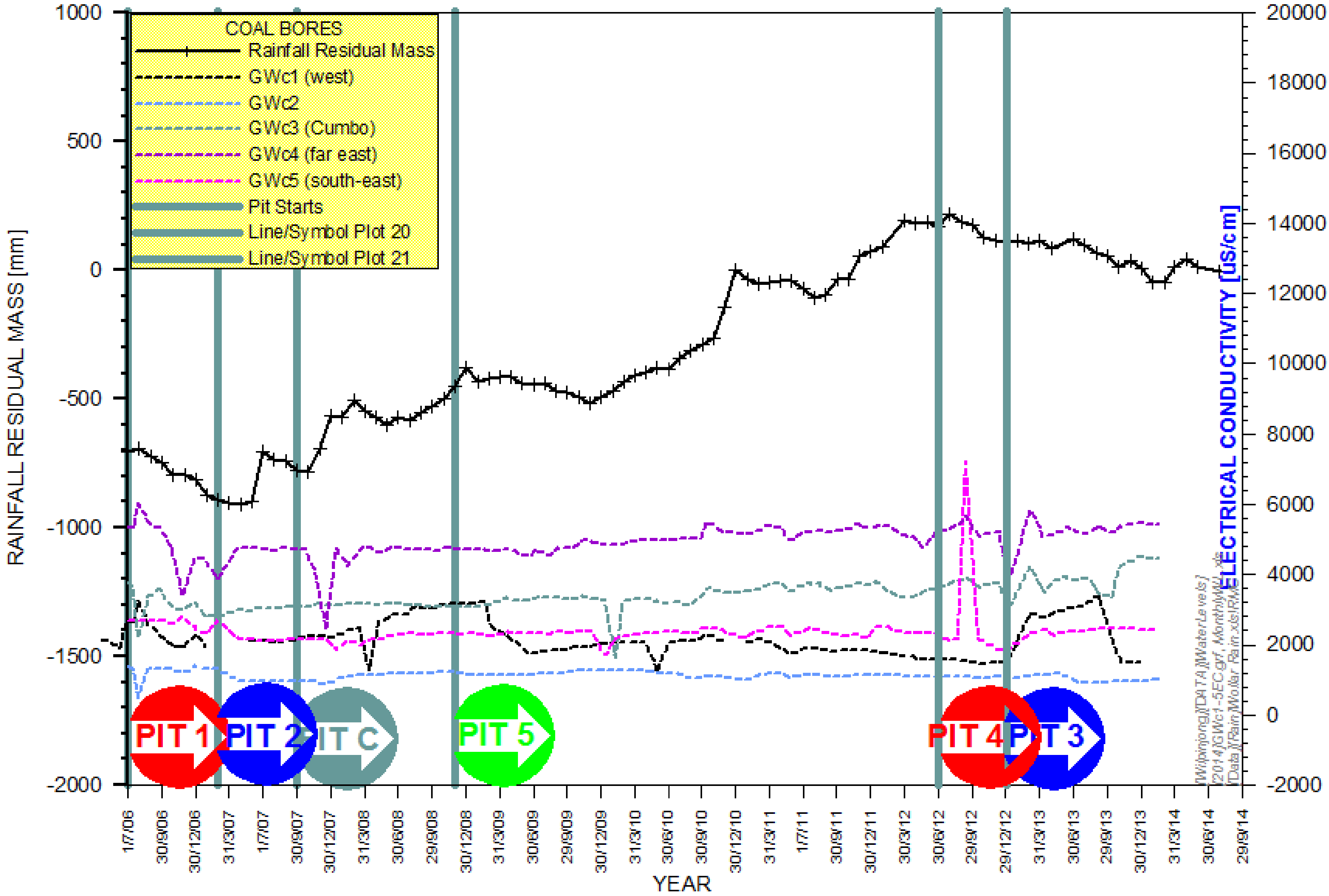
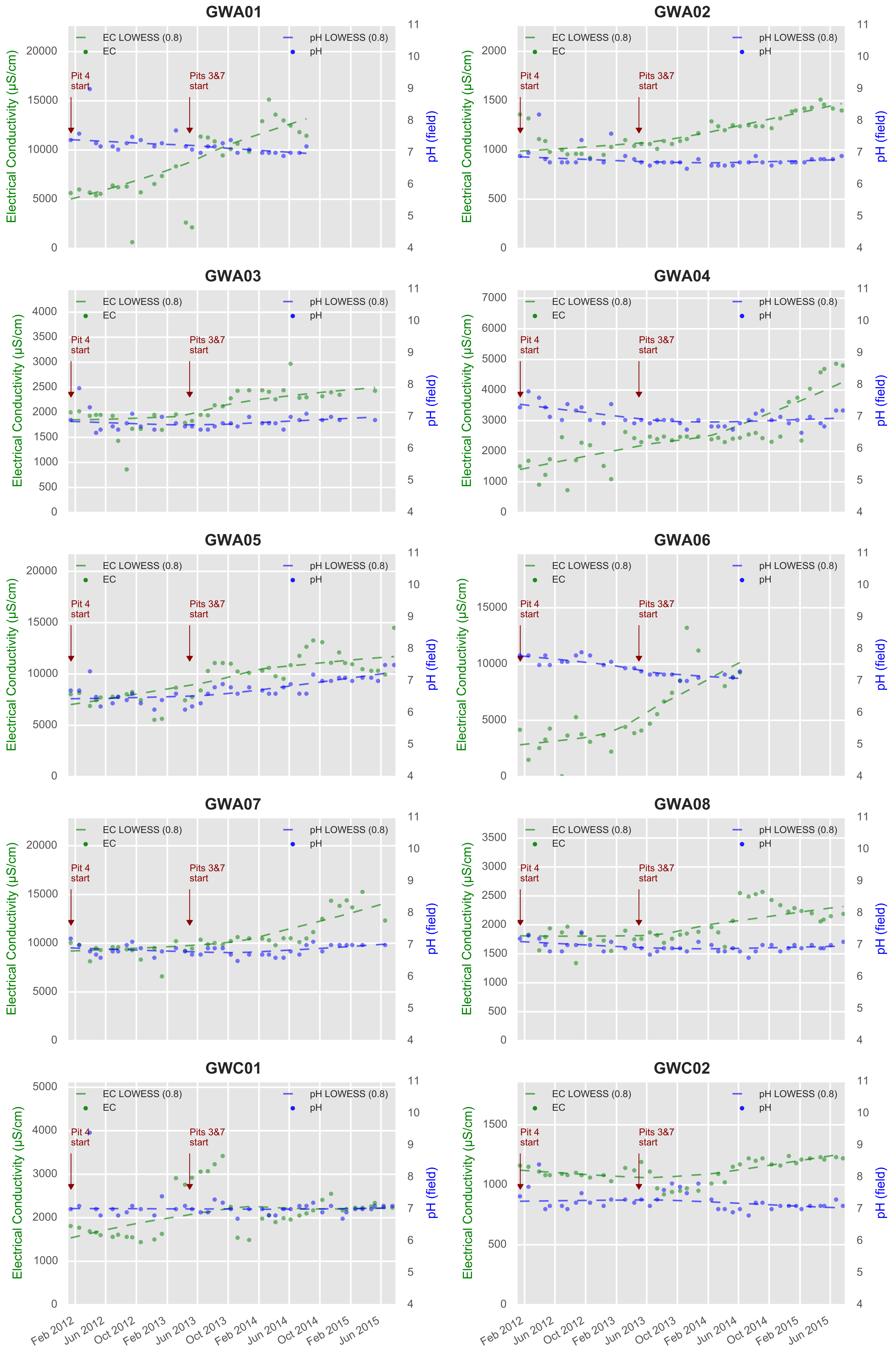
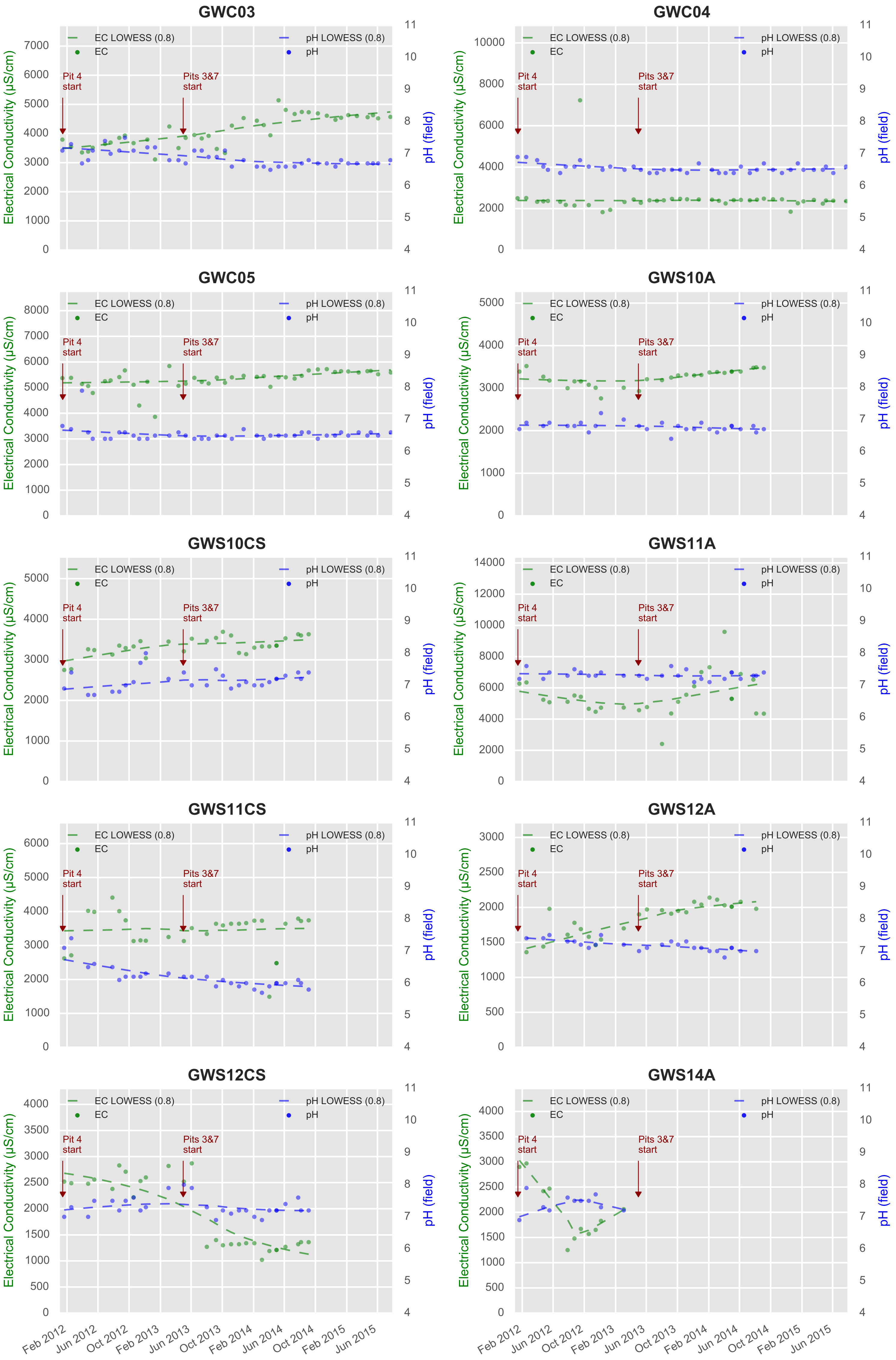


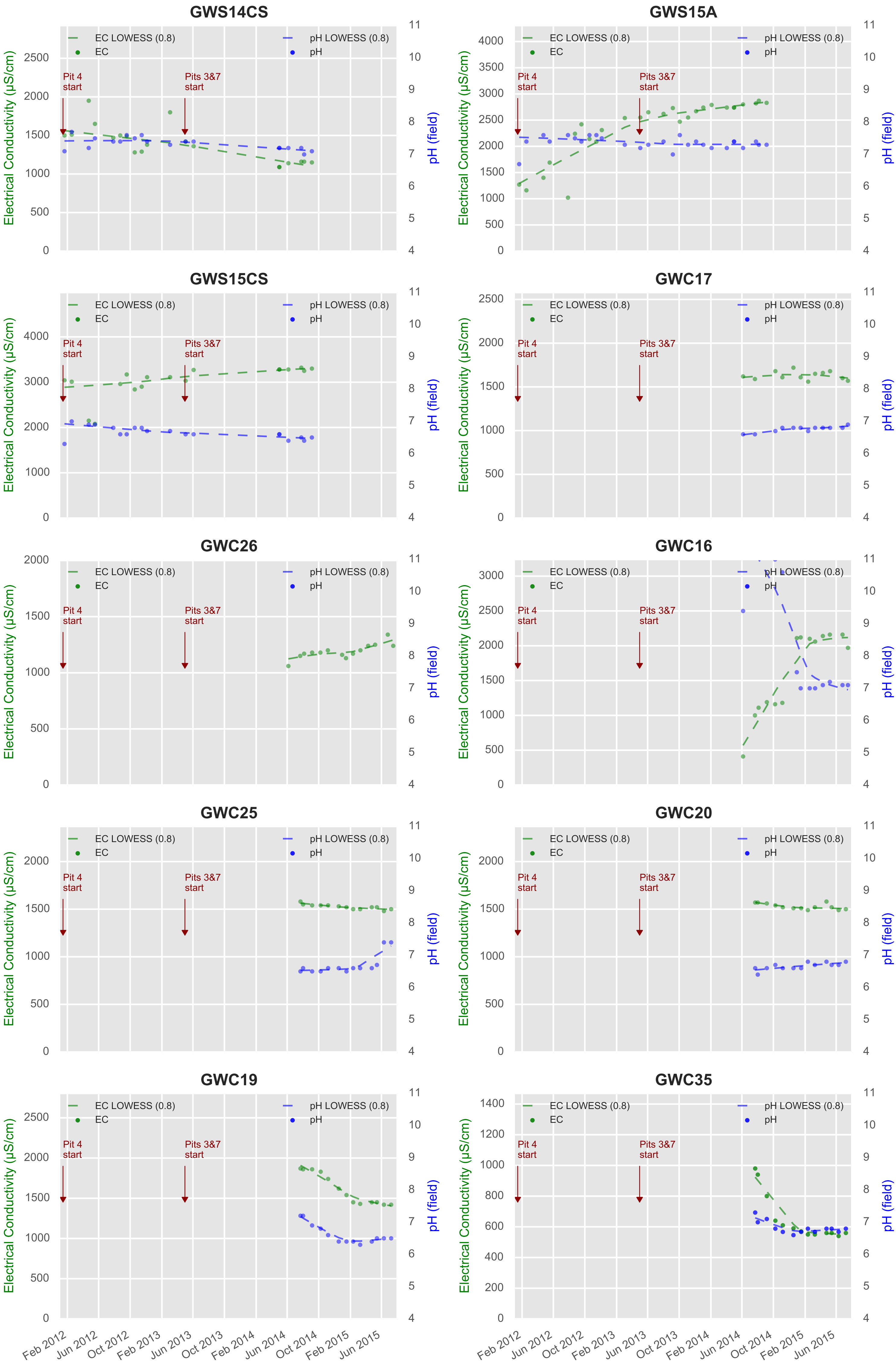
Figure C-21. Electrical Conductivity Temporal Variations in Coal (µS/cm)

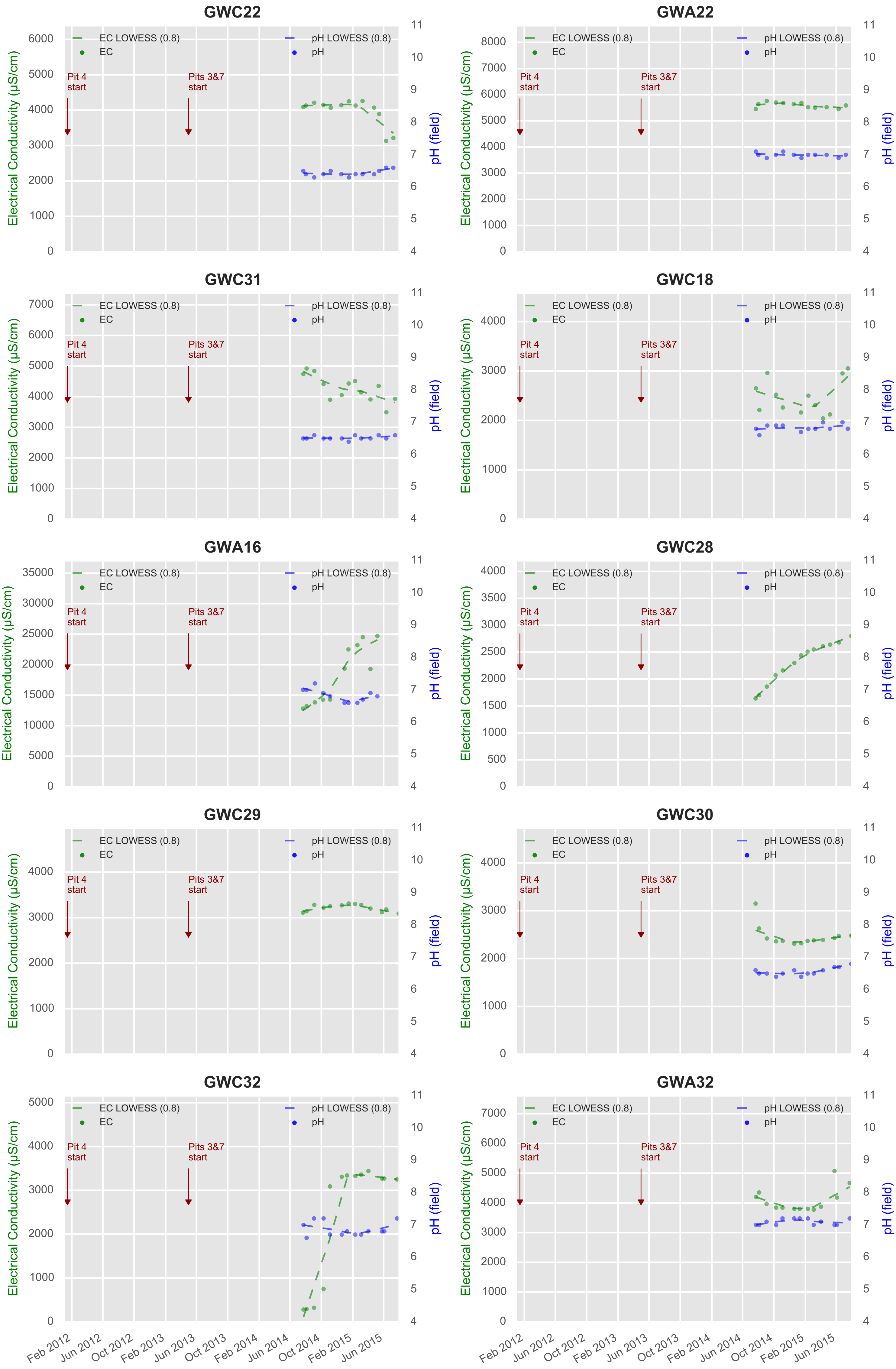
APPENDIX D – GROUNDWATER QUALITY

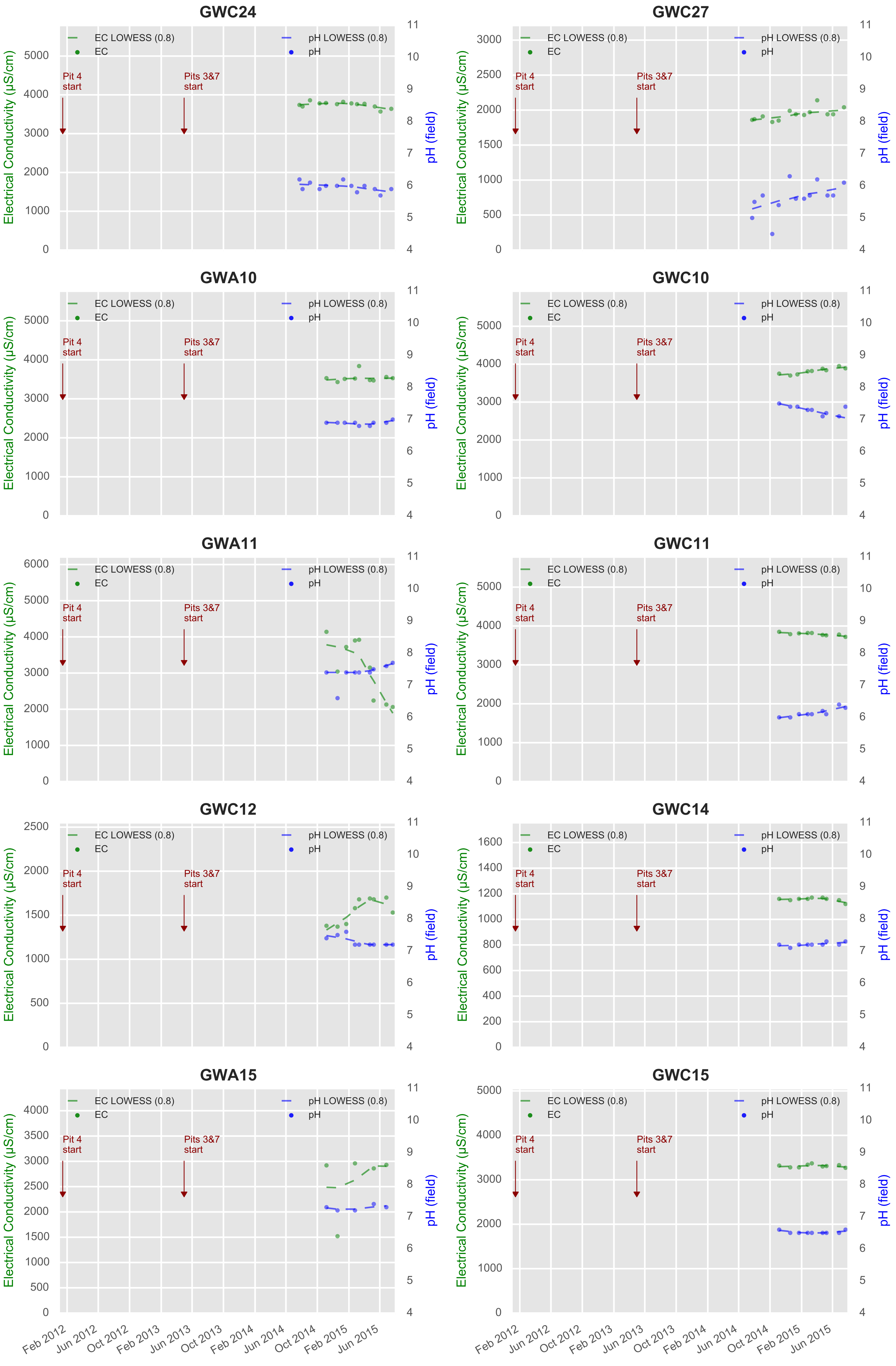
Time series Plots of Groundwater pH and Electrical Conductivity (EC)


GWA01
GWA02
GWA03
GWA04
GWA05
GWA06
GWA07
GWA08
GWC01
GWC02
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
Feb 2012
Jun 2012
Oct 2012
Feb 2013
Jun 2013
Oct 2013
Feb 2014
Jun 2014
Oct 2014
Feb 2015
Jun 2015

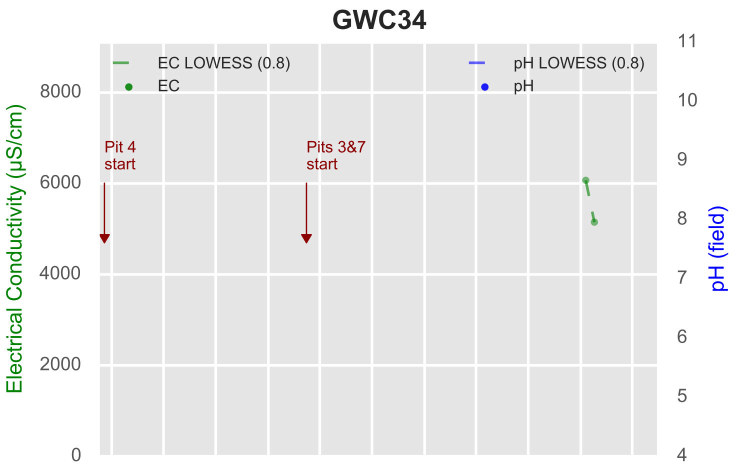

GWC03
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWC04
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWC05
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS10A
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS10CS
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS11A
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS11CS
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS12A
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS12CS
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
GWS14A
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
Feb 2012
Jun 2012
Oct 2012
Feb 2013
Jun 2013
Oct 2013
Feb 2014
Jun 2014
Oct 2014
Feb 2015
Jun 2015

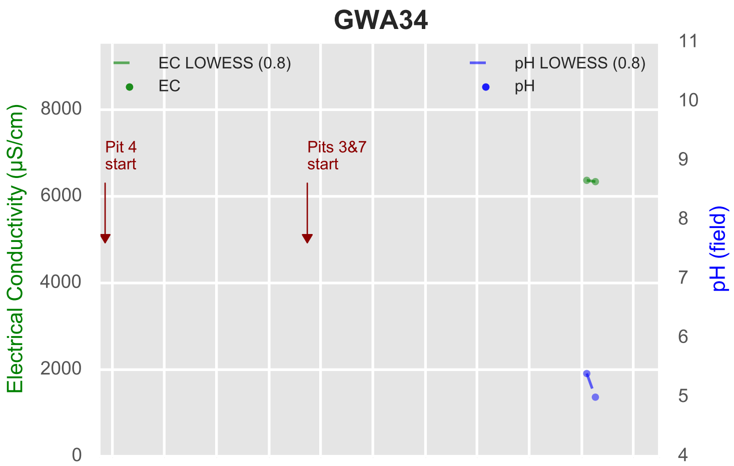

GWS14CS
GWS15A
GWS15CS
GWC17
GWC26
GWC16
GWC25
GWC20
GWC19
GWC35
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4
start
Pits 3&7
start
Electrical Conductivity (µS/cm)
pH (field)
Feb 2012
Jun 2012
Oct 2012
Feb 2013
Jun 2013
Oct 2013
Feb 2014
Jun 2014
Oct 2014
Feb 2015
Jun 2015

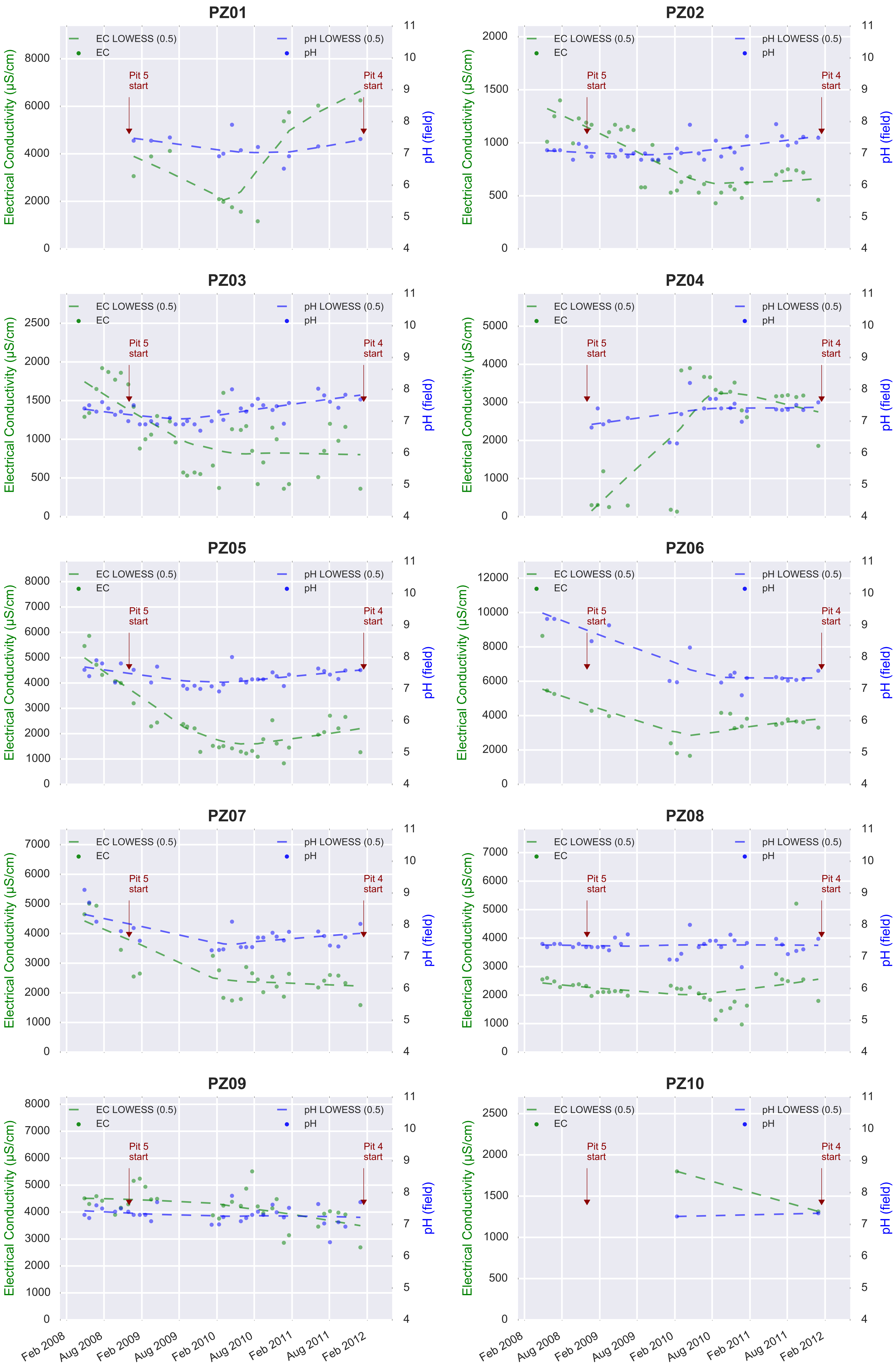

GWC22
GWA22
GWC31
GWC18
GWA16
GWC28
GWC29
GWC30
GWC32
GWA32
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
Feb 2012
Jun 2012
Oct 2012
Feb 2013
Jun 2013
Oct 2013
Feb 2014
Jun 2014
Oct 2014
Feb 2015
Jun 2015

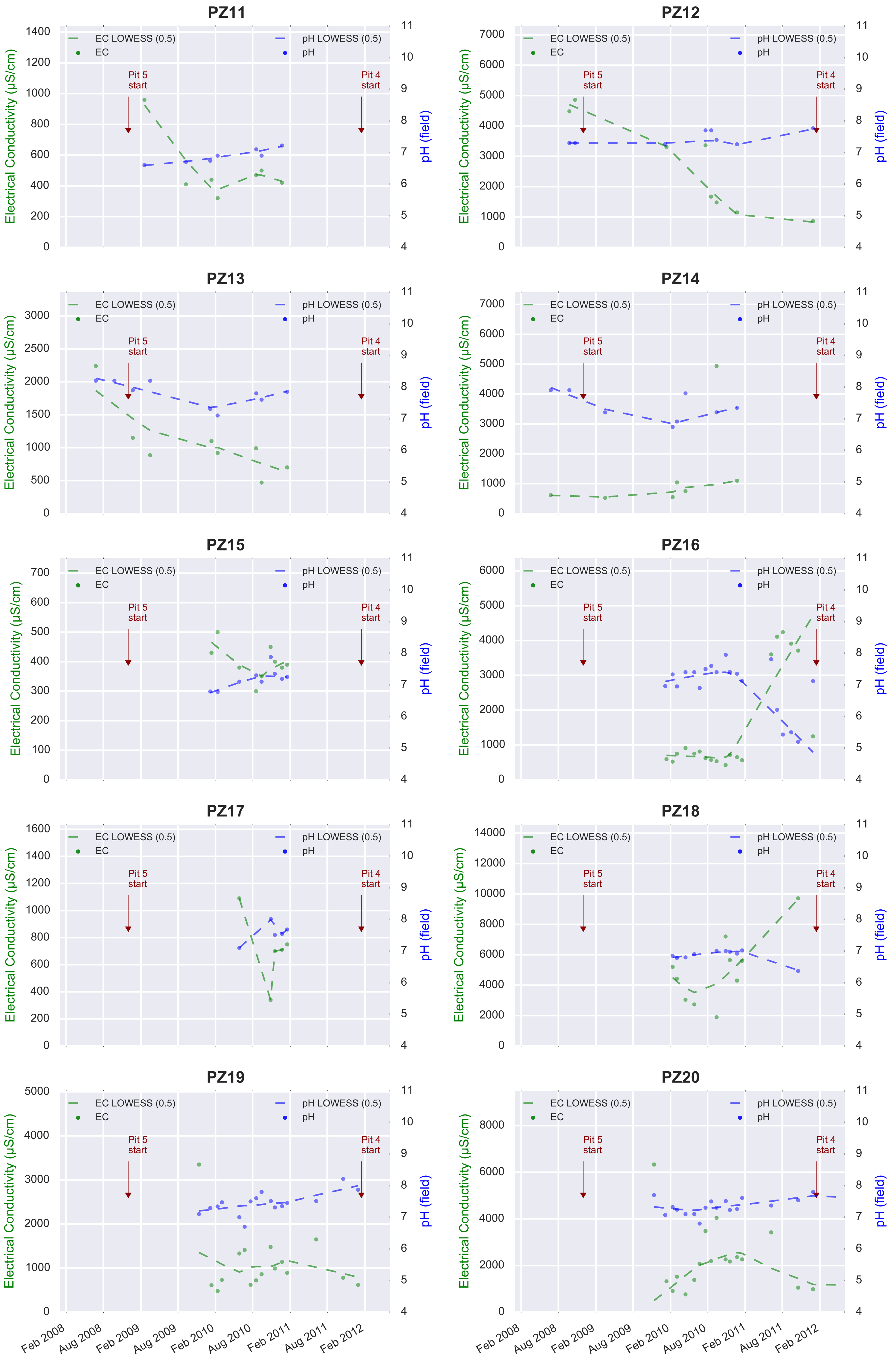


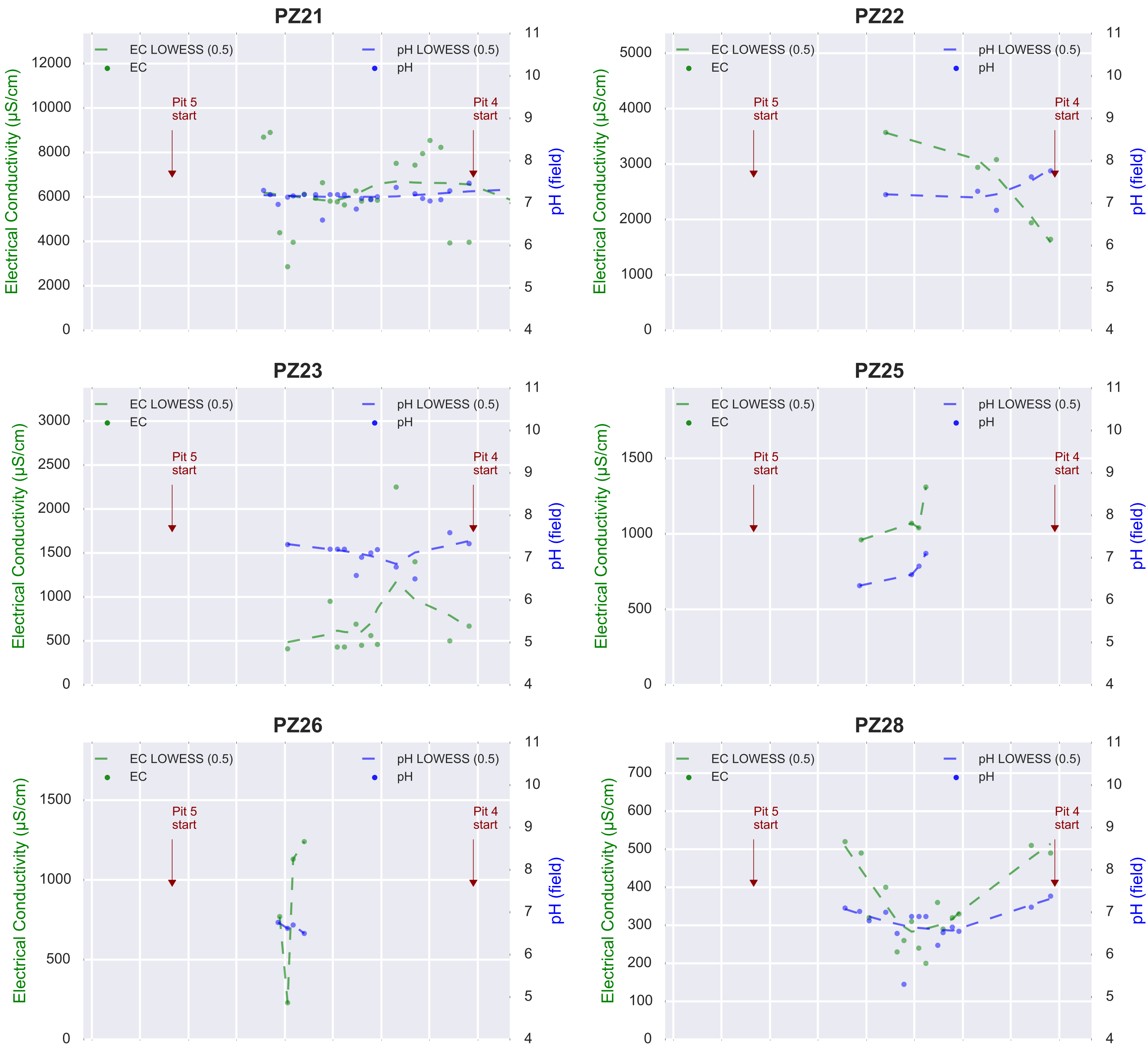
GWC24
GWC27
GWA10
GWC10
GWA11
GWC11
GWC12
GWC14
GWA15
GWC15
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4 start
Pits 3&7 start
Electrical Conductivity (µS/cm)
pH (field)
Feb 2012
Jun 2012
Oct 2012
Feb 2013
Jun 2013
Oct 2013
Feb 2014
Jun 2014
Oct 2014
Feb 2015
Jun 2015


GWC34
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4
start
Pits 3&7
start
Electrical Conductivity (µS/cm)
pH (field)
0
2000
4000
6000
8000
4
5
6
7
8
9
10
11


GWA34
EC LOWESS (0.8)
EC
pH LOWESS (0.8)
pH
Pit 4
start
Pits 3&7
start
Electrical Conductivity (µS/cm)
pH (field)
0
2000
4000
6000
8000
4
5
6
7
8
9
10
11


PZ01
PZ02
PZ03
PZ04
PZ05
PZ06
PZ07
PZ08
PZ09
PZ10
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5
start
Pit 4
start
Electrical Conductivity (µS/cm)
pH (field)
Feb 2008
Aug 2008
Feb 2009
Aug 2009
Feb 2010
Aug 2010
Feb 2011
Aug 2011
Feb 2012


PZ11
PZ12
PZ13
PZ14
PZ15
PZ16
PZ17
PZ18
PZ19
PZ20
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (μS/cm)
pH (field)
Feb 2008
Aug 2008
Feb 2009
Aug 2009
Feb 2010
Aug 2010
Feb 2011
Aug 2011
Feb 2012


PZ21
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (µS/cm)
pH (field)
PZ22
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (µS/cm)
pH (field)
PZ23
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (µS/cm)
pH (field)
PZ25
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (µS/cm)
pH (field)
PZ26
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (µS/cm)
pH (field)
PZ28
EC LOWESS (0.5)
EC
pH LOWESS (0.5)
pH
Pit 5 start
Pit 4 start
Electrical Conductivity (µS/cm)
pH (field)

APPENDIX E – GROUNDWATER MODEL CONFIDENCE

Assessment of groundwater model confidence
(based on Barnett *et al*, 2012)

Wilpinjong Extension Project (WEP) – Groundwater Model:

Model Confidence Assessment based on 2012 Modelling Guidelines (Barnett *et al*, 2012)

Table 2-1: Model confidence level classification—characteristics and indicators

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
Class 3	• Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported. • Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. • Reliable metered groundwater extraction and injection data is available. • Rainfall and evaporation data is available. • Aquifer-testing data to define key parameters. • Streamflow and stage measurements are available with reliable baseflow estimates at a number of points. • Reliable land-use and soil-mapping data available. • Reliable irrigation application data (where relevant) is available. • Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	• Adequate validation* is demonstrated. • Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable. • Long-term trends are adequately replicated where these are important. • Seasonal fluctuations are adequately replicated where these are important. • Transient calibration is current, i.e. uses recent data. • Model is calibrated to heads and fluxes. • Observations of the key modelling outcomes dataset is used in calibration.	• Length of predictive model is not excessive compared to length of calibration period. • Temporal discretisation used in the predictive model is consistent with the transient calibration. • Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. • Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model. • Steady-state predictions used when the model is calibrated in steady-state only.	• Key calibration statistics are acceptable and meet agreed targets. • Model predictive time frame is less than 3 times the duration of transient calibration. • Stresses are not more than 2 times greater than those included in calibration. • Temporal discretisation in predictive model is the same as that used in calibration. • Mass balance closure error is less than 0.5% of total. • Model parameters consistent with conceptualisation. • Appropriate computational methods used with appropriate spatial discretisation to model the problem. • The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	• Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain. • Provide information for sustainable yield assessments for high-value regional aquifer systems. • Evaluation and management of potentially high-risk impacts. • Can be used to design complex mine-dewatering schemes, salt-interception schemes or water-allocation plans. • Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models. • Assessment of complex, large-scale solute transport processes.
Class 2 *Cont'd overleaf*	• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	• Validation* is either not undertaken or is not demonstrated for the full model domain. • Calibration statistics are generally reasonable but may suggest significant errors in parts of the	• Transient calibration over a short time frame compared to that of prediction. • Temporal discretisation used in the predictive model is different from that used in transient	• Key calibration statistics suggest poor calibration in parts of the model domain. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Stresses are between 2 and 5 times greater than those	• Prediction of impacts of proposed developments in medium value aquifers. • Evaluation and management of medium risk impacts.

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key Indicator*	*Examples of specific uses*
Class 2 *Cont'd*	Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive. Streamflow data and baseflow estimates available at a few points. • Reliable irrigation-application data available in part of the area or for part of the model duration.	model domain(s). • Long-term trends not replicated in all parts of the model domain. • Transient calibration to historic data but not extending to the present day. Seasonal fluctuations not adequately replicated in all parts of the model domain. • Observations of the key modelling outcome data set are not used in calibration.	calibration. • Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. • Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.	included in calibration. • Temporal discretisation in predictive model is not the same as that used in calibration. Mass balance closure error is less than 1% of total. • Not all model parameters consistent with conceptualisation. • Spatial refinement too coarse in key parts of the model domain. • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.	• Providing estimates of dewatering requirements for mines and excavations and the associated impacts. • Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins. • Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones.
Class 1	• Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information. • Observations and measurements unavailable or sparsely distributed in areas of greatest interest. No available records of metered groundwater extraction or injection. • Climate data only available from relatively remote locations. • Little or no useful data on land-use, soils or river flows and stage elevations.	• No calibration is possible. • Calibration illustrates unacceptable levels of error especially in key areas. • Calibration is based on an inadequate distribution of data. • Calibration only to datasets other than that required for prediction.	Predictive model time frame far exceeds that of calibration. • Temporal discretisation is different to that of calibration. • Transient predictions are made when calibration is in steady state only. • Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.	• Model is uncalibrated or key calibration statistics do not meet agreed targets. • Model predictive time frame is more than 10 times longer than transient calibration period. • Stresses in predictions are more than 5 times higher than those in calibration. • Stress period or calculation interval is different from that used in calibration. • Transient predictions made but calibration in steady state only. • Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time. • Model parameters outside the range expected by the conceptualisation with no further justification. • Unsuitable spatial or temporal discretisation. • The model has not been reviewed.	• Design observation bore array for pumping tests. • Predicting long-term impacts of proposed developments in low-value aquifers. • Estimating impacts of low-risk developments. • Understanding groundwater flow processes under various hypothetical conditions. • Provide first-pass estimates of extraction volumes and rates required for mine dewatering. • Developing coarse relationships between groundwater extraction locations and rates and associated impacts. • As a starting point on which to develop higher class models as more data is collected and used.

WCM mine inflow data of reasonable quality

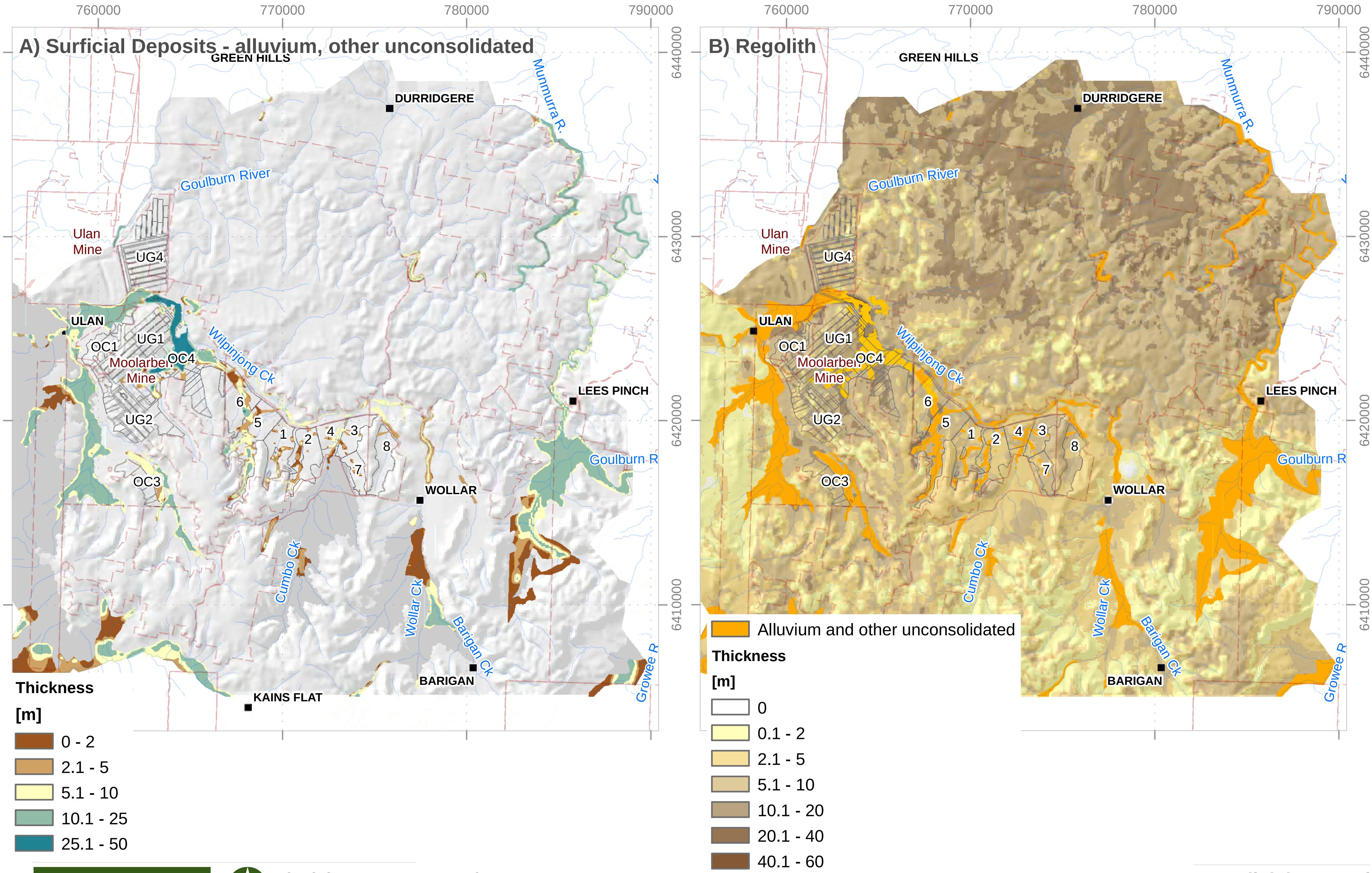
recovery

For neighbouring GW users

(*Refer Chapter 5 for discussion around validation as part of the calibration process.)

APPENDIX F – GEOLOGICAL MODEL

Isopachs from the regional geological model



Scale: 260,000 at A4
GDA 1994 MGA Zone 55

0 1.25 2.5 5 7.5 10 km

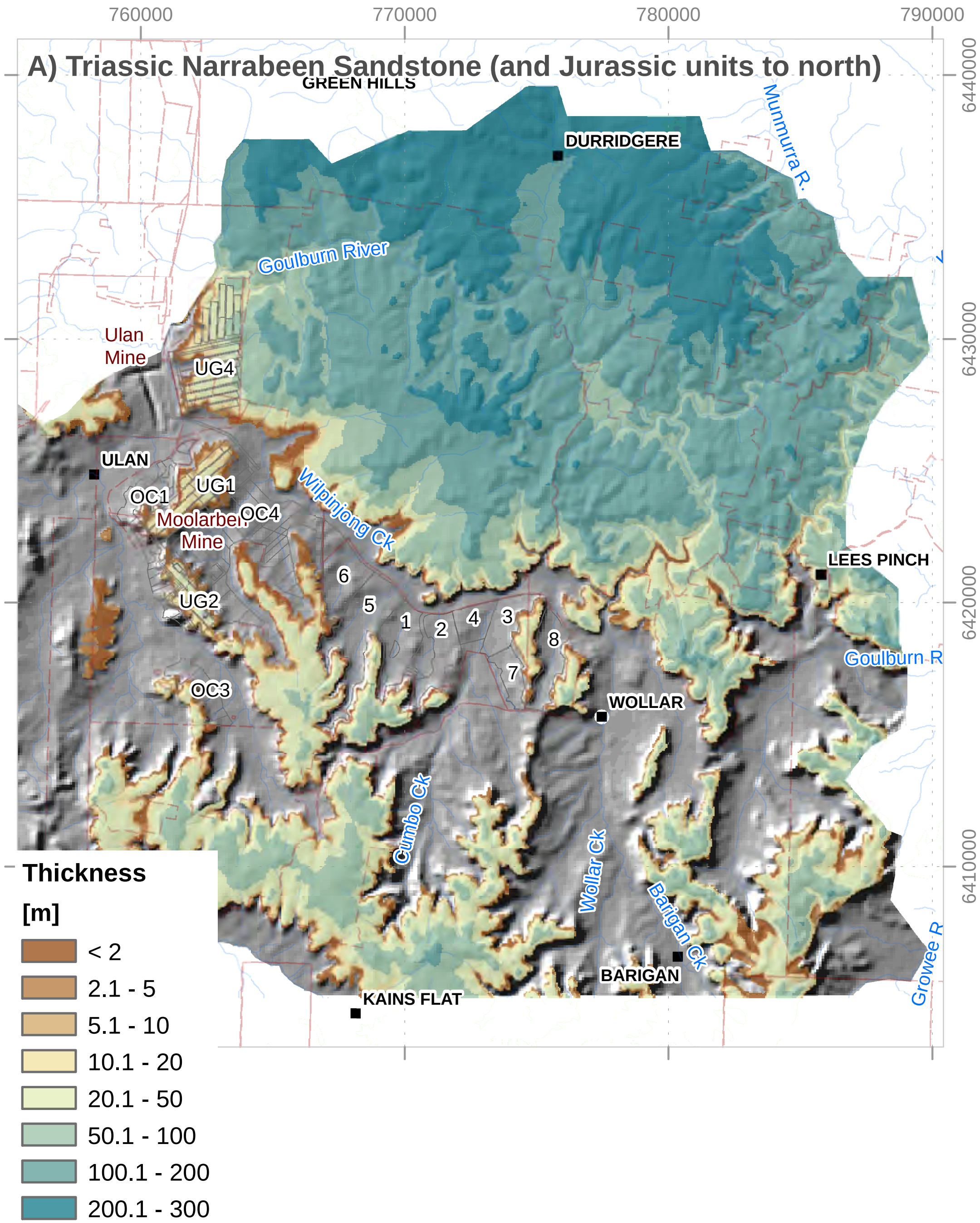
Rev: A | WMinchin | 25/10/2015
C:\HydroSim\WIL006\GIS\Maps\Deliverable\WIL006_Appendix_GeolModelIsopachs_Surficial_a.mxd

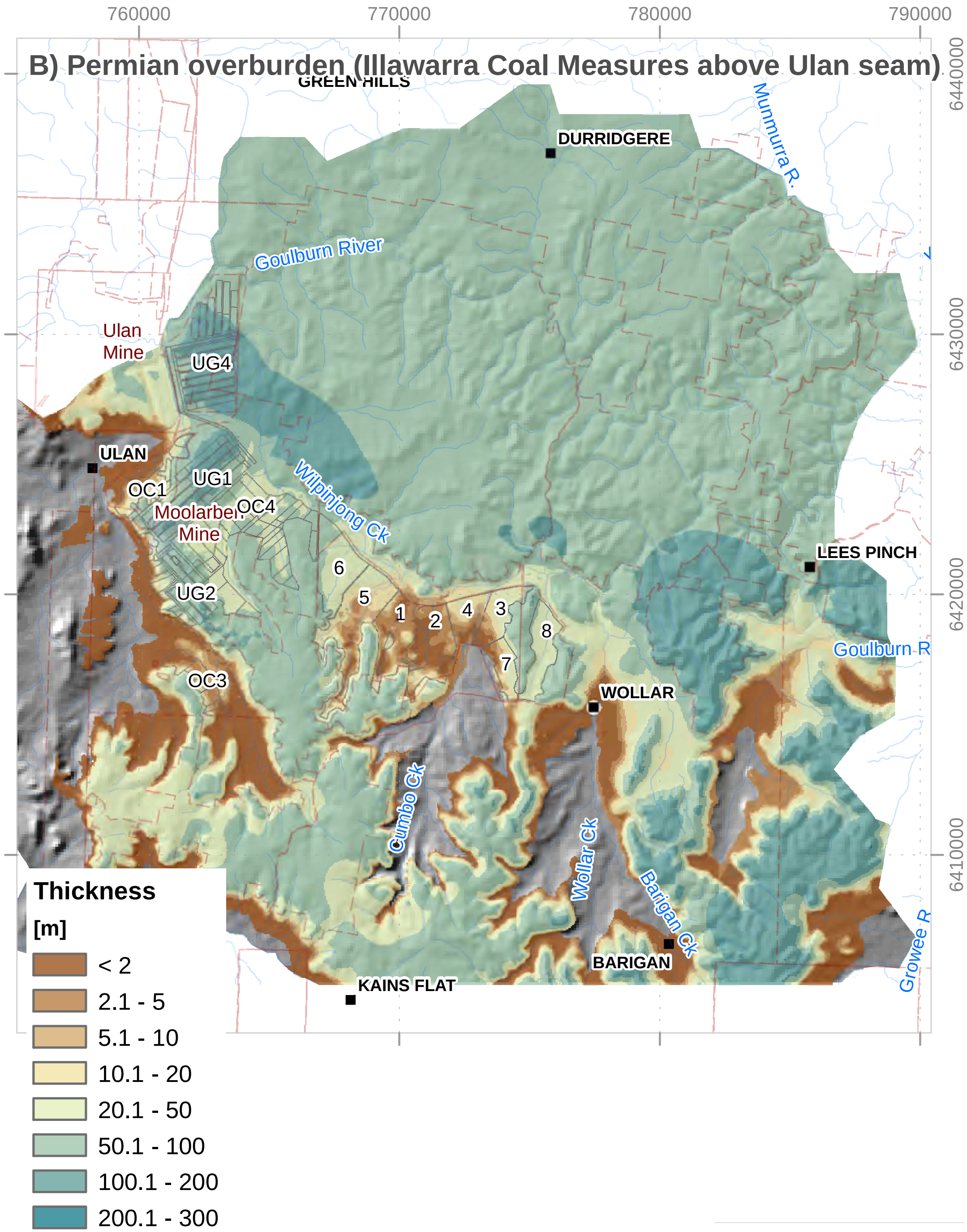
HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Geological Unit Isopachs for the WEP Regional Model
Surficial Deposits adn Regolith

Figure F-1





Scale: 260,000 at A4
GDA 1994 MGA Zone 55

0 2.5 5 7.5 10 km

Rev: A | WMinchin | 25/10/2015
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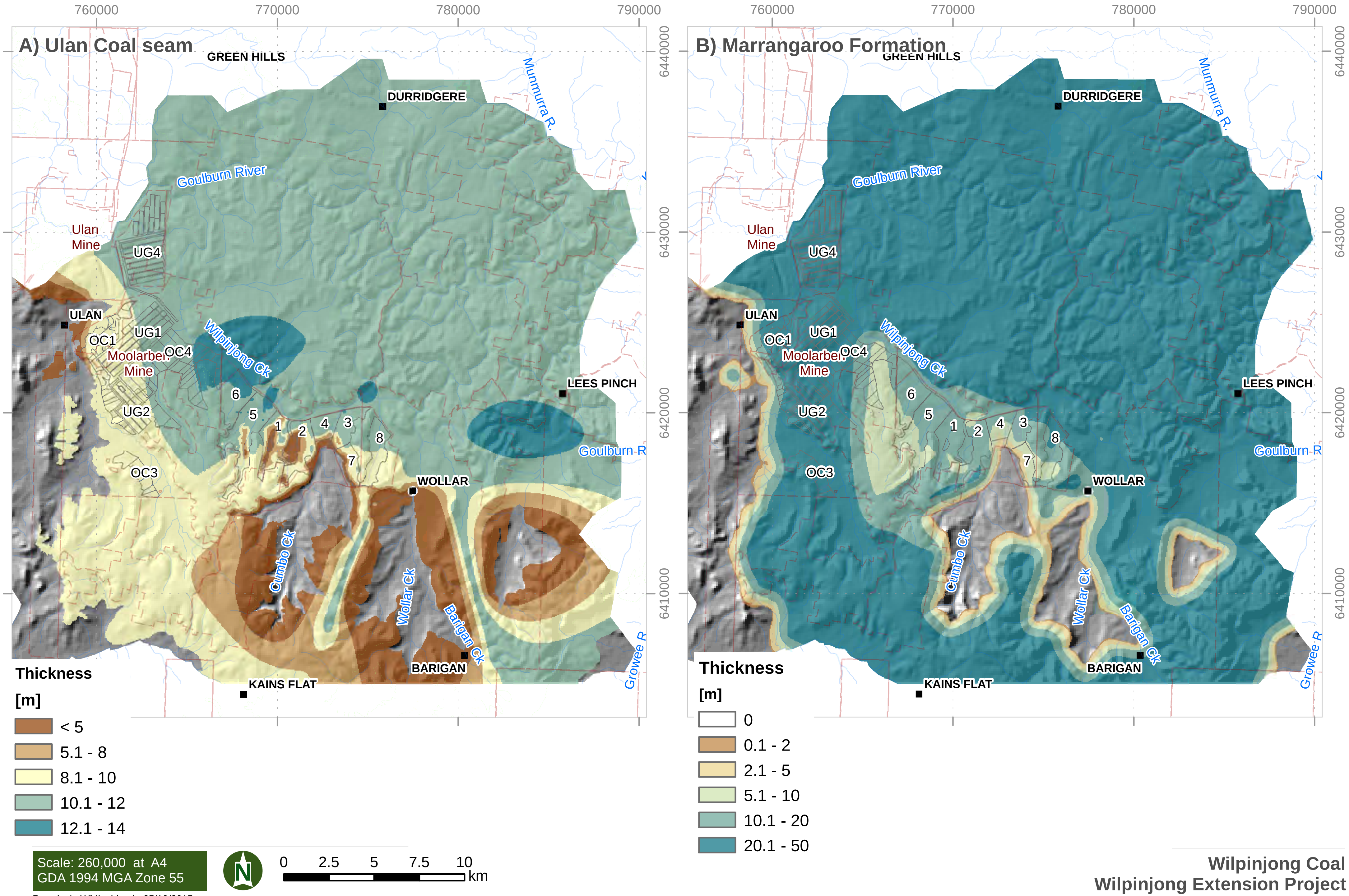
HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Geological Unit Isopachs for the WEP Regional Model: Triassic Sandstone and Permian overburden

Figure F-2



Rev: A | WMinchin | 25/10/2015

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HYDROSIMULATIONS

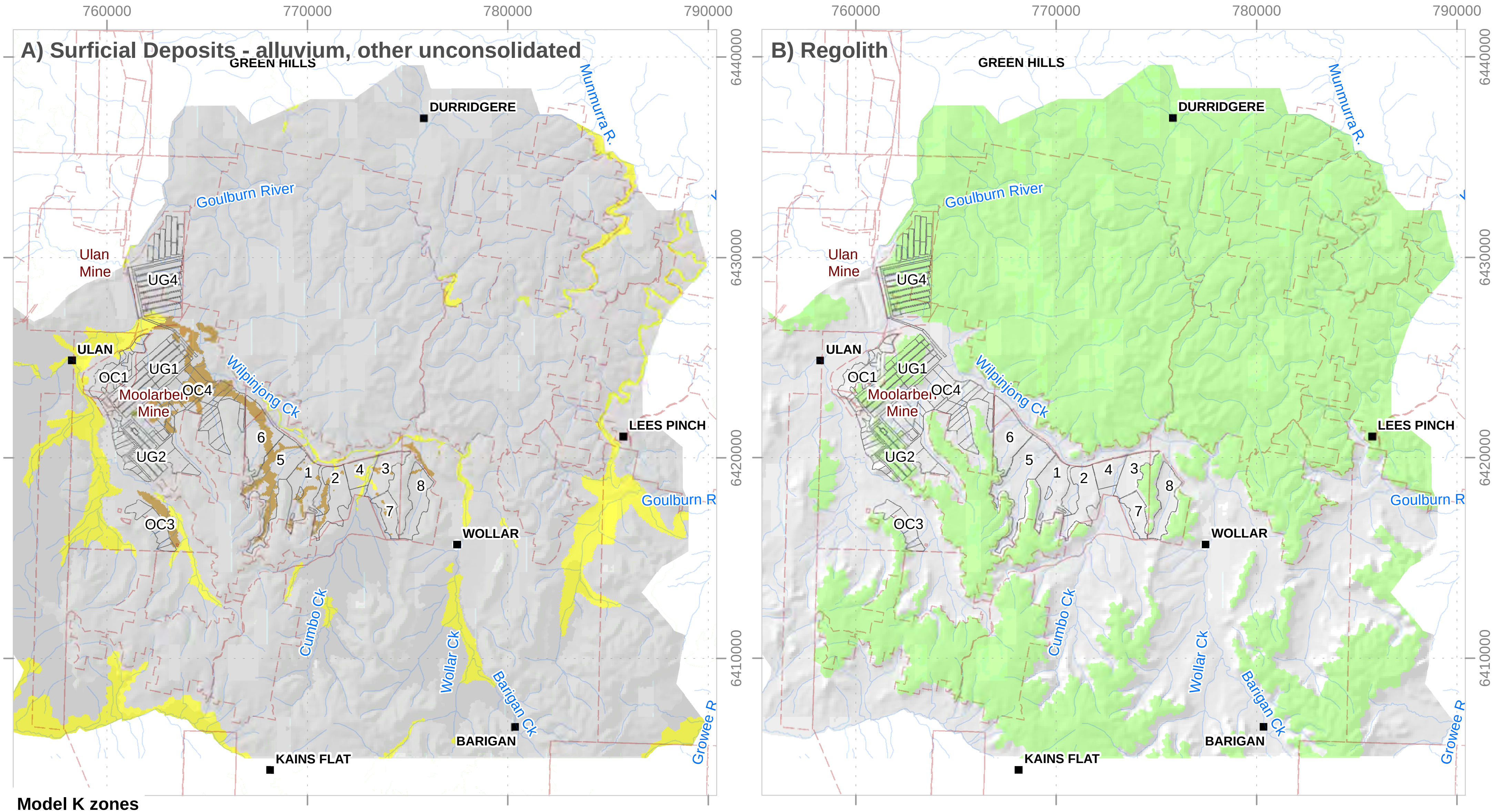
Wilpinjong Coal
Wilpinjong Extension Project

Geological Unit Isopachs for the WEP Regional Model: Ulan Coal seam and Marrangaroo Formation

Figure F-3

APPENDIX G – MODELLED HYDRAULIC CONDUCTIVITY

Hydraulic conductivity zones used in the groundwater flow model



Model K zones

Zone

- 1
- 10
- 20

Model K zones

Zone

- 2

Scale: 260,000 at A4
GDA 1994 MGA Zone 55

0 1.25 2.5 5 7.5 10 km

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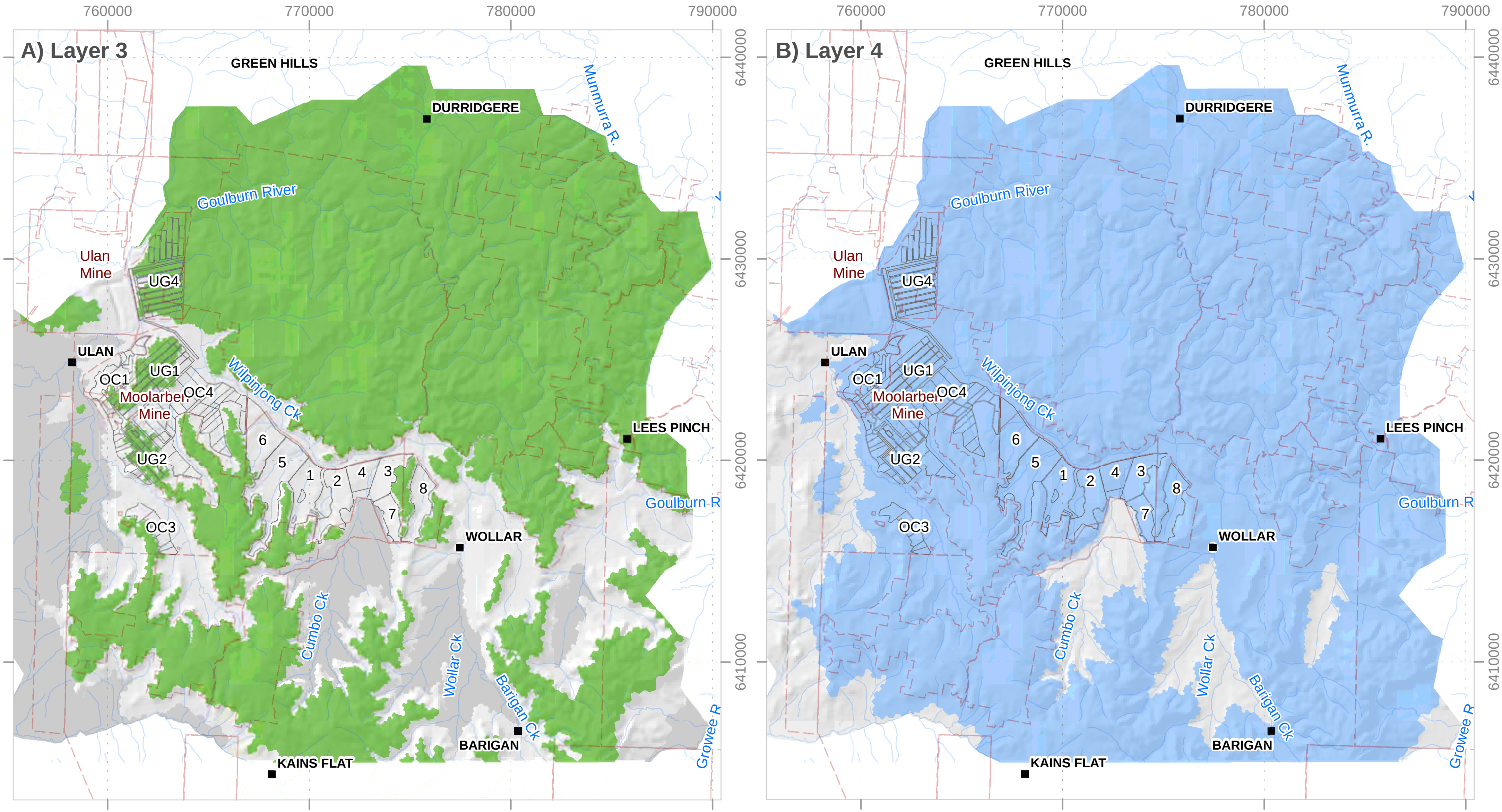
C:\HydroSim\WIL006\GIS\Maps\Deliverable\WIL006_Appendix_HydCondZones_Layer1&2_a.mxd

HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Hydraulic Conductivity Zones in the WEP Regional Model
Layers 1 and 2

Figure G-1



Model K zones

Zone

3

Model K zones

Zone

4

Scale: 260,000 at A4
GDA 1994 MGA Zone 55

0 1.25 2.5 5 7.5 10 km

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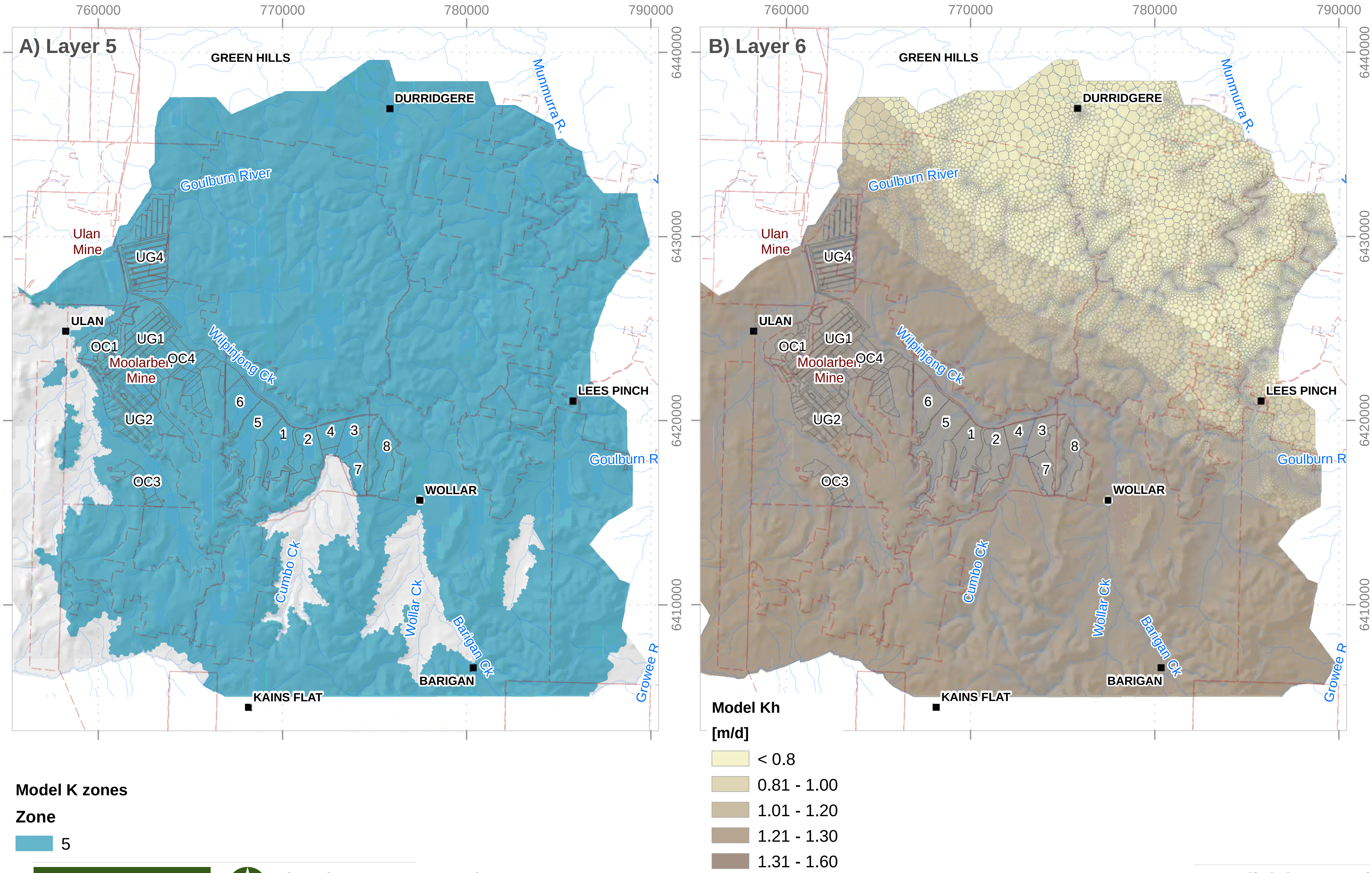
HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Hydraulic Conductivity Zones in the WEP Regional Model
Layers 3 and 4

Figure G-2



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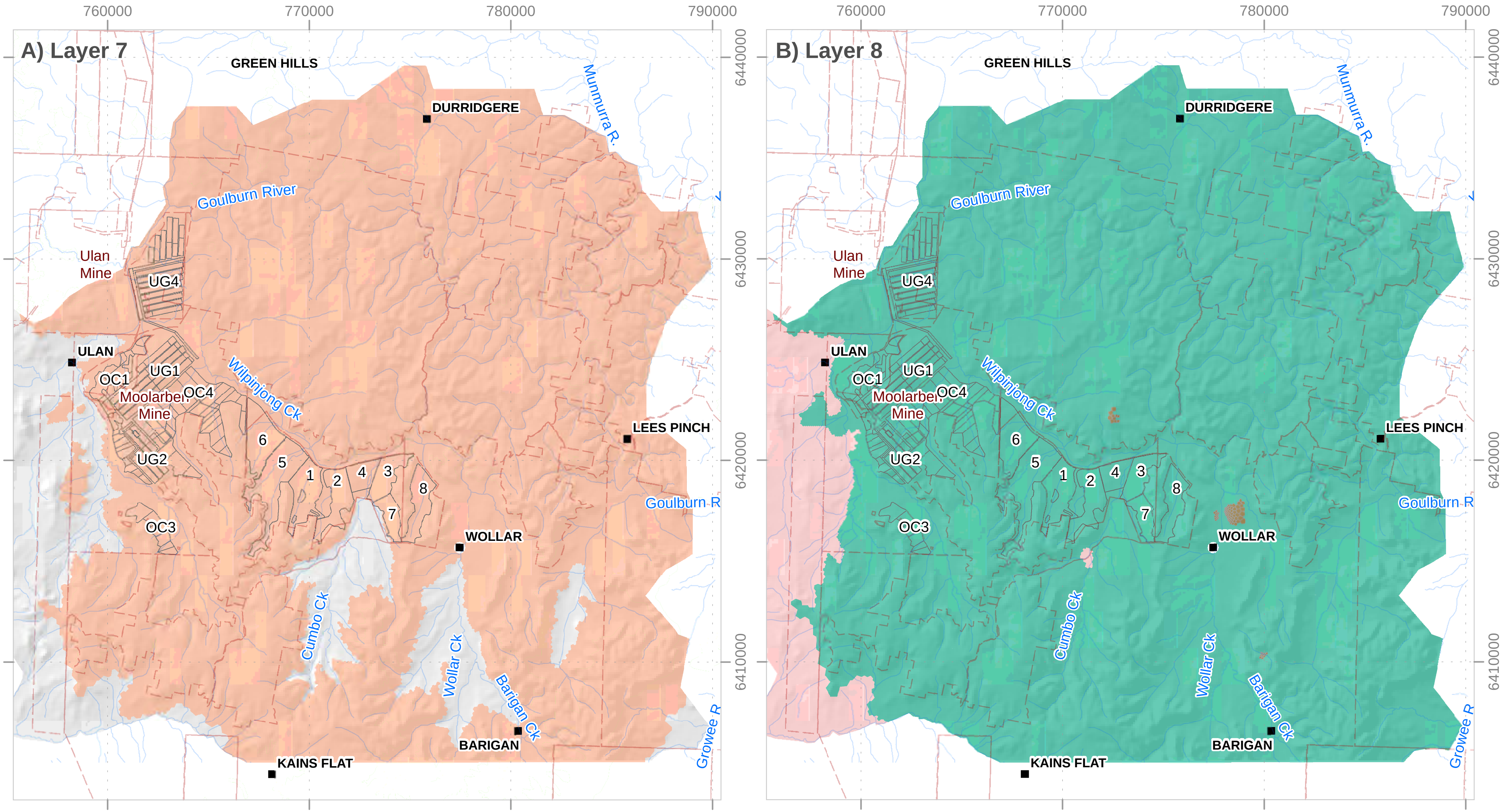
HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Hydraulic Conductivity Zones in the WEP Regional Model
Layers 5 and 6

Figure G-3



Model K zones

Zone

7

Model Kh

Zone

8

9

11

Scale: 260,000 at A4
GDA 1994 MGA Zone 55

0 2.5 5 7.5 10 km

Rev: A | WMinchin | 25/10/2015
C:\HydroSim\WIL006\GIS\Maps\Deliverable\WIL006_Appendix_HydCondZones_Layers7&8_a.mxd

HYDRO SIMULATIONS

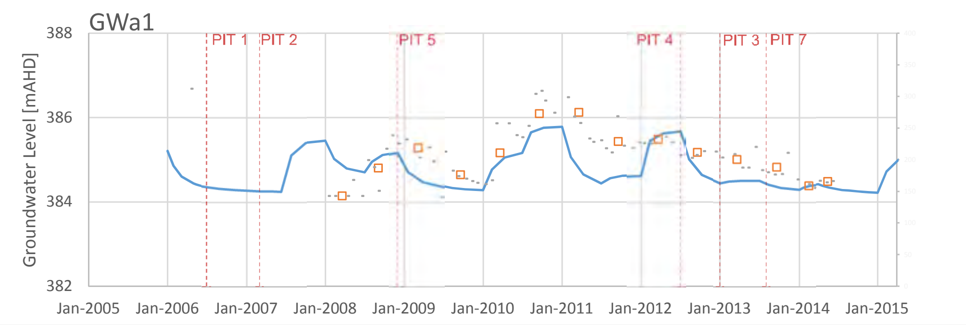
Wilpinjong Coal
Wilpinjong Extension Project

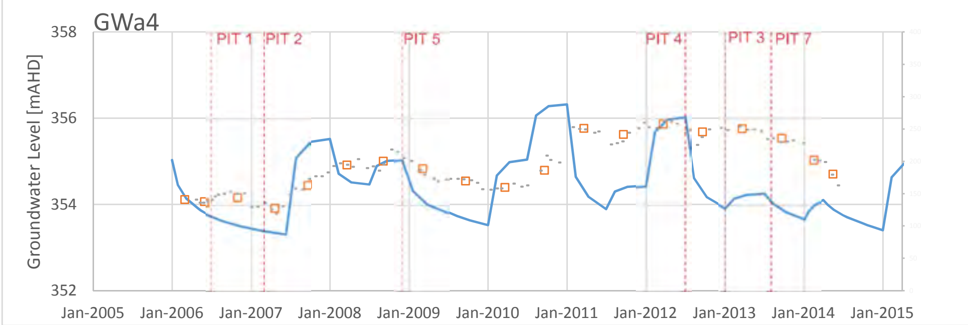
Hydraulic Conductivity Zones in the WEP Regional Model Layers 7 and 8

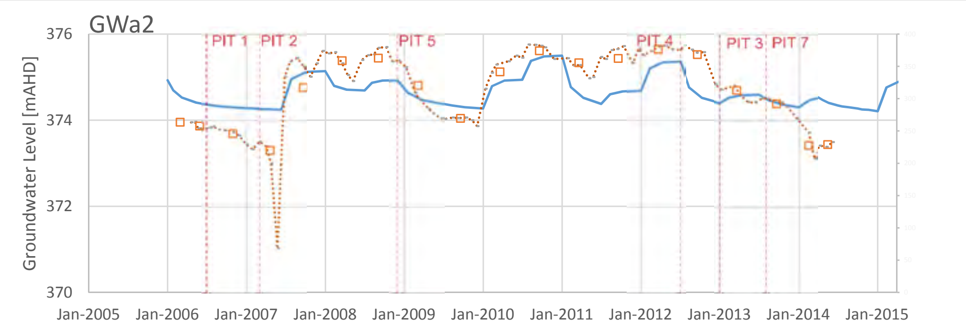
Figure G-4

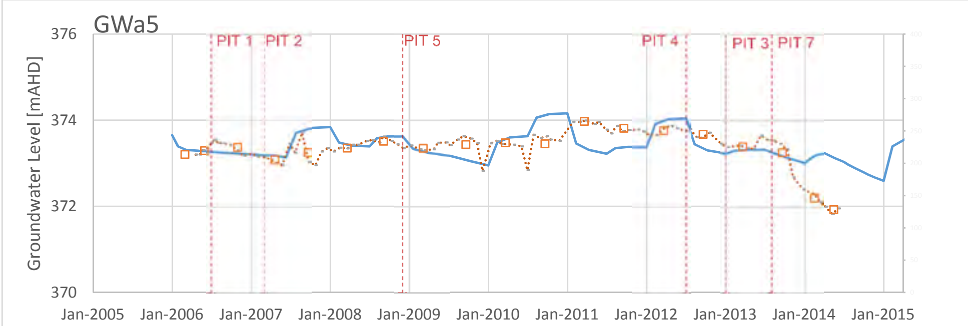
APPENDIX H – MODELLED GROUNDWATER LEVELS

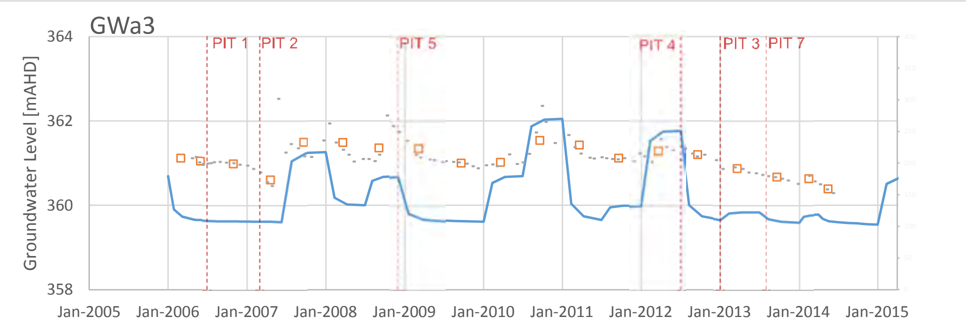
Modelled groundwater level hydrographs

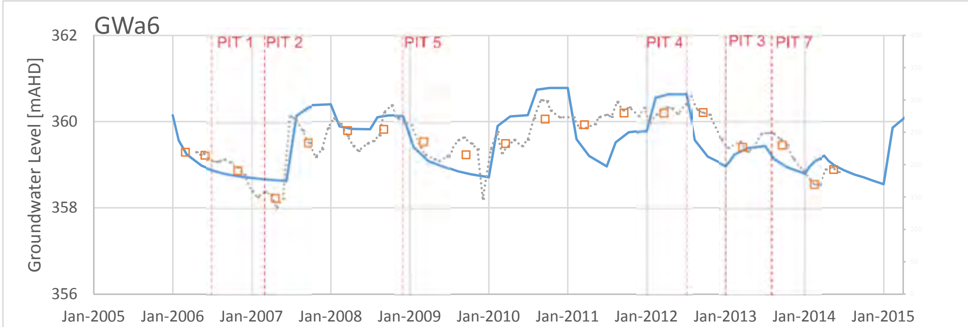

GWa1
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
388
386
384
382
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015

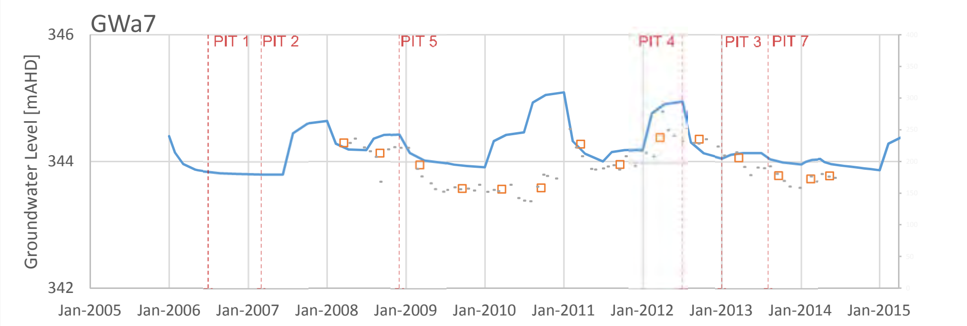

GWa4
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
358
356
354
352
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015

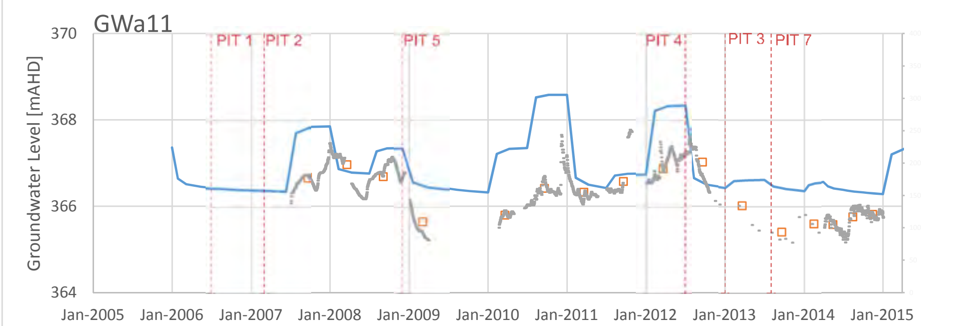

GWa2
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
376
374
372
370
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015

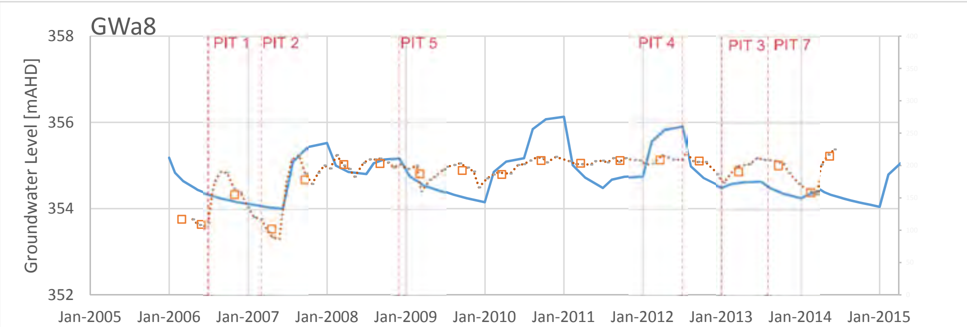

GWa5
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
376
374
372
370
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015

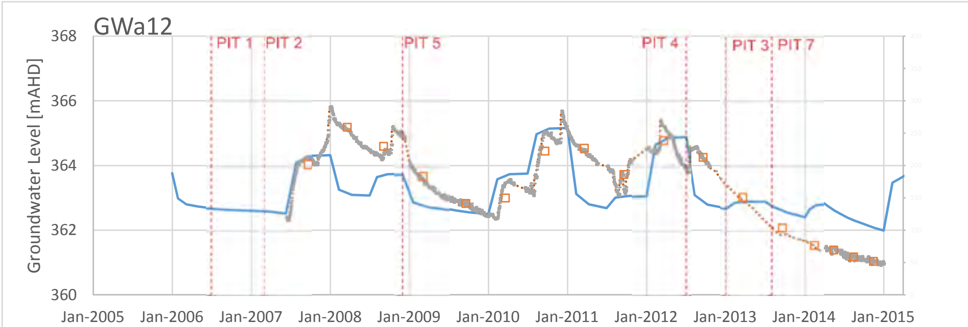

GWa3
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
364
362
360
358
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015

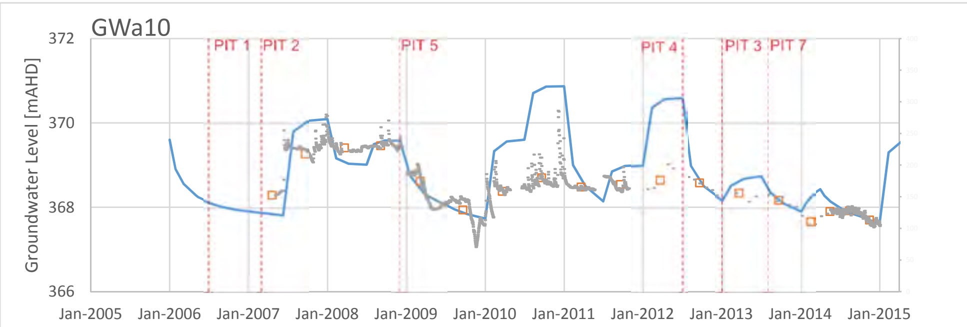

GWa6
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
362
360
358
356
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWa7
Groundwater Level [mAHD]
346
344
342
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWa11
Groundwater Level [mAHD]
370
368
366
364
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWa8
Groundwater Level [mAHD]
358
356
354
352
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWa12
Groundwater Level [mAHD]
368
366
364
362
360
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWa10
Groundwater Level [mAHD]
372
370
368
366
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
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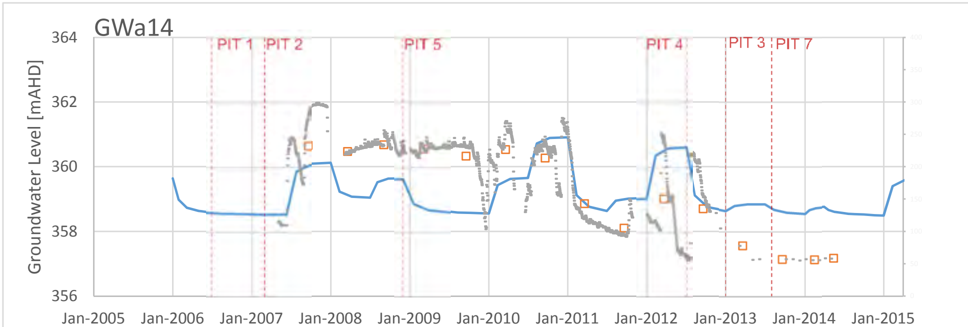
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWa14
Groundwater Level [mAHD]
364
362
360
358
356
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
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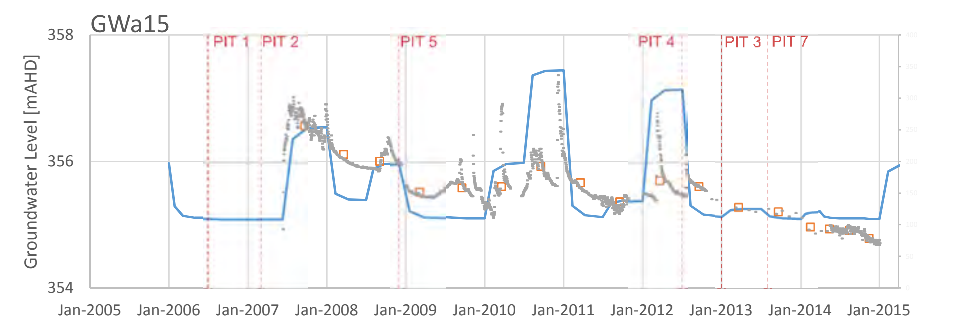
Jan-2014
Jan-2015


GWa15
Groundwater Level [mAHD]
358
356
354
PIT 1
PIT 2
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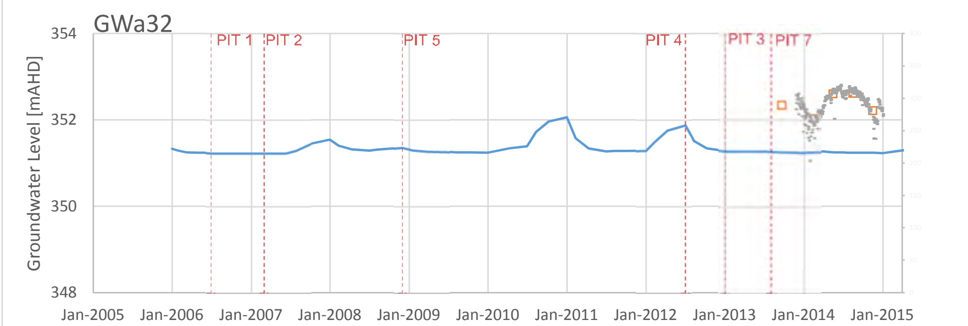
PIT 3
PIT 7
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWa32
Groundwater Level [mAHD]
354
352
350
348
PIT 1
PIT 2
PIT 5
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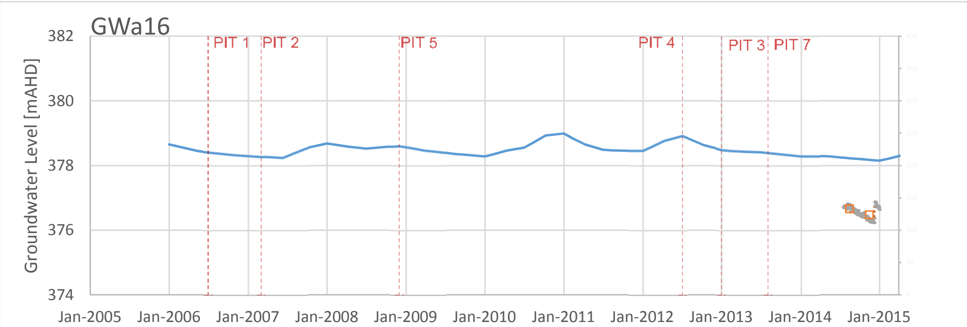
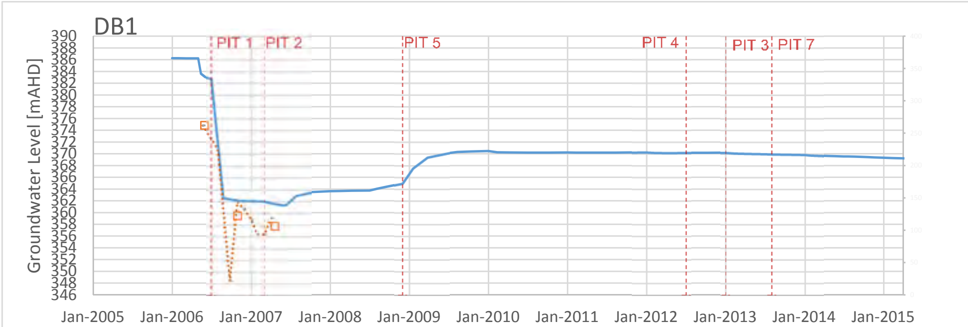
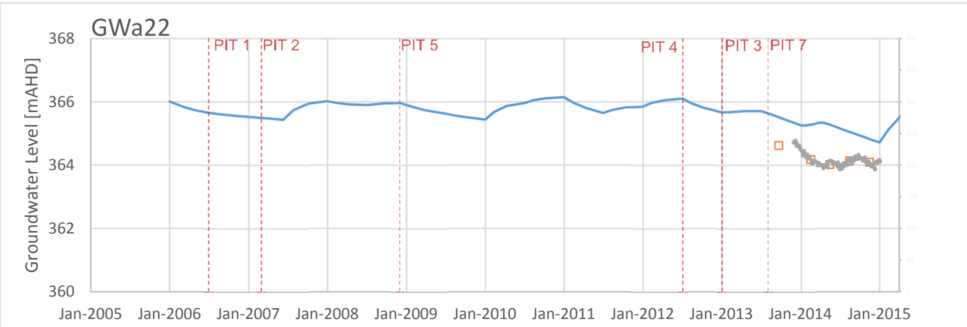
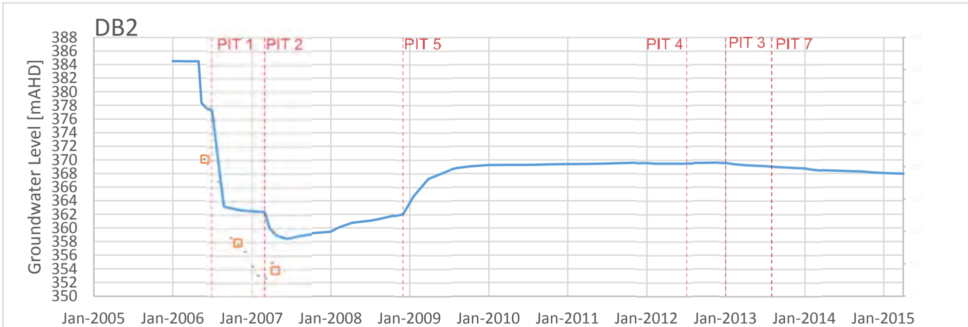
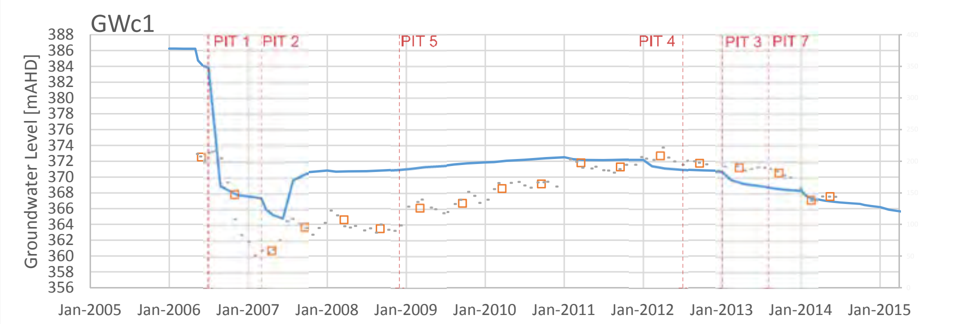
PIT 3
PIT 7
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWa16
Groundwater Level [mAHD]
382
380
378
376
374
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


DB1
Groundwater Level [mAHD]
390 388 386 384 382 380 378 376 374 372 370 368 366 364 362 360 358 356 354 352 350 348 346
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWa22
Groundwater Level [mAHD]
368
366
364
362
360
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


DB2
Groundwater Level [mAHD]
388 386 384 382 380 378 376 374 372 370 368 366 364 362 360 358 356 354 352 350
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWc1
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
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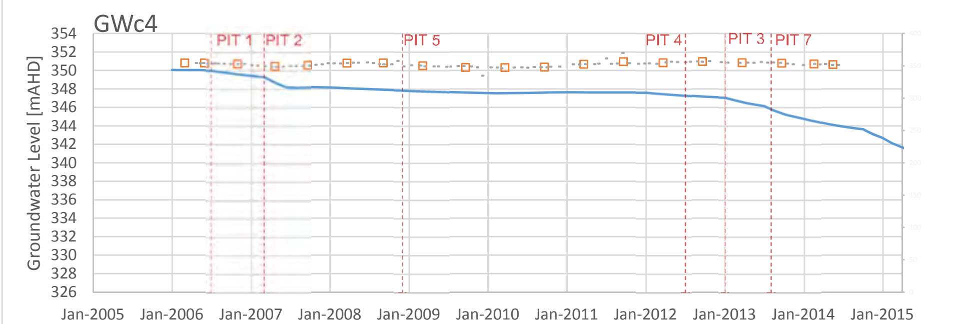
Jan-2013
Jan-2014
Jan-2015


GWc4
Groundwater Level [mAHD]
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PIT 4
PIT 3
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Jan-2013
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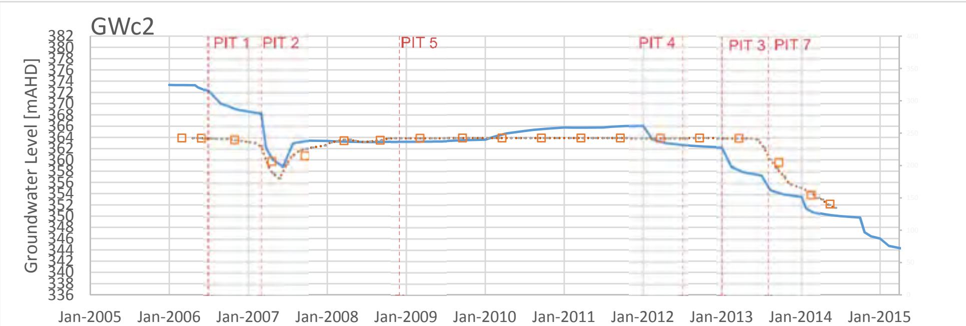
Jan-2015


GWc2
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
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Jan-2008
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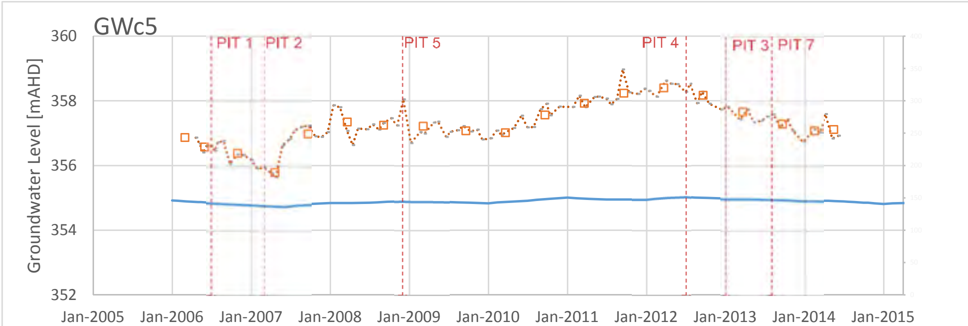
Jan-2013
Jan-2014
Jan-2015


GWc5
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
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Jan-2008
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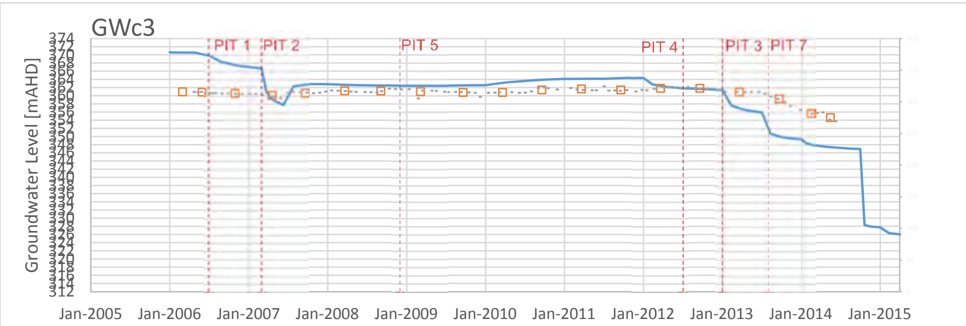
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWc3
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
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Jan-2008
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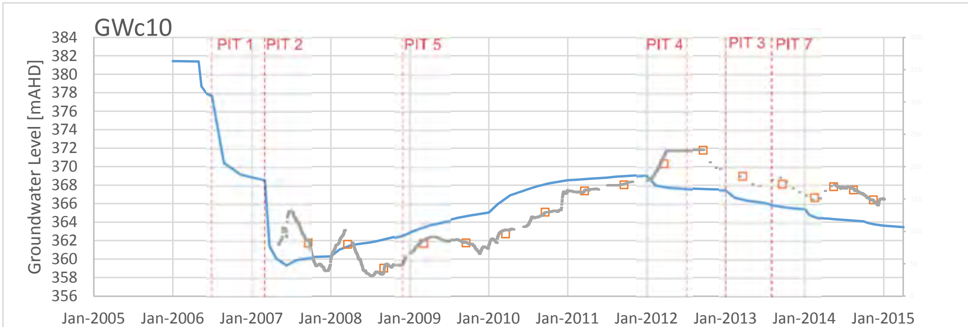
Jan-2013
Jan-2014
Jan-2015


GWc10
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Jan-2005
Jan-2006
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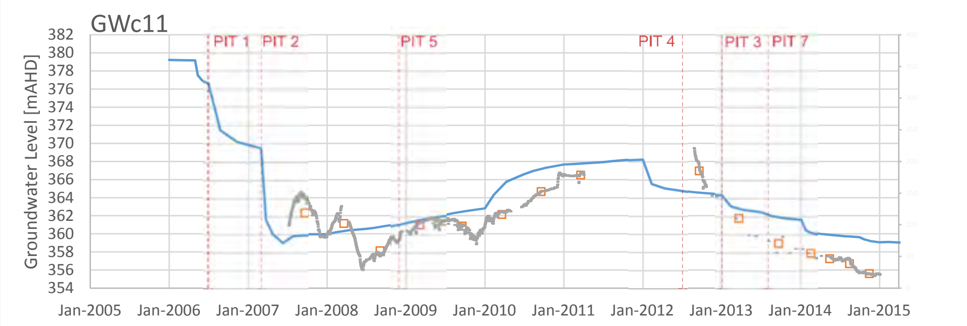
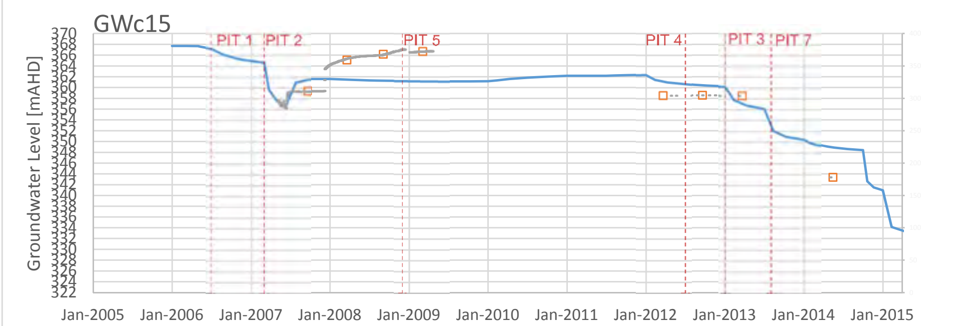
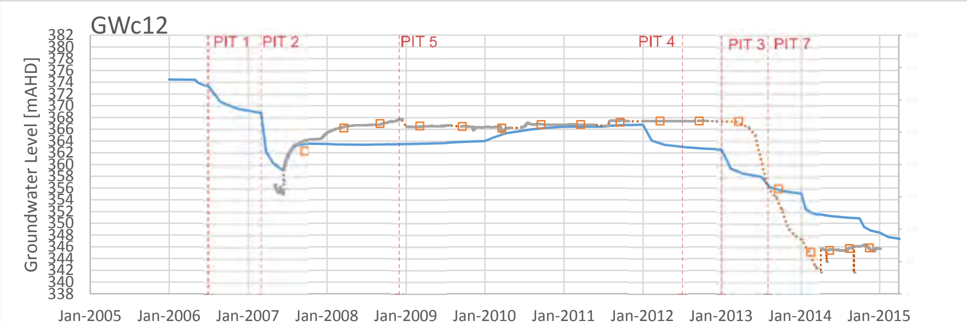
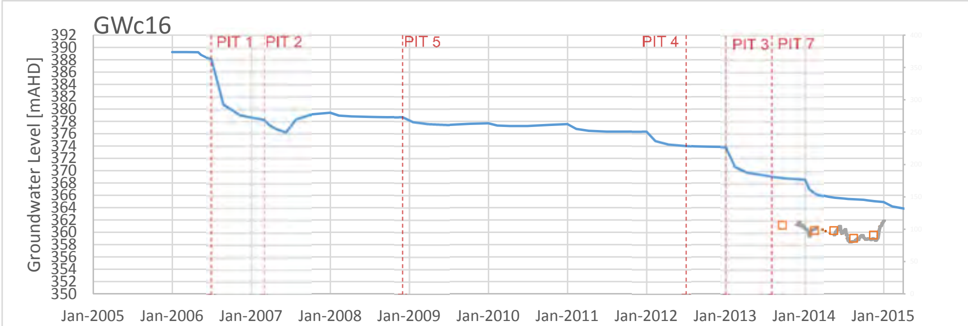
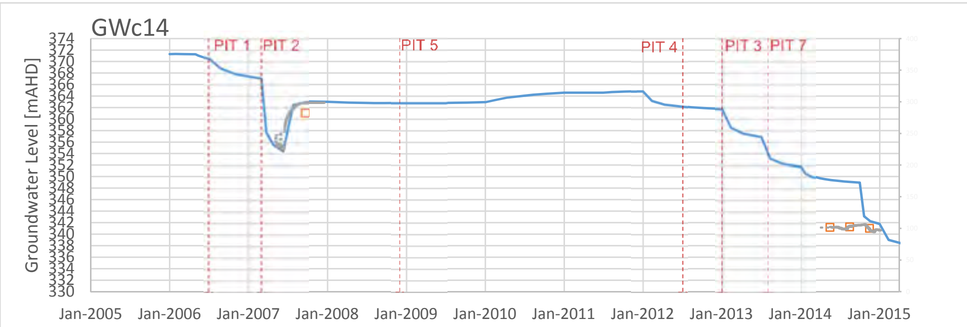
Jan-2013
Jan-2014
Jan-2015

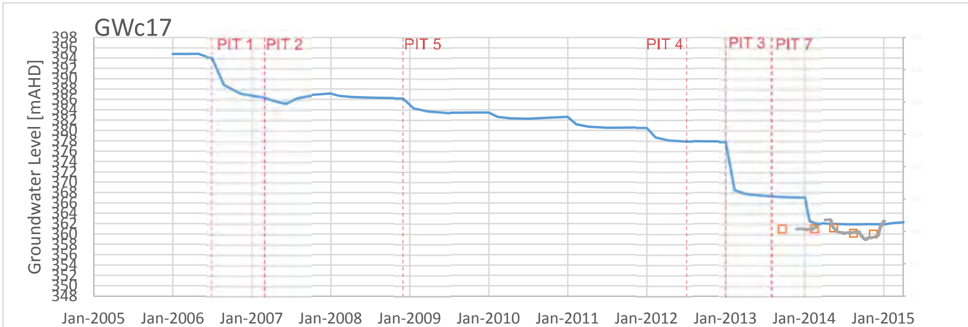

GWc11
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
382 380 378 376 374 372 370 368 366 364 362 360 358 356 354
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015

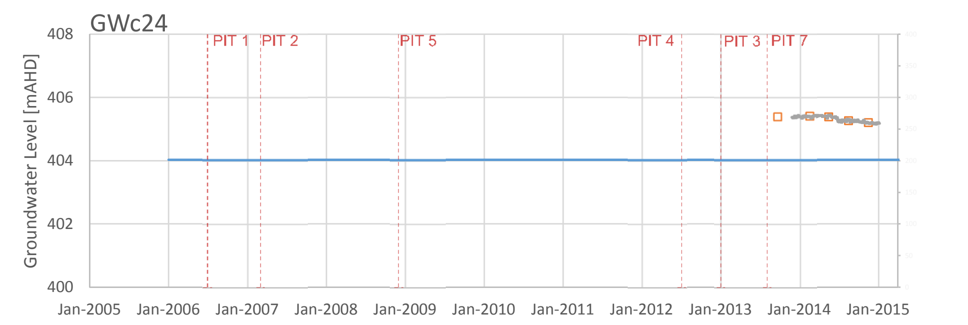

GWc15
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWc12
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWc16
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWc14
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWc17
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015


GWc24
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
408
406
404
402
400
Jan-2005
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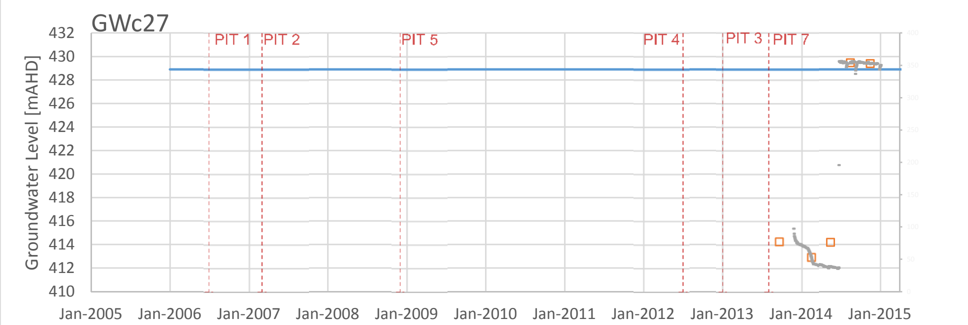
Jan-2013
Jan-2014
Jan-2015


GWc27
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
432
430
428
426
424
422
420
418
416
414
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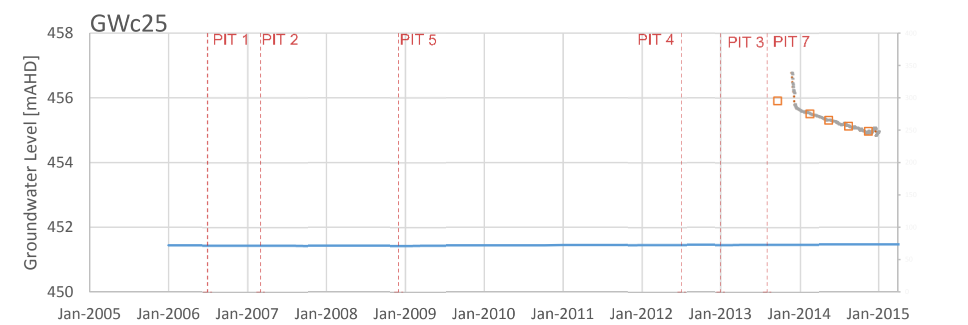
410
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWc25
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
458
456
454
452
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Jan-2005
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Jan-2007
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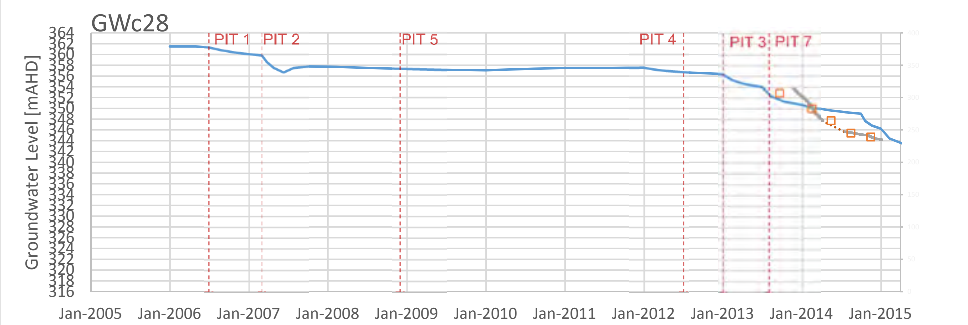
Jan-2013
Jan-2014
Jan-2015


GWc28
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005
Jan-2006
Jan-2007
Jan-2008
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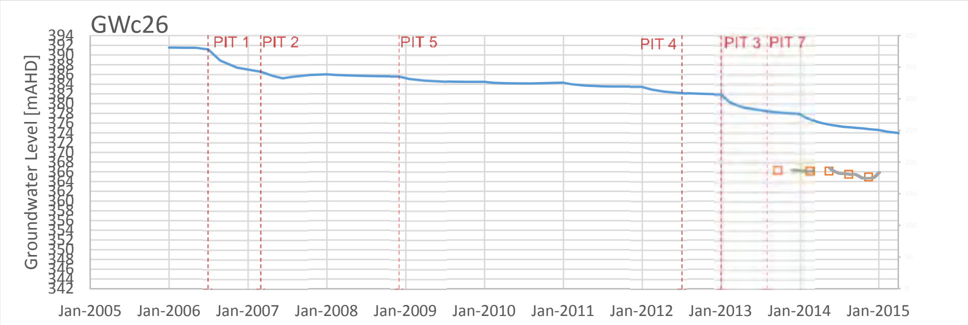
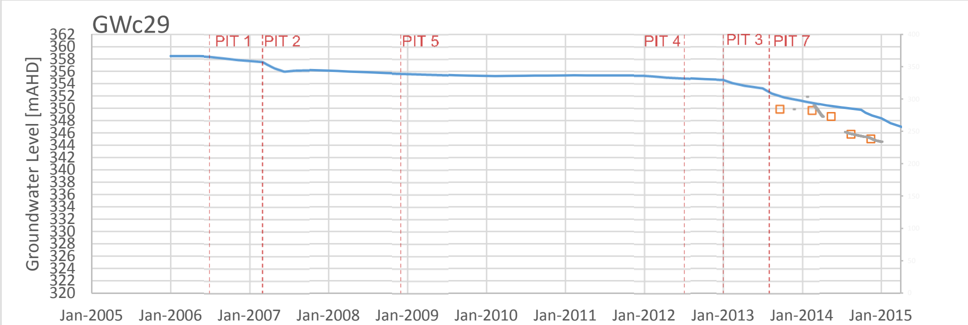
Jan-2013
Jan-2014
Jan-2015


GWc26
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015


GWc29
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005
Jan-2006
Jan-2007
Jan-2008
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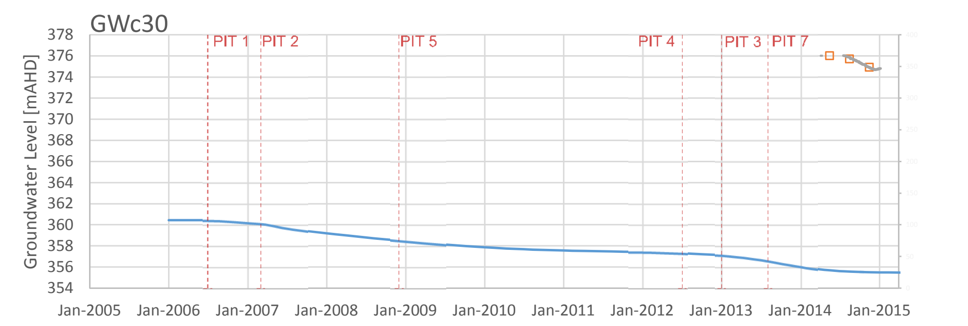
Jan-2013
Jan-2014
Jan-2015


GWc30
Groundwater Level [mAHD]
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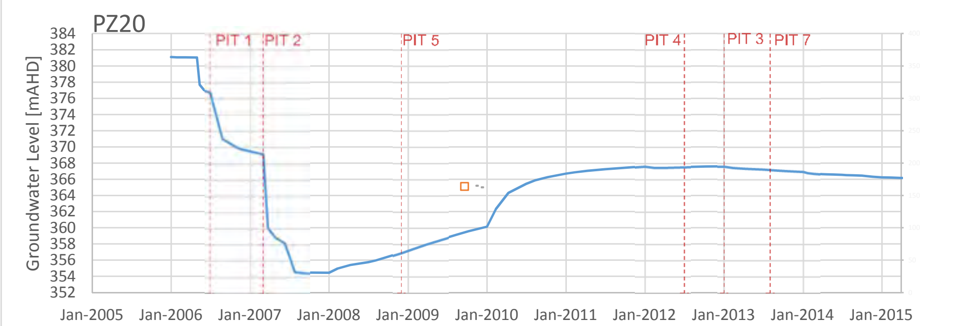
PIT 4
PIT 3
PIT 7


PZ20
Groundwater Level [mAHD]
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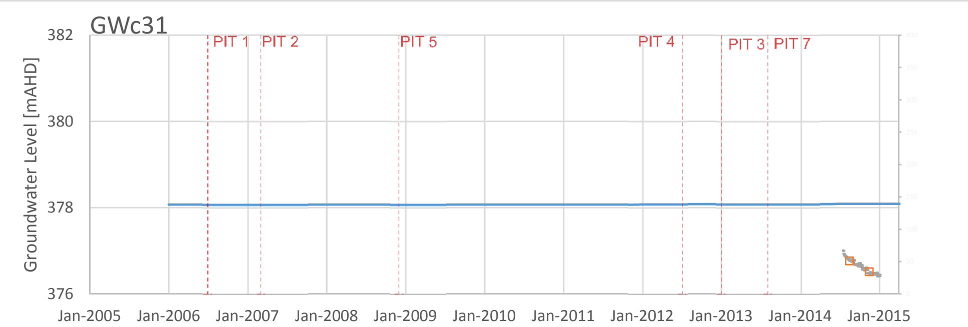
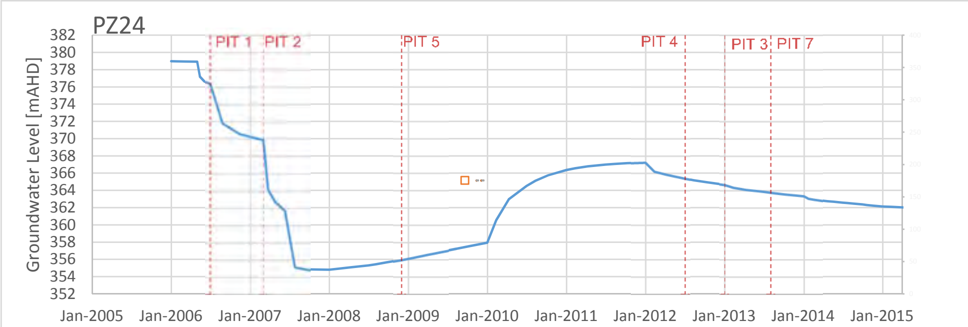
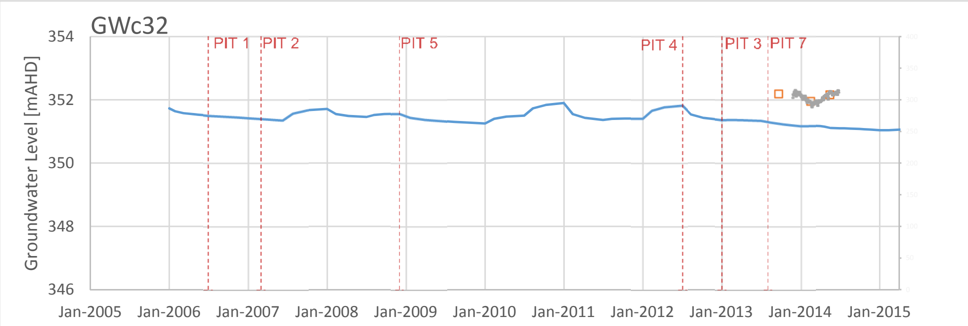
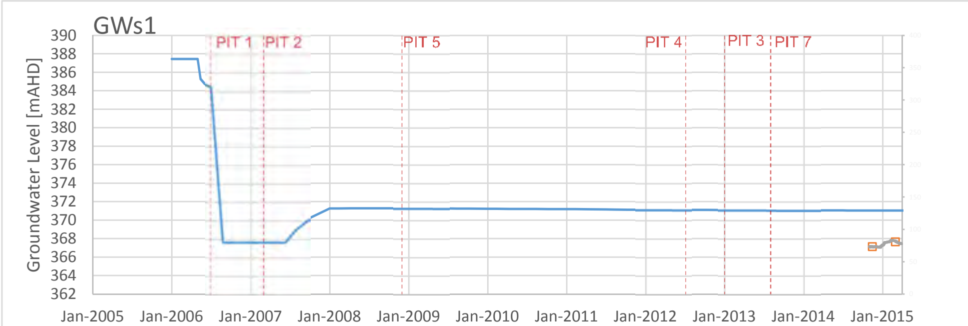
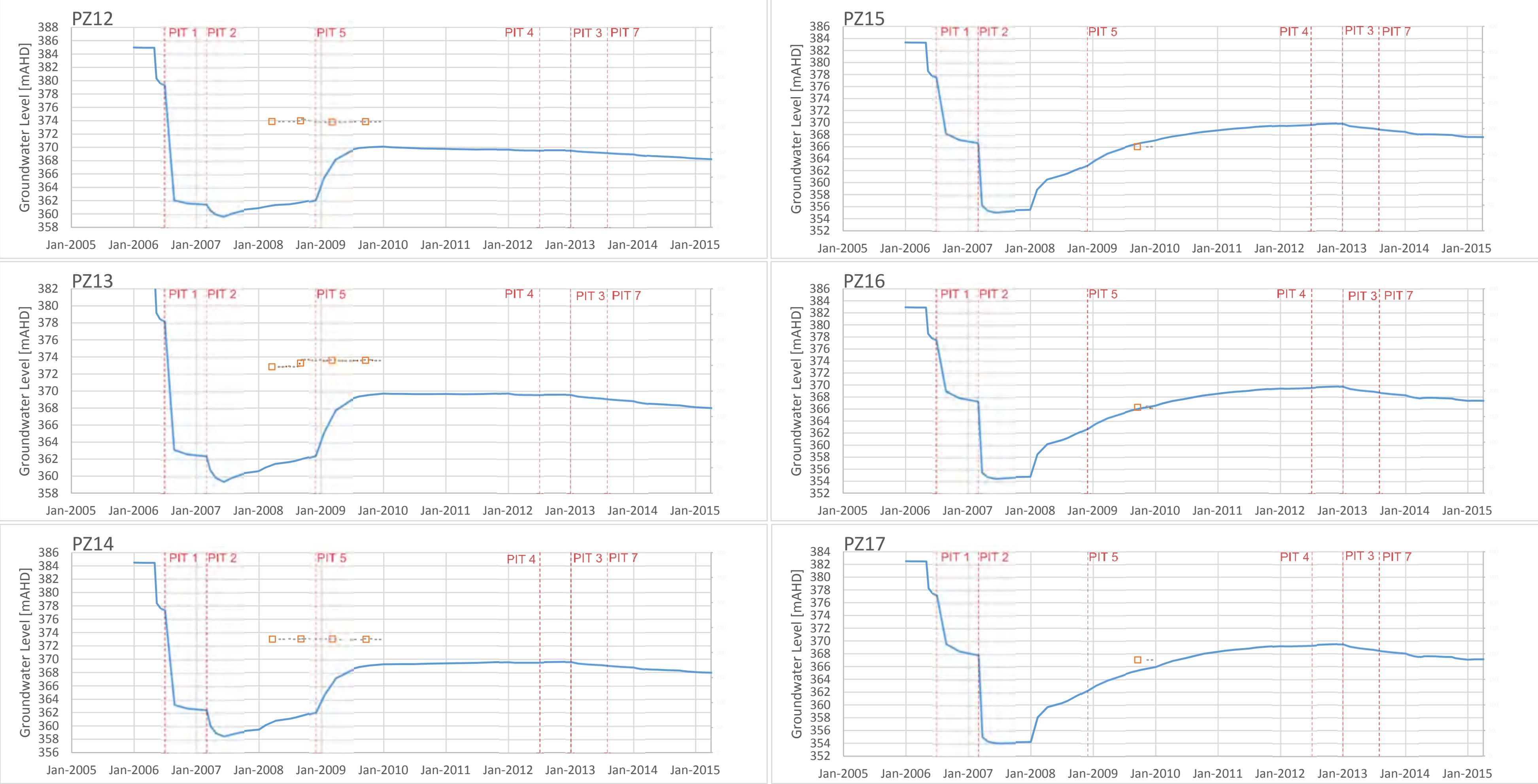
PIT 4
PIT 3
PIT 7


GWc31
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7


PZ24
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7


GWc32
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7


GWs1
Groundwater Level [mAHD]
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7


PZ12
PZ13
PZ14
PZ15
PZ16
PZ17
PIT 1
PIT 2
PIT 5
PIT 4
PIT 3
PIT 7
Groundwater Level [mAHD]
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015

APPENDIX I - DRAWDOWN ASSESSMENT

Impact assessment (predicted drawdown) at registered bores

Bore Drawdown Assessment - Census bores

BoreID	LocalID	Easting	Northing	DrillDep_m	In GW works list?	Assess	Aquifer	Predicted Max. Drawdown [m] Cumulative	WCM/WEP	Owner / Location description
GW053859	"Keylah"	769590	6419785	31	0	WCPL, other	Ulan	31	30	WILPINJONG COAL PTY LTD
GW024779	ERUL77	772725	6419860	41	0	WCPL, other	Marrangaroo	35	30	WILPINJONG COAL PTY LTD
GW024775	ERUL27	768725	6420790	45	0	WCPL, other	Marrangaroo	38	28	WILPINJONG COAL PTY LTD
GW024778	ERUL72	771760	6419700	32	0	WCPL, other	Ulan	29	26	approx 19m from Peabody Energy owned land (Lot 12/DP 755425)
GW024776	"Badgers Bend'	769750	6420875	49	0	WCPL, other	Marrangaroo	37	24	WILPINJONG COAL PTY LTD
GW024777	ERUL67	770640	6419500	26	0	WCPL, other	Marrangaroo	24	22	WILPINJONG COAL PTY LTD
GW052223	0	767660	6421210	54	1	WCPL, other	Marrangaroo	44	21	WILPINJONG COAL PTY LTD
GW060562	0	770625	6418800	41	0	WCPL, other	Shoalhaven Grp	15	10	WILPINJONG COAL PTY LTD
GW034640	0	765059	6422109	70	1	WCPL, other	Marrangaroo	40	9	ULAN COAL MINES LIMITED
GW024774	0	765310	6423700	91	0	WCPL, other	Marrangaroo	56	9	ULAN COAL MINES LIMITED
GW052937	0	777610	6416668	43	1	WCPL, other	Shoalhaven Grp	10	7	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW051430	0	769410	6417510	46	1	WCPL, other	Shoalhaven Grp	6	4	WILPINJONG COAL PTY LTD
GW051150	0	778750	6416130	31	1	WCPL, other	Ulan	6	4	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW051582	0	777481	6415887	38	1	WCPL, other	Shoalhaven Grp	6	4	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW051252	0	777355	6415774	34	1	WCPL, other	Shoalhaven Grp	4	3	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW059034	0	760820	6429050	89	0	WCPL, other	Marrangaroo	78	2.0	ULAN COAL MINES LIMITED
GW059038	0	760550	6429290	73	0	WCPL, other	Marrangaroo	74	1.9	ULAN COAL MINES LIMITED
GW054254	"Batey Hirons"	778690	6417680	35	1	WCPL, other	Permian Coal Me	3	1.7	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW080412	"Batey Hirons"	778116	6417714	6	0	WCPL, other	Permian Coal Me	3	1.6	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW080408	"Badgers Bend'	769551	6420978	5	0	WCPL, other	Permian Coal Me	3	1.5	WILPINJONG COAL PTY LTD
GW080413	"Batey Hirons"	778096	6417643	9	0	WCPL, other	Permian Coal Me	2	1.4	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW080411	"Keylah"	770522	6419618	5	0	WCPL, other	Regolith	1	1.1	WILPINJONG COAL PTY LTD
GW056057	0	778350	6414110	55	0	WCPL, other	Shoalhaven Grp	1	0.7	PEABODY PASTORAL HOLDINGS PTY LIMITED
GW080405	"Castleview"	770593	6417807	4	0	WCPL, other	Permian Coal Me	1	0.4	WILPINJONG COAL PTY LTD
GW080409	"Badgers Bend'	769766	6420693	2	0	WCPL, other	Regolith	1	0.4	WILPINJONG COAL PTY LTD
GW080407	"Castleview"	770489	6417970	3	0	WCPL, other	Regolith	0	0.3	WILPINJONG COAL PTY LTD
GW080127	"Wandoona"	777810	6415503	0	0	Private	Regolith	0	0.15	Wollar Road (east of township)
GW080410	"Badgers Bend'	769811	6420808	5	0	WCPL, other	Regolith	0	0.13	WILPINJONG COAL PTY LTD
GW059559	0	777561	6415829	0	1	WCPL, other	Regolith	0	0.11	PEABODY PASTORAL HOLDINGS PTY LTD

C:\HydroSim\WIL006\GIS\Data\Model\Processing\Bores_DrawdownAssessment\[Bores_DrawdownAssessment_GWworks&Census_CUMULATIVE.xlsx]Appendix_BoreCensus

Bore Drawdown Assessment - Registered bores

WORK_NO	LICENSE	HOLDER_SUR	LICENSED_P	East_z55	Nort_z55	Depth	InBoreCensus	Aquifer	Predicted Max. Drawdown [m] Cumulative	WCM/WEP only
0	20BL167719	WILPINJONG COAL PTY LIMITED	DOMESTIC,STOCK	769790	6420052	36	No	Permian Coal Me	19.7	16.3
GW052223	20BL115642	WILPINJONG COAL PTY LTD	DOMESTIC,STOCK	767784	6421391	2	Yes	Marrangaroo	44.1	20.9
0	20BL166292	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	775624	6417904	0	No	Permian Coal Me	14.0	12.9
GW201929	20BL171912	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	777614	6418848	34	No	Ulan	21.2	16.1
0	20WA211157	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	777625	6418602	22	No	Permian Coal Me	13.8	9.8
0	20BL137593	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	777822	6418413	1	No	Permian Coal Me	13.2	9.3
GW034640	20BL027911	ULAN COAL MINES LIMITED	DOMESTIC,STOCK	765164	6422292	28	Yes	Marrangaroo	40.5	9.1
0	20BL171686	PEABODY PASTORAL HOLDINGS PTY LTD	DOMESTIC,STOCK	779110	6417824	5	No	Permian Coal Me	10.0	6.5
0	20BL168604	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	780193	6417206	0	No	Permian Coal Me	8.6	5.2
0	20BL171054	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	780193	6417206	0	No	Permian Coal Me	8.6	5.2
GW052937	20BL112342	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC	779676	6416844	0	Yes	Permian Coal Me	7.7	4.7
0	20BL168136	PEABODY PASTORAL HOLDINGS PTY LTD	DOMESTIC	778875	6417165	36	No	Permian Coal Me	5.8	3.6
GW051430	20BL115862	WILPINJONG COAL PTY LTD	STOCK	769483	6417743	0	Yes	Shoalhaven Grp	6.4	4.0
Wollar Schoo	20BL173431	WOLLAR PUBLIC SCHOOL	RECREATION (GROUNDWATER)	777508	6416200	44	No	Shoalhaven Grp	6.2	4.0
GW051150	20BL113573	PEABODY PASTORAL HOLDINGS PTY LIMITED	STOCK	778876	6416311	15	Yes	Ulan	6.3	3.8
GW051582	20BL111698	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC	777587	6416069	0	Yes	Shoalhaven Grp	5.5	3.5
GW059559	20BL131333	PEABODY PASTORAL HOLDINGS PTY LTD	DOMESTIC	777663	6416005	0	Yes	Shoalhaven Grp	5.2	3.2
GW051252	20BL111924	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	777479	6415949	0	Yes	Shoalhaven Grp	4.4	2.7
GW054254	20BL114935	PEABODY PASTORAL HOLDINGS PTY LIMITED	STOCK	778814	6417854	0	Yes	Permian Coal Me	2.9	1.7
GW019567	20BL012964	PEABODY PASTORAL HOLDINGS PTY LIMITED	STOCK	784206	6416933	41	No	Marrangaroo	1.7	1.7
0	20BL168698	WILPINJONG COAL PTY LIMITED	STOCK	770424	6416373	0	No	Tertiary?	1.6	1.6
GW066420	20BL143078	PEABODY PASTORAL HOLDINGS PTY LIMITED	DOMESTIC,STOCK	779431	6416511	52	Yes	Permian Coal Me	2.1	0.8
GW029980	20BL023347	PEABODY PASTORAL HOLDINGS PTY LIMITED	CONSERVATION OF WATER,STOCK	786779	6417199	9	No	Marrangaroo	1.3	0.8
GW019568	20BL012963	PEABODY PASTORAL HOLDINGS PTY LIMITED	STOCK	783606	6415161	0	No	Shoalhaven Grp	0.8	0.5
GW078729	20BL167518	MOOLARBEN COAL MINES PTY LTD	DOMESTIC,FARMING,STOCK	762932	6417482	0	No	Shoalhaven Grp	1.5	0.3
GW800279	80BL236762	IMRIE	DOMESTIC,STOCK	765208	6431971	0	No	Narrabeen Grp	1.4	0.2
GW200546	20BL168271	MOOLARBEN COAL MINES PTY LTD	DOMESTIC,STOCK	764600	6415831	0	No	Shoalhaven Grp	0.8	0.14

Figures to accompany

Wilpinjong Coal Mine Extension Project

Groundwater Assessment

FOR

Wilpinjong Coal Pty Ltd

BY

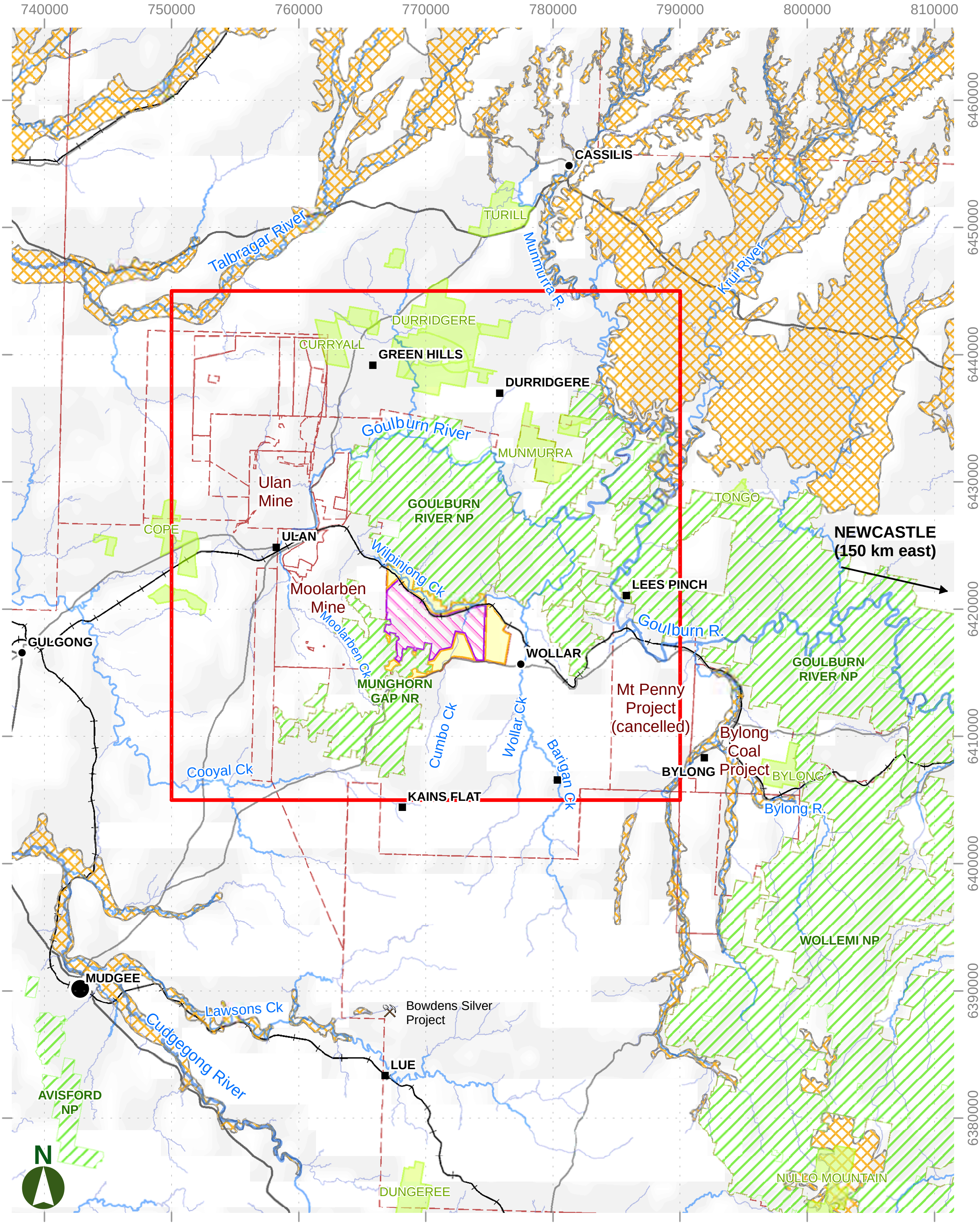
W. Minchin, Stuart Brown and Dr N.P. Merrick
Heritage Computing Pty Ltd
trading as
HydroSimulations

Project number: WIL006
Report: HC2015/042
Date: November 2015

DOCUMENT REGISTER

Revision	Description	Date	Comments
A	**First Draft**	**29 January 2014**	**Draft for comment, Sections 1-4**
B	**Second Draft**	**3 July 2014**	**Draft for initial review by Franz Kalf**
C	**Third Draft**	**29 October 2015**	**Complete draft for Franz Kalf, WCPL review**
D	**Final Draft**	**6 November**	**Final draft for WCPL, Franx Pakc review**
E	**Final**	**24 November**	

File:
c:\hydrosim\wil006\wp\figures\hc2015-042e_figures_wilpinjongextension-gwassessment_hydrosim.docx



National Park
NSW State Forest
Biophysical Strategic Agricultural Land (BSAL)
Study Area
Locality
NSW coal title
Wilpinjong Coal title
Mining Licence boundary
Exploration Licence boundary

Scale: 400,000 at A4
GDA 1994 MGA Zone 55

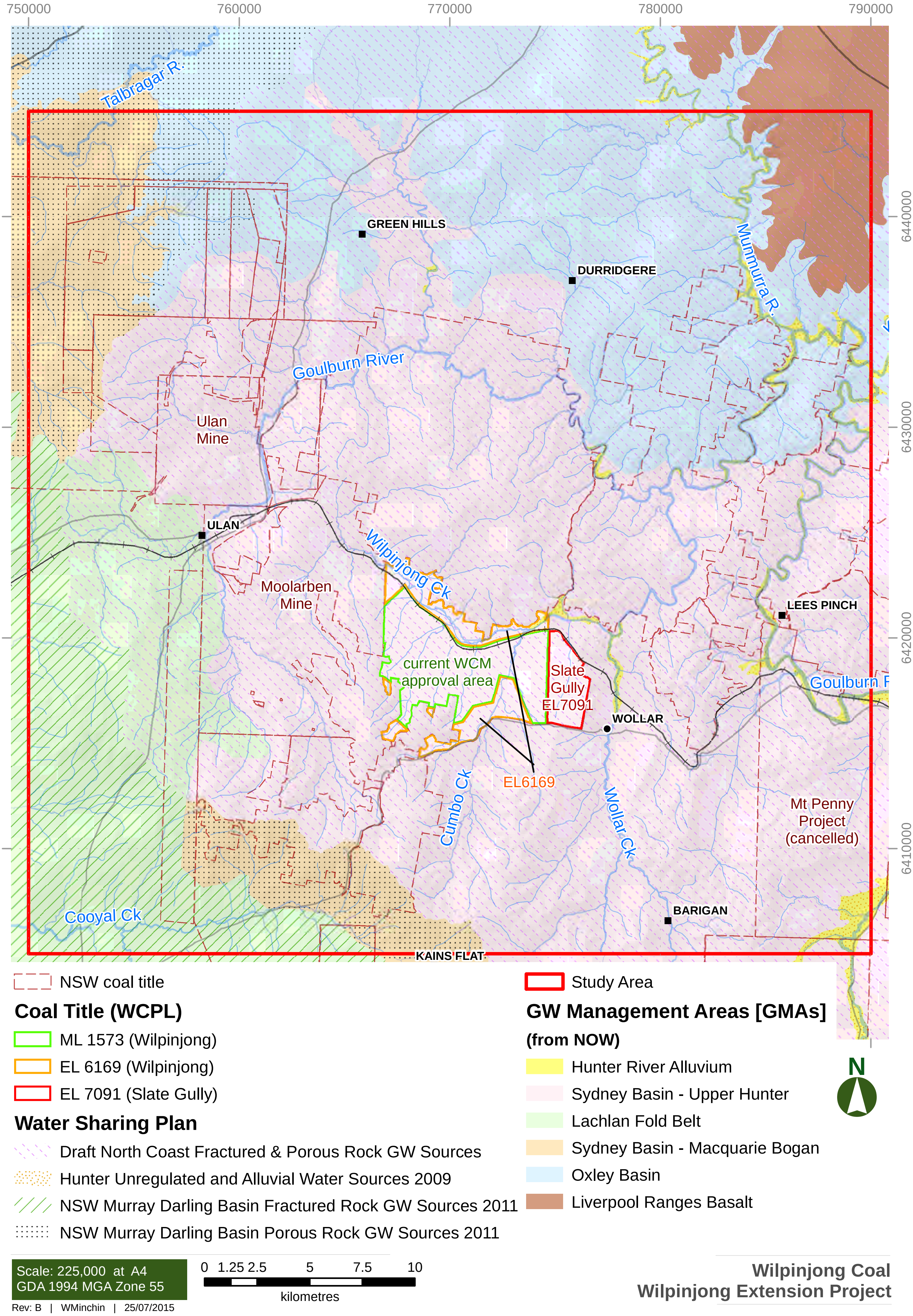
0 2.5 5 10 15 20
kilometres

Rev: B | WMinchin | 27/07/2015
C:\HydroSim\WIL006\GIS\Maps\Deliverable\WIL006_ProjectLocation_b.mxd

Wilpinjong Coal
Wilpinjong Extension Project

HYDRO SIMULATIONS

Project Location **Figure 1-1**



Rev: B | WMinchin | 25/07/2015
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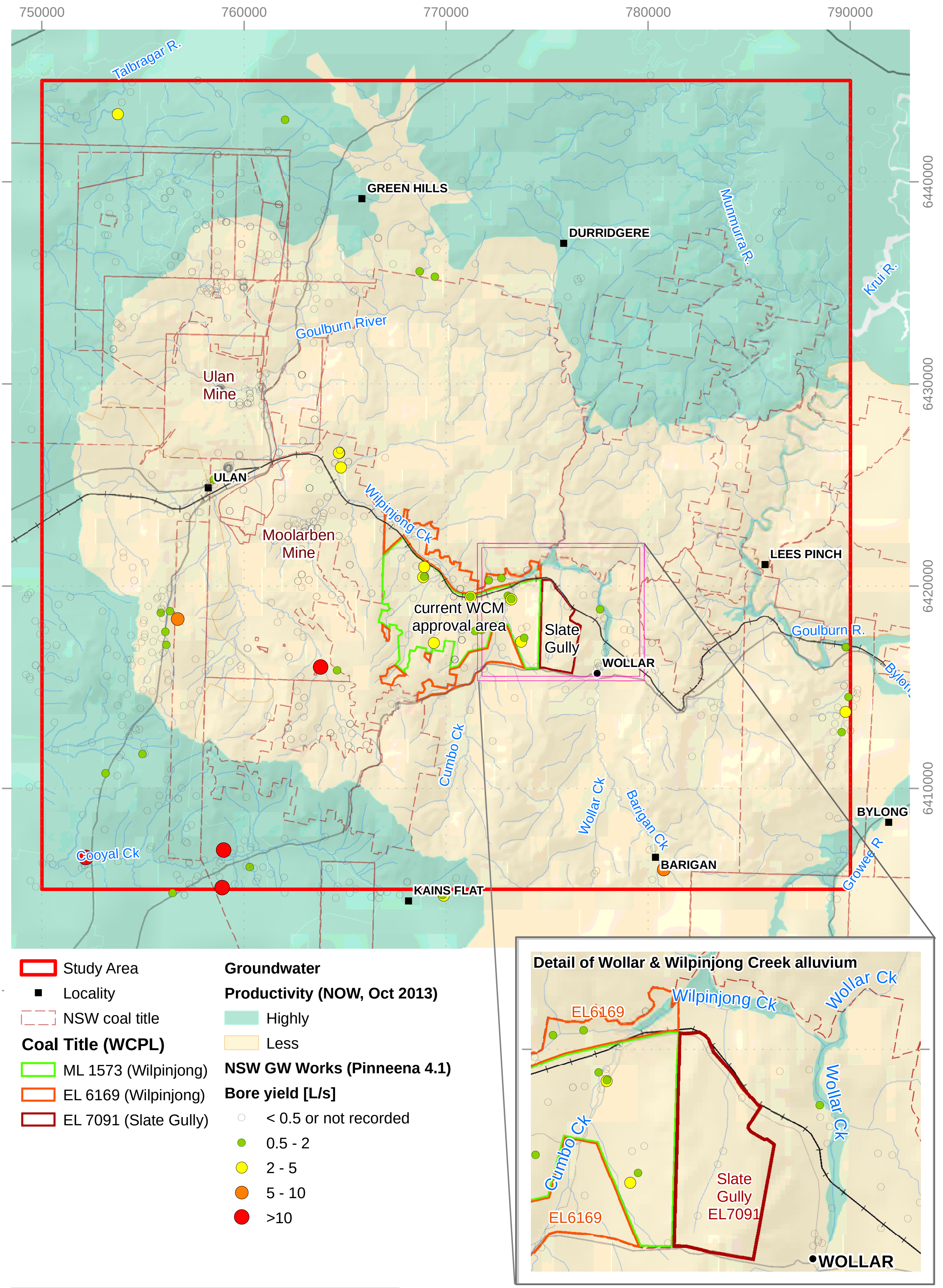
Wilpinjong Coal
Wilpinjong Extension Project

HydroSimulations

Groundwater Management Areas

Figure 1-2



Scale: 100,000 at A4
GDA 1994 MGA Zone 55

0 1.25 2.5 5 7.5 10
kilometres

Rev: B | WMinchin | 25/07/2015
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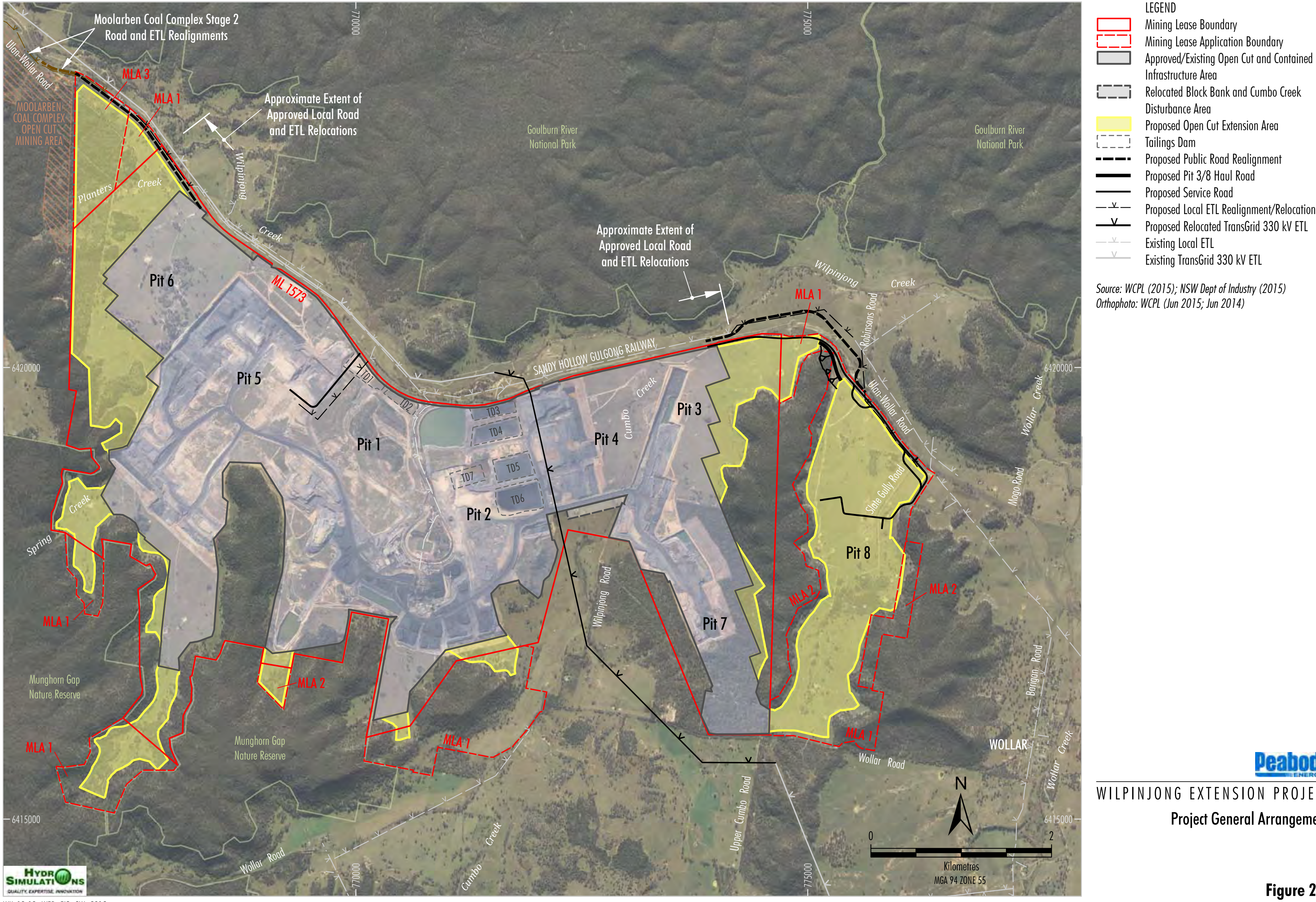
HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Groundwater Productivity

Figure 1-3



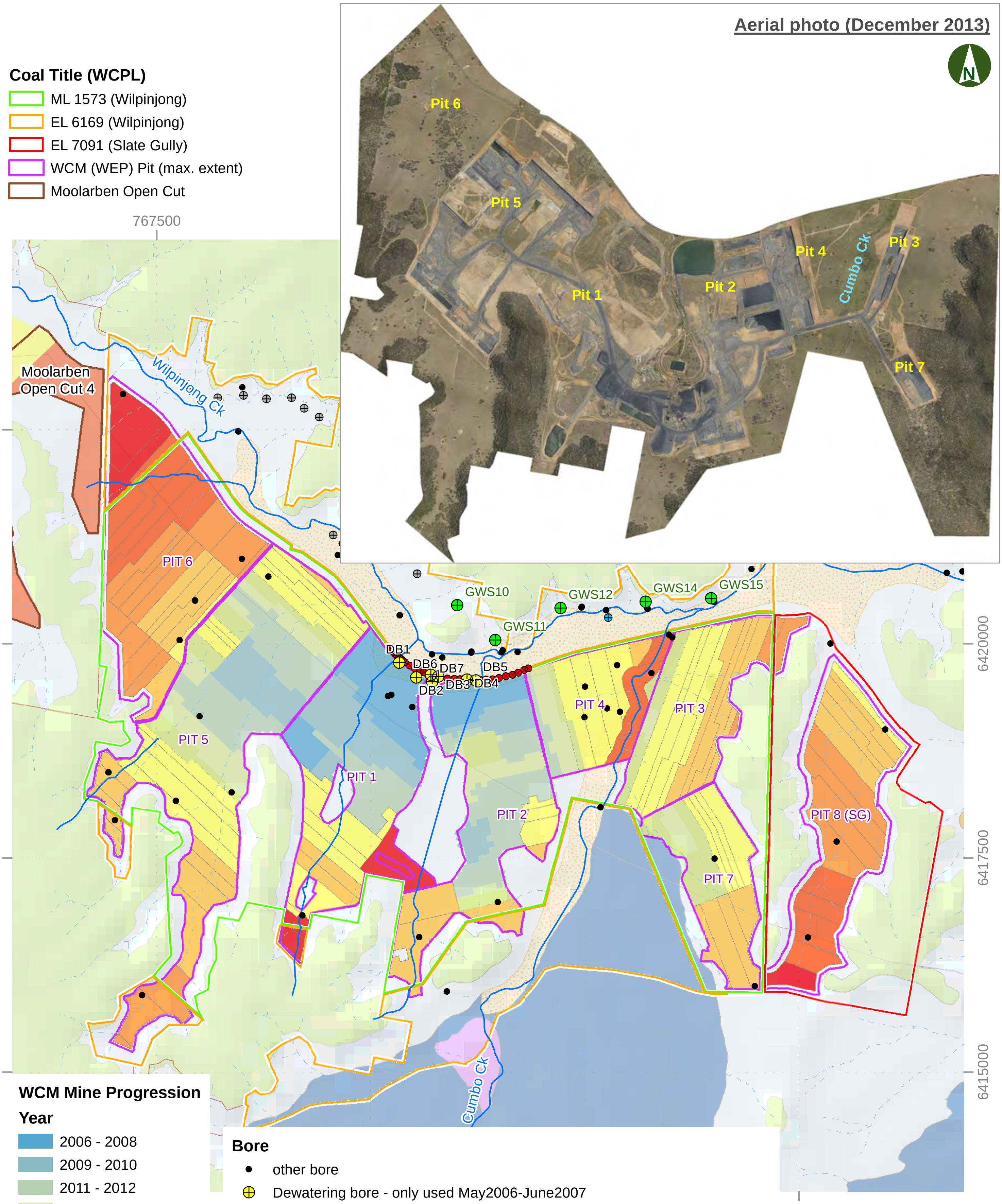
Source: WCPL (2015); NSW Dept of Industry (2015)
Orthophoto: WCPL (Jun 2015; Jun 2014)

WILPINJONG EXTENSION PROJECT

Project General Arrangement

Figure 2-1

WIL-12-12_WEP_EIS_GW_201C



Wilpinjong Coal
Wilpinjong Extension Project

Figure 2-2

Scale: 60,000
GDA 1994 MGA Zone 55

0 0.3 0.6 1.2 1.8 2.4 3 kilometres

C:\HydroSim\WIL006\GIS\Maps\Working\WIL006_WCM_MineSchedule_b.mxd
ProjNo: WIL-006 | Rev: B | Created by: WMinchin | Date: 28/07/2015

HydroSimulations

Mine Progression and Production Bores at WCM

Wilpinjong Coal Mine — EXCAVATION / Pumping Bores

Model Purpose	Stress Period	Start Date	End Date	Period Length	Cumul Days	PROJECT YEAR	PIT 1	PIT 2	PIT 3	PIT 4	PIT 5	PIT 6	PIT 7	PIT 8	Water Supply	Dewat-ering
Initialising	1 (SS)	31/12/2005	31/12/2005	1	1		"pre-development" steady state									
HISTORICAL	2	1/01/2006	30/04/2006	120	121											
	3	1/05/2006	30/06/2006	61	182		June									DB01-05
	4	1/07/2006	28/02/2007	243	425	1										
	5	1/03/2007	8/06/2007	100	525	1		March							WSB10-15	
	6	9/06/2007	31/12/2007	206	731	2										
	7	1/01/2008	30/06/2008	182	913	2										
	8	1/07/2008	30/11/2008	153	1066	3										
	9	1/12/2008	30/06/2009	212	1278	3					Dec					
	10	1/07/2009	31/12/2009	184	1462	4										
	11	1/01/2010	30/06/2010	181	1643	4										
	12	1/07/2010	31/12/2010	184	1827	5										
	13	1/01/2011	30/06/2011	181	2008	5										
	14	1/07/2011	31/12/2011	184	2192	6										
	15	1/01/2012	30/06/2012	182	2374	6										
	16	1/07/2012	31/12/2012	184	2558	7										
	17	1/01/2013	30/06/2013	181	2739	7			May				May			
	18	1/07/2013	31/12/2013	184	2923	8										
	19	1/01/2014	31/03/2014	90	3013	8										
	20	1/04/2014	30/06/2014	91	3104	8										
	21	1/07/2014	30/09/2014	92	3196	9										
	22	1/10/2014	31/12/2014	92	3288	9										
PREDICTION	23	1/01/2015	30/06/2015	181	3469	9										none
	24	1/07/2015	31/12/2015	184	3653	10									??	planned
	25	1/01/2016	30/06/2016	182	3835	10									??	
	26	1/07/2016	31/12/2016	184	4019	11									??	
	27	1/01/2017	30/06/2017	181	4200	11									??	
	28	1/07/2017	31/12/2017	184	4384	12									??	
	29	1/01/2018	30/06/2018	181	4565	12									??	
	30	1/07/2018	31/12/2018	184	4749	13									??	
	31	1/01/2019	30/06/2019	181	4930	13									??	
	32	1/07/2019	31/12/2019	184	5114	14									??	
	33	1/01/2020	30/06/2020	182	5296	15									??	
	34	1/07/2020	31/12/2020	184	5480	15									??	
	35	1/01/2021	30/06/2021	181	5661	15									??	
	36	1/07/2021	31/12/2021	184	5845	16									??	
	37	1/01/2022	30/06/2022	181	6026	16									??	
	38	1/07/2022	31/12/2022	184	6210	17									??	
	39	1/01/2023	30/06/2023	181	6391	17									??	
	40	1/07/2023	31/12/2023	184	6575	18									??	
	41	1/01/2024	30/06/2024	182	6757	19									??	
	42	1/07/2024	31/12/2024	184	6941	19									??	
	43	1/01/2025	30/06/2025	181	7122	20									??	
	44	1/07/2025	31/12/2025	184	7306	20									??	
	45	1/01/2026	30/06/2026	181	7487	20				Cumbo					??	
	46	1/07/2026	31/12/2026	184	7671	21				relocat'n					??	
	47	1/01/2027	30/06/2027	181	7852	21				south					??	
	48	1/07/2027	31/12/2027	184	8036	22									??	
	49	1/01/2028	30/06/2028	182	8218	23				Cumbo					??	
	50	1/07/2028	31/12/2028	184	8402	23				Creek					??	
	51	1/01/2029	30/06/2029	181	8583	24									??	
	52	1/07/2029	31/12/2029	184	8767	24				north					??	
	53	1/01/2030	30/06/2030	181	8948	25									??	
	54	1/07/2030	31/12/2030	184	9132	25									??	
	55	1/01/2031	30/06/2031	181	9313	25									??	
	56	1/07/2031	31/12/2031	184	9497	26									??	
	57	1/01/2032	30/06/2032	182	9679	27								Void	??	
	58	1/07/2032	31/12/2032	184	9863	27								S of	??	
	59	1/01/2033	30/06/2033	181	10044	28								Pit 8	??	
	60	1/07/2033	31/12/2033	184	10228	28									??	
RECOVERY	61	1/01/2034	31/12/2034	365	10593	R1		Void				Void				
	62	1/01/2035	31/12/2035	365	10958	R2		in				NW of				
	63	1/01/2036	31/12/2036	366	11324	R3		Pit2W				Pit 6				
	64	1/01/2037	31/12/2037	365	11689	R5										
	65	1/01/2038	31/12/2038	365	12054	R6										
	66	1/01/2039	31/12/2040	731	12785	R8										
	67	1/01/2041	31/12/2042	730	13515	R10										
	68	1/01/2043	31/12/2045	1096	14611	R13										
	69	1/01/2046	31/12/2050	1826	16437	R18										
	70	1/01/2051	31/12/2060	3653	20090	R28										
	71	1/01/2061	31/12/2070	3652	23742	R38										
	72	1/01/2071	31/12/2080	3653	27395	R48										
	73	1/01/2081	31/12/2090	3652	31047	R58										
	74	1/01/2091	31/12/2100	3652	34699	R68		Void				Void		Void		
	75	1/01/2101	31/12/2200	36524	71223	R168		NW of				NW of		S of		
	76	1/01/2201	31/12/2300	36524	107747	R268		NW of				NW of		S of		

(recovery of >100 years)

(void areas have modified hydraulic properties, including Sy = 1, and recharge = rainfall, ET = Pot Evap)

Moolarben — Open Cut / Underground — EXCAVATION

Stress Period	OC 1	OC 2	OC 3	OC 4	UG 1	UG 2	UG 4	Bore-field
1 (SS)	"pre-development"							
2								
3								
4								
5								
6								
7								
8								
9								
10								
11	May							
12	OC1							
13								
14								
15								
16								
17								
18								
19								
20		OC2						
21								
22								
23								
24				OC4	dev head			
25					dev head			
26					UG1			
27								
28								
29	Void							
30	near							
31	Goulburn							
32	River							
33								
34								
35								
36						dev head		
37						dev head		
38						dev head		
39						dev head		
40						dev head		
41						UG2		
42								
43								
44								
45								
46								
47								
48							dev head	
49							dev head	
50							dev head	
51							UG4	
52								
53								
54			OC3					
55								
56								
57								
58								
59								
60								
61								
62			Void					
63			near	Void				
64			Moolar-	adjacent				
65			ben Ck	to WEP				
66				Pit 6				
67								
68							2044	
69								
70								
71								
72								
73								
74								
75								
76								

(timing based on Stage 1 Modification 9 and Stage 2 PPR)

Wilpinjong Coal Mine 39 217.09 — RECHARGE TO OPEN CUT AREAS \ SPOIL

Stress Period	PIT 1	PIT 2	PIT 3	PIT 4	PIT 5	PIT 6	PIT 7	PIT 8
1 (SS)	natural	natural	natural	natural	natural	natural	natural	natural
2	natural	natural	natural	natural	natural	natural	natural	natural
3	natural	natural	natural	natural	natural	natural	natural	natural
4	natural	natural	natural	natural	natural	natural	natural	natural
5	natural	natural	natural	natural	natural	natural	natural	natural
6	5%	natural	natural	natural	natural	natural	natural	natural
7	5%	5%	natural	natural	natural	natural	natural	natural
8	5%	5%	natural	natural	natural	natural	natural	natural
9	5%	5%	natural	natural	natural	natural	natural	natural
10	5%	5%	natural	natural	natural	natural	natural	natural
11	5%	5%	natural	natural	natural	natural	natural	natural
12	5%	5%	natural	natural	5%	natural	natural	natural
13	5%	5%	natural	natural	5%	natural	natural	natural
14	5%	5%	natural	natural	5%	natural	natural	natural
15	5%	5%	natural	natural	5%	natural	natural	natural
16	5%	5%	natural	natural	5%	natural	natural	natural
17	5%	5%	natural	5%	5%	natural	natural	natural
18	5%	5%	natural	5%	5%	natural	natural	natural
19	5%	5%	natural	5%	5%	natural	5%	natural
20	5%	5%	natural	5%	5%	natural	5%	natural
21	5%	5%	5%	5%	5%	natural	5%	natural
22	5%	5%	5%	5%	5%	natural	5%	natural
23	5%	5%	5%	5%	5%	natural	5%	natural
24	5%	5%	5%	5%	5%	natural	5%	natural
25	5%	5%	5%	5%	5%	natural	5%	natural
26	5%	5%	5%	5%	5%	natural	5%	natural
27	5%	5%	5%	5%	5%	natural	5%	natural
28	5%	5%	5%	5%	5%	natural	5%	natural
29	5%	5%	5%	5%	5%	5%	5%	natural
30	5%	5%	5%	5%	5%	5%	5%	natural
31	5%	5%	5%	5%	5%	5%	5%	5%
32	5%	5%	5%	5%	5%	5%	5%	5%
33	5%	5%	5%	5%	5%	5%	5%	5%
34	5%	5%	5%	5%	5%	5%	5%	5%
35	5%	5%	5%	5%	5%	5%	5%	5%
36	5%	5%	5%	5%	5%	5%	5%	5%
37	5%	5%	5%	5%	5%	5%	5%	5%
38	5%	5%	5%	5%	5%	5%	5%	5%
39	5%	5%	5%	5%	5%	5%	5%	5%
40	5%	5%	5%	5%	5%	5%	5%	5%
41	5%	5%	5%	5%	5%	5%	5%	5%
42	5%	5%	5%	5%	5%	5%	5%	5%
43	5%	5%	5%	5%	5%	5%	5%	5%
44	5%	5%	5%	5%	5%	5%	5%	5%
45	5%	5%	5%	5%	5%	5%	5%	5%
46	5%	5%	5%	5%	5%	5%	5%	5%
47	5%	5%	5%	5%	5%	5%	5%	5%
48	5%	5%	5%	5%	5%	5%	5%	5%
49	5%	5%	5%	5%	5%	5%	5%	5%
50	5%	5%	5%	5%	5%	5%	5%	5%
51	5%	5%	5%	5%	5%	5%	5%	5%
52	5%	5%	5%	5%	5%	5%	5%	5%
53	5%	5%	5%	5%	5%	5%	5%	5%
54	5%	5%	5%	5%	5%	5%	5%	5%
55	5%	5%	5%	5%	5%	5%	5%	5%
56	5%	5%	5%	5%	5%	5%	5%	5%
57	5%	5%	5%	5%	5%	5%	5%	100%
58	5%	5%	5%	5%	5%	5%	5%	5%
59	5%	5%	5%	5%	5%	5%	5%	5%
60	5%	5%	5%	5%	5%	5%	5%	5%
61	5%	100%	5%	5%	5%	100%	5%	5%
62	5%	5%	5%	5%	5%	5%	5%	5%
63	5%	5%	5%	5%	5%	5%	5%	5%
64	5%	5%	5%	5%	5%	5%	5%	5%
65	5%	5%	5%	5%	5%	5%	5%	5%
66	5%	5%	5%	5%	5%	5%	5%	5%
67	5%	5%	5%	5%	5%	5%	5%	5%
68	5%	5%	5%	5%	5%	5%	5%	5%
69	5%	5%	5%	5%	5%	5%	5%	5%
70	5%	5%	5%	5%	5%	5%	5%	5%
71	5%	5%	5%	5%	5%	5%	5%	5%
72	5%	5%	5%	5%	5%	5%	5%	5%
73	5%	5%	5%	5%	5%	5%	5%	5%
74	5%	5%	5%	5%	5%	5%	5%	5%
75	5%	5%	5%	5%	5%	5%	5%	5%
76	5%	5%	5%	5%	5%	5%	5%	5%

highlighted cells indicate when new areas being backfilled

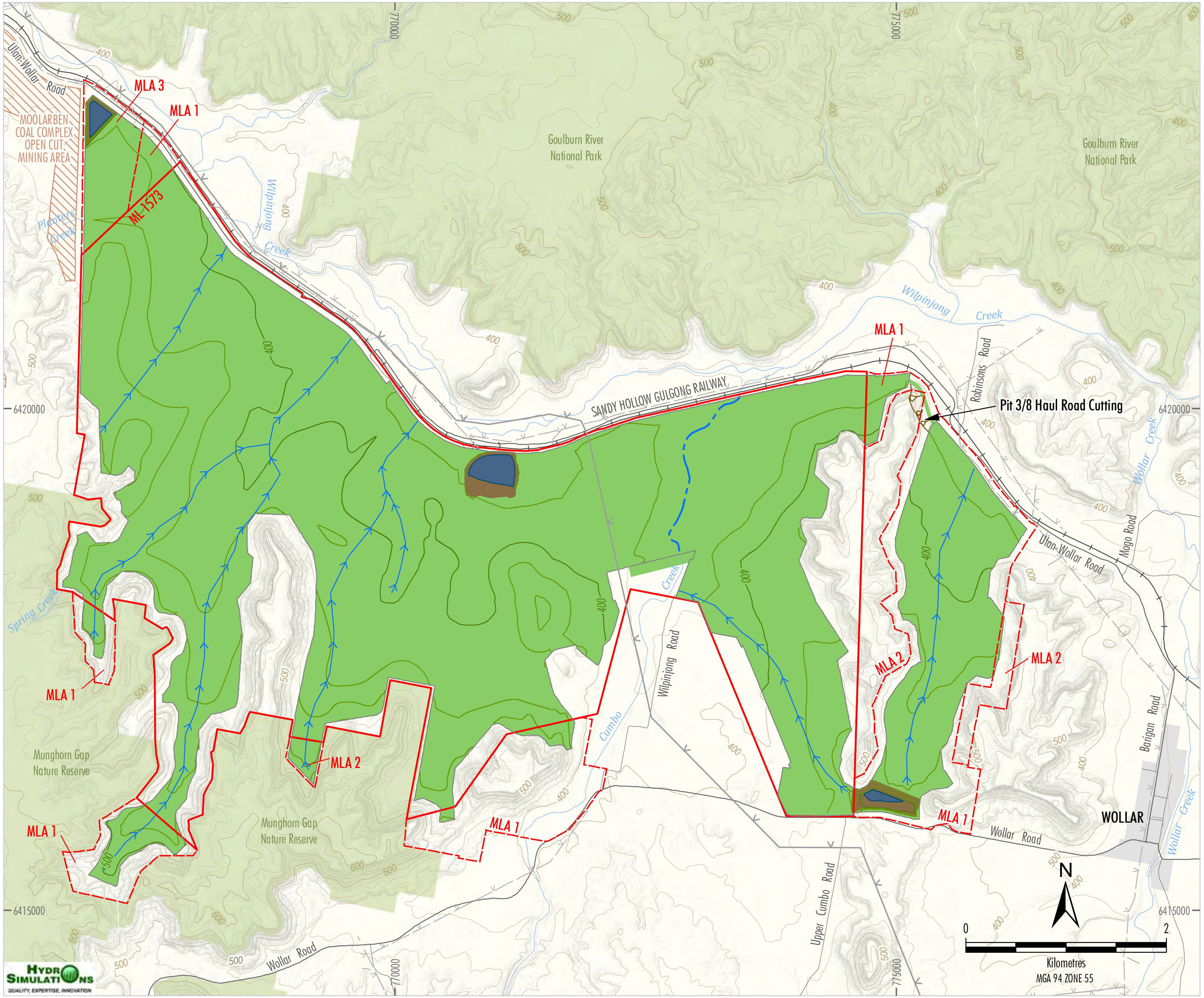
100% indicates direct rainfall simulated on final void (from that time onward)

DAMS / TAILINGS DAMS

Stress Period	Pit1 South	RWD (pit 2)	Pit2 West	CWD (pit 1)	Ed's Lake (pit 1)	CWD-1 (pit 8)	CWD-2 (pit 8)	TAILINGS DAMS
1 (SS)	"pre-development"							
2								
3								
4		early 2007		early 2007				
5								TD 1
6			mining		mining			(pit 1)
7			end-2007		mining			
8								
9								TD 2
10					mid-2009			(pit 1)
11								TD 3
12								(pit 2)
13	mining							
14	late 2011							TD 4
15								(pit 2)
16								TD 5
17								(pit 2)
18								
19					October			TD 6
20					SEDIMENT			(pit 2)
21					DAM			
22								
23								Apr-15
24								TD 7
25	pump-down							(pit 2)
26	pump-down							
27	expanded					2017		conting-
28	area							ency
29								only
30								
31								
32								
33	pump-down							
34	pump-down							
35								
36								
37							2022	
38								
39						2023		
40								
41								
42								
43								
44								
45								
46							2026-27	
47								
48								
49								
50								
51	pump-down							
52	pump-down							
53	pump-down							
54	RO brine							
55	2031							
56								
57		mining						
58								
59								
60								
61			becomes					
62			Pit 2 void					
63								
64								
65								
66								
67								
68								
69								
70								
71								
72								
73								
74								
75								
76								

WCPL report that all dams and storages are unlined

Figure 2-3 Comparative Schedule of Mine Development



WIL-12-12_WEP_EIS_GW_203F

LEGEND

- Mining Lease Boundary
- Mining Lease Application Boundary
- Established Rehabilitation
- Final Void
- Final Void Waterbody [1]
- Conceptual Cumbo Creek Realignment
- Drainage Line
- Existing Surface Contour
- Final Landform Contour
- Local ETL
- Realigned TransGrid 330 kV ETL

[1] Pit 8 Final Void is predicted to be dry during periods of low rainfall.

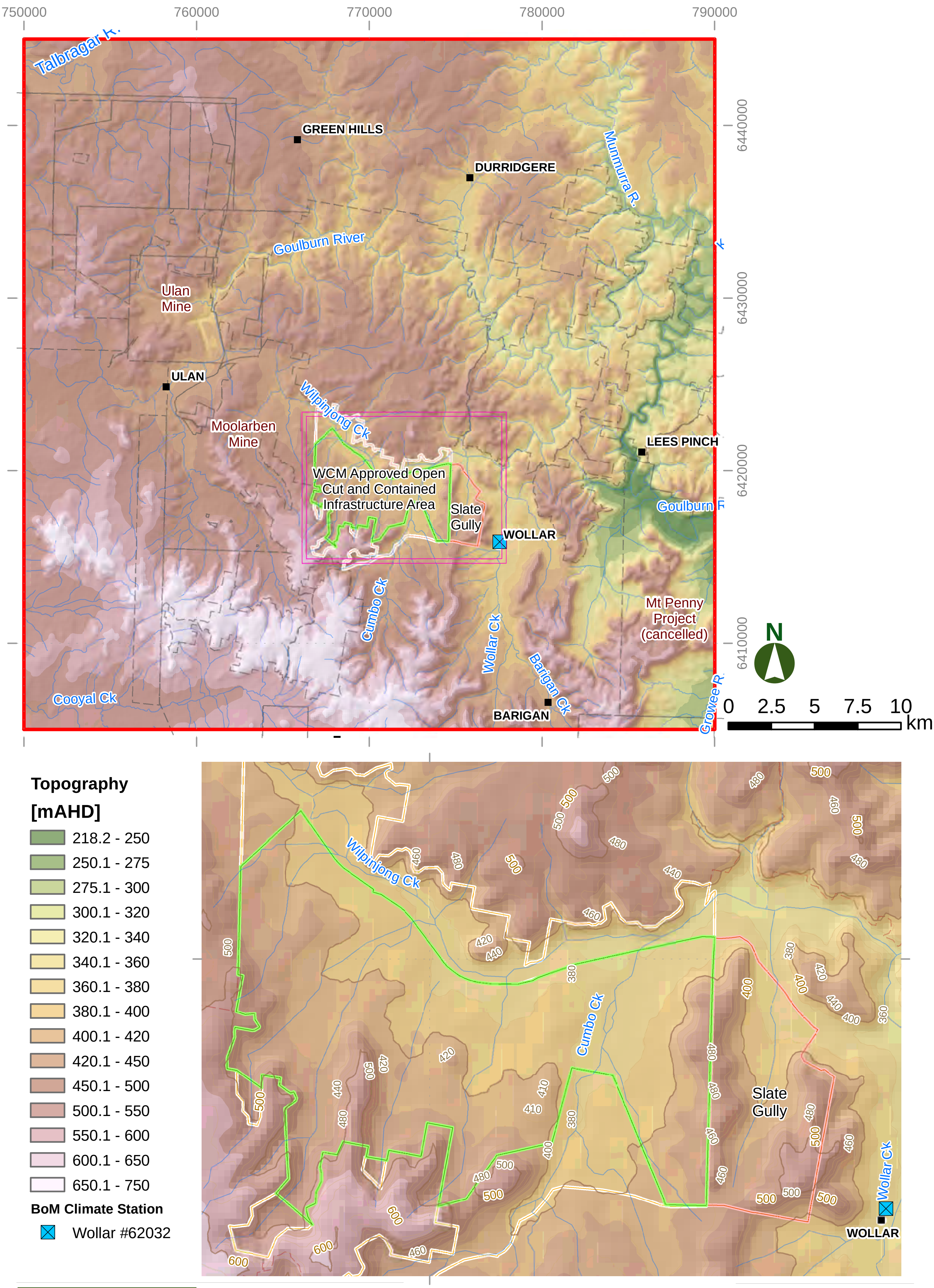
Source: WCPL (2015); NSW Dept of Industry (2015); NSW Land & Property Information (2015)

Peabody ENERGY

WILPINJONG EXTENSION PROJECT

Post-mining Landform and Final Voids

Figure 2-4



Scale: 280,000 at A4
GDA 1994 MGA Zone 55

0 0.5 1 2 3 km

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HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Topography

Figure 3-1

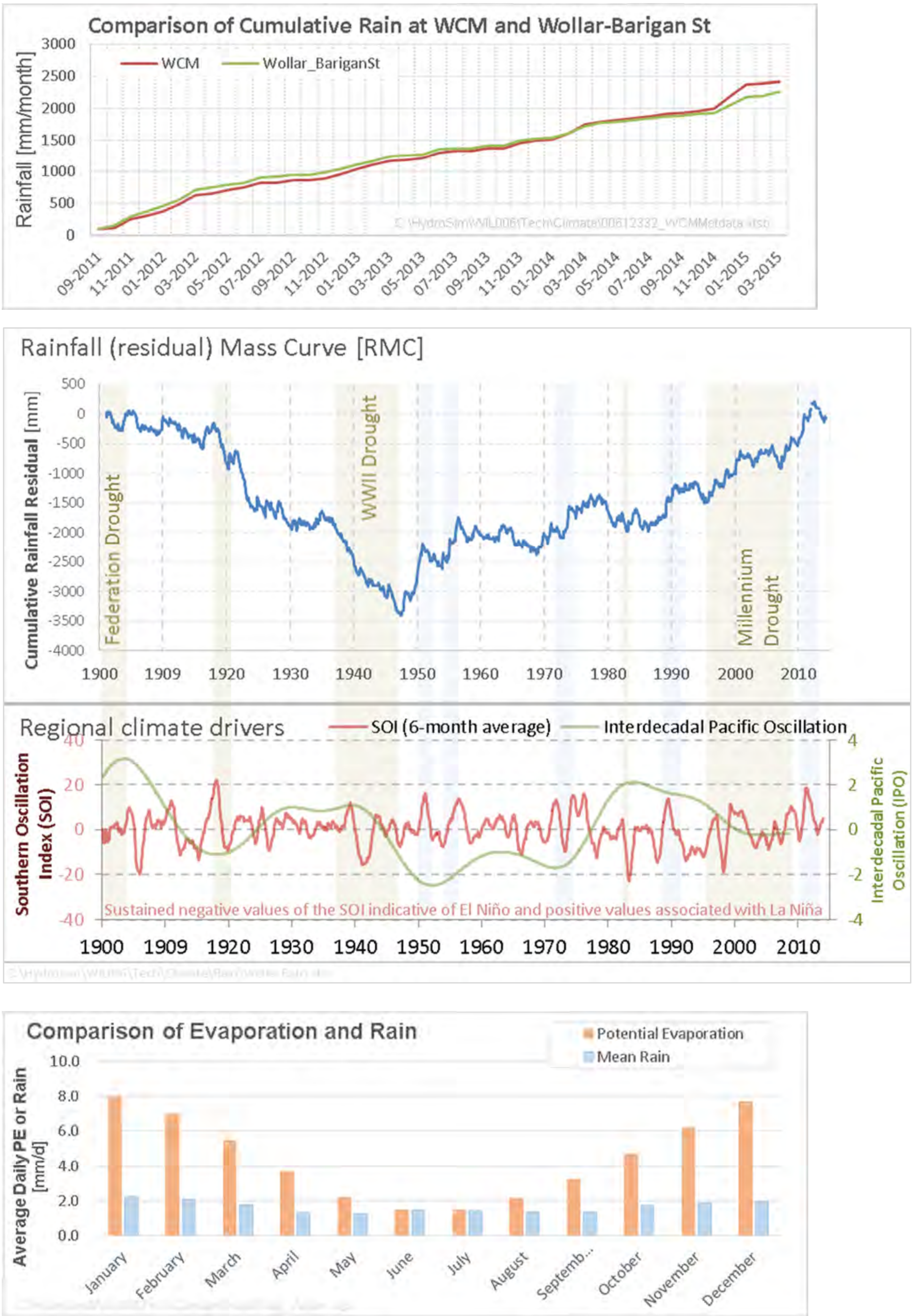
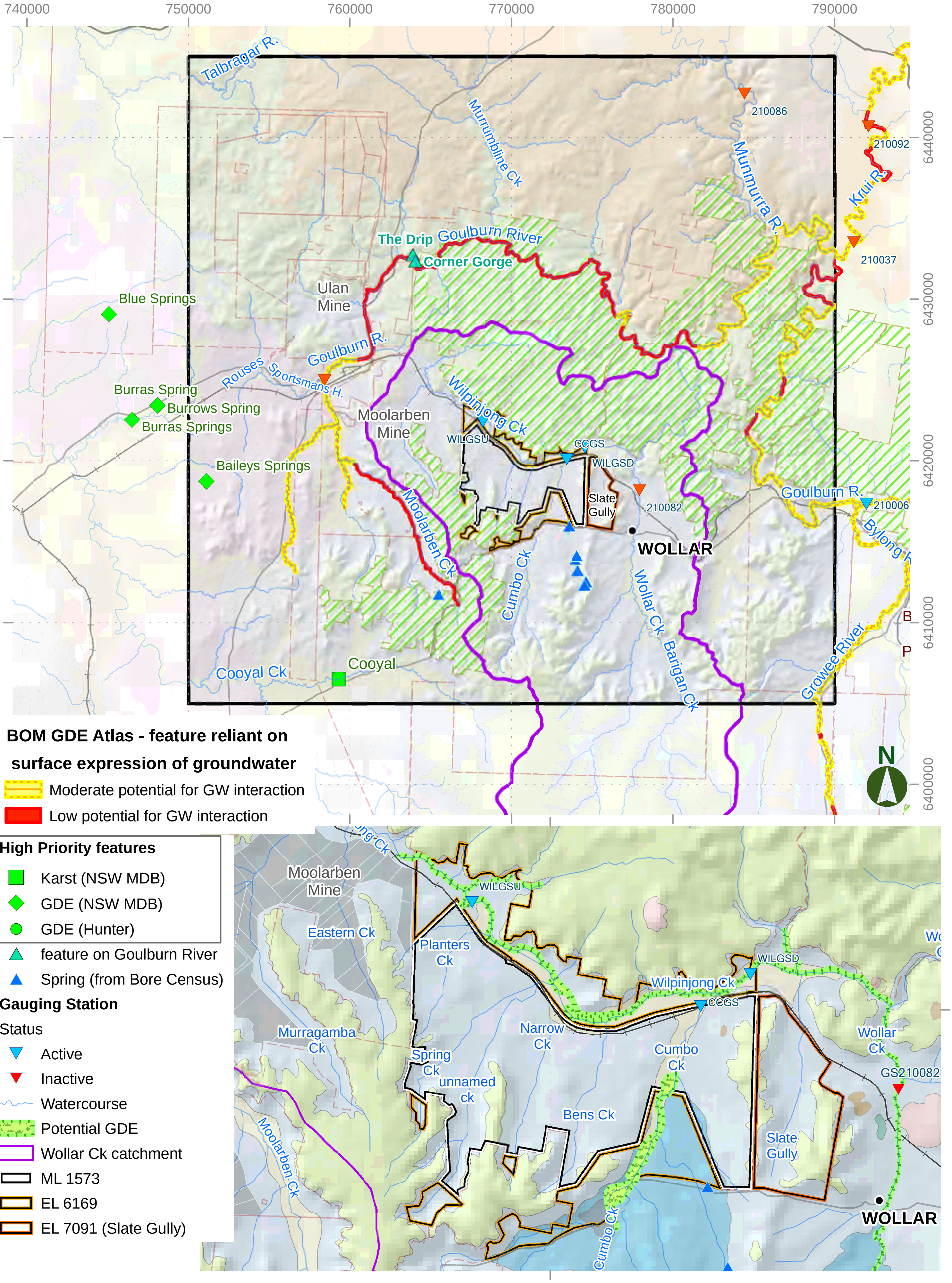


Figure 3-2 Summary of Rainfall and Evaporation at WCM



Scale: 110,000 at A4
GDA 1994 MGA Zone 55

0 1.5 3 6 9 12
kilometres

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HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Drainage Network and Environmental Features

Figure 3-3

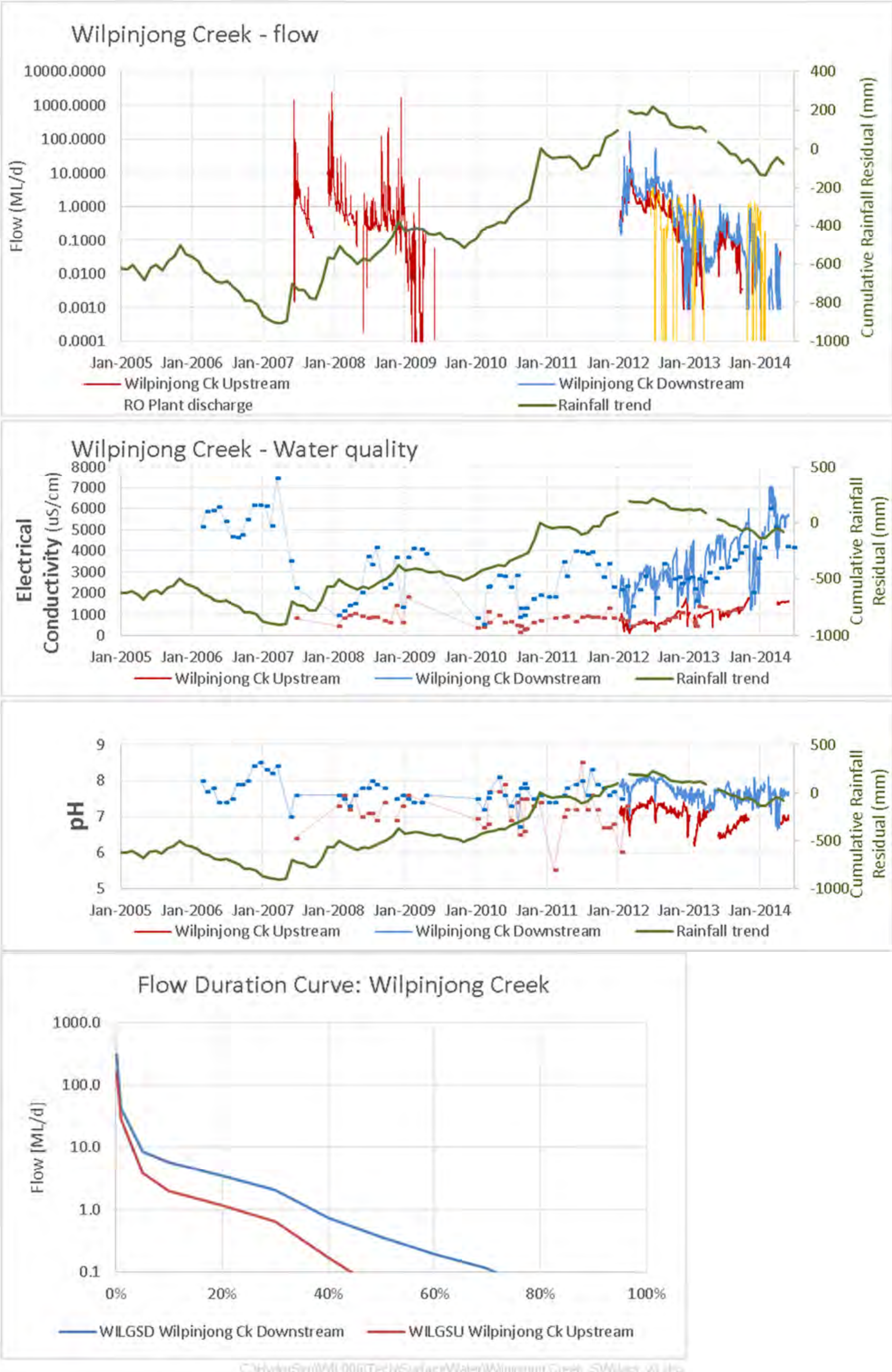


Figure 3-4 Summary of Flow in Local Watercourses

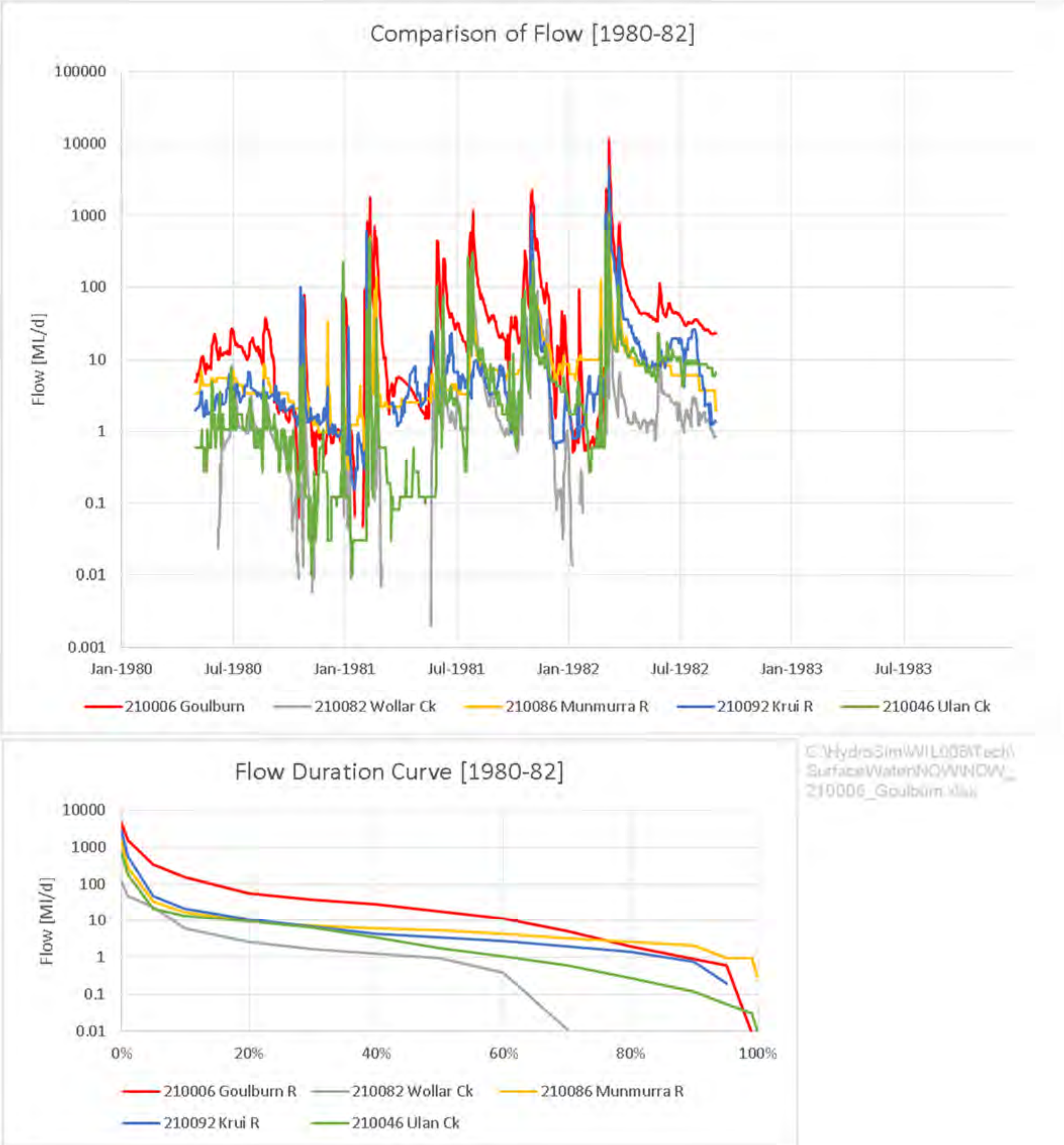
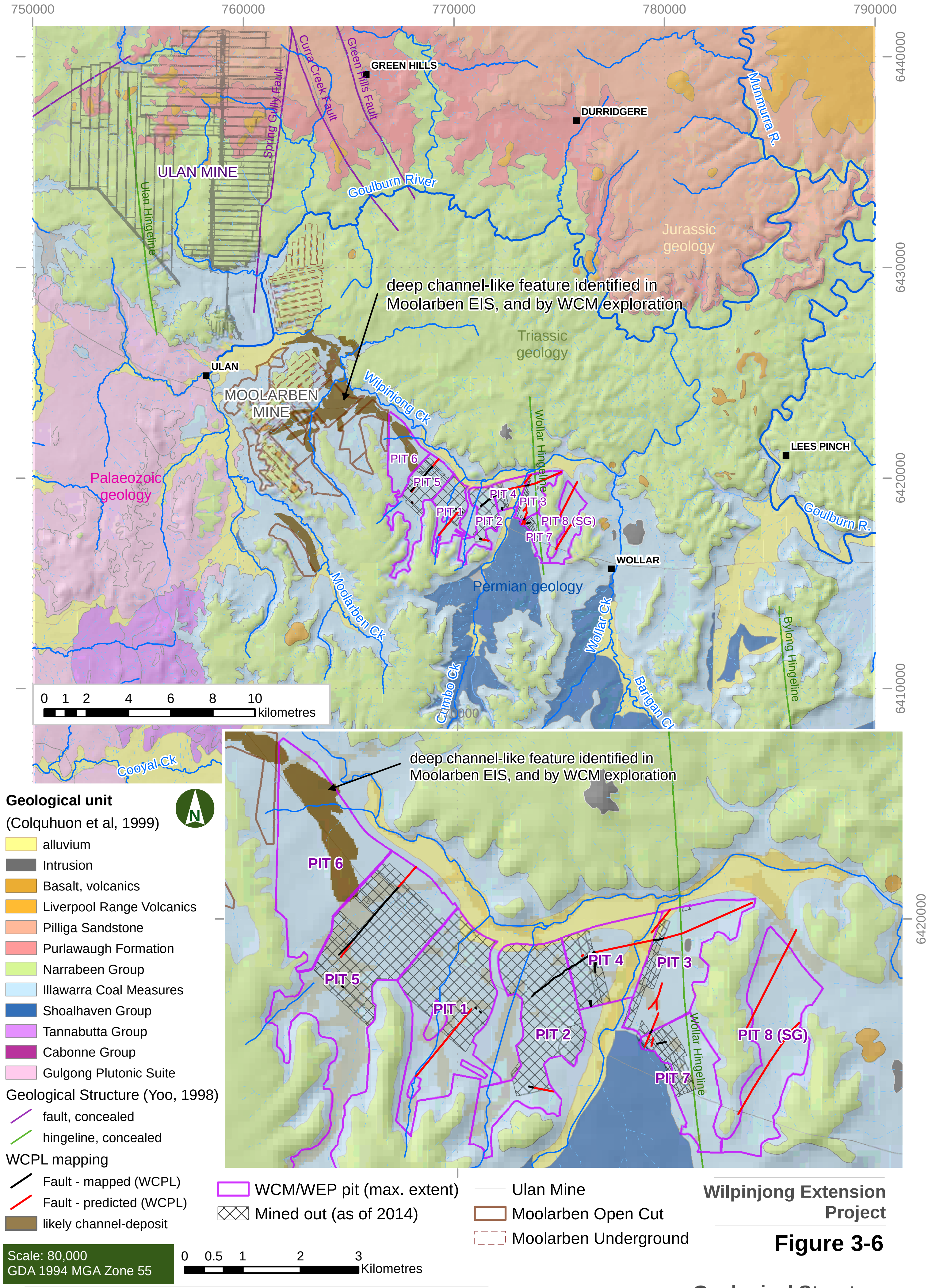


Figure 3-5 Flow in Watercourses in the Region around WCM



Wilpinjong Extension Project

Figure 3-6

Geological Structure and Outcrop Mapping

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ProjNo: WIL-006 | Rev: C | Created by: WMinchin | Date: 10/09/2015

HydroSimulations

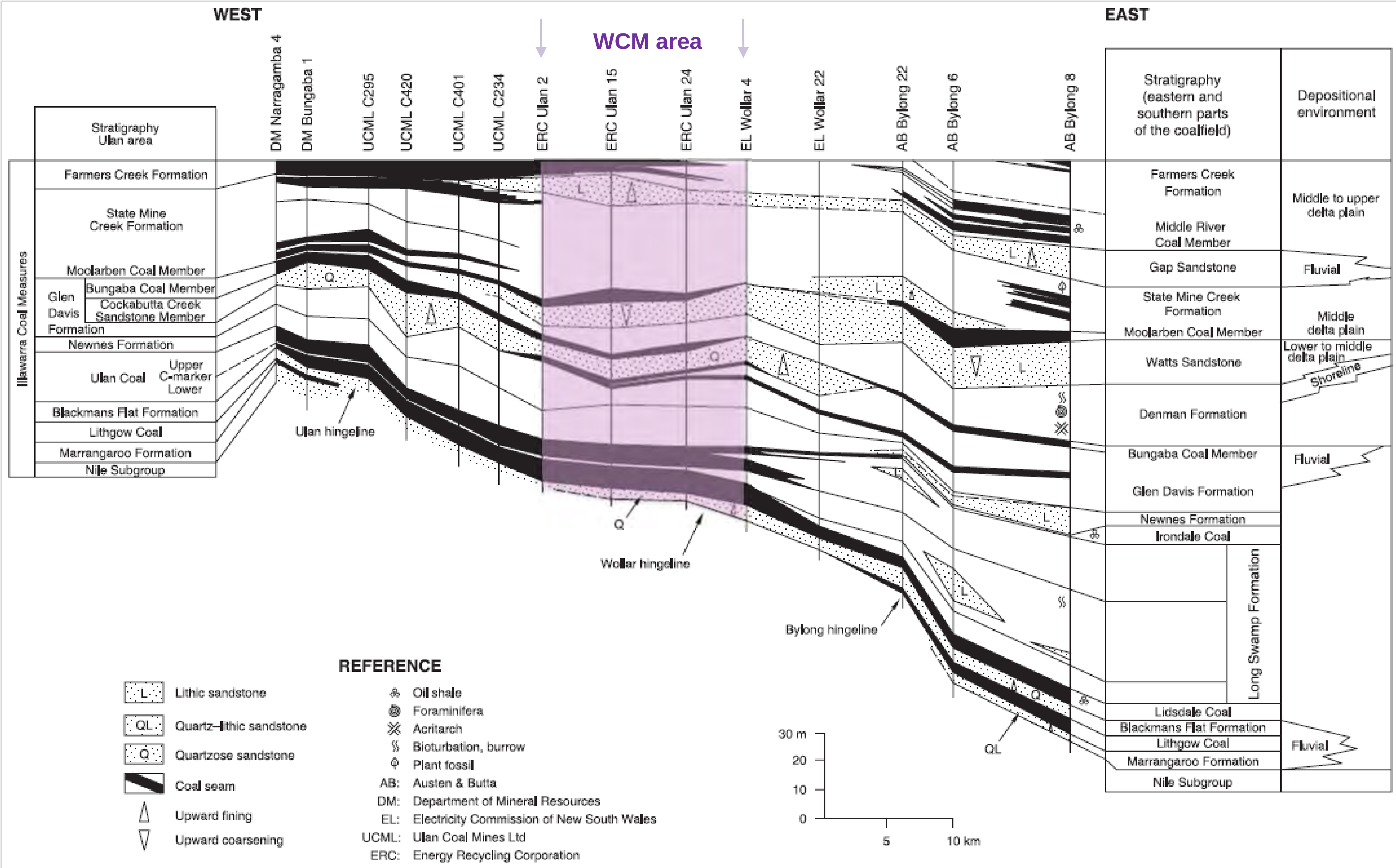
Age	age approx	Group	Subgroup	Name		lithology
Quaternary – recent						alluvium
Tertiary						alluvium, colluvium
	<66 Mya					various volcanics / basalts
Jurassic	<200 Mya					various igenous intrusions / breccia
				Pilliga Sandstone		pebbly, lithic sandstone
				Purlawaugh Formation		Sandstone, mudstone, claystone, coal
				intrusions		e.g. syenite, latite
Triassic	200 Mya			intrusions		e.g. syenite, latite
				Napperby Formation		
	210 Mya	**Narrabeen Grp**				
						Sandstone / siltstone
						Lithic sandstone
	230 Mya					Conglomerate
Permian		**Illawarra Coal Measures**		Farmers Creek Fm		
				State Mine Creek Fm		
				Moolarben Coal Member		
				Bungaba Coal Member		
				Cockabutta Creek Sandstone		
				Glen Davis Formation		
				Newnes Formation		
				Ulan Seam	upper C-marker lower	
				Blackmans Flat Conglomerate		
				Lithgow Coal		
				Marrangaroo Conglomerate		
			Nile Subgroup			
		Sholhaven Group				
	260 Mya			Rylstone Volcanics		
Carboniferous						granites, undifferentiated
Devonian						undifferentiated
Silurian						undifferentiated
Ordovician						undifferentiated

adapted from:

Yoo, 1998 *Western Coalfield Regional Geology (northern part) 1:100 000, 1st edition. Geological Survey of New South Wales, Sydney.*

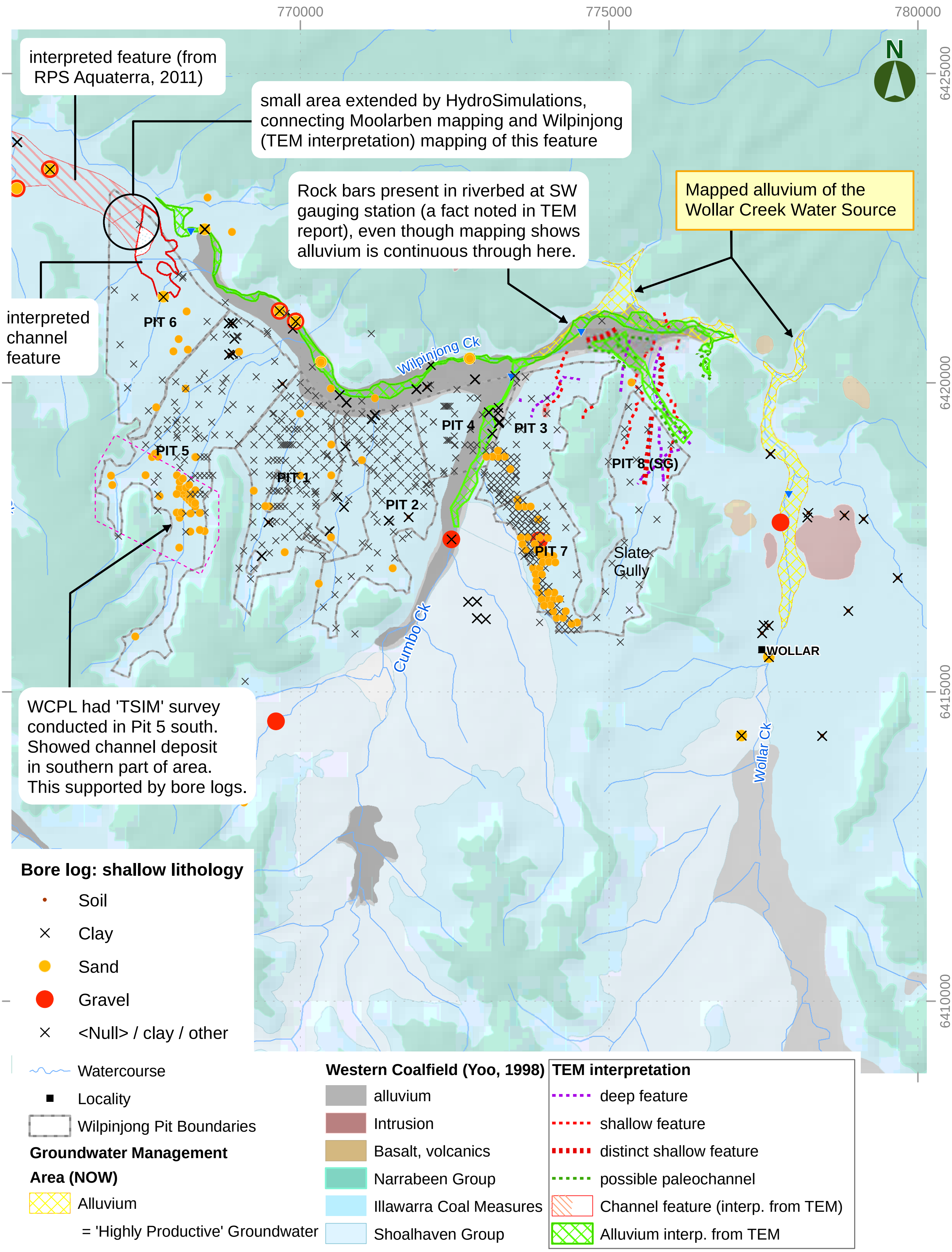
C:\HydroSim\WIL006\Model\GeologicalModel\[ModelLayers Comparison.xlsx]StratColumn_report

Figure 3-7 Stratigraphy of the Western Coalfield



(from Yoo *et al*, 2001)

Figure 3-8 Stratigraphic Correlation within the Illawarra Coal Measures in the Western Coalfield



Scale: 80,000
GDA 1994 MGA Zone 55

0 0.5 1 2 3 kilometres

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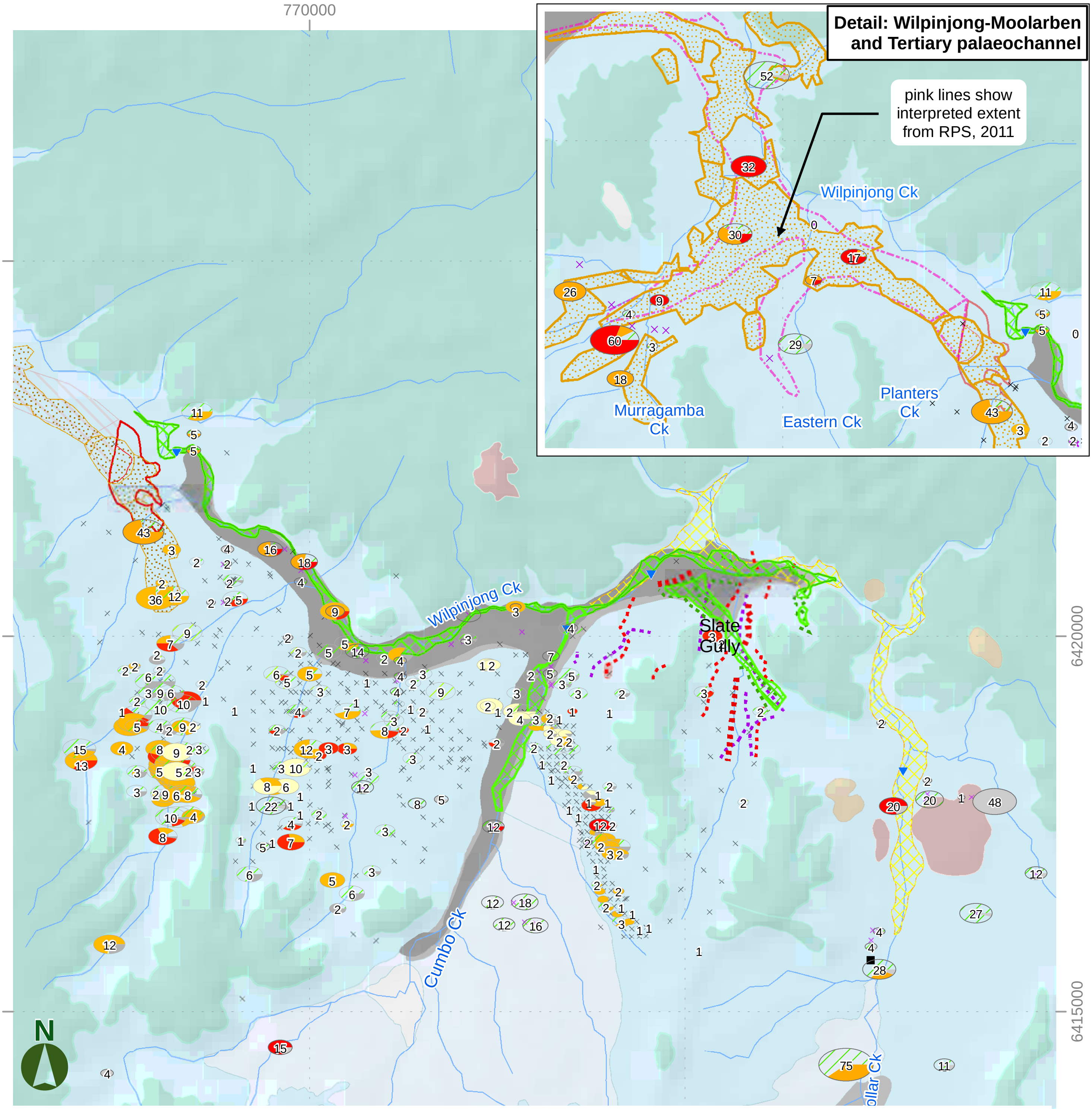
ProjNo: WIL-006 | Rev: D | Created by: WMinchin | Date: 19/11/2015

HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Figure 3-9
Comparison of Alluvium Mapping near Wilpinjong Coal Mine



Lithological summary from bore logs

sized by total thickness of unconsolidated material, [in metres]

8.8

- Clay
- Silt
- Sand
- Gravel
- Alluvium
- Soil

This is included where raw data simply stated "alluvium" with no further info on grain-size.

- GW work (bore)
- Exploration Bore
- alluvium
- Intrusion
- Basalt, volcanics
- Narrabeen Group
- Illawarra Coal Measures
- Shoalhaven Group

Groundwater Management Area (NOW)

Alluvium = 'Highly Productive' GW

TEM interpretation

- deep feature
- shallow feature
- distinct shallow feature
- possible paleochannel
- Alluvium (Yoo, 1998)

RPS (2011) or GW Imaging (2014)

- Tertiary Palaeochannel interp.
- Alluvium interp. from TEM

"Sandrock" / Palaeochannel

- (interp. from this study)

Scale: 75,000
GDA 1994 MGA Zone 55

0 0.5 1 2 3 kilometres

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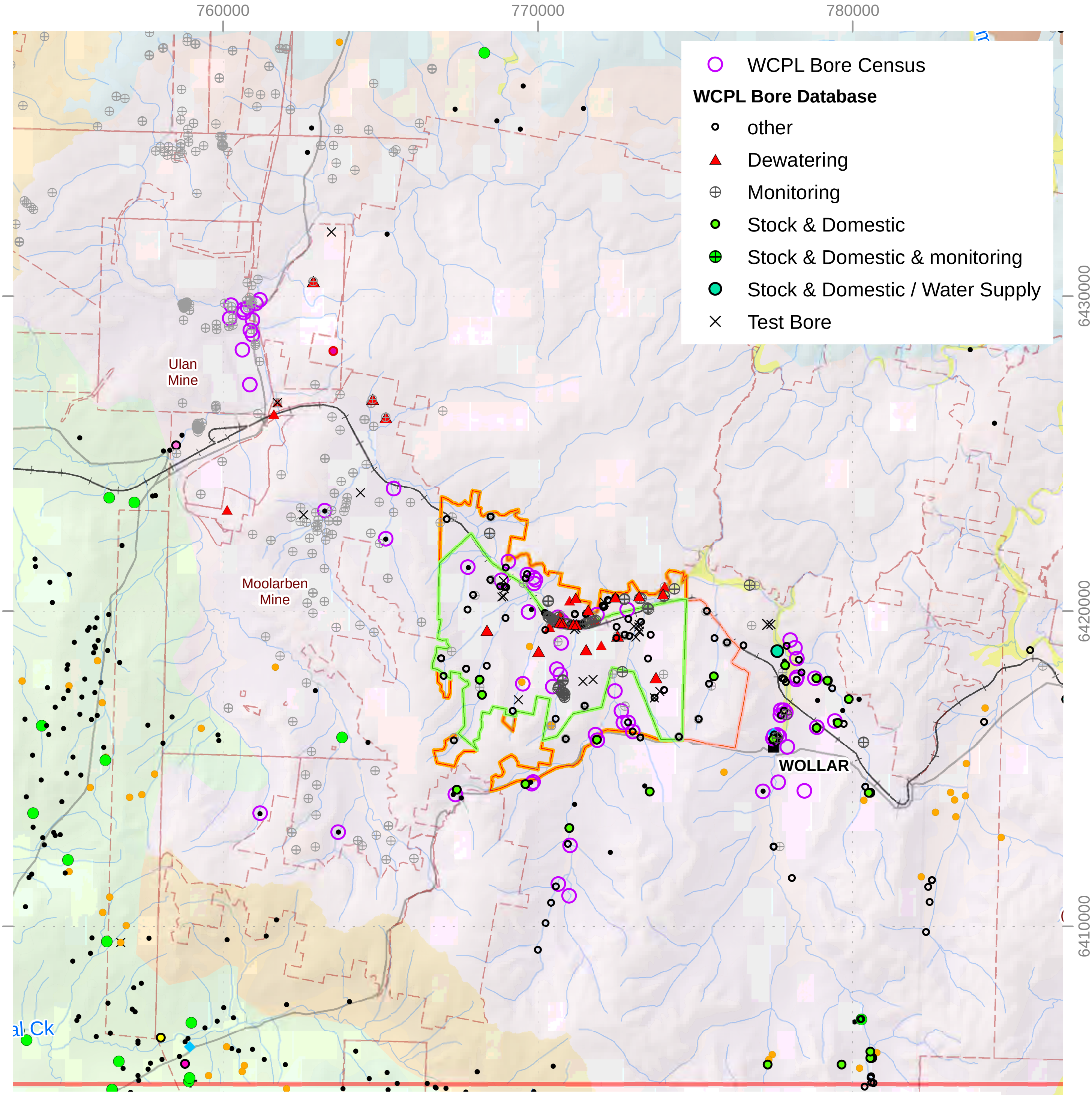
ProjNo: WIL-006 | Rev: B | Created by: WMinchin | Date: 03/08/2015

HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Figure 3-10

Depth and Lithology of Unconsolidated Sediments



Registered Bore / Works

Purpose (Pinneena 4.1)

- COMMERCIAL
- CONSERVATION OF WATER,STOCK
- DOMESTIC
- DOMESTIC,FARMING,STOCK
- DOMESTIC,INDUSTRIAL,IRRIGATION,STOCK
- DOMESTIC,STOCK
- PISCICULTURE,DOMESTIC,IRRIGATION,STOCK
- FIRE FIGHTING,MONITORING BORE,STOCK
- INDUSTRIAL
- INDUSTRIAL,IRRIGATION
- INDUSTRIAL,MINING
- IRRIGATION
- DOMESTIC,IRRIGATION
- IRRIGATION,STOCK
- DOMESTIC,FARMING,IRRIGATION,STOCK
- DOMESTIC,IRRIGATION,STOCK
- MINING
- DEWATERING (GROUNDWATER)
- DEWATERING (GROUNDWATER),INDUSTRIAL,MINING
- MONITORING BORE
- RECREATION (GROUNDWATER)
- STOCK
- G/WATER EXPLORATION
- TEST BORE

Scale: 180,000 at A4
GDA 1994 MGA Zone 55

0 1 2 4 6 8
kilometres

N

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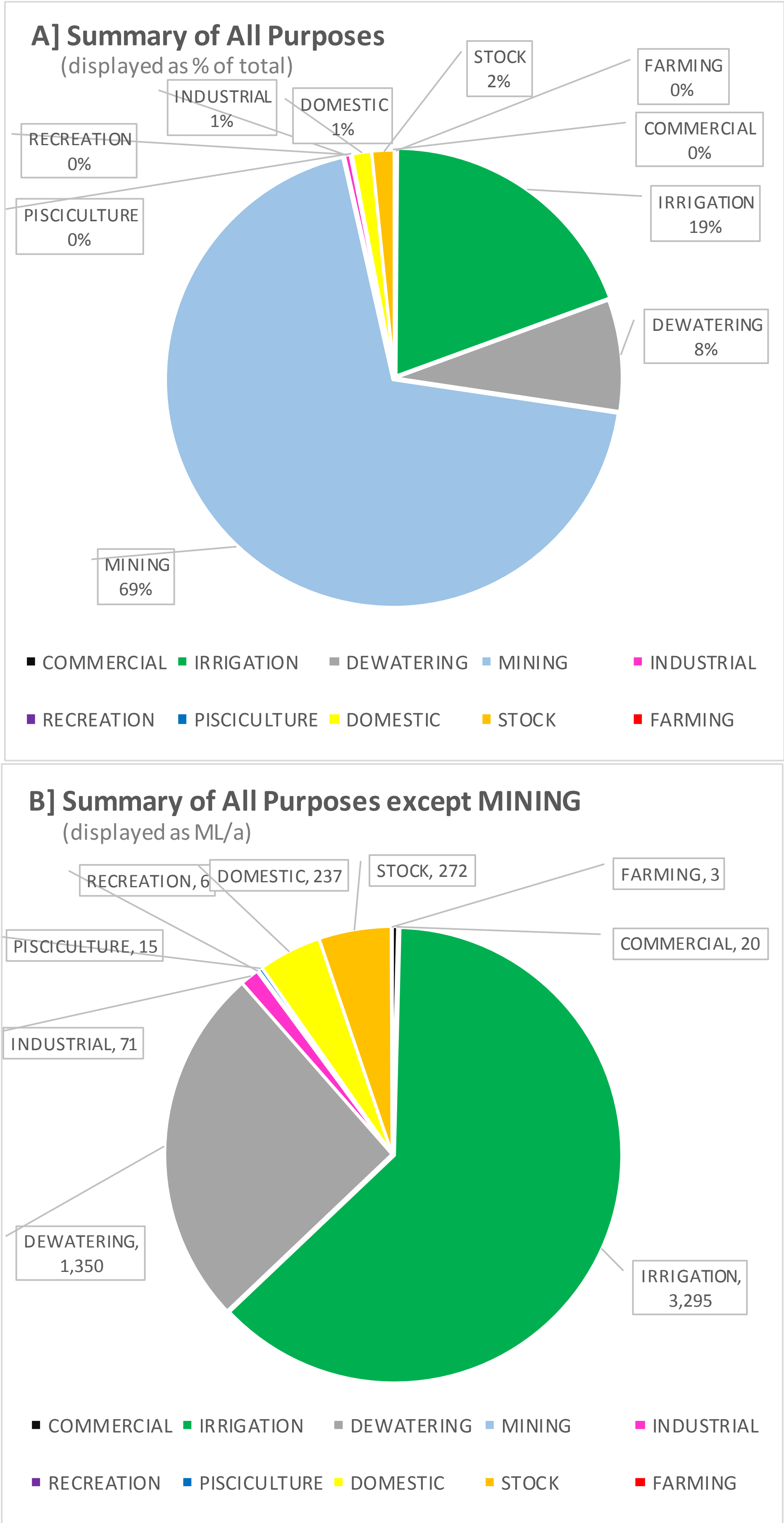
HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

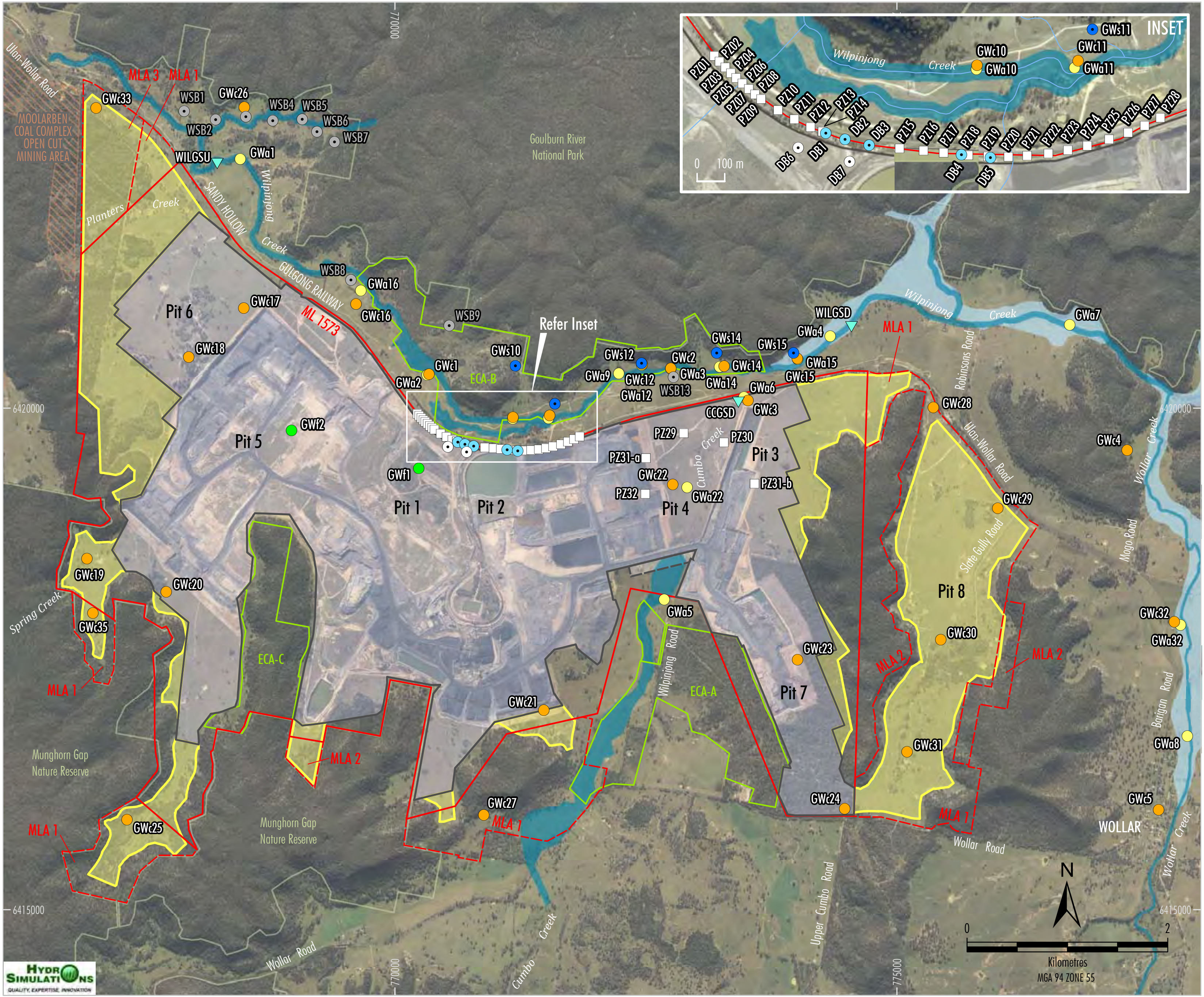
Location of Registered Groundwater Users

Figure 3-11



C:\HydroSim\WIL006\Tech\Groundw aterUse\NOW_Nov2014\[Hunter_Licensed_Bores.xlsx]FIGURE

Figure 3-12 Summary of Groundwater Use

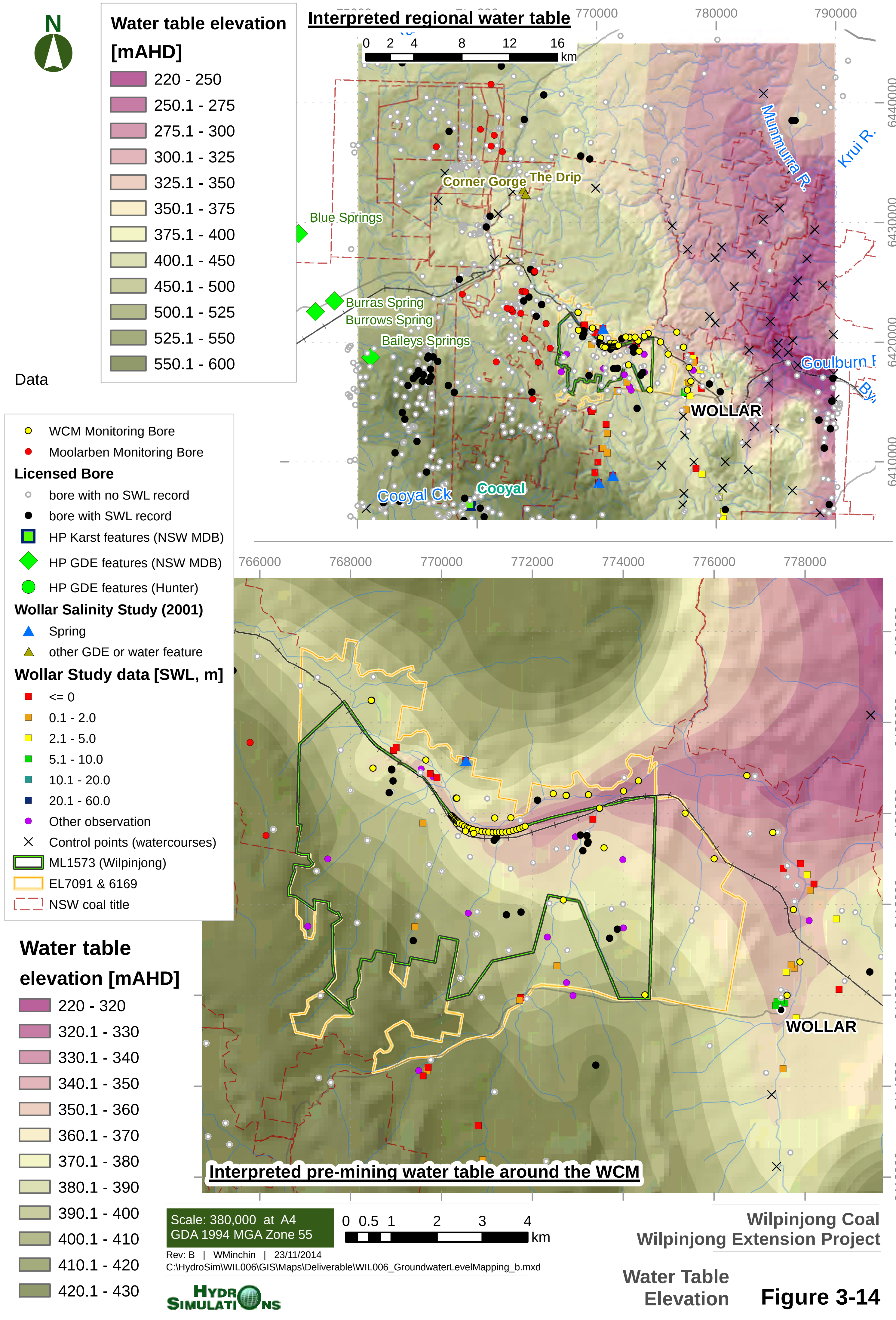


WILPINJONG EXTENSION PROJECT

Monitoring and Data Locations at Wilpinjong Coal Mine

Figure 3-13

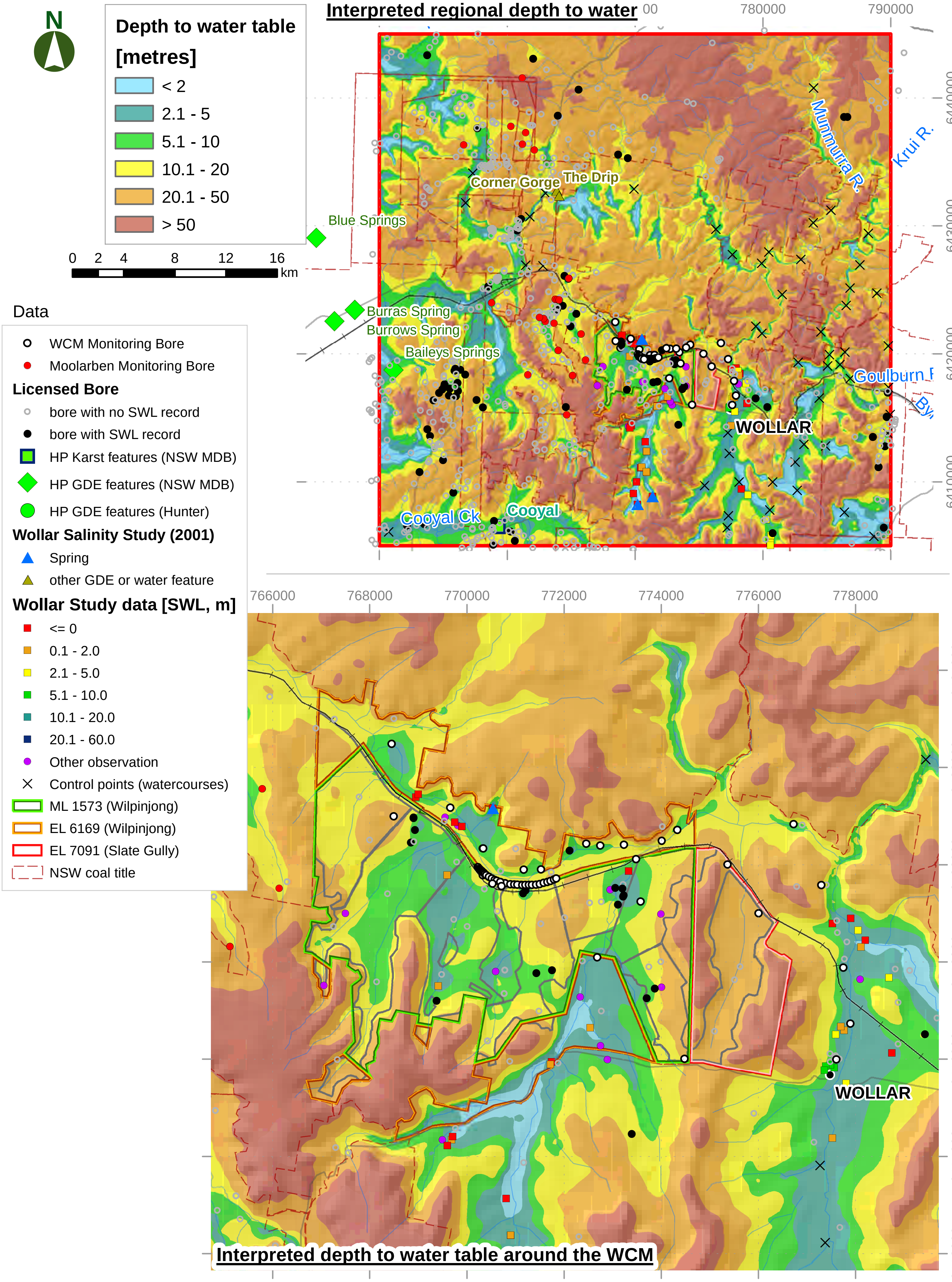
WIL-12-12_WEP_EIS_GW_204E



Wilpinjong Coal
Wilpinjong Extension Project

Water Table Elevation

Figure 3-14



Scale: 380,000 at A4
GDA 1994 MGA Zone 55

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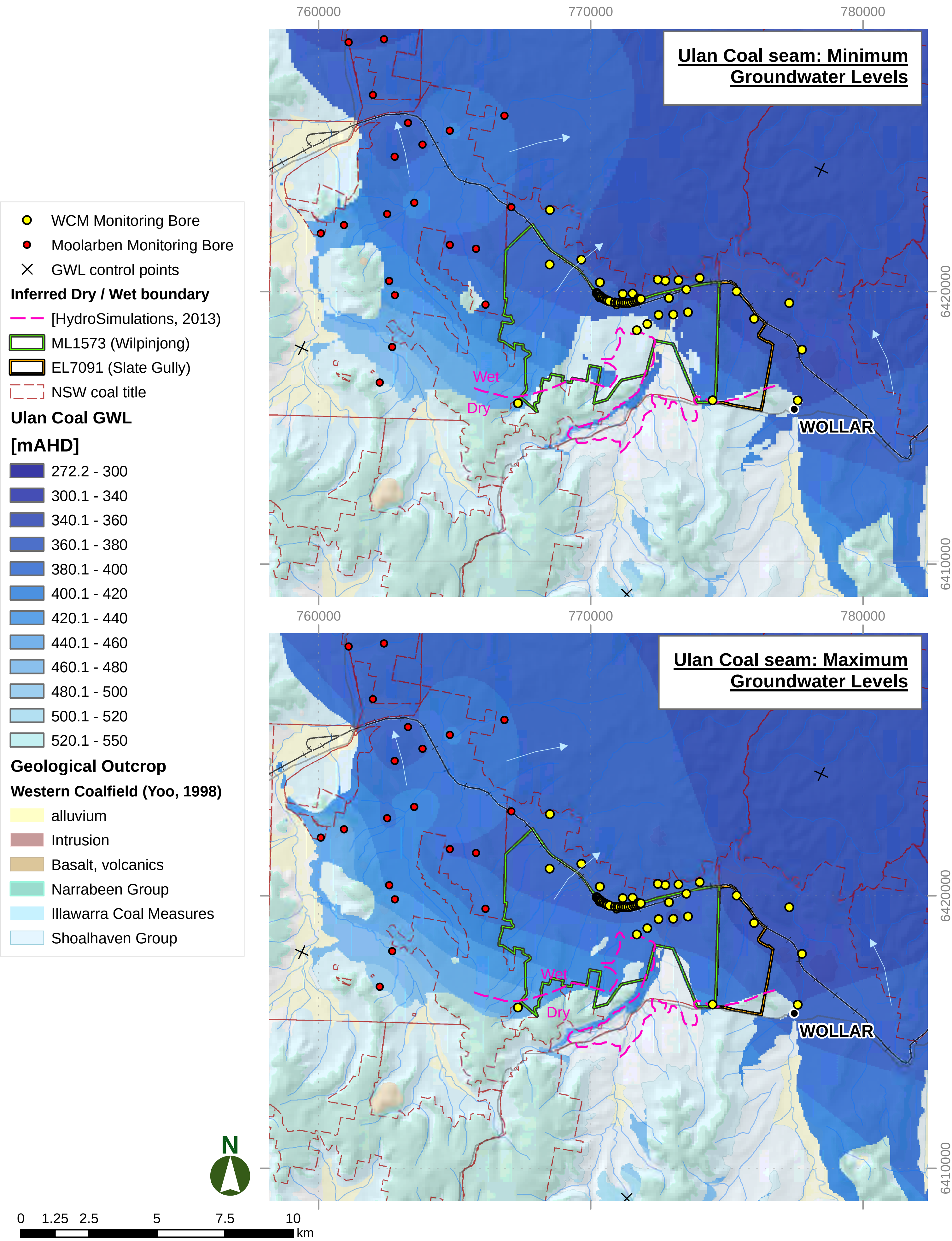
C:\HydroSim\WIL006\GIS\Maps\Working\WIL006_GroundwaterLevelMapping_DepthToWTb.mxd

Hydro Simulations

Wilpinjong Coal
Wilpinjong Extension Project

Interpreted Depth to Water **Figure 3-15**



Scale: 175,000 at A4
GDA 1994 MGA Zone 55

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HydroSimulations

Wilpinjong Coal
Wilpinjong Extension Project

Groundwater Levels:
Ulan Coal seam

Figure 3-16

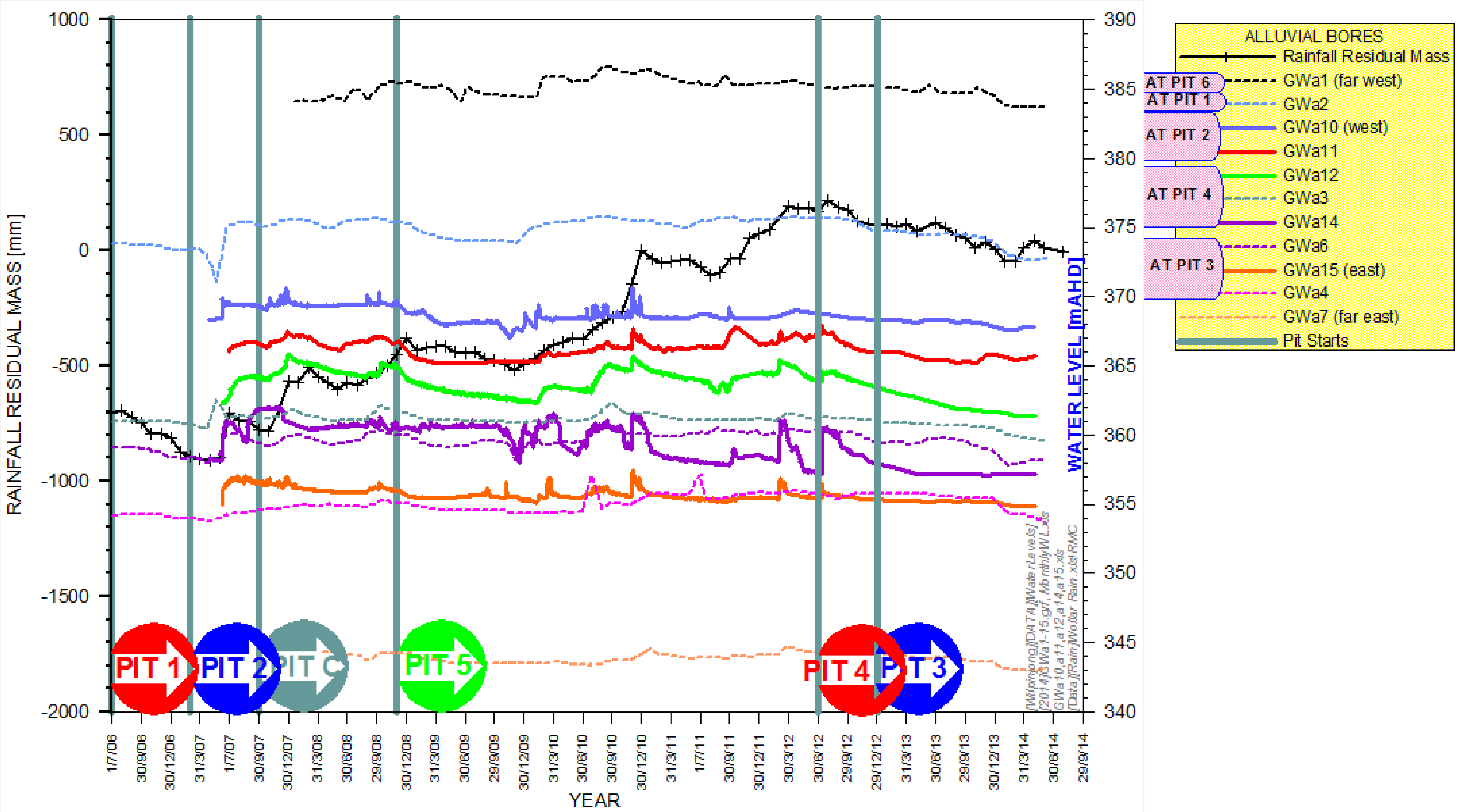


Figure 3-17 Water level trends – Alluvial groundwater system

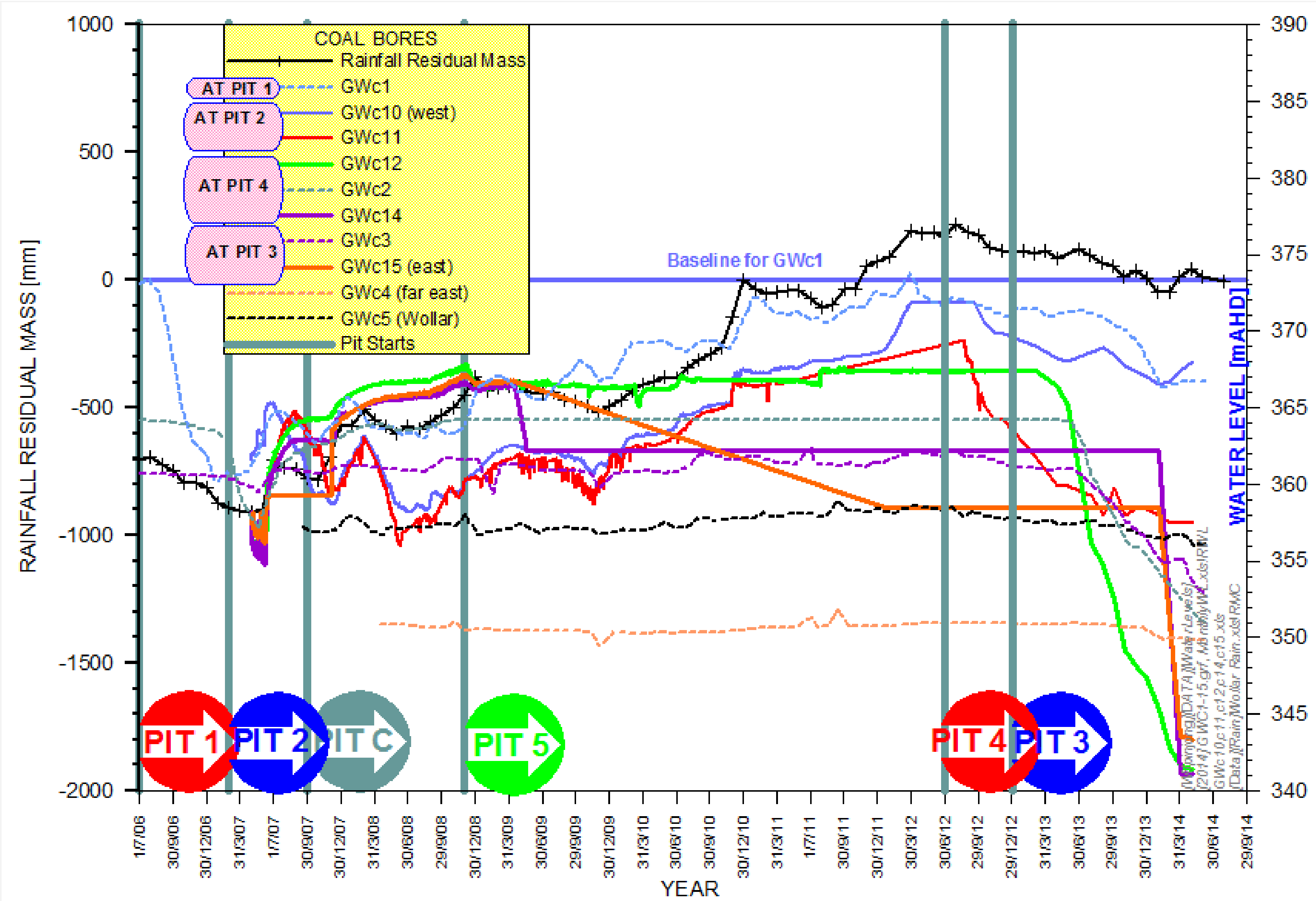


Figure 3-18 Water level trends – Permian groundwater system

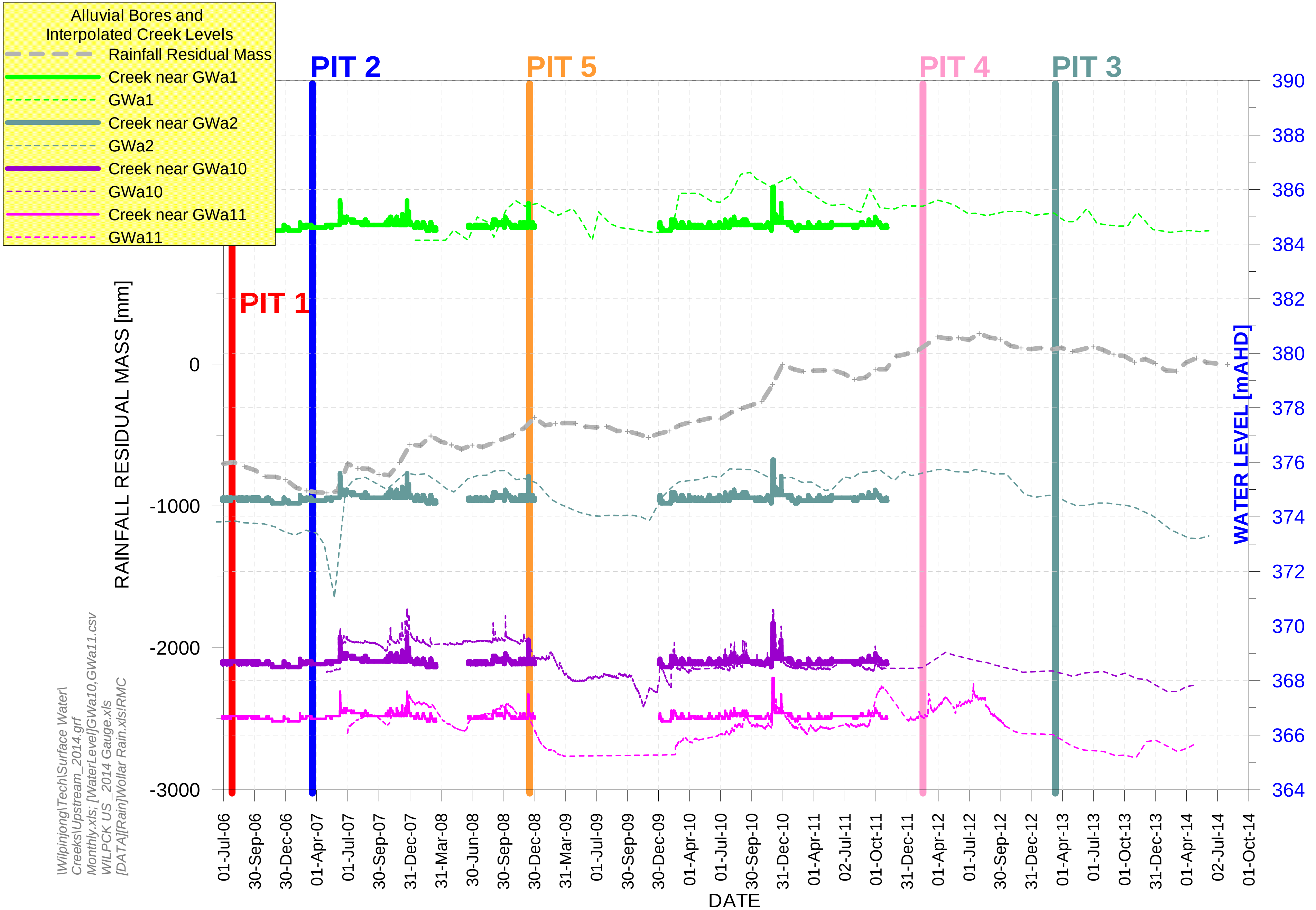


Figure 3-19 Groundwater Levels compared with Wilpinjong Creek levels: Upstream of Pit 2

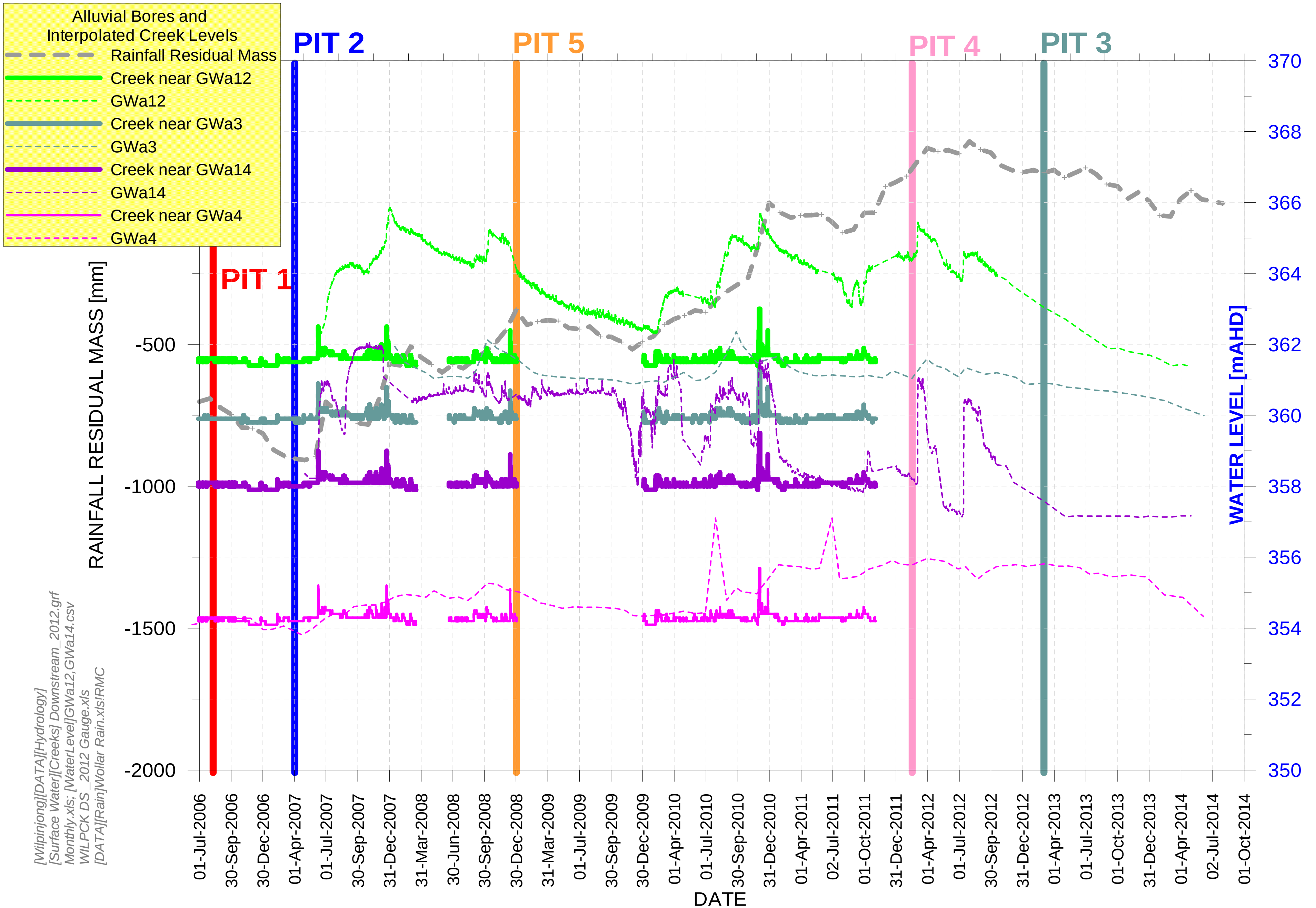
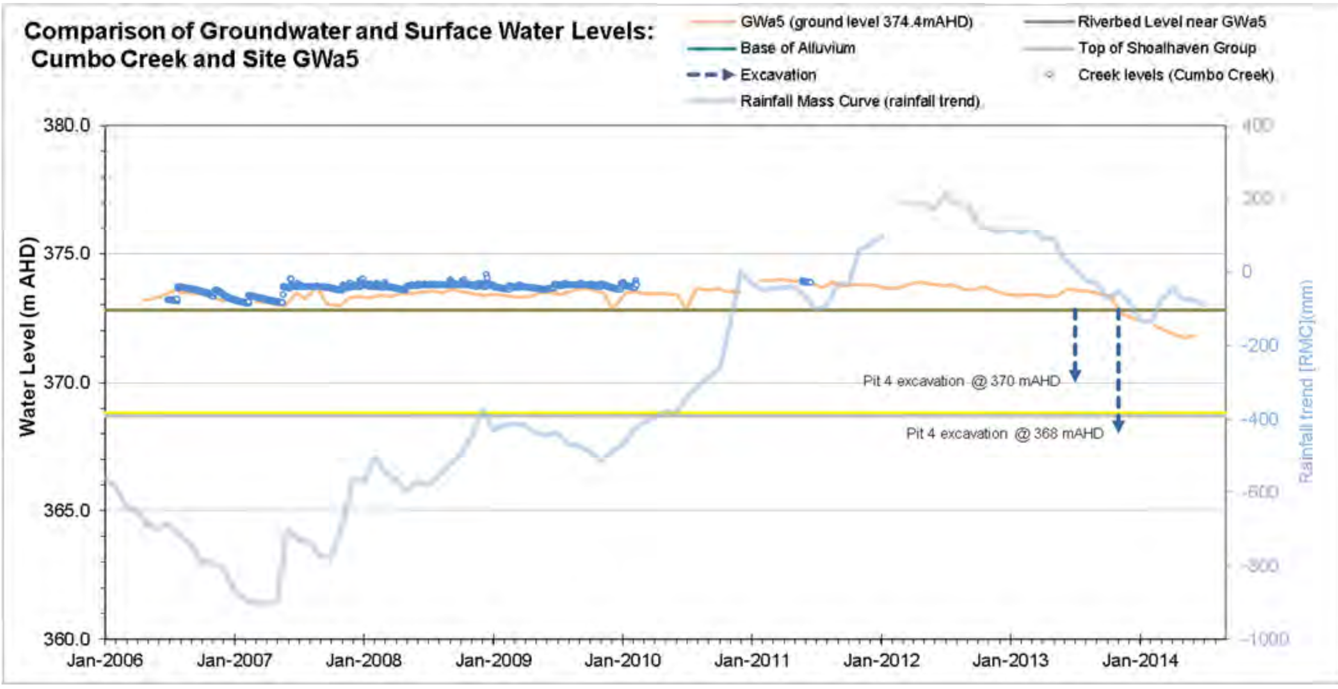
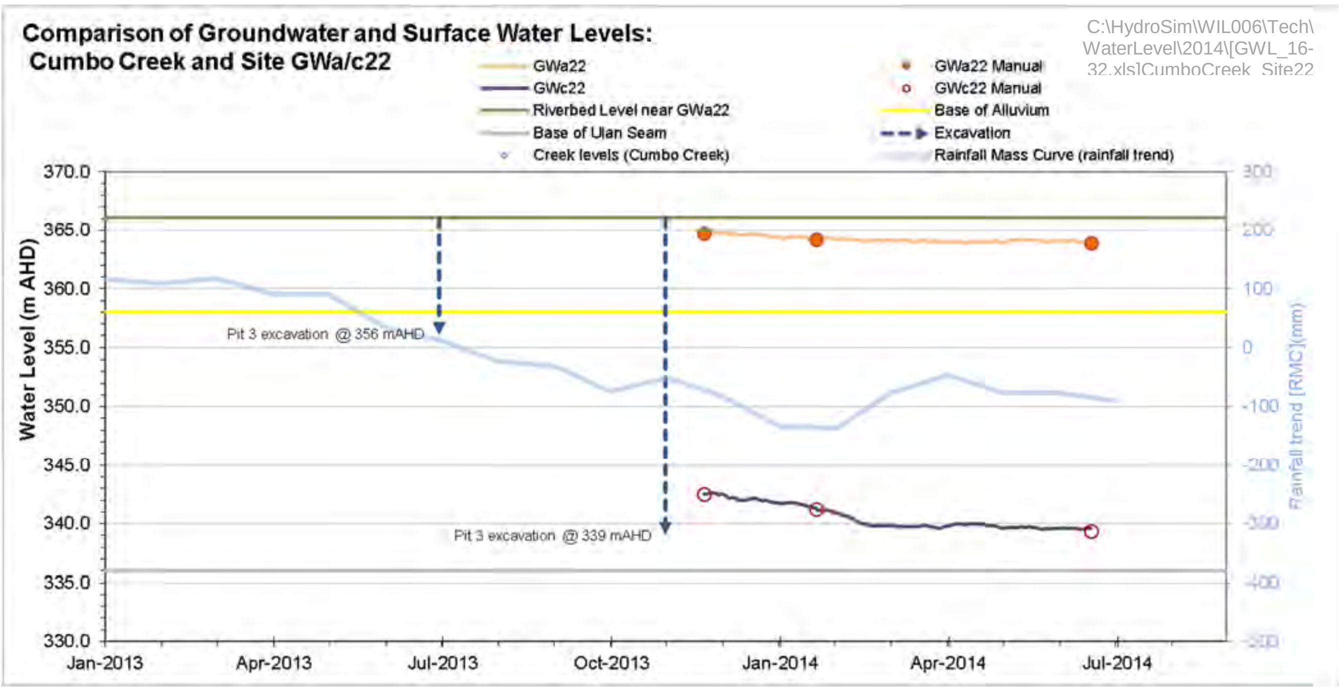


Figure 3-20 Groundwater Levels compared with Wilpinjong Creek levels: Downstream of Pit 2

A] Site GWa5

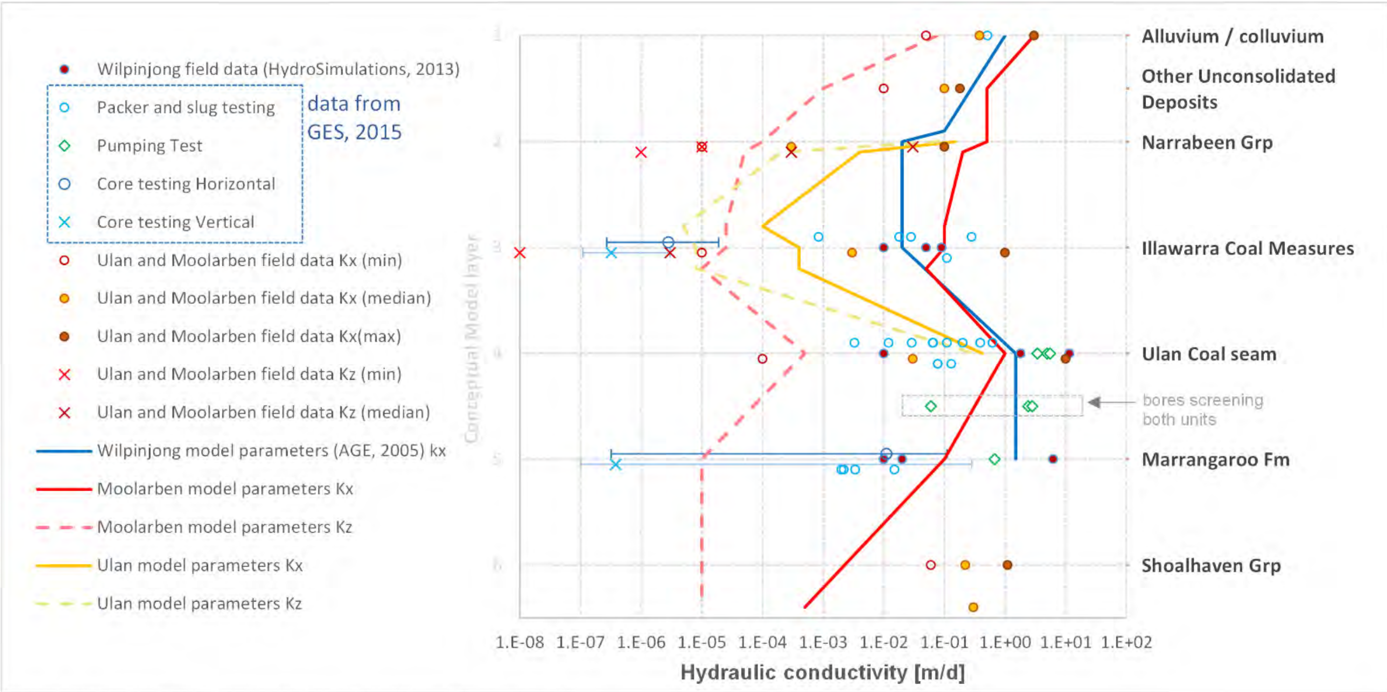


B] Site GWa22 and GWc22



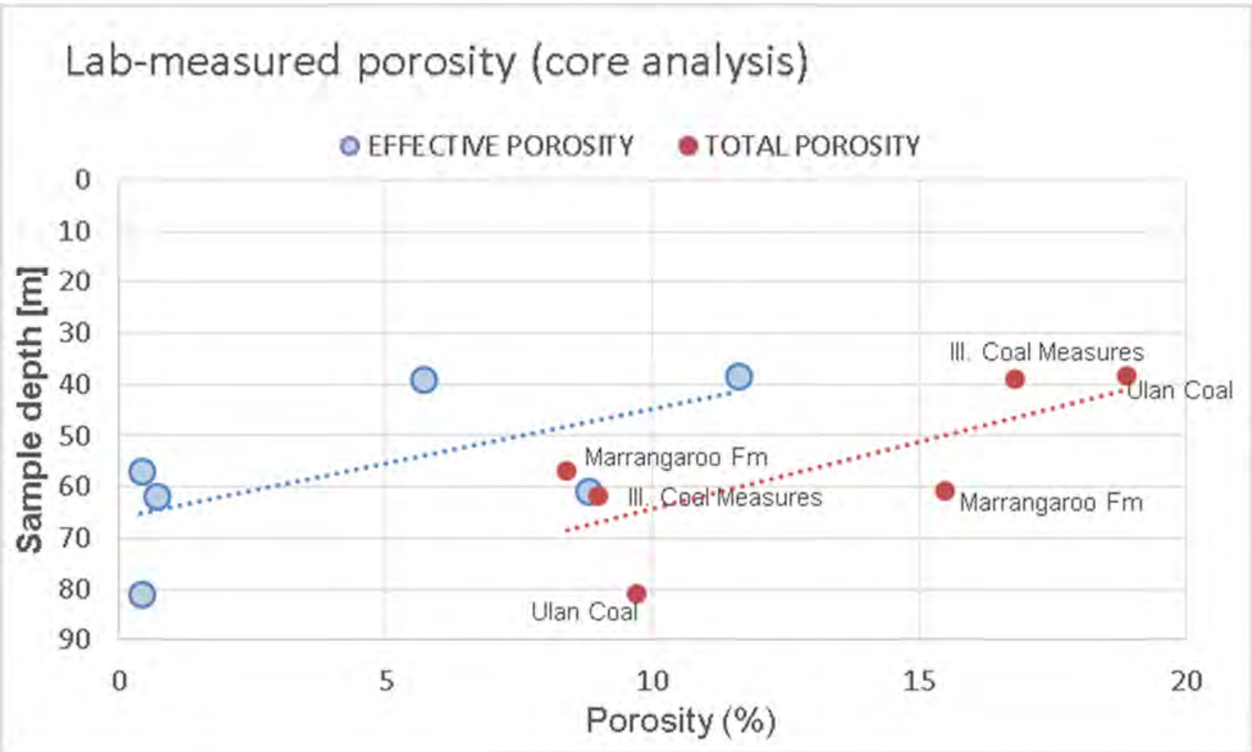
note different X-scale in A] and B]

Figure 3-21 Groundwater Levels compared with Cumbo Creek water levels



C:\HydroSim\WIL006\Tech\AquiferProperties\AquiferProperties.xlsx

Figure 3-22 Summary of Permeability from Field Testing and Modelling



C:\HydroSim\WIL006\Tech\AquiferProperties\Wilpinjong_CoreData.xlsx

Figure 3-23 Summary of Porosity from Laboratory Testing

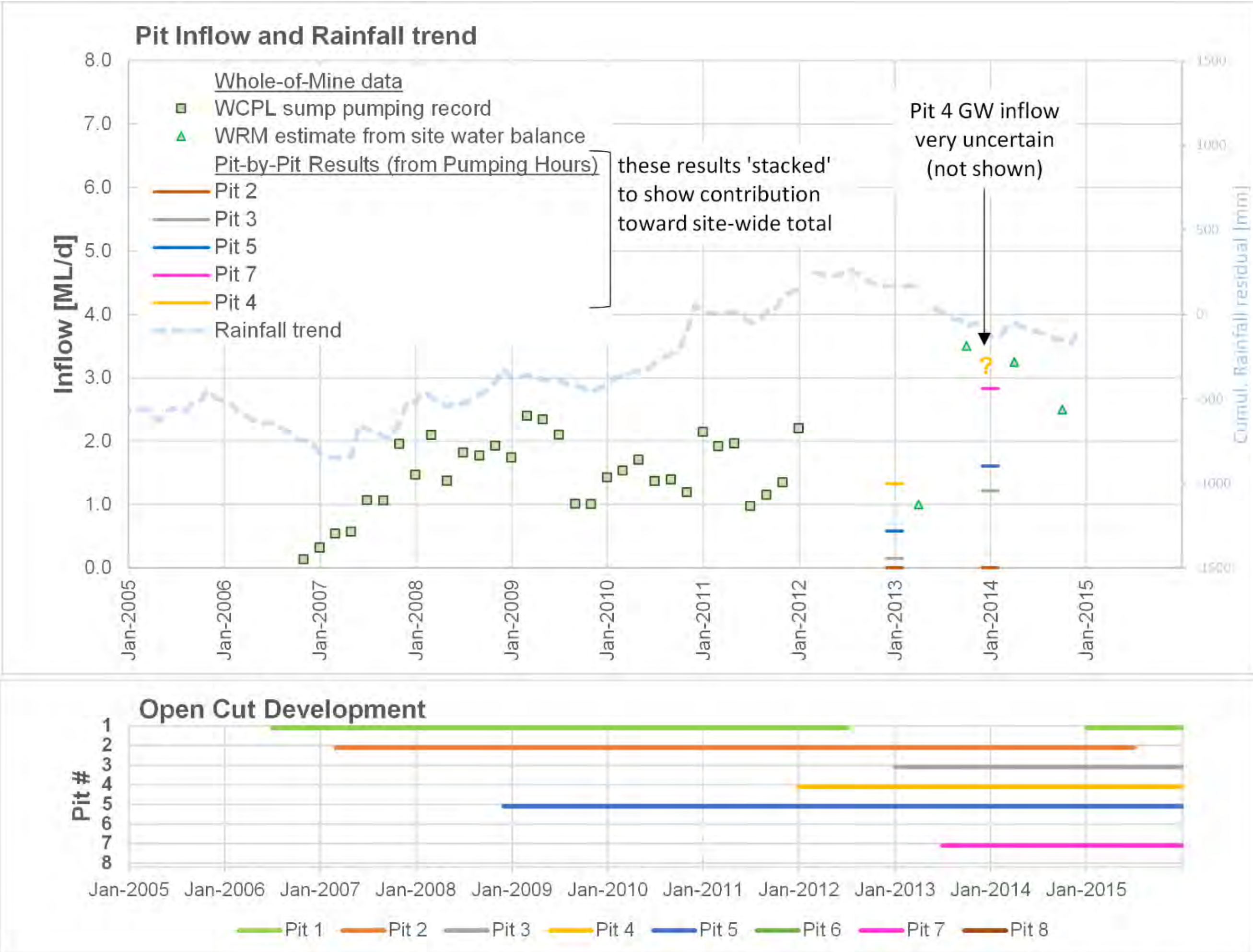


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Figure 3-24 Historical inflows to Wilpinjong Coal Mine open cuts

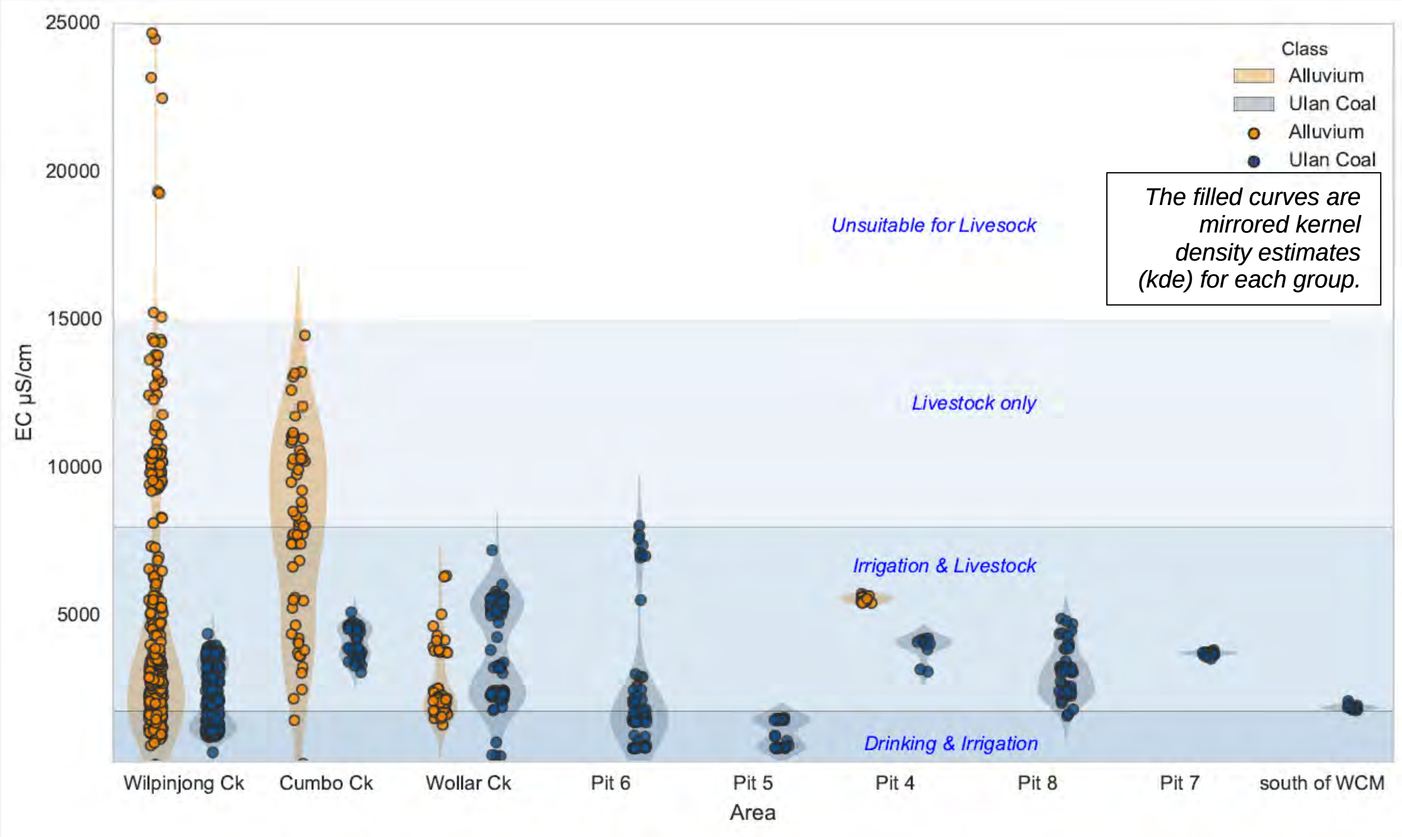


Figure 3-25 Strip plot showing the range in groundwater EC for Alluvium and coal measures

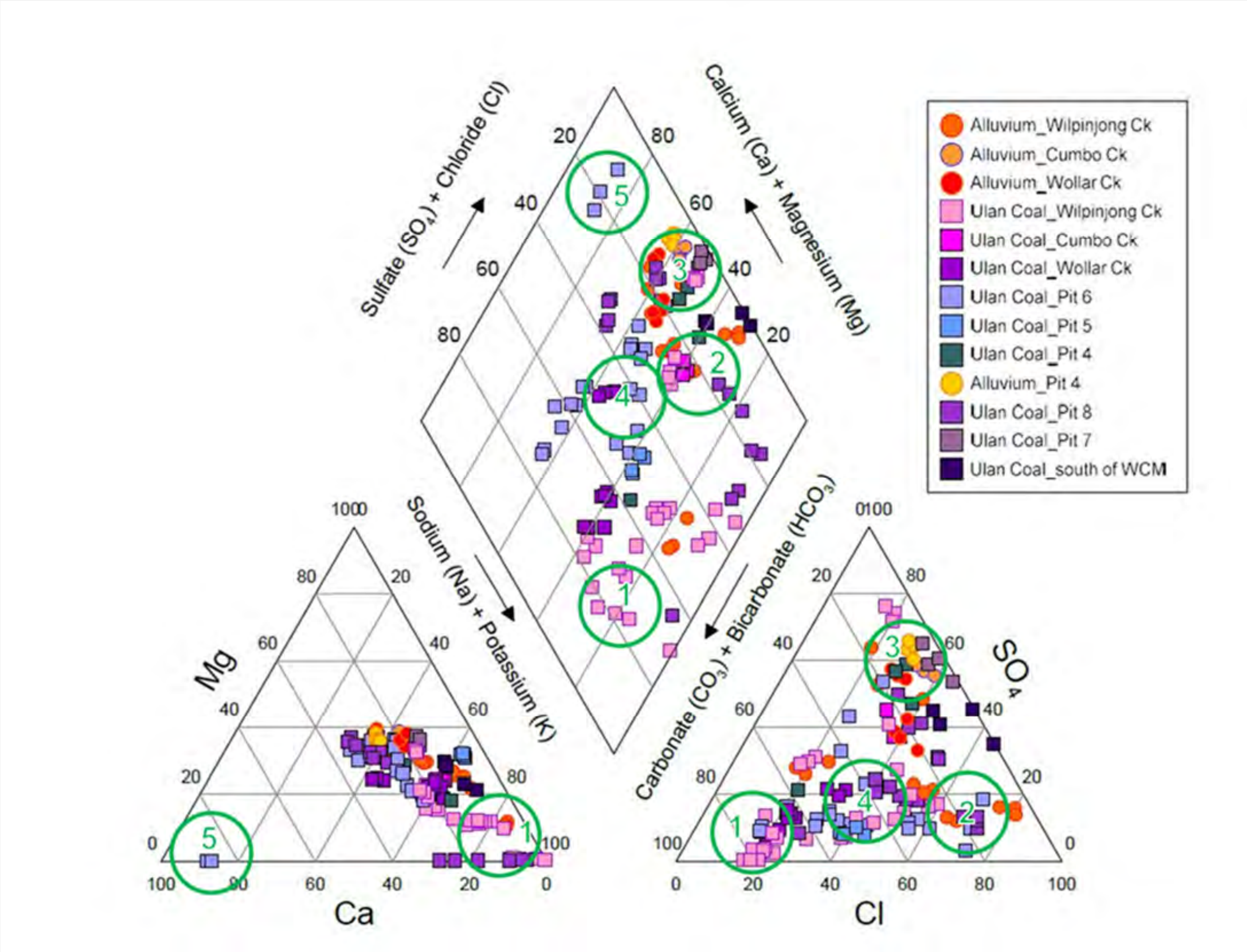


Figure 3-26 Piper Diagram summarising major ion composition of groundwater samples (meq/L)

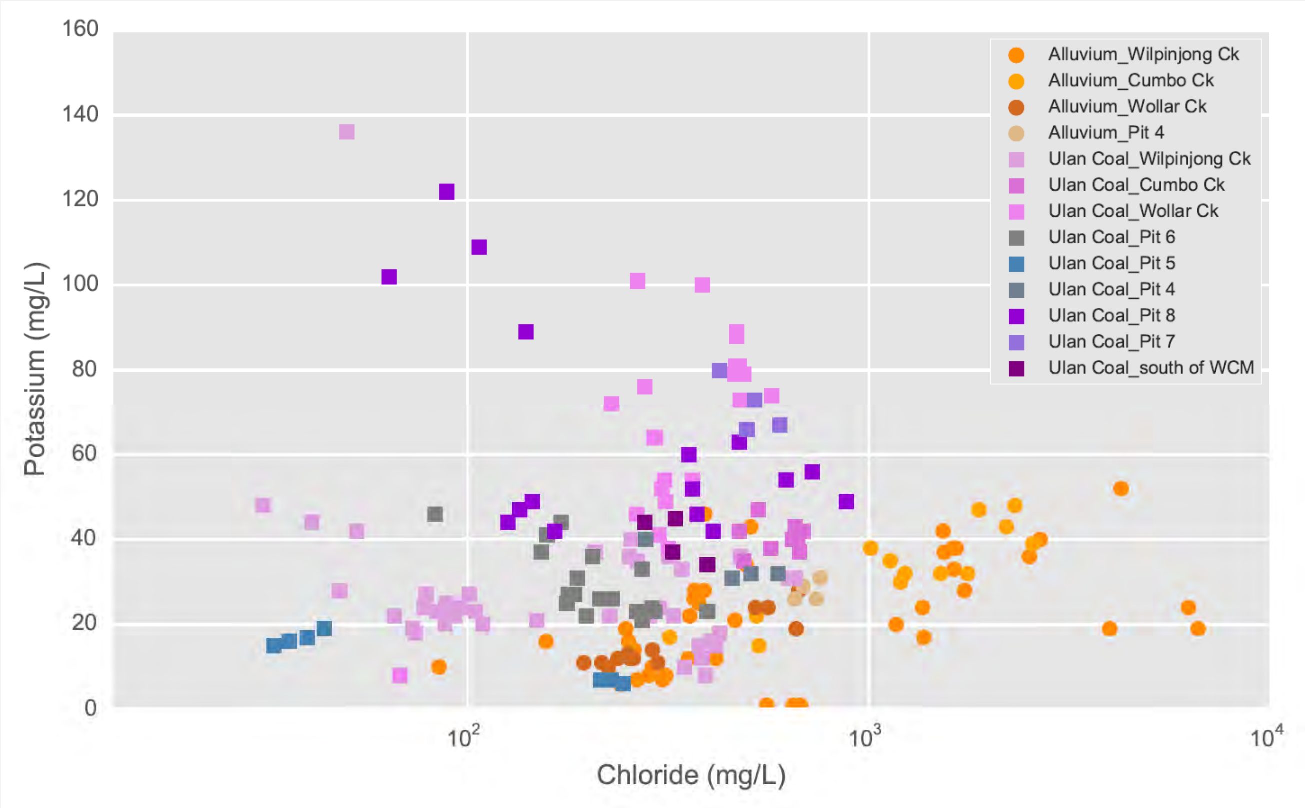


Figure 3-27 Bivariate plot of potassium versus chloride concentration in groundwater

(boxes define the median and 25th / 75th percentiles; whiskers define the 5th / 95th percentiles)

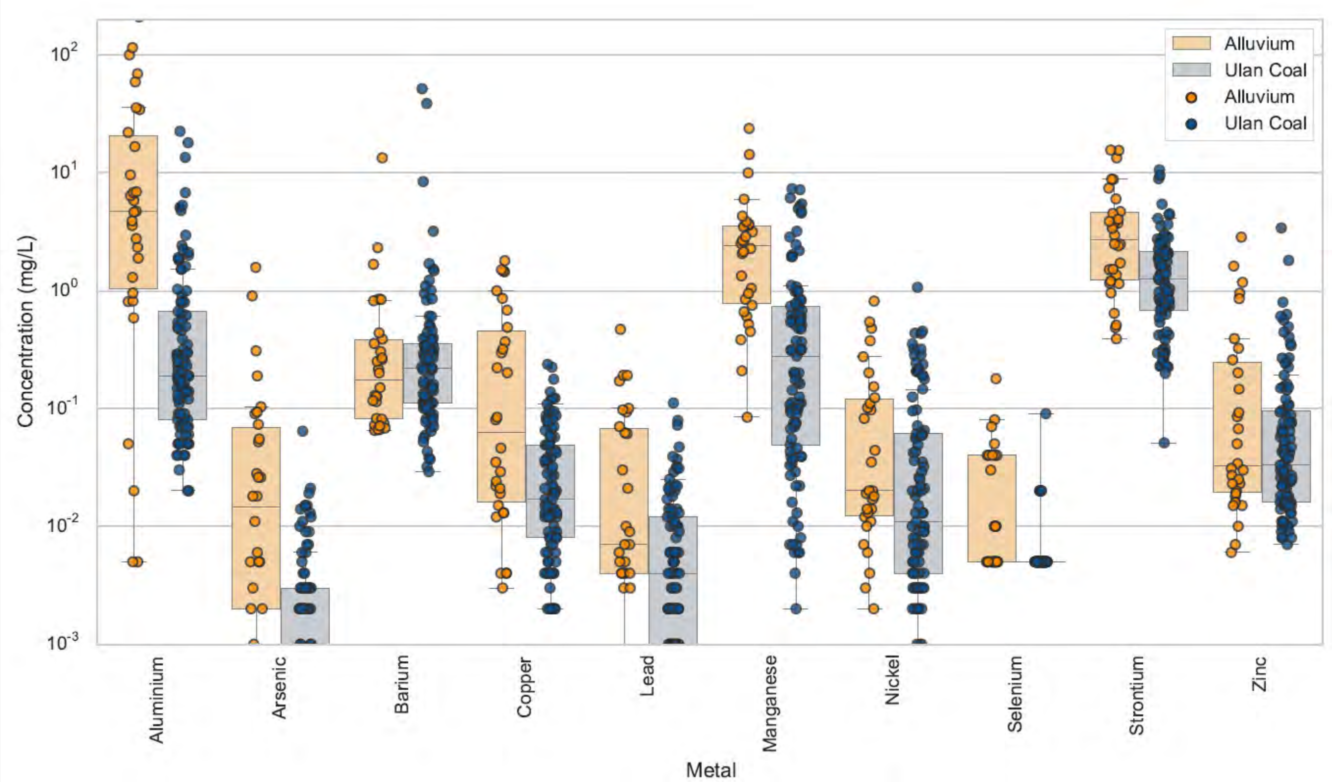


Figure 3-28 Box plot of trace metal concentrations in groundwater

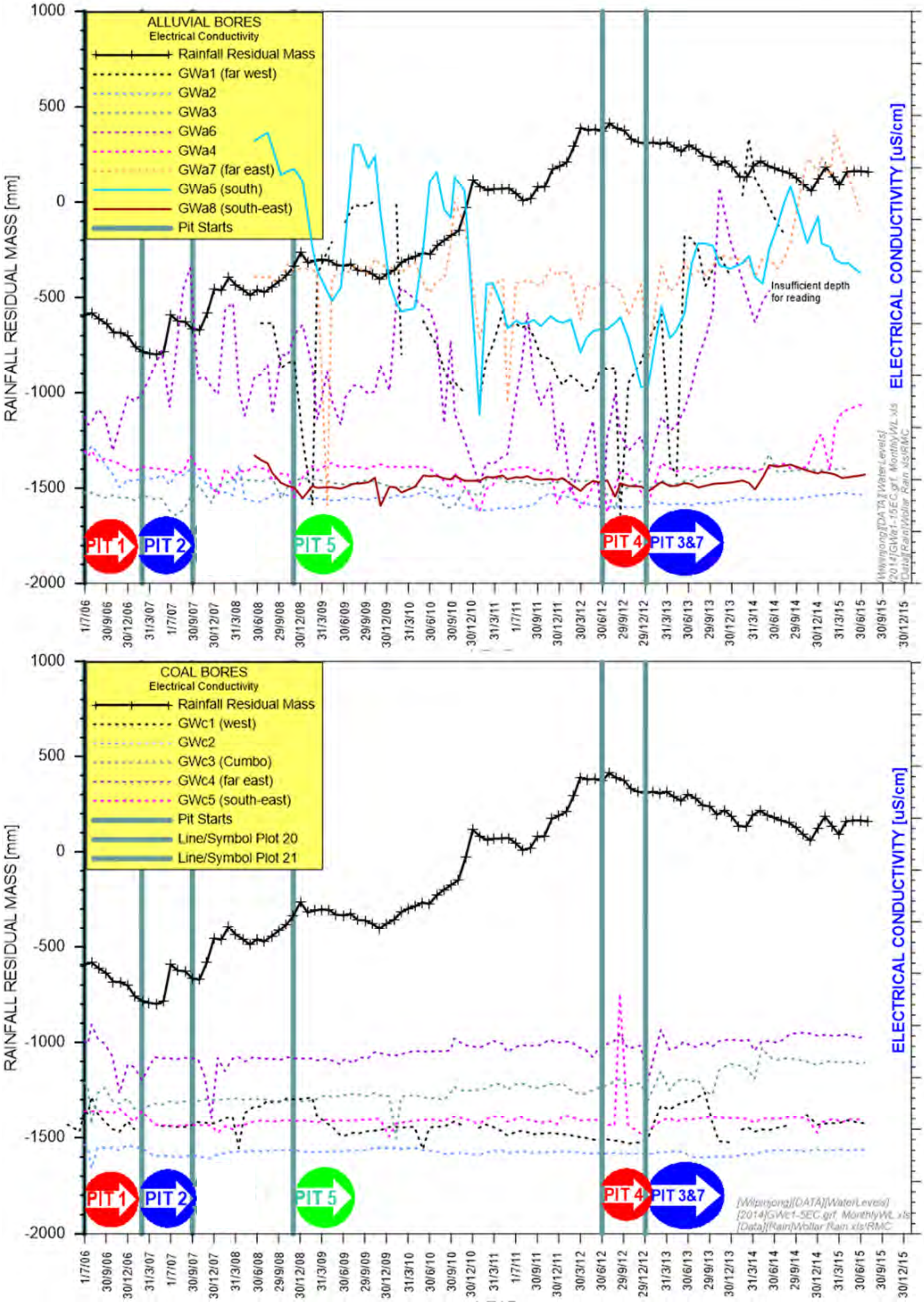


Figure 3-29 Temporal Change in Electrical Conductivity at WCM

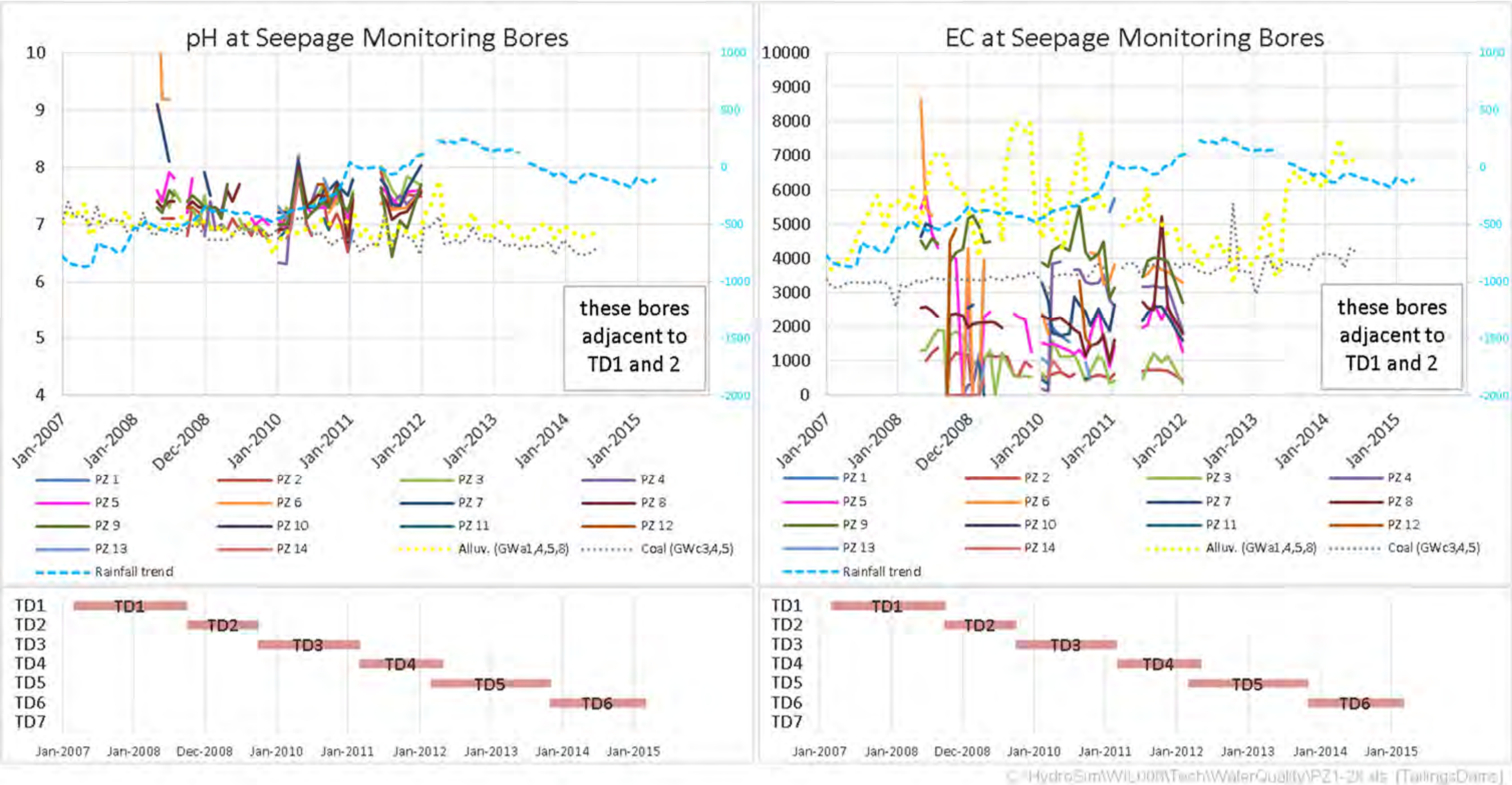


Figure 3-30 Record of pH and Electrical Conductivity near TD1 and 2

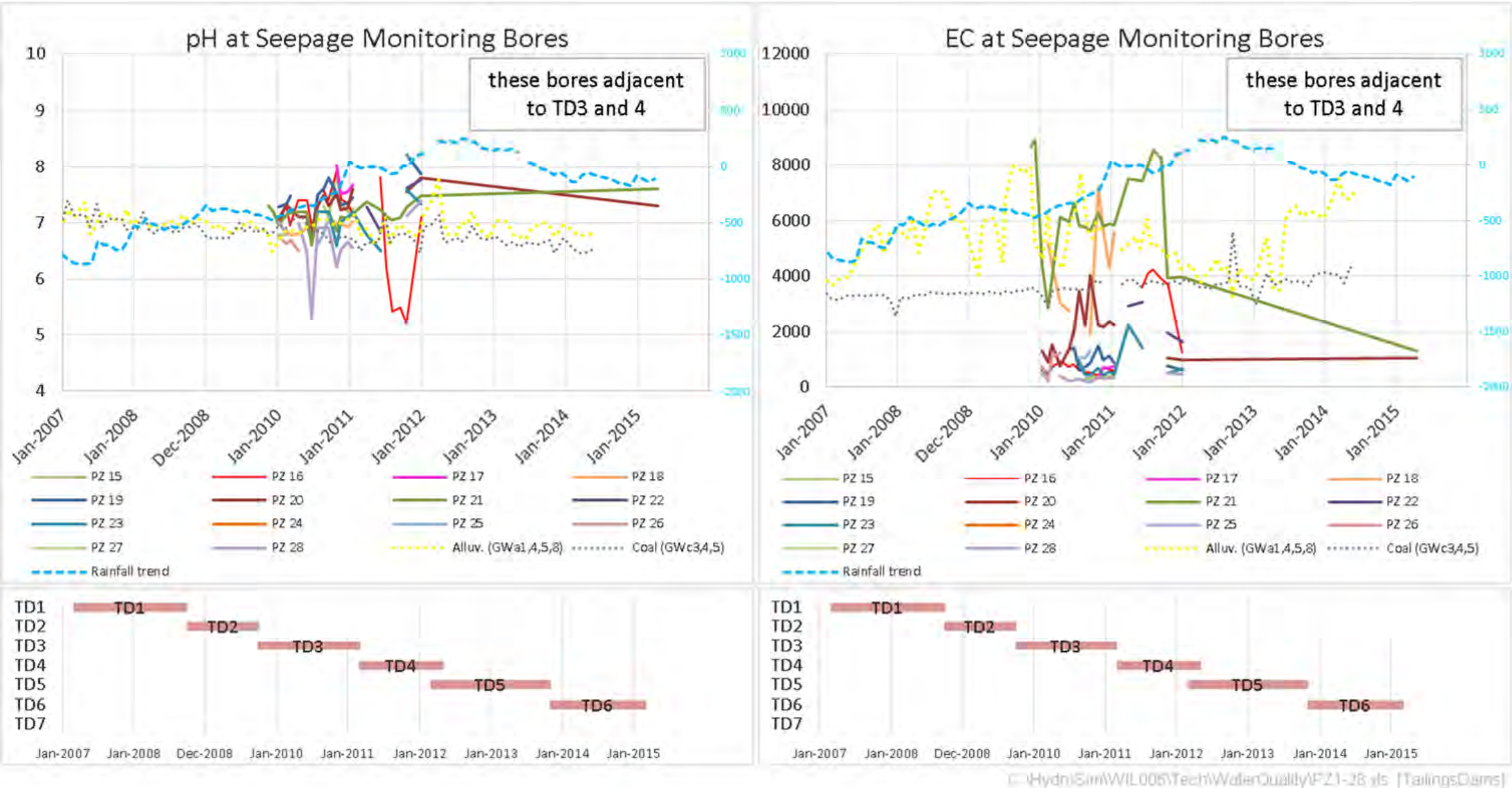


Figure 3-31 Record of pH and Electrical Conductivity near TD3 and 4

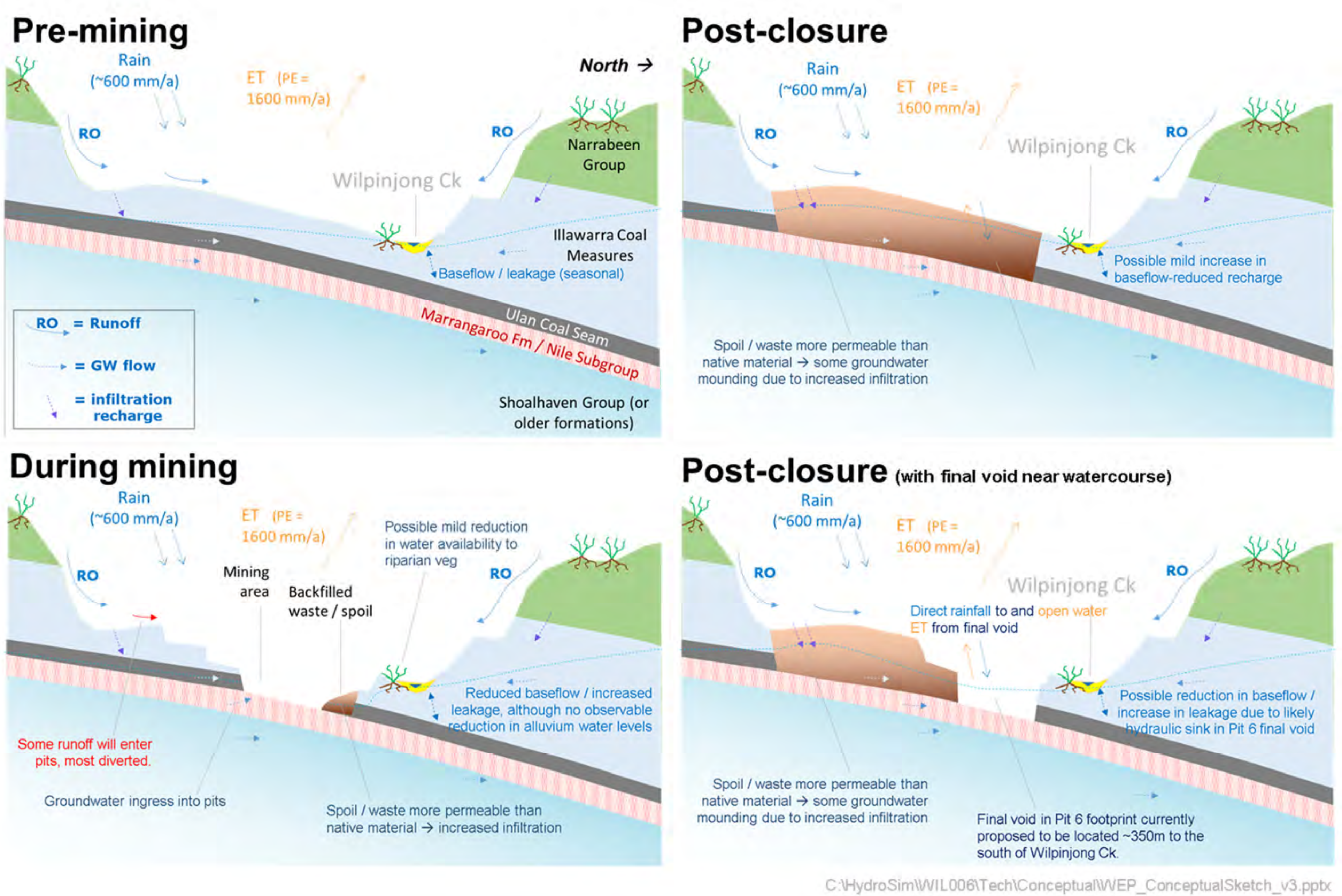
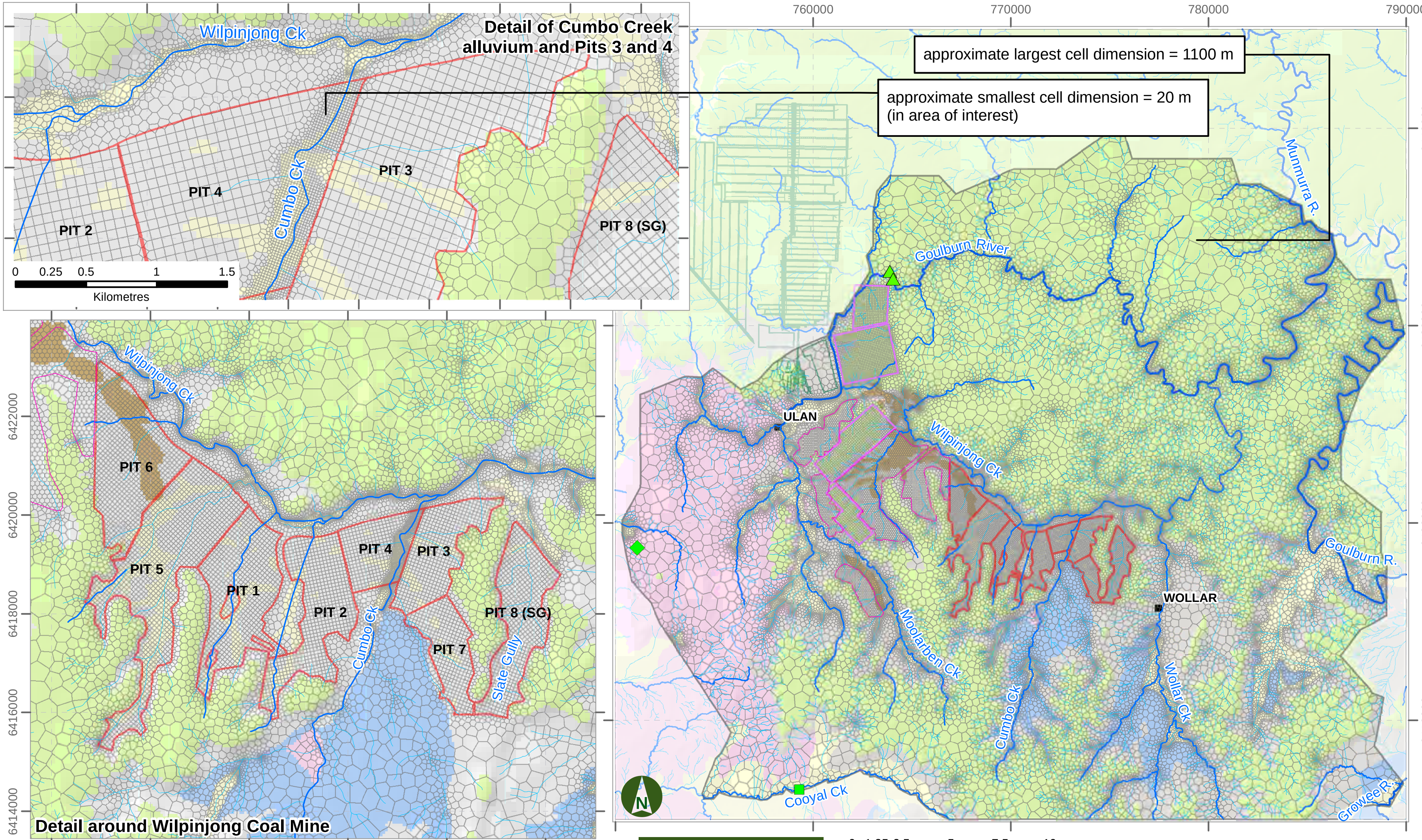


Figure 4-1 Hydrogeological Conceptual Model



0 0.5 1 2 3 4
Kilometres

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Scale: 250,000 at A4
GDA 1994 MGA Zone 55

0 1.25 2.5 5 7.5 10
kilometres

Wilpinjong Coal
Wilpinjong Extension Project

Outcrop geology

- Alluvium / weathered
- Tertiary (?)
- Narrabeen Group
- Illawarra Coal Measures
- Shoalhaven Group
- Palaeozoic formations
- Model cell
- WCM (WEP) Pit (maximum extent)
- Moolarben Open Cut
- Moolarben Underground Mine
- Ulan Mine

HYDROSIMULATIONS

Groundwater Model Domain and Mesh

Figure 5-1

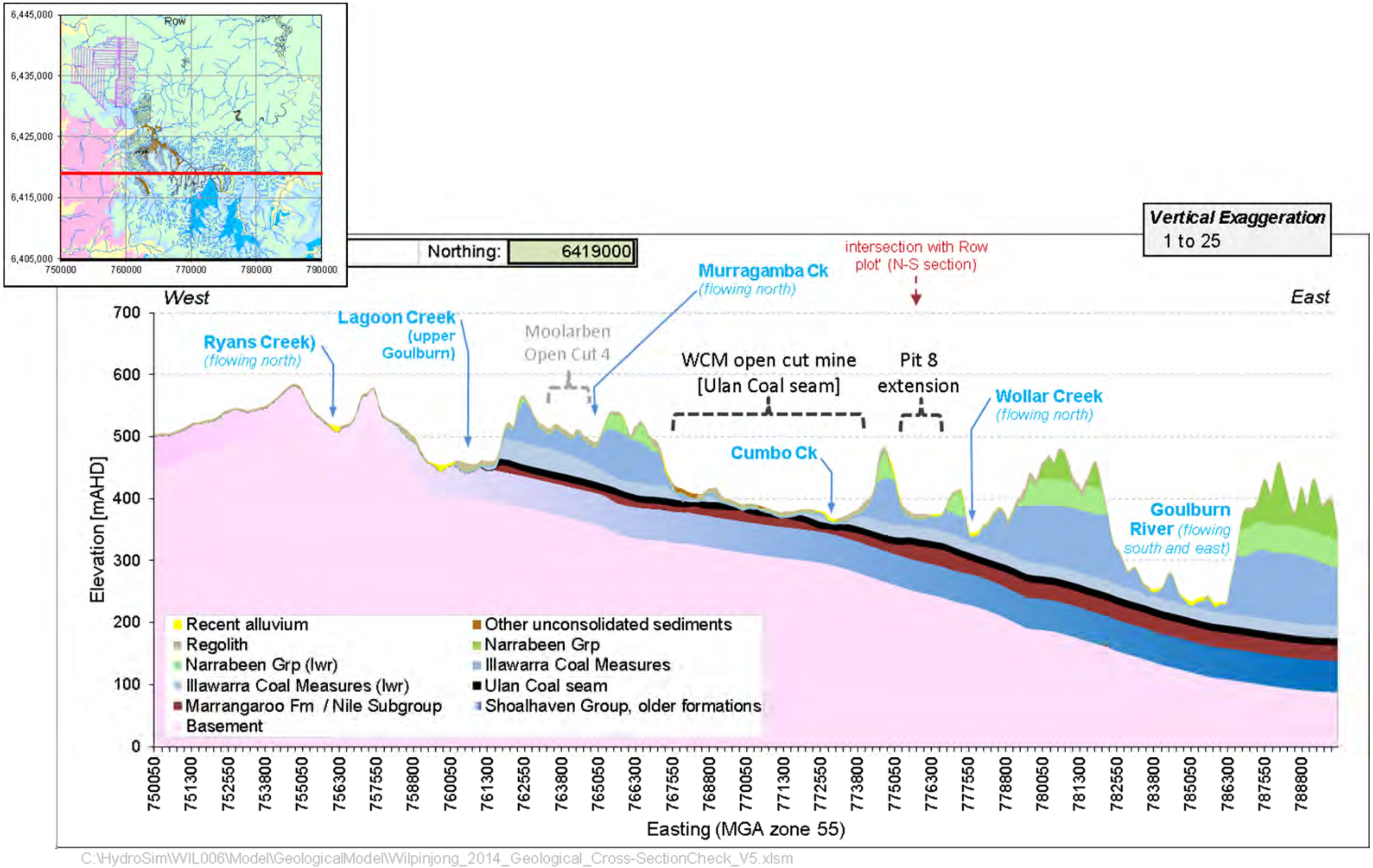


Figure 5-2 Geological Model cross-section: West-East

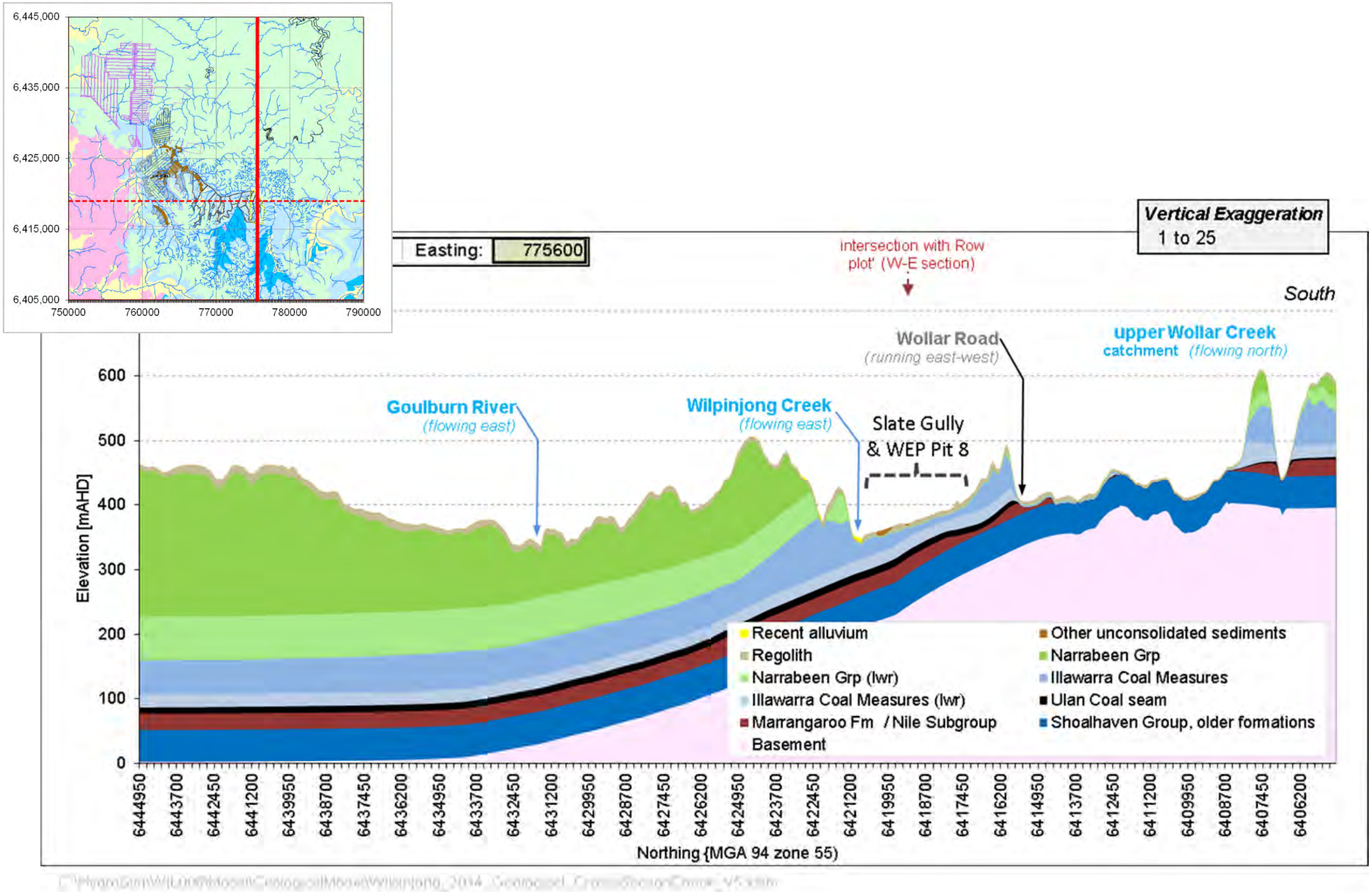
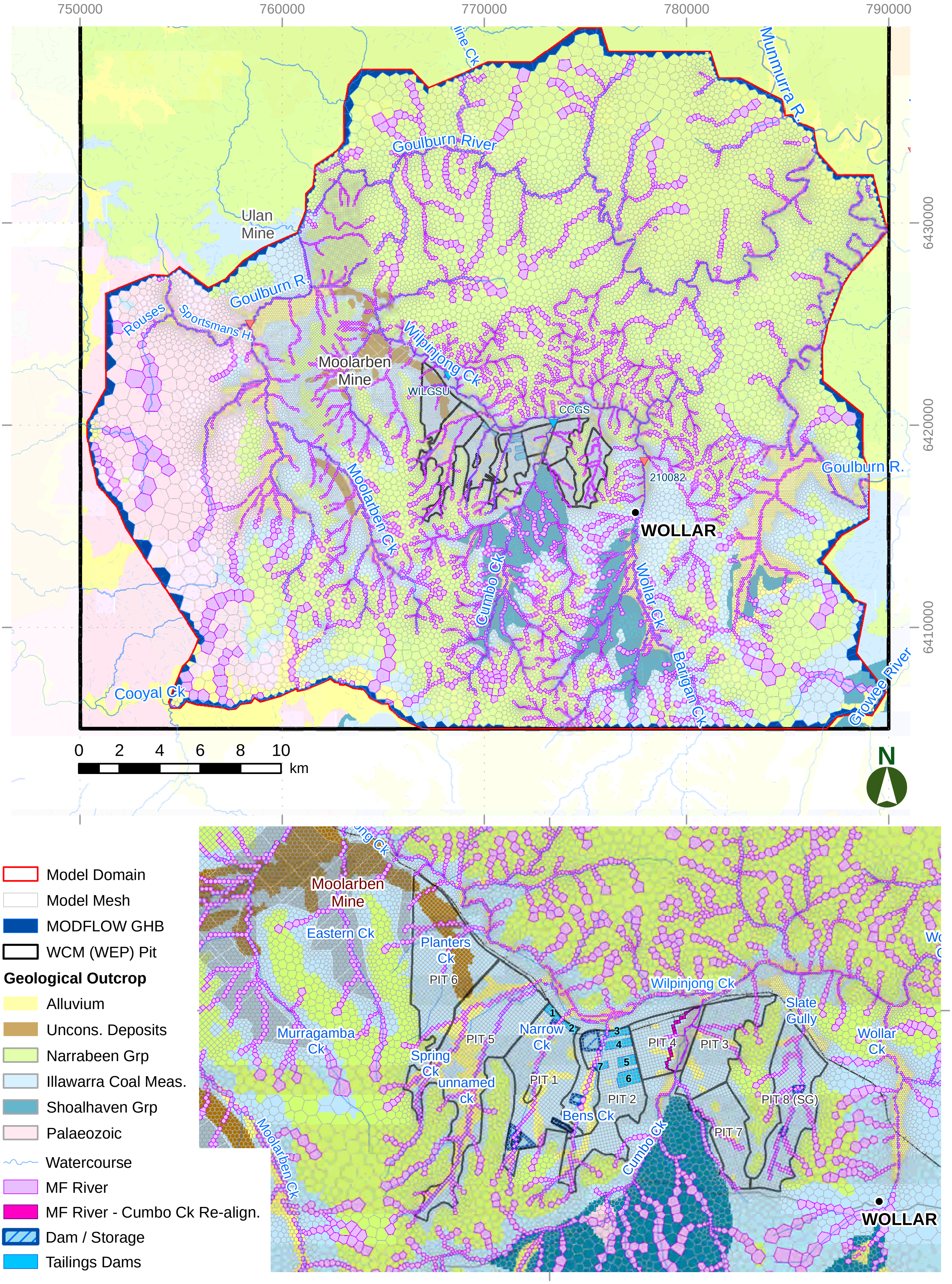


Figure 5-3 Geological Model cross-section: North-South



Model Domain
Model Mesh
MODFLOW GHB
WCM (WEP) Pit

Geological Outcrop

Alluvium
Uncons. Deposits
Narrabeen Grp
Illawarra Coal Meas.
Shoalhaven Grp
Palaeozoic

Watercourse
MF River
MF River - Cumbo Ck Re-align.
Dam / Storage
Tailings Dams

Scale: 110,000 at A4
GDA 1994 MGA Zone 55

0 1 2 3 4 km

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HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Model Boundary Conditions

Figure 5-4

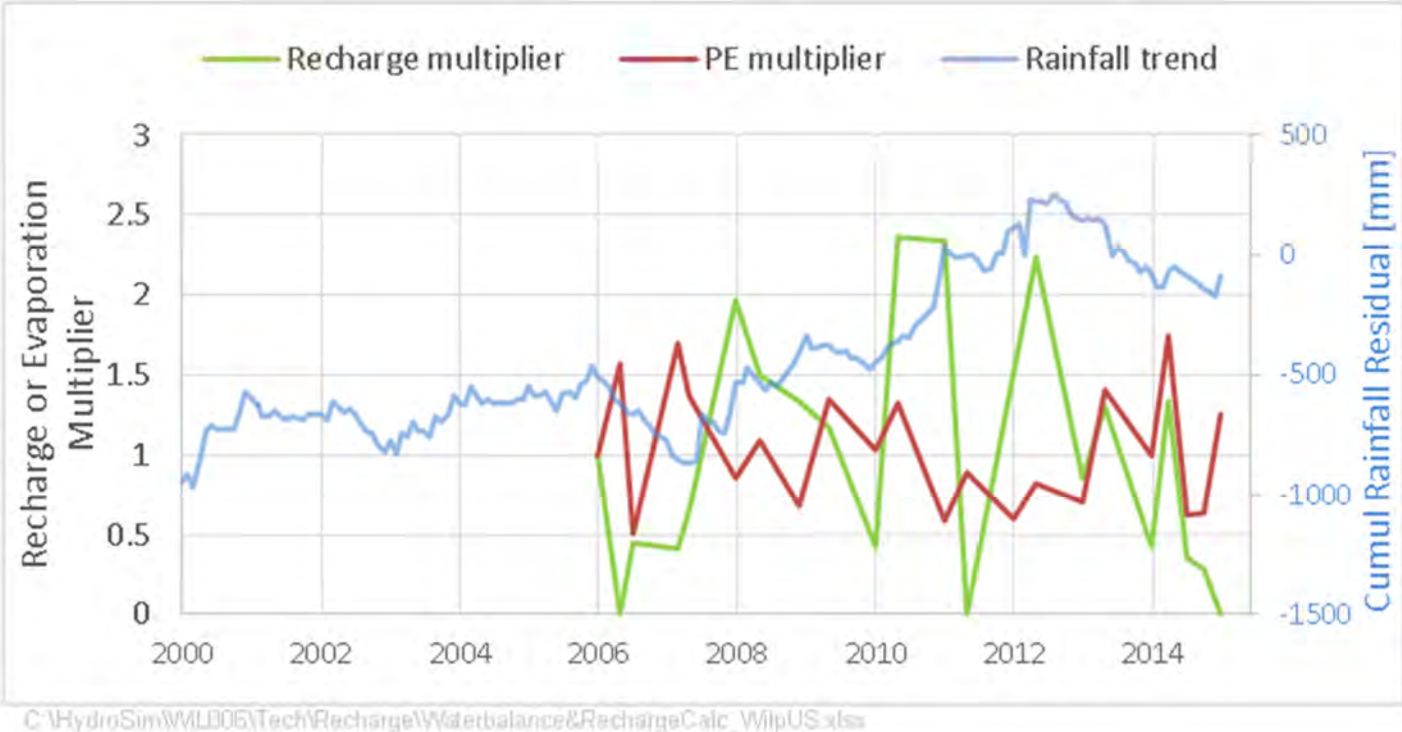


Figure 5-5 Modelled Recharge and Evaporation sequence

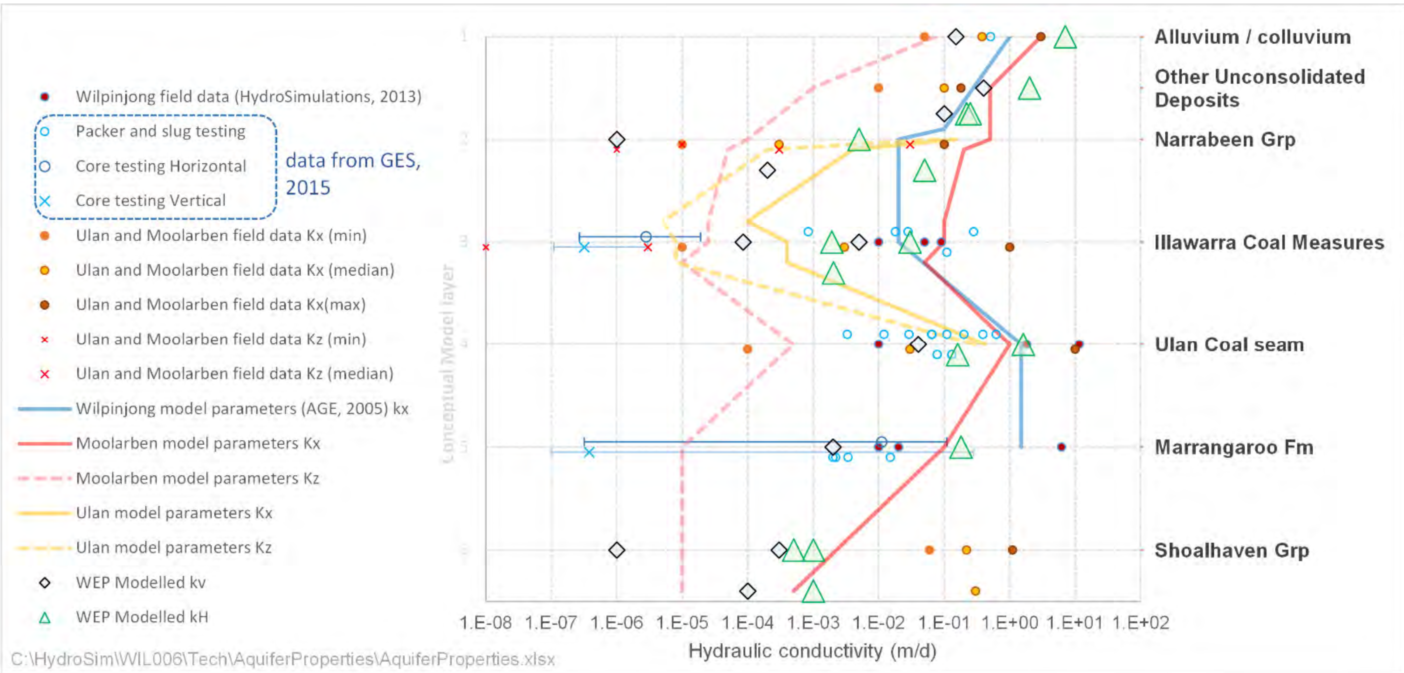
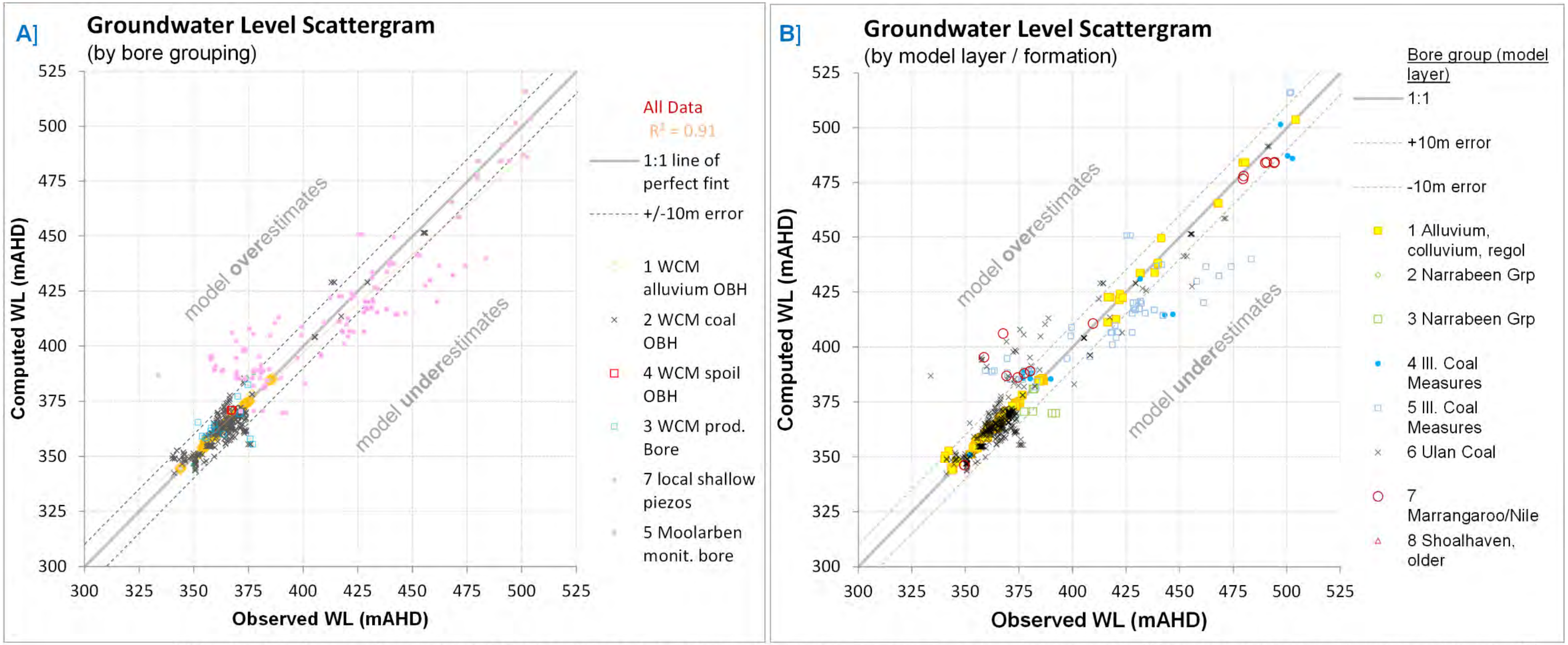


Figure 5-6 Comparison of Modelled Hydraulic Conductivity and Measured Data



Note: the data shown on these two charts is the same in each, but classified in different groupings, i.e. by 'monitoring group' in [A] and by hydrostratigraphic unit (model layer) in [B]

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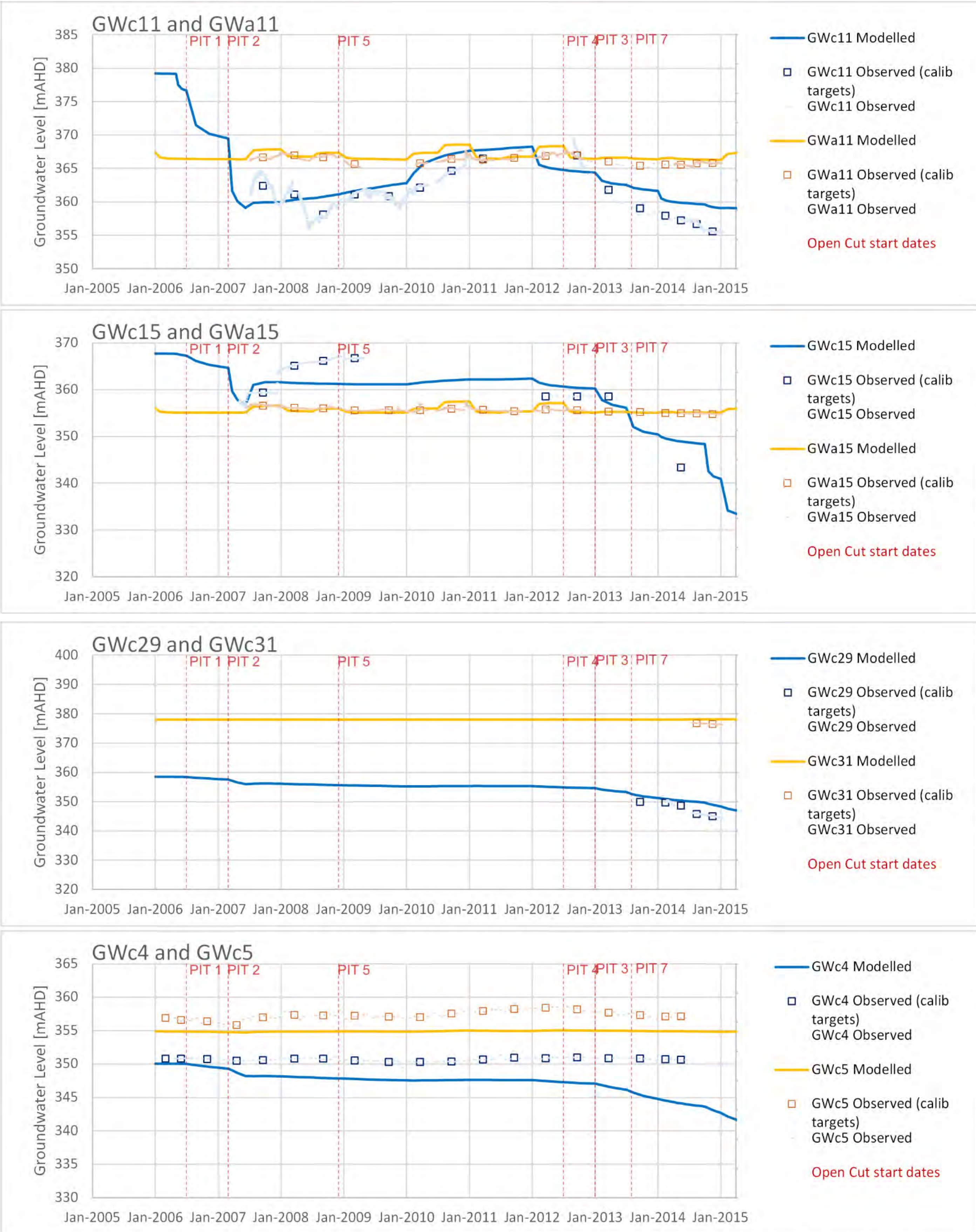
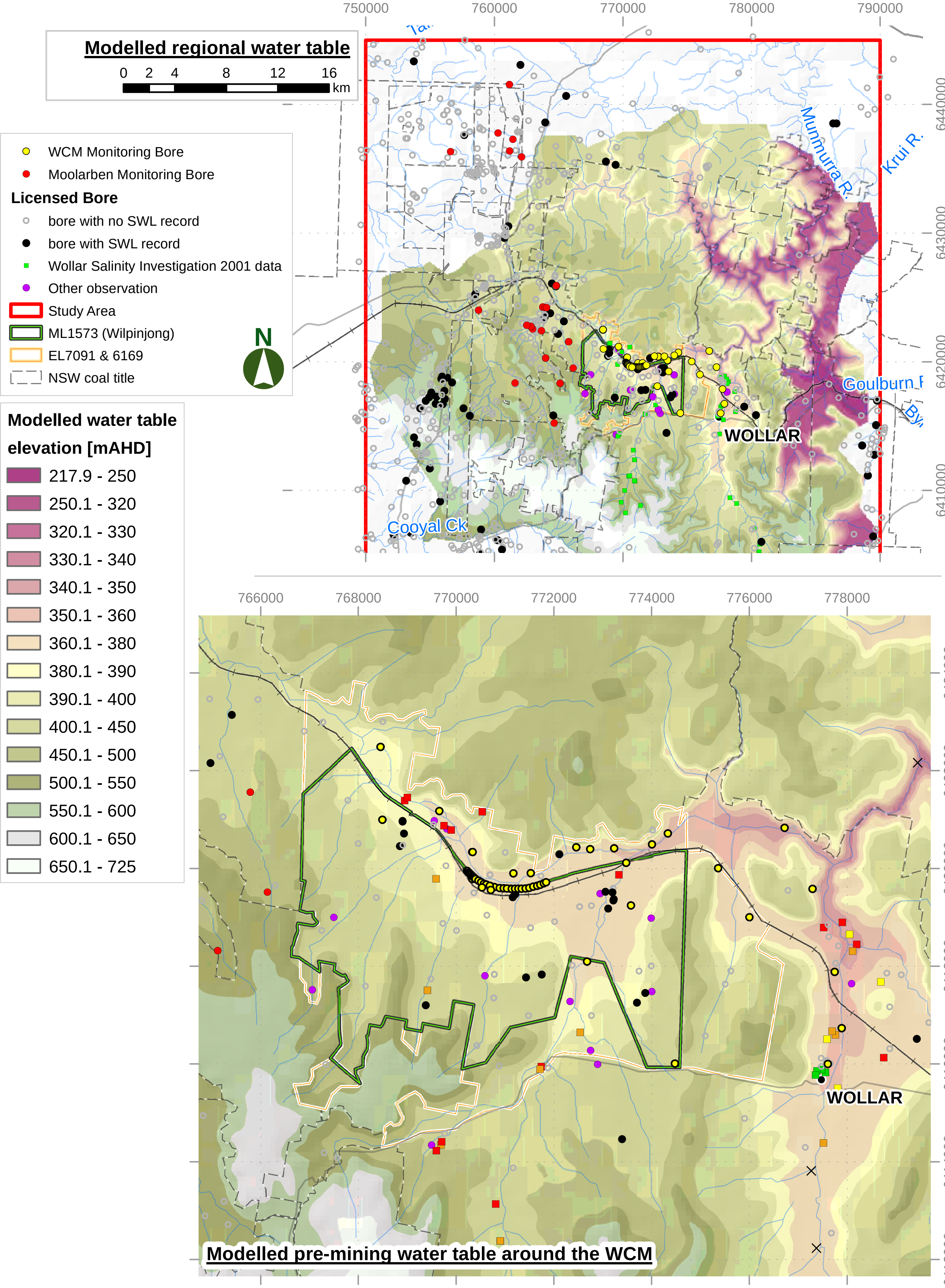
Figure 5-7 Summary of Calibration to Groundwater Levels



file:///C:\HydroSim\WIL006\Model\Processing\Calibration\Heads\TransientHeads_WilpV02TR24_spoilstor.xlsx

Figure 5-8 Selection of Model Groundwater Level Hydrographs



Scale: 100,000 at A4
GDA 1994 MGA Zone 55

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HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Modelled Water Table Elevation

Figure 5-9

WCM Monitoring Bore
Moolarben Monitoring Bore
GWL control points

Inferred Dry / Wet boundary

[HydroSimulations, 2013)
ML1573 (Wilpinjong)
EL7091 & 6169
NSW coal title

Ulan Coal GWL (observed / inferred) [mAHD]

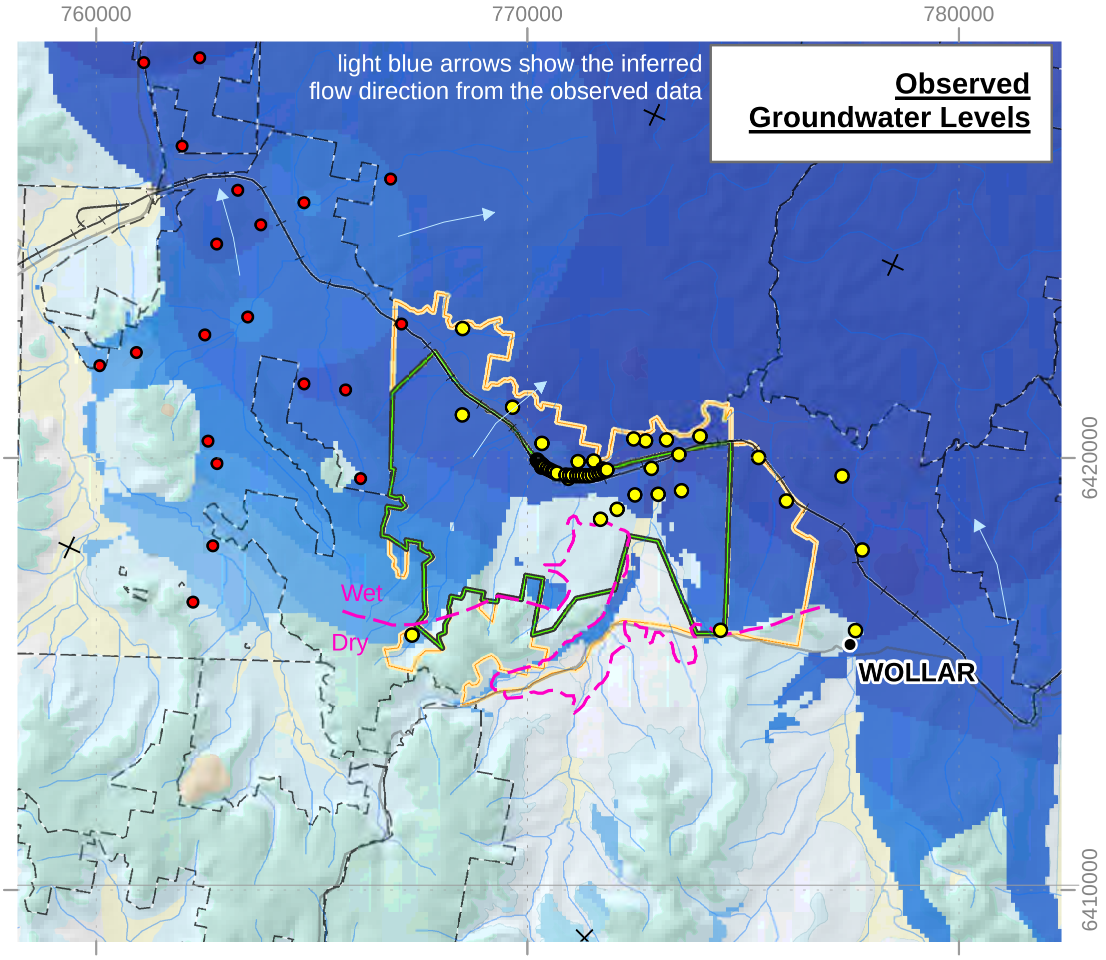
272.2 - 300
300.1 - 340
340.1 - 360
360.1 - 380
380.1 - 400
400.1 - 420
420.1 - 440
440.1 - 460
460.1 - 480
480.1 - 500
500.1 - 520
520.1 - 550

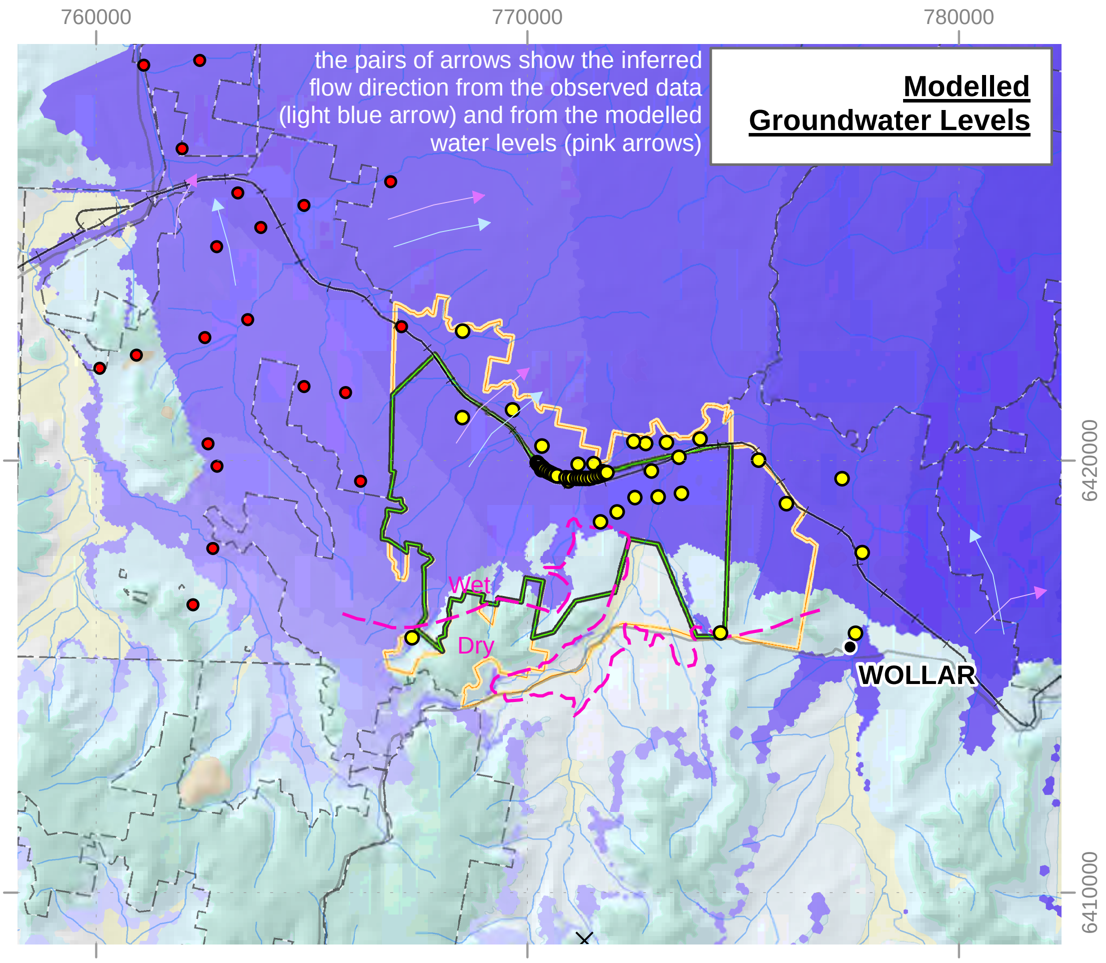
Modelled GWL in Ulan Coal seam [mAHD]

227.8 - 240
240.1 - 260
260.1 - 280
280.1 - 300
300.1 - 340
340.1 - 360
360.1 - 380
380.1 - 400
400.1 - 420
420.1 - 440
440.1 - 460
460.1 - 480
480.1 - 500
500.1 - 520
520.1 - 650

Geological Outcrop Western Coalfield (Yoo, 1998)

alluvium
Intrusion
Basalt, volcanics
Narrabeen Group
Illawarra Coal Measures
Shoalhaven Group





0 1.25 2.5 5 7.5 10 km

N

Scale: 175,000 at A4
GDA 1994 MGA Zone 55

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HYDROSIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Modelled and Observed Groundwater Levels: Ulan Coal Seam

Figure 5-10

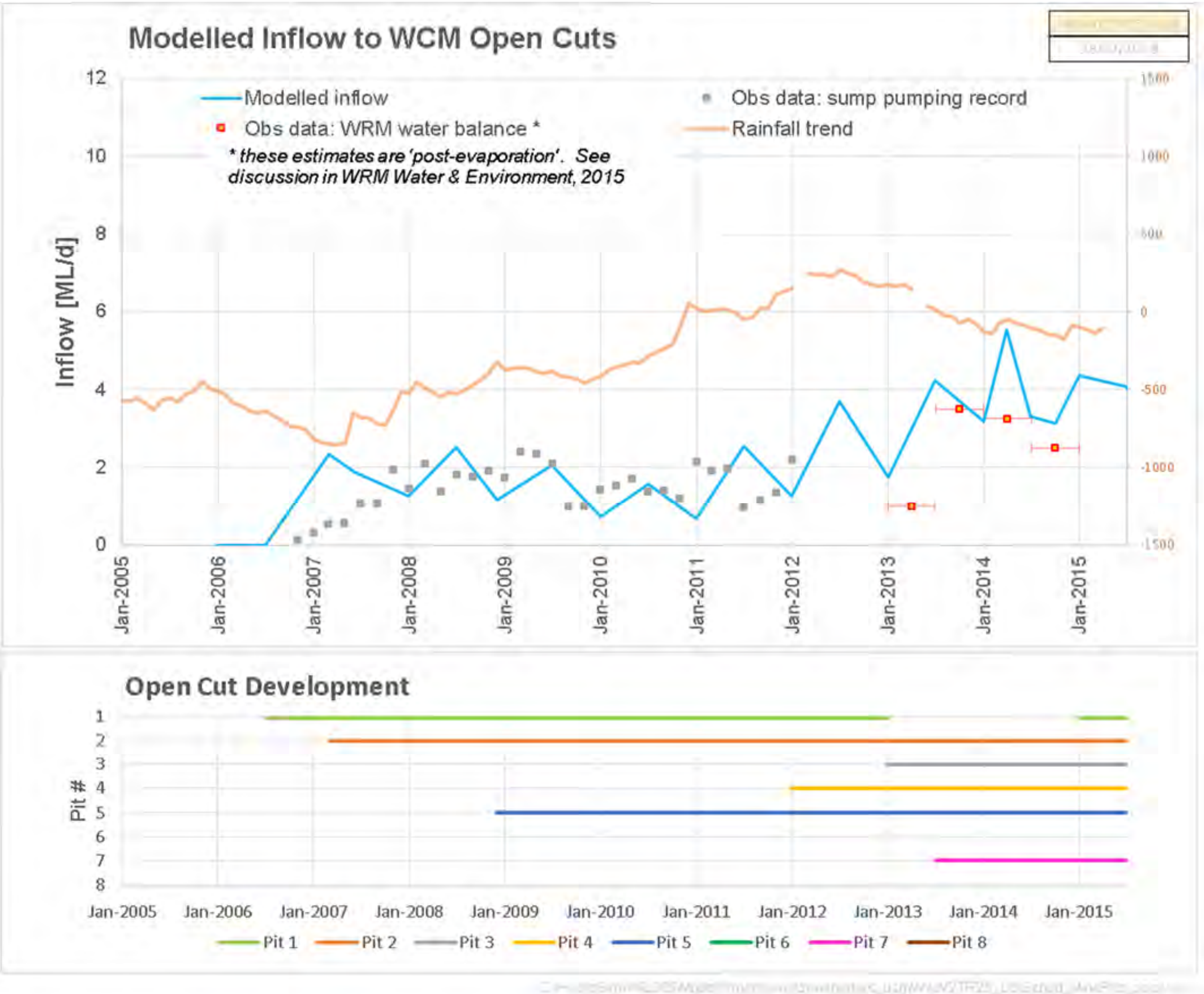


Figure 5-11 Comparison of Modelled and Inferred Mine Inflow

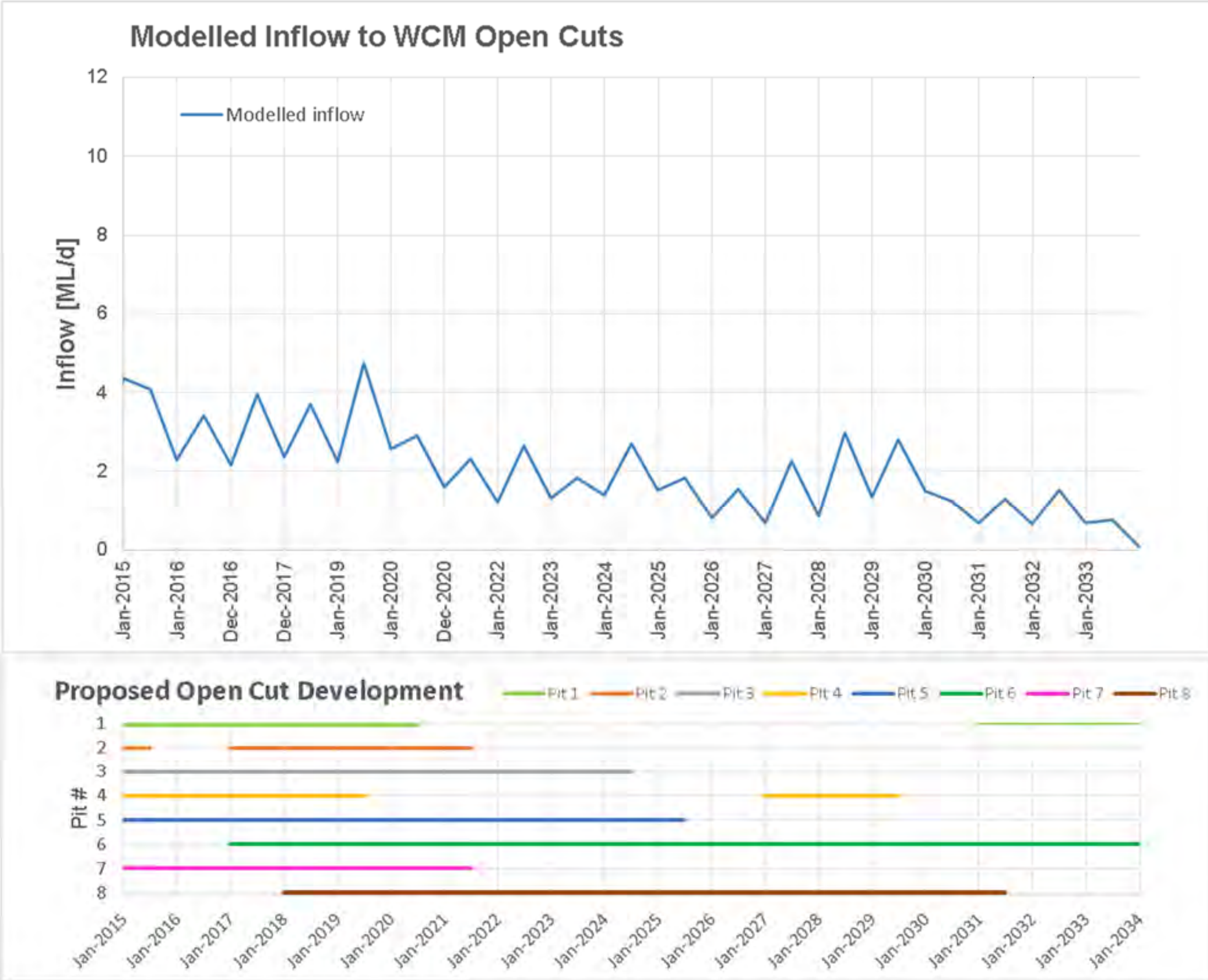


Figure 6-1 Predicted Groundwater Inflows

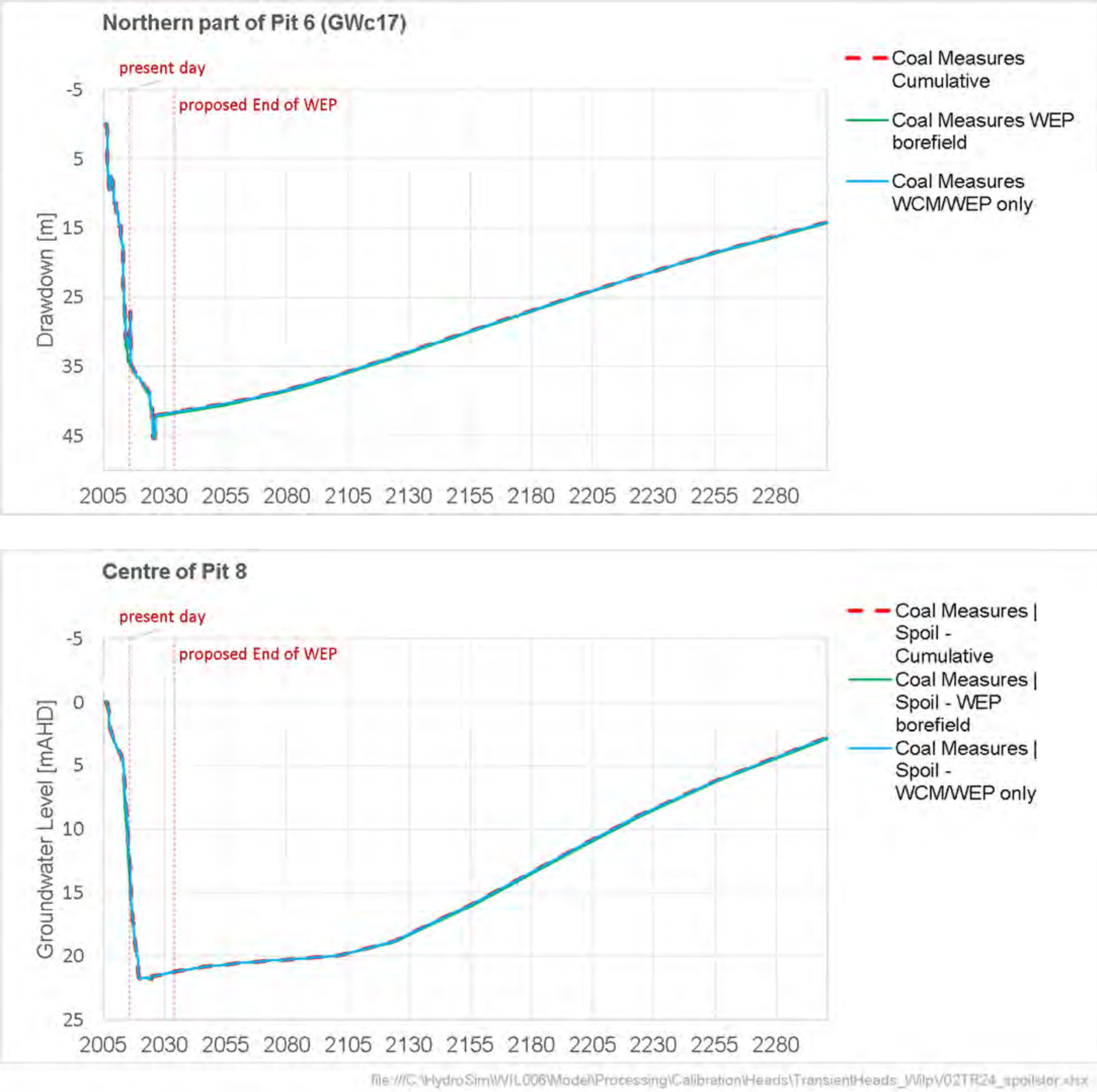


Figure 6-2 Predicted Drawdown – within WCM open cuts

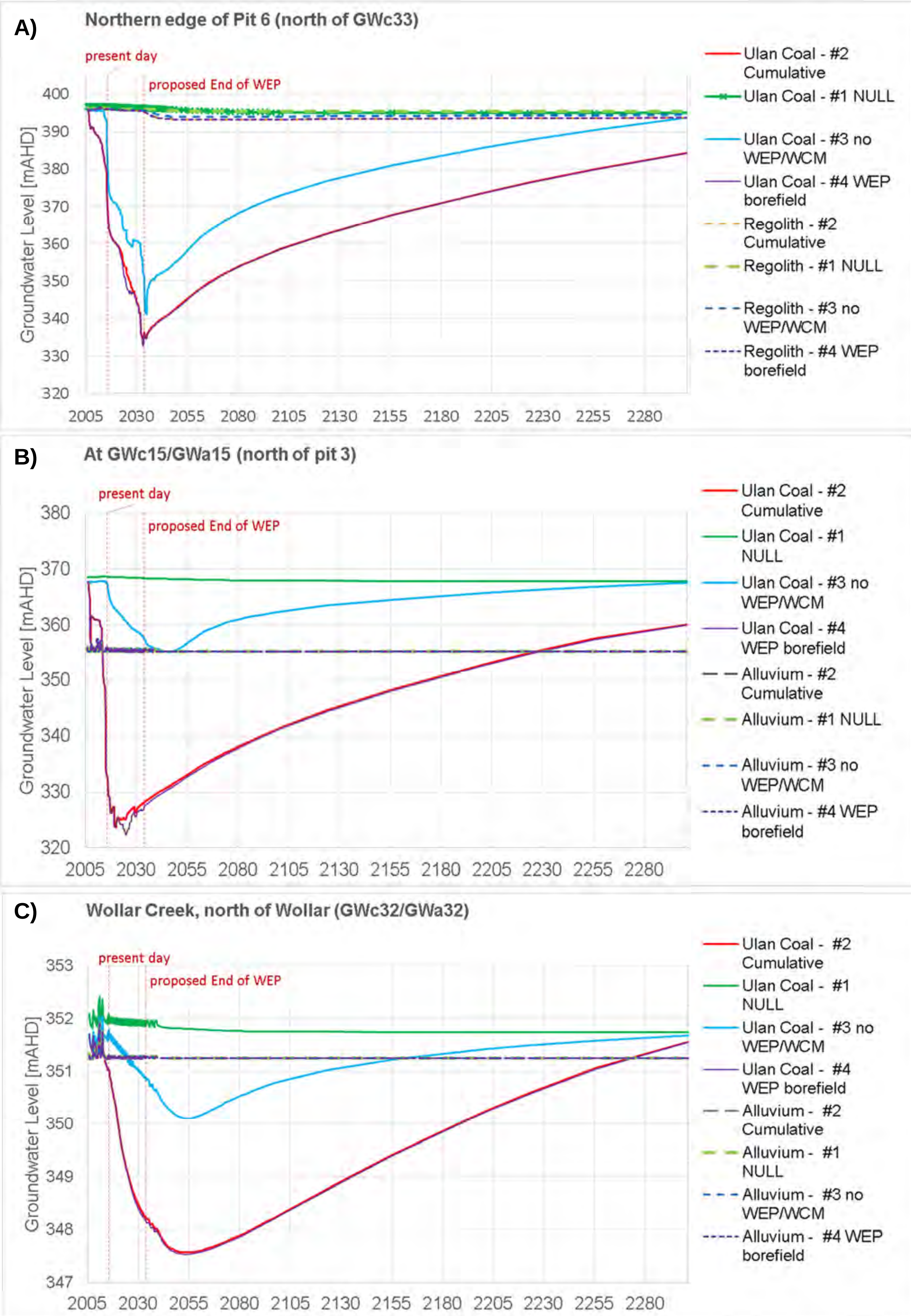


Figure 6-3 Predicted Groundwater Levels – around WCM/WEP

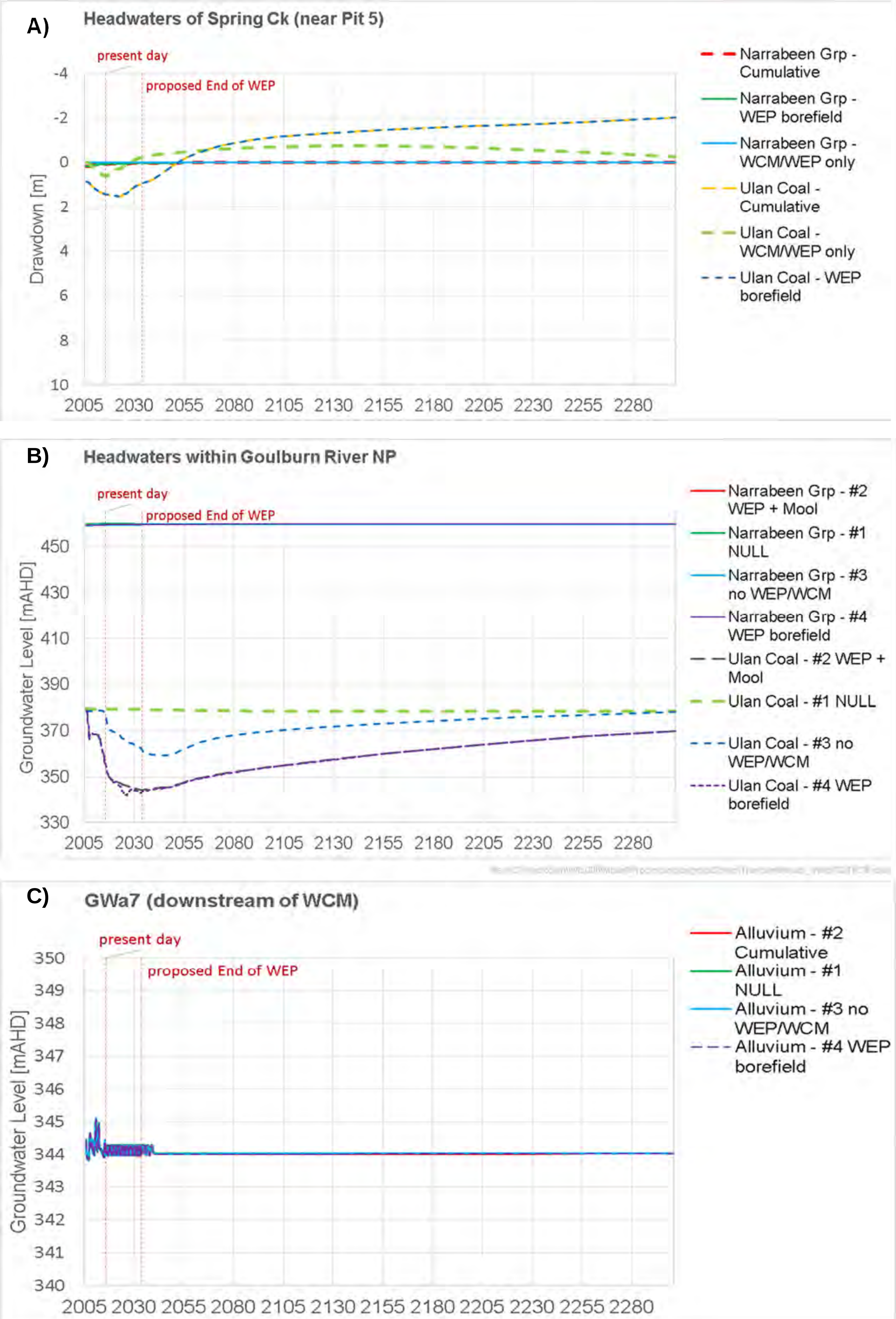
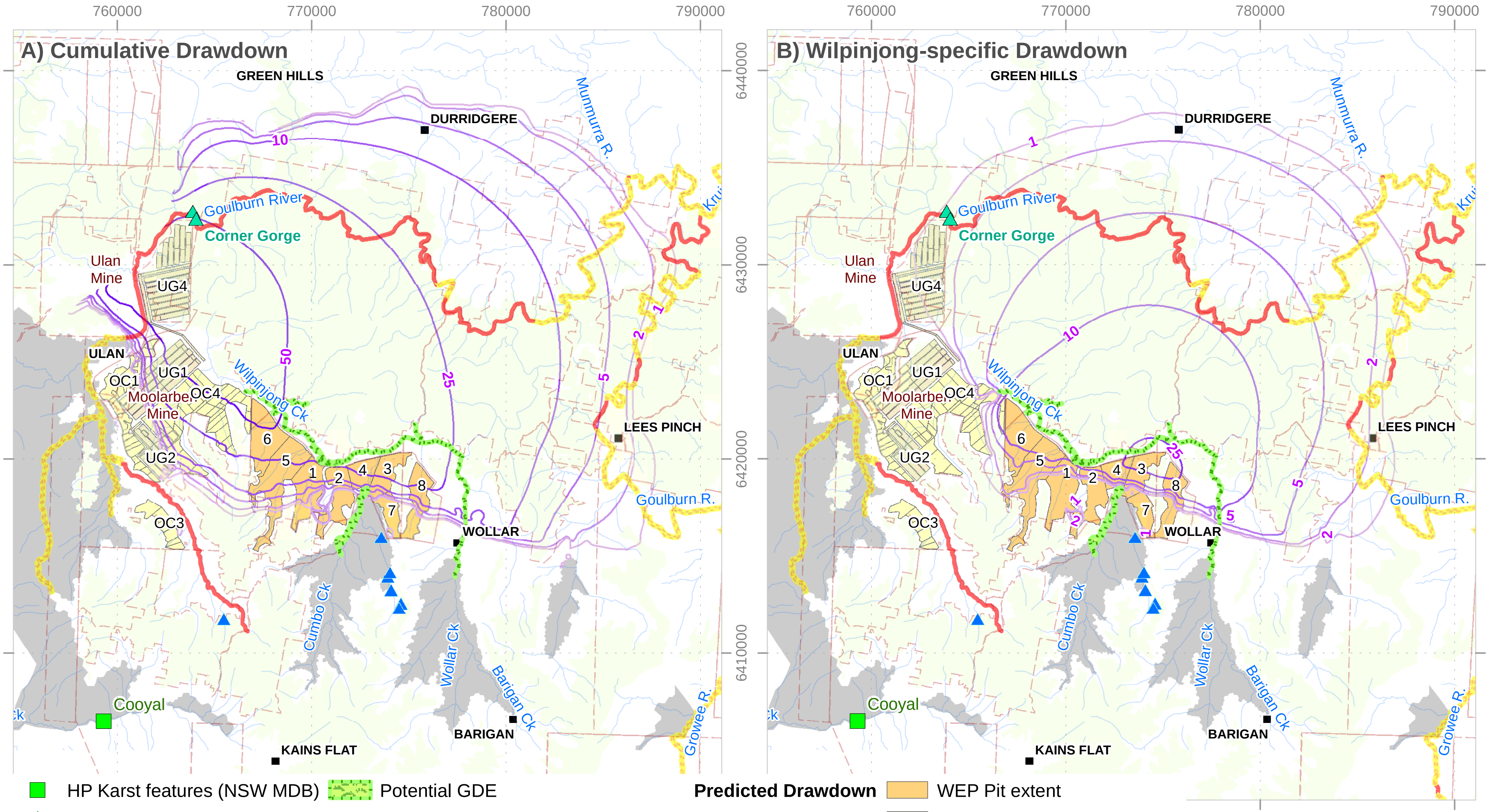


Figure 6-4 Predicted Drawdown: springs and creeks



HP Karst features (NSW MDB)
HP GDE features (NSW MDB)
HP GDE features (Hunter)
feature on Goulburn River
Spring (from Bore Census)

Potential GDE

BOM GDE Atlas - feature reliant on surface expression of groundwater

Moderate potential for GW interaction
Low potential for GW interaction

Predicted Drawdown [metres]

1
2
5
10
25
50

WEP Pit extent
Moolarben Open Cut area
Moolarben Underground Area
Triassic outcrop

Ulan Seam extent

inactive (absent)

Scale: 270,000 at A4
GDA 1994 MGA Zone 55

0 2.5 5 7.5 10 km

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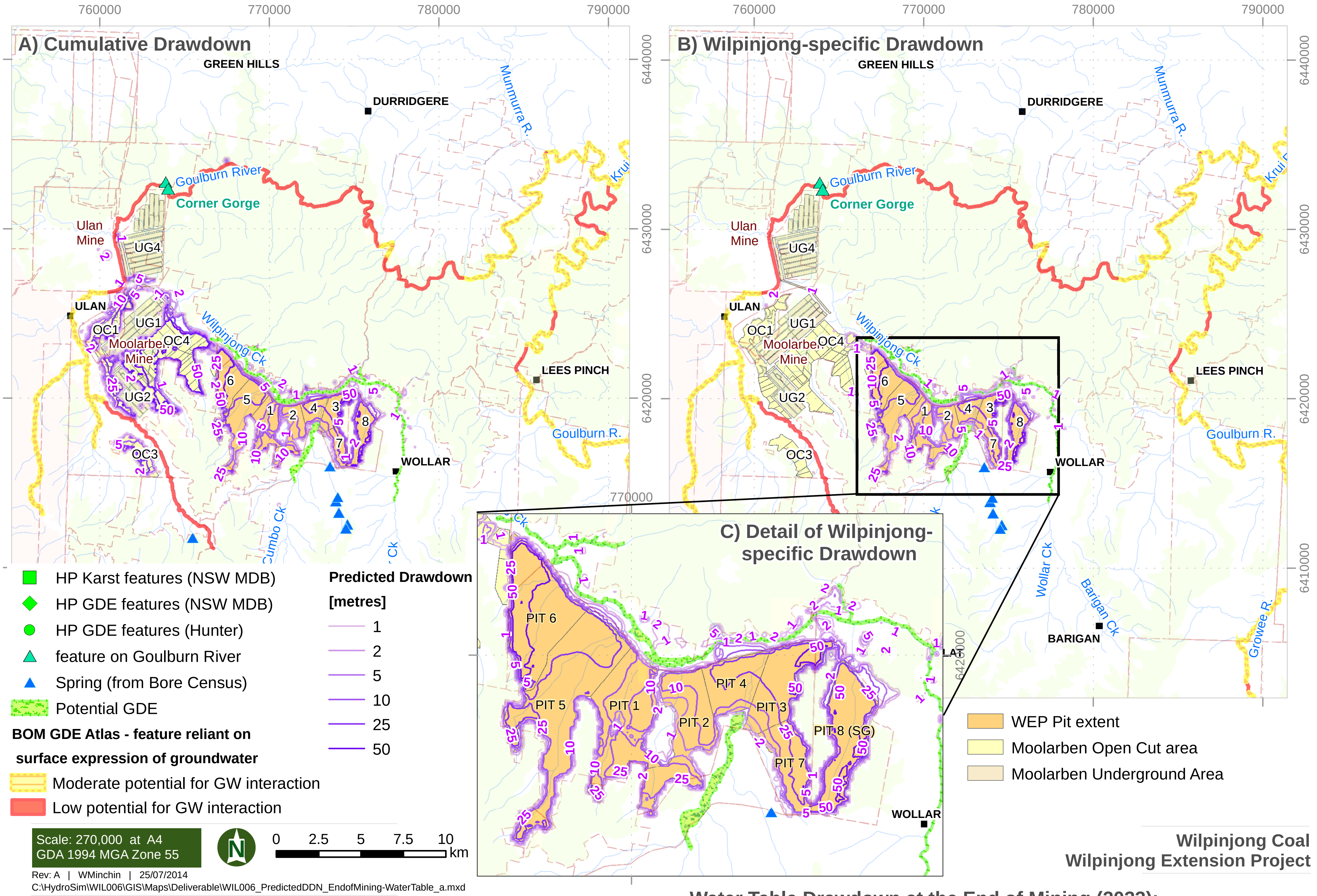
HYDROSIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Ulan Coal Seam Drawdown at the End of Mining (2033): Cumulative and Wilpinjong-specific effects

Figure 6-5



HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Water Table Drawdown at the End of Mining (2033): Cumulative and Wilpinjong-specific effects

Figure 6-6

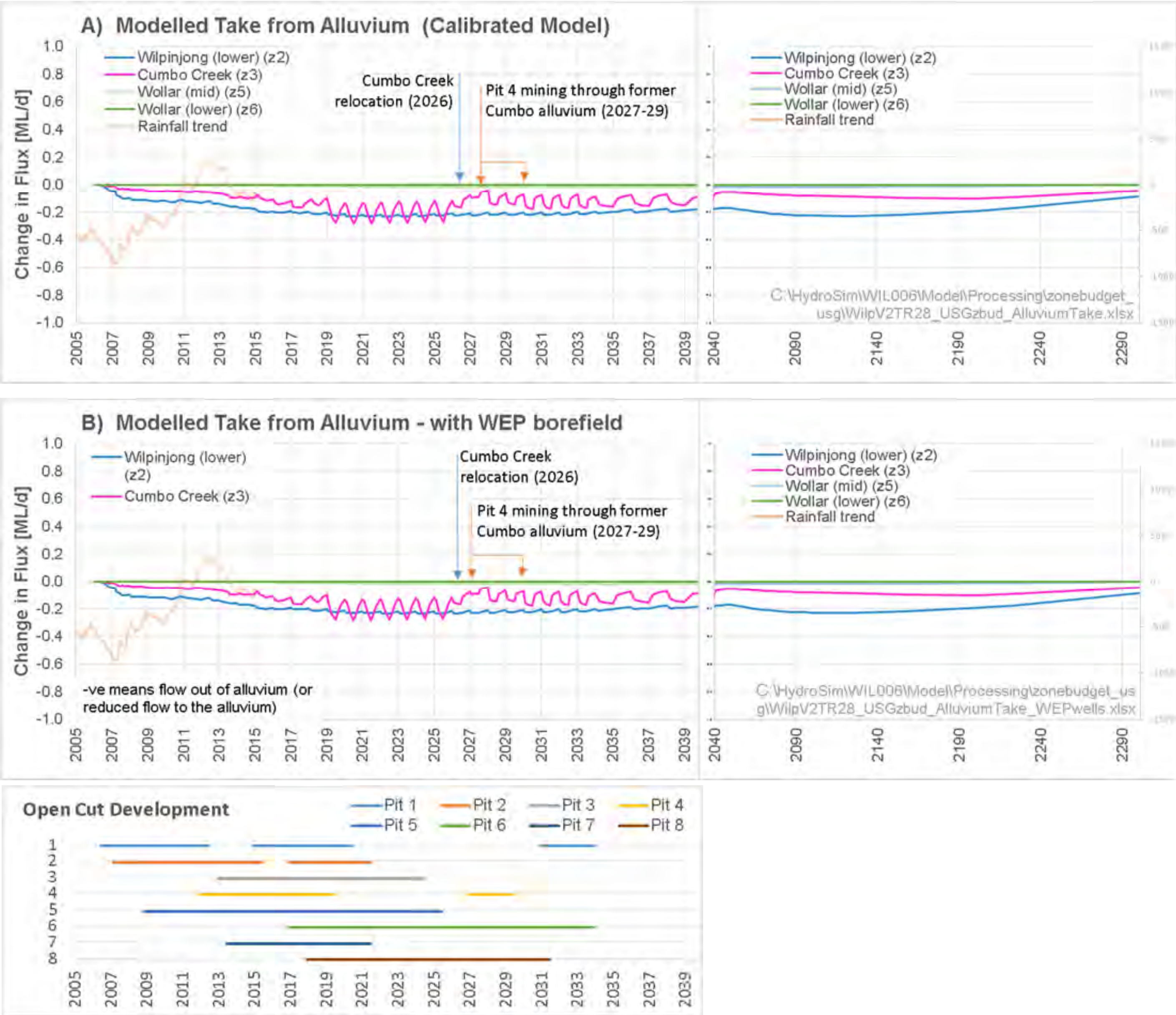


Figure 6-7 Predicted Vertical Flux Between Rock and Alluvium

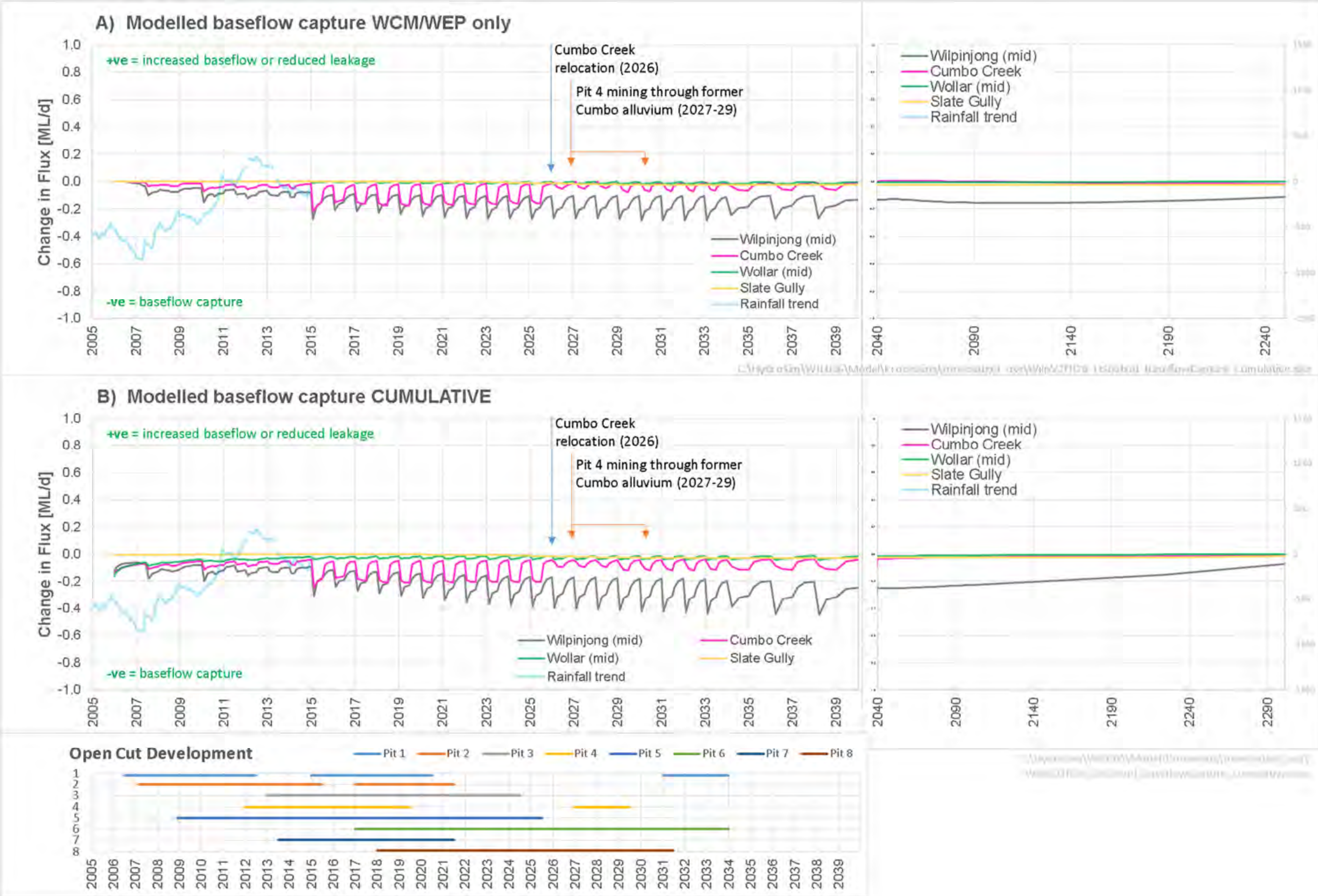
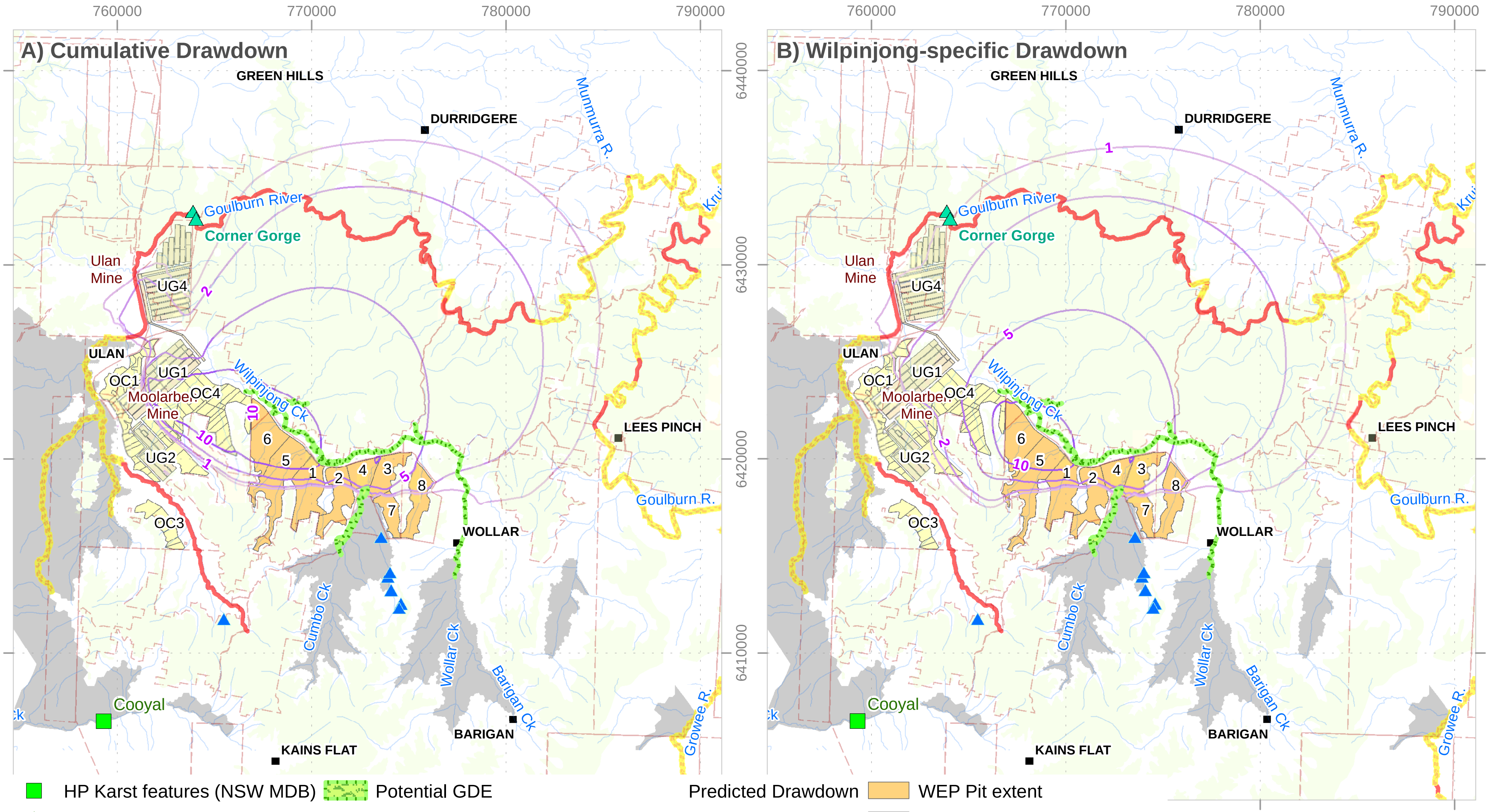


Figure 6-8 Predicted Baseflow Capture



HP Karst features (NSW MDB)

HP GDE features (NSW MDB)

HP GDE features (Hunter)

feature on Goulburn River

Spring (from Bore Census)

Potential GDE

BOM GDE Atlas - feature reliant on surface expression of groundwater

Moderate potential for GW interaction

Low potential for GW interaction

Predicted Drawdown [metres]

1

2

5

10

25

50

WEP Pit extent

Moolarben Open Cut area

Moolarben Underground Area

Triassic outcrop

Ulan Seam extent

inactive (absent)

Scale: 270,000 at A4
GDA 1994 MGA Zone 55

0 2.5 5 7.5 10 km

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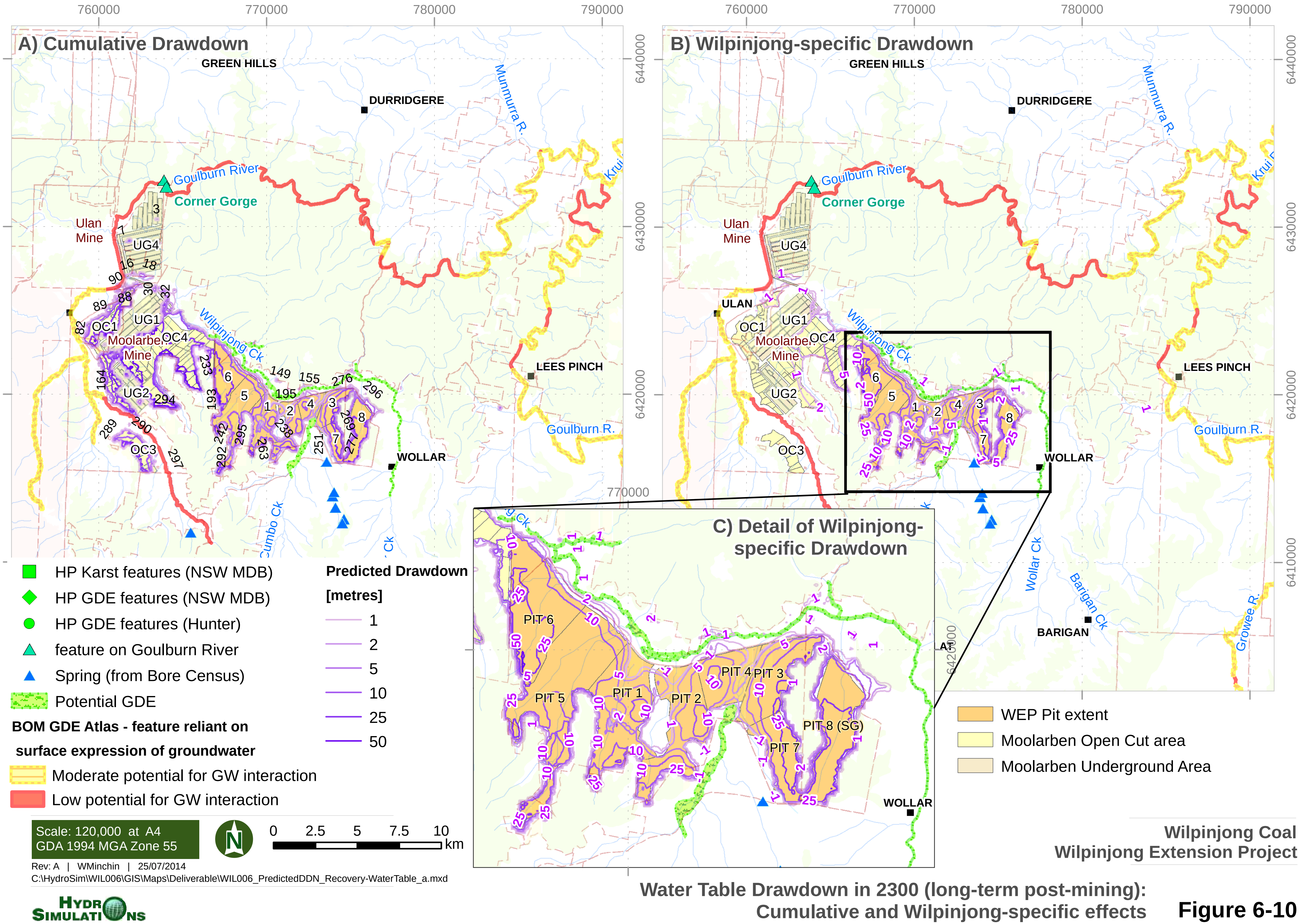
HYDRO SIMULATIONS

Wilpinjong Coal
Wilpinjong Extension Project

Ulan Coal Seam Drawdown in 2300 (long-term post-mining): Cumulative and Wilpinjong-specific effects

Figure 6-9



Water Table Drawdown in 2300 (long-term post-mining): Cumulative and Wilpinjong-specific effects

Figure 6-10